National Solar-Terrestrial Research Program (1984)

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Board on Atmospheric Sciences and Climate
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National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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The Committee on Solar-Terrestrial Research is pleased to acknowledge the support of the National Science Foundation, the Air Force, the National Aeronautics and Space Administration, and the National Oceanic and Atmospheric Administration. However, any opinions, findings, conclusions, or recommendations expressed herein are those of the authors and do not necessarily represent the views of these agencies.

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PREFACE

In response to a request from several concerned federal agencies--the Department of Defense, the National Science Foundation, the National Oceanic and Atmospheric Administration, and the National Aeronautics and Space Administration--the Board on Atmospheric Sciences and Climate asked its Committee on Solar-Terrestrial Research to undertake this study. It was requested now because of a strong shared conviction on the part of the federal agencies, the scientific community, and the Office of Science and Technology Policy that there is an urgent need to achieve a thorough understanding of our solar-terrestrial environment. In addition, there is a belief that achieving such understanding will require a well-planned and organized effort to elucidate the physical and chemical processes controlling the complex interactive behavior of the solar-terrestrial system.

This report recommends the formation of a National Solar-Terrestrial Research Program to implement the recommendations of the earlier National Research Council study *Solar-Terrestrial Research for the 1980's* (1981). The earlier study, which took over 18 months to complete and involved the participation of more than 50 scientists, specifically identified the principal scientific and management recommendations required for a balanced solar-terrestrial program. The present study was undertaken by the Committee on Solar-Terrestrial Research in the fall of 1983. Together, the two studies constitute a set that prescribes a broad-gauged solar-terrestrial program.

Chapter 1 briefly discusses solar-terrestrial research, including specific examples of the major scientific problem areas affecting our understanding of the coupled solar-terrestrial system. Chapter 2, as already mentioned, calls for the establishment of a National Solar-

Terrestrial Research Program and summarizes three recommendations that must be implemented for a well-balanced program. Chapter 3 describes the recommendations more fully, and Chapter 4 discusses the justifications for the recommendations.

The Committee on Solar-Terrestrial Research takes this opportunity to thank the many contributors to the report. We gratefully acknowledge the cooperation and support of many people in the National Research Council, particularly Herbert Friedman, Chairman of the Commission on Physical Sciences, Mathematics, and Resources; Thomas F. Malone, Chairman of the Board on Atmospheric Sciences and Climate; and Thomas A. Donahue, Chairman of the Space Science Board. We also acknowledge the cooperation and support of various agency officials, especially R. Behnke, E. W. Bierly, A. Christiansen, R. S. Greenfield, and D. S. Peacock of the National Science Foundation; J. T. Lynch, J. D. Rosendhal, S. D. Shawhan, S. G. Tilford, and M. J. Wiskerchen of the National Aeronautics and Space Administration; J. H. Allen, D. M. Hunt, and H. Leimbach of the National Oceanic and Atmospheric Administration; R. C. Sagalyn of the Air Force; and P. Try of the Department of Defense.

Devrie S. Intriligator, *Chairman*
Committee on Solar-Terrestrial Research

EXECUTIVE SUMMARY

We recommend a National Solar-Terrestrial Research Program of importance to the nation, as well as to its scientific community. This program will enable us to increase significantly our understanding of the key physical mechanisms coupling the solar-terrestrial system. Solar-terrestrial research is the study of the essential processes by which energy in all forms is generated by the Sun, is transported to Earth, and ultimately vitally influences the terrestrial environment. The principal science issue today in solar-terrestrial research is to understand this coupled system. We stress that the recommended science are not subsets of one another and that all require funding in parallel for a balanced program.

RECOMMENDATION 1. We recommend an approved new start for the International Solar-Terrestrial Physics Program, a major observational mission that is already well along in NASA's planning.

RECOMMENDATION 2. We recommend an increase in annual solar-terrestrial research funding above present levels by $65 million in fiscal year 1986, to be held level (in 1984 dollars) over the next decade, to support other essential programs.

RECOMMENDATION 3. We recommend that there be formal interagency coordination among the interested federal agencies for the implementation and conduct of the National Solar-Terrestrial Research Program discussed in this document.

Only the fullest possible understanding of the physics and chemistry of the solar-terrestrial system will make it possible to evaluate the effects of growing human influences on our environment. Of all the planets, Earth and its biosphere present the widest range of interacting physical and chemical processes. We now have the technical resources and the skilled personnel to study this living system on a day-to-day basis and on a global scale. This is a challenge to which we must respond without delay.

1

INTRODUCTION

Almost all of the energy resources available to man--light, wood, water power, wind, coal, and oil--can be traced to the solar radiation intercepted by the Earth. It is indeed providential that the Sun is so stable, for even minor variations in solar illumination of the Earth have been found to be closely correlated with ice ages. The potentially hazardous invisible emanations from the Sun are much more variable. Without proper shielding, astronauts and space-based systems could be exposed to catastrophic doses of radiation from great flares. Solar activity also produces disturbances in communications and in electrical power distribution, effects that are clearly important from both practical and national security viewpoints.

More than ever, mankind appreciates that human activity can significantly affect the environment and that space is an essential part of economic and social progress.

Solar-terrestrial research is the study of the essential processes by which energy in diverse forms is generated by the Sun, is transported to Earth, and ultimately vitally influences the terrestrial environment. It deals with the direct irradiation of the upper atmosphere by the full spectrum of electromagnetic radiation and with the transport of particles and fields from the Sun, through the interplanetary medium, to and through the magnetic field of the Earth and into its atmosphere.

Solar-terrestrial research is concerned with the critical complex interplay of physical and chemical processes in every element of the Sun-Earth system. The principal science issue in solar-terrestrial research today is the need for understanding the coupled system.

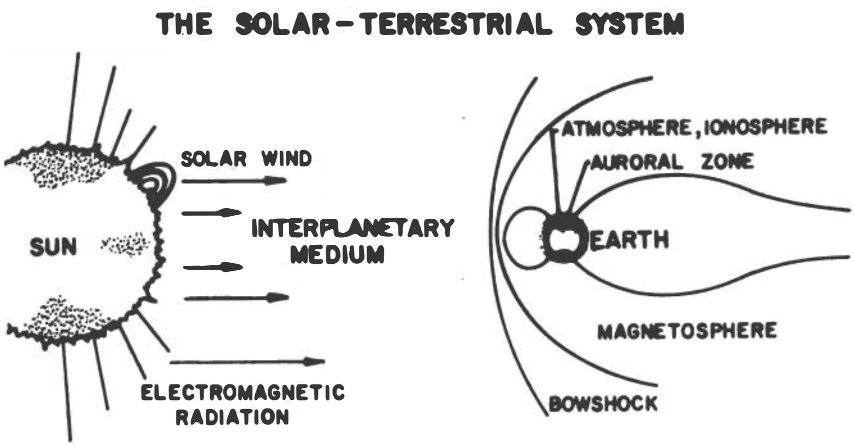

FIGURE 1 The Solar-terrestrial system (courtesy of D. S. Intriligator, Carmel Research Center).

The solar output reaches the Earth either through electromagnetic radiation or the magnetized plasma streams of the solar wind (see Figure 1). The electromagnetic radiation directly drives the circulation of the atmosphere, while the solar wind drives a diverse collection of fundamental phenomena ranging from the acceleration of particles in interplanterary space to geomagnetic storms and the aurora. A further complication results because the Sun is a variable star, with transient outbursts such as solar flares and long-term cyclic changes in solar magnetism.

There are major complex scientific dilemmas surrounding our understanding of the coupled solar-terrestrial system. The following three examples illustrate these problems.

Processes within the solar convection zone give rise to the magnetic field, which is carried toward the Earth by the solar-wind plasma. The solar wind is deflected by the Earth's intrinsic magnetic field, thus producing the magnetosphere. The variable orientation of the interplanetary magnetic field with respect to the fixed orientation of the Earth's internal dipole field determines the extent to which processes within the magnetosphere and the auroral zone perturb the ionosphere and atmosphere. In this complex chain of cause and effect it is necessary to determine the major mechanisms responsible for the generation of the solar magnetic field, its important interactions with the magnetospheric field, and the effect of the ionosphere and atmosphere on the resulting interaction.

As a second example, it is known that small changes in the solar radiative output can significantly influence the ozone chemistry of the atmosphere. Despite its thinness (0.3 cm at atmospheric pressure), the ozone layer plays an essential role in the preservation of life on Earth since it absorbs nearly all of the potentially lethal solar-ultraviolet radiation that enters the atmosphere. In this critical chain of cause and effect it is necessary to determine the Sun's short-term and long-term variability in the relevant (175-242 nm) wavelength range and the corresponding variations in atmospheric ozone.

A third example concerns the response of the coupled Sun-solar wind-magnetosphere-ionosphere-atmosphere system to transient events originating at the Sun. These give rise to both radiative and plasma effects. Solar extreme-ultraviolet and x-ray outputs can be dramatically increased for short periods, producing substantial atmospheric-chemistry perturbations related to both the ozone budget response and the enhanced ionization. A traveling shock wave in the solar wind triggers a violent magnetosphere response, resulting in strongly intensified auroral activity. To understand this sequence it is necessary to determine the nature of the flare process; the manner in which a shock disturbs the solar wind, including its local acceleration of particles and its perturbations of the interplanetary magnetic field; the important and complex changes induced in the magnetosphere by the passage of the shock; and the major chemical consequences of sudden enhancements in the level of atmospheric ionization from both radiative and particle energy.

The solar-terrestrial system also provides us with a unique laboratory for investigating questions of astrophysics and of many other branches of science. For example, the increasing precision of measurements, numerical modeling, and theory applied to space-plasma problems amounts to a revolution in technique relative to 10 years ago. As a result, the study of space plasmas has become one of the primary motivations and experimental areas for basic plasma research. The solar-terrestrial system is the primary laboratory in which astrophysical processes of great generality can be studied in situ. In addition, the Sun is the only star available for close-up, detailed studies. The physical processes responsible for its structure and dynamic energy transformation phenomena are still not understood, but they are particularly important to the understanding of other main-sequence stars, and they serve as a model of many stellar phenomena. For example, study of solar activity is providing insight into stellar wind flows from the Beta Cephei class of pulsating stars such as Sigma Scorpius. Also, the magnetospheres of Earth and Jupiter are much more accessible than the magnetospheres of neutron stars or galaxies, and our knowledge of planetary magnetospheres has yielded important insights into how pulsars and radio galaxies may behave. Our studies provide knowledge of the evolutionary history of the Sun-Earth system and of the solar system. Some of the plasma processes, which are so important for the development of controlled thermonuclear power, were first identified and analyzed within the context of solar-terrestrial research. High-energy particle acceleration by shock waves--at the Sun and in the interplanetary plasma--is relevant to both astrophysics and laboratory plasma physics.

This report presents an implementation strategy for the recommendations contained in the NRC report *Solar-Terrestrial Research for the 1980's* (see Appendix A). That report emphasizes the need to develop a unified physical description of this coupled system. Other independent NRC reports, such as *Solar-System Space Physics in the 1980's: A Research Strategy* and *Space Plasma Physics: The Study of Solar-System Plasmas* (see Appendix B) illustrate the unanimity of this conclusion among solar-terrestrial researchers and researchers in many related scientific fields. In responding to this challenge, we are recommending a National Solar-Terrestrial Research Program for the unified study of the intricate causal chain by which events on the Sun significantly influence our environment on Earth.

In studying these important causal connections, we must necessarily achieve a synthesis of many disciplines including solar physics, interplanetary physics, magnetospheric physics, ionospheric physics, aeronomy, and atmospheric physics and chemistry. The various elements of the solar-terrestrial system have been explored aggressively, and many of these elements are well understood individually. In some cases, major progress has been made in understanding the mutual interactions of these elements. The time has come to put all the pieces of the puzzle together. Recent technological advances and theoretical understanding of the individual aspects are such that a well-planned, adequately funded interdisciplinary effort should lead to significant advances in our understanding of the system as a whole. Favorable action by the government beginning in fiscal year 1986 can bring this global initiative to pass.

2

SUMMARY OF RECOMMENDATIONS

We recommend the establishment of a National Solar-Terrestrial Research (STR) Program. We present here only those elements that we consider to be most vital. We refer the reader to the report *Solar-Terrestrial Research for the 1980's* (see Appendix A) for additional science justifications and for a description of other useful programs needed for a broad-based effort. Other recent studies that are pertinent are listed in Appendix B.

This proposed program is fiscally conservative and relies heavily on already existing or planned programs. It balances major observational efforts (Category A) with a vigorous program of theory, data analysis, and ground-based and suborbital research (Categories B and C) to maximize the results from the whole program. These categories (A, B, and C) have been established on the basis of the scale of resources required for their completion. We emphasize that this separation has been done for budget planning purposes only, with Category A components being "major" (over $100 million), Category B components "moderate" (each on the order of $10 million per year), and Category C components "modest" ($1 million to $5 million per year each). *We stress that these categories are not subsets of one another, and all should be funded in parallel for a balanced program.* Priorities have been established within the categories, with Priority 1 the highest priority and Priority 2 of very high priority. The increment of $65 million in fiscal year 1986, to be held level (in 1984 dollars) over the next decade, should be allocated to the appropriate federal agencies: the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the Department of Defense (DOD).

RECOMMENDATION 1. *We recommend an approved new start for the International Solar-Terrestrial Physics Program, a major observational mission that is already well along in NASA's planning.*

CATEGORY A. Major Components (each over $100 million in total)

The International Solar-Terrestrial Physics Program (ISTP) [Priority 1]

We acknowledge and are pleased that the federal government has approved the Upper Atmosphere Research Satellite (UARS) and the Solar Optical Telescoope (SOT) missions. We view ISTP, UARS, and SOT as integral elements of the National Solar-Terrestrial Research Program. We urge that these approved missions proceed expeditiously.

RECOMMENDATION 2. *We recommend an increase in annual solar-terrestrial research funding above present levels by $65 million, to be held level (in 1984 dollars) over the next decade, to support Category B and C components.*

CATEGORY B. Moderate Components (each $10 million to $20 million per year)

Initiative in Data Analysis [Priority 1]
Solar Variability [Priority 1]
Magnetosphere-Ionosphere Coupling [Priority 1]
Middle-Atmosphere Studies [Priority 1]
Rapid-Turnaround Projects [Priority 2]

CATEGORY C. Modest Components (each $1 million to $5 million per year)

Increased Acquisition of IMP-8 Data [Priority 1]
Coordinated Campaigns [Priority 1]
Ground-Based Synoptic Measurements [Priority 1]
Solar Seismology [Priority 2]
Global Electric Circuit [Priority 2]
Educational Programs [Priority 2]
Thermospheric Measurements [Priority 2]
Stokes Polarimeter [Priority 2]

RECOMMENDATION 3. *We recommend that there be formal interagency coordination among the interested federal agencies for the implementation and conduct of the National Solar-Terrestrial Research Program discussed in this document.*

3

EXPANDED PROGRAM DESCRIPTION AND RECOMMENDATIONS

RECOMMENDATION 1

CATEGORY A. Major Components

This category comprises approved, continuing, or previously recommended major spacecraft missions. Our recommendation in this category is for a fiscal year 1986 new start for the International Solar-Terrestrial Physics Program. This mission has equal priority with the previously approved Upper Atmosphere Research Satellite and the Solar Optical Telescope missions.

Major New Start: International Solar-Terrestrial Physics Program (ISTP) [Priority 1]

The International Solar-Terrestrial Physics Program (ISTP) plans for six new spacecraft systems in key regions that will investigate the chain of processes from the solar interior to the Earth's magnetosphere and ionosphere. This is a joint U.S.-European-Japanese Program involving three U.S. spacecraft. The U.S. portion of this program was previously called the Origin of Plasmas in the Earth's Neighborhood (OPEN). It is proposed to launch the ISTP spacecraft in the period from 1989 to 1992 and that the resulting data base be accessible to the worldwide scientific community. Measurements of the solar wind, the interplanetary magnetic field, and related parameters are essential to many phases of solar-terrestrial research. The first ISTP spacecraft, WIND (scheduled for launch in late 1989), will conduct these fundamental interplanetary observations. The SOLAR spacecraft will study the Sun's output; the MULTIPOINT series will investigate the microphysics of the magnetopause; and POLAR, EQUATOR, and TAIL spacecraft will survey the flow of energy and particles through the magnetosphere. The National Research Council's Space Science Board has strongly endorsed ISTP. In view of the critical nature of all the ISTP measurements, we strongly recommend that the ISTP be given a fiscal year 1986 new start.

Upper Atmosphere Research Satellite (UARS)

The most effective means for acquiring comprehensive data on the upper atmosphere is the use of remote-sensing instruments on a satellite. Current technology has made it possible to develop instruments that can measure, with high precision on a global scale, incident solar radiation, ozone and other chemical species, and the temperature and motion of the upper atmosphere. The UARS program takes advantage of these capabilities and will provide for the first time the global data set required to probe chemistry and dynamics and the radiative and magnetospheric inputs of the upper atmosphere. The Space Science Board strongly endorsed UARS. We strongly support NASA's commitment to UARS as an important new start program in fiscal year 1985.

Solar Optical Telescope (SOT)

The Solar Optical Telescope (SOT) will provide frontier observations of solar magnetic, velocity, and intensity fields with unprecedented spatial resolution. The SOT observations will be fundamental for understanding the physical bases of both solar variability (time scales from days to years) and solar activity (seconds to hours). After the initial flight and two or three reflights, each lasting 7 to 10 days, SOT is expected to become one of the major facilities of an Advanced Solar Observatory, which would function for at least 6 to 12 months as a free flyer or on a space platform. The Space Science Board strongly endorsed SOT. We strongly support a timely launch of this scientifically important and cost-effective facility.

RECOMMENDATION 2

We recommend the implementation of the following Category B and Category C components of the National Solar-Terrestrial Research Program.

CATEGORY B. Moderate Components

Initiative in Data Analysis [Priority 1]

It is vital that there be a new initiative in data analysis to make full use of existing and planned ground-based and space-based data in order to investigate the many connections that exist between various components of the solar-terrestrial system. To achieve this goal, the cognizant agencies, NSF, NOAA, and NASA, should undertake a substantial augmentation of existing programs. This initiative has three major elements:

a. *Modeling, simulation, and analysis of existing data*. An increment of approximately $10 million per year is required for this important effort. Preference should be given to research projects that investigate the interconnection of the various elements of the solar-terrestrial chain. This analysis effort should complement NASA's Solar-Terrestrial Theory Program and Guest Investigator Programs, which should be continued.

b. *Computer Networking*. The establishment of a computer network to enable scientists to interchange data and models more effectively is critical. An initial commitment of about $10 million per year in fiscal year 1986 and 1987 in order to establish a "STR network," including minicomputer hardware as necessary, and approximately $3 million per year thereafter is needed. The system should include NASA's expanded Space Physics Analysis Network and National Space Science Data Center, the NSF incoherent-scatter radar data base and the NOAA World Data Centers, as well as individual scientists at various institutions. Forthcoming observational programs should be encouraged to incorporate their data into the system (see Appendix E).

c. *Workshops*. A series of workshops is vital to assimilate and analyze interdisciplinary data. A funding level near $2 million per year is necessary for supporting pre-workshop and postworkshop studies and analyses as well as the workshops themselves. Studies that focus on the significant interconnection of links in the solar-terrestrial chain should be emphasized. The Study of Traveling Interplanetary Phenomena (STIP) sponsored by the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) is a good example of such an interdisciplinary study. The development of computerized data bases and analysis software is technologically feasible and necessary to maximize the scientific return. These costs are included in our estimate.

Solar Variability [Priority 1]

The initiation of a systematic long-term study of the total solar irradiance (the "solar constant") and the solar ultraviolet spectral irradiance is critical. A funding augmentation averaging about $10 million per year is needed. The most direct link between the Sun and the Earth is the flow of radiative energy, and even small variations can have profound effects on the atmosphere and ionosphere. Space-based observations through NASA, NOAA, and DOD should be enhanced by ground-based NSF- and NOAA-sponsored observations.

Magnetosphere-Ionosphere Coupling [Priority 1]

It is important to enhance and upgrade the existing ground-based instruments studying the coupling among the magnetosphere, ionosphere, and thermosphere. A funding augmentation of approximately $10 million per year is needed for a vigorous program of well-planned and coordinated ground-based and spaceborne measurements of key ionospheric and atmospheric parameters. Funds should be allocated to upgrade the chain of incoherent-scatter radar stations and other existing instruments (e.g., magnetometers, photometers). Through NSF and NASA, funds should be used to develop new techniques and sensors for ground-based and spaceborne measurements.

Middle Atmosphere Studies [Priority 1]

Support for the initiatives recommended by the U.S. Panel on the Middle Atmosphere Program (MAP) is required. This includes an aggressive theoretical and ground-based program of study of the radiation, chemistry, and dynamics of the upper mesosphere, middle-atmosphere waves and turbulence, and long-term measurement of dynamically and chemically important quantities. A funding augmentation of about $5 million per year is needed.

Rapid-Turnaround Projects [Priority 2]

Significant strengthening of rapid-turnaround projects such as balloons, rockets, Spartans, and other Shuttle payloads is needed. This increase in small-scale flight opportunities is essential to promote the development and testing of new instrumentation, for the more rapid testing of theoretical ideas, and to provide for training in experimental techniques for graduate and postdoctoral students. In addition, these activities will be useful for coordinated campaigns. A funding augmentation of $10 million per year is the minimum required.

CATEGORY C. Modest Components

Increased Acquisition of IMP-8 Data [Priority 1]

NASA should ensure the maximum interplanetary data acquisition from IMP-8, which obtains the only near-Earth measurements currently available of interplanetary magnetic field and solar-wind density, speed, and temperature. A funding level near $2 million per year is necessary to maintain tracking. We consider this to be the highest priority in Category C.

Coordinated Campaigns [Priority 1]

A series of coordinated campaigns, triggered either by specific solar or interplanetary events or by predesignated "world days," to facilitate the study of interconnections within the Sun-Earth system is critical. These campaigns will coordinate data acquisition, postobservational studies, and data analysis. The required funding is estimated to be $2 million per year.

Ground-Based Synoptic Measurements [Priority 1]

A long-term program for the acquisition of synoptic measurements of the solar-terrestrial system by means of ground-based facilities is vital. These measurements should include optical solar data (e.g., spectroheliograms), radio observations (e.g., dynamic radio spectra, radioheliograms), interplanetary radio scintillations, terrestrial magnetic activity (e.g., Auroral Electrojet Index), ionospheric and atmospheric parameters (e.g., density, electric fields), and high-energy cosmic rays (e.g., neutron monitors). A funding augmentation of about $2 million per year is required.

Solar Seismology [Priority 2]

An instrumentation and theory program in helioseismology for probing the convective zone of the Sun and for understanding the dynamics of the solar interior is needed. Funding at a level of about $2 million per year is needed.

Global Electric Circuit [Priority 2]

A coordinated theoretical and observational effort is needed to explore the electrodynamic coupling among the troposphere, the ionosphere, and the magnetosphere. A funding level near $1 million per year is needed to augment balloon and rocket experiments and global modeling efforts.

Educational Programs [Priority 2]

The NSF should enhance its educational and research program to train qualified scientists in solar-terrestrial research. A funding increase of at least $1 million per year is necessary to enhance undergraduate, graduate, and postdoctoral education.

Thermosphere Measurements [Priority 2]

A program is required to measure neutral atmosphere parameters in order to study the effects of electromagnetic and particulate solar radiation and the interaction between the ionosphere and the neutral atmosphere. A funding level near $2 million per year is required to develop innovative ground-based techniques.

Stokes Polarimeter [Priority 2]

The construction of a new generation Stokes polarimeter to be incorporated in a telescope with active optics at a ground-based site with very-high-quality seeing conditions is needed to measure the small-scale magnetic and velocity fields on the Sun and to determine their relation to both solar variability and solar activity. Development and implementation of this instrument is expected to cost about $2 million per year.

RECOMMENDATION 3

Interagency Coordination for the National Solar-Terrestrial Research Program

Since the emphasis of the National Solar-Terrestrial Research Program is to understand the coupling between the various components of the system, efforts from individual groups or agencies cannot solve these complex problems in isolation. Interagency coordination is essential to maximize the scientific outputs of this program. We believe that the scientific effectiveness of the National Solar-Terrestrial Research Program can be significantly increased by interagency coordination. Intergroup and international coordination will further enhance the significant scientific output of the national programs in solar-terrestrial research.

4

JUSTIFICATION FOR THE RECOMMENDATIONS

RECOMMENDATION 1.

CATEGORY A. Major Components

The National Solar-Terrestrial Research Program outlined here seeks to emphasize the interconnections between disciplines by a coordinated observational and analytical study. This requires sophisticated simultaneous measurements of each of the key regions, by in situ measurements or by remote sensing as needed. The major spacecraft missions provide important observations and a focus for coordinating ground-based, rocket, balloon, and Shuttle experiments. We are confident that great new discoveries and insights will result from these improved measurements and new instrumentation.

The field of solar-terrestrial research has seen a revolution in the last few years, with many unexpected but important coupling phenomena observed. Exciting new discoveries have shown the impact on the magnetosphere of outflowing energized ionospheric plasma. The existence of electrostatic double layers have been demonstrated, leading to an alternative outlook based more on the continuity of electric current than on the motion of magnetic field lines. Such double layers may be of basic importance on the Sun, and within the auroral circuit, and give a new importance to small-scale phenomena in the global system. The discovery of coronal holes as a major source of high-speed solar-wind streams has led to a necessity for three-dimensional models of solar-wind generation. Variability in solar ultraviolet flux can affect stratospheric ozone levels, with serious consequences to the biosphere. Magnetospheric convection has been shown to drive upper-atmospheric motions via ion-neutral collisions, and surprisingly, the converse has also been shown to be true--the upper atmosphere keeps the magnetosphere in motion. These and other discoveries of the past few years, which would not have been possible without latest-generation instruments and techniques, have emphasized the interconnections among the different regions of the solar-terrestrial system and the necessity of feedback among theory, data analysis, and state-of-the-art observations.

Certain measurements are essential for investigating the coupling mechanisms. The major spacecraft missions, taken together, provide critical data with the high precision and resolution required. The specific measurements are described in detail in Appendix C, along with a description of the kinds of instruments and analysis techniques that are required. The combination of ISTP, UARS, and SOT will provide these crucial measurements. It is urgent, therefore, both for scientific and practical benefits, that the federal government ensure that these major missions are flown in a timely manner.

RECOMMENDATION 2

CATEGORY B. Moderate Components

Initiative in Data Analysis [Priority 1]

There already exists a substantial data base for use in the National Solar-Terrestrial Research Program. In light of new insights into the pertinent physical mechanisms, new analytical techniques, and newly available technology for dealing with this vast amount of data, it is necessary to conduct analytical and theoretical studies that concentrate on the coupling between different physical regimes. When a spacecraft is first flown, it is natural to concentrate on local phenomena. As our understanding of the coupling mechanisms (e.g., magnetic-field-aligned electric currents) increases, it becomes vital to analyze jointly data from many different sources: spacecraft, ground-based instrumentation, and rockets, for example. Theoretical models are now sophisticated enough that meaningful confrontations with data can be performed. Lastly, synoptic surveys of data (e.g., particle precipitation patterns measured from magnetospheric spacecraft) are important in developing global models (e.g., solar, interplanetary, and thermospheric dynamic models).

The initiative that we propose uses three sophisticated tools for mining the lode of solar-terrestrial data: computer modeling and simulation, computer networking, and computer-based workshops that combine data from multiple sources. These are discussed further in Appendix D.

Solar Variability [Priority 2]

The solar radiant output appears to vary slightly in total power, and more significantly it varies in its distribution with wavelength. However, both types of variations have important consequences for the Earth's upper atmosphere. Therefore, a first goal of any study of solar luminosity is to measure the variation of the solar constant over time scales from seconds to solar cycles. These measurements are needed as inputs to climate models and eventually in climate prediction, if solar variability can be predicted. Measurements made with the Active-Cavity Radiation Intensity Monitor (ACRIM) on the NASA Solar Maximum Mission (SMM) satellite have shown that the Sun's total irradiance--radiant output--varies by as much as 0.1 or 0.2 percent on a time scale of days. This variation is important and may significantly affect the Earth's atmosphere. In some cases, decreases in solar irradiance also seem to correlate with the occurrence of sunspots on the Sun's visible disk. Much remains to be learned about this correlation, its underlying physical mechanisms, and its influence on the Earth's atmosphere.

In view of the importance of total irradiance variations to terrestrial atmospheric phenomena and their possible relation to the 11-year sunspot cycle, it will be important to extend the ACRIM measurements to overlap with even more-sensitive measurements planned from the UARS mission in 1989. Supporting solar magnetograms, spectroheliograms, and white-light images are crucial for understanding and interpreting the spacecraft data.

A continuing program of ultraviolet spectral irradiance measurements is in progress and is also planned for the remainder of this decade both from the Shuttle [Spacelab and Environment Observation Missions (EOM)], from UARS, and from the NOAA operational satellites. It is essential to establish the credibility of widely differing measurements of the spectral irradiance, which may be due to changes in the Sun or differences in instrument calibration or sensitivity. Therefore, the planned NASA and NOAA programs should be augmented with strong support for both laboratory calibration, in-flight intercalibration, and the additional calibration that can be derived from analyzing supporting solar magnetograms and spectroheliograms. Supporting extreme ultraviolet spectroheliographs would be of considerable value if they were obtained from each EOM flight.

With this program of augmentation, more reliable information concerning solar radiation will be available for studies of the Earth's atmosphere.

Magnetosphere-Ionosphere Coupling [Priority 1]

A vast portion or the magnetosphere is electrically connected to the polar regions through the magnetic field lines. The polar regions are truly a window to outer space from which the solar wind-magnetosphere interactions can be studied. The ionosphere is not a passive element in this interaction--it plays a principal role in the global electric circuitry of the entire magnetosphere-atmosphere system. This circuit is extremely complex and constantly changing. Ground-based studies of the system include both radio and optical techniques. Incoherent-scatter radar measurements provide a wealth of information about the ionosphere including electric fields, current densities, ionospheric conductivities, Joule heating rates, ion-neutral collision rates, ionospheric composition, neutral wind and temperature, and precipitating particle fluxes. A great deal of progress has been made in recent years in establishing a meridional chain of radars extending from the polar cap to the equator. However, parts of the system employ old equipment that is in great need of repair and upgrading. Recent developments in electro-optical technology are stimulating research in ionospheric mapping, neutral dynamics and composition, particle precipitation, and spectroscopy of the upper atmosphere. Each radar's usefulness can be enhanced by adding a cluster of relevant sensors (e.g., photometers, Fabry-Perot interferometers, all-sky imagers), and funds are needed as well to develop and implement new instrumentation concepts fully. Cooperative efforts on an international scale involving radar and optical networks along with concerted global modeling of relevant phenomena can further enhance our understanding of the important coupling mechanisms.

Middle Atmosphere Studies [Priority 1]

Two augmentations for the Middle Atmosphere Program are needed. The first focuses on the mesosphere and the stratosphere, which is the frontier for demonstrable penetration of effects of solar variability and on possible solar-cycle effects that may impact our knowledge of climatically and chemically significant anthropogenic perturbations. An array of either mesosphere-stratosphere-troposphere (MST) or ST radars and lidar systems observing small-scale structures will enhance understanding of critical physical mechanisms contributing to the maintenance of the structure and dynamics of the middle atmosphere. The second major augmentation relates to measurement of variations of constituents on time scales of the order of several solar cycles. Measurements of stratospheric aerosol content and the radiatively important long-lived ozone chemistry precursors (e.g., N_2O, CH_4, $CFCl_3$, CF_2Cl_2, H_2O), including particularly a time series of profiles from the ground to the upper stratosphere at selected locations, are necessary.

Rapid-Turnaround Projects [Priority 2]

There are two needs for rapid-turnaround projects. The first is a need for studying the coupling associated with transient events that may have only a few hours' advance notice. The second is a need for observational projects that can be initiated and completed in a few years. Balloon and rocketborne hardware are ideal for satisfying these requirements. These should be launched, if possible, near clusters of ground-based instruments in order to study as many aspects of the coupled system at once as possible. These projects allow for prompt testing of theoretical models. For example, a launch into a pulsating aurora could distinguish between competing models of the location of the instability that triggers it. These projects also provide a testing ground for innovative instrumentation, including "space truth" for new ground-based instrumentation and a training ground in both instrument development, flight, and data analysis for graduate and postdoctoral students. Shuttle experiments and Shuttle-launched payloads such as Get-Away Specials, Spartans, and Hitchhikers are also useful in fulfilling this need.

CATEGORY C. Modest Components

Increased Acquisition of IMP-8 Data [Priority 1]

A continuing set of synoptic in-situ measurements of interplanetary parameters is essential for the entire solar-terrestrial research community. The only spacecraft currently in position to provide such data is IMP-8, and we are pleased that it has performed long past its design lifetime. Continued acquisition of these data is imperative until a suitable replacement can be launched. The WIND spacecraft of ISTP is ideal but is not scheduled to be launched until late 1989 and at present has no real-time capability. Operational/research spacecraft, using off-the-shelf space-proven instruments, should be considered for prompt launch to supply these data on a continuous quick-time basis; however, in the interim, IMP-8 is in the solar wind 60 percent of the time and for a modest outlay of funds can provide necessary input parameters for solar-terrestrial research.

Coordinated Campaigns [Priority 1]

It will be important to coordinate our selected solar, interplanetary, magnetospheric, ionospheric, and atmospheric studies into an integrated program so that the entire Sun-Earth linkage is defined and understood. This will require not only joint observational efforts but also joint postobservational studies and data analyses. Coordination of observations can be provided by combining several of our recommended activities. For example, in response to a solar flare or a stable large coronal hole observed on the central solar meridian, the network of incoherent-scatter radar stations could be activated, and balloons and rockets studying tropospheric, stratospheric, mesospheric, and ionospheric responses could be launched. An analogous program called STIP (Study of Traveling Interplanetary Phenomena) has been successful, as was a global electric-field campaign during the International Magnetospheric Study. The present program of "world days" should be expanded to include these kinds of campaigns. International cooperation in all phases of these efforts can maximize the scientific return.

Ground-Based Synoptic Measurements [Priority 1]

Long-term synoptic measurements should be performed from ground-based sites. These facilities should maintain continuity of observations at strategically placed sites in national and international networks. A variety of observations are important for comparison with in situ measurements and other phenomena. For example, ground-based measurements of type II radio bursts, H-alpha observations of flares, and eruptive prominences can be correlated with interplanetary measurements of events originating on the Sun and their subsequent ionospheric and atmospheric consequences. Another example is ionospheric conductivity enhancements, which are correlated with 10.7-cm solar radio flux, readily measured from Earth.

Solar Seismology [Priority 2]

Helioseismology provides the only available means for probing the dynamic region beneath the Sun's visible surface, especially the convection zone that holds the key to solar activity. Essential information for understanding global oscillation phenomena includes excitation, damping, lifetime, and long-term variations of normal modes, rotational splitting, meridional flows, and velocity-brightness phase relationship. A global national and international network of appropriately deployed stations can be expected to provide the almost continuous coverage that is required to exploit solar seismology to the utmost. A single polar station offers extended data collection for 3 months of the year. The global network should include at least two or three stations with the capability of spatial resolution (required to scan the full range of depth within the solar interior) as well as a number of full-disk Dopplergraphs.

Global Electric Circuit [Priority 2]

The electrical coupling among the magnetosphere, ionosphere, and troposphere is an important aspect of solar-terrestrial research, and it needs to be studied. Potentials on the order of 100,000 volts occur both between the ground and the upper atmosphere and between the dawn and dusk sides of the polar ionosphere. The latter potential is known to be dependent on solar-wind electric fields; a coupling to the tropospheric circuit has been suggested. Coordinated measurements, including balloon flights over high-latitude incoherent-scatter radar and other ground-based facilities, along with global simulations and other theoretical studies, will elucidate whether the postulated significant coupling between these two current systems exists.

Educational Programs [Priority 2]

Training of the next generation of researchers is a high priority. It is critical that students obtain a broad-based interdisciplinary knowlege of physical and chemical processes that are basic not only to solar-terrestrial research but to other disciplines as well. Training should be increased in instrument design and multidisciplinary projects.

Thermospheric Measurements [Priority 2]

Several neutral atmospheric parameters will not be available with sufficient accuracy in the next decade. Such parameters include neutral winds and the neutral atmospheric composition in the thermosphere. Most of the energy involved in magnetosphere-ionosphere coupling is eventually deposited in the thermosphere. Lack of accurate thermospheric measurements (e.g., oxygen concentration) is a serious deficiency for the interpretation of ionospheric measurements and for the development of realistic theoretical models. A polar-orbiting spacecraft at thermospheric altitudes with a single payload of off-the-shelf instruments such as those flown on Atmosphere Explorer-C or Dynamics Explorer-2 is needed for these neutral measurements and to provide the global pattern of particle precipitation, convection electric fields, and field-aligned currents to complement the ground-based instrumentation with high spatial resolution but smaller field of view. An Explorer-class spacecraft or additions to operational spacecraft could be used to fulfill this need. In addition, these data requirements may be satisfied by the development of innovative ground-based techniques.

Stokes Polarimeter [Priority 2]

The properties or solar magnetic fields underlie virtually every aspect of solar variability, including changes of total irradiance (associated with sunspots), changes in ultraviolet spectral irradiance (associated with changes of chromospheric emission), and disturbances of the interplanetary medium (associated with coronal mass ejections). A new-generation Stokes polarimeter located on a telescope equipped with seeing-adaptive optics at a ground site with long periods of subarc-second seeing conditions will provide observations that are fundamental for understanding the basic mechanisms of solar variability. With a rapid access capability and availability to a broad range of users--including students--such a facility could be devoted to a wide range of problems including preparation for, calibration of, and follow-up of the limited 7- to 10-day duration flights of SOT and of Sunlab (reflights of Spacelab II instrumentation).

RECOMMENDATION 3

Interagency Coordination for the National Solar-Terrestrial Research Program

The National Solar-Terrestrial Research Program will involve significant commitments by a number of federal agencies; good interagency coordination is therefore essential to maximize the scientific return. National interagency coordination is necessary to ensure a proper mix between spaceborne and ground-based observations, as well as a good balance between data analysis, modeling, simulation, theory, and experiment. Experience has shown that efforts to broaden the observational base and the interactive participation of qualified scientists results in an important increase in scientific output for only small incremental financial support. Many of the major spaceflight missions and ground-based facilities that are operational or planned for solar-terrestrial research have the character of national or international observatories. Some informal interagency coordination is already taking place, but strong formal coordination is needed. Good interagency coordination and good coordination with the scientific community will maximize the scientific output from these observational efforts. The collection, archiving, and wide distribution of scientific data from a large variety of sources over long periods of time has played an important role in advancing the field of solar-terrestrial research and in the future should play an even greater role. The continuity of long-term observing programs tends to be given low priority by the science agencies concerned. This work is so important for the long-range health and scientific output of the field that a focused and well-coordinated national program must ensure the long-term commitment for these observations. Close attention should also be given to possible international collaboration. Through well-coordinated interagency and international cooperation we can maximize the short-term and long-term scientific benefits of the National Solar- Terrestrial Research Program.

5

SUMMARY

We recommend a National Solar-Terrestrial Research Program that is of importance to the nation, as well as to its scientific community. This program is based on previous NRC reports that reflect the consensus of the community. They show that solar-terrestrial research has now reached a critical point, where a major step forward is possible. During the last decade, major discoveries and theoretical advances related to the individual components have taken place; these are now the base for the next step, which is to understand how these individual components interact. Of all the planets, the Earth and its biosphere presents the widest range of interacting physical and chemical processes. We now have the technical resources to study the entire system as a whole on a day-to-day basis and on a global scale. We must take this opportunity to rise to the challenge, for we live in the solar-terrestrial system.

APPENDIX A

Recommendations from *Solar-Terrestrial Research for the 1980's*, H. Friedman and D. S. Intriligator, co-chairmen, Committee on Solar-Terrestrial Research, National Research Council, National Academy Press, Washington, D.C., 1981.

1. *The Solar Radiative Output*

a. We recommend the initiation of a long-term national program to study variations of solar luminosity and spectral irradiance.

b. We recommend a broadly based program of theory and ground-based and spaceborne observations to understand the fundamental mechanisms of solar variability.

2. *Linkage between the Sun, the Interplanetary Medium, and the Magnetosphere*

a. We recommend observational and theoretical studies of physical processes responsible for quasi-steady interplanetary flows, solar-wind acceleration and dynamics, and the three-dimensional structure of the heliosphere.

b. We recommend observational and theoretical studies of how transient events on the sun propagate into and through the interplanetary medium.

c. We recommend a coordinated program of observational and theoretical studies to determine how energy and momentum are transferred between the solar wind and magnetosphere, both for quasi-steady-state and transient conditions.

3. *Linkage between the Magnetosphere, Ionosphere, and Atmosphere*

a. We recommend a coordinated scientific effort to understand the magnetosphere-ionosphere-atmosphere energy-transfer processes in magnetic-field-line regions that pass through the auroral zone, the polar caps, and the geomagnetic tail.

b. We recommend a coordinated scientific effort to understand the global coupling of the magnetosphere-ionosphere-atmosphere system.

4. *Linkage between the Sun and Elements of the Atmospheric System*

a. We recommend an effort to determine the effects on the chemistry and energetics of the middle atmosphere of both (i) exchange processes with the troposphere and thermosphere and (ii) solar variability.

APPENDIX B

Studies Relevant to Solar-Terrestrial Research

The Upper Atmosphere and Magnetosphere, F. S. Johnson, chairman, Geophysics Study Committee, National Research Council, National Academy of Sciences, Washington, D.C., 168 pp., 1977.

Space Plasma Physics: The Study of Solar-System Plasmas, S. Colgate, chairman, Space Science Board, National Research Council, National Academy of Sciences, Washington, D.C., 96 pp., 1978.

Upper Atmosphere Research in the 1980's: Ground-Based, Airborne, and Rocket Techniques, F. S. Johnson, chairman, Committee on Solar-Terrestrial Research, National Research Council, National Academy of Sciences, Washington, D.C., 60 pp., 1979.

Solar-System Space Physics in the 1980's: A Research Strategy, C. Kennel, chairman, Committee on Solar and Space Physics, Space Science Board, National Research Council, National Academy of Sciences, Washington, D.C., 82 pp., 1980.

The Middle Atmosphere Program: Prospects for U.S. Participation, G. C. Reid, chairman, Panel on MAP, Committee on Solar-Terrestrial Research, National Research Council, National Academy of Sciences, Washington, D.C., 24 pp., 1980.

Solar-Terrestrial Research for the 1980's, H. Friedman and D. S. Intriligator, co-chairmen, Committee on Solar-Terrestrial Research, National Research Council, National Academy Press, Washington, D.C., 143 pp., 1981.

Solar Variability, Weather, and Climate, J. Eddy, chairman, Geophysics Study Committee, National Research Council, National Academy Press, Washington, D.C., 106 pp., 1982.

Study of the Upper Atmosphere and Near-Earth Space in Polar Regions, J. G. Roederer, chairman, Polar Research Board, National Research Council, National Academy Press, Washington, D.C., 42 pp., 1982.

Research Recommendations for Increased U.S. Participation in the Middle Atmosphere Program (MAP), J. Mahlman, chairman, Panel on MAP, Committee on Solar-Terrestrial Research, National Research Council, National Academy Press, Washington, D.C., 12 pp., 1984.

Solar-Terrestrial Data Access, Distribution, and Archiving, M. Shea and D. Williams, co-chairmen, Joint Data Panel of the Committee on Solar and Space Physics and the Committee on Solar-Terrestrial Research, National Research Council, National Academy Press, Washington, D.C., 31 pp., 1984.

IN PREPARATION

Physics of the Sun, S. Colgate, chairman, Space Science Board, National Research Council.

Space and Astrophysical Plasma Physics, C. Kennel, panel chairman, part of a major physics survey, Board on Physics and Astronomy, National Research Council.

APPENDIX C

Solar-Terrestrial Data and Instrumentation

I. *Required Data*

To conduct a fruitful and comprehensive scientific research program to investigate the solar-terrestrial system, we have identified the following data as essential:

Solar Measurements

- Solar x-ray and/or ultraviolet imaging
- Solar radio emission (the entire radio spectrum from microwave up to metric wavelengths)
- Solar imaging coronal electron densities
- Solar magnetic fields

Interplanetary Measurements

- Plasma (bulk velocity, density)
- Interplanetary magnetic-field vector
- Interplanetary hectometric and kilometric radio emission
- Interplanetary electric fields
- Energetic particles

Magnetospheric Measurements

- Magnetic fields
- Electric fields
- Plasma distribution functions
- Energetic particles

Ionospheric Measurements

- Plasma currents parallel and perpendicular to the magnetic fields
- Electron densities and temperatures
- Wind velocities
- Thermospheric gravity waves

Particle composition
Joule heating
Auroral imaging
Precipitating particles

Atmospheric Measurements
Stratospheric composition
Mesospheric composition
Thermospheric composition
Atmospheric densities, temperatures, and motions
Wave structures and turbulence

Some of these data sets are readily available with many of the sensors developed and in operation. These will require routine maintenance and nominal upgrading costs in the next decade. Some sensors require extensive upgrading and training of additional personnel to provide adequate data coverage.

Comparable measurements in other planetary magnetospheres and at other bodies (e.g., comets) are useful and provide depth for solar-terrestrial research studies.

Of major concern are solar-terrestrial data sets that are not readily available. For example, a major gap exists in the availability of interplanetary-medium parameters, particularly solar-wind and magnetic-field data, for the next 6 years. Near-Earth ISEE-3 data have ceased being transmitted, as the spacecraft moves toward the comet Giacobini-Zinner. Coverage of IMP-8 data is expected to be reduced to 30 percent, and the ability to reactivate IMP-7 is uncertain at this time. Although we strongly endorse efforts to increase the coverage of interplanetary data from existing and operative sensors, we note that a small, simple spacecraft, utilizing space-proven instruments, could be built and launched in a timely manner and should be actively pursued by interested agencies.

Other key parameters that may not be available include the ionospheric electric fields, field-aligned currents, and characteristics of the particle precipitation (from which the ionospheric conductivity can be determined). The early re-entry of Dynamics Explorer 2 means that currently no satellite is able to make these comprehensive, simultaneous measurements. Present DOD and NOAA operational spacecraft routinely include precipitation electron detectors, and the next satellite in the Defense Meteorological Satellite Program (DMSP) will include ionospheric flow measurements. We applaud these enhancements and strongly recommend that instruments to measure ionospheric flows and field-aligned currents be included in all DMSP and NOAA Tiros spacecraft. These inexpensive and off-the-shelf instruments, when placed together in one satellite, provide a comprehensive set of observations that is essential to truly understand magnetosphere-ionosphere coupling. Thus the scientific usefulness of these missions can be substantially increased at low cost. Furthermore, these spaceborne measurements of fundamental ionospheric parameters, will enable the ISTP and UARS missions along with the ground-based observational programs to realize their full potential.

II. *Required Instrumentation*

The following instrumentation is required to provide the data outlined above:

Solar Instrumentation

- Solar Dopplergraph
- Fourier tachometers
- Active solar-optics system
- Spaceborne imager in x-ray and/or ultraviolet wavelengths
- Solar coronagraph (both ground-based and spaceborne)
- Solar radio sensors (both ground-based and spaceborne)
- Two-dimensional radio heliograph telescope
- Swept-frequency solar radio sensors
- Solar optical telescopes (both ground-based and spaceborne)
- Vector magnetographs (both ground-based and spaceborne)

Instrumentation to Measure the Interplanetary Medium

- Satellite instrumentation to be carried on a spacecraft in the interplanetary medium:
  - Solar-wind plasma analyzer
  - Interplanetary magnetic field detector
  - Long-wavelength solar radio receiver
  - Electric-field detector
  - Energetic particle detector
- Ground-based interplanetary scintillation array

Magnetospheric Instrumentation
- Magnetometers (both ground-based and spaceborne)
- 3-D plasma analyzers
- Electric-field sensors
- Energetic-particle detectors

Ionospheric Detectors
- Fabry-Perot interferometers
- All-sky camera imagers
- Spectrometers
- Coherent and incoherent radar systems
- Riometers
- Photometers
- Balloonborne electric-field, particle, and x-ray detectors

Atmospheric Detectors
- MST or ST radars
- Lidar
- Fabry-Perot interferometer

Ground-Based Cosmic-Ray Detectors
- Neutron monitors

III. *Unattended Geophysical Observations*

Instrumentation for obtaining unattended ground-based measurements of electric and magnetic fields exists, but there is a need for support for the construction and maintenance of stations, especially in the critical high-latitude regions. A specific budgetary item earmarked for the erection and maintenance of a chain of electric and magnetic sensors is recommended in order to provide a comparatively inexpensive yet invaluable solar-terrestrial synoptic data base.

The MST radar technology is currently used to obtain a long-term data base of auroral-zone middle-atmosphere neutral wind measurements. Preliminary analyses have detected effects of solar and magnetospheric variability down to the mesopause (86 km). Further analysis will be used to search for effects in the mesosphere. The possibilty of such effects warrants continued support of these facilities.

APPENDIX D

Essential Methods for Coordinated Research

I. *Theory, Modeling, and Data Analysis*

The recent implementation or the NASA Solar-Terrestrial Theory Program illustrates the value of a program separate from missions that is specifically attuned to the needs of analytical and numerical scientific analyses. Further, the success of the SCOSTEP SMY, STIP, IMS, and MAP symposia has dramatically illustrated the value of combining the analytical/numerical studies with specific events in which interdisciplinary data sets have been merged for joint coordinated studies. The overwhelming response of the community to the Announcements of Opportunity for the funded NASA theory program has demonstrated the need for a greater effort in this direction and for a broadening of the scope of the program to include combined theory and data-analysis investigations. The latter should be encouraged by the availability of additional support at NSF, NOAA, and NASA.

II. *Computer Networks*

Computer technology has reached the stage where vast new opportunities in interdisciplinary, interactive data analysis, theoretical studies, and combined theory and data interpretation are possible through networking. In recognition of this, several study committees have already dealt with the concepts of data management and sharing and the design of networks that link institutions involved in solar-terrestrial research. One pilot program (based at Marshall Space Flight Center) is in operation as a result, and the design of a system for the ISTP era is under consideration. An augmentation to NASA and NSF funding for computer facilities would support implementation of a long-term organized Solar-Terrestrial Research Computer Network. This network would be used to solve scientific problems and at the same time establish the essential elements for domestic software and data sharing and science coordination for the future ISTP period. (See Appendix E.)

III. *Workshops*

Dedicated science workshops that have been conducted under the umbrellas of the IMS, STIP, and MAP programs produced the environment that is essential for driving interdisciplinary prospective and retrospective studies. The need for the education, motivation, and inspiration that results from regular workshops should be recognized as an integral part of the solar-terrestrial research program. Latest results of the theory and data-analysis efforts collectively presented at a dedicated annual gathering would drive future work including modifications of the computer network. Budgeting augmentations would be required to conduct annual workshops over the next 10 years. These programs should include data analyses, numerical simulation, and theory--all focused on the unambiguous requirement of data confrontations for the entire Sun-Earth linkage.

APPENDIX E

Principal Recommendation of *Solar-Terrestrial Data Access, Distribution, and Archiving*, M. A. Shea and D. Williams, co-chairmen, Joint Data Panel of the Committee on Solar and Space Physics and the Committee on Solar-Terrestrial Research, National Research Council, National Academy Press, Washington, D.C., 1984.

We recommend that a pilot program be started by NASA that would lead to the establishment of a solar-terrestrial Central Data Catalog and Data Access Network (CDC/DAN). The Central Data Catalog (CDC) should be established as a relational data base, should be supported by a query language, and should be accessible from remote terminals. This would allow data to be identified by relationships with other data elements As a minimum the CDC should contain information as to data location, type, level of processing, time periods covered, quality, formats, cost, and availability. The CDC and the sources and users of solar-terrestrial data should be connected via computer networking to create the Data Access Network (DAN). The CDC will be the primary node for information about the data. The incorporation of user and data base nodes into the CDC/DAN permits, as resources allow, the growth of the CDC/DAN from a query catalog to an electronic mail and request service, to a browse capability of survey data sets including graphics, to the availability of on-line data sets throughout the network, to, finally, a browse capability of remote high-resolution data sets. In addition to the catalog and network, the CDC/DAN must also have a staff to manage the creation and maintenance of the catalog. Thus the CDC/DAN concept defines a data management organization. A possible location for the CDC node is the National Space Science Data Center (NSSDC), and the pilot program could begin by using subsets of existing NSSDC and National Geophysical Data Center (NGDC) data sets.