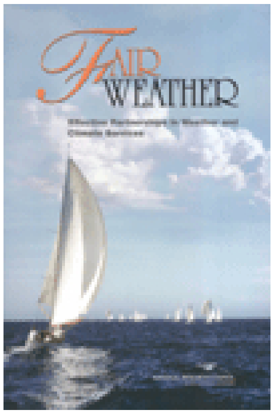

Fair Weather: Effective Partnerships in Weather and Climate Services

Committee on Partnerships in Weather and Climate Services, Committee on Geophysical and Environmental Data, National Research Council

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FAIR WEATHER

Effective Partnership in Weather and Climate Services

Committee on Partnerships in Weather and Climate Services

Committee on Geophysical and Environmental Data
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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

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David Chang, retired, Atmospheric and Environmental Research, Inc., Lexington, Massachusetts
Stanley Changnon, emeritus, Illinois State Water Survey and University of Illinois, Champaign
Surajit Chaudhuri, Microsoft Research, Redmond, Washington
Bennett Z. Kobb, Institute of Electrical and Electronics Engineers, Inc., Arlington, Virginia
Clifford Mass, University of Washington, Seattle
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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Christopher A. Sims, Princeton University. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Preface

Over the last four decades the provision of weather and climate services in the United States has evolved from an almost exclusively governmental function to one carried out by a combination of federal, state, and local government agencies (referred to collectively as the public sector), the private sector, and academia. This change has improved and diversified weather and climate services, but has also raised questions about the proper roles of the various sectors and the potential for actual or perceived competition. A recent National Research Council report discussed the roles of the public, academic, and private sectors in a broad range of environmental disciplines (including weather), and proposed guidelines for purchasing data and products for public purposes, dealing with data restrictions, and privatizing government functions. This report focuses on the provision of civilian weather and climate services, barriers to communication among the sectors, and opportunities for improving the effectiveness of the weather and climate enterprise.

In gathering information for this report, the committee solicited input from representatives of the three sectors, key user communities—agriculture, aviation, weather risk management, and emergency management—and experts in public policy, technology transfer, social science, and information technology. In addition to holding meetings, the committee visited several weather companies, National Oceanic and Atmospheric Administration facilities, and academic organizations. These include AccuWeather; NBC; WeatherData; WSI Corp.; Massachusetts Institute of Technology; Penn State University; the University Corporation for Atmospheric Research; National Weather Service (NWS) headquarters; National Climatic Data Center; Climate Diagnostics Center; Forecast Systems Laboratory; Climate Diagnostics Laboratory; and NWS forecast offices in Tauton, Massachusetts; State College, Pennsylvania; and Wichita, Kansas. Altogether, the committee held four committee meetings and six site visits. To facilitate communication with the broader community, the committee hosted a "town hall" meeting at the 2002 American Meteorological Society annual meeting and maintained a web site with meeting and background information. The committee actively solicited public comment and received dozens of letters.

Finally, information was gathered from the literature and from web sites. The information from web sites provided in this report was correct, to the best of the committee's knowledge, at the time of publication. It is important to remember, however, the rapidly changing content of the Internet. Resources that are free and publicly available one day may require a fee or restrict access the next, and the location of items may change as menus and home pages are reorganized.

The committee would like to acknowledge the many individuals who briefed it, wrote letters, or provided background material or other input. They include Elliot Abrams, David Bacon, Ray Ban, Thomas Baumgardner, Nancy Bellar, James Block, Charles Bostian, William Brandon, Lee Branscome, Francis Bretherton, Bill Brune, Bruce Budd, Craig Burfeind, David Chang, Stanley Changnon, Don Coash, John Couzelis, Michael Dangelo, William Depuy, Randy Dole, Rainer Dombrowsky, Kelvin Droegemeier, John Dutton, Steve Easley, Dick Elder, Kerry Emmanuel, Allen Eustis, Nick Faust, Margaret Fowke, John Freeman, Joe Friday, Michael Fritsch, Craig Fugate, Fred Gadomski, Rodger Getz, Mark Gildersleeve, Mary Glackin, Russell Gold, David Goodrich, Edward Gross, Richard Grumm, Ron Guy, Jim Hansen, Robert Hart, James Hatch, Chance Hayes, Jack Hayes, Stan Heckman, Steven Hilberg, David Hofmann, Charles Hosler, Ian Hunter, Lodovica Illari, Doug Jonas, Tom Karl, Frank Kelly, Jack Kelly, Michael Kleist, Paul Knight, Rob Korty, Kevin Lavin, Greg Lawson, Sharon LeDuc, Alexander MacDonald, Greg Mandt, Marvin McInnis, David McLaughlin, Greg McRae, Jim Menard, Rick Murnane, Barry Lee Myers, Evan Myers, Joel Myers, Celeste Oakes, David Ondrejik, Chris Orr, Joseph Ostrowski, Alan Plumb, Irwin Prater, Jeff Reaves, Kenneth Reeves, Dan Ristic, Steven Root, Jim Severson, Jeffrey Shorter, Michael Smith, Richard Spinrad, Carl Staton, Mike Steinburg, Peter Stone, Michael Stonebraker, Robert Thompson, Lloyd Treinish, Lou Uccellini, Bill Weaving, Jonathan Weinberg, Roger Williams, Greg Withee, Megan Woodhead, John Wroclawski, and John Zillman. The committee also thanks Edward Johnson and Peter Weiss of the NWS Strategic Planning Office for their detailed responses to letters from the private sector and to numerous questions from the committee. Thanks go to the study director, Anne Linn, and

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John A. Armstrong, *Chair*
Committee on Partnerships in
Weather and Climate Services

Contents

Executive Summary

Weather and climate directly affect the U.S. economy and the health and safety of its citizens. Weather-related damages amount to $20 billion per year, and hundreds of millions of dollars are saved each year by taking action based on improved forecasts, warnings, and other weather services. A growing number of people are moving to areas that are vulnerable to extreme weather events, increasing the social and economic costs of weather-related disasters. Because of the pervasive influence of weather and climate on society, it is important to have the best weather and climate information the nation can afford. In the United States, the weather and climate enterprise has evolved since its inception in the 1800s to include three sectors, each of which plays a unique and vital role:

1. The National Weather Service (NWS) is responsible for protecting life and property and enhancing the national economy. To carry out its mission, it maintains an infrastructure of observing, communications, data processing, and prediction systems and conducts research on which the public (federal, state, and local government agencies), private, and academic sectors rely. It also negotiates data exchange agreements with other countries.
2. Academia is responsible for advancing the science and educating future generations of meteorologists.
3. The private sector (weather companies, meteorologists working for private companies or as private consultants, and broadcast meteorologists)

is responsible for creating products and services tailored to the needs of their company or clients and for working with the NWS to communicate forecasts and warnings that may affect public safety.

This three-sector system has led to an extensive and flourishing set of weather services that are of great benefit to the U.S. public and to major sections of the U.S. economy. However, the system also has a certain level of built-in friction between the public, private, and academic sectors for the following reasons:

- each sector contributes in varying degrees to the same activities—data collection, modeling and analysis, product development, and information dissemination—making it difficult to clearly differentiate their roles;
- the sectors have different philosophies of sharing data and models with the other sectors and the general public;
- advances in scientific understanding and technology permit new user communities to emerge and change what the sectors are capable of doing and want to do; and
- all members do not share the same expectations and understanding of the proper roles and responsibilities of the three sectors.

Some level of tension is an inevitable but acceptable price to pay for the excellent array of weather and climate products and services our nation enjoys. But the frictions and inefficiencies of the existing system can probably be reduced, permitting the three sectors to live in greater harmony.

At the request of the NWS, the Committee on Partnerships in Weather and Climate Services was established to undertake the following tasks:

- Examine the present roles of the public, private, and academic sectors in the provision and use of weather, climate, and related environmental information and services in the United States.
- Identify the effects that advances in observing, modeling, forecasting, and information dissemination technologies may have on the respective roles of the public, private, and academic sectors.
- Examine the interface between the various sectors, identify barriers to effective interaction, and recommend changes in policies or practices that could improve the potential for providing weather and climate information.
- Make recommendations regarding how to coordinate the roles most effectively among the various sectors.

Advances in science and technology are driving the evolution of the weather and climate enterprise. As little as a decade ago, federal government agencies collected nearly all of the data and developed and ran nearly all of the forecast models. Today, state and local government agencies, universities, and private companies deploy their own instruments, and some run their own models or models developed by others. Advances in scientific understanding and modeling will soon enable more accurate seasonal to interannual forecasting, thereby creating both new opportunities for providing climate services and the potential for new sources of friction between the sectors. The rapid changes in science and technology underlying weather and climate forecasting are likely to continue. Therefore, the committee's primary conclusion is that *it is counterproductive and diversionary to establish detailed and rigid boundaries for each sector outlining who can do what and with which tools*. Instead, efforts should focus on improving the processes by which the public and private providers of weather services interact. Improving these processes would also help alleviate the misunderstanding and suspicion that exist between some members of the sectors. However, there is no "magic bullet" that will bring "fair weather" to the partnership. The recommendations below are first steps on a journey that will take time, effort, and persistence to complete.

STRENGTHENING THE PUBLIC-PRIVATE PARTNERSHIP

In an attempt to foster collaboration rather than conflict, the NWS has adopted a series of policies to guide its interactions with the private sector since the 1970s. The 1991 public-private partnership policy and its predecessors have taken the same approach—to define the roles of the NWS and the private sector and to provide guidelines for avoiding competition. However, defining exactly what activities should be carried out by the NWS is a matter of interpretation—social, political, and legal—and the interpretation changes as new laws are enacted. Moreover, the current policy specifies that the NWS will not provide services that the private sector is currently providing or could provide, unless otherwise directed by law. This guideline is untenable because the private sector can now do much of what the NWS legitimately does, and there may be good public policy reasons for the NWS to carry out certain activities, even if the private sector does or could do them. Although the 1991 policy does not work as intended, the committee believes that a policy is necessary—one that emphasizes processes for interactions among the sectors and takes account of newer federal government laws and policies.

Recommendation 1. The NWS should replace its 1991 public-private partnership policy with a policy that defines processes for making decisions on products, technologies, and services, rather than rigidly defining the roles of the NWS and the private sector.

Ideally, the policy would be expanded beyond the NWS to include all relevant parts of the National Oceanic and Atmospheric Administration (NOAA) that participate in the weather and climate enterprise. These include the National Environmental Satellite, Data, and Information Service, which operates meteorological satellites and the long-term weather and climate archive; the Oceanic and Atmospheric Research division, which operates research laboratories; and the NWS, which generates forecasts and provides weather and climate services.

Any policy to guide the nature of partnerships should be developed in consultation with all stakeholders. Mechanisms for facilitating communication among the sectors include an NWS advisory committee and periodic meetings of stakeholders. An advisory committee could deal with a variety of strategic issues associated with a particular sector or with the weather and climate enterprise as a whole. To be effective, however, its membership must include representation from all sectors (both users and providers of weather services), and NWS management must be serious about listening to its advice. Establishing such an advisory committee would send a strong signal to the broader meteorological community that the NWS really wants input that will benefit the weather and climate enterprise.

Recommendation 2. The NWS should establish an independent advisory committee to provide ongoing advice to it on weather and climate matters. The committee should be composed of users of weather and climate data and representatives of the public, private, and academic sectors, and it should consider issues relevant to each sector as well as to the set of players as a group, such as (but not limited to)

- **improving communication among the sectors,**
- **creating or discontinuing products,**
- **enhancing scientific and technical capabilities that support the NWS mission,**
- **improving data quality and timeliness, and**
- **disseminating data and information.**

Scientific meetings, NWS-sponsored user meetings, and the occasional forum on the public-private partnership provide a means for improving communication among the sectors. Because the meetings are outside the NWS policy-making process, they complement the recommended advisory committee. However, the committee believes that meetings held to deal with partnership issues should be institutionalized by an organization seen as neutral by all parties. The American Meteorological Society, whose membership is evenly divided among the sectors and which has hosted such meetings since 1948, may provide a possible venue for a sector to air its complaints and seek creative solutions.

Recommendation 3. The NWS and relevant academic, state, and private organizations should seek a neutral host, such as the American Meteorological Society, to provide a periodic dedicated venue for the weather enterprise as a whole to discuss issues related to the public-private partnership.

ENHANCING THE CONTRIBUTIONS OF THE THREE SECTORS

In addition to creating or institutionalizing the processes described above, there are steps that each sector can take on its own to improve the effectiveness of the weather and climate enterprise.

National Weather Service

To fulfill its mission to protect life and property and enhance the national economy by issuing weather warnings, watches, and advisories, the NWS must collect high-quality data, develop and run atmospheric models, and generate forecasts. The models and products (including forecasts) developed in this information chain are available to the public, where they are used by individuals as well as by the academic and private sectors to create specialized weather products, tools, and models. This arrangement satisfies the government's obligation to make its information as widely available as possible to those who paid for it—the taxpayers. Although some in the private sector would prefer that the NWS not issue forecasts, the committee believes that scientific, legal, and economic arguments overwhelmingly support the continued dissemination of NWS forecasts and other weather products. Not only has the infrastructure supporting the forecast already been paid for, but disseminating forecasts provides a measure of visibility to the NWS, which helps ensure continued congressional support for the expensive infrastructure needed to generate weather and climate services.

Recommendation 4. The NWS should continue to carry out activities that are essential to its mission of protecting life and property and enhancing the national economy, including collecting data; ensuring their quality; issuing forecasts, warnings, and advisories; and providing unrestricted access to publicly funded observations, analyses, model results, forecasts, and related information products in a timely manner and at the lowest possible cost to all users.

The expected improvements in meteorological observations, scientific understanding, and computational and communications technologies will create many opportunities for improving NWS information services. Despite objections from some in the private sector, it is both efficient and suitable for the NWS to adopt commonly available technologies that improve its ability to carry out its mission. In particular, Internet and digital database technologies offer powerful, low-cost means of increasing the availability and usefulness of NWS data, forecasts, and other weather products to a large population.

Recommendation 5. The NWS should make its data and products available in Internet-accessible digital form. Information held in digital databases should be based on widely recognized standards, formats, and metadata descriptions to ensure that data from different observing platforms, databases, and models can be integrated and used by all interested parties in the weather and climate enterprise.

To meet evolving user needs within a limited budget, the NWS must decide on an ongoing basis which products to create and which to phase out. Such decisions must balance a number of sometimes conflicting objectives, such as operating efficiently, keeping the public-private partnership healthy, and ensuring that products benefiting the public are made available. For example, it is socially beneficial for the NWS to create products related to public health, even if the private sector sees such products as a business opportunity. The NWS has recently developed guidelines for deciding which products to incorporate into operations, although they do not cover all the complexities of product development. However, the NWS has yet to formulate guidelines for determining which products and services to discontinue.

Recommendation 6. The NWS should (1) improve its process for evaluating the need for new weather and climate products and services that meet new national needs, and (2) develop processes for discontinuing dissemination of products and services that are specific to particular individuals or organizations or that are not essential to the public.

The 135 NWS weather and river forecast offices are mandated to create products tailored to their geographic region. The local offices are given a certain level of autonomy, which fosters innovation and benefits the weather and climate enterprise. However, the large number of offices makes it difficult to communicate and enforce NWS policy. As a result, the products created by the forecast offices vary, as does their attitude toward cooperation with the private sector. The creation of standard home pages for all NWS offices should help present a more uniform face to the public, but more has to be done to ensure that the NWS offices act in a way that is consistent with overarching NWS policies yet permits creativity at the local level.

Recommendation 7. NWS headquarters and regional managers should develop an approach to managing the local forecast offices that balances a respect for local innovation and creativity with greater control over the activities that affect the public-private partnership, especially those that concern the development and dissemination of new products or services.

The public relies on the trustworthiness of NWS data; the private sector relies on high-quality, timely NWS data to produce specialized products for clients; and all sectors rely on the NWS to maintain scientifically valid meteorological and climatological databases. Consequently, the NWS must ensure that its data and information products are accurate, reliable, objective, openly available, and produced and reported according to rigorous scientific standards. Feedback from the community suggests that the NWS is generally doing a good job in these areas, although greater attention should be paid to ensuring the scientific validity of information generated by automated systems and to adopting probabilistic methods for communicating uncertainties where appropriate.

Recommendation 8. The NWS should continue to adopt and improve probabilistic methods for communicating uncertainties in the data and forecasts where such methods are accepted as scientifically valid.

In addition to maintaining standards for existing instruments and products, the NWS is well positioned to play a lead role in developing standards and formats for new data sources (e.g., state and local government agencies, private weather companies) and for new technologies (e.g., wireless communications). Although incompatible formats are inevitable in a highly distributed and rapidly evolving system such as the weather and climate information system, harmonizing standards greatly increases the usefulness of new data sources and avenues of communication and creates a "level playing field" for many prospective users.

Recommendation 9. The NWS should retain its role as the official source of instrumentation, data, and data collection standards to ensure that scientific benchmarks for collecting, verifying, and reporting data are maintained. It should lead efforts to follow, harmonize, and extend standards, formats, and metadata to ensure that data from NWS and non-NWS net-

works, databases, and communications technology can be integrated and used with relative ease.

Private Sector

The private sector has made many valuable contributions to the weather and climate enterprise, from satisfying user needs for specialized products not developed by the NWS, to collecting local data that supplement the national network, to ensuring the widest possible dissemination of NWS watches, warnings, and advisories. Private sector use of NWS data, which form the basis of many commercial products, greatly increases the value of the data and further justifies the high cost of the national observing system infrastructure. In response to an invitation to all sectors issued by the committee, a relatively small number of commercial weather companies highlighted problems with NWS data quality and timeliness and with the public-private partnership, particularly regarding existing or potential duplication of effort. Problems concerning data quality are addressed in Recommendation 4, and problems concerning the public-private partnership are addressed in Recommendations 1 and 2. However, some of the letters suggest that significant misunderstanding exists about the organizational structure of NOAA and the laws governing the actions of the federal government and academia. In particular, the NOAA laboratories, the National Climatic Data Center, and academic organizations develop products and services—some of which may be commercially viable—to carry out their respective missions. These organizations are not bound by the current NWS public-private partnership policy. Rather, if they wish to sell products, they abide by technology transfer laws and conflict-of-interest policies (see Recommendation 11, below). The private sector should take care to avoid misinterpreting the legitimate actions of other sectors as partnership violations. Such misinterpretation creates frustration and mistrust in the other sectors.

Recommendation 10. The commercial weather sector should work with the other sectors, using mechanisms such as those proposed in this report, to improve the techniques and processes by which the weather and climate enterprise as a whole can minimize friction and inefficiency.

Academic Sector

The academic sector carries out much of the research that supports advances in operational meteorology in both the public and the private sectors. In addition, it plays an essential role in the weather and climate enterprise by educating the next generation of scientists and practitioners.

Under the Bayh-Dole Act, universities (and government laboratories) are encouraged to commercialize their research results. Meteorology departments are increasingly taking advantage of opportunities for science and technology transfer by creating independent for-profit companies. Most have guidelines in place for creating a bright line between the department and the spin-off company and for avoiding conflicts of interest. Others can learn from the best practices of industries that have gone down this path in the past, such as the computer and biotechnology industries. Not only must appropriate practices be followed, but they must be perceived by the outside community as being followed.

Recommendation 11. Universities seeking to commercialize weather-related research results should follow transparent procedures for transferring technology and for avoiding conflicts of interest. These procedures should be given wide exposure to remove perceptions of unfair competition.

All Sectors

Each sector in the weather enterprise has different motivations and rewards for working together. The key benefits of widespread cooperation are increased efficiency and the availability of more and better weather and climate products. Partnerships are most likely to succeed when the sectors maintain an ongoing dialogue, and when they have a mutual respect for and understanding of each partner's skills, cultural approach, and organization framework. A key element of the latter is public attribution of the contributions (i.e., data and models) of the other sectors. The committee notes that none of the sectors consistently recognizes and gives attribution to the contributions of the other sectors. Such attribution is also important for gaining public support for the large investments required in the weather and climate information system.

1

Introduction

There can be no doubt that weather is important to the U.S. economy and to the health and safety of its citizens. Estimates vary, but 25% (Box 1.1) to 42%[1] of the U.S. gross domestic product is affected by weather, and hundreds of millions of dollars are saved each year by taking action based on improved forecasts and weather warnings. Although it is not easy to estimate the number of lives saved or injuries avoided as a result of improved weather information, the number of fatalities from tornadoes and hurricanes in the United States has declined significantly since the 1930s, despite changing demographics, which place a growing number of people and supporting infrastructure in areas vulnerable to extreme weather events.[2] Such extreme events are projected to increase over the coming century,[3] further magnifying their social and economic costs. Short-term fluctuations in weather can cause or aggravate health ailments ranging from allergies to rheumatism to heat stroke,

[1]Bureau of Economic Analysis figures reported in National Research Council, 1998, *The Atmospheric Sciences Entering the Twenty-First Century*, National Academy Press, Washington, D.C., p. 25.

[2]S.A. Changnon, R.A. Pielke, Jr., D. Changnon, R.T. Sylves, and R. Pulwarty, 2000, Human factors explain the increased losses from weather and climate extremes, *Bulletin of the American Meteorological Society*, v. 81, p. 437-442.

[3]Intergovernmental Panel on Climate Change, 2001, *Climate Change 2001: Synthesis Report*, R.T. Watson and the Core Writing Team, eds., Geneva, Switzerland, 184 pp.

Box 1.1 Impact of Weather on the U.S. Economy

- Weather- and climate-sensitive industries account for about 25% of the nation's gross domestic product (GDP), or about $2.7 trillion. Industries directly affected by weather (e.g., agriculture, construction, energy, transportation, outdoor recreation) account for nearly 10% of GDP.
- Drought causes an average annual loss of $6 billion to $8 billion.
- The average annual damage caused by tornadoes, hurricanes, and floods is $11.4 billion. More accurate hurricane watches and warnings are estimated to have saved $2.5 billion in damage costs annually. Reducing the length of coastline under hurricane warnings saves between $600,000 and $1 million per coastal mile annually in costs of evacuations and other preparedness actions.
- Property losses associated with the 1997-1998 El Niño were $2.6 billion, including nearly $2 billion in crop losses. Altering planting decisions based on improved El Niño forecasts has saved $265 million to $300 million annually.
- Seventy percent of air traffic delays are attributed to weather, resulting in $4.2 billion lost in economic efficiency.

SOURCE: National Oceanic and Atmospheric Administration, NOAA economic statistics, May 2002, and references therein. Available at <http://205.156.54.206/pub/com/NOAAeconomicstatistics0402.pdf>.

and climate change plays an important role in diseases transmitted by insects and ticks, which are sensitive to variations in temperature and humidity.[4] Weather and climate change also affect the distribution of native and invasive species.

Because of the pervasive influence of weather and climate on society, it is important to have the best weather and climate information the nation can afford. In the United States, the approach is to harness the resources and creativity of the government (primarily the National Oceanic and Atmospheric Administration [NOAA] for civilian purposes), academia, and the private sector in the weather enterprise. Each of these sectors produces and disseminates weather products (e.g., drought maps, precipitation trends) and services (e.g., aviation forecasts) to carry out its respective mission: broadly speaking, NOAA's National Weather Service (NWS) is responsible for protecting life and property and enhancing the national economy;[5] academia is responsible for advancing the science and educating future

[4] World Health Organization Fact Sheet 266, December 2001, <http://www.who.int/inf-fs/fact266.html>.

[5] National Weather Service, 1999, *Vision 2005: National Weather Service Strategic Plan for Weather, Water and Climate Services*, <http://205.156.54.206/sp/strplan.htm>.

generations of meteorologists; and the private sector (weather companies and private meteorologists working in the media) is responsible for creating products and services needed by specialized customer groups and for working with the NWS to communicate forecasts and warnings that may affect public safety. This arrangement has benefited the nation by providing better and more comprehensive weather and climate services than could be provided by any one alone.

On the other hand, although created for different purposes, some of the products and services offered by the different sectors are similar, which creates potential friction and inefficiencies in the weather enterprise. A number of attempts have been made to better differentiate the roles of the sectors, but with limited success (see "History of the NWS-Private Sector Partnership" below). The problem is inherent in the existing system for the following reasons:

- The activities of the sectors overlap. Each sector relies, to a greater or lesser extent, on shared data collection, modeling and analysis, and information dissemination.
- The capabilities of the sectors change with advances in technology and declining costs of computing. Many activities that used to require substantial government infrastructure (e.g., some sophisticated modeling) can now be done using desktop computers and the Internet.
- The usefulness of a product to a particular sector changes. For example, a specialized technology developed by the private sector loses much of its commercial value when it becomes commonplace and is adopted by the other sectors.
- The products and services offered by the sectors change as new user groups emerge and the needs of existing users evolve. For example, improved scientific understanding and forecasting have permitted new industries to factor in weather and climate projections. Rapidly changing markets and increasingly high expectations of users for speed and convenience decrease the life span of many products and services.
- All members do not share the same expectations and understanding of the proper roles and responsibilities of the three sectors (Appendix B).

Therefore the question is how to take advantage of all that the different sectors have to offer while minimizing conflict and inefficiency. This can be a difficult question to answer because data on the scale of operations and the actual costs of the three sectors are limited, making it difficult to determine how to optimize the efficiency of the system. Moreover, the characteristics of the weather and climate enterprise appear to be unique, making it difficult to apply lessons learned from other disciplines. For example, the science underlying the weather enterprise is mature, giving rise to increasingly accurate forecasts on which the public can rely on a daily basis. On the other hand, other types of forecasts (e.g., economics, marketing) depend on substantially less well developed science and are therefore relied on less.

At the request of the NWS, the National Research Council Committee on Partnerships in Weather and Climate Services was established to undertake the following tasks (see also Appendix A):

- Examine the present roles of the public, private, and academic sectors in the provision and use of weather, climate, and related environmental information and services in the United States.
- Identify the effects that advances in observing, modeling, forecasting, and information dissemination technologies may have on the respective roles of the public, private, and academic sectors.
- Examine the interfaces between the various sectors, identify barriers to effective interaction, and recommend changes in policies or practices that could improve the potential for providing weather and climate information.
- Make recommendations regarding how most effectively to coordinate the roles among the various sectors.

An analysis of these issues for the environmental sciences in general appears in the National Research Council report, *Resolving Conflicts Arising from the Privatization of Environmental Data*.[6] This report begins with the results of that analysis and examines the issues as they pertain to public, private, and academic partnerships for creating civilian weather and climate services. The stresses affecting the sectors providing weather services and the sectors providing climate services are similar, but weather issues are the most contentious and receive the most attention. Friction among the climate sectors is not yet a serious problem, although it could become important when improved understanding of the atmosphere draws private companies into making longer-term forecasts for events such as El Niños.[7] However, the improvements that the committee recommends for the weather enterprise should also be applicable to climate issues.

Because the NWS is the primary public weather agency in the United States and constitutes the largest party in the public-private-academic part-

[6]National Research Council, 2001, *Resolving Conflicts Arising from the Privatization of Environmental Data*, National Academy Press, Washington, D.C., 99 pp.

[7]The most recent attempt to curtail NOAA's climate activities was in 1995 when the House of Representatives proposed dismantling the Department of Commerce. The bill, which did not pass, would have abolished the regional climate centers and privatized the NOAA research laboratories and data centers. H.R. 1756, Department of Commerce Dismantling Act, 104th Congress, 1st session.

nership, the committee paid attention both to the NWS parent organization, the National Oceanic and Atmospheric Administration, in general, and to the NWS in particular. The activities of other government agencies that purchase or produce weather services (e.g., Federal Aviation Administration, Department of Defense, Department of Agriculture, National Institutes of Health, state government agencies) are discussed only to the extent that they affect NWS partnerships.

HISTORY OF THE NWS-PRIVATE SECTOR PARTNERSHIP

The NWS has its roots in the Smithsonian Institution, which supplied weather instruments to telegraph stations and created an extensive observation network in 1849 (Table 1.1).[8] Weather services were supplied by the Telegraph Service and the U.S. Army Signal Corps until 1890, when Congress created a Weather Bureau in the Department of Agriculture.[9] For more than 50 years, the Weather Bureau operated as the primary organization for conducting weather research, making observations, issuing weather warnings, and providing forecasts and other weather information to the public. However, the return of Air Force and Navy meteorologists from World War II battlefields led to a rapid expansion of commercial weather services.[10] To clarify the relationship between the Weather Bureau and private meteorologists, the American Meteorological Society (AMS) convened a conference in 1948.[11] The resulting "six-point program" developed by the chief of the Weather Bureau, representatives of industrial weather consulting services, and the AMS (Appendix B) was never adopted as formal policy by the Weather Bureau. Instead, the Weather Bureau issued a circular letter to all of its offices providing guidelines for cooperating with the private sector.[12] The letter specified that Weather Bureau employees should not provide "individualized services" such as those provided by the private sector. Requests for such services were to be referred to the AMS, which would pass them on to private consultants.

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[8]The framework for much of this section is given in Appendix B. A time line showing the evolution of the NWS can be found at <http://www.erh.noaa.gov/er/gyx/timeline.html>.

[9]NWS Organic Act, October 1, 1890, Session I, ch. 1266, 26 Stat. 653-55.

[10]Prior to World War II, the only significant private sector meteorologists were with the major airlines. See Advisory Committee on Weather Services, 1953, *Weather Is the Nation's Business*, Department of Commerce, U.S. Government Printing Office, Washington, D.C., 59 pp.

[11]American Meteorological Society, 1949, Report of the executive secretary, 1948, *Bulletin of the American Meteorological Society*, v. 30, p. 140-141.

[12]Weather Bureau, 1948, Policy with respect to private practice of meteorology and instructions regarding cooperation with private meteorologists, Circular Letter 22-48, March 9.

The broad changes in the weather enterprise led the Department of Commerce, which had operated the Weather Bureau since 1940, to convene an advisory committee in 1953 to review civilian weather issues, including those arising from the emergence of a private practice in meteorology.[13] That advisory committee found several instances in which field offices provided services to individuals in direct competition with private meteorologists, in part because the circular letter did not "clearly establish the relationship between the Weather Bureau and private meteorologists." Noting that the development of the commercial sector should lead to greater efficiency of the Weather Bureau, the advisory committee recommended

- that the Weather Bureau actively encourage the development of private meteorology;
- that private meteorologists create radio and television weather programs without censorship of any kind;
- that the circular letter be canceled in favor of a new directive based on the six points agreed to at the 1948 AMS meeting; and
- that a special committee be created in the Department of Commerce to review complaints and determine which services should be discontinued by the Weather Bureau.[14]

Most, but not all, of these recommendations were eventually implemented (no special committee was formed to manage complaints), spurring a substantial expansion of the commercial weather industry.[15]

In the decades that followed, debate over the roles of the Weather Bureau (from which the National Weather Service emerged in 1970) and the private sector continued. In 1978 the NWS updated its policy on industrial meteorology, specifying that NWS products were to be provided to the private sector on a nondiscriminatory basis and that specialized services should be provided by the private sector.[16] Beginning in the early 1980s, Congress began a sustained effort to privatize government functions. The transfer of civilian meteorological satellites to the private sector was considered and rejected,[17] but the privatization of products and services gained

[13]Advisory Committee on Weather Services, 1953, *Weather Is the Nation's Business*, Department of Commerce, U.S. Government Printing Office, Washington, D.C., 59 pp.

[14]Advisory Committee on Weather Services, 1953, *Weather Is the Nation's Business*, Department of Commerce, U.S. Government Printing Office, Washington, D.C., p. 46.

[15]C.C. Bates, 1976, Industrial meteorology and the American Meteorological Society—A historical overview, *Bulletin of the American Meteorological Society*, v. 57, p. 1320-1327.

[16]National Weather Service, 1978, Policy on industrial meteorology, *National Weather Service Operations Manual 78-24*, Part A, Chapter 55, pp. 1-3.

[17]H.R. 6798, Atmospheric, Climatic, and Ocean Pollution Act of 1982, 97th Congress, directed the NWS administrator to submit a report on the appropriateness of privatizing meteorological satellites. The Land Remote Sensing Commercialization Act of 1984 (Public

steam. House and Senate reports regularly admonished the NWS to privatize services and to avoid competing with the private sector, and in 1991 the NWS responded by updating its 1978 policy on industrial meteorology.[18] The 1991 policy acknowledges the desirability of a public-private partnership and defines the roles of the NWS and commercial weather companies with the goal of avoiding unnecessary competition with the private sector. Subsequently, Congress directed the privatization of several specialized services, including agriculture and non-federal, non-wildfire fire weather services (1995), and the NWS further curtailed its activities by issuing guidelines prohibiting event-specific forecasts (1996).[19]

At about the same time, the Office of Management and Budget issued a circular mandating full and open access to government data (i.e., information is made available without restriction for no more than the cost of preparing and disseminating the information).[20] This policy was in line with a long-standing NWS practice of providing affordable data to all (Table 1.1).[21] However, the formal data policy and restrictions on NWS activities did not settle the debate about roles and responsibilities of the public and private sectors, and in the late 1990s the Commercial Weather Services Association spearheaded a lobbying effort to change the NWS Organic Act and prevent competition with the private sector.[22] These efforts have not succeeded, and the debate continues today.[23]

Law 98-365) prohibits the "leasing, selling, or transferring to the private sector, commercializing, or dismantling any portion of the weather satellite systems."

[18]The National Weather Service and the Private Weather Industry: A Public-Private Partnership, 56 Federal Register 1984, January 18, 1991.

[19]Reports 104-196 and 104-139 to accompany H.R. 2076, Departments of Commerce, Justice, and State, the Judiciary, and related agencies appropriations bill, fiscal year 1996, 104th Congress, 1st session; Memorandum from the Assistant Administrator for Weather Services to NWS directors, June 7, 1996. The contents of the memorandum were codified in Guidelines for support of special events, NWS Operations Manual Letter 04-00, July 17, 2000.

[20]OMB Circular A-130, Management of Federal Information Resources, 1994; codified in the Paperwork Reduction Act of 1995. See 44 U.S.C. § 35 and 61 Federal Register 6428, February 20, 1996.

[21]The first NWS policy concerning data dissemination was issued in 1978 (Policy on industrial meteorology, *National Weather Service Operations Manual*, Part A, Chapter 5, December 20, 1978). Under the 1990 Budget Reconciliation Act (56 Federal Register 33259), NOAA charged fair market value to commercial users for certain data, information, and products in FY 1991 and FY 1992.

[22]For example, see the testimony before the House of Representatives Subcommittee on Energy and Environment by Michael S. Leavitt on behalf of the Commercial Weather Services Association on April 9, 1997, 105th Congress, 1st session, and by Joel Myers on behalf of AccuWeather, Inc., on March 25, 1998, 105th Congress, 2nd session.

[23]Further commentary on this debate can be found in Appendix B, and specific examples of contentious issues are given in Appendix D. These issues are discussed further in Chapter 3.

TABLE 1.1 Milestones in Meteorology

Year	Event
1814	Surgeon General of the Army orders his staff to begin recording the daily weather during the War of 1812[a]
1845	Telegraph system envisioned as a great tool for weather forecasting by Joseph Henry, secretary of the Smithsonian Institution[a]
1870	Congress directs the Secretary of War to provide observations from the interior of the United States and the Great Lakes[a]
1870s	Army Signal Corps provides daily weather maps and forecasts in the United States[b]
1873	Establishment of the International Meteorological Organization and international agreement on full and open exchange of meteorological data
1890	National weather function is transferred from Signal Corps to U.S. Weather Bureau[a]
—	Operational surface network is established in the United States; data are communicated by teletype
1905	First marine weather report broadcast at sea[a]
1920s	Operational radiosonde network is established
1922	Lewis Fry Richardson's book *Weather Prediction by Numerical Process* is published
1926	First full-time broadcast meteorologist is hired by a radio station, WEEI, Boston[c]
1934	First private sector meteorologist is hired by a utility company[d]
1935	First private (value-added nongovernmental) forecast is made by a meteorologist for a client
1936	Private meteorological instrument company is formed—Vaisala in Finland
1939	Carl-Gustav Rossby demonstrates the usefulness of linearized perturbation equations for numerical weather prediction[e]
1940s	Operational radiosonde networks are established around the world[b]
1943	First aircraft flight into a hurricane to collect observations[a]
1944	National radiosonde network enables the prediction of a hurricane directly into a surface high-pressure system[a]
1944	Eye and spiral bands of a tropical cyclone are observed by radar on a U.S. Navy ship[a]
1944	Weather forecasts for next few days convince General Eisenhower to delay D-day from June 5 to June 6[f]
1946	First group of private weather service companies begins operations[d]
1948	First weather forecast is presented on television
1948	First successful forecast of a tornado[g]
1950	First experimental 24-hour forecast of 500-millibar heights over North America on the ENIAC computer[h]
1950s	Operational radar networks are established[b]
1954	Weather radar is first used on a television weathercast[c]
1955	First operational numerical weather prediction[i]
1960	First private meteorological consulting, research, and development company (TRC) is formed
1960	Launch of the first operational weather satellite, TIROS-I[j]
1963	E. Lorenz publishes the first paper on limits of atmospheric predictability[k]
1963	First live satellite images are displayed on television
1968	Private environmental research companies (e.g., ERT) form to meet concerns about air quality

1969	Nimbus 3 is launched carrying two infrared sounders; first atmospheric soundings based on satellite remote sensing are obtained
1975	First geostationary satellite (GOES-1) is launched, making possible animations of cloud photographs
1981	First commercial Doppler radar is installed at a TV station[c]
1983	First computerized color graphics of weather maps are presented on television
—	First live radar images are displayed on television
1983-89	Lightning detection network is established in the United States
1986	First climate forecast of sea-surface temperature in the tropical Pacific[j]
1989	NWS modernization program begins
1995	WMO Resolution 40 governing the use of weather and climate data is passed[l]
—	First ensemble forecasts are produced
1995	Radio occultation sounding of the Earth's atmosphere is demonstrated in GPS/MET experiment[m]
1997	TRMM satellite is launched; first weather radar in space
2000	NWS modernization program concludes

NOTE: GPS/MET = Meteorological applications of the Global Positioning System; WMO = World Meteorological Organization.

[a]R.H. Simpson, ed., 2002, *Coping with Hurricanes: A Historical Analysis of 20th Century Progress*, American Geophysical Union Monograph, Washington, D.C., in press.

[b]National Research Council, 1998, *The Atmospheric Sciences Entering the Twenty-First Century*, National Academy Press, Washington, D.C., 384 pp.

[c]R. Leep, 1996, The AMS and the development of broadcast meteorology, in *Historical Essays in Meteorology, 1919-1995*, J.R. Fleming, ed., American Meteorological Society, Boston, p. 481-507.

[d]D.B. Spiegler, 1996, A history of private sector meteorology, in *Historical Essays in Meteorology, 1919-1995*, J.R. Fleming, ed., American Meteorological Society, Boston, pp. 417-441.

[e]E. Kalnay, S.J. Lord, and R. McPherson, 1998, Maturity of operational numerical weather products: Medium range, *Bulletin of the American Meteorological Society*, v. 79, p. 2753-2769.

[f]J.M. Stagg, 1972, *Forecast for Overlord, June 6, 1944*, W.W. Norton, New York, 128 pp.

[g]<http://www.nssl.noaa.gov/Golden Anniversary/>.

[h]J.J. Tribbia and R.A. Anthes, 1987, Scientific basis of modern weather prediction, *Science*, v. 237, p. 493-499.

[i]National Research Council, 2000, *From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death*, National Academy Press, Washington, D.C., 80 pp.

[j]National Research Council, 2000, *Issues in the Integration of Research and Operational Satellite Systems for Climate Research: Part I. Science and Design*, National Academy Press, Washington, D.C., 152 pp.

[k]E. Lorenz, 1963, Deterministic nonperiodic flow, *Journal of Atmospheric Science*, v. 20, p. 130-141.

[l]WMO, 1996, *Exchanging Meteorological Data: Guidelines on Relationships in Commercial Meteorological Activities. WMO Policy and Practice*, WMO No. 837, Geneva, Switzerland, 24 pp.

[m]R. Ware, M. Exner, D. Feng, M. Gorbunov, K. Hardy, B. Herman, Y. Kuo, T. Meehan, W. Melbourne, C. Rocken, W. Schreiner, S. Sokolovskiy, F. Solheim, X. Zou, R. Anthes, S. Businger, and K. Trenberth, 1996, GPS sounding of the atmosphere from low Earth orbit: Preliminary results, *Bulletin of the American Meteorological Society*, v. 77, p. 19-40.

INTERNATIONAL DIMENSIONS

Weather and climate are inherently global phenomena, and their analysis requires measurements from observing systems located in other countries. The United States has obtained weather data from other countries through international agreements reached through the World Meteorological Organization (WMO) and its predecessors since the late 1800s. WMO is an intergovernmental agency of the United Nations, and its 185 members are all representatives of the national meteorological and hydrological services in their country.[24] The United States is a major contributor to WMO, providing about 25% of the WMO budget, and is also the major participant and contributor to international observing systems and research programs. The NWS is the U.S. member of WMO and represents the public, private, and academic sectors. For several years the U.S. delegation to the WMO executive committee meetings has included private sector advisers in addition to public and academic sector advisers at the invitation of the NWS. These advisers participate in the discussions but do not vote, and their presence signals the importance of all three sectors to the weather enterprise. No other WMO member has included private sector representation on its delegations.

As members of WMO, countries agree to work together to set standards and exchange data and products. Such agreements can be difficult to craft because each government has its own approach to the provision of weather services. In the past, most data were freely shared, but increasing costs, declining budgets, and different philosophies about the role of federally funded meteorological services have led some countries to fully or partly privatize weather services. For example, New Zealand created a government-owned corporation (New Zealand MetService) to "grow as a commercially successful business delivering worldwide weather and information presentation services."[25] Many European meteorological offices are now organized with commercial arms that compete with the private sector for commercial contracts. The United States is one of a few countries that continues to provide full and open access to data and that has a thriving commercial weather industry. For example, there are fewer than 30 private weather companies in Europe and more than 400 private weather companies in the United States.[26]

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[24] <http://www.wmo.ch/index-en.html>.

[25] 2000-2001 Annual Report, p. 2, <www.metservice.co.nz>.

[26] P. Weiss, 2002, Borders in Cyberspace, 19 pp., <ftp://ftp.cordis.lu/pub/econtent/docs/peter_weiss.pdf>.

ORGANIZATION OF THE REPORT

In this report the committee examines the roles of the public (primarily the NWS), academic, and private sectors in providing weather and climate services and identifies barriers and opportunities for improving interactions among the sectors. The complete committee charge is given in Appendix A. Chapter 2 reviews the roles and motivations of the three sectors and the needs of the users they serve. Additional detail on the roles of the sectors in modeling and observing systems is given in Appendix C. Chapter 3 describes interactions among the sectors, including successful partnerships as well as conflicts and misunderstandings. Some of the examples used in the chapter were provided by private sector companies, and their letters and the NOAA responses are given in Appendix D. Chapter 4 provides the legal, social, policy, and economic framework for the weather and climate enterprise. A white paper commissioned by the committee outlines the social issues in greater detail and is given in Appendix E. Chapter 5 discusses the impact of scientific and technological advances (data collection, modeling, forecasting, and dissemination) on partnerships. Chapter 6 recommends ways to improve the effectiveness of the U.S. weather enterprise. A different view of many of these topics is given in Appendix B, a commissioned paper that provides an overview of the NWS-private sector partnership. Finally, biographical sketches of committee members and a list of acronyms and abbreviations are given in Appendixes F and G, respectively.

2

The U.S. Weather and Climate Enterprise

The goal of any weather or climate information system is to provide credible information that the public needs, including forecasts, warnings, and information on which to base quality-of-life decisions (e.g., likely demand for air conditioning or heating). Preparing a forecast or weather advisory begins with the collection of data from a variety of specialized sensors. The data are calibrated, validated, checked for quality, analyzed to determine the state of the atmosphere, and incorporated into models of the atmospheric and hydrologic systems. Finally, meteorologists integrate the model predictions with local information and their knowledge of specific weather phenomena to generate forecasts, advisories, and other weather and climate products. The products and services cover the past, present, and future states of the atmospheric and hydrologic systems and are issued on scales ranging from a few minutes for a tornado warning, to tomorrow's weather forecast (now extending 10 to 14 days), to seasonal and interannual climate outlooks, to decades and centuries assessments. User demand and the economic and social benefits of more accurate forecasts and more useful products drive the collection of better data (new measurements, more sensitive or accurate instruments, denser coverage) and the development of more realistic models, so the weather information system is constantly improved. All three sectors—public, private, and academic—contribute to the weather and climate information system, and all have an interest in improving its quality and usefulness. In this chapter the committee describes the current weather and climate information system, the goals and motivations of the three sectors for contributing to it, and some user demands driving improvements to the system.

THE WEATHER AND CLIMATE INFORMATION SYSTEM

The U.S. government invested about $2.7 billion in fiscal year 2002 for meteorological operations and supporting research, 93% of which was channeled through the National Oceanic and Atmospheric Administration (NOAA), the Department of Defense (DOD), and the Department of Transportation (DOT).[1] The NOAA share (including satellite operations, weather and climate services, research, and archiving) is $1.6 billion, of which $745 million supports National Weather Service (NWS) activities and $2.3 million supports the six regional climate centers.[2] Weather-related research, including in-house government research and academic research funded by government agencies, constitutes about 17% of the federal budget for weather activities.[3] A significant but unknown amount of money is also invested by the private sector and state agencies to create weather and climate services. There are about 400 commercial weather companies and independent contractors in the United States,[4] with revenues of about $500 million.[5] All but four states have a state climatologist,[6] and most contribute funding to the regional climate centers as well as to relevant state government agencies (e.g., transportation, environment, natural resources, emergency management). The value of data and products generated by the entire U.S. weather enterprise, including the media and financial services, is estimated to be in the billions and perhaps tens of billions of dollars.[7]

Each of the sectors participates in the weather enterprise for different reasons. The government participates because weather information and forecasts are critical to public safety, which is a government responsibility, they enhance the national economy, and they are necessary to support a

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[1]Other agencies that offer meteorological services and support associated research include the U.S. Department of Agriculture, Department of Interior, Environmental Protection Agency, National Aeronautics and Space Administration, and Nuclear Regulatory Commission. See Office of the Federal Coordinator for Meteorological Services and Supporting Research, *The Federal Plan for Meteorological Services and Supporting Research, Fiscal Year 2002*, <http://www.ofcm.gov/fp-fy02/fedplan.htm>.

[2]See National Climate Program Act, <http://www.cfda.gov/public/viewprog.asp?progid=184>.

[3]Office of the Federal Coordinator for Meteorological Services and Supporting Research, *The Federal Plan for Meteorological Services and Supporting Research, Fiscal Year 2002*, <http://www.ofcm.gov/fp-fy02/fedplan.htm>.

[4]A voluntary list of more than 320 commercial weather providers is maintained by the NWS Office of Strategic Planning and Policy at <http://205.156.54.206/im/dirintro.htm>.

[5]R.A. Guth, 2000, Japan's weather mogul to storm U.S., *Wall Street Journal*, p. B15.

[6]A list of state climatologists appears at <http://lwf.ncdc.noaa.gov/oa/climate/state climatologists.html>.

[7]Placing a value on weather information is difficult, in part because of a paucity of information on the size, investments, and revenues of the commercial weather industry. The

variety of national needs (e.g., agriculture, military, transportation). Providing reliable weather and climate information to the public requires expensive observing systems, long-term monitoring, and the synthesis of current and retrospective data from around the world, all of which NOAA, as a government agency, is well placed to do. NOAA has the primary civilian responsibility for installing and maintaining weather observing systems, negotiating data exchange agreements with other countries, and operating a climate data center that will hold the data in perpetuity. These functions are carried out by different parts of NOAA (Figure 2.1). State governments also collect data and operate data centers for the economic and public benefits they bring to the state.

Weather information disseminated to the public takes the form of forecasts, advisories, and other weather products. It is essential that the public be able to trust this government-generated information. Trust results from five primary characteristics of the information: (1) accuracy, (2) reliability,[8] (3) objectivity, (4) open and unrestricted access, and (5) scientifically based error estimates. Making data easy and affordable to obtain also helps NOAA (and to some extent state agencies) fulfill its mandate of promoting scientific understanding of weather and climate phenomena, creating a more informed public, providing unbiased information (e.g., for legal or forensic purposes), and giving the commercial weather industry an opportunity to flourish.

The academic sector (i.e., universities and nonprofit research corporations such as the University Corporation for Atmospheric Research [UCAR])[9] participates in the weather enterprise to fulfill its research and education mission. Scientists want to better understand the state of the

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value of weather and climate services, not including the media and financial services, is estimated to be $500 million to $1 billion. See R. Pielke, Jr., and R.E. Carbone, 2002, Weather impacts, forecasts, and policy: An integrated perspective, *Bulletin of the American Meteorological Society*, v. 83, p. 393-403; W.D. Nordhouse, 1986, The value of information, in *Policy Aspects of Climate Forecasting*, R. Krasnow, ed., Resources for the Future, Washington, D.C., pp. 129-134; R.M. Adams, K.J. Bryant, B.A. McCarl, D.M. Legler, J. O'Brien, A. Solow, and R. Weiher, 1995, Value of improved long-range weather information, *Contemporary Economic Policy*, v. 8, p. 10-19. If media and financial services are considered, the value of the market is considerably higher. For example, in 2000, weather derivatives contracts with a total value of $2.5 billion were issued in the United States (PricewaterhouseCoopers, 2001, The weather risk management industry: Survey findings for November 1997 to March 2001, A report to the Weather Risk Management Association, <http://www.wrma.org>).

[8]The reliability of forecasts refers to their timeliness and dependability of delivery and to their trustworthiness. Thus, reliable forecasts are delivered on a fixed, dependable schedule; their accuracies and errors are known to the user; and they contain no surprises.

[9]UCAR is a nonprofit corporation operated under the government's Federally Funded Research and Development Center (FFRDC) program and supported primarily by public funds.

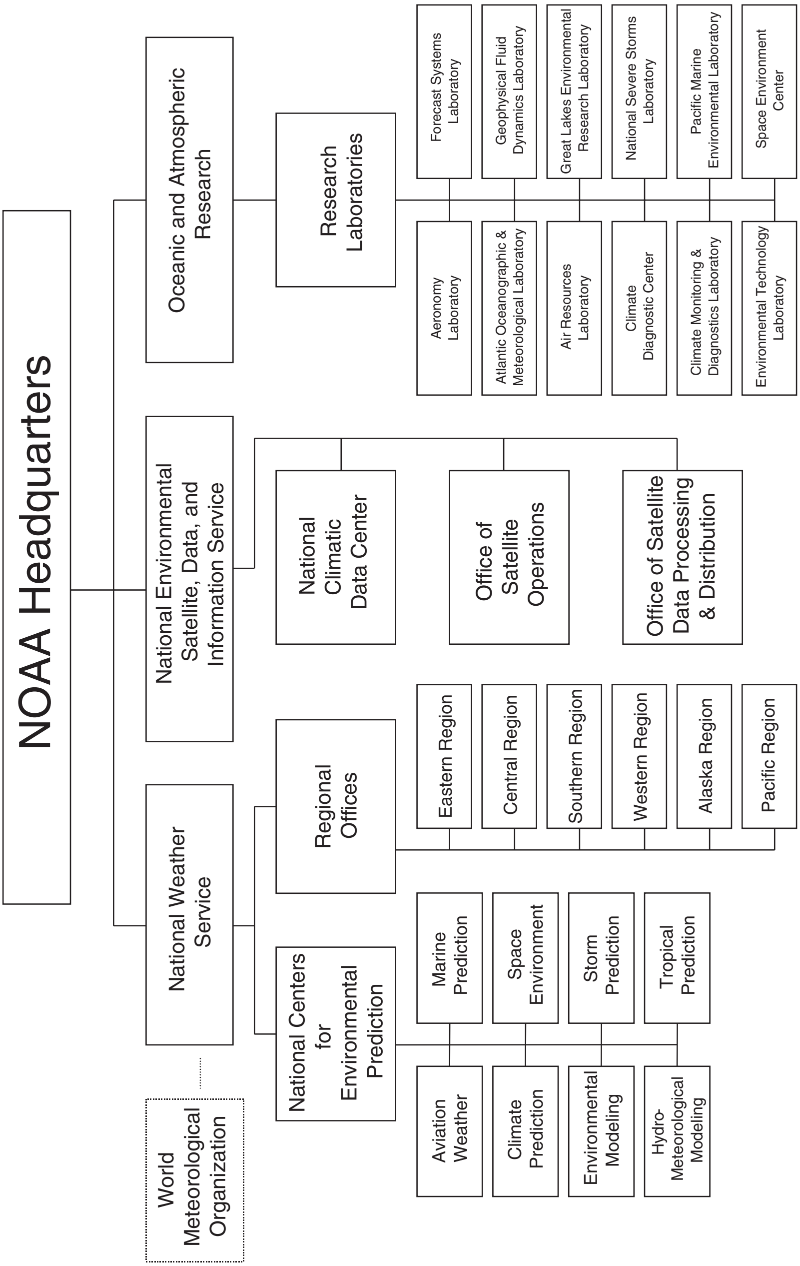

FIGURE 2.1 NOAA divisions that participate in the weather and climate enterprise.

atmosphere and related systems such as the oceans and how they are changing. They also want to communicate this knowledge to their colleagues, students, funding agencies (primarily NOAA, the National Science Foundation [NSF], and the National Aeronautics and Space Administration [NASA]), the local community, and the general public. The resulting research results, models, technology, and information are generally placed in the public domain, either in scientific publications or on the web, or are transferred to the private sector. Some university researchers also consult for the weather industry for fees, and the resulting research is usually proprietary.

Finally, private companies—weather companies, university spinoffs, and the media—participate in the weather enterprise to sell weather products and services on an ongoing basis in a commercial market. Many industries (e.g., utilities, transportation, insurance, agriculture) also have meteorologists on staff to prepare weather products for internal purposes. Market incentives encourage private companies to generate innovative products or ways of presenting weather information. Private companies are usually highly specialized and provide products and services that are tuned to the needs of specific paying customers. Revenues are generated from a broad customer base (government, private, academic, general public), through either direct sales or advertising.

CURRENT ACTIVITIES OF THE SECTORS

Observations

A variety of federal, state, local, private, and international organizations collect and exchange meteorological data. An overview of the complexities of the U.S. observing system is given in Appendix C. NOAA collects data from satellites (e.g., images of clouds, global atmospheric temperature and water vapor profiles, and winds), reconnaissance aircraft (e.g., snow cover, profiles via dropsondes in tropical storms and hurricanes), upper-air balloons (vertical profiles of winds, temperature, and humidity), and land and marine surface sites (e.g., precipitation, streamflow, air and sea-surface temperature, humidity, winds, and other variables) (Table 2.1). Some of these stations are automated, such as those located at airports, and an additional 11,000 ground stations are staffed by volunteers through NOAA's Cooperative Observer Network.[10] NOAA also obtains

[10]The Cooperative Observer Network was established in 1890 to make meteorological observations, primarily for agricultural purposes. Today the network supports a wide variety of meteorological and hydrological applications and is the only nationwide source of data on surface precipitation and the only source of systemic observations of surface snow. See National Research Council, 1998, *Future of the National Weather Service Cooperative Observer Network*, National Academy Press, Washington, D.C., 65 pp.

TABLE 2.1 Federal Facilities or Stations for Taking Meteorological Observations, FY 2001

Type of Observation	NOAA	Other Agency	Total	% NOAA
Land surface	841	2942	3783	22
Ships	140	541	681	21
Buoys	95	0	95	100
Other marine stations	260	2	262	99
Atmospheric profilers	0	7	7	0
Upper-air balloons	108	237	345	31
Upper-air rockets	0	2	2	0
Radars	181	140	321	56
Aircraft	3	10	13	23
Satellites	4	5	9	44

SOURCE: Office of the Federal Coordinator for Meteorological Services and Supporting Research, *The Federal Plan for Meteorological Services and Supporting Research, Fiscal Year 2002*, <http://www.ofcm.gov/fp-fy02/fedplan.htm>.

real-time access to weather data from 184 countries through the World Weather Watch, including data from 9 satellites, 10,000 land stations, 7,000 ship stations, and 300 moored and drifting buoys.[11]

The core observations collected under the auspices of NOAA are supplemented by data collected by other federal agencies, state agencies, private companies, and academia. For example, DOD collects weather data to support military operations, and DOT collects data to improve the safety and efficiency of air, railroad, coastal waterway, and highway transportation systems.[12] At the state level, all but four states deploy roadway weather information sensors, and several operate networks of soil moisture instruments. Some even own automated weather observing systems.[13] Both state and private sector organizations collect local and regional air quality measurements. For-profit companies also measure basic meteorological parameters from ground stations (about 10,000 sensors)[14] and from sensors

[11]The World Weather Watch is the backbone of the World Meteorological Organization's activities. See <http://www.wmo.ch/index-en.html>.

[12]Office of the Federal Coordinator for Meteorological Services and Supporting Research, *The Federal Plan for Meteorological Services and Supporting Research, Fiscal Year 2002*, <http://www.ofcm.gov/fp-fy02/fedplan.htm>.

[13]For example, see the Iowa Mesonet at <http://mesonet.agron.iastate.edu/pipermail/dailyb/2002-June/000125.html>, Michigan airport sites at <http://www.michigan.gov/aero/0,1607,7-145-6775_7025—,00.html>, and Florida Automated Weather Network at <http://fawn.ifas.ufl.edu/>.

[14]One of the largest networks is operated by AWS Convergence Technologies, Inc., which collects temperature, humidity, wind, pressure, and precipitation data at 5,000 sites. See <http://www.aws.com>.

mounted on commercial aircraft (Appendix C). In addition, many television stations own a Doppler radar and operate networks of meteorological sensors, and many have dozens of observers in the field. Finally, some universities make local measurements or maintain networks for research purposes, such as SuomiNet.[15] A few universities partner with government agencies and private companies to create state and regional networks, such as the Oklahoma Mesonet and MesoWest.[16]

Some of the data collected by private sector companies are used by the NWS for creating forecasts and warnings, particularly if the data are unique. For example, commercial airlines collect temperature, humidity, and wind data and provide them in real time to the National Centers for Environmental Prediction (NCEP), where they have proven very valuable to numerical forecasts. They also make them available for non-real-time government and academic research purposes (Appendix C). Another example is the lightning data that the NWS purchases from Vaisala-Global Atmospherics, Inc., which owns the nation's only lightning network.[17] However, the cost, difficulty of keeping track of and enforcing restrictions, and uncertainties about the quality of proprietary data mean that most private sector data are not used for public purposes (see Chapter 4).

Modeling

The federal government—mostly the eight NWS National Centers for Environmental Prediction but also DOD (the Navy and Air Force)—runs operational global and regional models. NCEP develops models for weather prediction (1-15 days), ocean prediction (daily to annual), and climate prediction (monthly, seasonal to interannual). These models are used by government agencies, academia, and the private sector. Other countries also produce numerical weather and climate models, such as the models of the European Centre for Medium-Range Weather Forecasts (ECMWF), but some of their model output is restricted, hindering their use by all sectors, particularly the private sector.[18]

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[15]SuomiNet is a university-based network of Global Positioning System receivers that produce vertical profiles of water vapor. A description is given in R.H. Ware, D.W. Fulker, S.A. Stein, D.N. Anderson, S.K. Avery, R.D. Clark, K.K. Droegemeier, J.P. Kuettner, J.B. Minster, and S. Sorooshian, 2000, SuomiNet: A real-time national GPS network for atmospheric research and education, *Bulletin of the American Meteorological Society*, v. 81, p. 677-694.

[16]<http://okmesonet.ocs.ou.edu/>, <http://www.jmet.utah.edu/jhorel/html/mesonet/info.html>.

[17]See <http://www.lightningstorm.com/ls2/discover/nldn/index.jsp>. Global Atmospherics, Inc., originated as a commercial spinoff from the University of Arizona.

[18]National Research Council, 1998, *Capacity of U.S. Climate Modeling to Support Climate Change Assessment Activities*, National Academy Press, Washington, D.C., 65 pp.

Numerical models are used for both weather and climate forecasting. Weather forecast models are deterministic and must start out with initial conditions based on observations that are as accurate as possible. The accuracy and skill of the deterministic forecasts diminish with time until the limit to deterministic atmospheric predictability is reached, which is approximately two weeks. In contrast to weather forecast models, climate models are run for months to many years into the future. They generally contain models of the components of the climate system—the atmosphere, ocean, land, and ice—and these components interact in the coupled climate model. Details of the initial conditions of the climate models are of less importance than those of the weather prediction models, although climate models run out for a few months to a couple of years require good estimates of the ocean structure, especially near the surface. Climate models are used in many ways—to understand present and past climates, to project the climate many years into the future under various scenarios of climate forcing (such as changing greenhouse gas emissions or land use patterns), and to predict short-term climate change associated with seasonal and interannual variability (e.g., El Niño events).[19]

Academic scientists create atmospheric models capable of simulating weather and climate phenomena primarily for research and education purposes. Examples include the highly detailed models of convective cloud clusters produced by Colorado State University or models of squall lines produced by Oklahoma University. Some models are also run in an operational mode in which the resulting predictions are provided to the public, usually via the World Wide Web. The fifth-generation Penn State-National Center for Atmospheric Research (NCAR) Mesoscale Model (MM5)[20] is often used this way (see the Antarctica rescue example in Chapter 3). Other models are intended to supply predictions for local use by state governments and private companies.[21] Unlike NCEP models, however, these academic models do not have to be run every day on schedule, nor do they have to deliver specified products. Academic models are used by all the sectors. For example, in 2000, MM5 was used by 44 universities, 28 federal and state agencies, 60 foreign organizations, and 28 private companies.[22]

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[19]National Research Council, 2001, *Improving the Effectiveness of U.S. Climate Modeling*, National Academy Press, Washington, D.C., 128 pp.

[20]Mesoscale weather models numerically simulate and predict atmospheric phenomena with horizontal scales ranging from a few to several thousand kilometers (i.e., weather systems with horizontal dimensions ranging from those of thunderstorms and cyclonic rain bands to tropical and extratropical cyclones).

[21]For example, the University of Maryland is seeking funding from state transportation agencies for transportation applications of its regional MM5.

[22]National Research Council, 2000, *From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death*, National Academy Press, Washington, D.C., 80 pp.

To better serve specific needs, the private sector usually modifies models developed by academia or the NWS, using initial conditions obtained from NCEP global models. For example, WSI runs a version of MM5 and the NWS seasonal model, which are in the public domain. The models are often run in operational or on-demand mode, depending on customer needs. Mesoscale models are useful complements to the global models run by NCEP and other international weather centers because they are scalable, will run on personal computers, produce very local predictions, and meet market demand for frequent forecast periods and updates. However, national and regional-scale models are also used. For example, Weather Central, Inc., runs Adonis, a variation of a University of Wisconsin model, at high resolution on a national scale. The predictions from these tailored models, as well as from NWS models, are used by hundreds of television stations to prepare their forecasts and graphics.

Forecasts and Other Weather and Climate Services

Weather Services

All three sectors produce forecasts and provide weather services. The major services provided by the NWS include weather advisories, watches, warnings, and forecasts; river forecasts; aviation weather services; marine weather services; fire weather services; tsunami warnings; and community preparation for weather-related disasters or storms. Forecasts and warnings are prepared by and disseminated through a national network of 122 weather forecast offices and 13 river forecast centers. The weather forecast offices are experts in their local areas and are responsible for watches, warnings, advisories, forecasts, and community interactions for an assigned geographic area. NCEP provides guidance on specific weather phenomena, from short-range forecasts to seasonal and interannual climate outlooks; the models used to prepare the forecasts; and forecasts and warnings from its specialized centers (e.g., tropical storms, aviation and marine weather). Other NWS offices deal primarily with topic-specific issues, such as aviation services. In addition to their primary research activities, some of the NOAA research laboratories develop numerical models, improve forecast methods, and produce other weather and climate services. They also provide training on the use of weather software and technologies developed at the laboratories to other government agencies (in the United States and abroad)[23] and the private sector. Systems and software are placed in the

[23]For example, the Forecast Systems Laboratory provides consulting on the development of wind profilers to DOD, NASA, and the Department of Energy, as well as the governments of Canada, Australia, New Zealand, China, Japan, and the European Union. See <http://www.fsl.noaa.gov/~vondaust/fir99/fir99c.html>.

public domain, but ongoing technical support and weather and climate services to users are subject to full cost recovery.[24]

The academic sector creates weather products for research and educational purposes. A number of meteorology departments operate a campus weather service to train students to create and disseminate local forecasts. Some of the products are quite practical in nature, such as forecasts produced by Penn State University for the *New York Times* weather page.[25] Penn State faculty members believe that this activity helps educates the students in the department. At the universities that the committee visited, professors drew a distinction between developing a unique product to advance the science and educate students and the general public, and providing commercial products, which they did not see as a university role. However, these products may also have value in the marketplace.

The private sector is a major generator of forecasts and weather products and services. These products and services are generally aimed at specific users who want products tailored to their application, local area, or economic need, compared to the more general weather products created by the NWS. Some companies use publicly available government information and add value by packaging the information in a form that is easier to understand or more convenient to use. For example, television stations use colorful graphics to make weather patterns predicted by the NWS more understandable to the public. However, an increasing number of products are a sophisticated synthesis of data, analyses, and model output gathered from government, academic, and private sources. Examples include weather forecasts with wind and temperature information to help trucking companies improve fleet fuel efficiency or wave and sea forecasts aimed at helping shipping companies reduce shipping time and costs.

Climate Services

NOAA, state government agencies, and academia provide longer-term climate data and services, including historical climate and paleoclimate records, seasonal to interannual predictions, and decadal to centennial as-

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[24]Presentation to the committee by S. MacDonald, director, NOAA's Forecast Systems Laboratory, June 26, 2002.

[25]The Penn State Department of Meteorology has produced the weather page for the *New York Times* since the mid-1980s. Penn State provides a proprietary weather map and explanation; WSI provides standard meteorological information, such as global temperatures. Funding is provided through a research grant-in-aid for weather development. There are no deliverables, and the department is given considerable freedom about the content of the weather page. Presentation to the committee by Fred Gadomski, instructor, Pennsylvania State University, at State College, Pennsylvania, January 9, 2002.

sessments. Within NOAA the National Climatic Data Center (NCDC), in partnership with the NWS, provides a wide range of climate data, information, and products that are used for planning purposes, such as designing buildings as well as power and water systems and for hedging against extreme weather and climate events.[26] For example, regional climate data were recently used to support decisions on dam operations in the Grand Canyon.[27] The regional climate centers provide climate information in their multistate area, develop climate products, conduct applied climate research, and monitor and assess the impact of climate conditions (e.g., drought, soil moisture) on the region.[28] State climatologists perform a similar function in their state and also provide an important link to local users, including state and local officials and the media.

The NWS has the primary responsibility for developing operational seasonal to interannual predictions, such as those related to improving El Niño-Southern Oscillation (ENSO) forecasts.[29] However, as understanding of the atmosphere and forecasting skills improve, private sector interest in providing these predictions will likely increase. Work on decades and longer timescales (e.g., to distinguish between anthropogenic forcing and natural climate variability) is still mainly in the research stage and is handled by NOAA laboratories—particularly the Climate Diagnostics Center and the Climate Monitoring and Diagnostics Laboratory—and academia.

Standards

In addition to carrying out the tasks outlined above, NOAA sets and maintains the observational and historic standards and records for operational meteorology and climatology in the United States. As the weather, oceanographic, and climatic "source of record," NOAA is responsible for the collection of regular observations of the Earth's atmosphere and oceans,

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[26]NOAA, 2001, *NOAA's Climate Observations and Services*, Washington, D.C., 26 pp.

[27]R.S. Pulwarty and T.S. Melis, 2001, Climate extremes and adaptive management on the Colorado River: Lessons from the 1997-1998 ENSO event, *Journal of Environmental Management*, v. 63, p. 307-324.

[28]Information on the products and services of the regional climate centers can be found through links at <http://met-www.cit.cornell.edu/other_rec.html>.

[29]Seasonal to interannual forecasting grew out of the Tropical Oceans and Global Atmosphere Program (TOGA). Academic researchers developed many of the models, and forecasts and other products are produced by NOAA's Climate Prediction Center (among other organizations). An assessment of short-term climate prediction can be found in National Research Council, 1996, *Learning to Predict Climate Variations Associated with El Niño and the Southern Oscillation: Accomplishments and Legacies of the TOGA Program*, National Academy Press, Washington, D.C., 171 pp.

assembly of derived data from meteorological and climatic models, and calculation of climate averages. This task is difficult because data of different types and scales, often with incompatible formats and/or insufficient documentation, must be integrated and analyzed to be made useful to current and future generations of scientists. Failure to do so greatly diminishes the potential value of the climate record.[30]

NOAA is also responsible for verifying that its data and derived products (including forecasts) are rigorously checked for scientific validity. The meteorological and other user communities must be assured that advisories, warnings, and statements are prepared and verified in a scientifically objective manner. Finally, because weather and climate are global phenomena, the NWS must help set and adhere to international standards for data collection and exchange.

Archive

The primary archive for official weather and climate data is NOAA's National Climatic Data Center. NCDC holds more than 1.4 petabytes of data from state institutions (state climatologist program and regional climate centers), federal agencies (e.g., Departments of Agriculture, Commerce, Defense, Energy, and Transportation; NASA, NSF), and international organizations (e.g., World Meteorological Organization, world data centers).[31] However, 99% of the holdings are derived from NOAA-sponsored and -operated observing systems. The data and products, some of which extend back 200 years, are available at a nominal cost of retrieval and delivery to the customer and are used for operational, research, education, decision-making, business (e.g., consulting meteorology, legal, insurance, engineering, tourism), and individual purposes.

State climatologists and regional climate centers archive and disseminate data collected by state agencies and programs as well as data from NWS and cooperative observer stations in their state. Most of these data are available without restrictions, but the data are not always easily accessible and users often pay a small fee to obtain them.

Researchers also use the data collections hosted by NCAR. The data come from a variety of sources, including NCAR, university, NOAA, and ECMWF models and historical and global observations collected by other organizations. Private companies store data they collected, but operating a

[30]U.S. Global Change Research Program, 1999, *Global Change Science Requirements for Long-term Archiving,* Report of the Workshop, October 28-30, 1998, National Center for Atmospheric Research, Boulder, Colo., 78 pp.

[31]Briefing to the committee by Tom Karl, NCDC director, February 20, 2002.

long-term archive is not lucrative and some companies hope to eventually transfer their data to NCDC. Data held by private companies are available under whatever terms the company sets and cannot be considered part of the long-term climate archive.

USERS OF WEATHER AND CLIMATE INFORMATION

A strong positive feedback exists between increasing demand for weather and climate information and increasing accuracy of the information. As accuracy increases and as society's sensitivity to weather and climate increases, the number of applications, the degree of specialization of products, and the number of customers who can use the information will also increase. Continuing advances in forecast accuracy not only will enable greater protection of life and property, but will also improve environmental management and create new business opportunities.[32] One of these opportunities is helping users learn about useful weather and climate products and integrating imperfect forecast information into decision making.[33]

A wide variety of individuals and industries use weather and climate information to carry out their daily activities and to manage weather-related risk. The major users and uses of weather and climate information have been discussed in a recent National Research Council report *Making Climate Forecasts Matter*[34] and are summarized below.

Agriculture

The agriculture industry depends on weather and climate information for coping with weather and climate risk. Examples of *ex ante* (based on expectations) decisions that are influenced by weather information include choices of crop mix, cultivar traits, amount of land to cultivate, frost protection, herd size, and placement of animals on rangeland and pastures.[35]

[32] R.A. Pielke, Jr., and J. Kimpel, 1997, Societal aspects of weather: Report of the sixth prospectus development team of the U.S. Weather Research Program to NOAA and NSF, *Bulletin of the American Meteorological Society*, v. 78, p. 867-876; National Research Council, 1999, *A Vision for the National Weather Services: Road Map for the Future*, National Academy Press, Washington, D.C., 76 pp.; National Research Council, 2000, *From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death*, National Academy Press, Washington, D.C., 80 pp.

[33] S.A. Changnon and S.T. Sonka, 2002, A review of studies concerning use of climate forecasts by U.S. agriculture, *Midwestern Regional Climate Center Research Report 1*, Champaign, Ill., 34 pp.

[34] National Research Council, 1999, *Making Climate Forecasts Matter*, P.C. Stern and W.E. Easterling, eds., National Academy Press, Washington, D.C., 175 pp.

[35] National Research Council, 1999, *Making Climate Forecasts Matter*, P.C. Stern and W.E. Easterling, eds., National Academy Press, Washington, D.C., 175 pp.

Longer timescale climate forecasts may be used to develop hedging strategies, such as purchasing crop insurance or using commodities futures markets to lock in a desired price before producing a crop. *Ex post* (based on event realization) decisions that are influenced by weather and climate information include the timing and amount of irrigation, application of pesticide and fertilizer, rate of animal feed, marketing of animals, drying of grain, and in the extreme whether or not to continue to grow and harvest a weather-damaged crop. The conditions predicted in the forecast (hot, cold, wet, dry) are of primary importance for these purposes,[36] although inaccuracies in seasonal predictions require that they be taken with a grain of salt.

The Internet has been one of the biggest influences on the use of weather and climate information in agriculture.[37] In 2001, 43% of farms had access to the Internet and 55% had access to a computer. Farmers can now obtain general weather forecasts for any part of the country, near-real-time radar data every six minutes, accumulated precipitation data, drought indices,[38] and specialized forecasts and services. However, although the variety and accessibility of information products have never been greater, data coverage is still a limitation, especially west of the Mississippi where there are few cooperative observer stations. Linking mesonets and micronets would help fill in the data gaps and form a more effective observing network for agriculture applications.[39]

Forestry

Weather and climate information is relevant to many forestry practices, especially fire and pest management.[40] Wet winter-spring conditions stimulate vegetation growth that, when followed by dry summer conditions, leaves a large fuel load and increases fire risk. Long-term forecasts and other weather and climate products are used to make decisions on when and where to restrict burning. Drought indices are used to monitor moisture stress on commercial forests.

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[36]Presentation to the committee by S. Hillberg, director, Midwestern Regional Climate Center, June 27, 2002.

[37]Presentation to the committee by S. Hillberg, director, Midwestern Regional Climate Center, June 27, 2002.

[38]Important tools include the weekly U.S. Drought Monitor and the U.S. Seasonal Drought Outlook, both of which are prepared under a multiagency partnership. See <http://www.cpc.ncep.noaa.gov/products/expert_assessment/drought_assessment.html>.

[39]The NWS is compiling a database of non-NOAA mesonets for improving data coverage. Integrating these networks into the national observing system will require harmonization of standards, formats, and data policy.

[40]National Research Council, 1999, *Making Climate Forecasts Matter*, P.C. Stern and W.E. Easterling, eds., National Academy Press, Washington, D.C., 175 pp.

Pests and pathogen outbreaks are often induced and regulated by weather conditions. Weather information is used to help decide what pesticides to use and when and how they should be applied.

Water Supply and Flood Management

Weather and climate information is key to managing water supply systems at the individual, local municipal, and interregional levels.[41] Historical climate information is critical to planning the size and operation of reservoirs. Except in cases of flooding, water supply systems tend to respond slowly and cumulatively to weather and climate variability. Strategic reservoir water releases are governed in part by seasonal streamflow forecasts and by observed seasonal snowpack amounts. Surface irrigation water allocations are influenced by information about cumulative soil moisture conditions over the growing season.

Flood events occur on shorter timescales (days or even hours) than the weather and climate conditions that regulate normal water supply operations. Real-time weather information and forecasts are crucial for posting short-term warnings and deploying protective measures such as sandbagging, pumping, and evacuation.

Transportation

Both surface and air transportation systems rely heavily on weather information. The Federal Highway Administration promotes the deployment of integrated road weather systems. Motor carriers use forecasts of road conditions for routing and scheduling. Weather information used includes road condition and temperature maps, severe storm warnings, and satellite and radar imagery.[42] The marine cargo and passenger industries rely on integrated weather and navigation information systems, which provide high-resolution weather information and tools to compute alternative routes and fleet positions to accommodate different weather conditions.

The aviation industry uses a wide array of weather products, including radar imagery, current weather conditions, severe weather maps and warnings, hurricane tracking maps, winds and temperature aloft, and satellite imagery. These products are used extensively by airline operations control centers and flight crews.[43] Dispatchers need weather data for pre-flight

[41]National Research Council, 1999, *Making Climate Forecasts Matter*, P.C. Stern and W.E. Easterling, eds., National Academy Press, Washington, D.C., 175 pp.

[42]National Research Council, 1999, *Making Climate Forecasts Matter*, P.C. Stern and W.E. Easterling, eds., National Academy Press, Washington, D.C., 175 pp.

planning and in-flight monitoring; airline meteorologists need forecasts for major hubs and gateway cities; and pilots need data for tactical purposes. Each carrier must use weather data from an approved source, usually a government agency (mainly the NWS), but if that is not available, from a private observer or automated weather observing system. The Internet is an approved distribution channel of data, but the Federal Aviation Administration cautions users that weather information obtained from qualified Internet communications providers may not be accurate, timely, or useful.[44] Improvements that the industry would like to see include (1) Internet-based graphical products that portray current and forecast hazards to flight crews, (2) terminal-specific forecasts, (3) digital data that can be integrated into flight planning systems, and (4) more real-time data.

Energy

Producers and distributors of natural gas and electricity use weather and climate information to predict and monitor changes in demand and thereby improve planning in power production.[45] Cumulative indices of heat and cold, such as heating and cooling degree-days, are widely used to monitor demand across all classes of consumers (industrial, residential, commercial). Improvements in seasonal to interannual forecasts will improve predictions of energy demand on longer and longer timescales.

Petroleum producers use information on tropical weather systems, high winds and wave heights, and abnormal currents to manage offshore drilling operations and to plan the transportation of supplies and personnel.[46] Suppliers of hydroelectric power use streamflow forecasts and electric power distributors use weather forecasts to assist in dispatching crews to deal with the effects of severe weather on power lines or to take proactive measures to

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[43]Presentation to the committee from R. Gold, director, Airline Operations Control/Meteorology, Air Transport Association, November 5, 2001.

[44]Federal Aviation Administration, Criteria for Internet communications of aviation weather, Advisory Circular, November 1, 2002, <http://www1.faa.gov/ATS/ARS/QIPC/AC.DOC>.

[45]National Research Council, 1999, *Making Climate Forecasts Matter*, P.C. Stern and W.E. Easterling, eds., National Academy Press, Washington, D.C., 175 pp.

[46]M.G. Altalo, 2000, Defining the requirements of the U.S. energy industry for climate, weather, and ocean information, Report to NOAA's Office of Oceanic and Atmosphere Research, 146 pp.

minimize outage time.[47] Local natural gas distribution companies in some states use weather information to normalize their revenues in preparing applications to regulatory agencies for price changes.

Public Health

Extreme and prolonged cold and heat cause hypothermia and heat stress, and less directly, weather conditions influence disease ecologies that can result in major outbreaks of infectious diseases such as influenza, hantavirus pulmonary syndrome, and malaria. Weather information is routinely used to convey alerts for heat waves and extreme cold. Climate-based forecasts of disease outbreaks, such as influenza, are used to develop and disseminate vaccination programs. It may soon be possible to forecast pollution levels that trigger asthma or other respiratory problems.[48] Public health officials would benefit greatly from improved tools and procedures for incorporating weather information into risk management. Timely climate predictions, coupled with sophisticated models developed in collaboration with epidemiologists and entomologists, will offer new tools for combating disease.[49]

Disaster Insurance and Reinsurance

Insurers provide financial compensation to subscribers who experience loss from extreme weather events such as tornadoes, hurricanes, hail, and floods.[50] They also reduce the vulnerability of subscribers by offering incentives such as lower premiums to those who take preventive actions (e.g., making structural improvements to insured buildings, constructing on lower-risk property). Some insurers spread their own risk even further by purchasing reinsurance from private companies or the government. Reinsurance helps insurers cope with catastrophic loss such as the esti-

[47]B. Coley, 2001, untitled paper in *Opportunities for 21st Century Meteorology: New Markets for Weather and Climate Information*, First AMS Presidential Policy Forum, American Meteorological Society Annual Meeting, Albuquerque, N.M., January 17.

[48]National Research Council, 2000, *From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death*, National Academy Press, Washington, D.C., 80 pp.

[49]National Research Council, 1998, *The Atmospheric Sciences Entering the Twenty-First Century*, National Academy Press, Washington, D.C., 384 pp.

[50]National Research Council, 1999, *Making Climate Forecasts Matter*, P.C. Stern and W.E. Easterling, eds., National Academy Press, Washington, D.C., 175 pp.

mated $16 billion in insured losses from Hurricane Andrew in 1992.[51] Reinsurance spreads risk across a larger clientele (in some cases, all taxpayers) than are served by individual insurance companies.

Insurers and reinsurers use weather and climate information to calculate actuarial risk. Many insurance companies employ atmospheric scientists or contract with private weather service firms to aid in such calculations. A special type of insurance is provided by the weather derivatives industry, which uses weather information to defray risk associated with normal weather variability.[52] The weather derivatives industry depends on reliable, quality-controlled weather information from objective sources. In particular, the industry needs indices—heating and cooling degree-days, total precipitation, annual streamflow, and accumulated snowfall—tailored to the needs of specific clients (e.g., ski slope operators, natural gas distribution companies, outdoor apparel manufacturers). Further improvements in the analysis of weather derivatives will depend on improvements in seasonal prediction models (especially land-atmosphere interactions), dense geographic coverage of measurements, and homogeneous climate time series on daily and hourly timescales.[53]

Emergency Preparedness and Response

Responsibility for emergency preparedness and response falls mainly on governments at all levels (local, state, federal) and on nongovernmental organizations (e.g., the Red Cross). Emergency managers are concerned almost exclusively with extreme weather—drought, wildfires, floods, severe weather, and tropical cyclones—or temperatures.[54] Weather and climate information is used ex ante for issuing warnings and evacuations and positioning staff and supplies, and it is used ex post to manage rescues and

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[51] S.A. Changnon, D. Changnon, E.R. Fosse, D.C. Hognason, R.G. Roth, Sr., and J.M. Totsch, 1997, Effects of the recent weather extremes on the insurance industry: Major implications for the atmospheric sciences, *Bulletin of the American Meteorological Society,* v. 76, p. 711-720.

[52] Weather derivatives take several different forms, including (1) two-party "swaps" in which one party agrees to pay the other if a weather index settles above a certain level and the other agrees to pay if the index settles below that level, and (2) contracts to compensate a buyer if a weather variable settles below a predetermined level ("puts") or above a predetermined level ("calls"). See L. Zeng, 2000, Weather derivatives and weather insurance: Concept, application, and analysis, *Bulletin of the American Meteorological Society*, v. 81, p. 2075-2082.

[53] Presentation to the committee by R. Nathan, general manager, Weather Derivatives Group, Aquila, Inc., November 5, 2002.

[54] Presentation to the committee by C. Fugate, emergency manager, Florida, June 26, 2002.

coordinate cleanup operations.[55] Weather products that are useful to emergency managers include hazards assessments and maps, drought indices, and precipitation and severe weather forecasts, all of which are created by the NWS or the academic community and are available through the Internet. To get the most out of existing weather products, emergency managers need information in formats suitable to nonscientists and training to apply weather information to actions.

Because of the costly and disruptive nature of evacuations, it is important to have accurate forecasts of hurricane track and intensity, for example, to reduce overwarning.[56] Long-term warnings (one- to three-day forecasts) have improved greatly over the last five years and are now being used for decision making.[57] Further improvements should be aimed at providing longer lead times (some areas must be evacuated before a watch or warning is issued), better quantification of forecast uncertainties in hurricane and flood warnings, and tools for integrating probabilistic forecasts with other data sets.[58]

Other Users

Many other industries, groups, and individuals use, or could use, weather and climate information. For example, the construction industry uses weather information to schedule specific activities and to purchase materials. Fisheries managers use weather information to manage fleet operations and monitor fish stocks. The recreation industry uses weather information in a variety of ways ranging from issuing avalanche warnings, backcountry conditions, and boating conditions to managing snowmaking operations for skiing. The legal industry uses certified weather and climate information in court cases. The list of potential uses is long and growing longer as the accuracy and reliability of weather and climate forecasting improve and the portfolio of weather services offered to the public grows.

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[55] National Research Council, 1999, *Making Climate Forecasts Matter*, P.C. Stern and W.E. Easterling, eds., National Academy Press, Washington, D.C., 175 pp.

[56] For example, in 1999 the costs of evacuating people from 2000 miles of coast were comparable to the costs of damage caused by Hurricane Floyd. Hurricane warnings generally cover 300 miles of coastline, and hurricanes typically directly affect about 100 miles of coast. See R. Pielke, Jr., and R.E. Carbone, 2002, Weather impacts, forecasts, and policy: An integrated perspective, *Bulletin of the American Meteorological Society*, v. 83, p. 393-403.

[57] Presentation to the committee by C. Fugate, emergency manager, Florida, June 26, 2002.

[58] D.R. Wernley and L.W. Uccellini, 2000, Storm forecasting for emergency response: A United States perspective, in *Storms*, R. Pielke, Jr., and R. Pielke, Sr., eds., Routledge, N.Y., pp. 70-97.

SUMMARY

The public, private, and academic sectors collect data, run models, generate forecasts, and disseminate weather products to support their respective missions. NOAA operates the national observing system and is responsible for the U.S. contribution to the global observing system. State and local governments, academia, and the private sector supplement the national network with denser arrays of instruments. Integrating these local data into national databases will help fill data gaps, once the issues of standards, formats, data quality, and data policy have been resolved. Models are developed primarily by the NWS and academia, although the private sector is becoming more sophisticated in customizing existing models and developing its own. Weather and climate products produced by the NWS tend to be general, except for products aimed at industries specified in the NWS mission, such as aviation and emergency management. NWS and state agency products are also used preferentially by user groups that require official and/or unbiased information, such as the weather derivatives and legal industries. Other industries and user groups employ a combination of government, academic, and commercial products. Weather products created by the private sector (including meteorologists working in industries affected by weather) tend to be much more specialized than NWS products to meet the needs of particular user groups. Climate products fall mainly in the domain of NOAA, state climatologists, and regional climate centers, but the private sector will be an increasing player as the accuracy of seasonal to interannual forecasts improves and climate products become more useful to industries such as insurance, energy, health, and agriculture.

3

Public, Private, and Academic Partnerships

The overlapping roles of the government, academic, and private sectors in providing weather and climate services have led to both cooperation and conflict. Clearly, the public is best served when these sectors work together to take advantage of their different capabilities or to avoid duplication of effort. Such agreements in the weather industry are termed "partnerships," and they may be formal (i.e., a legal relationship) or informal. This chapter describes the National Weather Service (NWS) partnership policy, reviews examples of partnerships that have benefited users of weather and climate data and information, and summarizes areas of friction that may lead to inefficiencies in the weather enterprise.

NWS PUBLIC-PRIVATE PARTNERSHIP POLICY

The commercial weather industry now has the capability to provide many of the products and services that were once the exclusive domain of the federal government and vice versa. To avoid costly duplication of effort and to strengthen the public-private partnership, the NWS established guidelines for determining which activities it should undertake and which it should avoid (Box 3.1). According to the 1991 public-private partnership policy, the development of custom products needed by specific user groups and the television and radio dissemination of most NWS watches and warnings should be left to the private sector.

In addition to defining roles, the policy gives some general criteria for implementation, including the statement, "The NWS will not compete with

Box 3.1 Roles Defined in the NWS 1991 Public-Private Partnership Policy

In order to carry out its mission and foster this public-private partnership, NWS shall:

- Collect and exchange hydrometeorological data and information on a national and international basis;
- Issue warnings, and forecasts of severe weather, floods, hurricanes, and tsunami events which adversely affect life and property;
- Issue weather, river, and water resources forecasts, and related guidance materials used to form a common national hydrometeorological information base for the general public, private sector, aviation, marine, forestry, agricultural, navigation, power interests, land and water resources management agencies, and emergency managers at all levels of government;
- Provide climatological summaries, frequencies, and limits of hydrometeorological elements to establish a basis for various Federal regulations and design criteria and to support the real-time operations of federally-operated facilities;
- Provide private weather access to near real-time alphanumeric and graphical data and information through a variety of techniques;
- Establish basic quality controls for the observed and collected data, and provide the user community with sufficient information to evaluate data and forecast reliability and applicability;
- Conduct and support research and development of atmospheric and hydrometeorological models;
- Produce global, national, or general regional atmospheric models and river basin models.

The NWS also recognizes the important contribution that private broadcast meteorologists, newspapers, and news agencies make to the timely dissemination of NWS watches and warnings and other products that may require public response. The relationship is one of mutual support and cooperation. In order to protect the competitive nature of the privately-owned media, direct NWS participation with the radio and television media should be limited to those situations requiring urgent public action as in the case of severe or extreme weather and flooding or educational and preparedness activities.

The private weather industry provides:

- Tailored weather, river, and water resources forecasts, detailed hydrometeorological information, consultation, and data for weather, river, and water resources sensitive industries and private organizations;
- Value-added products such as weather and hydrologic-related computer hardware and software, observational systems, imaging systems, displays, communications, charts, graphs, maps, and images for clients;
- Climatological summaries, probability values of weather extremes, and similar material for specific design and construction problems.

SOURCE: The National Weather Service and the Private Weather Industry: A Public-Private Partnership, 56 Federal Register 1984, January 18, 1991.

the private sector when a service is currently provided or can be provided by commercial enterprises, unless otherwise directed by applicable law."[1] Some members of the private weather sector read this passage as prohibiting the NWS from providing information to the general public whenever the private sector *could* do so. The NWS interprets the policy to affirm that the NWS creates and disseminates forecasts and warnings to the public at large and does not provide customized weather products for specific individual clients. The NWS would decline to tailor a weather product, for example, for a local ski resort or a sports team because such a tailored product could be obtained from the private sector. A broader interpretation, the NWS insists, would be untrue to the intent of the policy statement. Thus, the 1991 NWS policy has not resolved the conflict.

SUCCESSFUL PARTNERSHIPS

Without a strong, effective collaboration among the government, academic, and private sectors, the general public would not have been the beneficiary of the great advances in weather and climate science and technology over the last 50 years. There are many successful partnerships between two or more of the sectors. Indeed, cooperation, rather than conflict, appears to be the normal mode of operation.

Government-Academic Partnerships

Because weather data are scientific in nature, the government rightly seeks to have a strong scientific component in its national weather programs. Indeed, a significant effort in the NWS modernization program was the effort to collocate new weather service offices in academic research environments.[2] (The great majority of state climate offices and regional climate centers are located at universities.) Of the 121 NWS offices, 20% are located at or near university campuses with atmospheric science departments. An example is the NWS State College office, which is located only a few blocks from the meteorology department at Penn State University (PSU). NWS employees at the State College office coauthor papers with PSU faculty, attend and give seminars at PSU, and work cooperatively in refining

[1]A similar statement can be found in early NWS policies. For example, the 1978 policy on industrial meteorology states, "NWS will not provide specialized services for business or industry when the services are currently offered or can be offered by a commercial enterprise." National Weather Service, 1978, Policy on industrial meteorology, *National Weather Service Operations Manual 78-24*, Part A, Chapter 55, pp. 1-3.

[2]National Research Council, 1991, *Toward a New National Weather Service—A First Report*, National Academy Press, Washington, D.C., 67 pp.

the widely used mesoscale model first developed at PSU, the MM5 model. PSU meteorology students also benefit from a close working relationship with the forecast office and the opportunity to work as interns in an operational setting. In this case, physical proximity fosters ongoing two-way communication, which is critical for establishing and maintaining successful partnerships.

Another example of a successful government-academic partnership concerns the rescue of an ice-bound ship in Antarctica. In early June 2002, the *Magdalena Oldendorff* supplied a number of Russian research stations in Antarctica with food and equipment and then became trapped in the thickening sea ice along the Antarctic continent. Storms in that area are fierce, with temperatures falling below –30°C and frequent blizzards with winds of greater than 60 knots. In response to a request for help, the South African ship *Agulhas* left Cape Town on June 16 carrying two rescue helicopters. The South African Weather Service provided the meteorological support for the rescue mission, using an experimental real-time weather prediction modeling system (Antarctic Mesoscale Prediction System [AMPS]) developed with National Science Foundation (NSF) funding by scientists at Ohio State University and the National Center for Atmospheric Research. The National Centers for Environmental Prediction (NCEP) provided in real time the gridded analysis and forecast data for AMPS. Modern information technology (e.g., the World Wide Web) was essential in obtaining data for the model from NCEP and disseminating the AMPS forecasts.[3] AMPS provided accurate forecasts in support of the *Agulhas* rescue mission, predicting both the passage and the intensification of a major storm as well as breaks in the weather that would permit helicopters to fly.[4] It took five days and three windows of slightly less cold and stormy weather to airlift all crew from the *Magdalena Oldendorff*.

This fruitful partnership between NCEP and academia, supported by NSF, had several benefits. First, it sped the transition of a research model into operations.[5] The close relationship between the end users (in this case the South African Weather Service) and the researchers improved scientific understanding and led to a more accurate forecast system in support of operations. Finally, the students involved in developing and using the model

[3]AMPS forecasts are available at <http://www.mmm.ucar.edu/rt/mm5/amps/>.

[4]Ian Hunter, manager of Marine Services of the South African Weather Service, personal communication, June 26, 2002.

[5]The difficulty of taking advantage of research to improve forecasts is described in National Research Council, 2000, *From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death*, National Academy Press, Washington, D.C., 80 pp.

and interacting with forecasters at McMurdo gained valuable experience, better preparing them for a career in operational or research meteorology.

Many of these government-academic partnerships involve state and local agencies. An example is the Northwest Regional Modeling Consortium, which was created in the early 1990s to collect upper-air observations over Puget Sound and improve predictions of local weather and air quality.[6] Today, 10 agencies pool resources to gather real-time data from two dozen networks in the Northwest and fund the application of a high-resolution mesoscale weather prediction model (MM5) to real-time atmospheric, hydrologic, and air quality prediction. The forecasts are disseminated through web pages. Everyone benefits from this long-standing collaboration: for example, the Forest Service uses the products to plan and control burns in forests and rangelands; the Washington State Department of Transportation uses the data to view predicted highway and weather conditions; academia uses the prediction system as a test bed for improving mesoscale model dynamics, physics, and data assimilation; and the private sector uses the on-line MM5 forecasts for a variety of specialized applications.

Government-Private Sector Partnerships

A particularly strong partnership exists between the government and the media in providing weather warnings to the public, especially during life-threatening events. The NWS relies on the media to distribute weather warnings to the public, and private sector companies have responded by developing technologies such as "crawling" of NWS warnings on TV; instant messaging via cell phone, pages, and "weather bugs" on computer monitors (see Chapter 5); and systems for tracking storms and tornadoes. A prime example was the historic tornado outbreak in Kansas and Oklahoma on May 3, 1999, in which 60 tornadoes were observed. More than 2000 homes were destroyed, another 7000 were damaged, and at least 45 people were killed.[7] Television stations in Oklahoma City were on the air continu-

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[6]C. Mass et al., 2003, Regional environmental prediction over the Pacific Northwest, *Bulletin of the American Meteorological Society*, submitted. Members of the consortia include the National Weather Service, University of Washington, Washington State University, U.S. Department of Agriculture Forest Service, Port of Seattle, U.S. Navy, Environmental Protection Agency, Puget Sound Clean Air Agency, Seattle City Light, and Washington State departments of ecology, natural resources, and transportation. In addition, Sun Microsystems, Inc., and Kuck & Associates have made contributions to the consortium (e.g., deeply discounted computers).

[7]See "The central Oklahoma tornado outbreak of May 3, 1999," <http://www.srh.noaa.gov/oun/storms/19990503/index.html>.

ously, passing on the many NWS warnings, advising the public on what action to take, and showing the tornadoes live via video feeds and on private radars with storm tracking and time-of-arrival technology. During the time the tornadoes were moving across the Oklahoma City area, 76% of households were getting information from TV or radio.[8] According to Harold Brooks at the National Oceanic and Atmospheric Administration's (NOAA's) National Severe Storms Laboratory, the loss of life might have been 15 to 20 times higher without the effective government-media cooperation. What made this partnership particularly successful was the strong working relationship that already existed between the NWS Oklahoma City forecast office and the area media.

An example of government-private sector cooperation that is currently being forged is the Homeland Security Initiative.[9] In the event of a biological or chemical attack, AWS Convergence Technologies will provide real-time access to data at no cost from its commercial network of 6000 automated weather stations—most of which are located in major metropolitan areas—to the NWS, the military, and emergency response agencies. The quality of the data and their application in NCEP models are currently being evaluated at NOAA's Forecast Systems Laboratory.[10] The NWS hopes to add this information to its large information base to better assess local weather conditions and predict where airborne hazardous materials could spread.

Private sector data have already proven valuable during national emergencies. The NWS routinely uses data collected from commercial aircraft[11] to assess and predict the state of the atmosphere. This capability contributed to analyses of dispersion of the smoke plume caused by the collapse of the World Trade Center on September 11, 2001. Such local information can assist emergency response teams, as long as preparations have been made to assimilate it in national models prior to an emergency.

[8]C. Long, Science plays key role before and after Oklahoma City tornado barrage, *Disaster-Relief*, June 1, 1999, <http://www.disasterrelief.org/Disasters/990601TornadoScience/>.

[9]<http://www.nws.noaa.gov/pa/homelandsecurity8-6-02.html>.

[10]Rainer Dombrowsky, chief, NWS Observing Services Division, personal communication, August 21, 2002.

[11]Aircraft data have proven to be very valuable in NCEP numerical forecast models as well. Approximately 100,000 U.S. observations a day from more than 500 commercial aircraft are managed by Aeronautical Radio, Inc., through the Aircraft Communications and Reporting System (ACARS). W.R. Moniger, R.D. Mamrosh, and P.M. Pauley, 2003, Automated meteorological reports from commercial aircraft, *Bulletin of the American Meteorological Society*, in press.

Academic-Private Sector Partnerships

The work force today and in the future requires highly educated graduates with increasingly diverse skills. In addition to their "traditional" knowledge and skills, meteorologists will need greater familiarity with economics, social science, and/or specific industries (e.g., agriculture, health care, transportation, energy). A number of universities and private companies are dealing with this challenge by developing partnerships to design new courses, bring private sector experience and tools into the classroom, and establish internships at private companies or at campus weather stations. For example, the University Corporation for Atmospheric Research (UCAR) Cooperative Program for Operational Meteorology, Education and Training (COMET) provides learning modules and offers opportunities for members of the private or academic sectors to participate as instructors, guest lecturers, or experts or to spend a sabbatical in the program.[12] The "WSI on Campus" program provides participating colleges and universities with workstations and animation software for training students in broadcast meteorology.[13] Williams Energy Marketing and Trading Company entered into a five-year partnership with the University of Oklahoma's school of meteorology to enhance weather and climate research, develop specialized technologies, and improve graduate and undergraduate meteorology education.[14] The agreement enabled the university to expand research on advanced weather analysis and prediction, apply a climate system model to energy-related concerns, purchase a supercomputer, create a computer laboratory for students, and fund graduate and undergraduate students. In return, Williams received licenses to the weather analysis and forecasting tools developed with its funding. By stimulating interaction among teachers, researchers, and students at universities with forecasters and other professionals in the government and private sectors, these cooperative programs should help meet the demand for a more broadly trained and flexible work force.

[12]<http://www.comet.ucar.edu/cometprogram.htm>; T.C. Spangler, V.C. Johnson, R.L. Alberty, B.E. Heckman, L. Spayd, and E. Jacks, 1994, COMET: An education and training program in mesoscale meteorology, *Bulletin of the American Meteorological Society*, v. 121, p. 1739-1772.

[13]<http://wws1.wsi.com/corporate/newsroom/releases/011501.asp>.

[14]"Williams signs $10 million weather and climate research alliance with the University of Oklahoma," University of Oklahoma press release, August 27, 2001. Due to downturns in the energy industry, Williams pulled out of the contract in summer 2002.

Government-Private-Academic Sector Partnerships

In some cases, all three sectors may cooperate because each has an interest in a particular improvement or because the expertise of all three sectors is required to address the problem. An example of the former is the partnership to improve the accessibility of NEXt generation weather RADar (NEXRAD) data. NEXRAD data are useful for a wide variety of operational, academic, and commercial purposes, but the large data volumes make it difficult to move data to users. The problem was initially addressed by restricting access to certain data. High-resolution Level 2 and real-time data were available only to the NWS. Academic users obtained high-resolution data through the National Climatic Data Center (NCDC), although the system for handling the data was cumbersome and unreliable, and private companies obtained lower-resolution data from the NEXRAD Information Dissemination Service (NIDS).[15]

In 1998, NOAA and several universities entered into a partnership to access and distribute NEXRAD Level 2 data in near real time.[16] Project CRAFT (Collaborative Radar Acquisition Field Test) was funded initially by the University of Oklahoma Regents, but several private companies later joined the project through sponsored research agreements with the lead academic institution, the University of Oklahoma. Private funds (about 10% of the total) helped defray equipment and staff costs associated with making the data widely available.[17] The private sector, through its academic partnership, has already begun providing NEXRAD Level 2 data to the outside community and using it to develop new value-added products.

A more visible partnership was created for the 2002 Winter Olympics in Salt Lake City. The partnership included private meteorologists, who provided site-specific forecasts at the various Olympic venues under the direction of KSL-TV chief meteorologist Mark Eubank.[18] NWS forecasters

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[15]NIDS was operated by four private sector companies that had contracted with the NWS to disseminate NEXRAD data. The NIDS agreement expired in 2000, and NEXRAD data are now provided to the private sector by the NWS. The change in distribution was spurred by three factors: (1) the switch to full and open distribution of data as a result of OMB Circular A-130; (2) a new NWS requirement for centralized data collection to improve the performance of numerical forecast models; and (3) technological advances that enabled centralized, cost-effective data collection and distribution. See presentation to the committee by E. Johnson, director, NWS Strategic Planning and Policy Office, November 5, 2001; see also example 17, Appendix D.

[16]The CRAFT partnership includes the National Severe Storms Laboratory, University of Oklahoma, UCAR, and the University of Washington. See <http://kkd.ou.edu/about_project_craft.htm>.

[17]Kelvin Droegemeier, Regents' Professor of Meteorology, University of Oklahoma, personal communication, September 2002.

[18]Prior to the 2002 Olympics, forecasts were provided by national weather services. For

were responsible for general public safety information, including storm warnings and aviation- and security-related forecasts and information. Faculty and students from the University of Utah's meteorology department maintained weather sensors in the Salt Lake City area and also ran high-resolution (1-km) localized atmospheric models. The models relied heavily on data from the NWS and MesoWest, a mesonet of more than 3800 weather stations in the western United States operated by private, academic, and public entities.[19] This partnership was seen as a success by all, with Eubank writing afterward:

> Working together in the Olympic Partnership has been one of the most rewarding things I have ever done as a meteorologist. . . . When I first heard the proposal to have academia, government, and the private sector all work together in a common weather forecasting project I was slightly skeptical on how well it would work. As it turned out, that combination yielded greater results than the sum of its parts.[20]

Elements of Successful Partnerships

All sectors in the weather enterprise have, to some extent, different motivations and rewards for working together. As the examples above show, considerable cooperation exists among and between the sectors. Partnerships will be formed when there is a common interest in advancing the understanding and application of the science and when the desired outcome cannot be achieved efficiently by a single sector. They are most likely to succeed when there is

- a clear objective of the partnership;
- a mutual respect for and understanding of each partner's skills, cultural approach, and organizational framework; and
- early, regular, and meaningful dialogue among the partners. Although the Internet and distributed computing enable partners to be widely scattered, physical proximity permits face-to-face meetings and reduces the barriers to communication.

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example, in the 1996 Atlanta games, the Canadian Meteorological Service assisted by providing forecasters, especially those who spoke French.

[19]More than 110 agencies, universities, and commercial firms operate networks of weather sensors or contribute data to MesoWest, including the Bureau of Land Management, Soil Conservation Service, state resource and transportation departments, ski resorts and avalanche centers, and weather forecast offices. See <http://www.met.utah.edu/jhorel/html/mesonet/info.html>.

[20]<http://205.156.54.206/com/nwsfocus/fs030102.htm#Weather Support Group Completes First Segment of Olympic Forecasting>.

Some of the recommendations in Chapter 6 are aimed at institutionalizing these successes.

CONFLICTS BETWEEN THE SECTORS

The different motivations and overlapping activities of the sectors can lead to conflict and misunderstanding (see also Appendix B). At its open meetings and through its web site, the committee invited all sectors to submit written examples of conflicts that have occurred within the last five years. The committee heard from 11 companies, as well as from the Commercial Weather Services Association, which represents 30 companies and independent meteorologists. (No letters were received from the public or academic sectors.) Although statistical inferences could not be drawn from such an unsystematic sample of the commercial weather industry and it must be assumed that those with the greatest concerns are most likely to respond, the examples illustrate the types of issues that cause friction. The examples, half of which were provided by two companies, and responses from the relevant NOAA division, are given in Appendix D.

The examples cover issues such as the provision of similar products and services by multiple sectors, use of private sector technologies to improve federal products, dispute resolution, outsourcing, and data quality. Only one example concerns climate products (example 27); the others concern weather products and services. The examples can be grouped into several themes:

- ***NWS data are not always provided on a timely basis or with sufficient checks for errors*** (examples 15, 16, 24, and 25). NWS data and information products are the basis for many private sector forecasts and products. Consequently, it is essential that the data and products be provided to all interested parties on a regular schedule[21] and with proper attention to quality control. There appears to be no penalty to the forecast offices if NWS data or products are released late or with errors.[22] A significant number of formatting errors (e.g., discrepancies between the header and body of warnings; see example 24) have been reported. Delays and errors in the data adversely affect the quality of products and services

[21]Schedule-driven products are intended to be released at particular times of the day.

[22]It remains to be seen what effect the 2002 NOAA data quality guidelines (<http://www.noaanews.noaa.gov/stories/dataqualityguidelines.htm>) will have on this issue. Under the guidelines, weather warnings, forecasts, and advisories disseminated on or after October 1, 2002, should have the highest possible accuracy commensurate with the time-critical nature of the products. Individuals or organizations can request that information be corrected if it has harmed a legally protected interest and if the injury would be addressed by correcting the information.

provided by all sectors, making it harder to produce accurate forecasts and to build and retain customer loyalty. The NWS acknowledges these issues, but says that it has identified the sources of the problems and is taking actions to correct each of them.

Another type of error that is of concern to some users is the error in the observations themselves, which can negatively affect the numerical model forecasts and the climate data set, which in turn negatively affect a wide range of weather and climate products (examples 15, 16, and 25). Increasing amounts of data and more sophisticated quality control of the data in the analysis and modeling systems are addressing the impact of data errors on numerical weather prediction. The NWS expects that modernization of the Cooperative Observer Network, the planned upgrading of the Automated Surface Observing System (ASOS), and the institution of new quality control procedures will lessen these problems. Data quality issues are discussed further in Chapter 6.

- ***NWS products and services duplicate those developed by the private sector*** (examples 1-11 and 19-22). Both the NWS and the private sector view value-added products and services that are not directly related to the NWS mission as within the purview of private companies. However, it is difficult, if not impossible, to define what falls within the NWS mission to the satisfaction of all parties. The 1991 public-private partnership policy does not give specific guidance for product development, and the NWS is only now developing a strategy for determining what products it will create and for seeking comment from the community.[23] In the meantime, all three sectors sometimes create similar products. Commercial products that are too similar to freely available NWS or academic products will not be competitive in the marketplace. In contrast, a commercial product that is similar to another commercial product may still be profitable. Examples of products created by both the NWS and the private sector include ultraviolet and wind chill indices, point-specific forecasts, aviation and hydrologic services, and other specialized services. The NWS agrees that it is not appropriate for it to offer services tailored for newspapers (example 21). However, the NWS believes that many of the services in question are provided to comply with the NWS mission to protect life and property or other federal statutes (examples 1, 2, 5, 6, 11, and 22) or to meet operational requirements (example 10). Others are a result of advances in science and technology that yield higher temporal or spatial resolution products or improve forecast accuracy (examples 4 and 5). In other cases, the NWS disputes the company's interpretation of the facts (examples 3, 6, 8, 9, 19, and 20).

[23]NWS Policy Directive 10-102, NWS requirements for new or enhanced products and services, August 28, 2002, <http://www.nws.noaa.gov/directives/>.

A related private sector concern is that the government often uses technologies first adopted or developed by the private sector (examples 7, 12, and 13). As technologies become widely adopted by the NWS and others, the competitive advantage of the commercial adopter or developer is lost. An example is the use of color maps to convey weather information (example 7), which are now used widely throughout the weather enterprise. The NWS noted that it uses technologies in the public domain, regardless of which sector(s) produced them. Government adoption of commercial technologies is discussed further in Chapter 5.

- ***Federally funded centers and universities provide some of the same products and services as the private sector*** (examples 26-28). Universities, the NOAA laboratories and data centers, and state-supported organizations use taxpayer funds to develop products and services that may be commercially viable. The U.S. government encourages technology transfer to the private sector (see Chapter 4). New products that are based on government-sponsored technology may have a competitive advantage over existing products in the private sector. Examples given in Appendix D concern the environomics program (since renamed the National Climate Impact Indicators Program) at NCDC (example 27) and the provision of weather and hydrologic services in Vietnam by the Forecast Systems Laboratory (FSL: example 28), the facts of which FSL disputes. According to NCDC, environomics is a research, service, and monitoring program aimed at providing climate indicators to other government agencies.

A related issue is that some companies misidentify the affiliations, and therefore the primary roles and obligations, of other players in the weather enterprise. For example, the NWS is not responsible for the activities of NCDC (example 27) or the NOAA research laboratories (example 28). These centers are administered by different parts of NOAA and are not bound by the NWS 1991 public-private partnership policy (see "NWS Public-Private Partnership Policy" above and Figure 2.1). Similarly, UCAR is a private, nonprofit consortium of universities, not a government agency (example 26). A poor understanding of these institutional affiliations leads to perceptions of unfair practices (see Chapter 4)—whether or not they actually exist—and hinders good working relationships with the other sectors.

- ***Additional NWS services should be outsourced*** (examples 17 and 18). The provisions of Office of Management and Budget (OMB) Circular A-76 and the Federal Activities Inventory Reform (FAIR) Act call for activities that are not inherently governmental to be performed by the private sector whenever economically justified.[24] The NWS currently spends $50

[24]OBM Circular A-76, Performance of Commercial Activities, Implementation of the Federal Activities Inventory Reform (FAIR) Act of 1998 (Public Law 105-270).

million per year on outsourcing. One company states that the NWS could have outsourced NEXRAD radar dissemination, especially since the NIDS infrastructure was already in place (example 17). Another company suggests that the infrastructure for observing, communicating, and data processing be consolidated and contracted out to enable local forecast offices to focus on operations and research, rather than on routine systems operation and maintenance (example 18). In its response, the NWS notes that given the new NWS requirements for centralized NEXRAD data collection and distribution, it was more cost-effective to expand NWS capabilities than to contract out the service. The NWS notes that studies are under way to determine what additional NWS tasks should be outsourced in the future.

CONCLUSIONS

Despite sometimes vocal complaints from a small number of weather companies, cooperation among the sectors, rather than conflict, appears to be the norm. Indeed, all sectors are dependent on one another and share an interest in the weather and climate enterprise as a whole. When conflicts do occur, they are most likely to relate to which sector should produce a particular product or service. Such questions arise from the ambiguity in the 1991 NWS public-private partnership policy, as well as from misunderstanding of the laws, policies, and institutional arrangements that govern the activities of the different sectors. It is not the committee's purpose to adjudicate the appropriateness or inappropriateness of the activities described in the examples. Indeed, given the overlapping roles and responsibilities of the sectors, it may not be possible for anyone to do so. However, the issues raised merit careful consideration if the sectors are to better understand their different viewpoints and improve cooperation. Working against one another wastes time and resources that would be better spent developing products that users need. Some suggestions for enhancing cooperation and avoiding future conflicts among the sectors are given in Chapter 6.

4

Legal, Social, Policy, and Economic Framework

A framework of laws, policies, principles, and practices governs the activities of each of the three sectors involved in the weather enterprise. Differences in these practices and a lack of understanding of the practices of the other sectors can create barriers to collaboration. This chapter describes legal, social, economic, and data policy issues that affect the public, private, and academic sectors and their implications for creating partnerships.

LEGAL OVERVIEW

National Weather Service

The law governing the National Weather Service (NWS) directs it to collect meteorological data, provide meteorological forecasts, and produce a range of meteorological services. It also obliges the agency to make the information it collects and generates generally available to the public.

Statutory Authority

The principal statutory authority governing the NWS is the National Weather Service Organic Act of 1890,[1] currently codified as amended in 15 U.S.C. § 313:

[1]Act of October 1, 1890, Session I, ch. 1266, 26 Stat. 653-55.

> The Secretary of Commerce shall have charge of forecasting of weather, the issue of storm warnings, the display of weather and flood signals for the benefit of agriculture, commerce, and navigation, the gauging and reporting of rivers, the maintenance and operation of seacoast telegraph lines and the collection and transmission of marine intelligence for the benefit of commerce and navigation, the reporting of temperature and rain-fall conditions for the cotton interests, the display of frost and cold-wave signals, the distribution of meteorological information in the interests of agriculture and commerce, and the taking of such meteorological observations as may be necessary to establish and record the climatic conditions of the United States, or as are essential for the proper execution of the foregoing duties.

Under the statute, the NWS is charged to collect data on weather and climate, to provide forecasts and warnings of severe weather in order to protect life and property, and to create and disseminate forecasts and other weather information for the benefit of a wide range of weather-sensitive businesses and activities. Although the NWS has traditionally regarded public safety as its most crucial mission, the text of the Organic Act gives it broader responsibility. As well as charging the NWS to gather weather and climate data and issue weather forecasts and warnings, the law directs the NWS to collect and publicly distribute weather information useful to sectors of the nation's agriculture, communications, commerce, and navigation interests. In addition to the Organic Act, Congress has enacted several statutes that require the NWS to engage in specific meteorological tasks in cooperation with other government agencies and lay out the services to be provided by the NWS forecast offices.[2]

As an executive agency within the Department of Commerce, the NWS is also subject to laws applying to federal agencies generally. In particular, the Paperwork Reduction Act, as amended in 1995, requires each agency to

[2]See, for example, 42 U.S.C. § 8910 (acid precipitation database) and 49 U.S.C. 44720 (collection and processing of aviation-related meteorological data). The NWS cooperates with the National Climatic Data Center, which archives NWS data under the Federal Records Act (44 U.S.C. Chapter 31) and provides it to users. Additionally, the Weather Service Modernization Act, October 29, 1992, Public Law 102-567, Title VII, 106 Stat. 4303, limits the Secretary of Commerce's discretion in restructuring the NWS. The act requires that the Secretary certify that no degradation in weather service will result from closing, consolidating, automating, or relocating any NWS field office. Regulations promulgated under the Weather Service Modernization Act list the basic weather services provided by local field offices: "(a) surface observations, (b) upper air observations, (c) radar observations, (d) public forecasts, statements, and warnings, (e) aviation forecasts, statements, and warnings, (f) marine forecasts, statements, and warnings, (g) hydrologic forecasts and warnings, (h) fire weather forecasts and warnings, (i) agricultural forecasts and advisories, (j) NOAA weather radio broadcasts, (k) climatological services, (l) emergency management support, [and] (m) special products and service programs" (15 C.F.R. § 946.4).

"improve the integrity, quality, and utility of information to all users within and outside the agency, including capabilities for ensuring dissemination of public information, public access to government information, and protections for privacy and security."[3] Section 3206(d) of the act provides:

> (d) With respect to information dissemination, each agency shall—
> (1) ensure that the public has timely and equitable access to the agency's public information, including ensuring such access through—
> (A) encouraging a diversity of public and private sources for information based on government public information;
> (B) in cases in which the agency provides public information maintained in electronic format, providing timely and equitable access to the underlying data (in whole or in part); and
> (C) agency dissemination of public information in an efficient, effective, and economical manner;
> (2) regularly solicit and consider public input on the agency's information dissemination activities;
> (3) provide adequate notice when initiating, substantially modifying, or terminating significant information dissemination products; and
> (4) not, except where specifically authorized by statute—
> (A) establish an exclusive, restricted, or other distribution arrangement that interferes with timely and equitable availability of public information to the public;
> (B) restrict or regulate the use, resale, or redissemination of public information by the public;
> (C) charge fees or royalties for resale or redissemination of public information; or
> (D) establish user fees for public information that exceed the cost of dissemination.

As required by the act, the White House Office of Management and Budget (OMB) issued Circular A-130, most recently revised in December 2000, which instructs executive agencies on their responsibilities under the statute.[4] The circular emphasizes the statute's prohibition on restrictive or exclusive information dissemination arrangements. It also directs agencies to make their information available to the public in useful form and through multiple outlets. In particular, it recommends that, where feasible, agencies disseminate information to the public in electronic form over the Internet. The Government Paperwork Elimination Act further emphasizes this point and requires government agencies to move from paper-based systems and transactions to on-line interactions with users by 2003.[5]

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[3]See 44 U.S.C. § 3506(b)(1)(c).
[4]65 Federal Register 77677, December 12, 2000.
[5]44 U.S.C 3504.

The 1991 Policy Statement

In 1989 the National Oceanic and Atmospheric Administration (NOAA) published a new draft policy statement outlining the respective roles of the NWS and the private weather industry and requested public comment.[6] In January of 1991, after receiving and responding to comments received from the private weather industry, the World Meteorological Organization (WMO), libraries, researchers, and members of the general public, NOAA issued a revised policy statement entitled "The National Weather Service and the Private Weather Industry: A Public-Private Partnership" (see Chapter 3).[7] The policy purports to govern the NWS, but does not apply to any other division of NOAA. Although NOAA could revise or rescind the policy using the same notice and comment procedure it used to adopt it, it has not sought to do so. Nor has it publicly clarified the extent to which the policy may have been modified, narrowed, or superseded by subsequent laws, regulations, or administrative policies.

A number of disputes have arisen as to the policy's meaning and legal effect. As discussed in Chapter 3 and Appendix B, the language is worded so broadly that it may be interpreted in many ways. However, the public-private partnership policy must be interpreted in the context of statutes, executive orders, and agency policies governing the NWS. Statutes take precedence over executive orders and agency regulations and policies. Similarly, policies set at higher levels of government (e.g., OMB) take precedence over policies set by hierarchical inferiors. Finally, the latest agency policy or executive order takes precedence over earlier policies. *Thus, any interpretation of the partnership policy that obliges the NWS to cease providing weather services if private businesses wish to offer them would be inconsistent with the NWS's responsibilities under the Organic Act and its obligations under the Paperwork Reduction Act, OMB Circular A-130, and the Government Paperwork Elimination Act.* To be consistent with federal law, the policy must be interpreted more narrowly. Potential solutions for resolving the ambiguity in the policy are discussed in Chapter 6.

Liability

As long as weather cannot be predicted with 100% accuracy, liability will be an issue for all sectors that provide weather information to the public. Inaccurate, inadequate, or delayed weather information can result in financial or bodily harm, sometimes triggering lawsuits. Although the

[6] 54 Federal Register 52839, December 22, 1989.
[7] 56 Federal Register 1984, January 18, 1991.

government does not always win weather-related court cases, most claims against the federal government and some claims against state governments are resolved in favor of the government on the basis of immunity.[8] Private sector forecasters have no such immunity and may be liable for damages if it can be proven that the forecast was not made in good faith, was not made using reasonable care, or was made with intent to deceive. Weather companies protect themselves by writing contracts that limit their liability to clients and by purchasing liability insurance. Most weather companies carry general liability insurance, which covers injuries on company property, and many also carry errors and omissions insurance, which covers actual and alleged defects in the work of the meteorological staff.[9] Insurance is needed regardless of whose information is being delivered—the federal government's or the company's. Because the amount and terms of insurance are adjusted to the types of claims one would expect given the market and customer using the information, liability is not a barrier to private sector provision of weather services.

Federal Technology Transfer Law

Divisions of NOAA that conduct or fund research are subject to federal laws promoting the transfer of federally sponsored or developed technology to the private sector. The 1980 Bayh-Dole Act,[10] the 1980 Stevenson-Wydler Technology Innovation Act,[11] and a series of recent amendments[12] direct federal agencies to enter into cooperative research and development agreements, set standards for licensing of federal government patents, and facilitate private sector and university patenting of inventions developed through federally sponsored or collaborative research.[13] These legal instru-

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[8]R. Klein and R.A. Pielke, Jr., 2002, Bad weather? Then sue the weatherman! A review of legal liability for predictions and forecasts, Parts I and II, *Bulletin of the American Meteorological Society*, in press.

[9]M.R. Smith, 2002, Five myths of commercial meteorology, *Bulletin of the American Meteorological Society*, v. 83, p. 993-996.

[10]Public Law 96-517, Section 6(a), 94 Stat. 3019 (1980), codified as amended at 35 U.S.C. §§ 200-212.

[11]Public Law 96-480, 94 Stat. 2311-2320 (1980), codified as amended at 15 U.S.C. §§ 3701-3714.

[12]See National Technology Transfer and Advancement Act, Public Law 104-113, 4-6, 110 Stat. 775, 1995; National Competitiveness Technology Transfer Act, Public Law 101-189, 103 Stat. 1352, 1674-1679, 1989; Federal Technology Transfer Act, Public Law 99-502, 100 Stat. 1785, 1986; National Cooperative Research Act, Public Law 98-462, Sec. 2, 98 Stat. 1815, 1984, codified as amended at 15 U.S.C. §§ 4301-4305.

[13]R. Eisenberg, 1996, Public research and private development: Patents and technology transfer in government-sponsored research, *Virginia Law Review*, v. 82, p. 1663-1667.

ments are also employed by universities creating spinoff companies. Such spinoffs have been successful in achieving a major government goal of commercializing federally funded research results for the public's benefit.[14] However, they also create the potential for changing the motivations of research universities and for creating real or perceived financial conflicts of interest (Appendix B). Perceptions that research is directed by profit motives rather than the pursuit of knowledge could diminish public trust in research.

Transferring technology to the private sector creates the potential for conflicts of interest, and universities and government agencies have developed best practices and guidelines for dealing with them. NOAA does not have agency-specific guidelines on avoiding conflicts of interest, but follows government-wide rules of ethics and Department of Commerce guidelines.[15] Guidelines developed by the National Institutes of Health and the National Science Foundation require investigators to disclose significant financial interests that would reasonably appear to be affected by the research they propose.[16] Their host institutions are required to maintain an appropriate conflict-of-interest policy, determine whether a conflict of interest exists, and protect the funding agency from bias due to conflicts of interest. A 1998 General Accounting Office report found that the 10 major research universities examined had all established policies and procedures for meeting federal requirements on avoiding conflicts of interest.[17]

ECONOMIC CONTEXT

In seeking to define public versus private roles, economists tend to think in terms of which outcome would be most efficient. In many cases, it is more efficient for private sector companies than government agencies to

[14]Presentation to the committee by James Severson, president, Cornell Research Foundation, Inc., February 20, 2002. At least two-thirds of inventions are created using federal research dollars. Before the Bayh-Dole Act was passed in 1980, only 4% of inventions were licensed. Today 33% of inventions are licensed. In 2001, 450 companies were formed, nearly double the number formed just five years earlier. Statistics on invention disclosures, patent applications, licenses and options completed, and new companies formed can be found at <http://www.autm.net/surveys/2000/summarynoe.pdf>.

[15]For example, the Department of Commerce issued a memo in May 2000 prohibiting NWS employees from investing in weather futures or weather derivatives.

[16]National Institutes of Health, 1995, Objectivity in research, *NIH Guide*, v. 24, July 14, 42 pp., <http://grants.nih.gov/grants/guide/notice-files/not95-179.html>; National Science Foundation, 2002, *Grant Policy Manual*, NSF 02-151, Arlington, Va., section 510, <http://www.nsf.gov/pubs/2002/nsf02151/gpm02_151.pdf>.

[17]General Accounting Office, 1998, *Technology Transfer: Administration of the Bayh-Dole Act by Research Universities*, GAO/RCED-98-126, Washington, D.C., 83 pp.

provide services. The private sector is more likely to be responsive to specific individual customer needs and it is less burdened with bureaucracy. Transferring services to the private sector also frees up resources for activities that can be carried out only by government agencies, such as those promoting the health and safety of the public. Consequently, U.S. policy is to privatize government functions when possible.[18]

However, not all government functions can be privatized because of their cost structure and/or public good properties.[19] The collection and distribution of weather information fall into this category. Scientific information, such as weather information (including forecasts), has properties that make it a public good. First, scientific practices require that data be open to scrutiny to everyone willing to pay the incremental cost of distribution. Thus, the production of scientific information should be nonexclusionary. Second, scientific information is nonrivalrous because providing the information to one party does not diminish the information available to another party. By definition, a public good is both nonexclusionary and nonrivalrous; thus, weather information is a public good. The public-good aspect of weather information makes it difficult, if not impossible, for commercial companies to provide the information efficiently.[20]

The second reason the NWS must continue to collect weather data concerns the cost structure of weather data. The incremental cost of distributing a copy of the information is typically very small, sometimes even negligible, compared to the initial cost of collecting and synthesizing the data and producing an information product. The NWS budget for collecting weather data is $88 million in fiscal year 2003,[21] whereas the cost of dissemination, especially over the Internet, is negligible. The high cost of

[18]For example, appropriations language commonly directs agencies to privatize specialized services (NOAA) or data collection (National Aeronautics and Space Administration). See conference report on H.R. 4635, Departments of Veterans Affairs and Housing and Urban Development, and Independent Agencies Appropriations Act, 2001, House of Representatives, 106th Congress, 2nd Session, October 18, 2000; H.R. 1553, National Weather Service and Related Agencies Authorization Act of 1999, Senate, 106th Congress, 1st Session.

[19]These issues are discussed in greater detail in National Research Council, 2001, *Resolving Conflicts Arising from the Privatization of Environmental Data*, National Academy Press, Washington, D.C., 99 pp.

[20]Private markets have failed demonstrably to provide public meteorological services. See J.W. Freebairn and J.W. Zillman, 2002, Funding meteorological services, in *Meteorological Applications—2002 Papers*, J.E. Thornes, ed., The Royal Meteorological Society, London, v. 9, pp. 45-54.

[21]FY 2003 President's Budget for NWS Systems. The budget includes NEXRAD and Automated Surface Observing System (ASOS) operations and maintenance, marine observations, radiosonde and upper-air observations, Cooperative Observer Network, lightning data purchase, and aircraft observations, but excludes satellite data.

collecting weather data fosters the creation of monopolies. Yet even if a private sector monopoly were created, it could not recover all of the costs of developing and operating the instruments, as experience in Europe shows.[22] Consequently, the NWS is and must be the primary collector of weather data in the United States, although private sector companies supplement the national network with additional instruments.

In contrast, the cost characteristics are different for value-added products, and it is easy to exclude certain groups from using them. For example, site-specific short-term forecasts for spraying and field operations can be restricted to a paying farmer or consortium of farmers.[23] As a result, there is greater potential for competition and profit in the creation of value-added products and services tailored to particular customers. Individual firms will retain some degree of monopoly, so a perfectly competitive market will not be achieved. Similarly, public sector organizations producing value-added products are subject to inefficiencies due to incentives based on factors other than user demand, such as congressional direction, internal rivalries, and lack of direct connection between costs and new projects.[24] Society must thus make case-by-case judgments of which sector(s) should create value-added products. In some cases (e.g., the high cost of commercial services excludes some consumers), the public may be best served if the public sector provides the value-added service.

In 2000 a team of economists writing for the Computer & Communications Industry Association proposed criteria for determining which online and informational activities should be undertaken by the government and which should be undertaken by the private sector (Box 4.1). The economists divided activities into three categories: (1) those that the government should perform (green light), (2) those that the government should be cautious about undertaking (yellow light), and (3) those that should generally be carried out by the private sector (red light).[25] The report concludes that the NWS has struck the right balance by carrying out clearly governmental functions, such as providing the official weather warnings and watches, while enabling a vigorous private sector by making data widely available

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[22]P. Weiss, 2002, Borders in Cyberspace, 19 pp., <ftp://ftp.cordis.lu/pub/econtent/docs/peter_weiss.pdf>.

[23]Such products can have social benefits, even though they are not a public good in the economic sense. For example, the use of short-term forecasts for spraying operations can reduce the amount of fertilizer or pesticide applied, producing both cost savings for the farmer and benefits to the environment and public health.

[24]Dysfunctional incentives are discussed in C. Wolf, Jr., 1988, *Markets or Governments: Choosing Between Imperfect Alternatives*, MIT Press, Cambridge, Mass., 220 pp.

[25]J.E. Stiglitz, P.R. Orszag, and J.M. Orszag, 2000, The role of government in a Digital Age, a report commissioned by the Computer & Communications Industry Association, 154 pp.

Box 4.1 Principles for On-line and Informational Government Activity

"Green Light" Activities

- Providing public data and information is a proper government role.
- Improving the efficiency with which governmental services are provided is a proper government role.
- The support of basic research is a proper government role.

"Yellow Light" Activities

- The government should exercise caution in adding specialized value to public data and information.
- The government should provide private goods, even if private sector firms are not providing them, only under limited circumstances.
- The government should provide a service on-line only if private provision with regulation or appropriate taxation would not be more efficient.
- The government should ensure that mechanisms exist to protect privacy, security, and consumer protection on-line.
- The government should promote network externalities only with great deliberation and care.
- The government should be allowed to maintain proprietary information or exercise rights under patents and/or copyrights only under special conditions (including national security).

"Red Light" Activities

- The government should exercise substantial caution in entering markets in which private sector firms are active.
- The government (including government corporations) should generally not aim to maximize net revenues or take actions that would reduce competition.
- The government should only be allowed to provide goods or services for which appropriate privacy and conflict-of-interest protections have been erected.

SOURCE: J.E. Stiglitz, P.R. Orszag, and J.M. Orszag, 2000, The role of government in a digital age, A report commissioned by the Computer & Communications Industry Association, 154 pp.

and by refraining from certain activities. These principles have been cited widely,[26] but the committee finds that they are too general to provide much help in determining which sector should undertake a particular task. Their

[26]The report generated several news stories and can be found on the web sites of numerous government agencies, scientific organizations, information societies, and economics departments.

Box 4.2 Roles of the Sectors in Collecting Environmental Data and Developing Products

The NRC report *Resolving Conflicts Arising from the Privatization of Environmental Data* presents the rationale for public funding of data collection and analysis, and for public, academic and private sector distribution of value-added products from information systems that are intended to serve the public. These arguments, which are based on economic and policy considerations, are summarized below.

Public Funding of Data Collection and Analysis

1. The total cost of the information system is dominated by the costs of making the observations and assembling, validating, and synthesizing them into dependable, scientifically valid, well-documented products.
2. The cost of making and distributing additional copies of each core product is negligible compared to the cost of generating the master copy. This implies that the average cost per copy decreases as the total number of copies increases (the phenomena of "declining average costs").
3. The core products (the limited number of synthesized products that serve a wide group of users, and have been quality controlled, calibrated, and validated according to accepted scientific standards) of a public-purpose information system are intended to help establish facts for all. It is highly undesirable for society that their use for public purposes be encumbered by intellectual property rights.
4. The social return generated from use of the data and analysis products of public-purpose information systems may dwarf private returns.
5. In the presence of declining average costs, homogeneous product markets (i.e., those in which the products desired by customers are identical and price is

application to specific cases (e.g., example 1 [ultraviolet index], Appendix D) would be subject to interpretation and become a new source of conflict.

On the other hand, the principles laid out in a recent National Research Council (NRC) report may be useful for determining which sector(s) should collect and analyze data and produce value-added products (Box 4.2). According to these principles, the practice of collecting and analyzing weather data using taxpayer funds makes sense because weather observations—particularly satellite observations—are expensive to collect, but inexpensive to disseminate, especially over the Internet (items 1 and 2). Second, it is essential that the core analysis products (e.g., models, forecasts, warnings) be made available at low cost and without restrictions to everyone (item 3). Burdensome restrictions would make it difficult and/or expensive for the other sectors to use or add value to these products and models or to contribute their own improvements to the analysis process. The NWS disseminates its data and products on a full and open basis, thereby ensuring that the only avenue for commercial competition) tend to become monopolized. In particular, it is difficult for a commercial company to recover the cost of generating core products without imposing restrictions on their re-use and resale. Monopolization typically reduces the total number of sales compared to what would be socially desirable, and thus leads to a reduction in social welfare.

Commercializing Value-Added Products

7. Value-added products may be distributed in a differentiated products market (i.e., several firms produce similar but distinct products) for which the prospects for rigorous competition are likely to be better. Multiple firms competing in a market are also more likely to create products that meet customer demands for quality and timeliness.
8. The community of end users of the core products and their derivatives is diverse. A flexible, extensive system for distributing that information is essential for maximizing the societal benefit of the information system.
9. For some communities of end users, competing commercial enterprises that add value to the core products and other sources of information are likely to flourish.
10. Public-sector distribution of value-added products is appropriate when the application is directly related to performance of the agency mission.
11. The scientific research community may choose to distribute their own value-added products paid for out of research funds. These products are likely to spawn additional specialized products, some of which may open new markets for commercial application.

SOURCE: National Research Council, 2001, *Resolving Conflicts Arising from the Privatization of Environmental Data,* National Academy Press, Washington, D.C., 99 pp.

all citizens have access to information vital for the protection of life and property. If such information were sold by private vendors, it is unlikely that everyone would choose to buy it, putting a substantial fraction of the population at risk. In addition, the vendor would not capture in its revenues all the value that weather and climate information has for society (item 4).

In contrast, it is desirable to have public, private, and academic entities create and distribute value-added weather and climate products (Box 4.2). The market for such products is large and differentiated, thus permitting competition among several organizations (item 7). The markets for forecasts on broadcast news hours or for agriculture forecasts are examples of differentiated products markets. Moreover, the customer groups that use weather and climate information are diverse and new customer groups are continually being added as forecast accuracy and reliability improve (item 8). Meeting all their needs requires multiple avenues to innovative products from all three sectors (items 9, 10, and 11). The NWS creates specialized value-added services relevant to its mission (e.g., fire weather and aviation products). The private sector conducts market research and develops tailored solutions for specific clients (e.g., snow forecasts for individual ski resorts, hourly updates of hurricane landfall predictions for a specific power plant). And the academic sector creates value-added products for research and education purposes (e.g., numerical prediction of local weather).

DATA POLICY

As noted in Chapter 2, different sectors of the weather enterprise require sometimes conflicting data policies. U.S. law[27] requires the NWS to make its data, forecasts, and standard information products available to all on a full and open basis. The widespread availability of NWS weather data and forecasts ensures their widest use in warning systems that are vital to the public's safety and well-being (see Box 1.1). The open data policy is also essential for the health of the academic sector, which must be able to scrutinize the data and methods by which they were collected, test the models, and contribute its own improvements to the weather enterprise.[28] Value-added providers in all sectors, who rely on low-cost data as a basis for their information products, also benefit from full and open access to government data. Indeed, the relatively small size of the value-added community in Europe suggests that charging high prices for the underlying data would make value-added work too expensive to undertake.[29]

Although the U.S. government does not hold intellectual property rights, other organizations exert copyright, patents, and other forms of intellectual property protections in order to control access to data and information products.[30] As a result, raw data collected by private sector companies, state agencies, or academic institutions funded in part by commercial companies may be subject to high prices and/or restrictions on use. These

[27]OMB Circular A-130, 65 Federal Register 77677, December 12, 2000.

[28]National Research Council, 2001, *Resolving Conflicts Arising from the Privatization of Environmental Data*, National Academy Press, Washington, D.C., 99 pp.

[29]The notion that the benefits to the treasury that accrue from corporate and individual taxes from value-added activities stimulated by open-access policies far exceed any revenues that might be generated through cost recovery policies is discussed in P. Weiss, 2002, Borders in Cyberspace, 19 pp., <ftp://ftp.cordis.lu/pub/econtent/docs/ peter_weiss.pdf>. Based on U.S. success in creating an information industry, the European Union is now considering a more open data policy. See *Public Sector Information: A Key Resource for Europe*, 1998, Green Paper on Public Sector Information in the Information Society, European Commission Report COM(1998)585, Luxembourg, 28 pp.

[30]National Research Council, 1997, *Bits of Power: Issues in Global Access to Scientific Data*, National Academy Press, Washington, D.C., 235 pp.; National Research Council,

include Doppler radars operated by television stations, mesonets such as those deployed by transportation departments to monitor road conditions, and micronets such as those used to monitor growing conditions in a particular field.[31] Such supplements to the national observation network are very useful, but if the data cannot be used for other applications, their value to the weather enterprise as a whole is limited.

The World Meteorological Organization has a two-tiered approach to disseminating data collected by member government agencies. Under the provisions of WMO Resolution 40, a defined set of basic data and products that are necessary for the protection of life and property are distributed on a full and open basis.[32] The remaining data may be subject to restrictions to prevent their use for commercial purposes outside the receiving country without the agreement of the originating member. Until the resolution was passed, countries had been withholding data to prevent private sector companies (largely in the United States) from selling weather products within the country that collected the data. Because companies were able to obtain the data at low cost through the NWS, their products could be sold for less than comparable products created by privatized weather agencies, which had to recoup data collection costs. Conditions more favorable to European companies were created in 1999, when the European Commission approved a legal framework (ECOMET) for providing access to basic meteorological data and products for commercial applications.[33] However, neither agreement has been formally evaluated to determine its impact on data access.

Although national governments collect and disseminate most weather and climate data, value-added products are created by the public, private, and academic sectors. Most data products generated with private money are intended to be sold, and access is controlled to permit the company to earn a return on its investment. Of course, some samples are given away

2000, *The Digital Dilemma: Intellectual Property in the Information Age*, National Academy Press, Washington, D.C., 340 pp.; National Research Council, 2001, *Resolving Conflicts Arising from the Privatization of Environmental Data*, National Academy Press, Washington, D.C., 99 pp.

[31]Examples include the Oklahoma Mesonet <http://okmesonet.ocs.ou.edu/>, MesoWest <http://www.jmet.utah.edu/jhorel/html/mesonet/info.html>, and the Little Washita Micronet <http://www.nps.ars.usda.gov/projects/projects.htm?accn_no=401626>.

[32]The international convention is "free and unrestricted." This term is fully equivalent to "full and open" used in this report. WMO Resolution 40 is described in WMO, 1996, *Exchanging Meteorological Data: Guidelines on Relationships in Commercial Meteorological Activities, WMO Policy and Practice*, WMO No. 837, Geneva, 24 pp.

[33]ECOMET is an economic interest grouping of 20 national meteorological services in Europe and Turkey. See <http://www.meteo.be/ECOMET>.

(e.g., forecasts on web sites) to stimulate sales of other products. In contrast, the general practice in the academic meteorology community is open sharing of all data and products. Many scientists put weather products generated for scholarly or educational purposes on the web to ensure their widest distribution and/or to satisfy grant requirements. However, when academia works with the private sector, the resulting product may not end up in the public domain.[34] For example, in the spring of 2002 the Department of Meteorology at the University of Oklahoma announced that it would limit access to real-time forecasts, which were developed with a combination of federal and private funds, to protect the interests of its private sector partners (Appendix B). Although this policy has been reconsidered, the example illustrates the difficulties of reconciling different data requirements.[35]

Similar difficulties arise from government-industry partnerships. A data policy has to be negotiated that permits commercial objectives to be achieved while producing the credible data that the public sector needs as well as satisfying laws and regulations governing public access to data and products.[36] Satisfying both demands is difficult, which is one reason why there have been so few successful examples (see Chapter 3). Government-academic partnerships, on the other hand, are easier to create because both partners share the same philosophy toward data.

The NRC report *Resolving Conflicts Arising from the Privatization of Environmental Data* outlines conditions under which the federal government could purchase environmental data from commercial vendors and privatize data collection and product development, while continuing to meet its public obligations (Box 4.3). Discontinuing government services in favor of private sector provision is commonly in the public interest, provided that competition leads to better products and services at lower prices. In such cases, government resources could be used to develop products (1) that benefit broad and diffuse groups of users, (2) that are considered too risky for the private sector to undertake, or (3) that would be too expensive to purchase from the private sector. A key conclusion of that report is that such decisions must be made on a case-by-case basis, using criteria such as those listed in Box 4.3, and they must be reevaluated as circumstances change (e.g., advances in science and technology, which in the weather

[34]Academic researchers funded by industry are generally more willing to accept data restrictions. See H. Brooks and L.P. Randazzese, 1998, University-industry relations: The next four years and beyond, in *Investing in Innovation: Creating a Research and Innovation Policy That Works*, L.M. Branscomb and J.H. Keller, eds., MIT Press, Cambridge, Mass., pp. 361-399.

[35]Information on the data policy of the Center for Analysis and Prediction of Storms is available at <http://www.caps.ou.edu/wx/>.

[36]National Research Council, 2001, *Resolving Conflicts Arising from the Privatization of Environmental Data*, National Academy Press, Washington, D.C., 99 pp.

Box 4.3 Criteria for Purchasing Commercial Data and for Privatizing Government Data Collection and Product Development

The NRC report *Resolving Conflicts Arising from the Privatization of Environmental Data* identifies criteria for ensuring that public needs continue to be met when the private sector contributes data to the national network or when the public interest would be served by transferring data collection or product development from the government to the private sector (privatization). These criteria, many of which overlap, are listed below.

Supplementing the National Database with Commercial Data

Circumstances under which data collected by commercial entities may be suitable for public-purpose information systems include the following:

- The data fulfill public sector needs. For example, data intended for scientific purposes must fulfill both immediate research objectives and long-term scientific goals. This in turn requires that the government acquire all the data rights (i.e., full and open access) within a specified period of time.
- The data are of suitable quality and have undergone credible calibration and validation techniques to assure they meet that quality. If the objectives include contributing to future research needs, full documentation is required. When the data are initially available for confidential scientific audit, the vendor must make a commitment to publish the full record of that audit when commercial reasons for confidentiality are no longer applicable.
- Because it takes several years to fully develop data products, there must be a reasonable prospect of a long-term supply of data.

Privatizing Data Collection

Transferring data collection from the government to the private sector may be in the public interest if all of the following conditions are fulfilled:

- A commercial capability for supplying the necessary data exists.
- The private sector is likely to provide a stable, long-term information supply.
- There is an effective process for conveying scientific or operational requirements to the private sector.
- The content and conditions of access to data sets (in particular, full and open access) would fulfill public sector needs.
- There is an established process for ensuring quality assurance and quality control of the commercial data.
- A substantial commercial market for the data exists that would not be compromised by the full and open access provided to the government and could reduce costs to the government.

Privatizing Value-Added Products

Criteria for the government to discontinue an existing product line in favor of its production by private entities include the following:

(continued)

- There are no overriding considerations, such as health and safety, that require continuing government control.
- Government-funded functions (e.g., scientific research, education, government operations) would not suffer greatly from restricted access to the product.
- Private sector organizations are interested in taking over the function.
- The research and development underpinning the application is mature (i.e., there are no significant uncertainties surrounding the interpretation of the available data for the purpose at hand).
- A demonstrable market that supports vigorous competition exists or is at least plausible, thereby reducing the possibility of a private monopoly. This is particularly important when the government and its affiliates would be the major customers.
- Existing users would not be harmed significantly if product availability were interrupted. For example, gaps in the long-term climate record may prevent detection of rapid temperature changes, thereby hindering scientific research and environmental policy making.

SOURCE: National Research Council, 2001, *Resolving Conflicts Arising from the Privatization of Environmental Data*, National Academy Press, Washington, D.C., 99 pp.

enterprise are essentially continuous). Such criteria are especially important for making decisions on activities that are not obviously within the purview of either the federal government or the private sector. In the weather and climate enterprise, the criteria could be used to decide, for example, whether the NWS should provide weather services to a particular industry (e.g., agriculture) or for a specific application (e.g., fire hazard).[37] The devil is in the details, so these decisions will have to be made by the stakeholders involved in the activity in question.

PERCEPTIONS OF UNFAIRNESS

A barrier to cooperation among the sectors that is commonly overlooked is the perception of what is fair to a particular party.[38] For example, some in the private sector want the federal government to establish a "level playing field" in the market for weather services (Appendix D). In particular,

[37]As a result of lobbying, the NWS no longer provides these services. See Chapter 1, "History of the NWS-Private Sector Partnership."

[38]The committee commissioned a paper on the issues of "fairness" in the context of government relations and services. The specific examples in Appendix E relate to government actions in the telecommunications field, but the principles illustrated are applicable to many of the issues that have arisen between the NWS and the private sector.

because the NWS is supported by tax revenues, it is said to have an "unfair competitive advantage" in the provision of services that the private sector would like to provide. On the other hand, taxpayers feel they have a right to receive services based on the tax-supported activities of the NWS as cheaply as possible. Therefore, the NWS should not be barred from providing such services if it can do so at an incremental cost lower than the private sector can. Understanding how perceptions of unfairness, whether justified or not, form can lower the barrier to the public-private partnership. A vocabulary and conceptual framework by which all parties can work on these problems is described below. This framework is discussed in depth in Appendix E.

Positive theories of fairness and self-serving behavior attempt to describe and analyze what *is*, as contrasted to *normative* moral theories that prescribe what *ought to be*. Among the common patterns of behavior that have been identified by this research, four are of special relevance to the weather and climate enterprise.

Status Quo Property Rights. A common notion is that one is entitled to something simply by virtue of having enjoyed it in the past. Status quo property rights are clearly in the minds of private sector weather service providers when they assert that the NWS should not provide any services that the private sector is already providing. Note that such status quo property rights are in conflict with the perceived rights of the taxpayers mentioned above.

Perceived Contracts. Behavior may be perceived as unfair if a contract is seen to have been violated. The 1991 NWS public-private partnership policy states that the NWS "will not compete with the private sector when a service is currently provided or can be provided by commercial enterprises, unless otherwise directed by applicable law." This policy is seen by some in the private sector as a "contract," whatever its legal status actually is. In line with this perception, some of the services now provided by the NWS are seen by some parties as a "breach of contract." Correspondingly, a change in the policy, without some kind of "compensation," would also be perceived by some parties as a breach of contract.

Cognitive Dissonance. Perceptions of unfairness are often exacerbated by misunderstanding the facts. This phenomenon has been studied extensively by social scientists, beginning with Leon Festinger's seminal 1957 book, *A Theory of Cognitive Dissonance*.[39] Festinger held that our minds hold simplified models of reality that we are reluctant to abandon. Evidence that

[39]L. Festinger, 1957, *A Theory of Cognitive Dissonance*, Stanford University Press, Stanford, Calif., 291 pp.

contradicts these models leads to "cognitive dissonance" and is rejected or ignored while we seek more evidence to support our cherished model.[40] In his 1759 treatise, *The Theory of Moral Sentiments,* Adam Smith put it more harshly, "He is . . . bold who does not hesitate to pull off the veil of self-delusion which covers from his view the deformities of his own conduct."[41]

Institutional Design. Research on the "positive theory of fairness" (especially in the regulatory arena) implies that policy makers who base their recommendations solely or primarily on principles of economic and scientific rationality, and give short shrift to concerns of unfairness, do so at their own peril. In particular, while the committee takes no position on the actual extent of cognitive dissonance, self-delusion, and self-serving behavior in the weather industry, the well-documented prevalence of these phenomena in human activities suggests the importance of creating institutions that minimize their effects. Designing institutions in which all participants feel they are being treated fairly is difficult and may be impossible, but some useful steps can be taken. For example, a thorough, transparent, and credible system of information dissemination can help minimize the associated costs of dysfunctional behaviors such as cognitive dissonance and self-serving denial. Suggestions for ensuring that NWS policies are sensitive to fairness issues are discussed in Chapter 6.

CONCLUSIONS

Legal, economic, and public policy arguments indicate that the NWS should continue to collect weather and climate data and to disseminate them on a full and open basis. It is economically efficient for the private sector to create value-added products from low-cost government data, but social benefits also arise from having universal access to certain value-added products created by the academic and public sectors (e.g., educational products, models, emergency preparedness tools). Which sector should create a particular value-added product must be decided on a case-by-case basis. Whatever decision is made must be perceived to be as fair as possible—within the constraints of federal laws, regulations, and policies—to all parties, or the public-private partnership will suffer.

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[40]Of course, other theories may explain "denial." Prison inmates, for example, plead that they are innocent or that they have been unjustly incarcerated because of extenuating circumstances. Their behavior may simply reflect their belief that their protestations will shorten their sentences (Appendix E).

[41]A. Smith, 1759, *The Theory of Moral Sentiments,* reprinted in 1976 by Liberty Classics, Indianapolis, p. 263.

5

Impact of Scientific and Technological Advances on Partnerships

Advances in science and technology drive the evolution of the weather and climate information system. Scientific, operational, and, increasingly, business requirements determine what observations to make, how the information should be analyzed, and what products to create. The scientific understanding generated by developing and using these data and products, together with improvements in instrumentation and computation, lead to a new set of requirements. The new capabilities that emerge from this evolving system can change what the sectors are doing or want to do—sometimes dramatically—and thus directly affect public, private, and academic partnerships.

Despite sharp declines in the telecommunications industry and Internet start-up companies, new technologies and products continue to be introduced at a rapid rate.[1] Rapid technological change, intense competition, and the creation of new markets are expected to continue or even increase in the coming decade. This chapter reviews scientific and technological changes in the weather and climate information system that have the potential to affect partnerships. The committee focuses on how the evolution of technology might alter the balance between the sectors, rather than on specific technologies, which have been the subject of numerous reports.[2]

[1]Hudson Trend Analysis, 2002, *Final Report to the National Oceanic and Atmospheric Administration*, Hudson Institute, Washington, D.C., 161 pp.

[2]Technologies such as broadband, the Internet, embedded networked systems, weather satellite systems, and modeling are described in the following reports: National Research

The history of technology shows that changes come in two main forms: those that can be reasonably well predicted and those that cannot.[3] Predictability falls off rapidly with time, so the focus here is on technological changes in the weather enterprise that are occurring now or that may occur over the next five to eight years. There are many computer and communications technologies that may have an impact on both the weather enterprise and the relationships among the partners. Examples include modeling, networking technologies, visualization, human-computer interfaces, and technologies for storing, structuring, and exchanging data. This report focuses on technologies that were deemed to have particular impact on partnerships. Predictable technological changes will have (somewhat) predictable impacts on public, private, and academic partnerships. However, there will surely be surprises as well, which will place unexpected stresses on existing partnerships and create new opportunities for cooperation. In either case, the weather and climate services offered in 2008 or 2010 will likely be very different from the services offered today. A longer view taken by a previous National Research Council (NRC) committee (Box 5.1) is consistent with the trends described in this report.

CHANGES IN THE SECOND HALF OF THE TWENTIETH CENTURY

Fifty years ago weather observations were made with in situ instruments or by eye or ear and plotted by hand on paper weather maps (Table 1.1). Observations were analyzed subjectively, and forecasts were based largely on the empirical skill of government forecasters. Weather and cli-

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Council, 2002, *Broadband: Bringing Home the Bits*, National Academy Press, Washington, D.C., 336 pp.; National Research Council, 2001, *The Internet's Coming of Age*, National Academy Press, Washington, D.C., 236 pp.; National Research Council, 2001, *Embedded, Everywhere: A Research Agenda for Networked Systems of Embedded Computers*, National Academy Press, Washington, D.C., 236 pp.; National Research Council, 1999, *Adequacy of Climate Observing Systems*, National Academy Press, Washington, D.C., 51 pp.; National Research Council, 1999, *Assessment of NASA's Plans for the Post-2002 Earth Observing Missions*, National Academy Press, Washington, D.C., 49 pp.; National Research Council, 1999, *A Vision for the National Weather Service: Road Map for the Future*, National Academy Press, Washington, D.C., 76 pp.; National Research Council, 1998, *The Atmospheric Sciences Entering the Twenty-First Century*, National Academy Press, Washington, D.C., 384 pp.

[3]Predictable changes include semiconductor technology for which Moore's Law has since 1965 predicted the improvement in semiconductor performance and price, with consequent geometric improvements in computation and data communication. Technological surprises include the World Wide Web and the pervasive presence of the Internet in our lives, neither of which was foreseen a decade ago.

Box 5.1 2025 Vision of Weather and Climate Forecasts

An NRC report *A Vision for the National Weather Service: Road Map for the Future*[a] looked ahead to the year 2025 to much improved weather and climate forecasts and how information derived from these forecasts would be increasingly valuable to society. The report envisions weather forecasts approaching the limits of atmospheric predictability (about two weeks) and new forecasts of chemical and space weather, hydrologic parameters and other environmental parameters. It describes the use of ensemble forecasts that project nearly all possible future states of weather and climate and how these ensembles can be used in a probabilistic way by a variety of users. It asserts that as the accuracy improves and measures of uncertainty are better defined, the economic value of weather and climate information will increase rapidly as more and more ways are found or created to use information profitably. New markets, such as the weather derivatives market, will be created. Some markets will be strengthened (e.g., forecasting for transportation, energy, and agriculture). Other markets may diminish, such as the role of human forecasters in adding value to numerical forecasts beyond one day or in preparing graphical depictions of traditional weather forecasts.

[a]National Research Council, *A Vision for the National Weather Service: Road Map for the Future*, National Academy Press, Washington, D.C., 76 pp.

mate information was disseminated to the public in text format, by radio, or through simple graphical displays on black-and-white television. The weather information system was run almost entirely by the National Weather Service (NWS), with academia focused on basic research and the private sector just beginning to emerge.

The atmospheric sciences community has made enormous progress over the past 50 years since the first weather radars and satellites started an era of remote sensing and the first numerical models of the atmosphere generated 24-hour forecasts of 500-mb (~18,000 ft or 5.5 km) circulation patterns. Advances in technology, including remote sensing from satellites, radars, and in situ sensors; computers; information and communication technologies; and numerical modeling, coupled with increased understanding derived from investments in research, have produced a weather and climate information system in the United States that is at the cutting edge of science and technology.

As scientific understanding and computational capabilities improved throughout the second half of the twentieth century, private companies found opportunities to use government data to create value-added products for clients. However, as little as 10 years ago (1992), federal government agencies still collected nearly all of the data and developed and ran the forecast models (Table 1.1). Today the situation is radically different. Declining instrument costs have permitted state and local government agencies, universities, and private companies to deploy Doppler radars and arrays of in situ instruments. Increased computing power[4] and bandwidth at rapidly dropping prices have enabled a substantial number of private companies and universities to run their own models or models developed by others. The development of new communications technologies (e.g., Internet, wireless devices) has reduced dissemination costs, increased the availability of weather data, and created new markets for weather and climate information. Indeed, advances in networking have transformed the weather and climate enterprise (Box 5.2). Finally, the widespread availability of visualization tools has made it easier for all sectors to display and better communicate weather information. These changes have made it possible for each of the sectors to provide services that were only recently in the domain of another sector (e.g., examples 4, 5, and 7, Appendix D) and thus have become a source of tension in the weather and climate enterprise.

CURRENT AND NEAR-TERM ADVANCES

Data Collection

Weather and climate phenomena and their impact on society occur on a variety of scales, from flooding in a farmer's field to global weather patterns affected by changes in the jet stream. Studying these different phenomena and developing products and tools to mitigate their impacts requires data of different spatial coverage and resolution, collected from a mixture of satellite instruments, local arrays, and independent stations. Satellite instruments provide high spatial and temporal resolution global coverage. The satellite observations are complemented by in situ measurements from radiosondes, aircraft, and surface stations. Doppler radars track and monitor small-scale severe storms and precipitation systems. Most instruments collect data continuously, but some are event driven. Examples include the lightning detection network, which is triggered by cloud-to-ground lightning strikes, and reconnaissance aircraft that fly into hurricanes. Other meteorological instruments can be adjusted to collect higher-resolution data for specific events—for example, geostationary satellites and radars, which can scan at a higher rate over areas of severe weather, thereby providing greater temporal resolution (on the order of minutes)

[4]The computers running global prediction models are 20 times more powerful than those a decade ago. W.J. Cook, 1996, Ahead of the weather, *U.S. News and World Report*, April 29, p. 55-57.

Box 5.2 Network Communications

Networking is having an increasing impact on all aspects of the weather and climate enterprise. Advances in network technologies have enabled automated data collection, as well as remote access to specialized computing servers that support models and forecasting. Networking has also dramatically increased the speed at which weather products are available and the number of users they reach. However, networking is not monolithic. The networking required for remote sensors and data collection may be wireless and self-organizing and may or may not have to be high bandwidth. Distributed and remote modeling and forecasting require extremely high bandwidth reliable networks to specific locations. However, excessively high or reliable bandwidths are not required for disseminating weather forecasts, watches, warnings, advisories, and other information products to the public.

The advances in networking rely to a large extent on improvements to underlying technologies. Terrestrial and satellite radio technologies provide access to instruments and enable operation in conjunction with ad hoc, self-organizing networks,[a] in which the sensors on the net may also play a role in the infrastructure of the network itself as routers and forwarders of traffic.[b] Advances in extremely high speed networks have come not only from improvements in copper-based technologies, but also from enormous strides in optical networking.[c] Several different advances are having and will continue have an impact on dissemination. First, as computer prices decline, home and office computers are becoming increasingly pervasive. The widespread availability of personal computers made the provision of network services possible, but it was the combination of e-mail, the World Wide Web, and web browsers that made them economically viable. Today, the majority of office workers in the United States have networked workstations on their desks. Second, the rise in the wireless cellular telephone and other wireless technologies is enabling people to stay connected while mobile. The combination of computer networks and wireless technologies dramatically increases the avenues for broad, rapid dissemination of urgently important weather information.

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[a]An example is the micron-sized sensors under development that would be dispersed from aircraft to gather and relay real-time data for meteorological and military purposes. See S. Burnell, Dust-sized sensors could monitor weather, *United Press International*, October 30, 2002, <http://www.upi.com/view.cfm?StoryID=20021030-031519-2481r>.

[b]The effectiveness of such sensors depends on the power and infrastructure of the network. Every time an antenna is turned on for sending or receiving, it uses significant amounts of power compared with the power required to make measurements or perform simple computations like data compression. The relationship between transmission distance and power is exponential. For an untethered device dependent on irreplaceable battery power, the trade-off is clear—shorter and less frequent communication yields a longer life span of measurements. If one is placing devices in remote locations, there is great advantage to making every device a sensor, even if part of its responsibility is to relay information from neighboring sensors toward a concentration point. Such a system must be organized to both conserve power effectively and deliver the data, by turning nodes on and off as required. In such a system, the data will follow different routes at different times and work around nodes whose power has been completely depleted. Examples of current research in these areas can be found at <http:www.cs.ucla.edu/csd/CENS.html> and <http://www.sigmobile.org/mobihoc>.

[c]Optical networking holds the promise of providing both extremely low latency (speed of light) and high bandwidth because many wavelengths can occupy the same fiber without interference.

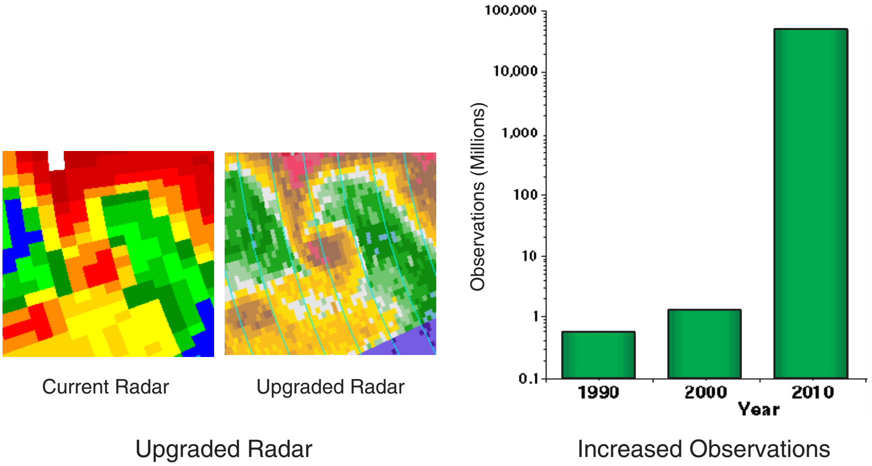

FIGURE 5.1 More frequent and detailed observations will greatly increase the resolution, coverage, and volume of data to be assimilated. *Left*: Improved resolution provided by upgraded radars. *Right*: The number and frequency of meteorological observations will increase over the next decade. Although most of this increase will come from new satellites, it also reflects expansions planned for the Cooperative Observer Network and other surface observational networks, additional aircraft reports, and additional radar data. SOURCE: National Weather Service.

than normal for that event. This mixture of observing approaches is also a cost-effective way of meeting the needs of the diverse weather and climate communities.

New observing systems currently being considered are intended to provide better accuracy, resolution, and coverage (Figure 5.1), as well as to maintain continuity with current observing systems. The latter is important not only for weather prediction but also for preserving the continuity of the climate record.[5] Over the next five to eight years, existing measuring systems such as rawinsondes and mobile radars must be maintained and upgraded.[6] Satellite observations (e.g., hyperspectral remote sounding instruments on geostationary and polar-orbiting satellites, and Global Positioning System [GPS] receivers on low Earth orbiting satellites) and ground-based

[5]National Research Council, 1997, *Toward a New National Weather Service: Continuity of NOAA Satellites*, National Academy Press, Washington, D.C., 51 pp.

[6]National Research Council, 1998, *The Atmospheric Sciences Entering the Twenty-First Century*, National Academy Press, Washington, D.C., 384 pp.

remote sensing systems such as radars and GPS receivers will continue to be provided by the U.S. government and its international partners.[7] Some of these systems (e.g., satellites) are still too expensive for the commercial weather industry to invest in. Sensors that can be deployed on aircraft or on the ground are becoming cheaper, smaller, and more powerful, primarily because of the continued decrease in cost and increase in capability of semiconductors. As a result, universities, state governments, and the private sector can increasingly afford to purchase, install, and maintain low-cost sensors for purposes that would not have been considered in the past (e.g., monitoring ice conditions on individual highway bridges).[8] More expensive sensors can also be cost-effective to the private sector if it holds a monopoly on the data (see Chapter 4), as in the case of lightning data.[9] It may soon be possible to deploy networks that reconfigure themselves in response to changing situations, thus providing optimal data coverage at relatively low cost.[10] Some of these sensor networks can be automated, further reducing operating costs, although automation raises questions about transmission delays and the robustness and reliability of the underlying networks.

The growth of private networks raises both scientific and policy issues. Most data collected by private companies and some data collected by state and local government agencies are proprietary (see Chapter 4). Since proprietary data and the methods by which they were collected cannot be scrutinized, it is difficult to determine whether the sensors were deployed in a scientifically rigorous manner (e.g., rooftop sensors may give unrepresentative temperature readings) or whether the resulting data were handled according to accepted scientific practices (e.g., calibration, validation, and quality control procedures). This uncertainty limits the value of proprietary data to the weather and climate enterprise.

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[7]Planned instruments include the Cross-track Infrared Sounder, the Geosynchronous Imaging Fourier Transform Spectrometer, Doppler LIDARs, scatterometers, and GPS receivers, among others. See National Research Council, *Satellite Observations of the Earth—Accelerating the Transition from Research to Operations*, National Academy Press, Washington, D.C., in preparation.

[8]National Research Council, 2001, *Embedded, Everywhere: A Research Agenda for Networked Systems of Embedded Computers*, National Academy Press, Washington, D.C., 236 pp.

[9]A start-up company, Airborne Research Associates, has developed a network of lightning sensors that capture all flashes, including cloud to cloud, not just cloud to ground, as is currently provided by Vaisala-Global Atmospherics, Inc.

[10]Presentation to the committee by D. McLaughlin, director of the Microwave Remote Sensing Lab, University of Massachusetts, May 16, 2002.

Modeling and Forecasting

The atmosphere-ocean-land system is complex and yields its secrets slowly. Models for understanding the system and for generating forecasts are only as good as the level of scientific knowledge, quality and coverage of input data, and computer-processing capabilities permit. Numerical models incorporate the dynamical equations governing the changing state of the atmosphere and oceans and fill in the spatial and temporal gaps in the global observing system (see Chapter 2 for an overview of weather and climate models). Such models are gradually getting better as the "three legs of the stool" get stronger (i.e., more and better observations, more powerful computers, better scientific understanding). They will continue to do so as very high resolution data and algorithms describing processes such as cloud interactions and land-surface and boundary-layer physics are incorporated.[11]

Advances in understanding and improved data coverage place increasing demands on processing capabilities. Indeed, one of the primary constraints on the accuracy and quality of forecasts is the computational effort required (1) to process effectively the large volume of observations that are collected and (2) to run numerical weather prediction models with high spatial resolution. For example, a recent NRC report found that ensemble models require 20 Gflops each day for weather prediction and 2.5 Tflops each day for short-term climate prediction.[12] Advances in high-performance computing (both hardware and software) will improve the precision and accuracy of weather forecasts. For example, the new NWS supercomputer—an IBM-built massively parallel machine that uses more than 2700 conventional microprocessors—will be able to resolve differences in weather for Manhattan and Queens.[13] Japan recently developed the Earth Simulator, a new supercomputer based on specialized hardware that will model climate change.[14] Given the rate of progress predicted by Moore's Law, it will be possible to forecast weather on a half-mile grid by 2015,[15] although insufficient observations may limit the usefulness of these models in some situations.

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[11]National Research Council, 1999, *A Vision for the National Weather Service: Road Map for the Future*, National Academy Press, Washington, D.C., 76 pp. Research opportunities for the atmospheric sciences are also outlined in National Research Council, 1998, *The Atmospheric Sciences Entering the Twenty-First Century*, National Academy Press, Washington, D.C., 384 pp.

[12]National Research Council, 2001, *Improving the Effectiveness of U.S. Climate Modeling*, National Academy Press, Washington, D.C., 128 pp.

[13]IBM Gets Contract for Weather Supercomputer, *New York Times*, June 1, 2002, <http://www.nytimes.com/2002/06/01/technology/01SUPE.html?pagewanted=print&position=bottom>.

[14]<http://www.es.jamstec.go.jp/esc/eng/outline.html>.

[15]IBM Gets Contract for Weather Supercomputer, *New York Times*, June 1, 2002, <http://www.nytimes.com/2002/06/01/technology/01SUPE.html?pagewanted=print&position=bottom>.

Advances in visualization technology could potentially help to improve the effectiveness of weather forecasts by making it easier for users to interpret large volumes and/or different types of data.[16] An example is the virtual geographic information system being used to provide interactive, three-dimensional visualizations of severe weather in northern Georgia.[17] The system combines petabyte-sized NEXt generation weather RADar (NEXRAD) and terrain data sets with information on human habitations (e.g., buildings, roads). The visualization grid size can be varied, allowing greater detail to be seen in some parts of the weather system than others. Integrating visualization tools with high-resolution weather models makes it possible to study the real-time development of storms in three dimensions, albeit crudely compared to what will be possible in the near future.

Advances in modeling and the computational and visualization tools that support them can be made by all three sectors, but access to improved models may vary. New or improved models generated by the public or academic sector are likely to be placed in the public domain, whereas models developed by the private sector (or commercialized government agencies in other countries) are likely to be proprietary. Nevertheless, the results of near-term scientific and technological advances are (1) more widespread use of sophisticated models in the academic and private sectors and (2) increasingly accurate forecasts extending further into the future. For example, the average lead time for tornado warnings in the United States increased from 6 minutes in 1991 to 10 minutes in 2001 (Figure 5.2). Four-day forecasts are as accurate today as two-day forecasts were 20 years ago.[18] The current limit for scientifically valid deterministic forecasts is 10-14 days, but as the forecast accuracy (Box 5.3) of longer-term events (i.e., seasonal and longer) increases, it opens new avenues of research in the academic sector and new business opportunities in the private sector, especially in agriculture, energy, and insurance.[19]

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[16]L.A. Treinish, 2002, Coupling of mesoscale weather models to business applications utilizing visual data fusion, in *Third Symposium on Environmental Applications: Facilitating the Use of Environmental Information*, American Meteorological Society, Orlando, Fla., pp. 94-101.

[17]This partnership between the Georgia Institute of Technology and the University of Oklahoma was funded by the National Science Foundation and the Georgia Emergency Management Agency, and NOAA's National Severe Storms Laboratory is testing the system. See presentation to the committee by Nick Faust, Georgia Institute of Technology, May 16, 2002, and <http://www.cc.gatech.edu/gvu/datavis/research/weather/weather.html>.

[18]National Research Council, *Satellite Observations of the Earth—Accelerating the Transition from Research to Operations*, National Academy Press, Washington, D.C., in preparation.

[19]National Research Council, 1999, *A Vision for the National Weather Service: Road Map for the Future*, National Academy Press, Washington, D.C., 76 pp.

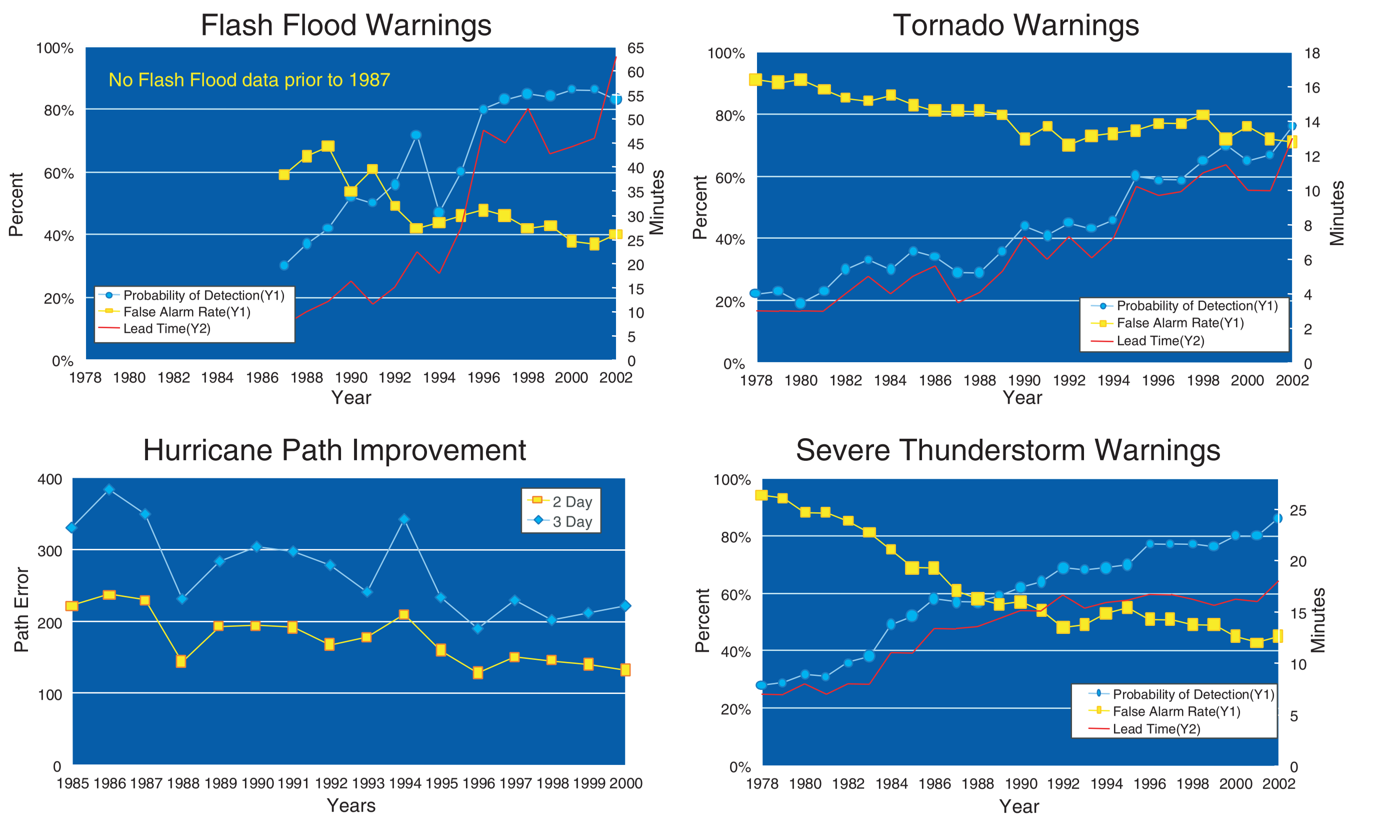

FIGURE 5.2 NWS metrics showing improvements in predicting hurricane paths from 1985 to 2000 and improved lead times (red line) and decreased false-alarm rates (yellow line) for flash flood, tornado, and severe thunderstorm warnings from 1978 to 2002. SOURCE: National Weather Service.

Box 5.3 Forecast Accuracy and Skill

Trends in objective, quantitative measures of accuracy and skill are very important in determining how forecasts are improving over time. The *accuracy* of a forecast is estimated quantitatively by comparing one or more elements or variables of the forecast, such as temperature, pressure, wind, or precipitation, to the corresponding observed value of the same variable or to an analysis of the variable using many observations. Measures of accuracy include mean, absolute, and root-mean-square (RMS) errors, and correlation coefficients between predicted and observed or analyzed variables, among others. Thus, the accuracy of a model's or a forecaster's five-day temperature forecast for a season might be expressed as a mean error of 1°C and an RMS error of 3.5°C.

A forecast is said to have *skill* if it has an accuracy above some simple method of prediction, such as persistence (tomorrow's forecast variable equals today's observed variable) or climatology (tomorrow's forecast is the climatological value of the variable). The accuracies of these simple forecast methods serve as a baseline for the model or human forecast, and the latter forecasts are said to have skill only if they are more accurate than the simple forecast method.

SOURCE: R.A. Anthes, 1983, Regional models of the atmosphere in middle latitudes, *Monthly Weather Review*, v. 111, p. 1306-1335; *Glossary of the American Meteorological Society*, 2000, Boston, p. 688-689.

Dissemination

The goal of any weather and climate information system is to deliver accurate, timely information to users. Throughout the 1950s weather data and products were transmitted through regional and national teletype lines and printed at rates of 300 words per minute.[20] NWS forecast maps drawn from the numerical models were transmitted to both internal and outside users via the National Facsimile Analog Circuits at 120 scan lines per minute. General forecasts and forecast products were delivered to the media by teletype, facsimile, mail, or hand. Weather warnings were broadcast over National Oceanic and Atmospheric Administration (NOAA) Weather Radio as well as television and commercial radio.

The advent of digital communications increased the speed of data transmission and created new avenues for delivering data to users, such as the Internet, cable, satellite television, and wireless devices. The Internet is now

[20] The History of Computing Project (Hardware, Teletype Development), <http://www.thocp.net>.

widely available[21] and is a powerful, low-cost, convenient means for all sectors to disseminate weather and climate products and, in some cases, to allow access to the underlying data. All three sectors embraced the Internet, but e-government initiatives in the 1990s[22] gave the NWS added impetus to adopt Internet- and computer-based technologies in its daily operations and in their interactions with the public. Indeed, the NWS earned straight A's in the Federal Performance Project for above-average communication and the use of information technology to improve the accuracy and timeliness of forecasts and to restructure the agency.[23] The NWS now provides weather products in both text and graphical format on its web site, in addition to its traditional dissemination vehicles (e.g., NOAA Weather Radio, printed bulletins). Users can also access certain NWS models (e.g., the Global Forecast System), model analyses, forecasts, and databases from their desktops. Information analysis and search tools allow Internet users to obtain more specialized weather data—anywhere, anytime. For example, both NWS and private sector web sites allow users to obtain weather forecasts by zip code.

Another means by which the NWS is improving access to data is the National Digital Forecast Database (NDFD), which will produce experimental digital forecasts over the conterminous United States by June 2003. Prior to 1998, most NWS data were in analog form.[24] With the NDFD, NWS forecasts will be in digital form and organized in a database, offering much greater flexibility in the way they can be used (Box 5.4). Users will be able to download only the information they need, and they will be able to combine different data and manipulate them on their own site. For example, suppose a user wants to calculate an hourly wind chill index in a

[21]The Internet evolved from a Department of Defense Advanced Research Projects Agency (ARPA) project called Arpanet. Using this foundation, the National Science Founcation (NSF) funded the creation of a network of networks, called the Internet. Backbone speeds increased from 56 kbps in 1986 to 448 kpbs over multiplexed T1 links in 1988 to 1544 kpbs over num-multiplexed T1 links in 1989 to 45 Mbps over T3 links in 1992. In 1995 the regional networks became independent of NSF and the commercial Internet service provider structure evolved over the next few years. The development of the Internet is described in National Research Council, 1994, *Realizing the Information Future*, National Academy Press, Washington, D.C., 285 pp., and National Research Council, 2001, *The Internet's Coming of Age*, National Academy Press, Washington, D.C., 236 pp.

[22]National Research Council, 2002, *Information Technology Research, Innovation, and E-Government*, National Academy Press, Washington, D.C., 168 pp.

[23]The Federal Performance Project is a partnership between *Government Executive* magazine and George Washington University's Department of Public Administration that rates federal agencies' management abilities. See J. Dean, 2001, Information management: Risking IT, *GovExec.com,* <http://www.govexec.com/fpp/fpp01/ s4.htm>.

[24]Presentation to the committee by Bruce Budd, meteorologist-in-charge, Weather Forecast Office-Central Pennsylvania, January 10, 2002. Meteorological services in other countries

Box 5.4 Database Technology

The NWS has traditionally stored weather data in multiple large data sets. This approach limits the usefulness of NWS data to end users. Programs to use the data must be written by experts who understand the format of each data set. These programs can be executed only on the entire data set; they cannot be executed on a subset of the data or against multiple, merged data sets without planning either in the original programs or additional programming.

A database management system offers a more flexible approach to managing and using data. The database architecture separates the structure of the data from the applications that manipulate them. Hence, end users can develop programs that meet their specific needs, such as new and different functions on the data, or subsetting or merging data in databases. In addition, abstraction of the database to a conceptual model makes it possible to modify the physical organization of the data without disturbing the application software or the users' logical view of the data. This may be necessary as the amount and kinds of data collected increase or change.

Significant investment in database technology will improve the ability of users to analyze the vast amount of weather information that is being collected.[a] Ideally, the database or databases should be designed to meet the needs of the weather community as a whole. Current database representations of weather data can contain inconsistencies that lead to erroneous analyses. Integrating databases from multiple sources can improve weather forecasts but remains a significant challenge because of the varied formats, semantics, and precision of each data source.

[a]National Research Council, 2003, *IT Roadmap to a Geospatial Future*, The National Academies Press, Washington, D.C., 136 pp.

particular town. Such an index cannot be computed from an analog forecast of "sunny, windy, and turning colder, with temperatures falling into the 20s tonight." Rather, digital hourly temperature and wind speed data for the grid point closest to the town are required. Such data will be available from the digital database. Of course, the deterministic nature of NDFD products may give users an unwarranted sense of the precision of the data, so care is warranted when using the database.

have been using digital forecast databases for several years. Examples include the Canadian SCRIBE (R. Verret, G. Babin, D. Vigneux, J. Marcoux, J. Boulais, R. Parent, S. Payer, and F. Petrucci, 1995, SCRIBE: An interactive system for composition of meteorological forecasts, *11th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology*, American Meteorological Society, Dallas, Tex., January 15-20, pp. 56-61), and the U.K. Horace system <http://www.met-office.gov.uk/research/nwp/publications/nwp_gazette/dec99/ horace.html>.

By providing access to digital data not currently available in standard products, the database will improve the ability of all the sectors to produce high-quality weather services, particularly as temporal and spatial resolution increases. The initial spatial resolution is 5 km and the temporal resolution is 3 hours for 1-3 days and 6 hours for 4-7 days.[25] In the future, the NWS plans to increase the spatial and temporal resolution and integrate other information into the database. In 5 to 10 years, the NDFD will include observations; analyses; weather, water, and climate forecasts from the forecast offices and the National Centers for Environmental Prediction; as well as watches, warnings, and advisory information.

These improvements in the NDFD will greatly increase the number of opportunities for the private sector to provide value-added products and create new services. On the other hand, the public at large may well demand more detail in weather forecasts, and not all of this added detail can be expected to come from the private sector. Improvements in the science and technology of weather forecasting and enhanced opportunities for rapid and targeted dissemination will all continue to challenge the partnership.

Making use of the full range of modern database technology can have a much larger impact on the weather enterprise than even the NDFD will have, because the NDFD will initially provide database access only to NWS forecast products. As described in Box 5.4, the use of a database management system for archiving and distributing the underlying data can greatly improve the usability and flexibility of the database. Such flexibility could have a significant economic impact on the whole community by allowing users to extract more value from the data.

Internet dissemination can be passive (i.e., users find and download copies of the information they want) or active (i.e., data are transmitted selectively to users). Most Internet weather dissemination is passive, but an increasing number of companies are offering services that push real-time weather forecasts and warnings to a user's workstation. The WeatherBug is one of a number of such products (Box 5.5). This new method of dissemination could reach a vast number of people who spend their day in front of workstations, away from televisions or radios.

There appears to be widespread agreement in the weather community that structuring information to be disseminated has significant benefit. Previously, NWS forecast products were only available as text or maps. By agreeing on an exchange structure (e.g., Extensible Markup Language [XML], Simple Object Access Protocol [SOAP]), the data can be handled and analyzed by programs much more easily and accurately, making them

[25]NWS Meteorological Development Laboratory, personal communication, October 2002.

Box 5.5 WeatherBug

The WeatherBug is a web-push product developed by AWS, Inc., to provide real-time weather information to clients. The system is based on the AWS Worldwide School Weather Network, which consists of more than 5000 automated weather sites. The WeatherBug and similar products allow users to connect to the site closest to a specified zip code in order to receive weather information, such as temperature, humidity, and heat index, in real time.[a] In addition, users are immediately notified when the NWS issues a storm watch or warning for the user-specified zip code. The product can be downloaded free with sponsor ads or for a small monthly fee without ads.

[a]Of course, data quality may be an issue since details about instrument sites, data collection, and quality control procedures are not available.

SOURCE: <http://ww3.weatherbug.com/aws/default.asp?cid=1>.

easier for all sectors to use. The NWS is moving toward distributing structured data, either through the web or through other avenues.

Advances in wireless and semiconductor technologies have created new opportunities for the private sector to deliver weather information to clients via portable wireless devices, such as cell phones, personal digital assistants, and pagers. All standard digital cell phones have a feature called "cell broadcasting" that allows text messages to be pushed to all phones in a given cell at no additional cost.[26] Because the message is broadcast from the control channel, the system does not overload. Pushing warnings via cell phone offers two advantages over NOAA Weather Radio: (1) weather warnings can be provided to a specific cell, rather than to an entire county, which reduces the number of irrelevant warnings that users hear, and (2) cell phones can store warnings. However, a number of technical issues must still be resolved before cell phone capabilities can be fully exploited. These include developing priority override, ringer suppression, and better user interfaces (to distinguish, for example, between an advertisement and an emergency alert) and dealing with the diversity of cell phone standards prevalent in the U.S. marketplace.

Some wireless devices take advantage of geographic information and computer graphics to provide more sophisticated weather services. GPS capabilities enable weather services to be tailored for and delivered to

[26]Presentation to the committee by Charles Bostian, professor of electrical and computer engineering, Virginia Tech, May 15, 2002.

precise locations. Improvements in computer graphics enable real-time visualization and display of weather information. For example, Digital Cyclone offers a service that allows mobile users to access local weather forecasts, view animated radar for the user's location, and receive severe weather updates on a wireless device.[27] Such services may reduce people's vulnerability to severe weather when they are traveling.

To take advantage of wireless services to the public, the NWS need not invest in a new communications infrastructure. Indeed, the NWS has no plans for disseminating weather information via wireless devices.[28] However, the NWS can provide watches, warnings, and other weather products in formats and structures that are most useful to companies that are developing the applications. The NWS has provided similar services for industries developing other media (e.g., television) in the past. Of course, there is no guarantee that companies that are currently passing along NWS weather warnings to wireless device users will continue to provide this service in the future. However, weather information is of such interest to the public that regulatory mechanisms may not be required to encourage expansion of this new avenue of dissemination.[29]

Given the rapid technological advances in both wired and wireless communications, all sectors must constantly evaluate the costs and utility of the various dissemination approaches for meeting customer needs. Cooperation between the NWS and the private sector will greatly facilitate the efficient use of dissemination technologies that serve both the specialized user and the general public.

Data Archiving

Maintaining a long-term archive poses significant challenges for the U.S. weather and climate enterprise. The deployment of a new generation of satellites in the coming decade (National Aeronautics and Space

[27]Digital Cyclone combines its proprietary weather forecasting system with NWS data to create localized weather forecasts. Information on Digital Cyclone's Mobile My-Cast service can be found at <http://www.my-cast.com/mobile/index.jsp>.

[28]Presentation to the committee by Ed Johnson, director, NWS Office of Strategic Planning and Policy, February 19, 2002.

[29]Regulatory mechanisms have had limited success in enforcing public policy mandates. For example, in 1996 the Federal Communications Commission (FCC) mandated that cell phone carriers transmit the address and phone number of 911 callers to the public safety answering point. However, many carriers have not implemented the E-911 mandate, citing the high cost of compliance. See J.H. Reed, K.J. Krizman, B.D. Woerner, and T.S. Rappaport, 1998, An overview of the challenges and progress in meeting the E-911 requirement for location service, *IEEE Communications Magazine*, April, p. 30-37.

Administration's [NASA's] Earth Observing System [EOS], Next Generation Geostationary Operational Environmental Satellite [GOES], and the Department of Defense-NASA-NOAA National Polar-Orbiting Operational Environmental Satellite System [NPOESS]) and the enhancement of NEXRAD present major data management challenges to the National Climatic Data Center (NCDC). Data volumes are projected to increase to 40 petabytes or more by 2010.[30] However, the challenge of ingesting data is dwarfed by the challenge of retrieving them.[31] Other challenges include managing disparate types of data, developing a rapid-access storage and retrieval system, and providing on-line access to data (in accordance with the federal government's e-government initiative).[32] Fortunately, technological advances will alleviate some of these problems. The cost of storage capacity will likely continue to drop dramatically; 200 Gbyte disks are available for as little as $399,[33] although problems in increasing large-scale storage capacity remain. The problems range from understanding the physics of making rotating devices move faster reliably to increasing bandwidth for communicating with the devices. One can predict that significant increases in capabilities and decreases in cost will continue, but the imbalances will remain.

Advances in database technology now permit companies to manage very large databases and archives.[34] For example, the TerraServer project demonstrated that large volumes of geospatial data (more than 20 terabytes of maps and aerial photographs) could be disseminated on-line by a very

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[30]NCDC currently holds 1.4 petabytes of data. The EOS satellites are generating about 60 terabytes of data per year, and the NPOESS satellites will generate 200 terabytes of data per year beginning in 2009. These data will be made available on the same terms as current satellite data (i.e., full and open access). See National Research Council, 2000, *Ensuring the Climate Record from the NPP and NPOESS Meteorological Satellites*, National Academy Press, Washington, D.C., 51 pp.

[31]See, for example, National Research Council, 1995, *Preserving Data on Our Physical Universe*, National Academy Press, Washington, D.C., 167 pp.; National Research Council, 2000, *Ensuring the Climate Record from the NPP and NPOESS Meteorological Satellites*, National Academy Press, Washington, D.C., 51 pp.; National Research Council, 2002, *Assessment of the Usefulness and Availability of NASA's Earth and Space Science Mission Data*, National Academy Press, Washington, D.C., 100 pp.

[32]Testimony on NOAA's FY 2003 budget regarding satellite data utilization and management by Conrad C. Lautenbacher, Jr., Undersecretary of Commerce for Oceans and Atmosphere, before the Subcommittee on Environment, Technology and Standards Committee on Science, U.S. House of Representatives, July 24, 2002.

[33]See a story about Western Digital's "Drivezilla" in ZDNet at <http://zdnet.com.com/2100-1103-946929.html>.

[34]A survey of some of these technologies that are relevant to data centers is given in National Research Council, 2003, *Government Data Centers: Meeting Increasing Demands*, The National Academies Press, Washington, D.C., 56 pp.

small staff.[35] The world's largest database system (BaBar), which runs on 100 servers and distributes data to 75 institutions around the world, has stored more than 668 terabytes of data from the Stanford Linear Accelerator.[36] These and other academic and private sector advances in geospatial data management could greatly improve the usefulness of the nation's weather and climate record to all sectors. Long-term archive issues are not currently a priority for weather companies, but as forecasting skill improves to permit seasonal and longer-term weather predictions, the quality and accessibility of archived weather and climate data will become increasingly important to the private sector, creating a new source of stress on the partnership.

CONCLUSIONS

Advances in science and technology over the last 10 years have drastically changed the capabilities of the three sectors as well as the expectations of their respective users. Barriers to entry have been lowered, eroding previously exclusive roles. For example, data collection and modeling are no longer exclusively the role of the federal government, and visualization techniques are no longer used exclusively by the private and academic sectors. Modeling and forecasts have improved, and new methods of communicating weather and climate information have emerged, creating opportunities for providing new products and serving new user communities. Major shifts include the use of wireless technologies and long-range (climate) forecasts by the private sector, and the implementation of Internet search tools and the National Digital Forecast Database by the NWS.

Prudent public policy must be based on the assumption that rapid advances in scientific understanding and technology will continue. These changes make it inadvisable to define sharp boundaries for what each sector can and cannot do. Indeed such prescriptions would be obsolete and ineffectual before they could be promulgated. Instead, the public, private, and academic sectors must work diligently to improve the processes and mechanisms by which they will deal with the problems and differences that are certain to arise. Recommendations for these improved processes are discussed in Chapter 6.

[35]TerraServer is a test bed for developing advanced database technology. It is operated as a partnership between Microsoft Corporation, the U.S. Geological Survey, the Russian Sovinformsputnik Interbranch Association, and other organizations. See <http://terraserver.homeadvisor.msn.com/About.aspx?n=AboutWhatIs>.

[36]<http://www.slac.stanford.edu/BFROOT/www/Public/Computing/Databases/index.shtml>.

6

Improving the Effectiveness of the Weather Enterprise

The joint participation of the public, private, and academic sectors in the U.S. weather enterprise has had the following benefits, among others:

- **Better data coverage**. The National Weather Service (NWS) national network is supplemented in some cases with local weather data from arrays of instruments deployed by universities, state governments, regional consortia, and private companies.
- **Wider information dissemination**. Weather information is now available through increasingly pervasive and immediate avenues, including radio, television, newspapers, web sites, cell phones, pagers, and personal digital assistants.
- **More realistic and scalable models**. Improvements in understanding of atmospheric and ocean phenomena, coupled with advances in computing and access to more data, have brought advanced modeling capabilities to the desktops of meteorologists in all sectors.
- **Increased infusion of cutting-edge technology**. Innovations developed in the academic, public, and private sectors are regularly adopted by the other sectors, fueling further innovation.
- **Greater number of specialized products**. The large number of companies seeking market niches yields a far more diverse menu of weather products and services than could be offered by the government alone.

Although involving the three sectors enhances the overall capabilities of the system, it also leads to friction and inefficiencies in the forecasting system. In carrying out its legislated responsibilities, the NWS must make continuous weather predictions on all spatial and temporal scales. The resulting forecasts can be specialized, to some extent, by private companies for local and/or individualized applications. Inefficiencies result from the necessary duplication of some of the efforts to prepare these two types of forecasts. However, it must be recognized that to satisfy the different requirements and objectives of the three sectors, and thus achieve the economic and public benefits to the nation, the weather forecasting system as a whole cannot be perfectly efficient.

Similarly, some level of friction is inevitable in a three-sector system when activities overlap and advances in science and technology change what the sectors are capable of doing. An increasing role of the private sector in data collection, for example, could make it more difficult to maintain the open access to data upon which weather and climate applications depend. Advances in modeling and improvements in forecast accuracy, particularly extending forecast accuracy to seasonal and longer timescales, will open new business opportunities for predicting the effects of El Niño and other climate events on industries such as agriculture, energy, and insurance. And new methods of dissemination will reduce some business opportunities (e.g., making government data more accessible) and create others (e.g., personalized weather services via wireless devices).

A number of ideas have been proposed that putatively would increase the efficiency of the weather and climate information system and decrease friction among the sectors. Some in the private sector have suggested eliminating some weather services from the NWS or ending research grants, which they view as subsidies, by atmospheric science funding agencies (e.g., National Science Foundation, National Oceanic and Atmospheric Administration [NOAA], Department of Defense) to scientists creating value-added products.[1] Some NWS officials and academic researchers have proposed that companies contribute their data without restrictions to the general pool. However, these suggestions have shortcomings (see Chapter 4), and none have proven to be practical to implement. A better solution is to use criteria such as those given in Box 4.3 to make case-by-case decisions on which sector should undertake a particular activity. Rigid boundaries between the sectors are hard to define, and any such definitions quickly become obsolete as technological capabilities and user demands evolve. Consequently, any precise and detailed division of responsibility that the

[1]For example, see testimony before the House of Representatives Subcommittee on Energy and Environment by Michael S. Leavitt, on behalf of the Commercial Weather Services Association on April 9, 1997, 105th Congress, 1st Session.

three sectors agreed upon today—if such an agreement were even possible—would quickly become out of date and hinder future improvements of the weather information system. *One of the committee's strongest conclusions is that a different approach is needed—one that emphasizes improved processes for dealing with conflicts and change, rather than proscribed activities.* In this chapter, the committee recommends ways to strengthen weather and climate partnerships and the contributions of the three sectors.

STRENGTHENING PARTNERSHIPS

Partnerships are created to take advantage of the strengths of different players and thereby achieve a result that could not be achieved by a single player. There are many successful examples of partnerships in the weather and climate enterprise, particularly among federal and state government agencies and academia. These are relatively easy to establish because the partners share the same philosophy toward open data access and both are at least partly oriented toward improving public services and advancing the science. Partnerships between the private sector and academia or the NWS can be more difficult to establish, but the payoff is high (e.g., widespread dissemination of severe weather warnings and advisories to the U.S. public through the media). The current relationship between the NWS and the private sector is far from ideal, but each sector can take several steps to improve it, as detailed below.

Revising the 1991 Public-Private Partnership Policy

Far from resolving the roles and responsibilities of the NWS and the commercial weather industry, the ambiguity in the 1991 NWS public-private partnership policy raised new questions and misunderstandings (see Chapter 4 and Appendix B). The growth of a technologically sophisticated private sector has made the approach of defining roles even more untenable than it was in the 1970s when the first such policy was crafted.[2] Moreover, the legal interpretation of the 1991 policy has changed with the passage of subsequent laws and policies (see Chapter 4). The NWS has a number of options for addressing these problems:

1. Retain the policy in its current form. The ambiguity in the language provides flexibility, although this flexibility will continue to create friction between the sectors.

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[2]National Weather Service, 1978, Policy on industrial meteorology, *National Weather Service Operations Manual 78-24*, Part A, Chapter 55, pp. 1-3.

2. Modify the policy to make it consistent with federal law, particularly the NWS Organic Act, Weather Service Modernization Act, and e-government initiatives. In particular, any language suggesting that the NWS should not disseminate information electronically to as wide an audience as possible is inconsistent with the Paperwork Reduction Act and the Government Paperwork Elimination Act. Adding an explanation of the legal framework in which the NWS operates might also prove helpful to the nonlawyers in the community.

3. Modify the policy to remove the following phrase: "The NWS will not compete with the private sector when a service is currently provided or can be provided by commercial enterprises." The private sector can do much of what the NWS legitimately does, so capability is a poor criterion for differentiating the roles of the sectors. Moreover, private firms can offer many services that they choose not to offer, preferring to use scarce resources on projects with superior returns. Finally, there are good public policy reasons for the NWS to carry out certain activities, even if the private sector does or could do them.

4. Rescind the policy and rely on existing federal laws and policies to decide what activities to undertake.

5. Replace the policy with a new one outlining the relationship between the private sector and all parts of NOAA concerned with weather and climate services.

6. Revise the policy to emphasize processes for making decisions, rather than rigid definitions of roles and responsibilities.

Implementing options 1 through 4 without instituting other mechanisms for making decisions would hardly create a good business environment or promote an improved working relationship between the sectors. Indeed, the NWS might then expect that certain private companies would believe that the "contract" has been violated (see Chapter 4 and Appendix E) and continue their efforts to lobby for legislation more favorable to them (see Chapter 1, "History of the NWS-Private Sector Partnership"). The NWS has resisted such efforts in the past for public policy reasons (see Chapter 4).[3] The committee concludes that some combination of options 2, 5, and 6 would best foster the NWS-private sector partnership. Moreover, a policy that focuses on processes rather than proscriptive boundaries (option 6) would avoid the practical problems of the current NWS policy.

[3]J. Kelly, 2001, Weather, water, and climate information in the 21st century: Opportunities for the risk management community, 3rd Annual Weather Risk Management Association Convention, Bermuda, June 6.

Recommendation 1. The NWS should replace its 1991 public-private partnership policy with a policy that defines processes for making decisions on products, technologies, and services, rather than rigidly defining the roles of the NWS and the private sector.

Because of public confusion about the roles of NOAA's satellite and research divisions in weather and climate services, the policy would ideally be expanded beyond the NWS to include all relevant parts of NOAA. Of course, any policy on the public-private partnership should be developed in consultation with all stakeholders, both inside and outside NOAA. Such an open process could help lead to a policy that is perceived as fair by all sectors (see Chapter 4, Appendix E). Although enacting such a policy would not resolve all issues associated with the provision of weather and climate services, simply coming to an agreement would be a significant achievement.

Facilitating Communication Among the Sectors

Organizations generally benefit from ongoing external advice, particularly when multiple stakeholder groups have a strong interest in the outcome of decisions. The NWS formerly had an industrial meteorologist on staff who served as an ombudsman to deal with interactions between the NWS and the private sector. Under the NWS headquarters reorganization of 2000, that responsibility is now shared by the Office of Climate, Water and Weather Services and the Strategic Planning and Policy Office. Today, writing letters and e-mail to NWS officials and participating in regular meetings of user groups associated with different offices and projects are the primary mechanisms available for raising concerns. Although letters often result in a satisfactory explanation or change in behavior on the part of the NWS, the private sector has no recourse when they do not. Lobbying Congress is an option that some companies have used, but the outcome may not always be in their or the public's interest (Appendix B).

In August 2002 the NWS established a new mechanism for gaining feedback on the creation of new or enhanced products and services.[4] The new policy lays out principles for deciding whether a product should be modified or created (Box 6.1) and steps for evaluating external comments and deciding whether the product should be made operational. The NWS is to be commended for engaging the community in product planning, although the policy does not cover all of the complexities of product development, as outlined in the sections below. Moreover, the evaluation process

[4]NWS Policy Directive 10-102, NWS requirements for new or enhanced products and services, August 28, 2002, <http://www.nws.noaa.gov/directives/>.

Box 6.1 NWS Principles for Modifying Existing or Creating New Products and Services

- **Mission connection.** Describe the mission connection.
- **Life and property first.** Put life and property first in the allocation of resources and the development and dissemination of products and services.
- **No surprises.** Provide all users, including those in the private sector, adequate notice and opportunity for input into decisions regarding the development and dissemination of products and services.
- **The taxpayers own the data.** Open and unrestricted dissemination of publicly funded information is good policy and the law.
- **Equity.** Be equitable in dealings with various classes of entities and do not show favoritism to particular classes of partners, particularly those in the academic and commercial sectors. Do not provide a service to a segment of the user community that cannot be provided to all similar types of users.
- **Maintain and explain the routine.** When faced with requests for specifically tailored services, make sure that the customer fully understands which products the NWS "routinely" provides. Refer requests for specifically tailored products or services to the private sector.

SOURCE: NWS Policy Directive 10-102, NWS requirements for new or enhanced products and services, August 28, 2002, <http://www.nws.noaa.gov/directives/>.

should be expanded to include an objective determination of whether the user understands the product or will make a useful decision based on it.

The product generation process and user group meetings are useful ways of keeping the community informed about potential new NWS products. However, neither mechanism permits users to provide input in the early stages of a decision (i.e., the idea formulation stage). One way in which the NWS can obtain early feedback is to establish an advisory committee, under either the Federal Advisory Committee Act (FACA)[5] or some other mechanism that gives the committee official status. Such an advisory committee, whose membership includes academic, private sector, and public interest (federal, state, nonprofit) representatives, as well as NOAA and other agency executives and experts, would also enhance cooperation among the sectors. Although the areas in which advisory committees are

[5]The Federal Advisory Committee Act defines the boundaries within which federal advisory committees operate, with special emphasis on open meetings, public involvement, and reporting. FACA does not apply if the intent of the committee is to provide information or viewpoints from individual attendees as opposed to advice, opinions, or recommendations from the group acting in a collective mode. See Management of federal advisory committees, <http://gsa.gov/Portal/>.

allowed to give advice are circumscribed, there is ample scope for constructive input. If the membership is well chosen and the senior agency management listens to its advice, independent advisory committees can be very effective in providing feedback on plans for collecting data and releasing new products and on defining long-term strategies. An advisory committee could also benefit NOAA and the NWS in the long run by making more outside players in the weather and climate enterprise aware of the importance of core NWS activities.

Recommendation 2. The NWS should establish an independent advisory committee to provide ongoing advice to it on weather and climate matters. The committee should be composed of users of weather and climate data and representatives of the public, private, and academic sectors, and it should consider issues relevant to each sector as well as to the set of players as a group, such as (but not limited to)

- **improving communication among the sectors,**
- **creating or discontinuing products,**
- **enhancing scientific and technical capabilities that support the NWS mission,**
- **improving data quality and timeliness, and**
- **disseminating data and information.**

The NWS had an external users' council in the mid-1980s to provide a mechanism for communicating with commercial data providers and exploring ways to disseminate data.[6] After a few years, the council was transformed to an annual users' meeting, often held at the annual meeting of the American Meteorological Society (AMS). In the late 1990s the NWS considered reestablishing an external council, perhaps through the AMS, to resolve issues of mutual concern to the NWS and the commercial weather industry.[7] Instead, the users' meetings were continued and supplemented with meetings of major constituent groups (e.g., emergency managers). In addition, NWS headquarters was reorganized as part of the modernization effort, and two offices were charged with the responsibility to better support the industrial meteorology community.[8]

[6]A. Eustis, NOAA National Environmental Satellite, Data, and Information Service, personal communication, October 2002.

[7]See discussions on a proposed NWS-private sector meteorology partnership initiative, American Meteorological Society Board of Private Sector Meteorology, January 13, 1998, <http://www.ametsoc.org/AMS/PrivateSector/ 980113_meeting.html> and February 2, 1998, <http://www.ametsoc.org/AMS/PrivateSector/ 980202_meeting.html>.

[8]The Strategic Planning and Policy Office addresses policy issues that affect the agency as a whole, including the public-private partnership, and the Office of Climate, Weather, and

The NWS users' meetings are a good mechanism for obtaining feedback from commercial meteorologists, but they are controlled by a single stakeholder—the NWS. In contrast, the AMS has facilitated a dialogue between the sectors since 1948.[9] Its membership is evenly divided between government, academic, and commercial meteorologists, so in theory no sector has a stronger voice than the others. The AMS could hold periodic forums, meetings, or other events to encourage each sector to air its complaints and misunderstandings about the actions and practices of the other sectors. Such meetings would complement the activities of the recommended advisory committee by improving communication among the sectors outside of the decision-making arena.

Recommendation 3. The NWS and relevant academic, state, and private organizations should seek a neutral host, such as the American Meteorological Society, to provide a periodic dedicated venue for the weather enterprise as a whole to discuss issues related to the public-private partnership.

ENHANCING THE CONTRIBUTIONS OF THE THREE SECTORS

The interdependence and rapid evolution of government agencies, academia, private companies, and other organizations concerned with weather and climate make it challenging to optimize the weather information system as a whole (see Appendix B). It is easy to envision how NWS services, for example, might be aligned to achieve a single national goal. However, there are many, sometimes conflicting, national goals related to the provision of weather and climate services. Formulating a policy about one (e.g., enhance the national economy) might make it harder to achieve another (e.g., protect life and property). Moreover, whatever policy is chosen to meet a particular goal is likely to have dramatic consequences for different sectors and user groups. This problem is exacerbated because no single entity is responsible for deciding what products and services should be provided, who should provide them, how and to whom they should be provided, and where competition would be desirable. As noted in a recent National Research Council report, "No one sets the priorities, no one fashions the agenda."[10] Consequently, the "playing field" and the "rules of

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Weather Services addresses all NWS service programs and customers, including commercial meteorologists. See <http://www.weather.gov/im>.

[9]The AMS has hosted a number of policy forums on the public-private partnership, from the 1948 conference that yielded the six-point program (see Box B.1) to the 2001 conference that yielded a thoughtful set of position papers. See Opportunities for 21st century meteorology: New markets for weather and climate information, American Meteorological Society presidential policy forum, <http://www.ametsoc.org/AMS/>.

[10]National Research Council, 1998, *The Atmospheric Sciences Entering the Twenty-First Century*, National Academy Press, Washington, D.C., p. 58.

the game" of this complex system are constantly evolving in an ad hoc manner as individual sectors make key decisions. Also, as different sectors lose their status quo property rights, they feel unfairly treated by the system (Chapter 4, Appendix E). Dealing with these issues will require cooperation from all parties.

National Weather Service

Many of the tasks laid out in the NWS Organic Act are as important to the public welfare and national economy today as they were in 1890. These include data collection; quality control; issuance of weather forecasts, warnings, and watches; and dissemination of information and products. Data collection is properly a government role, particularly given the cost structure and public-good properties of weather data and the need for making international exchange agreements (Box 4.2). Although the data are collected primarily to generate forecasts and warnings, their value is increased if they are validated, checked for quality, and disseminated as widely as possible, thereby making them useful for a wide range of other applications. Indeed, this is the rationale for federal laws mandating the dissemination of high-quality information at low cost. Most private companies agree that the government should continue to collect and disseminate weather and climate data on a full and open basis, but not all companies agree that the NWS should disseminate forecasts. However, the committee notes that forecasts have to be made to generate watches, warnings, and advisories, and it makes economic sense to disseminate these useful intermediate products to the public, which has already paid for them.

The value of meteorological data collected by NOAA and its international partners lies not only in the short-term economic and social benefits that accrue from use of the newly collected data, but also in the long-term studies of changes in the Earth's atmosphere. Such studies are possible only if there is a reliable, accessible, long-term archive. Because of the need for a long-term scientific and financial commitment to the data, the stewardship of atmospheric observations is a proper function of the government and should continue to be carried out by the National Climatic Data Center.

Recommendation 4. The NWS should continue to carry out activities that are essential to its mission of protecting life and property and enhancing the national economy, including collecting data; ensuring their quality; issuing forecasts, warnings, and advisories; and providing unrestricted access to publicly funded observations, analyses, model results, forecasts, and related information products in a timely manner and at the lowest possible cost to all users.

Government agencies routinely adopt technologies and products developed by the academic and private sectors to operate more efficiently and meet their mission. (The same is true of the other sectors.) The expected improvements in meteorological observations, scientific understanding, and computational and communications technologies will create many opportunities for improving NWS information services. Despite objections from some private companies (see Appendix D), the NWS should continue to adopt technologies that improve its ability to carry out its mission. In particular, the NWS should continue to explore ways to increase the amount and usefulness of information disseminated passively over the Internet. The Internet provides a means of reaching a large population and providing access to more NWS capabilities at low cost. The new Digital Forecast Database, for example, will improve the ability of the NWS to provide observations, analyses, forecasts, and warnings in convenient forms, including tables, images, graphics, and other types of visual displays. Similarly, graphics and icons on NWS web sites—if selected with an understanding of what the displays mean to the user—can improve the communication of weather information to the public. On the other hand, technologies that improve the effectiveness of the weather enterprise but are not integral to NWS operations (e.g., wireless communications) should be supported, not adopted (see Recommendation 9).

Recommendation 5. The NWS should make its data and products available in Internet-accessible digital form. Information held in digital databases should be based on widely recognized standards, formats, and metadata descriptions to ensure that data from different observing platforms, databases, and models can be integrated and used by all interested parties in the weather and climate enterprise.

Adopting new technologies requires an initial investment, but *not* adopting technologies also has a cost. Any decision that the NWS makes in this regard will affect the other sectors. For example, color graphics were developed by academia and commercial graphics companies and were first deployed in the weather services by the private sector (see example 7, Appendix D). Their use by the NWS should not be seen as unfair competition; rather, such adaptations of technology should be seen as "catching up." However, copying leading-edge technological developments that in and of themselves still confer substantial added value might stress the partnership.

Advances in science and technology lead to the creation of new models and products, which in turn open new avenues of research and development. Consequently, an ongoing question for the NWS, with its limited resources, is which products and services in response to identified requirements it should create. If the NWS is to develop new products and services within a fixed budget, it must either become more efficient in its operations or phase out some services. Increasing efficiency is an ongoing effort for most organizations, and the NWS has recently developed guidelines for what products to incorporate into operations.[11] However, the NWS has no formal process for identifying candidate products and services to discontinue.[12] The criteria listed in Box 4.3 may be helpful in this regard.

The NWS has already stopped producing certain products such as fruit-frost and event-specific forecasts. Some private companies would like the NWS (and academia) to discontinue hourly and long-range forecasts or any product that is targeted to a specific user group (e.g., aviation) or local area (e.g., weather forecasts by zip code). However, there may be public-benefit reasons (e.g., open data access) for the NWS to continue to create specialized products, even if the private sector is already producing them. Moreover, there is no guarantee that the private sector would create the discontinued product or that it would continue to provide it if the profitability of doing so declines. For example, agriculture weather products discontinued by the NWS in response to congressional direction have in some cases been taken up by state governments,[13] but in other cases they have not. Providing advice on which NWS products should be created and which should be discontinued could be a useful role of the multisector advisory committee recommended above (Recommendation 2).

The committee emphasizes that specialized weather and climate information that is primarily of interest to specific individuals or organizations, but is not essential for the protection of life and property or to the overall enhancement of the national economy, should be provided by the private sector through fees for value-added services, rather than by the government through taxation of the public.

Recommendation 6. The NWS should (1) improve its process for evaluating the need for new weather and climate products and services that meet new national needs, and (2) develop processes for discontinuing dissemination of products and services that are specific to particular individuals or organizations or that are not essential to the public.

The NWS relies on its 135 weather and river forecast offices to provide forecasts and other products for their geographic region and to interact

[11]NWS Policy Directive 10-102, NWS requirements for new or enhanced products and services, August 28, 2002, <http://www.nws.noaa.gov/directives/>.

[12]Some guidelines for privatizing government functions are given in National Research Council, 2001, *Resolving Conflicts Arising from the Privatization of Environmental Data*, National Academy Press, Washington, D.C., 99 pp.

[13]For example, Florida has installed an automated weather network to support agriculture services. See <http://fawn.ifas.ufl.edu/>.

with local officials and the public. Providing a certain level of autonomy fosters innovation, which benefits the weather and climate enterprise. On the other hand, the profusion of offices makes it difficult to communicate and enforce NWS policy. Staff at the NWS offices that the committee visited seem to have received varying guidance from NWS headquarters on generating products. Moreover, under the new NWS guidelines for creating products, new or enhanced regional or local products created by the local offices are approved by the cognizant NWS regional director(s) and do not have to be approved by NWS headquarters.[14] Consequently, significant variability exists in what and when products are disseminated, the extent to which they are checked for quality, and the attitude of the office about cooperation with the academic and private sectors. For example, an NWS forecast office recently offered specialized services for newspapers, even though such services were not mission related (see example 21, Appendix D). Such actions violate the public-private partnership "contract" and create resentment and mistrust within the private sector (Chapter 4, Appendix E). The NWS is taking steps to present a more uniform face to the public. The creation of standard web pages for all NWS offices[15] and the new NWS policy for creating new products and services represent a good start in this direction, but more has to be done if the NWS offices are to gain the trust of the private sector and be responsive to NWS strategic goals.

Recommendation 7. NWS headquarters and regional managers should develop an approach to managing the local forecast offices that balances a respect for local innovation and creativity with greater control over the activities that affect the public-private partnership, especially those that concern the development and dissemination of new products or services.

The public relies on the trustworthiness of NWS data, the private sector relies on NWS data to produce high-quality value-added products for clients, and all sectors rely on the NWS to maintain scientifically valid meteorological and climatological databases. Consequently, it is essential that proper attention be paid to maintaining scientific standards for collecting, verifying, and reporting data and for communicating uncertainties. The NWS generally, but not always, deals with its data and products in a scientifically rigorous way. Information generated by some computer sys-

[14]Local, regional, and national products undergo the same public notice and comment procedures.

[15]NWS Policy Directive 60-1, Technical and content requirements for Internet servers, February 8, 2002.

tems, for example, is not always scientifically valid. The Advanced Weather Interactive Processing System misleadingly translates hail sizes estimated by volunteer observers as "pea," "marble," "nickel," or "golf ball" to a hundredth of an inch.[16] The same system uses a report of a single 6-foot tree down to confirm warnings of winds of 55 knots or higher. Products generated within the Interactive Forecast Preparation System present deterministic high and low temperatures seven days out, which is not viewed as scientifically valid by the broader meteorological community.[17] Before implementing systems that generate data, forecasts, and other products, care should be taken that the information is scientifically valid, that it communicates the uncertainties and probabilities inherent in forecasting, and that it maintains the high standards that the general public has come to rely on from the NWS.

An area in which scientific methods are not being fully utilized is making and disseminating forecasts in probabilistic terms. The AMS recently endorsed the use of probabilistic methods that would permit users to make decisions based on quantified uncertainties.[18] However, the NWS policy continues to rely on deterministic information (e.g., maximum and minimum temperatures, dewpoint, sky cover, wind) for three- to seven-day forecasts. As the organization responsible for setting the scientific standard for operational meteorology, the NWS should take the lead in adopting probabilistic forecasts. Doing so would require forecasters to become more familiar with user needs and expectations. It would also require NWS management to support the development and use of forecaster tools and systems that facilitate the generation of probabilistic information as a more integral part of the forecasting process. As experience in communicating the probability of precipitation in a particular area shows, the public can understand and use probabilistic forecasts.[19]

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[16]See Yesterday's Storm Reports, NWS Storm Prediction Center, <http://www.spc.noaa.gov/climo/reports/>.

[17]American Meteorological Society statement on enhancing weather information with probability forecasts, January 2002, <http://www.ametsoc.org/AMS/POLICY/enhancingwxprob_final.html>.

[18]The AMS definition of predictive probability is "a numerical measure of the degree of confidence in the occurrence of an event, considering all information (data, models, and judgement) utilized in the forecasting process. This measure must obey the laws of probability theory." American Meteorological Society statement on enhancing weather information with probability forecasts, January 2002, <http://www.ametsoc.org/AMS/POLICY/ enhancingwx prob_final.html>.

[19]National Research Council, 2003, *Communicating Uncertainties in Weather and Climate Information: A Workshop Summary*, The National Academies Press, Washington, D.C., 56 pp.

Recommendation 8. The NWS should continue to adopt and improve probabilistic methods for communicating uncertainties in the data and forecasts where such methods are accepted as scientifically valid.

The types of data collected for weather forecasting are quite varied, and each type tends to be formatted and documented in a different way. This lack of uniformity creates problems in the archival and subsequent retrieval and use of observational data.[20] As the primary collector of weather and climate data, the NWS should play a lead role in developing data formats and standards. The NWS already sets the standards for weather data collected under the auspices of NOAA and participates in setting international standards through the World Meteorological Organization. However, an increasing amount of data is being collected by organizations that may not adhere to established formats and standards or even understand the importance of compatible data to the broader weather enterprise. If this trend continues, it could have serious implications for the continued development of high-quality products by all sectors.

Diverse and incompatible standards are also a problem in the context of communications technology. The NWS should provide leadership in harmonizing and/or developing interface standards for the delivery of weather forecasts, watches, and warnings over cellular devices. To support wireless dissemination of standard forecasts and NWS warnings by private companies, the NWS may have to develop tailored machine-readable formats for its weather products that can be manipulated by cellular carriers and content providers. The NWS has developed such formats in the past to take advantage of other communications technologies such as radio and television. Such compatibility greatly enhances the usefulness of these new data sources and avenues of communication and creates a level playing field for many prospective users.

Recommendation 9. The NWS should retain its role as the official source of instrumentation, data, and data collection standards to ensure that scientific benchmarks for collecting, verifying, and reporting data are maintained. It should lead efforts to follow, harmonize, and extend standards, formats, and metadata to ensure that data from NWS and non-NWS networks, databases, and communications technology can be integrated and used with relative ease.

[20]T.R. Karl, V.E. Derr, D.R. Easterling, C.K. Folland, D.J. Hofmann, S. Levitus, N. Nicholls, D.E. Parker, and G.W. Withee, 1995, Critical issues for long-term climate monitoring, *Climatic Change*, v. 31, p. 185-221; U.S. Global Change Research Program, 1999, *Global Change Science Requirements for Long-Term Archiving*, Report of the Workshop, October 28-30, 1998, National Center for Atmospheric Research, Boulder, Colo., 78 pp.

Private Sector

Private sector concerns conveyed to the committee (Appendix D) fall into two broad categories: those that pertain to perceived violations of the 1991 NWS public-private partnership policy and those that pertain to the quality and timeliness of data released to the public. The issue of data quality and timeliness is addressed in Recommendation 4 above). It was difficult to judge the merits of complaints about the public-private partnership because the committee received little quantitative indication that actions taken by the NWS caused financial harm to private companies. Moreover, the committee believes that the NWS public-private partnership policy is outmoded and should be revised (see Recommendation 1).

As noted in Chapter 4 and Appendix E, misunderstanding the facts can exacerbate perceptions of unfairness. The private sector must recognize that federal law encourages the adoption of effective technologies by government agencies, as well as the development of academic spinoff companies that will compete with them. As in other industries, companies in the commercial weather industry must stay on the leading edge of technology in a competitive marketplace. Many successful technologies and applications eventually become commonplace and therefore provide little competitive advantage to the companies that developed them. Trying to prevent others from using technologies in common use across all sectors wastes energy and resources that would better be spent in identifying and responding to new user demands. Of course, real examples of inappropriate competition (e.g., NWS forecast offices providing specialized services to newspapers) should continue to be brought to the attention of the responsible organization.

Recommendation 10. The commercial weather sector should work with the other sectors, using mechanisms such as those proposed in this report, to improve the techniques and processes by which the weather and climate enterprise as a whole can minimize friction and inefficiency.

Academic Sector

Researchers have been creating and disseminating practical weather products for more than 50 years.[21] Where the purpose is science and education, meteorology departments themselves disseminate the information. Where the purpose is commercialization, universities create separate for-

[21]C.C. Bates, 1976, Industrial meteorology and the American Meteorological Society—A historical overview, *Bulletin of the American Meteorological Society*, v. 57, p. 1320-1327.

profit companies that will compete with other private companies. The committee saw no evidence that universities are not drawing this distinction.

Advances in scientific understanding will continue to create new opportunities for science and technology transfer from academia (and NOAA laboratories). The transfer of new weather service technology to the private sector follows the same path as that followed by the computer, software, networking, and biotechnology industries.[22] Their experience and precedent have much to offer to the atmospheric sciences (Appendix B). "Best practices" for transferring technology to the private sector and avoiding conflicts of interest have been collected by the Council on Governmental Relations.[23] Additional guidance can be found in conflict-of-interest guidelines established by government agencies funding academic researchers, such as the National Science Foundation, and in the policies of research universities. Such practices include

- having written policies and procedures covering scientific conduct, intellectual property, and the administrative and financial management of government-funded programs;
- disclosing and reviewing significant financial interests (e.g., consulting fees, equity interests, intellectual property rights) that would compromise a faculty member's objectivity in teaching and basic research;
- ensuring that a student's degree-oriented research does not become entangled with a faculty member's outside commercial interests;
- devoting most proceeds to teaching and research (under the Bayh-Dole Act, universities must share royalties with inventors); and
- refraining from offering special deals to the company for space, labor, data, or technology (i.e., a bright line is drawn between the university and that company).

Recommendation 11. Universities seeking to commercialize weather-related research results should follow transparent procedures for transferring technology and for avoiding conflicts of interest. These procedures should be given wide exposure to remove perceptions of unfair competition.

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[22]See, for example, National Research Council, 1999, *Funding a Revolution: Government Support for Computing Research*, National Academy Press, Washington, D.C., 302 pp.; National Research Council, 2001, *Capitalizing on New Needs and New Opportunities: Government-Industry Partnerships in Biotechnology and Information Technologies*, National Academy Press, Washington, D.C., 360 pp.

[23]Council on Governmental Relations, 2001, Managing externally funded programs at colleges and universities: A guide to good management practices, <http://www.cogr.edu/COGR%20brochure%20final.pdf>.

IMPROVING THE WEATHER SYSTEM INFRASTRUCTURE

The ability of each of the sectors to carry out its goals and objectives depends on the continuation of large public investments in observations and modeling. The academic and private sectors have publicly supported increasing NOAA's budget to sustain the weather information system. These sectors also contribute to this expensive system through individual taxes and, for the private sector, corporate taxes. However, another type of support that is generally absent is attribution of the source of data and models used to develop and deliver products and services. The committee notes that none of the sectors consistently recognize and give attribution to the contributions of the other sectors (e.g., see examples 5, 12, and 13, Appendix D). Such attribution is important for gaining public support for the large investments required. The member of the House of Representatives who famously proposed abolishing the NWS because the Weather Channel provides forecasts[24] is symptomatic of the lack of public understanding of where and how forecasts are generated.

Another way in which all sectors can contribute to the weather enterprise is to work to place as much data as possible in the public domain. Data collected using taxpayer dollars—whether by federal, state, or local government agencies or by researchers funded by federal grants—should be made available to the public as soon as possible after collection. This is usually, but not always, the case. Although it cannot be expected that companies will always place proprietary data in the public domain, privately collected data sets that have limited commercial value but potentially great scientific value could be made available for research purposes. Improving data access works to the benefit of all sectors in the weather enterprise.

The committee believes that the recommendations made here would, if implemented by the various stakeholders, substantially reduce the occasional frictions and inefficiencies in the U.S. weather and climate enterprise. Despite a certain level of built-in friction, the committee believes that the enterprise can continue to flourish, to reach new levels of accuracy in weather and climate forecasts, and to provide even more valuable services to the public.

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[24]J. Anderson, 1995, Serving up this year's top turkeys, *Washington Post*, November 23, p. B23.

Appendixes

Appendix A

Committee Charge

1. The panel will examine the present roles of the public sector, the private sector, and the academic community in the provision and use of weather, climate, and related environmental information and services in the United States.

2. The panel will identify the effects that advances in observing, modeling, forecasting, and information dissemination technologies may have on the respective roles of the public, private, and academic sectors.

3. The panel will examine the interface between the various sectors described above in the provision and use of weather, climate, and related environmental information services and identify barriers to effective interaction. In particular, the panel will examine the legal, institutional, or policy (e.g., data access, distribution and dissemination, intellectual property) foundations of the various sectors and identify resulting barriers that are "culturally" produced. The panel will consider these issues in the context of present information policy statutes and guidance, and recommend changes in policies or practices that could improve the potential for responding to various environmental threats ranging from severe weather events to episodes of extreme air pollution to prolonged droughts.

4. The panel will make recommendations regarding how most effectively to coordinate the roles among the various sectors described above so that each can make the most cost-effective investments in needed infrastruc-

ture, efficiently share the information generated from that infrastructure, and provide a necessary planning baseline for users of weather, climate, and other environmental information to understand what to expect from the government in the future. Recommendations will focus on identified barriers to improved interaction and will include principles to guide policy formulation in evolving areas of interaction among the sectors.

Appendix B

Public-Private Provision of Weather and Climate Services: Defining the Policy Problem

Roger Pielke, Jr.
University of Colorado

Note: The committee commissioned the following white paper from a leading expert on policy issues related to weather and climate services. Dr. Pielke's views, as expressed below, may not always reflect the views of the committee or vice versa.

INTRODUCTION

In the United States a broad and interrelated set of government, private, and academic entities provides weather and climate services. For present purposes, a weather and climate service is defined to mean information provided about the past, present, or future state of features related to the atmosphere with the intent that decision makers will use such information to their benefit. The various entities that comprise the nation's weather and climate services enterprise evolved a great deal over the twentieth century with little discussion or debate of appropriate roles and responsibilities, with a few notable exceptions. Even so, the United States is among the most advanced (if not the most advanced) nations in the world in the efficient production and effective use of weather information. Yet as science, technology, markets, and demands related to weather information evolve, lack of discussion or debate of appropriate roles and responsibilities has the potential to limit future progress of the nation's weather and climate services enterprise.

In those few cases where discussion and debate have occurred, satisfactory resolution has not. Consequently, many have arrived at differing and conflicting expectations about roles and responsibilities of the various entities that provide weather and climate services. A policy problem exists to the extent that these differing expectations impede the development and delivery of products and services that would have value to decision makers.

Roles and responsibilities for the provision of weather and climate services differ by sector. The National Weather Service (NWS), non-NWS government agencies, academia, and the private sector each play a unique as well as shared role in the provision of services. Because of the overlap and blurring of activities among these sectors it is important not to ascribe monolithic status to any one of them. For instance, universities and government labs are involved with commercialization of research as a result of government policies that encourage technology transfer. For-profit companies routinely compete with federal labs and universities for federal research dollars. These same entities compete with each other for contracts for the provision of services to companies and foreign governments. The NWS relies on a range of contractors and purchases a number of services from the private sector to fulfill its mission. Further, the complex tapestry of sectors, institutions, and services means that to understand the proper role of any subset requires some sense of the whole. Like the blind men and the elephant, partial perspectives are likely to mislead.

The purpose of this paper is to define the policy problem associated with the present state of roles and responsibilities within the weather and climate services enterprise. Recommendation of alternative courses of action goes beyond the present focus. The paper begins with a discussion of issues centered on particular "sectors," noting however the considerable difficulty associated with identification of clear boundaries between sectors. It needs to be emphasized that many examples are provided in the text below in order to illustrate the complexities involved in issues of roles and responsibilities. Such examples are meant to be illustrative and diagnostic, not prescriptive; no claim is made here as to the appropriateness or inappropriateness of the activities discussed. However, this is the essential point of the paper: in many cases, it is difficult if not impossible to judge which actions are appropriate and which are not, given the lack of community agreement on roles and responsibilities.

UNDERSTANDING COMPLEXITIES IN ROLES AND RESPONSIBILITIES WITHIN THE WEATHER AND CLIMATE SERVICES ENTERPRISE

The National Weather Service

The NWS and its predecessors have for more than a century had legislative authority for governmental provision of weather services. In this role, agency officials have long been sensitive to potential conflict with the private sector.

Contemporary debate is quite similar to debate on this topic that took place more than a half-century ago. Following World War II, numerous military meteorologists found themselves returning to life as civilians and

Box B.1 Six-Point Program on Public-Private Sector Relationships

1. Advise all field offices that industrial meteorology is a legitimate field of endeavor and should be encouraged and aided by the Weather Bureau in the interest of the national economy.
2. Advise all organizations now served by the Weather Bureau that they are not getting an individualized and specialized service (i.e., added information and/or more service than is normally given the general public) and furnish them with a list of consulting firms approved for teletype service.
3. Advise individuals or organizations seeking specialized services that it is not a Weather Bureau function and with their consent refer the matter to the Central Office of the Weather Bureau for transmittal to the American Meteorological Society and the meteorological consultants.
4. Advise all Weather Bureau personnel that they should be alert to point out and develop cases in business where the employment of a consulting meteorologist would aid in developing applied meteorology.
5. Accept grants from individuals or organizations for research and statistical surveys only when they cannot be accomplished by or with private consulting meteorologists.
6. The service of looking after interest of private concerns and the initiating of special advice for commercial uses is the field of consulting meteorology and the Weather Bureau will make it a practice to refer to the field of consulting meteorologists requests for services of this kind.

SOURCE: American Meteorological Society, 1949, Report of the executive secretary, 1948, *Bulletin of the American Meteorological Society*, v. 30, p. 140-141.

seeking to use their expertise in weather to make a living.[1] The resulting growth of commercial weather services led the American Meteorological Society (AMS) to arrange for a conference in 1948 "to clarify the relationship between the Weather Bureau and private meteorologists." This conference resulted in an agreement between the chief of the Weather Bureau, representatives of Industrial Weather Consulting Services, and the AMS. This agreement was titled the "Six-Point Program" and is reproduced in its entirety in Box B.1. The agreement was, however, never adopted as formal policy by the Weather Bureau.[2]

[1]American Meteorological Society, 1949, Report of the executive secretary, 1948, *Bulletin of the American Meteorological Society*, v. 30, p. 140-141.

[2]Weather Bureau, 1948, Policy with respect to private practice of meteorology and instructions regarding cooperation with private meteorologists, Circular Letter 22-48, March 9.

Perhaps seeking to get out ahead of the AMS agreement, two weeks prior to the AMS conference the Weather Bureau issued a "Circular Letter" to all of its offices on "Policy with Respect to Private Practice of Meteorology and Instruction Regarding Cooperation with Private Meteorologists."[3] The letter stated, "All employees should be familiar with the policy on extension of applied meteorology and development of private meteorological services to meet commercial and industrial requirements beyond the scope of government services." The letter cautioned, "The Weather Bureau must not permit an impression that it has 'exclusive rights' in the science and practice of meteorology." The letter provided the following guidance for determining if a particular service was appropriate for the Weather Bureau:

> Usually, a question on whether a private request is within the province of a government service or should be referred to private sources can be decided by comparison with similar cases in other professions, such as engineering or law. In analogous cases the matter is one for a private engineer or a lawyer, it probably falls within the province of the private meteorologist.

The guidance provided by the letter was apparently inadequate or insufficient to resolve debate for long because in 1953 the Department of Commerce (DOC) convened an Advisory Committee on Weather Services comprised of eight meteorologists—of which six worked in the private sector, one for the AMS, and one for a university—to review and evaluate "civil weather matters" with a focus on the public-private sector issue.[4]

The committee found the "Circular Letter . . . does not clearly establish the relationship between the Weather Bureau and private meteorologists" and recommended that it be "cancelled" in favor of the AMS Six-Point Program.[5] The committee found that the ambiguity resulted, at least in part, because

> the organic act under which the Weather Bureau still functions was written at a time long before present developments and applications of the science to business and industry could have been envisioned. It is necessary, therefore, that a redefinition of functions be made to recognize the changes since that time. . . . While all of the recommendations of this report can be implemented under the existing organic act, we feel it is desirable that a study be made to determine whether the basic law should be revised.[6]

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[3]Weather Bureau, 1948, Policy with respect to private practice of meteorology and instructions regarding cooperation with private meteorologists, Circular Letter 22-48, March 9.

[4]Advisory Committee on Weather Services, 1953, *Weather is the Nation's Business*, Department of Commerce, U.S. Government Printing Office, Washington, D.C., p. 6.

[5]Advisory Committee on Weather Services, 1953, *Weather is the Nation's Business*, Department of Commerce, U.S. Government Printing Office, Washington, D.C., p. 45.

[6]Advisory Committee on Weather Services, 1953, *Weather is the Nation's Business*, Department of Commerce, U.S. Government Printing Office, Washington, D.C., p. 2.

Since the 1950s, debate has waxed and waned. In the early 1980s, the Reagan administration proposed the privatization of government weather satellite operations. A protracted and public debate ensued.[7] Weather satellite operations were not privatized, but the debate created sufficient impetus for the NWS and the private sector to discuss codification of roles and responsibilities. One result was NWS adoption in 1991 of a statement on the public-private partnership in the provision of weather services.

According to the 1991 statement, "the primary mission of the NWS is the protection of life and property and the enhancement of the national economy."[8] The report introduces specific guidance on proper roles and responsibilities of the government and private sector. "The NWS will not compete with the private sector when a service is currently being provided or can be provided by commercial enterprises, unless otherwise directed by applicable law."[9] No guidance is provided on how the policy would be implemented, including mechanisms for dispute resolution, oversight, sanctions, and accountability to the policy. Not surprisingly, little evidence can be found to suggest that either the NWS or the private sector had interest in reconciling the ambiguities resulting from the 1991 policy. Perhaps more accurately, actors in the NWS and the private sector saw in the 1991 statement what they wanted to see and acted accordingly. Evidence for this conclusion is found in debate that occurred during the late 1990s when the Commercial Weather Services Association (CWSA) spearheaded an effort to formalize in the NWS legislative mandate the language of the 1991 statement. The NWS objected. The CWSA legislative effort did not succeed.

The 1991 policy statement, like its predecessors, was insufficient to reconcile debate about roles and responsibilities. In a 1997 review of the NWS conducted at the bequest of the Secretary of Commerce before taking over as NWS administrator, General Jack Kelly wrote:

> The 1890 Organic Act contains some outdated wording and does not reflect the current capabilities of the private sector weather industry. Within the NWS, government agencies (both Federal and local) and the private sector, disagreement exists as to what is the appropriate mission for and the level of services and products required from the NWS. A review (U.S.

[7] P. Cox, 1983, Fair weather: Government weather forecasting soaks taxpayers to shower benefits on special interests, *Reason*, June, p. 23-30.

[8] National Weather Service, 1993, Policy and guidelines governing National Weather Service and private sector roles; *NWS Operations Manual* Chapter A-06, July 30, 1993, <http://www.nws.noaa.gov/im/a06toc.htm>.

[9] In response to a comment raised during the public comment period the NWS pointed to the fruit-frost program as an example of a service provided in competition with the private sector due to a mandate in legislation.

> Congress or DOC) should be conducted to determine the NWS mission for the 21st Century and lead to an updating of the Act.[10]

Similar sentiments have been expressed by many members of the private sector.[11] So despite the existence of an NWS policy statement since 1991 on the provision of weather services by NWS, debate continues unabated on proper roles and responsibilities.

The primary reason for differing perspectives on roles and responsibilities related to the National Weather Service stems from a conflict inherent in the multiple missions that the agency is expected to serve. The frequently invoked Organic Act of 1890 gives the NWS responsibility for public safety through the provision of storm warnings *and* responsibility for enhancing economic activity. The relevant text is as follows (15 U.S.C. 9 §313):

> The Secretary of Commerce shall have charge of the forecasting of weather, the issue of storm warnings, the display of weather and flood signals for the benefit of agriculture, commerce, and navigation, the gauging and reporting of rivers, the maintenance and operation of seacoast telegraph lines and the collection and transmission of marine intelligence for the benefit of commerce and navigation, the reporting of temperature and rain-fall conditions for the cotton interests, the display of frost and cold-wave signals, the distribution of meteorological information in the interests of agriculture and commerce, and the taking of such meteorological observations as may be necessary to establish and record the climatic conditions of the United States, or as are essential for the proper execution of the foregoing duties.

If the NWS mandate were *only* to support economic activity or *only* to provide storm warnings it would be relatively straightforward to develop clear guidance for roles and responsibilities,[12] but the twin objectives can come into conflict. These twin objectives and the conflict that can result

[10]John "Jack" Kelly, in the Kelly Report, p. 58, <http://www.publicaffairs.noaa.gov/nws3.html>.

[11]See, for example, the testimony before the House of Representatives Subcommittee on Energy and Environment by Michael S. Leavitt, on behalf of the Commercial Weather Services Association, April 9, 1997, 105th Congress, 1st Session; and by Joel Myers on behalf of AccuWeather, Inc., March 25, 1998, 105th Congress, 2nd Session.

[12]These dual objectives confound approaches to resolve public-private sector conflicts grounded in economic theory. If the NWS served only economic ends, the economic theory provides clear guidance (see, e.g., National Research Council, 2001, *Resolving Conflicts Arising from the Privatization of Environmental Data*, National Academy Press, Washington, D.C., 99 pp.). However, the public safety mandate trumps economics in many cases. Even so, economic issues lead to sources of conflict. Among these are ever lower barriers to entry for new providers of added value, technology-driven rapid obsolescence of past modes of delivering weather services, and the public-good "issues of scope" that arise when publicly funded data are used to create for-sale products.

were referred to explicitly by Jack Kelly in his 2001 address at the annual meeting of the American Meteorological Society:

> The challenge for the meteorological community is to balance governmental responsibilities to provide warnings and forecasts for everyone subject to weather-related hazards with the private sector's responsibility to tailor forecasts for use by specific entities, build markets, and mitigate risk by developing more effective means to integrate weather, water and climate information into commercial business plans, strategies and decisions. While the National Weather Service and private sector entities each have distinct roles in the weather information dissemination process, we must continue working strategically as partners for the public good and the economic benefit of our country as a whole.[13]

Whatever one's views on the respective roles of government and the private sector, the existing NWS mandate necessitates reconciling missions established in law that have built-in conflicts. To date such reconciliation has not occurred, and the attempt to codify such reconciliation in the 1991 NWS policy statement is flawed according to both perceptions and practice.

Non-NWS Government

If the roles and responsibilities of the NWS can be characterized by attempts to grapple with conflicting missions established in law, non-NWS governmental roles and responsibilities might be said to have an opposite situation. Few missions are explicitly provided in law, leaving the provision of services to ad hoc implementation and oversight.[14] At the outset, an important exception should be made for weather and climate services provided by the military in support of national security. Such services are beyond the scope of the present analysis, leaving for present discussion weather services provided by agencies such as the non-NWS National Oceanic and Atmospheric Administration (NOAA), Federal Aviation Administration (FAA), Department of Agriculture, and Department of Transportation.

Consider the range of issues raised by the following examples:

- The Aviation Digital Data System (ADDS) is an on-line tool that provides weather information to the aviation industry and is sponsored by the FAA, operated by the National Center for Atmospheric Research

[13]J. Kelly, 2001, Opportunities for 21st century meteorology: New markets for weather, water and climate information, American Meteorological Society Policy Forum, Albuquerque, N.M., January 17. <http://www.ametsoc.org/AMS/atmospolicy/presforums/albq2001/kelly.pdf>.

[14]Important exceptions are the Climate Services Act of 1975 and the U.S. Global Change Research Act of 1991.

(NCAR), and disseminated via the NWS Aviation Weather Center on a NOAA web site. However a disclaimer featured prominently on the ADDS web site notes that it is not a product of the NWS. The ADDS web site describes its mission as to "make available to the aviation community digital and graphical analyses, forecasts and observations of meteorological variables."[15] The FAA has plans to use ADDS as the basis for briefings provided to commercial pilots.[16] In this case a "quasi-operational" product is provided essentially outside the NWS using some NWS infrastructure.

- A nonprofit corporation (University Corporation for Atmospheric Research [UCAR]), operated under the government's Federally Funded Research and Development Center (FFRDC) program and supported by public funds, capitalized a subsidiary private company, Weather Information Technologies, Inc., or WITI.[17] WITI worked closely with a publicly funded research entity also under UCAR management, the National Center for Atmospheric Research, on projects such as using National Weather Service weather forecast models to provide information to consumers by zip code[18] and competed for and won a $15 million contract to provide Hong Kong with consultative services for the design of a new airport.[19] WITI was sold in 1999.
- The Forecast Systems Laboratory (FSL) of NOAA provides wind profiler systems and consulting on such systems to the U.S. Department of Defense, National Aeronautics and Space Administration, and Department of Energy, as well as the governments of Canada, Australia, New Zealand, China, Japan, and the European Union.[20]
- The Department of Transportation, in its Intelligent Transportation Systems program, sponsors an initiative called FORETELL in partnership with several state governments and the Canadian government, and operated by a private sector contractor, Castle Rock Services.[21] The goal of the initiative is to provide weather information to public and private sector decision makers.[22] The federal government has a wide range of experience at the interface of public institutions and private entities.[23]

[15]<http://adds.aviationweather.noaa.gov/projects/adds/info/>.
[16]T. Horne, 2002, ADDS on the move, *AOPA Pilot*, January.
[17]<http://www.bcbr.com/sep96/witi2.htm>.
[18]<http://www.ucar.edu/communications/staffnotes/0009/ucarf.html>.
[19]<http://www.ucar.edu/communications/quarterly/fall93/prescorner>.
[20]<http://www.fsl.noaa.gov/~vondaust/fir99/fir99c.html>.
[21]<http://www.foretell.com/help/Foretell/about.htm>.
[22]<http://www.its.dot.gov/TravelManagement/fortell.htm>.
[23]See, for example, General Accounting Office, 1995, *Government Corporations: Profiles of Recent Proposals*, GAO/GGD-95-57FS, Washington, D.C., 62 pp.

Each of these examples, and these are but a few of many possible such examples, illustrates the significant degree of activities that fail to fit any "textbook" description of weather and climate services. The situation is made more complex by the various government policies encouraging the commercialization of government technology, including the role of FFRDCs. Given the complexity of governance and incentive structures in the context of the lack of formal policies or procedures, it would be extremely difficult for participants with differing perspectives to arrive at judgments of proper roles and responsibilities of non-NWS government providers of weather and climate services. Nor is it at all clear if anyone has responsibility for coming to such judgments.

Academia

If the provision of weather and climate services by non-NWS government agencies can be characterized as complex, then the provision of weather and climate services by organizations in academia is akin to the "wild wild west" where a frontier mentality reigns. As weather and climate services have demonstrated increasing value in the economy, members of the academic community have rushed to cash in. Although consulting by academics has a long and respected tradition in the atmospheric sciences and many established private sector meteorological services firms had their origins as university start-ups, the recent decade has seen explosive growth in the formation of such entities. The federal government has encouraged university-based technology transfer through legislation such as the Bayh-Dole Act of 1980.

Other reasons for this trend are the growing support among universities of commercial activities, which is itself motivated by federal policy, decreasing funding from state and federal sources, and the highly visible success of commercialization activities in other areas of technology such as biotechnology and information technology. In the atmospheric sciences there does exist a high degree of variability across institutions for the support of commercialization.[24]

The twin influences of an environment that encourages commercialization and the fact that the atmospheric sciences have not yet gained the visibility (and thus demands for accountability) of other areas of technology mean that many activities are being initiated before the development of generally accepted criteria for proper roles and responsibilities. By way of

[24]R.A. Pielke, Jr., 2001, *Weather Research Needs of the Private Sector: Workshop Report*, U.S. Weather Research Program, Palm Springs, Calif., December 2000. <http://sciencepolicy.colorado.edu/pielke/ workshops/private.sector/private.sector.report.pdf>.

contrast, in other areas of technology policy such as biotechnology and information technology, there exists a history of debate and discussion of roles and responsibilities. In weather and climate services, the paucity of such discussion has set the stage for potential conflict.

Consider the complexities involved with the following examples:

- Northwest Research Associates, Inc.,[25] focuses primarily on performing research sponsored by the federal government. In early 2002 its web site stated that it operates an entity called Foresight Weather,[26] out of its Colorado-Research Associates[27] division subsidiary, focused on providing weather predictions to the energy industry. The Foresight Weather web site stated that it relies on scientists at the neighboring publicly funded National Center for Atmospheric Research to provide research and technology, and to serve as consultants in support of the products and services that Foresight Weather sells to its clients, primarily in the energy industry. NCAR is itself funded by the National Science Foundation (NSF) and other federal agencies to conduct research.
- Faculty at major research universities, such as Rhode Island, Oklahoma, North Dakota, Michigan, and others, operate or are otherwise associated with for-profit companies that provide weather and climate services. Many of these companies employ university graduate students working on government-provided grants and contracts focused on weather and climate research. Graduate student research can in principle serve the purpose of "killing two birds with one stone"—that is, providing knowledge in support of the government research grant obligation while at the same time contributing to a product or service sold for profit to a customer.
- The University of Oklahoma Department of Meteorology received $10 million in support from the Williams Companies.[28] The department also receives considerable public support for research, including designation as one of the first NSF Science and Technology Centers. In the spring of 2002, the department announced that it would limit access to certain products because of its relationship with certain private sector partners. The department then took a step back from this announcement and announced that it was reconsidering its data access policies.[29]

As is the case in the provision of services by non-NWS government agencies, coming to judgments of proper roles and responsibilities is

[25]<http://www.nwra.com/history.html>.
[26]<http://www.fswx.com/home/intro.index.htm>.
[27]<http://www.colorado-research.com/>.
[28]<http://www.caps.ou.edu/news/williamsgrant.htm>.
[29]Information on the CAPS data policy is updated on-line at <http://www.caps.ou.edu/wx/>.

made difficult by the various federal and state policies and incentives for those in academia to foster commercialization of science and technology.[30] Yet, unlike that case, academia has struggled mightily over the past decade to establish general mechanisms for making such judgments in the context of biotechnology, information technology, and other areas that have shown large commercial potential. The Association of University Technology Managers has sought to collect a set of "best practices" in academia for assessing such roles and responsibilities.[31] The application of such mechanisms to the atmospheric sciences is haphazard and unsystematic at best.[32]

Private Sector

The provision of weather and climate services in the United States by the private sector occurs in a wide range of manners. Figure B.1 illustrates the terrain of private sector activities in relation to the National Weather Service "service flow." It is important to recognize that while the NWS forms the foundation for a wide spectrum of "value-added" activities in the public and private sectors, there is a considerable (and underappreciated) set of activities also in the public and private sectors that provide weather and climate services *independent* of the NWS.

Many entities—particularly (but not limited to) television and other media—collect and report information on weather and climate independent of any government service. For example, in 2001 the American Meteorological Society presented an award to three Oklahoma television stations for their coverage of the May 3, 1999, tornado outbreak, which provided the public with details on the exact location and path of individual tornadoes unmediated by scientists or the government.[33] Many public and private organizations—ranging from the New York State Thruway Authority to State Farm Insurance to *USA Today*—collect weather and/or climate information for direct use or further dissemination to paying clients. A company called Global Atmospherics, Inc., owns the nation's only lightning detection network and sells its products to a range of customers, including the National Weather Service, The Weather Channel, and the

[30]R.A. Pielke, Jr., 2001, *Weather Research Needs of the Private Sector: Workshop Report*, U.S. Weather Research Program, Palm Springs. Calif., December 2000. <http://sciencepolicy.colorado.edu/pielke/ workshops/private.sector/private.sector.report.pdf>.

[31]<http://www.autm.net/index_n4.html>.

[32]R.A. Pielke, Jr., 2001, *Weather Research Needs of the Private Sector: Workshop Report*, U.S. Weather Research Program, Palm Springs. Calif., December 2000. <http://sciencepolicy.colorado.edu/pielke/ workshops/private.sector/private.sector.report.pdf>.

[33]<http://www.nssl.noaa.gov/publicaffairs/releases/ams_group.html>.

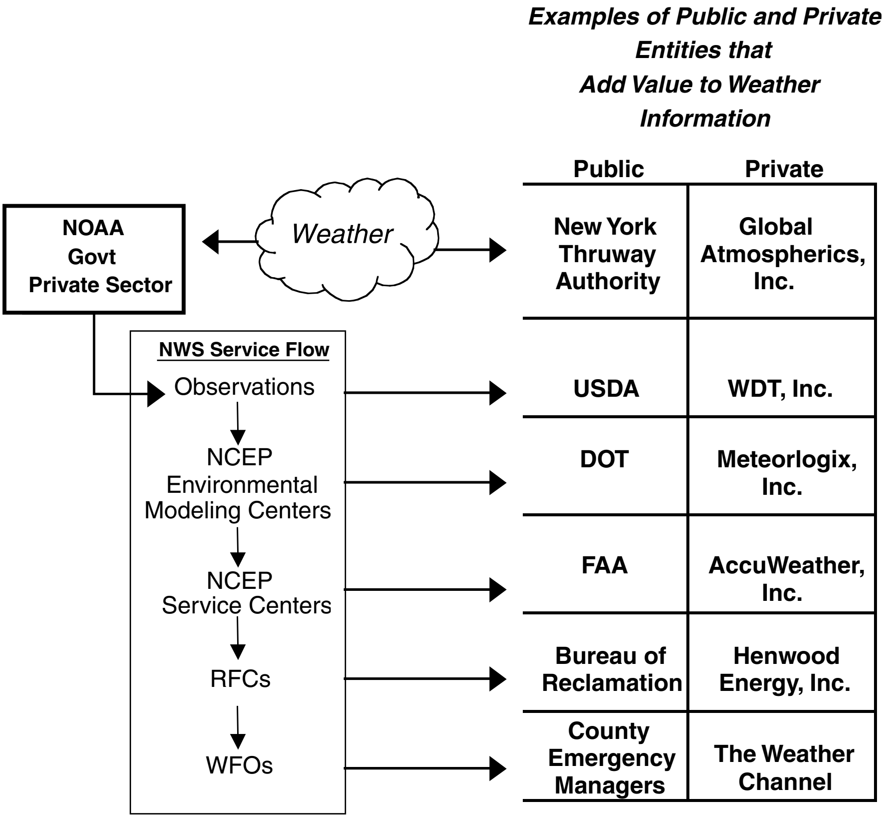

FIGURE B.1 Example of weather service providers. The notion and depiction of "NWS Service Flow" follows from D.R. Wernley and L.W. Uccellini, 2000, Storm forecasting for emergency response: A United States perspective, in *Storms*, R. Pielke, Jr., and R. Pielke, Sr., eds., Routledge, N.Y., pp. 70-97.

PGA Tour.[34] Another company, AWS Convergence Technologies, Inc., collects temperature data through its own private network and offers services based on those data.[35] The size of the market for the provision of weather and climate services independent of the NWS has not been rigorously assessed. However, an initial hypothesis (based on personal experience and nothing more) is that the size of this market is as large as and

[34]<http://www.lightningstorm.com/ls2/discover/nldn/index.jsp>. Global Atmospherics, Inc., is an example of research transferred from an academic setting, in this case the University of Arizona, to the private sector.

[35]<http://www.aws.com>.

likely larger than the market for products and services built upon the NWS infrastructure. The NWS encourages a view of weather and climate services constrained to those related to its products. However, a more comprehensive perspective results in a considerably more expansive view of "weather and climate services."

Nonetheless, many entities use the services of the NWS as the basis for providing value-added services. Value is added to products and services at every stage of the NWS "service flow," as shown in Figure B.1 and illustrated by examples. Some companies (and many for-profit entities originating in academia) use the raw data collected by the nation's atmospheric observing systems as input to proprietary weather forecast models. One such company is Weather Decision Technologies, Inc.[36] Other companies focus on the direct dissemination of NWS forecasts, with The Weather Channel the most widely known example.[37]

The NWS supports a great diversity of economic activities in the commercial meteorological industry through its products and services. The size of this market has also not been rigorously assessed, although estimates range from $500 million to more than $1 billion.[38] Given the diversity of economic activities, it should not be surprising that individual companies that create products and services based on raw observational data or that independently interpret NWS model output have suggested that the value-added products within the NWS service flow represent subsidized public competition. However, proper understanding of such claims much occur in the broad context of the diversity of organizations that rely on NWS information as input to the production of products and services.

The summarizing of cases above in each of the sectors reviewed here is provided not to implicate specific judgments, but to note that evaluation of roles and responsibilities is made difficult due to the complex and interwoven tapestry of the NWS and other government infrastructure, academia, and companies operating in the broader economy. Clearly, the perspectives

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[36]<http://www.wdtinc.com/>. Weather Decisions Technology, Inc., also has its origins as a university spinoff, from the University of Oklahoma.

[37]<http://www.weather.com/>. The Weather Channel (TWC) and the NWS have entered into agreements such that NWS formats its products in a manner that serves the needs of TWC (F. Batten and J.L. Cruikshank, 2002, *The Weather Channel: The Improbable Rise of a Media Phenomenon*, Harvard Business School, Boston, 304 pp.).

[38]R. Pielke Jr., J. Abraham, E. Abrams, J. Brock, R. Carbone, D. Chang, S. Cranford, K. Droegemeier, K. Emanuel, E.W. Friday, Jr., R. Gall, J. Gaynor, R.R. Getz, T. Glickman, B. Hoggatt, W.H. Hooke, E.R. Johnson, E. Kalnay, J. Kimpel, P. Kocin, B. Marler, R. Morss, R. Nathan, S. Nelson, R. Pielke Sr., M. Pirone, E. Prater, W. Qualley, K. Simmons, M. Smith, J. Thomson, and G. Wilson, 2002, Report of the U.S. Weather Research Program Workshop on the Weather Research Needs of the Private Sector, *Bulletin of the American Meteorological Society*, submitted.

of those in individual companies may differ dramatically on the issue of "government competition" depending primarily upon where each draws information from the NWS service flow. Correspondingly, it would be easy to envision *in principle* how the NWS service flow might be optimized to facilitate the market for any particular niche of companies associated with points of departure from the service flow. However, such optimization would likely have dramatic consequences for other companies in different niches, drawing from different points of departure in the service flow. This complexity (i.e., the policy and political challenge of "multiattribute optimization") is one reason why the NWS has had difficulty achieving a successful relationship with the private sector.

None of the previous discussion should be interpreted as either to condone present practices or to imply that claims of "unfair competition" are unjustified. Rather, the complex tapestry of the NWS in relation to the myriad agencies and companies that it supports makes assessment of present practices and claims an extremely challenging task. Consequently, it is understandable that multiple views on this subject have developed over decades and have defied good-faith attempts at resolution.

DEFINING THE PROBLEM

The problem then is that participants in the national enterprise for the provision of weather and climate services lack the means to judge appropriate roles and responsibilities from the standpoint of meeting national goals and the mechanisms to reach shared expectations on roles and responsibilities. Part of the reason for the lack of means and mechanisms is that the weather and climate services enterprise is highly complex and sprawls across government, private, and academic sectors. Further, national goals related to the provision of weather and climate services are many, and in the promulgation of goals into specific policies, many conflicts among policy objectives have been introduced. Conflict is exacerbated by national science and technology policies that force integration of the public and private sectors (e.g., the Bayh-Dole Act). The identification of conflicts—much less their resolution—is hampered by the lack of a "forest"-scale perspective on weather and climate services. Instead, there are many with a view of individual "trees." The lack of such a perspective means that debate and discussion over the decades have largely been engaged in by those with a clear stake in particular outcomes. Consequently, the provision of weather and climate services has been treated much less like a policy issue to be assessed and addressed than like a political issue to be won.[39]

[39]R.A. Pielke, Jr., and R.E. Carbone, 2002, Weather impacts, forecasts, and policy: An integrated perspective, *Bulletin of the American Meteorological Society,* v. 83, p. 393-403.

Why Judging Appropriate Roles and Responsibilities Matters

Coming to a stabilization of expectations regarding appropriate roles and responsibilities for the provision of weather and climate services matters for at least four reasons. These reasons are discussed in greater detail in the following subsections: (1) institutional conflict; (2) efficiency in resource use; (3) accountability, transparency, and legitimacy; and (4) conflicts of interest. Ultimately, the primary reason why this problem matters is that as long as it persists unresolved, it impedes the effective and efficient transfer of weather and climate knowledge from the science and technology community to decision makers in the form of useful products and services.[40] This impedance limits the benefits to society resulting from the nation's investments in the science and technology of weather and climate.

Institutional Conflict. Over many decades, some in the NWS and the private sector have expended time and resources working against each other rather in support of each other. The institutional conflict has resulted in behind-the-scenes legislative maneuvering, such as resulted in the mid-1990s termination of agricultural weather services provided by the NWS, and more recently in conflict over the CWSA push to modify the NWS Organic Act. Institutional conflict occurs in less public ways as well, such as occurred in the late 1990s when the NWS Employees Organization pushed to include private sector employees, specifically at AccuWeather, in its union.[41] While healthy competition can improve products and services and the efficiency with which they are delivered, to the extent that healthy competition becomes unhealthy conflict, products and services may in fact degrade. An example of unhealthy conflict occurs when public and private sector institutions use finite resources to position themselves politically or symbolically with respect to actual or perceived opponents. A specific example is the 1996 divestiture of agricultural weather services. The termination of such activities by the NWS was based largely on political maneuvering, not on assessments of whether or not the U.S. public would benefit from such a decision.[42] In such cases, public interests are arguably served less well than by alternatives.

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[40]R.A. Pielke, Jr., and R.E. Carbone, 2002, Weather impacts, forecasts, and policy: An integrated perspective, *Bulletin of the American Meteorological Society,* v. 83, p. 393-403.

[41]<http://www.nwseo.org/nat10-00.html>. AccuWeather employees voted not to join the NWSEO.

[42]General Accounting Office, 1996, *Privatization/Divestiture Practices in Other Nations*, GAO/AIMD-96-23, Washington, D.C., 36 pp.; General Accounting Office, 1997, *Lessons Learned by State and Local Governments*, GAO/GGD-97-48, Washington, D.C., 52 pp.

Efficiency in Resource Use. As science and technology produce results that lead to greater knowledge of weather and climate, new products and services are enabled. While the transfer of such knowledge into products in the public and private sectors faces many challenges, surmounting these challenges creates yet another dilemma. With a steady stream of products and services being made available, this means that there is a greater need for infrastructure to support those products and services. In the private sector, the marketplace balances supply and demand for products and services, and offerings expand and contract based on such forces. However, for the public sector, reconciliation of supply and demand is much more difficult in the absence of market mechanisms. To take an example, an NWS with finite operational resources is inherently limited in the products and services that it can offer because there is little capability to identify demand and to reconcile demand with supply (other than through the long-term budgetary process). Thus, if the NWS is to continually develop new products and services, it must either cease providing certain products and services (to free up operational capabilities) or become generally more efficient in its operations. Consequently, the NWS would generally benefit from a process that transfers services suitable for a market setting to the private sector. Discussion of the nature and criteria that might accompany such transfers goes beyond the scope of this paper, but the net effect of such transfers would be to make available resources in NWS for support of newly developed products and services. Currently, in the area of weather and climate, no such mechanism exists for identification of candidate products and services suitable for transfer. In other areas of government, by contrast, there are such mechanisms.[43]

Accountability, Transparency, and Legitimacy. The lack of stabilized expectations for roles and responsibilities in the provision of weather and climate services places obstacles in the way of citizens holding government accountable. Government accountability has been a high priority of Congress since the early 1990s; legislation such as the 1993 Government Performance and Results Act and statements such as the 2001 President's Management Plan emphasize accountability in the use of public expenditures.[44] Accountably depends upon clear goals, shared expectations for the pursuit

[43]See, for example, General Accounting Office, 1997, *Crop Insurance: Opportunities Exist to Reduce Government Costs for Private-Sector Delivery,* GAO/RCED-97-70, Washington, D.C., 156 pp.; General Accounting Office, 1996, *Privatization/Divestiture Practices in Other Nations*, GAO/AIMD-96-23, Washington, D.C., 36 pp.
[44]<http://www.whitehouse.gov/omb/budget/fy2002/mgmt.pdf>.

of those goals, and mechanisms to measure progress with respect to those goals. In the provision of weather and climate services, the lack of shared expectations for appropriate roles and responsibilities means that the public, through its elected representatives, has less ability to shape the evolution of products and services than it might under conditions of shared expectations. This stands in stark contrast to other areas of science and technology—information technology and biotechnology are two examples—where, although considerable debate persists, such debate is highly public and focused on appropriate goals, mechanisms, and measures of accountability.[45] Accountability is a hallmark of "good government," and irrespective of one's views on the particulars of policy issues associated with the provision of weather and climate services it is possible to find lacking the degree of accountability, transparency, and legitimacy of policy processes in this issue area.

Conflict of Interests. Academia in particular must carefully consider the potential for financial conflict of interest at the interface of research and commerce. As the fruits of atmospheric sciences research become increasingly valuable, the question is not if such a potential exists, but when, where, and more importantly what to do about it. This is a sensitive topic because it involves money and money is often a difficult issue to discuss openly. Fortunately, other professions have grappled with this issue and have much to offer the atmospheric sciences in terms of experience and precedent. In 1993, Harvard's Dennis Thompson defined conflict of interest in the *New England Journal of Medicine*:

> A conflict of interest is a set of conditions in which professional judgment concerning a primary interest (such as a patient's welfare or the validity of research) tends to be unduly influenced by a secondary influence (such as financial gain).

Thompson argued:

> The secondary interest is usually not illegitimate in itself, and indeed it may even be a necessary and desirable part of professional practice. Only its relative weight in professional decisions is problematic. The aim is not to eliminate or necessarily to reduce financial gain or other secondary interests (such as preference for family and friends or the desire for prestige and power). It is rather to prevent these secondary factors from dominating or appearing to dominate the relevant primary interest in the making of professional decisions.

[45]R.A. Pielke, Jr., and R.E. Carbone, 2002, Weather impacts, forecasts, and policy: An integrated perspective, *Bulletin of the American Meteorological Society,* v. 83, p. 393-403.

The question to be addressed, then, is not whether the boundary between research and commerce should blur—it has and it will. Indeed, the United States has a long history of using policy to intentionally blur this boundary, using technology policies to stimulate economic growth via public support for research, development, and technology transfer. The question facing the atmospheric sciences instead is what policies and procedures to promulgate and implement given present trends in the discipline. Since the mid-1980s, several disciplines, the medical profession being the most prominent, have been engaged in discussion and debate about conflict-of-interest policies and procedures.[46] The atmospheric sciences have much to learn from these debates.

CONCLUSION: ONE OF TECHNOLOGY POLICY'S LAST FRONTIERS?

Acceptance of the problem definition presented here would imply that progress toward its resolution will necessarily focus on establishing a "level playing field" for healthy competition rather than "drawing a line" restricting competition. To the degree that promulgation, adoption, and implementation of specific policies would facilitate judgments of appropriate roles and responsibilities, such policies will likely focus on the establishment of flexible processes rather than regulation or proscription of specific activities. Specific recommendations for how such policies might be formulated and implemented are beyond the scope of this paper. Clearly, adoption and enactment of such policies would not serve as a panacea to all issues associated with the provision of weather and climate services; simply coming to agreement on such policies would represent a significant achievement. It would nonetheless bring the atmospheric sciences more closely into the fold of other areas of technology policy where similar issues have a longer history.

To the extent that a lack of shared expectations has limited the transfer of scientific and technical knowledge into products and services, national interests are not served. Formulation and application of mechanisms that would allow for more efficient and effective judgments of proper roles and responsibilities of the various elements of the nation's weather and climate forecasting enterprise could lead to an increased pace of technology transfer

[46]See, for example, D.F. Thompson, 1993, Understanding financial conflicts of interest, *New England Journal of Medicine*, v. 329, p. 573-576; S. Krimsky and L.S. Rothenberg, 2001, Conflict of interest policies in science and medical journals: Editorial practices and author disclosures, *Science and Engineering Ethics*, v. 7, p. 205-218; M. Angell and J.P. Kassirer, 1986, Editorials and conflicts of interest, *New England Journal of Medicine*, v. 335, p. 14.

more in line with the rapid pace of scientific and technological developments. This would mean that a greater portion of the nation's considerable investment in the science and technology of the atmospheric sciences would result in societal benefit. This would in turn lead to the enhanced development of markets. Ultimately addressing the policy problem associated with the provision of weather and climate services will contribute to the useful application of science to national needs.

The general policy problem has unique features in the context of the different participants in the nation's weather and climate services enterprise. To summarize:

- The NWS and its private sector partners have made frequent attempts to establish means for judging appropriate roles and responsibilities, yet without complete success. The existing policy, the NWS partnerships statement of 1991, is widely perceived by those inside and outside the NWS to be deficient in important respects.
- Non-NWS government agencies comprise a hodgepodge of activities that with varying degrees of independence—from each other and the NWS—provide weather and climate services. With a few notable exceptions—the National Climate Act and the U.S. Global Change Research Act among them—there is little in the way of means for judging appropriate roles and responsibilities.
- Academic institutions are seeing a great rush toward the commercialization of weather and climate research and development. There exists in academia a substantial body of precedent for judging appropriate roles and responsibilities. However, for the most part, such precedents do not appear to have been applied routinely across the atmospheric sciences.
- The private sector is intimately integrated with and dependent upon each of the other sectors in varying degrees. Accurate understanding of the private sector cannot occur without a broad conception of the forest rather than of individual trees. Of note is the considerable (but unmeasured) market for weather and climate services that do not depend on centralized government provision of data, models, or forecasts.

The atmospheric sciences are at a crossroads in their historical evolution. For many years the development and delivery of products and services were almost exclusively a government activity. Today, the increasing perception and reality is that weather and climate services have real economic value in the marketplace. To best tap that value will require thinking comprehensively about the weather and climate enterprise, which has existed largely unchanged in important respects for more than a century.

Although specific recommendations for action needed to better tap the potential value of weather and climate services are beyond the scope of this paper, the first steps are to comprehensively recognize the weather and climate services enterprise and the need for the establishment of criteria and processes for judgments of appropriate roles and responsibilities. Weather and climate services are among the "last frontiers" of technology policy. In this regard, weather and climate services are following in the technology policy footsteps of areas such as biotechnology and information technology that have successfully tapped the power of the market to accelerate the transfer of knowledge into products and services that benefit society. Make no mistake: these areas with more developed technology policies continue to grapple with difficult questions at the interface of government, markets, and societal needs. But by taking these issues on, society is the ultimate beneficiary.

Appendix C

Major Systems Overview

Major Systems Overview

Information from Sensor Networks	Parameters
Surface Observations *Public Sector Network* • ASOS deployed in early to mid-1990s by NWS and FAA • Replaced human observer in most locations • Located at airports, WSFOs, etc. • 813 FAA and NWS ASOS • 180 DOD ASOS sensors • 1300 Federal AWOS • ~500 Non-federal AWOS • Another ~8500 COOP sensors *Private Sector Networks* • Deployed over last 20 years • School networks, local and state municipalities, utilities, television stations, private met companies • In most cases, provider maintains ownership rights to data • Approximately 10,000 sensors deployed • Also, ~2500 road-weather sensors deployed *Other Federal Government Networks* • Deployed in last 20 years • BLM, USDA, USGS, DOE, EPA, COE • ~13,000 sensors	*Technology* • ASOS contains a hygrothermometer, cloud height indicator, and precipitation identifier • Some sites have icing detectors used for reporting freezing rain • Thunderstorm information is also available at most sites **ASOS** • Provides dewpoint, temperature, present weather, and visibility • Measures continuously and updates data every minute, but does not transmit them • Transmits an observation when SPECI criteria are met • All observed data are used in the algorithms to create the final observation. The algorithms are complex and vary from sensor to sensor **AWOS** • Transmits an observation every 20 minutes *Maintenance* • All of the ASOS sensors are on a 90-day preventive maintenance schedule • The ASOS Operations and Monitoring Center monitors the ASOS 24/7 and opens trouble tickets for flagged or missing data • ASOS sensor outages vary from 24 to 120 hours depending on the type of outage and the level of activity of the airport • Human observers augment the observations at all federal towered airports while tower is open • At larger airports, dedicated weather observers are on duty 24 hours a day to augment and backup the ASOS • NCDC can acquire data from nearby cooperative observing stations to replace missing data

Processing	Collection and Dissemination
Overview • The information from automated sensors is collected, quality controlled, and formatted according to WMO standards if contributing to the climatological records • This does not preclude the use of sensors in private networks for private use; however, those sensors may not qualify as potential candidates for the government network • It is possible for the 1-minute data to be transmitted via FAA circuits. The FAA has recently begun transmitting these data as part of its ITWS. These data are taken, along with other information, and processed by algorithms to provide local warnings to controllers at airports • The new processor for the ASOS would allow for the 1-minute data to be captured and disseminated to an Internet server. AWOS should also be able to be modified to do this *Miscellaneous* • COOP sensors are not automated—they still require humans to take readings (this technology is in the process of being upgraded) • Not all sensors have the same manufacturer, model number, last time calibrated, etc. Information is important as metadata to normalize information with other sensors and for long-term record keeping. Sensors without metadata are not useful for climatology, etc. • Not all sensors in "other-federal" category have weather sensors	*Collection* • ASOS sensors connected via fiber optic cable to data collection package, which broadcasts data to processors in the airport control tower • At NWS sites, observations are sent via modem and dial lines to NWS computers at the local forecast offices for transmission over the AWIPS network to the NWSTG • At FAA sites, they are sent via dedicated circuits to an ARTCC then to the FAA communication centers in Atlanta and Salt Lake City before being routed to the NWSTG *Dissemination* • Via the Family of Services 9600 baud connection • Via the NOAA Port 3-T1 satellite broadcast • Via ftp from the OSO server in Silver Spring, Md. • Via the 4800 baud FAA-604 line

(continued)

Major Systems Overview—Continued

Information from Sensor Networks	Parameters
	Update Cycle • Disseminated from the NWS-FAA sensor every 20 minutes and updated when conditions warrant • Raw data are available at the ASOS for up to 12 hours. Processed METARs and SPEC1 are available for 31 days at ASOS, but only by NWS headquarters personnel
Upper-Air Observations *Public Sector* • Weather balloons (radiosondes) launched twice a day at ~50 stations nationwide • Deployed since 1950s • Implemented at a subset of WSFOs throughout the country and other NMHS offices throughout the world • Approximately 1500 observations per day globally	*Technology* • Temperature and humidity sensor attached to a balloon using GPS for position reports and transmitter to downlink information via NOAA satellites • Wind speed and direction determined from movement of balloon *Content* • Wind speed and direction • Temperature • Humidity • Pressure *Update Cycle* • Launched globally every 12 hours
NOAA Profiler Network *Public Sector* • First system deployed in August 1989 • Last system deployed in May 1992 • 35 systems total—most in central U.S. • Approximately one-third of systems have temperature profiling capability in addition to wind profiling • NOAA basic agreement defines cooperative program between OAR and NWS	*Technology* • "Clear air radar" technology using relatively long wavelengths (74 cm or 67 cm) • Temperature profiling is provided by a Radio Acoustic Sounding System • Each system has a surface meteorological sensor package • Each system also has a GPS-IPWV subsystem, which uses the GPS satellites to measure the amount of integrated precipitable water vapor in the atmosphere above the site *Content* • Profiles of horizontal wind speed and direction • Profiles of vertical wind speed and turbulence • During each cycle, measured raw data

Processing	Collection and Dissemination
Overview • These sensors carried on balloons are still among the few in situ sensors that provide vertical profiles of the atmosphere throughout the tropopause and lower stratosphere. Although the basic technology has not changed in recent years, using GPS for more accurate positioning of the balloon has shown great success in improving the wind speed and direction measurement • There are also plans to improve the accuracy of the relative humidity as well as provide more frequent updates of the information in the next few years	*Collection* • Data are transmitted from the balloon to a NOAA communications satellite and back down to the NWS Camp Springs, Md., facility *Dissemination* • Via the Family of Services 9600 baud connection • Via the NOAA Port 3-T1 satellite broadcast • Via ftp from the OSO server in Silver Spring, Md.
Overview • Wind profilers are designed to measure vertical profiles of horizontal wind speed and direction from near the surface to above the tropopause • Algorithms convert radar returns to winds and perform quality control on the data prior to release. Birds are a significant quality control issue. Current configuration has central data collection hub; hub operating costs are not supported by NWS operational funds • Each profiler operates and provides data on 6- and 60-minute cycles. For each cycle approximately 3000 bytes of information are produced. An additional 128 bytes of information are added to each cycle with the application of quality control	*Collection* • Primary collection is via dedicated 9.6 kbaud landline circuits directly from site to central processing facility in Boulder, Colo., every 6 minutes • Secondary collection is via a NOAA GOES-DCP 1-minute time slot (transmission rate at 100 baud) once per hour • In case of communications failure, the on-site receiver can store up to 10 days of data for later transmission *Dissemination* • Processed, quality-controlled data (profiler spectral moments, winds, temperatures; surface meteorological measurements; and GPS-IPWV are transmitted hourly via dedicated 56 kbaud landline circuit from Boulder, Colo., to the NWSTG

(continued)

Major Systems Overview—Continued

Information from Sensor Networks	Parameters
	are processed on-site into 3 spectral moments for 72 range gates (heights). On-site processing consists of 10 major steps including Fourier analysis, spectral averaging, power spectra calculations, D.C. and ground clutter removal, spectral moment calculations, and some quality control processing *Update Cycle* • Profiler wind and temperature acquisition cycle is 6 minutes. Typically 10 cycles are "averaged" together to form a single 1-hour average • Surface sensor cycle is 6 minutes • GPS data cycle is 30 minutes • No calibration of the profiler system is required • Surface meteorological sensors are calibrated by the NWS every year or after replacement • Replacement of defective parts is performed by NWS technicians
MDCRS Commercial Aircraft Data *Private Sector* • Deployed since late 1980s • Voluntarily collected by airline partners • The current agreement is that the airlines own the data for real-time domestic use • Participating airlines (AAL, NWA, UAL, UPS, DAL, Federal Express) get corporate advantage from the raw reports • Data are openly available for all government use as well as research use • The data are freely exchanged with other international NWP centers via GTS • The redistribution restrictions do not apply for post-real-time use	*Technology* • Temperature, wind, and pressure sensors are fitted on the aircraft and connected to the communications downlink for automatic reporting *Content* • Wind speed and direction • Wind speed and direction • Pressure *Update Cycle* • Dependent on airline—cost of communication is high • 80,000 to 100,000 reports per day from 500 aircraft • The airlines pay approximately 1 cent per observation. This can cost several hundred thousand dollars per year • ECMWF monitors the quality of these reports in real time, including development of error statistics for

Processing	Collection and Dissemination
• For 35 profilers each having 240 6-minute and 24 60-minute cycles per day, this produces approximately 28.9 megabytes per day	• A secondary backup method using the the Internet can be activated if the dedicated circuit fails • From the NWSTG, data are sent to the AWIPS WAN, NCEP, NOAA Port, and other NOAA organizations including NCDC, the Family of Services, and theGTS • NWS primary use of disseminated data is in the operational numerical weather prediction models and by local forecasters • At times, transmission to NWSTG and its corresponding notification of receipt are significantly delayed twice a day due to high traffic load at NWSTG. During these events, the delay results in data not being used in the weather models • 6- and 60-minute numerical profiler data, along with graphical displays, are also available in real time to the public from <http://profiler.noaa.gov>
Overview • Basic in situ sensors have been on aircraft for a number of years • Newer technologies are being developed to generate derived products such as turbulence. Automated (rather than pilot-generated) turbulence reports will be added. Moisture sensors are planned but not funded • More tuning of the algorithm is needed. It is a software modification to existing systems of the aircraft, so no mechanical upgrades are required, but the increased data rate must be agreed upon	*Collection* • Data are transmitted over a 1200-2400 baud VHF connection between aircraft and ground—then routed to NCEP • Sufficient bandwidth is available • The data are transmitted from individual aircraft to ARINC, where they are processed into BUFR format and sent to NWS and FAA at 5-minute intervals (the interval can be changed if needed). This is done via a T-1 type communications circuit • Alternative backup communications are being established between ARINC and NWS to ensure that all data are collected. The current delivery rate is well above 99% *Dissemination* • Not mass disseminated per airline request • Primarily used at NCEP for

(continued)

Major Systems Overview—Continued

Information from Sensor Networks	Parameters
	each aircraft. When "bad" reports are identified, ARINC is notified and it reports to the appropriate airline
Doppler Radar *Public Sector* • Deployed NEXRAD (WSR-88d) in early to mid-1990s • Replaced 1957 and 1974 generation radars • Joint program between DOC, DOT, and DOD *Private Sector* • Deployed since early 1990 • Television stations, corporate sponsors, etc. • Located throughout CONUS • More than 150 radars	*Technology* • NEXRAD Doppler radars connected to a 1988 generation processing system for converting to derived products • Narrow beamwidth, high-power translating to very sensitive returns • Range is 460 km for reflectivity products, 230 km for radial velocity and spectrum width products • Commercial systems have limited range of about half that of NEXRAD *Content* • Base data consist of spectral width, velocity, and reflectivity at 0.25-km resolution • Derived products include base reflectivity (1, 2, and 4 km); composite reflectivity (4 km); radial velocity (0.25, 0.5, and 1 km); and hourly, 3-hourly, and storm total rainfall • Up to 177 mbytes of data are captured per hour *Update Cycle* • 14, 9, or 5 tilts available every 5, 6, or 10 minutes depending on mode • Subset of tilts available every 5, 6, or 10 minutes for dissemination • Commercial radars offer 1- to 2-minute updates *Quality Control* • Clutter suppression and range unfolding are performed at the RDA • Radar calibrated to within 1 dB using a national standard. Automatic calibration check performed each volume scan. Preventative maintenance inspections ensure continued calibration of radar

Processing	Collection and Dissemination
	operational models and forwarded to NOAA's FSL for model development • All observations received at NCEP and FSL are stored—80,000-100,000 per day
Overview • Three major benefits of the NEXRAD radars are the spectral width and velocity (Doppler) readings, increased sensitivity, and the postprocessing, which generates more useful derived products • Universities and government research labs developed algorithms for derived products as part of the NWS modernization program. Public domain software then populated privately manufactured radars that were sold concurrently with the government's roll-out of the NEXRAD network. Today those radars are quite popular and quite powerful • There is a push among universities and some private sector entities to access the NEXRAD base data in addition to the derived products. These data can be used in NWP applications as well as input to private sector enhancements to derived product algorithms that have been slow to change within the government. The challenge is how to efficiently collect and disseminate this T-1 of information from 147 sites so that it is useful when it reaches its destination • A project spearheaded by the University of Oklahoma (CRAFT) has successfully prototyped the collection of base data from 58 sites in near real time	*Collection* • Derived data are transmitted from the Radar Product Generator through the AWIPS processor at the radar site to the AWIPS-WAN • 154 of the 158 sites produce a set of 18 derived products, which are sent to the NWS Central Radar server. The NWS sites record a set of Level 3 products, which are archived at NCDC • The base data (Level 2) are recorded on 8-mm tapes and archived at NCDC. Base data from about 58 sites are sent to NCDC in near real time via the CRAFT project • Private sector data are being collected over a private network (in a request-reply mode) *Dissemination* • Subset of derived products in unaltered format disseminated over NOAA Port broadcast satellite • Complete set in unaltered format is available over a dedicated T-1 connection to the Central Radar server in Silver Spring, Md. • Subset of derived products in image format is available on NWS web site • Base data from up to 58 sites are available through CRAFT (until November 2002) • Private sector data have not been made available for mass dissemination

(continued)

Major Systems Overview—Continued

Information from Sensor Networks	Parameters
	• Local site technicians repair the radar as required. No data collected while the radar is inoperative
Ocean Observations *Public Sector* • Marine Observation Network operated by NOAA's National Data Buoy Center • 60 U.S. moored buoys • 49 C-MAN stations • 10 U.S. drifting buoys and floats • 900 voluntary observing ships • 250 buoys worldwide, regional and other national stations *Academia* • Regional coastal buoy networks used mainly for research *Private Sector* • More than 200 coastal sensors throughout the U.S.	*Technology* • MON Buoys, C-MAN, and other station sensors calibrated by NDBC Calibration Laboratory. Pre- and postdeployment calibrations *Content from MON Network* • Air temperature • Sea-surface temperature • Sea-level pressure • Wind speed and direction • Continuous wind record • Humidity, dewpoint • Solar radiation • Surface ocean currents • Ocean current vertical profiles • Ocean temperature profiles • Significant wave heights • Average and dominant wave period • Wave direction and power spectra • Swell direction and power spectra • Regional networks record onboard or report to a central facility *Update Frequency* • Hourly (public sector) • Four times per hour (private sector)
Lightning Detection *Private Sector* • Owns and operates the National Lightning Detection Network • Deployed in late 1970s to early 1980s • Two networks merged to form Global Atmospherics, Inc., recently purchased by Vaisala, a Finnish company	*Technology* • Triangulated location detection by ground-based sensors • NLDN consists of more than 100 remote, ground-based sensing stations located across the U.S. that instantaneously detect the electromagnetic signals given off when lightning strikes the Earth's surface *Content* • Flash data and stroke data with date, time, latitude and longitude of flash or stroke, signal polarity, multiplicity, and amplitude

Processing	Collection and Dissemination
Overview • All moored buoys and C-MAN stations report in real time via NOAA GOES DAPS. All drifting buoy and float data report via NOAA POES • VOS data reported via INMARSAT AMVER SEAS • All MON data are automatically quality controlled at the NWSTG and released to NOAA's weather forecast offices, AWIPS, NCEP, U.S. National Archive Centers, internationally via GTS and the World Wide Web	*Collection* • Moored buoy, C-MAN, drifting buoy, and float data are transmitted via NOAA GOES and POES to NOAA downlink at Wallops Island from the buoy to a NOAA communications satellite and back down to the NWS Camp Springs facility *Dissemination* • Via the Family of Services 19200 baud connection • Via GTS under WMO bulletins • Via the NOAA Port 3-T1 satellite broadcast to EMWIN • Via ftp from the NWS OSO server in Silver Spring, Md. • Via NOAA Weather Radio broadcast • Via AWIPS LAN • Via NDBC home page
Overview • In the mid-1970s, three University of Arizona scientists, E. Philip Krider, Burt Pifer, and Martin Uman, began researching lightning properties and behavior. Over the next decade their research and the contributions of others resulted in the development of the only U.S. national lightning detection system, NLDN. Since 1989, the NLDN has monitored 20 million to 25 million cloud-to-ground lightning strikes that occur every year across the contiguous 48 states. The network operates 24 hours a day, 365 days a year	*Collection* • Data are transmitted from over 100 remote sensors via a satellite-based communications network to the Network Control Center operated by Vaisala-GAI, Inc., in Tucson, Ariz. Within seconds of a lightning strike, the NCC's central analyzers process information on the location, time, polarity, and amplitude of each strike. The lightning information is then communicated to users across the country *Dissemination* • Via 9600 baud satellite feed

(continued)

Major Systems Overview—Continued

Information from Sensor Networks	Parameters
	Update Cycle • Event driven (tenths of a second)
Satellites *Public Sector* • NOAA's National Environmental Satellite, Data and Information Service operates the nation's GOES and POES • NESDIS operates two geostationary satellites, one monitoring North and South America and the Atlantic Ocean and the other monitoring North America and the Pacific Ocean • Complementing GOES are two POES, circling the Earth in sun-synchronous orbit at an altitude of 450 miles • In cooperation with DOD, NASA, and NOAA, NPOESS is planned to begin operations in 2008	*Technology* • Geostationary satellites remain at a fixed point over the Earth's equator at an altitude of 23,000 miles above the Earth's surface. They detect and track severe weather, including hurricanes, thunderstorms, flood-producing systems, and extratropical cyclones *Content* • Vertical profiles of temperature and humidity • Visible and infrared images of clouds and the Earth's surface • Ocean temperatures (polar orbiting satellites) • Radiation measurements • Vegetation indices • In 2000 the NESDIS archive exceeded 1 petabyte (10^{15} bytes) *Update Cycle* • GOES observe the atmosphere and Earth's surface continuously. The POES pass over a given point on the Earth twice a day, so the two POES ensure that every point on Earth is measured four times a day

NOTE: AAL = American Airlines; ARTCC = Air Route Traffic Control Center; ARINC = Aeronautical Radio, Inc.; ASOS = Automated Surface Observing System; AWIPS = Advanced Weather Prediction System; AWOS = Automated Weather Observing System; BLM = Bureau of Land Management; C-MAN = Coastal-Marine Automated Network; COOP = Cooperative Observer Program; DAL = Delta Airlines; COE = U.S. Army Corps of Engineers; CRAFT = Collaborative Radar Acquisition Field Test; DAPS = automated processing system; DOD = Department of Defense; DOE = Department of Energy; ECMWF = European Centre for Medium-Range Weather Forecasts; EMWIN = Emergency Managers Weather Information Network; EPA = Environmental Protection Agency; FAA = Federal Aviation Administration; FSL = Forecast Systems Laboratory; GAI = Global Atmospherics, Inc.; GPS = Global Positioning System; GPS-IPWV = Integrated Precipitable Water Vapor; GTS = Global Telecommunications System; INMARSAT AMVER SEAS = International Mobile Satellite Organization Automated Mutual-Assistance Vessel Rescue System Shipboard Environmental Data Acquisition System;

Processing	Collection and Dissemination
Overview • GOES and POES are essential parts of the global observing system. They provide very high horizontal resolution data over the entire globe. These observations complement in situ observations, which tend to be concentrated over land areas. Satellite observations are especially important in the Southern Hemisphere, which has a very sparse network of in situ sensors • Satellite data are used by the public, private, and academic sectors for a variety of applications, including weather forecasting and warnings, climate monitoring, ocean services, and research • Other nations also operate geostationary and polar orbiting satellites, and these data are generally shared under the provisions of WMO Resolution 40	*Collection* • Data are downloaded from the satellites to ground-receiving stations and from there to NCEP and other users via landlines. Many users also have their own ground-based satellite data receivers and process the data directly upon receipt for their own uses

ITWS = Integrated Terminal Weather System; MDCRS = Meteorological Data Collection and Reporting System; METAR = aviation routine weather report; MON = Marine Observation Network; NCC = Network Control Center; NCDC = National Climatic Data Center; NCEP = National Centers for Environmental Prediction; NDBC = National Data Buoy Center; NESDIS = National Environmental Satellite, Data and Information Service; NEXRAD = NEXt generation weather RADar; NPOESS = National Polar-Orbiting Operational Environmental Satellite System; NWA = Northwest Airlines; NLDN = National Lightning Detection Network; NMHS = National Meteorological and Hydrological Services; NWS = National Weather Service; NWP = Numerical Weather Prediction; NWSTG = NWS Telecommunications Gate; OAR = Office of Oceanic and Atmospheric Research; RDA = Radar Data Acquisition; SPECI = Special Meteorological Aeronautical Report; UAL = United Airlines; UPS = U.S. Postal Service; USDA = U.S. Department of Agriculture; USGS = U.S. Geological Survey; WMO = World Meteorological Organization; WSFO = NWS Forecast Office.

Appendix D

Private Sector Comments

Note: At its meetings and through its web site the committee invited all sectors to provide examples of documented conflicts that had occurred within the last five years. Only private weather companies responded and their comments (with identifiers of companies and individuals removed) were forwarded to the relevant NOAA officials for response. Private sector comments are given in italics and NOAA responses are given in indented plain text.

COMMENTS ABOUT NWS

1. As you may know, our company entered into an agreement with Bauch and Lomb in 1994 to create an Ultraviolet Index that could be used in conjunction with weather forecasts to predict the impact of ultraviolet radiation on skin and eyes. At the time, the government did not have any such index. Through research and development, our company created a UV index. In an independent initiative, another company, in conjunction with another interested partner, also developed a UV index. Daily production of hourly forecasted values began and were published in the media.

As the public became aware, through press releases and other means, of these developments in the commercial weather industry, the U.S. National Weather Service, under the direction of Dr. Elbert W. (Joe) Friday, Jr., began a rushed program to develop their own UV index.

Meetings were held between the commercial weather industry and the National Weather Service over this concern. The ultimate result was that while taxpayer money was spent to recreate what had already been developed in private industry, the National Weather Service limited itself to ongoing daily preparation of its index for approximately 50 cities, valid, for noon only, at each location.

Through the commercial weather industry, both in the newspapers, and on television, radio, and web sites, access by the public to these privately created UV indexes became widespread.

Many in the National Weather Service did not seem pleased by the *situation when the commercial weather industry questioned why it was that the National Weather Service would expend public funds to create a product and produce a service when one was already developed and available from the commercial weather industry in response to what was perceived to be a business and market need.*

The governments of Australia and New Zealand began public awareness programs of the dangers of overexposure to the sun in the late 1980s, and Canada started an awareness program in 1992. Alarmed by increasing trends in skin cancers and cataract surgeries, the U.S. Environmental Protection Agency (EPA) and the Centers for Disease Control and Prevention (CDC) launched a similar health awareness program in 1993.

The Canadian government first devised a UV forecast index based upon the incident rate of UV-B radiation reaching the Earth's surface around noontime to help the public plan to appropriately protect themselves from overexposure. The EPA used the Canadian program as a model. Not having the necessary expertise, the EPA approached the National Weather Service early in 1993 about developing a U.S. Ultraviolet Index similar to the Canadian index. At the same time, several federal agencies (NOAA, USDA and the EPA) were deploying ground based observation networks to measure UV radiation reaching the Earth's surface. These networks would provide long-term data for purposes of trend detection as well as the necessary validation for any UV index forecast.

In November of 1993, the EPA invited atmospheric scientists, medical specialists and the private meteorological sector to discuss the possibility of a broad coalition. A major concern at that time was that none of the UV-B indices developed by any country included the effects of clouds. In response, the NWS examined the possibility of including existing NWS cloud forecast data in a UV index. After appropriate peer review, validation, and testing, the NWS concluded that including cloud cover in a UV index was feasible.

The EPA as well as television broadcast companies, including The Weather Channel, promoted the NWS development of a baseline UV index available to the broad public in a non-exclusive manner as a public health service. Following further consultations with the commercial meteorology sector and other interested parties, an experimental UV index was made available in May 1994 as a plain text bulletin for 58 cities. The NWS also made its data and the methods used to calculate the index broadly available to the private sector in order that these companies could create value-added products, such as hourly UV forecasts for ski resorts or the many locations for which NWS did not issue a UV forecast.

In cooperation with the American Meteorological Society, the NWS held several meetings during 1995-1996 to work in partnership with the private sector to help them expand to specific markets, cover the diurnal cycle, and provide information to cities not covered by the NWS. While some private sector companies did not agree that the NWS should issue any UV index, all parties did agree to work towards a standardized UV index scale.

After providing the UV index for several years with a consistently high degree of validation, (Long et al., *Bulletin of the American Meteorological Society*, 1996), in the summer of 1999, the EPA, the CDC, the American Academy of Dermatologists, the American Cancer Society, and members of Congress asked the NWS to expand its coverage beyond the original 58 cities to 160 cities. The EPA, NWS, private sector and medical community representatives met to consider ways to improve coverage. NWS rejected the EPA's suggestion that NWS provide UV indices for 160 cities. The NWS decided:

1. To continue to produce the daily UV index at the original 58 cities;
2. To deliver over the Internet in gridded format the data necessary for the private sector to create UV indices over the entire U.S., and;
3. Not to produce a contoured map graphic of UV on NWS Web pages.

The NWS has and continues to have good working relationships with most companies within the commercial weather industry and television broadcasters concerning the UV index product. All generally understand the limitations of any one sector's service, as well as the expanded possibilities for the private broadcasting and commercial meteorology sectors to communicate the UV index and attendant health messages to the public. By continuing to improve the UV index forecast, and by making the numerical output available to the private sector in gridded format for creation of graphical products, the NWS satisfies both its public health and its economic enhancement missions.

2. For many decades, the National Weather Service has utilized an index called Wind Chill to attempt to describe the effect of temperature on humans during windy conditions. It has been known the Wind Chill formula is flawed and significantly overstates cold, yet the NWS has continued to use it for these many decades and publish and distribute charts to the media, emergency managers and the public, which allow one to plot temperature and wind speed and calculate Wind Chill. Based on this formula, the NWS also issues wind chill advisories.

As a result, it can be argued that schools, businesses and other routine daily operations have, on many occasions, been prematurely curtailed while the NWS knew that the overstatement of values was costing the economy millions.

Our company began a research and development project a number of years ago to develop its own index that would better state the weather's effect on people. A patent is pending on this before the United States Patent Office.

The National Weather Service recently began, what appears to be an urgent drive to create a new Wind Chill index for use in the United States. How these actions related to our company's pending patent is not yet understood, but the National Weather Service and the consortium it established on the new Wind Chill index, are aware of the fact that a patent is pending.

The National Weather Service has announced that it will put into use the new Wind Chill index this winter of 2001-2002. They have also announced that they are only making certain adjustments to the old Wind Chill index that was used last year and that next year, in the winter of 2002-2003, they will make further changes to the new Wind Chill index they will use this year.

As a result, three different winters will have three different wind chill indices, which are not comparable to one another, all issued by the National Weather Service. In the span of a year and two days, three different NWS wind chill numbers will be valid. Our company believes this will be an issue of confusion for the public. Media outlets may still use the old charts and inconsistency may develop.

Whether the rush to bring out a new, revised Wind Chill index in this problematic fashion, is a response to our company's initiative is not known. But it does appear to fit the pattern that occurred with regard to the UV index in the 1990s.

> The National Weather Service, as part of its mission to help protect lives and property, has issued wind chill warnings and advisories since 1973, as one of its public safety products and services available to the American public. These products and services are regularly upgraded and improved to ensure public safety.
>
> The original version of the wind chill index was based on the 1945 scientific experiments of Antarctic explorers Siple and Passel. This research established an important relationship by recognizing that the combination of the two different elements—temperature and wind speed—could produce an effect greater than either element. However, they were working with the science available in the 1940s, and did not take into account other factors that impact wind chill.
>
> There has been general agreement in the scientific community for the past eight years that new and better science could produce a more accurate and useful wind chill index. Because of the National Weather Service's responsibility to protect lives, it was necessary to identify and thoroughly re-

search the factors influencing wind chill before making any changes. The final product must provide accurate data which would warn the public of danger to health and life. It was also necessary to create a standardized index that would be the most effective in promoting public safety and coordination between the U.S. and Canada.

The Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) and the National Weather Service created a Joint Action Group for Temperature Indices (JAG/TI) to bring together the best scientists from the academic community and the federal government to carry out the necessary research and testing processes. JAG/TI consists of representatives of the OFCM, several federal agencies (U.S. Air Force, Department of Energy, National Weather Service (National Oceanic and Atmospheric Administration), Federal Aviation Administration, Federal Highway Administration, and U.S. Department of Agriculture), as well as the Meteorological Service of Canada (Environment Canada), the academic research community (Indiana University, Purdue University), and the International Society of Biometeorology (ISB).

Using the advances in science, technology, and computer modeling which have occurred in the past decade, JAG/TI identified the factors other than temperature and wind speed that can impact human safety in severe winter weather conditions, and determined the most accurate way to measure them. These factors were identified, researched, and developed into the new wind chill formula using advanced computer modeling technology.

This formula was then clinically tested using human volunteers at the wind tunnel and climatic chamber of the Defense and Civil Institute of Environmental Medicine in Toronto, Canada. The results of these tests enabled JAG/TI to further improve the wind chill formula, which has been integrated into the computer models that produce NWS weather forecast products.

All the work done by the Weather Service to upgrade the index was carried out as part of the normal work of the NWS Office of Climate, Water and Weather Services. The timing of NWS implementation of a new wind chill index was driven by gradual improvements in the science and technology, and a methodical research, development and testing process which led up to initial implementation in 2001. The U.S. Department of Defense and the OFCM contributed funding, and Environment Canada provided facilities for the testing process.

This new wind chill index provides, for the first time, a specific danger level for frostbite, including warnings of the length of time until frostbite occurs at varying levels of wind chill. It is also the first time that a standardized index has been used for the U.S. and Canada.

Some private meteorological companies have developed their own wind chill formulas. The Weather Service has no problem with that. Indeed, these private efforts may well advance the state of the underlying science if they are subject to peer review and documentation in accordance with the principles set forth in *Resolving Conflicts Arising from the Privatization of Environmental Data* (National Academy Press, 2001).

3. For a number of years, we actively marketed our services to IDAHO POWER (IP), in Boise, Idaho. As the local utility in southwestern Idaho, IP's primary service concern was the city of Boise. IP personnel informed me they elected not to subscribe to our custom forecast services, because one of the meteorologists in the Boise NWS office would provide them a "tailored" forecast each morning at no cost. The NWS continued to supply a custom forecast for a number of years, until the Fall, 2000, when energy deregulation issues forced IP to change operational strategy. At that time, IP elected to subscribe to our services, as the NWS office could not provide the data in the required format. Clearly, this is an example of the NWS exceeding mandated policy.

The Boise weather office staff have not provided tailored forecasts to Idaho Power. Idaho Power did receive and use weather information from the NWS. They used the standard NWS Coded Cities Forecast (CCF) and computer generated temperature forecasts in their energy demand model. We believe they also use daily temperature and precipitation observations. All of these products are available to anyone, not made for a specific customer, and are part of the national suite of products.

4. This program from the National Weather Service (http://www.crh.noaa.gov/ict/gfe/temps.htm) duplicates what the private sector has done for years. Our company, literally since Day One of its founding 20 years ago, has produced point-specific hourly forecasts.

Currently, there are two private sector companies that produce animated mesoscale temperature images and both sell them to clients and distribute them through the media. Their products are FutureCast and MyCast. This new NWS program looks almost identical to these existing programs.

The general public simply does not need or use mesoscale hourly forecasts . . . but energy companies and certain industrial users do. I believe this is both a duplication and violation of the Public-Private Partnership Policy.

NWS forecasters have been formulating point-specific hourly forecasts for many years. For example, surface temperature is one of the primary factors affecting the onset of convection and hazardous freezing conditions associated with winter weather. In order to produce a core set of watch/warning/advisory/statements one must be able to forecast individual weather elements, such as temperatures, on an hour-by-hour basis. Our forecast grids are on a scale consistent with the state of the art/science in our forecast models. Increases in time and spatial resolution of NWS forecasts, now and in the past, have been enabled by advancements in the science and technology.

The example cited is a display of information produced by NWS forecasters using the Interactive Forecast Preparation System (IFPS). IFPS, long-planned as part of the NWS modernization and currently being implemented across NWS, allows forecasters to produce forecasts in digital form with higher resolution in space and time. Forecasters produce, manipulate, and publish forecasts in digital form with the resulting digital forecasts driving production of traditional NWS information products. This capability will also allow them to prepare products in multiple formats (e.g., graphics). The product in question is a straightforward graphical presentation of the underlying digital information from one NWS forecast office (Wichita).

The NWS is anticipating distribution of this type of data in various forms including digital data formats. It can then be used by the private sector to reformat and repackage to meet their customers' diverse needs. IFPS has been broadly publicized, including presentations at meetings of the American Meteorology Society and elsewhere.

5. Why does the NWS feel it needs to make 7 and 14 day public forecasts? See http://weather.noaa.gov/cgi-bin/iwszone?Sites=:ksz083.

On Wichita's NOAA Weather Radio, a listener can obtain 14 day forecasts (not available on the Web). As Joel Myers says, "Are they going to do 28 day forecasts and expect us to sell the 29th day?" While we were using NWS model guidance as a source of input, the private sector has made 7 day forecasts for 5+ years. This is duplication by the NWS and not required for public safety or consistent with the Weather Service's core mission.

Weather and climate phenomena are ongoing and dynamic. Historically, forecasters were only able to predict conditions at best a very few days in advance. Advances in science as well as in information and observational technologies now permit predictions in the one to two week time range with some skill, and are beginning to permit forecasting extreme climate events. For the NWS to achieve its core mission of protection of life and property and the enhancement of the economy, it must provide predictions for all time scales up to the limit of scientifically demonstrated skill.

Hence, NWS forecast products can be categorized into three broad categories. The first are short term warnings and forecasts of weather conditions, be they hazardous or benign. Typically, these products have valid time ranges from a matter of minutes for short-duration warnings (e.g., Tornado Warning), to up to 60 hours for Winter Storm Outlooks. In the medium range, there is a need to monitor weather conditions and to provide emergency managers, planners, forecasters and the public advance notice of potential threats through seven day forecasts, 6-10 day and "Week Two Threats Assessments." NWS also predicts extreme climate events, such as drought, excessive rain, and temperature extremes as far in advance as possible. Water, energy, transportation and other economic sectors use these forecasts to plan and avoid or mitigate risk. For example, the NWS seasonal climate forecast for 1997-1998 saved Californians $500 million to $1 billion as they were able to take mitigation measures six months in advance of heavy rains.

All of these are part of the national information database that the NWS provides for the protection of life and property and the enhancement of the national economy. We are unaware of any policy principle authorizing NWS to withhold this taxpayer-funded information from the public.

6. This is the form of a National Weather Service AIRMET (hazardous weather for small aircraft) report:

FOS WA 301912 AMD
AIRMET SIERRA UPDT 4 FOR IFR AND MTN OBSCN VALID UNTIL 302100
AIRMET IFR...WA OR CA...UPDT
FROM BLI TO 40SSW FMG TO MOD TO OAK TO FOT TO TOU TO BLI
OCNL CIGS/VIS BLW OVC010/3SM IN CLDS..PCPN AND BR. CONDS CONTG
BYD 21Z THRU 03Z.

AIRMET IFR...WA OR ID MT
FROM YDC TO 50NNE FCA TO HLN TO LKT TO BKE TO PDT TO YDC
OCNL CIGS/VIS BLW OVC010/3SM IN CLDS..PCPN AND BR. CONDS CONTG
BYD 21Z THRU 03Z OVR NRN ID/NWRN MT PTNS AREA...ELSW...CONDS ENDG
BY 21Z.

AIRMET IFR...CA...UPDT
FROM EHF TO HEC TO LAX TO 40W RZS TO EHF
OCNL CIGS BLW OVC010 OCNL VIS BLW 3SM IN CLDS AND PCPN. CONDS
CONTG BYD 21Z...ENDG BY 03Z.

AIRMET MTN OBSCN...WA OR CA ID MT WY NV UT

FROM YXC TO GTF TO BPI TO DTA TO BTY TO HEC TO 40W RZS TO FOT TO
TOU TO YDC TO YXC
MTNS OCNLY OBSCD IN CLDS AND PCPN. CONDS DVLPG/ SPRDG EWD DURG
PD...CONTG BYD 21Z THRU 03Z.

This coded report (dating from the days of low speed communications requiring "broken language" communications as a form of data compression) can be easily read by any pilot in the world. While the private sector was first to provide this data in plotted form, I have no problem with the NWS taking its basic aviation text data and plotting it on a simple map. See, for example http://www.awc-kc.noaa.gov/awc/airmets/wsairmet.gif.

While some contend it is "adding value" to plot this data, if that's the case it is such a low level of added value it is acceptable to me because it is a simple plot and the potential for enhanced aviation safety overwhelms the concern in this case.

Now view http://adds.awc-kc.noaa.gov/projects/adds/flight_path/. This is an entirely different matter. This is not simply aviation weather, it is flight planning. There are a number of commercial weather companies (Jeppessen, Universal, Lockheed, etc.) that do flight planning services. The NWS should not be competing with flight planning companies at even this level, but, it gets worse.

See http://www.awc-kc.noaa.gov/awc/iff/iffdp-menu.html. The NWS will create a custom flight package for international flights. For example, Continental Airlines can call and request a menu of products for a flight from Houston to London. The NWS will deliver it to the fax machine of Continental's choice, immediately before scheduled take-off and will provide a meteorologist to answer questions, elaborate, etc. (see phone number for that purpose on the Web page). This service did not exist five years ago (how did the airlines ever manage without this service from the NWS?). The NWS decided to duplicate what in-house airline meteorologists and companies like Kavouras, Universal and Jeppessen were already doing.

Aviation Digital Data Service. The Federal Aviation Administration (FAA) has asked NWS to participate in its effort to help the aviation community improve the safety and efficiency of flight planning through the development of an Aviation Digital Data Service (ADDS). The Federal Aviation Act, 49 USC 44720, requires NWS to furnish "reports, forecasts, warnings and other advice to the Secretary of Transportation and other persons" in order to promote safety and efficiency in air navigation. The FAA has tasked a product development team to develop methods to better gather, display, and utilize official National Weather Service aviation weather information. The FAA also created a team composed of government, industry, and association representatives, which has endorsed ADDS as a means by which both the FAA weather briefer and the pilot can "view the same weather graphics during weather briefings" (p. 39, *FAA Safer Skies: Focused Safety Agenda*, March 2000). The ADDS web site, http://adds.aviationweather.noaa.gov/, prominently states: "The Federal Aviation Administration funds and directs the Aviation Digital Data Service and the experimental weather products that it displays. These products have not been developed by and are not endorsed by the National Weather Service."

International Flight Folder Documentation Program. The International Civil Aviation Organization (ICAO) requires all countries to provide international flights with a minimum level of weather services. This requirement ensures flight safety and a consistent minimum level of services worldwide. The U.S. is a signatory to the 1947 ICAO Convention, and the Federal Aviation Act, 49 USC 44720, requires NWS to "establish and coordinate international exchanges of meteorological information required for the safety and efficiency of air navigation." The services in question—flight documentation—provide departing international flights with ICAO mandated information. The NWS has been providing this service for 50 years.

In 1998, NWS moved to a web-based production and delivery system and consolidated management at the Aviation Weather Center. Previously, the necessary documentation was manually assembled at numerous forecast offices. The Flight Documentation system is operated by the private sector under a NWS contract. The service only provides the minimum information required by ICAO. Most international carriers receive additional information and services from their own in-house meteorological staff or commercial weather firms.

7. Until 1999, the Storm Prediction Center (formerly the National Severe Storms Forecast Center) transmitted a daily list of all reports of tornadoes, large hail and damaging winds occurring during the previous 24 hours. Our company took this list, added reports from local National Weather Service offices that did not make the list and also added reports from the Associated Press' National Disaster Wire to which we were subscribers. Our company (and other commercial weather companies) then compiled this data into a new list, quality controlled it (i.e., checked the position of severe storm reports relative to the position of radar echoes to eliminate false reports), plotted the reports and (in our case) added radar storm tracks so clients (such as insurance companies, insurance adjusters, shingle companies, etc.) could view the location of storms in between reports so they could interpolate the location of potential losses.

In 1999, the Storm Prediction Center began plotting these reports on colorized maps and making them available on the web in real time. As a *result our company and other commercial weather companies have lost many of their clients for this service. While our product was superior to the National Weather Service's, many clients cancelled because of a "free" alternative. I estimate the annual loss of revenue to our company in the $15,000 to $20,000 range.*

As always, I support making the data available as part of the national infrastructure. However, the general public does not need colorized, real time maps of severe storm reports. This product is of interest to industry and is best served by the private sector.

> The National Weather Service, as part of its mission to protect lives and property, issues warnings for severe thunderstorms and tornadoes. The Storm Prediction Center (SPC) automatically collects and compiles reports of these events and sends them out as a table and in graphic format. The purpose of the report is to allow local NWS Weather Forecast Officers and emergency managers downstream from the storms to see the kind of severe weather approaching them. In order to effectively plan for pending events, emergency managers need to know what the approaching storms are capable of producing, e.g., 3/4" hail and tree damage, or F-5 tornadoes, or 3" hail and 100 kt winds.
>
> These products were developed in the late 1970s. Initially, the product was compiled manually and issued on an as time allows basis. Due to staffing reconfiguration with the establishment of the SPC, manual collection was no longer possible and in 1996 production of these products was automated. The data was collected and the products issued hourly. Presently the product is disseminated externally via NOAA Port and internally via AWIPS.
>
> Before 1999, computer limitations precluded putting anything but the report list on the Internet. Now, the only difference between the NOAA Port and AWIPS product and the Internet application is that tornado reports are colored red, hail reports green, and wind reports cyan. The colors help the product serve as a quick guide to forecasters and emergency managers who use this page as a quick reference for severe weather that has occurred upstream of their location. The underlying data on which the severe storm reports are based are likewise publicly available via NOAA Port.

8. The NWS wants to extend its hydrologic modeling activities to small ungauged urban watersheds. This is in conflict with commercial weather services: custom flood warning systems contracted by businesses or other entities. River forecast centers forecast long duration slow rise river response. These events are rarely life threatening and therefore not within the core mission of the NWS. Forecast offices do not have access to cutting edge technology available in the private sector for forecasting small basins *particularly in urban areas. Local hydrologic prediction services for a fee fall within the private sector and not the core mission of the NWS.*

The National Weather Service (NWS), as part of its mission to protect lives and property, has issued flood forecasts and warnings since its inception. The Organic Act of 1890 recognized the importance of hydrologic services by stating that the Weather Bureau:

> . . . shall have charge of the forecasting of the weather, the issue of storm warnings, the display of weather and flood signals for the benefit of agriculture, commerce, and navigation, and the gauging and reporting of rivers.

"The gauging and reporting of rivers" has since been transferred to the U.S. Geological Survey. NWS responsibility for "the display of . . . flood signals" has evolved from the posting of signals and telegraphing of forecasts and warnings to all affected parties to the dissemination of products via a number of mechanisms, including NOAA Weather Wire, NOAA Weather Radio, and the Internet.

NWS River Forecast Centers began forming in the 1940s in response to several disastrous flood events on major rivers across the nation. Taken together, these floods killed thousands of people. Flood-related fatalities still occur, but have decreased annually in spite of increased habitation of flood-prone regions. Unfortunately, deaths still occur even during individual floods considered to be minor in magnitude, and the NWS is devoting resources on several fronts to minimize flood impacts.

The NWS has been developing and using hydrologic models for small stream basins since the inception of its flash flood program in the 1970s. This year, the NWS will implement improved small basin hydrologic modeling capabilities to better meet its mission to save lives and property. The focus is on basins in rural and mixed-use areas. Modeling of small, ungauged urban watersheds is not being emphasized since watershed response to rainfall in urban areas is often controlled by complex storm drain systems. Such networks of underground conduits and concrete-lined channels are beyond the scope of models being considered by the NWS. The NWS acknowledges that such settings are better modeled by specialized entities, such as local flood control districts, and that the private sector may well play an important supporting role.

To ensure that the latest, cutting edge hydrologic modeling capabilities for small basins are developed for its forecast offices, the NWS is sponsoring the distributed modeling intercomparison project (DMIP). Observed data sets for small basins that are representative of those which are operationally available across the U.S. have been posted on the Internet (http://www.nws.noaa.gov/oh/hrl/dmip/index.html). On-line registration is open to all researchers who are invited to test these data sets in their distributed models, and results are compared to those from other entities to determine the most suitable distributed modeling approach for the operational NWS environment. The transition to operations is planned to occur over the next few years.

9. The NWS has an International Hydrologic Assistance program that provides assistance to other countries based on outmoded technology. The NWS is using taxpayer money to export outdated technology based on 1970s models (Sacramento model). The Department of Commerce or USAID (the U.S. Agency for International Development) could better coordinate business contacts directly providing opportunities to U.S. commercial weather services.

Nearly all funds expended in NWS international technology transfer projects are directed to the U.S. private sector or universities to implement projects. The NWS international hydrology technology transfer projects provide technology transfer, technical assistance and training to developing countries. This program is fully reimbursable and all projects are paid in full by counterpart country governments, donor organizations such as USAID or through loans by international finance institutions such as the World Bank.

The technology used in NWS projects is state-of-the-art. The National Weather Service River Forecast System contains a suite of models and techniques that perform well in the range of climatology, hydrology and topography experienced worldwide. The Sacramento model is only one of the models available to the NWSRFS. It has performed well for the river basins where it has been used to date. Providing credible river and flood forecast capabilities for most river basins requires an integrated hydrologic forecast system which not only uses existing technology and models but provides a flexible operating system for hydrologists to operate. It is important for countries to use operational systems with assured technical assistance and enhancements for the developing national meteorological and hydrological agencies.

10. The Office of Hydrologic Development recently solicited support for a new radar rainfall running total product. Private sector developers have already developed value-added products that could provide better hydrologic application. Either this fact is unknown or the NWS would like to compete. NWS would be within their core mission if they just gave access to base reflectivity and let commercial weather service providers develop value-added products that have commercial value.

The NWS Office of Hydrologic Development (OHD) applies science and technology to create precipitation estimates to support water forecasting and warning services. Development efforts are focused on satisfying NWS operational requirements. Throughout the past decade, NEXRAD rainfall estimates have been improved, based on science and technological advancements, and tailored specifically for NWS operational use. The example appears to refer to the NEXRAD Digital Storm-total Precipitation (DSP) product which is currently undergoing development. The DSP involves the reformatting of an existing NEXRAD rainfall estimate (the graphical storm-total precipitation product). The DSP product will have enhanced data resolution and be mapped to a grid that is more easily merged with products from adjacent radars within the operational environment of the NWS field offices. This new product will therefore provide our field forecasters with enhanced capabilities for forecasting applications that require quantitative rainfall information. The DSP product will be used within existing NWS precipitation algorithms to support new forecasting techniques to improve flash flood forecasting and warning services. This information also will be disseminated to all in accord with federal information dissemination policies.

11. The NOAA Service Assessment of Tropical Storm (TS) Allison related that flood level in Buffalo Bayou was underforecast by as much as 12 feet. I've added some of the relevant findings and recommendations that NOAA/NWS has made after Allison. Findings 1 and 2 suggest that better models are needed and that the AWIPS provides for a site-specific hydrologic model. In this report it is recommended that the NWS work with Harris County to develop a flash flood model to forecast ungauged basins in the local urban area. This service would be in direct competition with commercial weather providers such as ours that already offer and provide like services.

The relevant findings and background may be found at the following link ftp://ftp.nws.noaa.gov/om/assessments/allison.pdf.

Warning and Forecast Services

Finding 1: Forecasting proved to be difficult for some small rivers/bayous that rose rapidly to record levels. Forecasts for Buffalo Bayou at Shepherd Drive in Houston underforecast the river stage by 6 to 12 feet with little or no lead time. Also, the forecasts for the West Fork of the San Jacinto River near Conroe were not accurate. Both software and procedural problems have been identified by the WGRFC and the NWS Office of Hydrologic Development as contributing to these inaccuracies.

Recommendation 1a: The WGRFC, with the assistance of the NWS Office of Hydrologic Development, should make the necessary software corrections and implement procedural changes needed for small basins that respond rapidly during heavy rainfall. These changes should be made by April 1, 2002.

Recommendation 1b: Regions should evaluate RFC [River Forecast Centers] procedures for small basins that respond rapidly during heavy rainfall. RFCs should be tasked with changing procedures where inadequate.

How rainfall is distributed over a basin also affects how a river responds. With Allison, rainfall was concentrated at the lower end of the basin, and the RFC did not have a precedent for adjusting its procedure. For Buffalo Bayou, the time interval used for the forecast model was set at 6-hour time steps. A 3-hour interval is needed for basins that respond rapidly during heavy rainfall. A software problem existed in the model used to generate the forecasts for the West Fork of the San Jacinto River.

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Weather Forecast Offices

Finding 2: Because of the small size of the bayous in the Houston area, most are not included in the WGRFC forecast system. Harris County has initiated a project to develop new forecast tools for these small basins and has invited NWS participation in this effort. The NWS Advanced Weather Interactive Processing System (AWIPS) Release 5.1.2 includes a site-specific hydrologic model which can be used for small gauged basins.

Recommendation 2a: The WFO [Weather Forcast Office] Houston/Galveston MIC [Meteorologist-in-charge] and the WGRFC HIC [Hydrologic Information Center] should meet with the appropriate Harris County officials to determine the NWS role in the project. Once the NWS role is determined, progress will be tracked through the follow-up service assessment reporting process.

Recommendation 2b: Once the AWIPS site-specific hydrologic model is deployed in Build 5.1.2, WFO Houston/Galveston should determine what contribution this model would make to local flood warning operations.

The threat of competition from the government in these areas is a research and development deterrent and risk. We really appreciate your efforts to allow technology development to thrive in the open marketplace.

The National Weather Service, as part of its mission to protect lives and property, issues warnings for river and flash flooding. In many communities, a government-to-government partnership between the NWS and local government flood agencies exists to ensure a coordinated warning effort by sharing forecasts and observational data. The value of these partnerships was well illustrated during the record breaking floods associated with Tropical Storm Allison, June 5-10, 2001.

The effectiveness of the flood/flash flood warning system is significantly diminished when conflicting information is provided to the public and decision makers. The NWS coordinates on a continuous basis with local flood warning and emergency management agencies throughout all phases of a flood threat to ensure the rapid exchange of forecasts, data, and situation reports. The Tropical Storm Allison Service Assessment Team found that such a partnership, between the local NWS Office and the Harris County Flood Control District, resulted in a highly successful and coordinated warning effort.

Finding 1 of the Service Assessment report identified two NWS forecast points where changes in software and internal procedures would produce more accurate forecasts. The subsequent recommendations set options to correct the problems at the specific sites as well as at any other NWS forecast points where similar problems might exist. The scope of the finding and recommendations were strictly internal to the NWS and its mission.

The Assessment Team also learned (Finding 2) that the Harris County Flood Control District was interested in developing small basin flood forecasting models with the assistance of an engineering firm. It was a recommendation of the assessment team that the Weather Forecast Office (WFO) Houston/Galveston and the West Gulf River Forecast Center (RFC) meet with the Harris County Flood Control District to determine what, if any, role the NWS should play in this effort. At the very minimum, the team felt that the Houston/Galveston WFO should be aware and knowledgeable of the initiative to ensure consistent forecast and warning dissemination with the Harris County Flood Control District during future flood threats.

The team also felt that consideration should be given to the site-specific AWIPS capabilities being deployed to meet NWS mission requirements. Perhaps these could serve as an interim step if long-term developmental efforts were required by the district's engineering contractor.

The team's recommendations were strictly within the scope of the existing operational partnership between WFO Houston/Galveston and the Harris County Flood Control District. As a partner with the Harris County Flood Control District, the WFO does have the responsibility to cooperate and provide operational support to the local flood warning system. NWS, local government, and private sector partnerships have been the cornerstone of successful local flood warning systems throughout the nation. The findings and recommendations of the Tropical Storm Allison report are consistent with this well-established public-private partnership.

12. Does the NWS give the private sector credit when it uses technology originally developed by the private sector? For example, look at http://www.crh.noaa.gov/radar/latest/DS.p19r0/si.kict.shtml.

Color radar was developed by Technology Service Corporation of Los Angeles in 1976 (with Len Slesick and others serving as meteorological consultants) and remoting color radar was developed by Steve Kavouras in 1978. Where is the credit from the NWS to the private sector on this web site and others like it? I have not seen one.

Responses for 12 and 13 combined below.

13. During the September 24, 2001, tornadoes in the Washington, D.C., Metropolitan Area, the National Weather Service included the following information in one of its tornado warnings:

> *The tornado is expected to be . . . Over Hyattsville . . . 2 miles southeast of Bladensburg at 5:16 pm 2 mi. southeast of Adelphi . . . 2 miles southeast of Langley Park at 5:18 Over College Park . . . 3 mi. southeast of Hillandale at 5:20 etc . . .*

"Time of arrival" programs were developed by the private sector for broadcast use in the 1980s. The National Weather Service "adopted" this technology in its AWIPS system for use in NWS storm warnings. Again, I have not seen any indication of credit to the inventors from the National Weather Service.

Response to questions 12 and 13: All significant scientific and technical endeavors build upon prior art, whether generated in the private, academic or government sectors. Unless specific intellectual property restrictions are placed on particular developments, they are in the public domain. All major information systems, public and private, rely on work that has gone before. Such work is generally cited and incorporated into the scientific, engineering or other documentation underlying the particular system. To the extent that such systems utilize patented or other proprietary matter, the terms of their use are governed by contract. Such contracts may or may not require some sort of attribution to be contained in the final output products of such information systems.

From the federal government perspective, there is no policy or regulation specifying that federal agencies must include attribution in their information dissemination products to any or all of the art underlying their information technology systems. As a practical matter, to include attribution of such prior art in federal information products would be akin to the "credits" accompanying a commercial motion picture. To do so would unduly burden both the information system and the information product. Furthermore, as a matter of general policy, should NOAA/NWS need to enter into a contract to incorporate proprietary technology into an information system, it would seek to avoid agreeing to a contract clause requiring attribution. There are limited circumstances, e.g., where NOAA/NWS uses proprietary software or services under commercial terms, where attribution is given; for example, "This system is 'IBM an e-business solution (TM)' supported." These may be found at: http://www.nws.noaa.gov/credits.html.

14. Remember the Thailand NWP system. There were three U.S. bidders. The NWS would not give ANY recommendations because it "would show partiality" to one company over another. They could have said all three are responsible and respected companies and are capable of doing a great job. Instead the UK Met Office walked off with all the business totally supported by their government.

During 1997, the National Weather Service was approached by Department of Commerce trade officials on whether the U.S. government could provide support to U.S. consortia bidding on the Thai Meteorological Department's purchase of a super computer for weather prediction and modeling. Other National Meteorological Services (specifically at least the UK Met Office) were supporting bidders from their countries by offering training to the Thai Meteorological Department in global modeling should their particular national consortium win the contract.

This led to the question of whether NWS could offer similar types of training to the Thai Meteorological Department in support of U.S. companies bidding on the contract. Without intending to favor one U.S. company over another, the NWS reply was: (a) yes, we can offer training if the super computer ultimately contracted for by the Thai Meteorological Department was a vector computer purchased from a U.S. bidder because our global models at the time ran on vector machines, but (b) no, we could not offer training should a U.S. bidder offer a super computer using parallel processing because, at the time, our global models did not run on parallel processing machines.

Subsequently, the Thai Meteorological Department selected a parallel processing computer system and the UK Met Office was part of the winning consortium.

As a general matter, the NWS is willing to provide a reference at the request of a firm which provides goods or services to NWS. Such references would include a general statement regarding whether the goods or services were provided in a timely manner and were acceptable. We are unaware of any specific request for a reference from any of the U.S. bidders on the Thai contract.

15. The more sophisticated the weather computer models become, the more dependent they are on initializing with a data set that is as good as it *can be. Yet everyone who deals with observed weather will agree that in recent years the quality of our observed data set used to initialize the models has been steadily deteriorating. The government is spending billions of dollars to acquire new hardware and software to develop and run these models, but the same emphasis is not being given to ensure that the initial data put into the models is absolutely top quality. Quality control is an extra duty for most if they get time to do it. Training of cooperative observers is also an extra duty for various NWS regional headquarters after they accomplish all their higher priority duties. I'm not aware of anyone with an on site inspection responsibility and authority to ensure data quality. It's my belief that the government really has their priorities backwards on this issue. It has been estimated that nationally about $2.2 trillion is at risk each year in weather and climate sensitive components of the gross domestic product as determined from the Bureau of Economic Analysis data. For example, in winter a large portion of that risk is due to snowfall which is no longer measured by government automated observing sites. When commercial industry has $2.2 trillion at stake each year, why can't we pay more attention to the quality of data that feeds our multi-million dollar models? Why can't we create a function in a government agency that has the responsibility and authority to ensure the observations are the best they can be?*

I had the opportunity to visit the National Center for Environmental Prediction (NCEP) recently and I asked, as usual, a lot of questions. I asked one of the team leaders how they quality control the data they use as well as data going into the models and for the most part I was satisfied with the answer. Then the individual added that this quality control is an extra duty and they never have time to look at all the errors their software flags as questionable. Then he added that when the weather is changing most rapidly, their data error counts are highest and because they are so busy with other, higher priority tasks in those circumstances they rarely ever have time to do the data quality control (manual editing). When asked why they operate that way the response was there just aren't enough people. If these statements are true, the logic trail doesn't track. Bad data getting into an analysis or forecasting process or modeling effort can only result in a less than desirable output quality. So, first priority must be to ensure the best possible data is fed into every process or model. Or, in other words, only after the data quality is assured should any attempt be made to make a forecast or initialize a model.

Questions 15 and 16 both deal with various issues regarding quality control of observational data, further uses of the data for numerical weather prediction, and archival use for later analyses. The answers have been combined following Question 16 below.

16. The NWS has decided that (probably because of low funding) they *would depend more on cooperative observations. So, during a visit to NCEP, I asked a senior person in that facility who had responsibility to train cooperative observers, as well as check their equipment sighting and calibration. I was told that the regional center forecasters have this responsibility and it is an extra duty very low on their priority list of things they need to accomplish routinely. If this is true, it is reasonable to conclude that the issue of cooperative data quality may receive very little attention. If this is true, this is another example where priorities are exactly opposite to what they should be.*

My recommendation is that the NWS obtain the funding to properly deal with this issue of data quality. It may take tens or hundreds of millions of our tax dollars to do it right. If so, that's what should be requested as we cannot ignore this issue anymore. The public won't allow it much longer.

I'd suggest that there should be a whole section in the NWS or even some separate agency whose function it is to ensure data quality from start to finish. That means training cooperative observers, physically checking and calibrating equipment, creating procedures and algorithms for manual and automated repair of all errors before they get into forecast processes and models. I am aware that the National Climatic Data Center is doing a lot to quality control data they archive, but that it is also putting the data quality issue at the end of the process rather than at the beginning where it should be.

Properly dealing with data quality from the start may actually be the greatest improvement the NWS could make to bring both observation and forecast quality to the next level of excellence. I believe this is an issue the public will want to support especially if they are given the opportunity to understand what the real benefit can be.

Questions 15 and 16 touch in some way on essentially all of the weather information acquired, produced, distributed and retained by the National Weather Service (NWS) and its parent agency, the National Oceanic and Atmospheric Administration (NOAA). A complete answer to all of the issues raised is beyond to scope of this exercise. To help organize the response, each of the following topics is discussed briefly below:

1. Observations from systems operated by NWS/NOAA,
2. Observations acquired by NWS/NOAA from systems operated by others,
3. Data assimilation for numerical weather prediction, and
4. Retention and analysis at NOAA Data Centers.

These should cover the main points of Questions 15 and 16.

<u>Observations from systems operated by NWS/NOAA.</u> NWS/NOAA operates many observing systems based on land, air, sea, and space platforms and using both in situ and remote sensors. These systems provide environ-

mental information, often to meet multiple purposes, designed to meet standards for accuracy, precision, reliability, coverage (e.g., network density), etc., established for each system, with NWS/NOAA maintenance and oversight procedures designed to assure standards continue to be met. It is a challenge to balance system costs, both initial and ongoing, and the value of the information produced. Technological change continually affects these trade-offs.

Since the question is focused primarily on one of these NWS/NOAA observing systems, the Cooperative Observer Program (COOP) Network, our answer uses the COOP Network as an example of the diverse observing systems operated by NWS/NOAA.

The COOP Network has its roots in the early history of the country—the most prestigious award in the COOP program is named for Thomas Jefferson who was a volunteer weather observer. Volunteers provide space for observing systems and are trained by NWS to operate equipment maintained by NWS, with annual site visits to check equipment calibration and siting. Staff at NWS Weather Forecast Offices have specific responsibilities to carry out cooperative observer training and site visits. NWS has had a plan for improving cooperative observations since 1993, and received National Research Council endorsement of the overall technical approach proposed in the plan "Future of the National Weather Service Cooperative Observer Network," Section 4.

NWS's plan to substantially refurbish the COOP Network includes systematic quality control, from data collection to archiving and dissemination. For automated cooperative observations transmitted in real time, well-tested quality control procedures used on existing automated systems will be adapted to the COOP Network. Automated procedures will alert network technicians to potential problems.

The modernized COOP Network will utilize approximately 8,000 sites equipped with temperature and precipitation sensors to provide the dense temperature and precipitation observations necessary to track climate variability at regional and local levels. Approximately 1,000 sites in agriculturally sensitive areas will be further equipped with soil moisture, temperature, and evaporation sensors to monitor drought and the water cycle. The high-density, real-time data will improve NOAA's ability to forecast short-term (24-hour to 2 weeks) temperature and precipitation, including floods. The network will augment existing capabilities with a new source of real-time information for exploitation by the private sector, including the emerging weather risk management sector.

To estimate possible human effects on climate, climate records have to measure long-term trends with high reliability and precision. To meet this goal, NOAA has proposed a Climate Reference Network (CRN) to complement the modernized COOP Network. Both projects were originally conceived as part of a coordinated interagency plan to simultaneously meet climate monitoring needs and repair and upgrade the existing COOP Network.

The CRN will utilize approximately 250 paired sites equipped with a suite of instruments to provide highly accurate, long-term tracking of continental scale climate change. The CRN will provide continuous, highly accurate near-complete measurements of the surface energy balance that meet the exacting requirements of the meteorological and hydrological research community. The daily data will also provide the baseline measurements for calibration of the COOP Network and other observing systems. CRN sites will be carefully selected to best represent the climate regions of the United States and minimize the potential for human-related effects on the sites.

The modernized COOP network will provide the hourly temperature and precipitation data necessary for short-term forecasts as well as local information for inclusion in the climate record. While the CRN will depict each of its 250 sites with great detail, it does little to capture the regional and local nuances that the 8,000 site modernized COOP Network will depict. The detailed information from the CRN, however, will be useful for calibration of the less detailed, but more expansive COOP Network. The two systems will thus work together to form a comprehensive and detailed climate and weather record for the United States. Within the President's FY03 budget, the COOP modernization initiative will receive funding to modernize 200 COOP locations in the southeastern United States. A plan is being developed to fully modernize the COOP Network over the next six years.

The interplay between the characteristics of the COOP Network and the CRN can be seen as an example of a larger principle—diversity in observing networks provides an opportunity to strike a more efficient balance between observing system capabilities and costs. As another example, the question notes limitations in snow reports from NWS/NOAA automated observing stations. These automated systems provide continuous reports of observations critical to aviation safety and other purposes, but, for now, the most effective way to provide snowfall, snow depth and other selected weather elements is through manual observations by trained observers. NWS is committed to provide the necessary initial training and continuing education now and into the future in the context of the COOP Network modernization.

Observations Acquired by NWS/NOAA from Systems Operated by Others. Although NWS/NOAA operates extensive and diverse observing systems, significant amounts of the data used to forecast weather and climate come from external sources. These external sources are themselves diverse, including international information sources based on agreements reached through the World Meteorological Organization, and domestic sources from many cooperators and providers. Although NWS/NOAA cannot directly control information provided voluntarily by cooperators, many cooperators work closely with us on data quality issues and some adopt NWS/NOAA standards to varying degrees. It would be prohibitively expensive, and in some cases impossible, to replace these external information sources with sources under NWS/NOAA control, which means NWS/NOAA will always have to assimilate information from both internal and external sources to support numerical modeling.

Data Assimilation for Numerical Weather Prediction. Quality control (QC) is an integral part of the processing of meteorological data used in numerical weather prediction models. Automated QC techniques are a large part of the processing of the nearly 300,000 conventional reports (surface, marine, balloon, aircraft) and 1.9 million satellite observations that flow into the NWS each day. As the forecast modeling and data assimilation systems have become more sophisticated, analyses have become less sensitive to data errors that pass QC. In addition, the data quality and coverage are much better in some areas, so that any questionable data are less likely to pass the QC or have substantial impact on the analyses and forecasts. For example, high quality automated aircraft reports have increased substantially in the last several years and complement improved QC of rawinsonde (balloons released with meteorological instruments) data. Observing systems operated/managed by NWS are subject to various calibration checks to assure data quality and integrity (see above). Separate automated quality control algorithms have been developed for many of the different types of data, some of which are quite sophisticated and attempt to correct commonly occurring types of errors. Other automated techniques involve checking for gross errors, for horizontal and vertical consistency, as well as consistency in time. Automated techniques also compare data to short-term forecasts valid at the same time as the data. All data types are subjected to a final automated check in which each observation in turn is omitted from an analysis and then is compared to the resulting analyzed value and judged on its fit. The decision of whether to reject an observation is based on the results of all the checks, not just one. Manual (interactive) quality control is performed on some of the data that are highlighted by the automated techniques. Meteorologists use satellite pictures, information from the reporting stations and their meteorological expertise to decide whether to override the automated quality control procedures. NWS takes seriously its duty to assure data are adequately checked for accuracy. These data are essential input for all numerical weather and climate forecast models which provide guidance for the preparation of all NWS products.

Satellites already provide over 80% of the observations used in numerical model assimilation. For example, improved satellite data has already enhanced model forecast skill in the Southern Hemisphere substantially. The

National Polar-Orbiting Operational Environmental Satellite System (NPOESS) along with other planned satellite programs will produce a huge increase in satellite data. Recognizing the challenges associated with satellite data assimilation, NOAA and the National Aeronautics and Space Administration (NASA) agreed to establish and support the NASA/NOAA Joint Center for Satellite Data Assimilation (JCSDA) to optimize the use of research and operational satellite data in operational numerical prediction systems and to shorten the time between instrument launch and the operational use of the data. JCSDA exemplifies NOAA's commitment to advanced data assimilation in general.

Retention and Analysis at NOAA Data Centers. NOAA operates several data centers which have responsibility for long-term retention and analysis of environmental data. The question notes the role of one of these centers, the National Climatic Data Center (NCDC) in data quality control. NCDC has a statutory mission to describe the climate of the United States, and NCDC acts as the nation's scorekeeper regarding the trends and anomalies of weather and climate. NCDC's data and products fulfill needs ranging from building codes to power plant and space shuttle design. The archives at NCDC include both NOAA and external information sources from around the world, and NCDC is a world leader in methods for data post-analysis and quality control. NCDC's emphasis on quality control is essential to its mission, and will continue even though future data systems become more accurate and more complete.

In summary, NOAA/NWS is committed to providing the best possible observation record within the available resources. The diversity in observing systems is exploited by increasingly sophisticated quality control processes. The continued long-term trend resulting in more accurate numerical weather predictions is a testament to the overall success of this approach. The question implies NOAA/NWS should invest more in observing systems to assure higher quality observations and reduce the demands on data assimilation and quality control in later processing steps. Spending more money on any particular observing program normally results in better data; however resources are always limited. Balancing the strengths within the resources available for any one program against another allows NOAA/NWS to get more efficient and accurate overall results. Opportunities to leverage observations from sources external to NOAA increase the diversity of observational data types while increasing overall efficiency.

17. NIDS Transition. The private sector invented color radar, remote transmission of color radar images and radar networking (i.e., collecting the data from a number of radars and assembling the data into a mosaic). In 1991, four private sector companies, under contract from the National Weather Service, connected to each and every one of the NWS's new WSR-

88D radars. In 1999, the NWS decided to discontinue the contracts with the private sector companies for radar distribution.

In 1999, the private sector companies were already linked to every NWS WSR-88D radar with a direct connection. Each of the NEXRAD Weather Information Dissemination System (NIDS) providers had its own phone lines, own modem and own hardware. The only single point of failure was the radar itself. The network was fast and extremely reliable as indicated by independent studies conducted by the Federal Aviation Administration and others.

When the NWS made the decision to distribute WSR-88D data on a no-cost basis, it decided to do the entire job itself rather than contracting it to the private sector and taking advantage of the proven infrastructure already in place.

The new NWS radar network is a subset of its AWIPS network. It has multiple single points of failure (including the network hub in Silver Spring). It is slower than the NIDS private sector network (less than 2 sec. vs. 25 sec. on the NWS's best days) with delays of more than one minute and missed data common occurrences during major severe weather outbreaks —when it is needed the most.

While our company has lost revenue from the Weather Service's decision to distribute radar data free (on the order of $3,000 per month), I am 100% in favor of the NWS making its radar data available free of charge, as I believe all government data should be free to any citizen or taxpayer.

But, a better solution existed. Rather than the NWS trying to create a network from scratch, a competitive contract should have been awarded to one of the NIDS or other private sector company to provide this service, or, better still, two companies for greater redundancy.

The Commercial Weather Service's Association has written position papers supporting the National Weather Service's attempt to upgrade its network and provide redundancy. However, it will likely be 2003 before these problems are fully resolved.

Please refer to Ed Johnson's presentation at the second committee meeting for background on the history of NWS radar data distribution.

During 1990, NWS entered into an agreement with private vendors for each to collect and distribute radar products from up to 154 NWS, Federal Aviation Administration, and Department of Defense radar sites. The Next Generation Radar (NEXRAD) Information Dissemination Service (NIDS), provided by each of the private vendors, began operation in 1992 and was the sole source of radar products to the other government users and the private meteorological community. Non-government users of the radar products were required to acquire them from one of the private vendors. Each user had to sign a contract with a vendor to receive the products, which typically restricted their redistribution rights, and to pay the associated fees. The NIDS vendors themselves incurred costs in excess of $1 million annually to support telecommunications and other costs associated with gathering the data.

In 1999, the NWS began an effort to develop a system design and prototype for the central collection and distribution of radar products to replace the NIDS agreement. This was based on a newly validated NWS requirement for the central collection of radar data in order to improve the performance of its numerical forecast models.

The NWS estimated the cost of two approaches for central collection:

- Increase the bandwidth of the existing operational Advanced Weather Interactive Processing System (AWIPS) Wide Area Network (WAN) used by the NWS for its internal collection of observations, forecasts, and warnings to also centrally collect the radar products.
- Contract for a commercial solution to centrally collect the radar products.

In September 1999, NWS compared the cost and benefits of the two alternate approaches, and selected the option to use the AWIPS WAN, primarily due to the significant cost avoidance by leveraging off the operational AWIPS WAN infrastructure already in place at all NWS offices responsible for the radar product collection.

With regard to timeliness of service, an operational demonstration of the new Radar Product Central Collection/Distribution Service (RPCCDS), which included participation from the private sector, was conducted between September 19 and October 18, 2000. The 30-day demonstration provided objective measurements of the performance of the RPCCDS which significantly exceeded the preestablished criteria: an average of 636,000 products were collected each day from the 154 radar sites with a 99.1% reliability, in an average of 50.3 seconds from the time of collection to distribution to all users. The RPCCDS continues to exceed its preestablished performance criteria; for 2001 the system had a 99.7% reliability and end-to-end collection and distribution of the radar products was completed in an average of 40.2 seconds.

With regard to reliability of service, the hardware and WAN used in the AWIPS system for the collection of the radar products at the field offices and the Network Control Facility (NCF), as well as the radar servers themselves, are highly redundant. The NWS is in the process of putting in place a backup NCF to be collocated with the operational backup AWIPS Master Ground Station, in the event of a catastrophic failure of the NCF in Silver Spring, Maryland. The backup NCF with redundant communications connectivity is scheduled to be operational in September 2002.

> The RPCCDS implemented by the NWS offers users several benefits: Users now have multiple radar product access options. The operation of the RPCCDS and termination of the NIDS allowed the NWS to begin offering real-time Internet access to a subset of WSR-88D products in a user-friendly, display-ready, format. Former NIDS vendors now subscribe to the RPCCDS broadcast services, avoiding their previous central collection costs. Additional private vendors subscribe to the RPCCDS broadcast service, thereby increasing competition and offering users a broader range of commercial options of acquiring radar products and value-added commercial services.

18. We believe there is a significant opportunity to enhance the performance and cost-effectiveness of the National Weather Service (NWS) by reconsidering the way the underlying infrastructure for the observing, communication, and data processing systems are operated and maintained.

The National Oceanic and Atmospheric Administration (NOAA) and the NWS operate and maintain several networks of observing systems such as the NEXRAD radar, NOAA Satellites, Automated Surface Observing Systems (ASOS), upper-air observation systems and Wind Profiler radar, and integration systems such as the Advanced Weather Information Processing Systems (AWIPS). Due to the decentralized structure of NOAA and the NWS, responsibility for operation and maintenance of these assets is distributed to a combination of local, regional and national organizations. A typical example of this process is the NEXRAD radar. The Radar Operations Center in Norman, Oklahoma, has responsibility for centralized engineering, meteorological and software support. This responsibility is for all end users, including NWS, the Department of Defense and Department of Transportation sites. However, operation of the radar sites and routine maintenance activities are performed at local NWS offices with more complex maintenance functions performed at either the regional facilities or National Logistics/Reconditioning Centers. These activities, as well as configuration management, are administered and primarily performed by government personnel.

Over $40 million dollars was budgeted in FY 2001 for NEXRAD operation and maintenance. Although the NEXRAD example was cited, a similar approach is used for the other observing and forecast system assets. Although approximately $100 million is allocated for systems operations and maintenance (O&M) in the NWS FY 2001 budget, a significant percentage of the over $500 million spent from Operations and Research is used to fund local forecast office activities, such as routine system operation and maintenance.

We believe there is an opportunity to consolidate much of the O&M activity for the NWS and NOAA observing and forecasting systems. This consolidation would provide an opportunity for private sector involve-

ment. Over the years, it has been demonstrated that these types of manpower-intensive functions are performed more effectively by the private sector, by offering enhanced performance and lower costs to the government. This private sector O&M approach would also benefit NOAA and the National Weather Service by allowing them to focus on their core missions, which include more timely and accurate forecasts for the public. An expanded role for the private sector would also streamline the process for the introduction of new technologies, thus allowing the NWS to realize its strategic goals in a shorter time frame.

In summary, we believe that operation and maintenance of the national meteorological infrastructure provides a significant opportunity for redefining the public-private partnership. This approach is consistent with existing, proven public-private initiatives in the U.S. and will result in better services to the public and greater value for the taxpayer.

Since the 1950s, OMB Circular A-76 has called for those activities that are not inherently governmental to be performed by the private sector whenever economically justified. Over many years, the National Weather Service (NWS) has adhered to that policy and conducted many studies under OMB Circular A-76. Currently, NWS has 555 positions performed under contract by the private sector at a $50 million annual cost, including about 370 that provide maintenance of infrastructure (largely in NOAA Weather Radio, data buoy support, radar engineering support and upper air observations.)

Each year, NWS and NOAA are required by the FAIR Act to conduct an inventory of positions to determine which positions should be classified as Commercial Activities (CA). The inventory is divided between those CA positions that are inherently governmental and are retained in house, and those CA activities that are subject to the A-76 cost comparison process. In 2001, NWS's inventory totaled 619 CA positions (in addition to the 555 already contracted out). Within the 619 positions are some positions which provide maintenance of infrastructure. NWS's inventory was approved by NOAA, the Department of Commerce and OMB. In November 2001, OMB published the government-wide FAIR Act Inventory for public comment. No challenges were received from the public or private sector to the NWS portions of the inventory.

President Bush has directed that all agencies consider strategic sourcing of 50 percent of their CA positions over the next five years, with 15 percent being studied by the end of 2003. NWS has identified nine A-76 studies, covering 329 positions, to be performed at the rate of two per year over the next several years to meet the President's goal. The first study is under way and a second will be started early next fiscal year. These studies will cover all CA maintenance positions that are not considered inherently governmental.

> While NWS believes there are opportunities to look at private sector provision of maintenance services, we must also look at the impact on the provision of our core services. NWS's field electronic technicians are an integral part of our operational teams at our Forecast Offices. Likewise, some software development efforts are for broad based applications that can be reviewed for private sector competition, while other software activities are not amenable to contracting out.
>
> Additionally, cost comparisons of the past have not always shown savings by transferring functions to the private sector. In the area of large systems maintenance, NWS conducted A-76 reviews of both NEXRAD and ASOS in the early 1990s. For NEXRAD the government maintenance alternative cost avoidance was projected at $1.8 million per year over the 20- year life-cycle. For ASOS, government maintenance alternative cost avoidance was projected a $1.1 million per year over a 15-year life-cycle.
>
> In summary, NWS is ready to examine maintenance issues with the private sector, as we have in the past, and, where it makes mission and economic sense, partner with the private sector.

19. It appears that the NWS is no longer simply providing via the Internet weather information that they have developed to carry out their core mission. The agency appears to be further tailoring information for specific users and uses and specific kinds of businesses and even creating an "Ask the Meteorologist" feature to provide "private consulting" at government expense and in competition with the commercial weather industry.

> Features on NWS sites such as "Ask the Meteorologist" are intended for purely educational purposes to answer general questions including those about weather phenomena, how to understand NWS forecasts and warnings, etc. NWS has reviewed a large sample of the questions and answers under "Ask the Meteorologist" and identified none which could be considered inappropriate (e.g., provide private consulting). No examples of arguably inappropriate questions/answers have been brought to our attention.

20. The Wichita, Kansas, NWS office has launched a personalized weather forecasting web site. The National Weather Service office sent a personal message to 7 television stations, 5 radio stations, 2 various businesses and 29 government and other agencies (43 in all) soliciting them to use this new NWS service. At least 9 of these are customers of 9 different commercial weather companies. Obviously, they have contacted each one of these companies on an individual basis, something the NWS is not supposed to do.

This is in direct competition with the commercial weather industry and can have only negative impact on those in the commercial weather industry that provide these kinds of services, either by the Internet or more tradi-

tional means. And, appearing to be in violation of federal law and policies, these actions chill the opportunities for weather companies and small businesses in the weather marketplace.

As described above, the NWS had a two month public comment period on the NWS Web redesign. The e-mail from the Wichita office was sent during this comment period to 50 addressees external to NOAA who might be affected by changes to the Wichita office web site. The addressees were 35 emergency managers (30 local, 4 state level, and one Federal Emergency Management Agency contractor) with responsibilities for parts of the Wichita office's county warning area, and 15 media employees (8 TV and 7 radio) at stations with coverage of some part of the county warning area of the Wichita office. This outreach effort to NWS partners in the emergency management community and to critical local media which carry NWS forecasts, watches and warnings was in no sense an effort to solicit customers away from commercial information suppliers. NWS is generally unaware of any commercial service arrangements which emergency managers and the media may have, and has no desire to interfere with or influence these arrangements.

21. The National Weather Service is directly entering the commercial weather business by soliciting existing customers of the commercial weather industry through the creation of specialized products and services for the use by newspapers (see Dodge City, Kansas, NWS Forecast Office web site). I believe that this activity is prohibited under National Weather Service policy, especially the 1991 Public-Private Partnership Act and a variety of federal laws. Through design or otherwise, we appear to have rapidly growing activity by the National Weather Service that creates competition with the commercial weather industry of the United States, offering free services to specific users and industries at taxpayers' expense.

On April 4, 2002, Ms. Maria Pirone, President of the Commercial Weather Services Association, sent a letter to NWS complaining of the "Weather for the Newspaper" site on the Dodge City, Kansas, Weather Forecast Office web site. A similar letter from Mr. Barry Lee Myers of AccuWeather, Inc. was sent on April 11, 2002. The site was immediately discontinued, even though all of the information linked to that particular Web page was fully appropriate and otherwise publicly available NWS information. This was done to avoid confusion as to NWS policy. The NWS has never provided, and does not intend to provide, customized print-ready copy to newspapers or other specialized media outlets. NWS information is available to all users on equitable terms under the applicable legal principles outlined in the Paperwork Reduction Act of 1995, OMB Circular No. A-130, and other applicable authority. NWS provided prompt responses to both these letters.

22. In our complaint letter to the NWS, we pointed out several websites and practices with what appear to us to be clear violations of the spirit, if not *the letter of the NWS Public-Private Partnership Policy. The NWS response does not really answer the question of whether these practices violate the policy. Rather, it simply attempts to justify the practices by pointing out similar practices on other government web sites. This response begs the question of what applicability NWS policy has vis-à-vis the Internet.*

It appears that the NWS cites the Public-Private Partnership Policy as fact in public testimony, but ignores it whenever it suits their fancy. We want to be clear that we do not oppose the NWS use of the Internet for dissemination activities. However, we do find it objectionable when the NWS, with its enormous resources, feels compelled to enhance their Internet offerings by adding features and capabilities designed to compete with commercial web sites (such as zip-code weather and other navigation enhancements). There are plenty of commercial web sites that offer similar data to the public, for free. Who is the NWS attempting to serve with these sites?

The NWS general policy position regarding providing information over the Internet is provided above. NWS's response to the "complaint letter" which this item appears to address is repeated below for reference:

> . . . the "city/state/zip" search function . . . allows for easy access to local forecasts and warnings anywhere in the country. This feature, along with other improvements in website navigation, is becoming ubiquitous on commercial websites. It is likewise being implemented routinely on many government websites, including the Administration's premier "one stop" website, http://firstgov.gov, as well as on Congressional sites. A few examples are the U.S. House of Representative's website, http://www.house.gov/house/MemberWWW.htm; the Environmental Protection Agency's "EnviroMapper," http://www.epa.gov/enviro/html/em/index.html; the Census Bureau's "Gazetteer," http://www.census.gov/cgi-bin/gazetteer; and the Department of Energy's "Insulation Fact Sheet," http://www.ornl.gov/~roofs/Zip/ZipHome.html. The search features on all of these sites conform with directions from OMB Circular A-130, discussed above, to make effective use of ongoing advances in information technology to promote the utility of government information to all citizens.

The "city/state/zip" search function is also an important component in making information on government web sites more accessible to persons with disabilities. Section 508 of the Rehabilitation Act directs all federal agencies to provide, as much as possible, equivalent access to taxpayer-funded information for persons with disabilities. Clickable maps for locating information are difficult to navigate by the disabled, particularly the vision impaired, who need to use screen readers. The careful placement of a city/state/zip navigation feature on the page ensures that people needing to use screen readers can find a forecast about as easily as a non-disabled user can. Meeting the accessibility requirements was an important consideration in NWS's web page redesign, and NWS is proud of the accessibility award the design has already received.

As one of the hundreds of positive public comments on these enhancements stated:

> I like the change you are going to implement. My son and I are both disabled and transportation by ambulance is a necessity. Your consideration of the disabled is welcome and appreciated. We live in Whiting, New Jersey, in a senior village and isolated from the mainstream of many necessities like medical appointments, food shopping, etc. We must rely on other people for help and the volunteer groups are far and in between. Thank you for easier weather info!

NWS web sites are designed to provide convenient access to all users on equitable terms under the applicable legal principles outlined in the Paperwork Reduction Act of 1995, OMB Circular No. A-130, and other applicable authority. The city/state/zip search and other navigation features of NWS web sites are designed to meet this objective, not to compete with the private sector.

23. It appears that the weather for the newspaper page on the Dodge City, Kansas, office has been discontinued. However, the NWS has not explained why they have discontinued it, what their overall Internet strategy is, and where this fell within it.

See response to Question [22], above.

24. My area of interest is very narrowly focused: those text-based severe weather warnings, watches, and advisories issued by the National Weather Service and intended for public dissemination—tornado warnings, severe thunderstorm warnings, flash flood warnings, etc. My concerns involve communications and dissemination issues exclusively, as opposed to the meteorological and/or hydrological content of these NWS "products."

Since 1994, at NWS request, my company has provided the NWS with monthly logs detailing errors and exceptions (i.e., irregularities) we have observed in the coding and/or formatting of NWS severe weather products. These logs, provided pro bono, clearly establish that over 50 percent of all NWS severe weather products contain coding and/or formatting errors/exceptions that impede, and often prevent, timely automated (i.e., computer-based) dissemination directly to the public.[1]

Primary among these dissemination issues is that severe weather products are neither coded nor formatted consistently. Even where NWS policy is clear and unambiguous, product coding and/or formatting for identical product types often varies dramatically among the NWS regions, among various NWS offices within each region, and even within individual NWS

[1] A sample of these logs, which exceed 200 pages, was attached.

offices. It is equally clear that the NWS does not have in place any kind of real-time (i.e., bounded time) quality monitoring and/or quality control function to identify and/or correct coding errors, formatting errors, or what one manager at NWS Headquarters (NWSH) has glibly described as "creative diversions from policy."

Conversations with individuals at NWSH who are charged with developing important NWS policy indicate the following:

a) They have no knowledge of the years of NWSH development effort that preceded them on these major policy matters. It is unclear whether this information is unavailable to them or just that they found it either unusable or too much trouble to organize.

b) In one known case, a requirements document was revised to conform to the software implementation, i.e., the way the software development programmers had actually coded it—a software implementation that did not conform to preceding policy drafts. This tends to confirm a long-held suspicion that this practice—changing the policy document at the last minute to match the software implementation—may be a common occurrence.

c) There is often a lack of knowledge of previous NWS practice and of the existence of national and international standards. This often results in staff inventing their own unique coding forms, even when appropriate FIPS, ANSI, and/or ISO standards already exist, are well known, and are well documented.

This example provides extensive documentation of problems with the quality of short duration (tornado, severe thunderstorm and flash flood) National Weather Service (NWS) warnings. NWS is in direct communication with the individual who provided these examples to work out the details of remedial actions. The answers provided here will focus on root causes for NWS data quality problems and actions taken to reduce them. The NWS values the quality control feedback our private sector partners provide—especially when it includes sufficient detail to support thorough problem analysis, as is the case here.

Many of the examples of data quality problems with NWS warnings are the result of discrepancies between the header and the body, of these products. In simple terms, NWS warnings are made up of a header, which contains coded information identifying the type of warning and the times and places for which the warning applies, and a body, which provides further details regarding the threat. Discrepancies between the header and the body can be very serious—for example, if an NWS warning includes a particular county in the body of the warning, but fails to include the county in the header, a cable TV system serving the county might fail to interrupt programming with a crawler for the warning. Over the years, such automated use of information in the headers has increased, and the information content of NWS headers has been increased to support these services better. As a result, discrepancies between the header and the body of NWS warnings have become both more likely and more important to avoid.

NWS forecasters use a variety of automated systems to support rapid production of short duration warnings. The examples of data quality problems with these warnings have uncovered three general shortcomings in this complex man/machine system, and NWS is taking action to correct each of them.

First, a careful review of NWS policies and procedures which provide instructions for NWS forecasters regarding exactly how NWS warning products must be produced and formatted uncovered areas where greater precision is needed to ensure NWS produces consistent, machine-readable warnings. NWS Directives System Instructions 10-511 (Weather Forecast Office Severe Weather Products Specification) and 10-922 (Weather Forecast Office Hydrologic Products Specification) update the policy for short duration warnings and provide NWS managers and forecasters with clear and concise instructions regarding short duration warning procedures and formats (see http://www.nws.noaa.gov/directives/). NWS has worked with our private sector partners, including the individual providing the examples of data quality problems, to ensure these instructions reflect appropriate standards and are complete, clear, and accurate. Efforts have also been undertaken to ensure that NWS software systems are consistent with these instructions.

Second, discrepancies between the header and body of NWS warnings most typically happens when NWS forecasters manually edit the body of warnings created by automated formatting software but fail to accurately edit the header as well. These manual editing steps can be important to warning accuracy, but NWS needs to ensure the resulting product is consistent with all product format standards. To provide this assurance, NWS will implement a software based Quality Control program for short duration warnings in mid-2003. This program will check warnings for proper coding and format prior to dissemination. NWS partners and customers made significant contributions to the coding and format requirements for this Quality Control program.

Finally, NWS leadership continues to stress quality control to the forecasters at our Weather Forecast Offices. Greater management and forecaster diligence to avoid quality control problems with NWS warnings is already showing results.

The NWS values the quality control feedback our private sector partners and customers provide. We have a common goal to provide the best possible warning services, and we are working together to address the detailed concerns raised in this item.

25. At the committee's request, our company has tracked errors in NWS data. Attached are nine representative examples involving inaccurate reports, various adjustments, contemporaneous reports that are of questionable accuracy, and inaccuracies creeping into the climate record.[2] *While we do not normally track these kinds of errors we see them virtually every day. In fact we have a team devoted to reviewing weather statistics to try and create the greatest accuracy for newspaper clients where we face the daily challenge of putting into print accurate information, even though the daily record and climate record as reported by the NWS often contains discrepancies.*

Case 1. *In element A, the National Weather Service Summary reports low temperature for January 9, 2002, to be 22 degrees at 10:49am. This report was issued as of 4:42 pm January 9, 2002, as per element C. Attached are decoded hourly reports from the official surface observations (element B) which shows that the temperature, on the hour, had not dropped below 40 degrees.*

Case 2. *In the National Weather Service Max/Min Temperature and Precipitation table (element A), Doylestown reported 0.26 inches of precipitation in the 24 hour period ending at 7am. Our company's decoded observations (element B) indicated no precipitation had fallen during that 24 hour period of time although precipitation amounts were reported and decoded (element C). The previous day, snow fell at this location (element D). A typical, known error with ASOS equipment is a melting of snow long after the storm has ended and the equipment reporting it as new precipitation when none actually occurred. These should be caught, but the records from the National Climatic Data Center show the 6XXXX code indicating precipitation (elements E and F). The summary for the data from NCDC that goes into the official records indicates hourly precipitation (element G) and a 24-hour total of 0.26 inches of precipitation (element H). Even though this is a preliminary summary, it is unlikely to be caught and is inaccurate.*

Case 3. *Incorrect data is entering the climatic data stream due to erroneous reports from ASOS equipment. This hourly report from Mt. Pocono, PA, on December 15, 2000, shows 0.09 inches of precipitation being re-*

[2]The logs themselves, which exceed 50 pages, are not included in this report.

corded (element A) from a clear sky (element E). The summary of the unedited surface weather observations also shows the 0.09 of an inch (element B). The Local Climatological Data summary from NCDC for December 2000, indicates that the water equivalent of 0.09 fell on the 15th (element C) without any significant weather being reported that day (element D). The frozen precipitation from the day before melted on the 15th giving the false reading, and 18 months later, the error still exists in the records kept by the official agency charged with keeping climatological data.

Case 4. Precipitation in areas that do not normally receive substantial rain draws a high level of focus. In the newspaper industry, the deadlines are tight between when the information is collected and when papers must be published, especially along the West Coast. This leaves little time to sort through conflicting reports. The 4:27pm PST report from the National Weather Service office in San Joaquin Valley indicated that 0.18 of an inch of rain fell in Fresno on January 27, 2002, as of 4pm local time (element B). The hourly reports clearly indicated that 0.01 of an inch fell before midnight local time and that the total should really be 0.17 of an inch (element C). When the midnight report—issued at 12:27am local time—was released, 0.15 of an inch was the official measurement for the day. This amount does not show up anywhere unless any precipitation before 4am local time is thrown out (element D).

Case 5. The next day's reports from the same NWS office revealed additional problems. Rain totals for the 4:27pm local time report for January 28, 2002, in Fresno indicated that 0.01 of an inch was observed (element A), yet the month to date total was increased by 0.02 of an inch. It was later (4:54pm) corrected to reflect the proper month to date total (element C) based on the actual precipitation for the day (element E). However, the total precipitation for Bakersfield on the 4:27pm report was listed as a trace (element B), which was confirmed by hourly reports (element F). The 4:54pm report changed the precipitation total to 0.16 of an inch increasing the month to date and season to date totals by 0.01 of an inch and increasing the year to date totals by 0.11 of an inch (element D).

Case 6. The 4:26pm local time climate report for Eureka, CA, issued by the National Weather Service on January 8, 2002, indicated that 0.23 of an inch of precipitation fell that day bringing the month and year to date totals to 4.05 inches (element C). The report issued 8 hours later for the entire day January 8, 2002, showed a decrease to 0.04 of an inch of precipitation and a month and year to date total of 3.86 inches (element B). The season to date also was lowered by a similar amount. The report issued by the NWS *at 4:23pm local time the next afternoon (element A) kept the totals at the same level as shown in element B.*

Case 7. The hourly observations showed a high temperature on January 28, 2002, in Akron, OH, of at least 59 degrees tying the record for the day set in 1914 (element C). This was a rather noteworthy event and prompted many calls for interviews. By 5pm, the temperature has already begun to drop and the National Weather Service sent out the climate report at 5:25pm local time. This report indicated that the record had been tied at 4:09pm (element B). This is a non-standard reporting time and, more than likely, represented the official high for the day. However, an update was issued at 9:11pm, about 2 hours after the hourly observations indicated that the temperature had actually gotten to 60 degrees, setting a new record for the date. This update (element A) listed the new high as 60 degrees, but it occurred at exactly the same time reported 4 hours earlier (4:09pm).

Case 8. Equipment in the field can break down on occasion. However, that does not explain all of the unusual reports received from ASOS stations. At Harrisburg, PA, the ASOS at MDT showed 7 mile visibility and a clear sky below 12,000 feet (element A) and then suddenly the visibility dropped to 1.5 miles and rain was reported from the clear below 12,000 foot sky (element B). This same type of event has happened before at MDT (element D) and at many other stations for which we cite the example of Houston, TX, which went from 10 miles to 1.5 miles back to 10 miles in a 50 minute period of time during the middle of the day (element C). In that observation, varying visibility between 0.25 of a mile and 5 miles produced the 1.5-mile visibility. Fayetteville, NC, has also visibility errors more frequently than other stations (element E).

Case 9. South Bend, IN, appeared to receive 0.07 of an inch of precipitation on February 16, 2002, with another 0.01 of an inch on February 17, 2002, as reported by ASOS (element A and B). The National Weather Service climate summary through 4pm local time February 16 corresponded with the hourly observations indicating that 0.06 of an inch had fallen (element C).

The NWS midnight summary, however, changed the value to 0.09 of an inch of precipitation (element D) and kept it the next morning. The February 17 summary as of 4pm local time showed that 0.07 of an inch fell (element E) when the hourly reports indicated that 0.01 of an inch fell. Snowfall was also a problem. The 4pm NWS summary February 16 (element F) listed 0.6 of an inch of snow fell (a 10-to-1 ratio standard estimate). The midnight report kept the 10-to-1 ratio and changed the snowfall to 0.9 (element G). The 7:40am local time report the next morning listed a total *snowfall for February 16 of 0.3 of an inch (element H). The month and season totals were adjusted downward as well. That total was maintained on the report through 4pm February 17 when another 0.7 of an inch was added to the reduced totals (element I).*

This example presents nine representative cases of seeming problems in various National Weather Service observational summaries and in the climate data records maintained by the National Climatic Data Center (NCDC) based on these summaries. A brief discussion of the procedures used to create these summaries is needed to provide a framework to address these cases:

All of the representative cases begin with the Automated Surface Observing System (ASOS) as the initial provider of the information. ASOS continuously monitors the environment and feeds data to NWS Weather Forecast Offices (WFOs). Some WFOs issue an interim climate summary in the late afternoon, derived from an automated ASOS product, to provide an early look at temperature and precipitation information for that day. Each WFO creates and transmits a daily climate summary in the early morning which will include data from the interim climate summaries (if any) for the previous day, updated as necessary given additional information such as Cooperative Observer Program reports (see below).

NWS transmits the daily climate summaries to NCDC where they are collected to form preliminary climate data. NCDC performs further checks and eventual certification of the climate data (with several months lag time), using all available observational data, to create an official climate record.

In the ideal, the ASOS observations would be error-free and representative of actual conditions. Therefore the interim climate summary, daily climate summary, preliminary climate data, and final official climate record would all agree with each other and all reflect the best possible estimate of conditions. As the nine representative cases make clear, this ideal situation is not always met. There are a variety of reasons for this, beginning with the ASOS instrumentation.

Errors in ASOS data are generated in one of two ways:

1. The ASOS fails to perform as designed, experiences known shortcomings in certain instrumented observations, or is out of service; or
2. The ASOS is affected by non-meteorological environmental conditions.

When NWS staff are able to identify these errors, they manually correct data in the daily climate summary (but typically not in any interim summaries) to provide the highest quality information available. Thus, discrepancies and differences in reports occur due to either human intervention to correct ASOS errors or human errors made while correcting ASOS errors. With the above as background, the representative cases can be addressed:

Representative cases 2 and 3 are directly related to the shortcoming of the ASOS heated tipping bucket instrument. As is noted by the questioner, this instrument has known shortcomings in measuring snow. In some cases, snow can accumulate and not be measured until it is melted by warming temperatures. These measurements ("late tips") are then disseminated in the observation. When NCDC performs full quality control processing, checks for these specific situations are made, and when they occur, the data are flagged for further manual review and verification. NCDC can either make a precipitation estimate or mark the observation as missing. NWS recognizes the problems in this area. For some ASOSs, backup observations are available from COOP observers, contract observers, etc. When available, these backup observations are used to correct a faulty precipitation measurement, but for the sites noted in cases 2 and 3 (Doylestown and Mt. Pocono, PA), backup observations are not available. Plans to modernize the NWS COOP network will increase the availability of suitable backup observations. Plans to replace the ASOS instrument itself are also under way (see below).

Representative case 8 has several observations where the ASOS appears to be affected by non-meteorological environmental conditions: The decrease in visibility at observation site MDT (Harrisburg International Airport) appears to be associated with a smoke cloud from Canadian forest fires. There is not enough data to fully explain the situation at Fayetteville, NC, but it appears to be caused by either a condition local to the ASOS instruments or another environmental cause. NWS will investigate the location of this ASOS to determine if the location is adversely affecting the accuracy of observations. The observations from Houston, TX appear to be affected by construction at the airport which created dust interpreted by the ASOS as variations in visibility. In each of these cases, a human observer monitoring the ASOS during the time of the reports attests to the accuracy of the observation, whether the data are automated or edited by the observer.

Most of the representative cases (1, 4, 5, 6, and 9) are the result of inconsistencies due to multiple reports. The data for the interim climate summary uses temperature and precipitation information from ASOS. However, at many NWS offices, including the offices serving Madison (case 1), Fresno (cases 4, 5), Bakersfield (cases 4, 5), Eureka (case 6), and South Bend (case 9), there are alternative sources of reports, primarily COOP sites on or near the airports. If the ASOS is not operating properly or if the data are judged to be incorrect, NWS staff use information from these alternative sources to correct readings or to fill in gaps from the ASOS. The data from the interim (late afternoon) climate summary report is updated with the latest information and finalized in the daily climate summary issued early the next morning. Thus, when data in ASOS reports are compared to updated data in the early morning issuances, discrepancies are apparent.

Finally, the discrepancy noted in representative case 7 is simply due to a corrected report issued by NWS. The temperature value in the interim climate summary was reported incorrectly and was changed via a corrected climate summary report issued 4 hours later.

NWS standard format for climatological reports is defined in NWS Directives System Instruction 10-501 (Weather Forecast Office Statements, Summaries, Tables Products Specification, see http://www.nws.noaa.gov/directives/).

Planned Improvements. NWS is dedicated to providing observational products which are as accurate as possible using current technology and available resources. At the same time, work is under way to improve NWS observational data and services. The ASOS heated tipping bucket will be replaced with an improved All-Weather Precipitation Accumulation Gage (AWPAG) at selected ASOSs starting in 2003, with the planned upgrade completed before winter of 2004-2005. (AWPAG installation plans do not include every ASOS location; in particular the sites noted in cases 2 and 3 (Doylestown and Mt. Pocono, PA) are not planned for AWPAG installation as of this writing.) Many missing temperature readings, which then require gathering information from other sources, are due to limitations in the current technology of the ASOS dewpoint sensor. A new dewpoint sensor which eliminates these problems is being fielded now. Other ASOS improvements are in various stages of investigation and development.

COMMENTS ABOUT NOAA AND ACADEMIA

26. Over the past 10 to 15 years certain U.S. government weather agencies have become more and more active relative to direct competition with U.S. private industry. This competition is especially noticeable from NCAR/UCAR, FSL and the various labs. It is common for these agencies to directly offer products and services to foreign governments in direct competition to U.S. industry or to exclusively join with a single contractor in the U.S. to market one of their "products." I believe that these practices either are, or should be, prevented by law. U.S. industry pays the taxes that enable these organizations to develop software and equipment for the common good, not for use against the organizations that enable them to exist. Exclusive links with one contractor are just that—exclusive. If a U.S. government agency has code or hardware that can be marketed in some form, then why *should only one U.S. company be allowed to market it? That certainly is a disadvantage to the other contractors. Finally, while the UK MET and other national weather services are attempting to become "commercial," it was my understanding that the U.S. government was not on the same path. Why then do the U.S. weather agencies charge for software that can be exploited commercially? One would think, if the software is releasable, that it should be released freely to U.S. industry for use by U.S. business and to help U.S. private industry compete on a more even footing with UK MET (and others) who are trying hard to eliminate the private weather sector in the U.S.*

[This comment could not be directed to a specific individual, thus no response is given.]

27. As recently as October 24, 2001, the National Oceanic and Atmospheric Administration (parent agency of the National Weather Service) announced its new "Environmetrics" program. See http://lwf.ncdc.noaa.gov/oa/climate/research/environomics/ environomics.html.

In this program, NOAA and the National Weather Service tie various meteorological parameters to agricultural output and to residential heating demand.

For many years, commercial weather companies as well as meteorologists employed by private sector companies (such as Smith Barney, E.F. Hutton and others), have created various systems for relating meteorological parameters to economic output. The policy clearly defines this as a private sector activity:

> *c. The private weather industry is ideally suited to put the basic data and common hydrometeorological information base from the NWS into a form and detail that can be utilized by specific weather and water resources-sensitive users. The private weather industry provides general and tailored hydrometeorological forecasts, and value-added products and services to segments of the population with specialized needs.*

The National Climatic Data Center has a long history of collecting, quality controlling and analyzing climate information. This history includes an active Climate Monitoring program focused on providing information to the U.S. Administration and the general public on national and regional trends of climate events that impact the nation's economy and society. Indices have always been a vital part of this program. Drought indices such as the Palmer Drought Severity Index, Growing and Heating Degree Day indices, and the Climate Extremes Index and Greenhouse Response Index are just some examples of indices that provide information on weather and climate conditions that affect the nation's economy and society. Indices developed as part of NCDC's National Climate Impact Indicators Program (formerly known as Environomics), such as the Residential Energy Demand Temperature Index (REDTI) and the Moisture Stress Index (MSI) for corn and soybean crops, provide additional quantitative measures of climate's influence at the national level. The information conveyed with these indices assists the Department of Commerce in its role of providing information that strengthens the understanding of the U.S. economy and is essential to ensuring that political and business leaders have access to pertinent information that is part of any well-informed decision-making process. In addition, the sensitive nature of some indices such as the MSI, which provides indications of overall crop performance prior to the end of the harvest season, dictates that the data be calculated and coordinated with other government agencies, e.g., USDA.

28. FSL is bidding against our company right now in Vietnam to do the NWP. FSL pushed their modeling capability as well as their meteorological workstation. FSL wants to do the flash flood warning system in central Vietnam? No experience here; FSL is really selling against U.S. industry.

To the first comment—FSL has never submitted a proposal or a bid to anyone in VHMS (Vietnam Hydrometeorological Service) for any activity. To the second comment—FSL presented to VHMS in Hanoi in September 2001, an overview of FSL's organizational structure, information on projects FSL is working on in other Southeast Asian countries and an overview of the WorldWide Weather Workstation (W4) development. This presentation was part of the meeting sponsored by NWS under the bilateral U.S./Vietnam agreement signed in 1/01.

To the third comment—this comment is significantly off base. FSL is not responsible for any interaction with Vietnam with respect to flash flood mitigation, hydrological studies or hydrological forecasting. This is the responsibility of the NWS, and there has been considerable interaction between NWS and VHMS on these topics. I believe the company that submitted these comments knows this. With regard to the second part of the comment—". . . FSL is really selling against U.S. industry"—the purpose of FSL's visit to Vietnam was to gain an understanding of the current level of expertise in Vietnam, make them aware of some of the things FSL is doing and promote the potential for future interaction regarding training, which we are doing in other countries and for which I presented our just-completed Thailand training activities. It is quite difficult to be "selling" anything when there is no proposal on the table, no bid to address and little or no communication between the parties. My only contact with any VHMS personnel after the September 2001 NWS sponsored meeting was at an NWS APEC (Asian-Pacific Economic Cooperation) sponsored meeting in Orlando at the AMS annual meeting in January 2002. There I discussed with two VHMS representatives their current situation and agreed with them that training of personnel should precede purchasing of large quantities of meteorological equipment so that the personnel would understand the purpose of the equipment and how to integrate these products to improve their overall weather forecasting abilities. This type of training, if done by U.S. personnel of course, can lead to the exposure of the trainees to U.S. products, which in turn leads to purchases of these products. We have seen this happen in several countries. Finally, regarding Vietnam, there have been no letters, e-mails or phone calls by me to further promote the general discussion that took place at the APEC meeting in January.

FSL's Position on Working in Other Countries. U.S. industry does not do application training and training on how software systems can be integrated into operational weather activities—FSL does. Through this training, the level of weather and forecast knowledge is enhanced so that the country's operational weather organization can appreciate the value of U.S. services, computer products and meteorological equipment with respect to improving their regional, province and local forecasts. Our mission is technology transfer and we welcome industry partnerships through Federal Business Opportunity announcements or through different types of agreements which encourage U.S. industry to work with us. Through our international activities, we introduce technology to countries which can lead to sales for U.S. companies. For example, our interactions with CWB (Central Weather Bureau of Taiwan) influenced purchases of U.S. products of greater than $20 million for computers, network upgrades and mass storage and over $14 million for Doppler radars. Quite straightforwardly, our foreign visitors work on specific workstations, with specific computer networks and applications and meteorological equipment. When they return to their home country, they want to purchase these products with which they are familiar.

Appendix E

On Fairness and Self-Serving Biases in the Privatization of Environmental Data

Edward E. Zajac
University of Arizona

Note: The committee commissioned the following paper to explore an aspect of government-private sector interactions that is commonly overlooked—the issue of fairness. The paper summarizes the current research in this area, and its application to the weather and climate enterprise is discussed in Chapter 4. Dr. Zajac's views, as expressed below, may not always reflect the views of the committee or vice versa.

INTRODUCTION

The National Research Council (NRC) report *Resolving Conflicts Arising from the Privatization of Environmental Data*[1] does a beautiful job of identifying the main stakeholders in the privatization process, analyzing their interests and their probable gains and losses from privatization, and describing how the creation and distribution of the results of research should be structured in order to achieve economic (allocative) efficiency. The report, however, does not attempt to apply the fruits of fairness and self-service (denial) research to the problem of conflict prevention and resolution.

This may be a significant omission. There is in fact a large and rapidly growing literature on both fairness and self-serving behavior. I refer here to research that develops *positive* theories of fairness and self-service. *Positive* theories attempt to describe and *analyze* what *is*, as contrasted to *normative* moral theories that *prescribe* what *ought to be*. The positive theories are still evolving, and much remains to be done. Nonetheless, even in their present state, the theories have predictive power—not the power of the laws of physics, but often sufficient power to be useful. If nothing more, the theories give a vocabulary of words and concepts that can facilitate communication among stakeholders. They may thus streamline and elevate the debate. It would be ideal if elevating the debate were to prevent conflicts

[1]National Research Council, 2001, *Resolving Conflicts Arising from the Privatization of Environmental Data*, National Academy Press, Washington, D.C., 99 pp.

from arising in the first place. Perhaps this is too much to ask, but we can hope to minimize conflicts and, should they arise, to resolve them more rapidly and with less waste of resources on counterproductive argument and maneuvering.

Research on fairness and self-service was started at least four decades ago by psychologists with their work on *equity theory*.[2] In the last two decades, experimental economists have mounted a large fairness research effort, motivated by early experiments in which humans failed to show completely selfish, self-interested behavior—the behavior assumed by economic theory.[3] At the same time, researchers from every branch of the social sciences have made and continue to make contributions to the theory. The main research tools have been surveys, case studies, laboratory studies using human subjects, and development of theory that is informed by the empirical findings and stimulated by them.

In this paper, I give a very brief summary in the next two sections of the present state of theories of fairness and self-service. I do not claim that the summary is complete; rather it reflects my own view and research interests. Other fairness researchers' summaries might have a different emphasis.[4] The last section discusses the implications of the theory for policy design and implementation, first pointing out that privatization leads to a problem

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[2]See, for example, E. Walster, G.W. Walster, and E. Berscheid, 1978, *Equity Theory and Research*, Allyn and Bacon, Boston, 312 pp.

[3]A pioneering work that greatly stimulated economists' interest in fairness or distributive justice is W. Güth, R. Schmittberger, and B. Schwarze, 1982, An experimental analysis of ultimatum bargaining, *Journal of Economic Behavior and Organization*, v. 3, p. 362-388.

[4]For other taxonomies of fairness principles, see H.P. Young, 1994, *Equity: In Theory and Practice*, Princeton University Press, Princeton, N.J., 253 pp. (6 axioms as the basis of a mathematical characterization of distributive justice); B.H. Sheppard, R.J. Lewicki, and J.W. Minton, 1992, *Organizational Justice: The Search for Fairness in the Workplace*, Lexington Books, Cambridge, Mass., 228 pp. (18 principles of distributive, procedural, and systemwide justice); and S.W. Gilliland, 1993, The perceived fairness of selection systems: An organizational justice perspective, *Academy of Management Review*, v. 18, p. 694-734 (9 procedural rules that enhance the perceived fairness of selection procedures). The reader interested in positive fairness research can also find more in M. Bar-Hillel and M. Yaari, 1984, On dividing justly, *Social Choice and Welfare*, v. 1, p. 1-24; R. Cropanzano and J. Greenberg, 1997, Progress in organizational justice: Tunneling through the maze, in *International Review of Industrial and Organizational Psychology,* v. 12, C.L. Cooper and I.T. Robertson, eds., John Wiley, New York, pp. 317-370; J. Elster, ed., 1995, *Local Justice in America*, Russell Sage Foundation, New York, pp. 81-151; J. Greenberg, 1996, *The Quest for Justice on the Job: Essays and Experiments*, Sage, Thousand Oaks, Calif., 428 pp.; G. Jasso, 1990, Methods for the theoretical and empirical analysis of comparison processes, in *Sociological Methodology*, C. Clogg, ed., American Sociological Association, Washington, D.C., pp. 369-419. It should be noted in passing that there is also a large academic literature on negotiation, arbitration, and conflict resolution, per se (see, for example, M. Deutsch and P.T. Coleman, 2000, *The Handbook of Conflict Resolution: Theory and Practice*, Jossey-Bass, San Francisco, 649 pp.

of institutional design and then taking up "political fairness games." These are the political controversies that can arise when stakeholders try to convince regulators, legislators, or the courts of the fairness of their positions and the unfairness of their rivals' pleadings. As illustrations, I give very brief histories of two such games in telephony: (1) the deregulation of long-distance phone service and (2) the 14-year process of introducing cellular phone service in the United States. Finally, I discuss how the results of fairness and self-service research might be applied to policy design.

THE STRUCTURE OF FAIRNESS[5]

The Formal Principle of Distributive Justice; Material Principles

If you and I happen to find $400 on the street, we would probably divide it equally into $200 for you and $200 for me. On the other hand, if you put in three hours of work and I one hour to make something that we sell for $400, we would probably agree that you should get $300 and I $100. Finally, suppose we are given a frosted cake. Further, suppose you have a disease that requires you to consume three times as much sugar as a normal human being and I am normal. Then, I probably would not object to your having three-quarters of the cake while I had one-quarter of it. This example illustrates an important normative principle that goes back at least to Aristotle. We divided the $400 based on our claims to it. When we happened to find it on the street, we had equal claims; when we mutually made something, our claims were in proportion to our work effort; when we received the cake, our claims were based on different needs for sugar. The principle is variously called the *Formal* or *Aristotelian Principle of Distributive Justice*. A succinct statement of it is:[6]

> Equals should be treated equally and unequals unequally, in proportion to relevant similarities and differences.

The important point is that you should not divide a resource arbitrarily, but rather in proportion to the claims on it. Further, the claims should not be arbitrary, but should be based on something *relevant*. Left wide open is what the terms *equal*, *unequal*, and *similarities and differences* mean. These are usually clarified by the application of *material principles* of distributive justice. Research on positive theories of fairness and distribu-

[5]The material in this and the following section of this paper has been adapted from E.E. Zajac, 2002, What fairness-and-denial research could have told the Florida Supreme Court (and can tell the rest of us), *Independent Review*, v. VI, p. 377-397.

[6]This form of the Formal Principle is taken from A.E. Buchanan and D. Mathieu, 1986, Philosophy and justice, in *Justice: Views from the Social Sciences*, R.L. Cohen, ed., Plenum Press, New York, pp. 11-45.

tive justice consists mainly of trying to understand and explain under what circumstances human beings apply which material principle.

We have already encountered a couple of material principles in our example—*desert* (in the case of division in proportion to work effort) and *need* (in the case of the division of the cake). However, there are many other material principles, for example, *merit* (civil service jobs are often awarded on the basis of scores on competitive examinations); *seniority* (many union contracts require that pay be based on length of time on the job); and affirmative action, which has focused on the material principles of *ethnicity, age,* and *sex*.

Other material principles focus on the fairness of the procedures for dividing a resource, in particular that the procedures should be

- *nondiscretionary*—the rules for division and distribution of a resource should be set in advance and not deviated from,
- *nonmanipulative*—the rules should not be subject to strategic manipulation, and
- *noncoercive*—the divider of the resource should not have undue power.

Effects of History

Still other material principles are based on the effects of history. A common notion is that one is entitled to maintain a beneficial status quo established historically—in other terms, that one has a *status quo property right* or *entitlement* to something simply by virtue of having enjoyed it in the past. When a profession is first licensed, it is common for the extant practitioners to be "grandfathered-in" and exempted from the educational achievements and examinations required of new licensees. Likewise, when a new building code is adopted, existing buildings are often similarly grandfathered-in, sometimes with tragic consequences when an earthquake or hurricane occurs. Rent control has existed in Paris and London since World War I and in New York City since World War II. Controlled rents are often a fraction of market value, yet tenants feel strongly that they are entitled to them. Renters react to landlord pleadings before the New York rent control authority with derision and sometimes with violence.

In their seminal article in the *American Economic Review*, based on extensive surveys, Kahneman, Knetsch, and Thaler formulated an entitlement theory for business transactions based on a *reference transaction* determined by history.[7] Their data led them to conclude that transactors

[7]D. Kahneman, J.L. Knetsch, and R. Thaler, 1986, Fairness as a constraint on profit seeking: Entitlements in the market, *American Economic Review*, v. 76, p. 728-741.

feel that they have an entitlement to a historically set reference wage or price and that firms are entitled to a reference profit. Thus, after a severe snowstorm, customers will feel it is unfair if the town's hardware stores triple the price of snow shovels. Likewise, a big employer in a small town may go bankrupt and flood the town with skilled employees who lower market wages. Respondents in their surveys felt it would be unfair for the remaining employers to lower wages to market levels.

On the other hand, in other contexts, entitlements or status quo property rights are specifically *not* honored. Last year's Super Bowl winner has no special status in this year's NFL season, and, in general, athletic contests pay no attention to history. Everyone is supposedly considered equal before the law, and one's previous criminal history, whether exemplary or despicable, is often excluded from the evidentiary record in a criminal trial. Often by law the winner of government contracts is the lowest bidder, regardless of the history of the bidder's previous performance record, many times to the regret of the agency letting the contract.[8]

Thus, there are many material principles of justice—some dependent on history, others not. The above list is in fact not meant to be exhaustive, especially since material principles overlap. Seniority can be viewed as a combination of a status quo property right and desert, in that those who provide long and faithful service for an employer deserve more pay than those with short service. Likewise, status quo property rights are themselves sometimes a combination of historical entitlement and desert. Frontier squatters in the early nineteenth century United States established rights to a piece of land by carving their initials on the bark of a tree on the land ("tomahawk rights"), by planting a crop on it ("corn rights"), or by building a structure on it ("cabin rights"). The more years that crops were planted and the more numerous and extensive the structures, the greater is the element of desert in the squatter's claim.[9]

An open research question is, Does there exist a minimum, non-overlapping set of material principles that captures all of human fairness behavior, and if the set does exist, what material principles comprise it?[10]

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[8]For more on status quo property rights, see J. Elster, ed., 1995, *Local Justice in America*, Russell Sage Foundation, New York, pp. 81-151; R.M. Isaac, D. Mathieu, and E.E. Zajac, 1991, Institutional framing and perceptions of fairness, *Constitutional Political Economy*, v. 2, p. 329-370; E.E. Zajac, 1995, *Political Economy of Fairness*, MIT Press, Cambridge, Mass., 325 pp.; and E. Schlicht, 1998, *On Custom in the Economy*, Clarendon Press, Oxford, U.K., pp. 111-115.

[9]For a recent discussion of the establishment of squatters' rights on the early nineteenth century American frontier, see H. DeSoto, 2000, *The Mystery of Capital: Why Capitalism Triumphs in the West and Fails Everywhere Else*, Basic Books, New York, 276 pp.

[10]E. Schlicht (*On Custom in the Economy*, Clarendon Press, Oxford, U.K., pp. 111-115, 1998) advances a general theory of custom formation and the role of customs that subsumes

Contextual Effects or Institutional Framing

The fact that in some contexts history plays a crucial role in determining what is fair, while in other contexts it plays no role whatsoever, highlights an important aspect of fairness: context or the institutional setting frames how we view fairness. In the extreme, we may have the situation that what is considered fair in one context or institution may be considered unfair in another.

The literature on fairness repeatedly stresses this point. In economics, we have the example of human subjects having different views of fairness in experiments involving market and non-market settings. In such experiments, the subjects' task is to divide some economic pie, with payoffs to them in dollars. If the experiment is in a market-like setting and has a large number of subjects (say more than 20) in impersonal transactions (say by means of computers), the fairness of the varying payoffs the subjects receive almost never comes up. On the other hand, in experiments with a few subjects (say fewer than a half dozen) in a non-market setting and with face-to-face interactions, the fairness of the payoffs is very likely to come up. Little is known about in-between cases.

This reflects what we see in the real world. If we buy groceries at the supermarket, or a home in our community, or stocks through our broker, the fairness of what we paid is rarely an issue as long as the amount is in line with market prices. In market transactions, something impersonal—money—is exchanged for something tangible and material. Money depersonalizes the transaction.

It is a different story, however, when it comes to the division of assets in a divorce, to the assignment of hotel rooms to members of a tour group, or to the allocation of offices among faculty members. Allocation decisions such as these—ones that involve a small number of persons in face-to-face interactions in a non-market setting—can be intensely personal, and whether or not the allocation is fair can be *the central issue*.

Economics is not the only discipline to stress context effects in the determination of what is fair.[11] In philosophy, we have, for example,

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fairness and self-serving behavior. He adduces evidence, based on an extensive survey of the psychological and biological literature, that human beings have an innate "rule preference"—"a preference for psychological meaningful, or clear rules." He further argues that rule preference is the motivational force for custom formation. Fairness norms are special cases of customs, and Schlicht's theory may provide the desired parsimonious explanation of fairness principles. His theory is, however, very new and its general acceptance is still in the offing.

[11]For more on context effects or "institutional framing" see R.M. Isaac, D. Mathieu, and E.E. Zajac, 1991, Institutional framing and perceptions of fairness, *Constitutional Political Economy*, v. 2, p. 329-370, and E. Schlicht, 1998, *On Custom in the Economy*, Clarendon Press, Oxford, U.K., pp. 69-86.

Michael Walzer's *Spheres of Justice*, which stresses that *equality* will and should be interpreted differently in different contexts:

> Thus, citizen X may be chosen over citizen Y for political office, and then the two of them will be unequal in the sphere of politics. But they will not be unequal generally so long as X's office gives him no advantages of Y in any other sphere—superior medical care, access to better schools for his children, entrepreneurial opportunities, and so on.[12]

Likewise, from the psychological literature, we have the following statement by J. Greenberg:

> What makes a set of questions appropriate in one context may not make them equally appropriate in another. Questions about justice should be carefully matched to the context of interest.[13]

Fairness Overdetermination

Thus, fairness principles are context dependent, can overlap, and can even be contradictory. The principles can be formally applied, as when an organization adopts Robert's Rules of Order, or can be informally observed, as when people in England automatically form queues at bus stops. They can also be culturally dependent—Germans don't form queues at bus stops. There are thus typically many more fairness principles than an organization or institution needs to govern its functioning—what Elster calls "fairness overdetermination."[14]

Formally or informally, the institution will usually settle on an adequate number of fairness principles to use for its governance, ignore the rest, and operate peacefully in a governance equilibrium year after year without incident. All this may change if big external effects give some members of an institution opportunities for gain. Fairness overdetermination may give potential gainers the weapons they need. They may resurrect dormant fairness principles, using those that allow them to claim that they are being treated unfairly.

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[12]M. Walzer, 1983, *Spheres of Justice: A Defense of Pluralism and Equality*, Basic Books, New York, p. 19.

[13]J. Greenberg, 1996, *The Quest for Justice on the Job: Essays and Experiments*, Sage, Thousand Oaks, Calif., p. 402.

[14]J. Elster, ed., 1995, *Local Justice in America*, Russell Sage Foundation, New York, pp. 81-151.

Fairness Versus Unfairness

> What is fairness? Well, unless you are going to take the position that everyone should earn the same thing, fairness is going to be arbitrary.
>
> William F. Buckley (1992)[15]

Given the above discussion, Buckley's view is hardly surprising and, in fact, is common. Nonetheless, it is not quite correct. What we consider fair is obviously not *completely* arbitrary. The salaries within an organization could not be based on the color of an employee's eyes, nor could income taxes be based on a citizen's month of birth. In both cases, society would demand that salaries or income taxes be based on principles that were considered "fair." Yet Buckley's view is correct in that the complexity of the structure of fairness leaves room for much arbitrariness in its application.

If Buckley's view is common, so is outrage expressed over obviously unfair treatment, as undoubtedly would be the reaction if one indeed tried to apportion salaries by color of eyes and income taxes by month of birth. How can the public hold such contradictory views—that fairness is arbitrary on one hand, while unfairnesses are obvious on the other?

These views are not as contradictory as they may seem. Unless we are trained linguists, we are unable to describe the complete structure of English grammar. Yet when a foreigner makes a grammatical mistake in speaking English, we will probably recognize it immediately. Likewise, unless we are medical professionals, we will not understand in detail how the biology, physiology, and anatomy of the human body interact. Yet, we know when we feel pain or otherwise feel not quite "normal." The point is that we encounter complex patterns in all phases of our daily lives, patterns that we rarely are able to describe in detail. We are, however, much more readily able to detect that something in the pattern has changed and has gone awry.

So it is with fairness. Unless we specialize in studying fairness, we are likely to be unable to explain its structure, but we know when we have been "screwed," "shafted," or "taken to the cleaners" or, in a competition with rivals, when there is an outrageous lack of a "level playing field."

Contract-Breaking Behavior

Perceived unfair treatment is in fact a great energizer, and the rectification of unfairness strongly motivates the creation of new policy. Often the feeling of unfair treatment is the feeling that a contract, implicit or explicit,

[15] W. Buckley, 1992, If candidates say "fairness" grab your wallet and hold on, *Tucson (Arizona) Citizen*, March 17.

has been broken. The perceived unfairness of contract-breaking behavior seems to be universal and important.

SELF-SERVING BEHAVIOR AND ADAM SMITH'S "VEIL OF SELF-DELUSION"

> He is . . . bold who does not hesitate to pull off the veil of self-delusion which covers from his view the deformities of his own conduct. . . .
>
> This self-deceit, this fatal weakness of mankind, is the source of half the disorders of human life.
>
> Adam Smith, *The Theory of Moral Sentiments* (1759)[16]

Theory

Leon Festinger's 1957 book *A Theory of Cognitive Dissonance* is still a seminal work. In it Festinger laid out a general theory of the rejection of reality or, for want of a better term, of "denial." Somewhat oversimplified, his theory goes like this: Our minds hold simplified models of reality, models that we are loath to abandon. We do not welcome evidence that contradicts these models and thus leads to "cognitive dissonance." We try to reduce this dissonance in various ways, perhaps by rejecting the contradictory evidence or perhaps by ignoring it while we find more evidence to support the models in our minds. In extreme cases we might even admit to ourselves that our models are wrong.

Yet this may be rare, and often, especially when it suits our purposes, we reject reality with great conviction. We quickly pull Adam Smith's "veil of self-delusion" over our eyes. According to news accounts, Timothy McVeigh, the "Oklahoma City Bomber," went to his execution convinced that his killing of 168 innocent people was totally justified.[17]

As I understand it, not all psychologists accept Festinger's theory, at least not completely. Many alternative theories may explain denial. For example, prison inmates are notorious for pleading that they are innocent or, even if guilty, that they have been unjustly incarcerated because of extenuating circumstances. Their behavior can be explained by the theory of cognitive dissonance, but may simply be based on their belief that their protestations might somehow shorten their sentences.

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[16] A. Smith, 1759, *The Theory of Moral Sentiments,* reprinted in 1976 by Liberty Classics, Indianapolis, p. 263.

[17] Associated Press, 2001, McVeigh Says He's Sorry for Deaths, June 9.

Empirical Evidence of Self-Serving Behavior

Many of the above problems can be circumvented by narrowing the focus to test for the existence of self-serving behavior. Using surveys and controlled laboratory experiments, a large body of psychological research takes this approach. It demonstrates not only individual self-serving biases but group self-serving biases as well. Some of the results cited by Babcock and Lowenstein are the following:

individual self-serving bias:

> • Over half of survey respondents typically rate themselves in the top 50 percent of drivers, . . . ethics, . . . managerial prowess, . . . productivity, . . . health, . . . and a variety of desirable skills.
>
> • When married couples estimate the fraction of various household tasks they are responsible for, their estimates typically add to more than 100 percent.
>
> • People also tend to attribute their successes to ability and skill but their failures to bad luck.

group self-serving bias:

> [Princeton and Dartmouth] students viewed a film of [a football] game and counted the number of penalties committed by both teams. Princeton students saw the Dartmouth team commit twice as many flagrant penalties and three times as many mild penalties as their own team. Dartmouth students, on the other hand, recorded an approximately equal number of penalties by both teams. While the truth probably lies somewhere in between, the researchers concluded that it was as if the two groups of students "saw a different game."[18]

The interested reader can find a recent survey of this literature and the general literature on cognitive dissonance in Konow (2000).[19]

IMPLICATIONS

Privatization Means a Problem of Institutional Design

The privatization of environmental data will create new institutions. Thus, we are faced with a problem of institutional design. The trick is to

[18]L. Babcock and G. Lowenstein, 1997, Explaining bargaining impasse: The role of self-serving biases, *Journal of Economic Perspectives*, v. 11, p. 111.

[19]J. Konow, 2000, Fair shares: Accountability and cognitive dissonance in allocation decisions, *American Economic Review*, v. 90, p. 1072-1091.

design the institutions so that the individuals and groups of individuals participating in the institutions will feel that they are being treated fairly.

Achieving this goal is not easy. Fairness is a complex matter; moreover, it is context or institutionally dependent. This can lead to overlapping and even contradictory fairness principles. In addition, institutional design must cope not only with fairness but also with the human tendency for self-serving behavior and the rejection of evidence that does not accord with self-interest.

Poor institutional design that ignores fairness and self-service can result in counterproductive resource waste. An often-heard joke is: "X and Y's lawyers finally agreed on a divorce settlement. They had to—their fees had wiped out the assets in X and Y's marriage, and there was nothing left for them to take."

Unfortunately, even when lawyers work hard to avoid this disastrously counterproductive outcome, it can occur. Spouses may refuse to budge from demands for what each considers a "fair" settlement, and having large sums eaten up unnecessarily in lawyers' fees is not confined to divorces. Newspapers periodically report litigants spending thousands on litigation to settle a disagreement over a matter in which a few dollars are at stake.

Political Fairness Games and Two Case Studies

Fairness fights are also not confined to litigants in court battles. In the political arena, interest groups typically try to convince regulators or legislators of the righteousness of their cause and of the unfairness of the pleadings of rival interest groups. All of the groups involved will probably have had no trouble in finding "public interest" fairness arguments to buttress their pleadings. What is more, they may have convinced themselves that they are in fact acting in the public interest and not in their own interests. The result is what might be called "political fairness games" that are played out in the public arena, often with extensive media coverage. Most importantly, the games often result in a massive waste of resources.

In my experience in telecommunications, two dramatic examples come to mind—the deregulation of long-distance telephone service and the development of cellular mobile telephony. Both occurred in the 1970s and early 1980s, and both perhaps had elements of the controversies involved in the privatization of environmental data. I give a brief history of each, followed by a discussion of what might have been done to mitigate the deleterious effects of the fairness fights.[20]

[20]The deregulation of long distance and the development of cellular telephony both occurred during my 30 years of employment at Bell Laboratories (1954-1984). To present their histories as objectively as possible, I have relied primarily on published accounts of events rather than on my memory of them.

Deregulation of Long-Distance Telephone Service[21]

In 1971 the Federal Communications Commission's (FCC's) *Specialized Common Carrier* decision allowed MCI to provide long-distance telephone service between St. Louis and Chicago. The rationale was that MCI would provide a service not available from AT&T—cheap but low-quality service. MCI would thus not disturb AT&T's "natural" monopoly over the services it provided. MCI would also therefore not disturb AT&T's regulation by the FCC.

The decision, of course, introduced the camel's nose into the tent, and MCI started an aggressive campaign to expand from low-quality but cheap service to service of the same quality and extent as that provided by Bell.

During this period, AT&T could be viewed as a quasi-public corporation. The rates it charged were not those of a rapacious monopolist. Rather, they were set by regulators so as to yield AT&T's shareholders a "fair return on the fair value of AT&T's assets." AT&T also supported Bell Labs, an R&D establishment of more than 24,000 employees. Under a 1956 antitrust consent decree, Bell Labs' patents had to be licensed to anyone at "fair" rates, usually interpreted to mean a nominal 2-4% royalty on the revenues that the patent license generated. Since its inception, Bell Labs had done the bulk of the nation's telecommunications research and continued to do so after long-distance service was deregulated. Thus it, too, could be viewed as a quasi-public agency, playing a role in telecommunications analogous to that played by government research entities in other areas.

AT&T's management fiercely resisted attempts by MCI, and later by other common carriers, to invade its turf. AT&T viewed its telephone monopoly as a sacred trust that conferred on AT&T the duty to provide ultrareliable, high-quality service at affordable prices—"the best telephone service in the world."[22] MCI was considered an upstart with no understanding of this trust and duty, bent only on crass maximization of its profits.

The FCC largely supported AT&T's position. This forced MCI to go to the courts to seek relief (MCI got to be known as "a law firm with an

[21]For a more extensive discussion of the history of the long-distance controversy, see G.R. Faulhaber, 1987, *Telecommunications in Turmoil: Technology and Public Policy*, Ballinger, Cambridge, Mass., 186 pp.

[22]E.E. Zajac, 1990, Technological winds of creation and destruction in telecommunications: A case study, in *Evolving Technology and Market Structure: Studies in Schumpeterian Economics*, A. Heertje and M. Perlman, eds., University of Michigan Press, Ann Arbor, 351 pp., describes the AT&T-Bell Labs mind-set during the period when it had a monopoly on long-distance service.

antenna"), as it expanded first from private line service between St. Louis and Chicago to private line service elsewhere, then to interconnection with AT&T's network, and finally to the provision of switched service throughout the United States. In these battles, AT&T of course invoked its status quo property rights, while MCI claimed that AT&T's obstructionist tactics were denying the public the benefits of competition.

A basic issue was the allocation of AT&T's joint and common costs between the branches of AT&T that had no competition and continued to be regulated as before 1971 and the branches that were in competition, first with MCI and later with other rivals as well. On the surface, cost allocation would seem to be a trivial issue. In fact, it presents subtle and difficult definitional and mathematical problems, and is a bottomless pit of controversy in both the economics and the accounting professions. The cost allocation problem led to charges by Bell rivals that Bell's regulated services were unfairly cross-subsidizing its unregulated competitive services and that by means of such cross-subsidization AT&T was engaging in "predatory pricing."[23] AT&T and its rivals incessantly trotted out fairness arguments to demonstrate that they did not face a level playing field in the competition for the long-distance market. The charges provided fuel for political fairness games before the FCC and Congress, as well as for some legal fairness games played out before the courts (MCI won most of the games).

Discussion of the 1970s Long-Distance Telephony Fairness Game

With hindsight, had the FCC been more forceful and enthusiastic in embracing and encouraging competition in long-distance telephony, much of the resource waste that occurred could have been avoided. In the terminology and ideas of this paper, such action would have changed the context or "institutional frame" of the fairness fights. As it was, the FCC adopted a gradualist approach, putting its toe in the water with the 1971 *Specialized Common Carrier* decision and half-heartedly accepting court decisions that, over many years, allowed MCI more and more entry into the long-distance business.

The Civil Aeronautics Board (CAB) under Chair Alfred E. Kahn and Vice Chair Elizabeth E. Bailey in the late 1970s is a model of the sort of decisive behavior that I have in mind. In a few years, they deregulated the airlines and closed down the CAB. Kahn and Bailey were trained economists who specialized in regulation. They had the courage of their convic-

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[23]For an introduction to the theory of cross-subsidization and predatory pricing, see E.E. Zajac, 1995, *Political Economy of Fairness*, MIT Press, Cambridge, Mass., pp. 203-226.

tions, and their training and vast regulatory experience motivated them to acts that non-economists considered to be outrageously bold and that lawyers thought outrageously illegal. Perhaps it is too much to expect an FCC composed of the usual political appointees to act similarly.

In addition, an institutional innovation, facilitated by the breakup of AT&T in 1984, finally solved the cost allocation dilemma. Namely, the FCC abandoned rate of return regulation of AT&T in favor of price cap regulation, a regulatory method that largely avoided the calculation of costs. The price cap innovation could have been adopted much earlier but, unfortunately, was not.[24]

To my knowledge, no one has estimated the magnitude of the undoubtedly enormous cost to U.S. society of the long-distance telephone service fairness games of the 1970s and early 1980s.

Cellular Mobile Telephony[25]

The cellular mobile telephony concept envisions an antenna within each cell of a "beehive," with all of the antennae connected to a central computer. As the customer drives from Cell A into Cell B, the computer hands him off from the antenna in A to that in B. The design, of murky origins, promised great efficiency because the same bandwidth could be used by nonadjacent cells. This meant that it could be reused an estimated 16 to 64 times in a given market.

Until the late 1960s, the cellular concept was mainly a theoretical curiosity because of lack of availability of spectrum for mobile telephony. Ten percent of the spectrum that was available was allotted to AT&T as a "wireline common carrier" (WLCC) and 90% to about 500 "radio common carriers" (RCCs). The latter were mostly small "ma and pa" operations. In addition to the common carriers, specialized groups, mostly police and fire departments and taxicab companies, had their own mobile telephone service.

Prior to the introduction of cellular telephony, a land mobile customer connected by radio phone to an operator who patched him into the tele-

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[24]Ironically, the Telecommunications Act of 1996 and its interpretation and implementation by the FCC reintroduced the specific consideration of costs into the regulation of telecommunications carriers. As was to be expected, this reignited costing methodology controversies. These ended up at the U.S. Supreme Court, with the Court issuing an extensive opinion on telecommunications costing methodology on May 13, 2002. Maybe the Court's decision (U.S. Supreme Court, 2002, *Verizon Communications, Inc., et al. v. Federal Communications Commission et al.,* 535 U.S., May 13, 2002) will resolve the controversies once and for all, but I doubt it.

[25]The history of cellular mobile telephony recounted here is abstracted from K.E. Hardman, 1982, A primer on cellular mobile telephone systems, *Federal Bar News & Journal*, v. 29, p. 385-391.

phone network. By 1968, such land mobile service was saturated, with long waiting lists of customers desiring to subscribe. In response, the FCC initiated hearings, proposing to provide additional spectrum to land mobile by robbing it from the band allotted for ultrahigh-frequency (UHF) television stations and also to consider allocating the robbed spectrum to a cellular design based on preliminary AT&T studies. There rapidly emerged a furious political fairness game, fought principally before the Federal Communications Commission, but with trips to the courts. The FCC's initial position was that only AT&T and other WLCCs had the technical capability to develop and deploy the cellular design. The FCC consequently proposed allotting the entire robbed part of the UHF-TV spectrum to them.

The RCCs objected vigorously, invoking their status quo property rights. Moreover, under the 1956 consent decree, AT&T could not enter the non-Bell market for land mobile hardware. This was the domain principally of Motorola and GE, with 65-70% and 15% market share, respectively. Under the FCC's proposal, AT&T would be the sole buyer in the cellular hardware market and could make hardware suppliers dance to its tune. In particular, AT&T could put Motorola in competition with Japanese suppliers. Needless to say, Motorola jumped into the fray as well.

Thus, as the FCC struggled with the problem of relieving the saturation of the land mobile telephone market, it had four major stakeholder groups with strong status quo property rights to contend with—the WLCCs, the RCCs, the broadcast industry, and Motorola—and numerous minor stakeholders. The resulting political fairness game played out mostly before the FCC but with some trips to the courts. Approval of the deployment of cellular mobile telephony occurred only in 1982, *14 years after the FCC first contemplated the cellular design*! By then it was available in other parts of the world. When it finally decided to approve cellular, the FCC divided the spectrum made available for it into two parts, awarding one part to the local WLCC and the other to a "qualified" provider. Rohlfs, Jackson, and Kelly estimate that the playing of the political fairness game delayed the U.S. deployment of cellular by a decade or more and cost U.S. society about $86 billion (1991 dollars) in forgone benefits (about 2% of the 1991 U.S. gross national product).[26]

Discussion of the 1970s Cellular Fairness Game

In 1968, when the FCC decided to address the problem of saturation of land mobile telephone service, AT&T had 34,000 mobile customers and

[26]J.H. Rohlfs, C.L. Jackson, and T.E. Kelly, 1991, Estimate of the loss to the United States caused by the FCC's delay in licensing cellular telecommunications, National Economic Research Associates, Inc., White Plains, N.Y., November 8, 24 pp.

the 500 or so RCCs had 28,000.[27] Compared to the long-distance market, which generated roughly half of AT&T's revenues, land mobile was minuscule. In this regard, land mobile differed profoundly from long distance and in 1968 was probably of minor concern to the FCC.

On the other hand, there are many similarities to the situations in which long distance and land mobile found themselves during the 1970s and early 1980s. Both their fates were largely controlled by the FCC, or more precisely by FCC commissioners appointed by the Nixon, Ford, Carter, and Reagan administrations. In both cases, the commissioners regulated by the classic "due process" approach, compared to what might be called the "economic efficiency" approach used by the Kahn-Bailey-dominated CAB of the late 1970s.

In regulation, administrative law is the basis of "due process." As Supreme Court Justice Steven Breyer pointed out:

> Between 1945 and 1965, by way of reaction to excessive [regulatory] agency freedom, Congress passed and the courts enforced, the federal Administrative Procedures Act (APA). The act imposed certain procedural constraints on federal administrative bodies, whether located in the executive branch or in independent agencies. Its basic object was to achieve "fairness" rather than "control." It forms the basis of current federal administrative law.[28]

Needless to say, the APA's "fair" procedures are abundantly overdetermined in the Elster sense. It is hardly surprising that they triggered lengthy political fairness games in both the deregulation of long distance and the implementation of cellular mobile. As in the case of long distance, the FCC did not act decisively to award property rights to the various claimants as cellular technology unfolded.

Perhaps the most striking similarity was the eventual emergence in both cases of an institutional reform that eliminated much of the fairness fighting. In the case of long distance, it was the adoption of price cap regulation. In the case of cellular, it was the use of auctions to allocate spectrum. Economists had proposed auctioning the spectrum for years, but the FCC and the phone companies considered the proposal to be a "looney toons" idea that only out-of-touch-with-reality economists could dream up. However, by the time the FCC was ready to allocate spectrum for a new-generation digital cellular service, spectrum auctions had been successfully conducted in New Zealand and Australia. The FCC, over the vigorous

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[27]K.E. Hardman, 1982, A primer on cellular mobile telephone systems, *Federal Bar News & Journal*, v. 29, p. 385-391.

[28]S. Breyer, 1982, *Regulation and Its Reform*, Harvard University Press, Cambridge, Mass., p. 378.

objections of some members of Congress but with the support of the Clinton administration, opted to auction off the spectrum made available for digital cellular.

From a fairness game perspective, this accomplished two things: (1) auctions marketized spectrum allocation, thus minimizing arguments over the fairness of the allocation, and (2) auctions wiped out status quo property rights to the spectrum by introducing an allocation procedure that, from a political standpoint, was considered more fair than one based on status quo property rights. The FCC could have adopted spectrum auctions just as well in 1968, when it first contemplated cellular mobile telephony, as it did almost 30 years later.

Applying the Results of Fairness and Self-Service Research

The results of research outlined in earlier sections say that we can expect the following in the privatization of environmental data: stakeholders will expect that the Formal Principle will be applied and that material principles of justice will be invoked to give meanings to its vague terms. They will also expect procedures that affect resource allocations to be nondiscretionary, nonmanipulative, and noncoercive. If the stakeholders are benefiting from a status quo, they will likely expect the benefits to continue, unless there is a history of the status quo being ignored. Stakeholders will react quickly to perceived unfair treatment. Moreover, they will be prone to ignore evidence to the contrary and to find evidence to bolster their claims of unfair treatment. Particularly offensive to stakeholders will be a perception that some contract or understanding has been broken. When and if stakeholders feel they have been treated unfairly will depend on the context or institutional setting.

This may seem like a gloomy recital. At the same time, it also gives stakeholders in the privatization process a list of things to guard against and to try to forestall. They may even realize that, although it may be easy to feel that they are the victims of an "uneven playing field," rival stakeholders may have a different view of what constitutes a level playing field. The rivals may be very ingenious in coming up with arguments as to why *they* are in fact the victims. Furthermore, the rivals may hold these beliefs, as outlandish as they seem, with utmost sincerity.

The list suggests several things to do to avoid or, at least minimize, fairness fights. For example, material principles will have to be invoked to give the terms *equals, unequals, and relevant similarities and differences* specific meanings in the Formal Principle. These meanings should be as clear and unambiguous as possible. Otherwise, some stakeholder group or other will conclude that some contract has been broken and that it is being treated unfairly.

The fact that context is so important to perceptions of fair or unfair treatment suggests that lack of context definition may lead to fairness fights. However, it also suggests that invoking a specific context may be a tool for forestalling them. For example, in economic experiments regarding "fair" income distribution, there was a large variance in what college student subjects considered a fair minimum family income. When, however, prior to the experiments, the subjects received information on the Census Bureau's definition of the poverty-level income, the variance narrowed significantly.[29] Common knowledge of the poverty-level income gave the students a reference or focal point. This suggests that the more precisely new institutions of privatization are defined, the more likely are fairness fights to be avoided.

It also suggests that there is an advantage to using existing institutions that are stable. So, for example, respecting status quo property rights may in fact be a good idea, especially if this allows stakeholders to engage in mutually advantageous ("win-win") transactions. Schlicht states it well:

> . . . costly conflicts and coordination failures can be avoided by adopting some coordination device. . . .
>
> Once a coordination rule is selected for historical or other reasons, it can be sustained by the self-seeking behavior of individuals without any reference to commitment or preference. A coordination rule will remain in place as long as it is advantageous for each individual to observe it, provided the others do the same. This explains persistence. A typical assumption would be that the status quo—the perceived pattern—serves as a focal point, which can be used for coordination purposes.[30]

Finally, the privatization process should not lose sight of the importance of the institutional design leading to economic efficiency. Elsewhere I have argued that in general designs based solely on fairness, without regard to efficiency, may end up being considered unfair.[31] For example, according to Levine (1981), airline deregulation in the United States was to a large extent a reaction to the various inefficiencies introduced and propagated by the CAB's attempts to regulate "fairly."[32] In this regard, it should be

[29]P. Oleson, 2001, An experimental examination of alternative theories of distributive justice and economic fairness, Ph.D dissertation, Department of Economics, University of Arizona, Tucson.

[30]E. Schlicht, 1998, *On Custom in the Economy*, Clarendon Press, Oxford, U.K., p. 131.

[31]E.E. Zajac, 1998, The Telecommunications Act of 1996: A policy analysis test bed, in *Telecommunications Transformation: Technology, Strategy and Policy*, E. Bohlin and S. Levin, eds., IOS Press, Amsterdam, p. 301.

[32]M. Levine, 1981, Revisionism revised? Airline deregulation and the public interest, *Law and Contemporary Problems*, v. 44, p. 179-195.

remembered that the free market inherently promotes economic efficiency and, moreover, tends to be less plagued by fairness fights. Thus, the emphasis in the NRC's *Resolving Conflicts* report on marketizing public activities is well placed. We in fact saw this with the FCC's decision to auction off the spectrum allocated to digital cellular service.

Appendix F

Biographical Sketches of Committee Members

John A. Armstrong, *chair*, is retired IBM vice president of science and technology. He is the author or co-author of some 60 papers on nuclear resonance, nonlinear optics, photon statistics of lasers, picosecond pulse measurements, multiphoton spectroscopy of atoms, management of research in industry, and issues of science and technology policy. He received the George E. Pake Prize of the American Physical Society in 1989. He has served on numerous National Research Council (NRC) bodies, including the Commission on Physical Sciences, Mathematics, and Applications, where he was liaison to the Computer Science and Technology Board. He also chaired the recent NRC study *Managing the Space Sciences*. Dr. Armstrong is currently chair of the governing board of the American Institute of Physics, a member of the National Academy of Engineering, and a member of the National Science Board, Class of 2002.

Richard A. Anthes, *vice-chair*, is president of the University Corporation for Atmospheric Research (UCAR). His research interests include weather phenomena such as hurricanes and tropical cyclones. Following a faculty position at Pennsylvania State University, he joined the National Center for Atmospheric Research (NCAR), first as director of the Atmospheric Analysis and Prediction Division, then as director of NCAR. He become president of UCAR in 1988. Dr. Anthes has published over 100 articles and books. One book in particular, *Meteorology* (7th ed., Prentice Hall, 1996), is widely used at colleges and universities as a general introductory book to the field of meteorology for non-meteorology majors. Dr. Anthes chaired the NRC's Committee on National Weather Service Modernization and was a member on the Board on Atmospheric Sciences and Climate and the Committee on Earth Studies.

William Y. Arms is a professor of computer science at Cornell University. Although his background is in mathematics and operational research, his career has focused on applying computing to academic activities, particularly educational computing, computer networks, and digital libraries. He recently chaired a National Science Foundation workshop on a national digital library for undergraduate science, mathematics, engineering, and technology education and authored a section in an NRC report on the same subject. Dr. Arms is a former chair of the Association for Computing Machinery and serves as editor of D-Lib Magazine and a digital libraries and electronic publishing series by MIT Press.

William E. Easterling III is professor of geography and Earth system science and director of the Environmental Consortium and Environmental Resources Research Institute at the Pennsylvania State University. His current research focuses on modeling El Niño-Southern Oscillation effects on southeastern agriculture, social drivers of land use change in response to climate change in the Great Plains, and the use of high-resolution climate change scenarios to simulate crop yields. Dr. Easterling chaired the NRC Panel on the Human Dimensions of Seasonal-to-Interannual Climate Variability that produced the report *Making Climate Forecasts Matter*. He is the lead author of the chapter on agroecosystems and food security in the third assessment report of the Intergovernmental Panel on Climate Change and has edited three books related to the impact of climate change on society.

Richard S. Greenfield was the first director of the Atmospheric Policy Program of the American Meteorological Society (AMS). Before joining the staff of the AMS, he spent 25 years at the National Science Foundation, including nearly seven as director of the Division of Atmospheric Sciences. Dr. Greenfield's primary policy interests include weather and climate influences on national priorities, national and international approaches to data exchange issues, and public-private partnerships to provide weather and climate products and services. Internationally, he served as a U.S. delegate to the World Meteorological Organization and as a member of several of its commissions, panels, and boards. He has been the recipient of numerous honors and awards.

William W. Hoover (ret.) is currently a consultant for aviation, defense, and energy matters. He is the former executive vice president of the Air Transport Association of America, where he represented the interests of the

U.S. major airlines industry, particularly as they related to technical, safety, and security issues. Prior to holding that position, he served as the assistant secretary for defense programs at the U.S. Department of Energy, where he was responsible for the U.S. nuclear weapons development program. He is also a major general, U.S. Air Force (retired), and held positions of responsibility within the North Atlantic Treaty Organization, at the Pentagon with the secretary of the Air Force, and in Vietnam, where he commanded a combat air wing and flew as a fighter pilot. General Hoover currently chairs the NRC's Aeronautics and Space Engineering Board.

Jessica Litman is a professor of law at Wayne State University in Detroit, Michigan, where she teaches courses in copyright law, Internet law, trademarks, and unfair competition. Before joining the Wayne State faculty in 1990, she was an associate professor at the University of Michigan Law School. Ms. Litman is the author of the recently published book *Digital Copyright* (Prometheus, 2001). She has also published many articles on copyright, trademark, and Internet law and is co-author of the third edition of Ginsburg, Litman & Kevlin, *Trademark and Unfair Competition Law* (Foundation, 2001). Ms. Litman is a past trustee of the Copyright Society of the USA and a past chair of the American Association of Law Schools' Section on Intellectual Property. She has testified before Congress and before the White House Information Infrastructure Task Force's Working Group on Intellectual Property. She currently serves on the advisory board of Cyberspace Law Abstracts and the American Civil Liberties Union Committee on Intellectual Property and the Internet.

Gordon McBean is a professor in the departments of geography and political science at the University of Western Ontario and chair for policy at the Institute for Catastrophic Loss Reduction, which is supported by the Insurance Bureau of Canada. Prior to June 2000 he was the assistant deputy minister for the Meteorological Service of Canada, Environment Canada, and permanent representative of Canada to the World Meteorological Organization. In that position he directed a two-year analysis of weather services that redefined the role of the government. He is currently a member of the Task Force for the Canadian Information System for the Environment and the International Council for Science Advisory Committee for the Environment. He has served on several NRC committees, including the Panel on Climate Observing Systems Strategy. Dr. McBean has also served as a consultant to the Australian Bureau of Meteorology and co-chaired the Subpanel on Earth Observations of a review of Japan's National Space Development Agency.

Ravi V. Nathan is general manager of the Weather Derivatives Group at

Aquila, Inc., where he is responsible for strategic initiatives and day-to-day management of the weather derivatives business. An economist and financial analyst by training, Dr. Nathan has spent the past five years developing strategies for allowing businesses sensitive to the vagaries of weather to protect themselves against changes in costs and sales linked to variations in climate. Prior to working in the weather derivatives industry, he spent five years as an associate professor of finance at Northeastern Oklahoma State University and five years as a manager at Grindlays ANZ Bank in Bombay, India. Dr. Nathan is president of the Weather Risk Management Association and was a participant in the U.S. Weather Research Program Workshop on the weather research needs of the private sector.

Maria A. Pirone is director for global data products and services at WSI Corporation. She has over 25 years' experience in information technology, with the last 15 years in weather information services. She has degrees in chemistry and business administration and has held management positions in both marketing and technical development. She is currently responsible for the policy, direction, and revenue performance for WSI's global data and imagery products and services. Market responsibility includes media, aviation, government, industry, and education. She serves as liaison to both U.S. and international meteorological agencies for WSI and was appointed private sector advisor to the U.S. permanent representative to WMO for the 2000 Executive Council meeting in Geneva. Ms. Pirone is a member of the American Meteorological Society's Private Sector Board, the Federal Aviation Administration's Weather Research Program Product Development Team, and RTCA's Special Committee 195 for Datalink Applications for Aviation, and is president of the Commercial Weather Services Association.

Roy Radner is the Leonard N. Stern School Professor of Business at New York University. Prior to joining New York University, he was a distinguished member of the technical staff at AT&T Bell Laboratories, and a professor of economics and statistics at the University of California, Berkeley. Dr. Radner's research interests include the strategic analysis of global climate change, and theories of information processing and decentralization within firms. He is a member of the NRC Committee on Geophysical and Environmental Data, and a past member of the NRC High-Technology/Information-Technology Workforce. He is also a member of the National Academy of Sciences, a fellow of the American Academy of Arts and Sciences, and a distinguished fellow of the American Association for the Advancement of Science and of the American Economic Association.

Robert T. Ryan is chief meteorologist with WRC-TV in Washington, D.C. He began his broadcast career in 1970 while working as a research associate in the physics section of Arthur D. Little, Inc., in Cambridge, Mass. He has since won eight Emmys for excellence in broadcast meteorology. In addition to his broadcast activities, Mr. Ryan developed the 4-WINDS program (Weather Interactive Demonstration Schoolnet), which placed 200 interactive computerized weather stations in "at need" Washington areas schools. He has written several articles on the need to better communicate scientific information and is co-investigator of a NASA-funded cooperative agreement with WRC-TV to provide public access to Earth and space science data via television. Mr. Ryan is a fellow and former president of the American Meteorological Society, and is currently chair of the AMS Development Committee. He received the Charles Franklin Brooks Award for service to that society in 1997. He is a past member of the Board on Atmospheric Sciences and Climate.

Karen R. Sollins is a principal research scientist in the Advanced Network Architecture Group at the Massachusetts Institute of Technology Laboratory for Computer Science (LCS). Her research interests focus on support for network based systems and applications. Several years ago she led the Information Mesh Project, addressing architectural problems of an extremely long-lived global mesh of information, followed by work on issues of extreme scaling in the net. She was a guest editor of a special issue of *Personal Communication on Smart Environments* in October 2000. In addition to publishing, she has taken her work to the standards community and chaired a research group consisting of a mix of academics and members of industry to address infrastructural problems. In 1999 and 2000 she was a senior program director for networking research at the National Science Foundation, on leave from LCS.

NRC Staff

Anne M. Linn is a senior program officer with the Board on Earth Sciences and Resources of the National Academies. She has been with the board since 1993, directing the USA World Data Center Coordination Office, and staffing a wide variety of geophysical and data policy studies. In addition, she is the secretary of the International Council for Science (ICSU) Panel on World Data Centers, and a member of the ICSU Ad Hoc Committee on Data. Prior to joining the staff of the National Academies, Dr. Linn was a visiting scientist at the Carnegie Institution of Washington and a postdoctoral geochemist at the University of California, Berkeley. She received a Ph.D. in geology from the University of California, Los Angeles.

Cynthia Patterson is a study director and program officer with the Computer Science and Telecommunications Board (CSTB) of the National Academies. She is currently involved in several CSTB projects, including one on critical information infrastructure protection and the law, a project that explores the intersection of geospatial information and computer science research communities, and a congressionally-mandated study on Internet searching and the domain name system. Prior to joining CSTB, Ms. Patterson completed an M.Sc from the Sam Nunn School of International Affairs at the Georgia Institute of Technology. Her graduate work was supported by the Department of Defense and SAIC. In a previous life, Ms. Patterson was employed by IBM as an IT consultant for both federal government and private industry clients. Her work included application development, database administration, network administration, and project management. She received a B.Sc. in computer science from the University of Missouri, Rolla.

Shannon Ruddy is a senior project assistant with the Board on Earth Sciences and Resources at the National Research Council. She holds a B.A. in environmental science from LaSalle University in Philadelphia. Previously, she worked as a researcher for Booz-Allen & Hamilton in the Environmental Protection Agency's Region 3 CERCLA/Superfund records center.

Appendix G

Acronyms

ADDS	Aviation Digital Data System
AMPS	Antarctic Mesoscale Prediction System
AMS	American Meteorological Society
APA	Administrative Procedures Act
ASOS	Automated Surface Observing System
CAB	Civil Aeronautics Board
COMET	Cooperative Program for Operational Meteorology, Education and Training
CRAFT	Collaborative Radar Acquisition Field Test
CWSA	Commercial Weather Services Association
DOD	Department of Defense
DOT	Department of Transportation
ECMWF	European Centre for Medium-Range Weather Forecasts
ENSO	El Niño-Southern Oscillation
EOS	Earth Observing System
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FACA	Federal Advisory Committee Act
FAIR Act	Federal Activities Inventory Reform Act
FCC	Federal Communications Commission
FFRDC	Federally Funded Research and Development Center
FSL	Forecast Systems Laboratory
GDP	gross domestic product
GPS	Global Positioning System

NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NCEP	National Centers for Environmental Prediction
NDFD	National Digital Forecast Database
NEXRAD	NEXt generation weather RADar
NIDS	NEXRAD Information Dissemination Service
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-Orbiting Operational Environmental Satellite System
NRC	National Research Council
NSF	National Science Foundation
NWS	National Weather Service
OMB	Office of Management and Budget
PSU	Pennsylvania State University
RCC	radio common carrier
RMS	root-mean-square
UCAR	University Corporation for Atmospheric Research
UHF	ultrahigh frequency
UV	ultraviolet
WITI	Weather Information Technologies, Inc.
WLCC	wireline common carrier
WMO	World Meteorological Organization