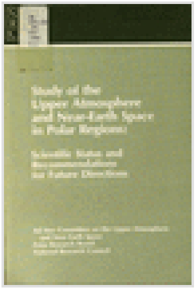

Study of the Upper Atmosphere and Near-Earth Space in Polar Regions: Scientific Status and Recommendations for Future Directions (1982)

Pages
53

Size
5 x 9

ISBN
0309327733

Ad Hoc Committee on the Upper Atmosphere and Near-Earth Space; Polar Research Board; National Research Council

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Scientific Status and Recommendations for Future Directions

Ad Hoc Committee on the Upper Atmosphere and Near-Earth Space

Polar Research Board

National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C.   1982

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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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Foreword

This document is one of a series prepared by the Polar Research Board that develop strategies for polar research. These studies are expected to be sufficiently searching to help guide polar research over the next two decades. The setting of priories is particularly important in times of financial stress and it is hoped that these studies will facilitate various groups, both within and outside of the government, in making choices.

Two studies were completed in 1981, An Evaluation of Antarctic Marine Ecosystem Research and this study, work continued on six others, and additional studies are expected to be activated in 1982.

The Polar Research Board appreciates the efforts of Juan Roederer, Chairman, Committee on the Upper Atmosphere and Near-Earth Space in the Polar Regions, and other members of this Committee in completing their task.

Charles R. Bentley, Chairman
Polar Research Board

Preface

The upper atmosphere in the polar and subpolar regions has been called "earth's window to outer space." Many deep-space phenomena can be "remote sensed" in the polar regions from ground, balloons, rockets, and low-altitude satellites, and many processes occur there that are responsible for extra-terrestrial effects on the behavior of the atmosphere. A vigorous research program in this discipline was launched during the International Geophysical Year (1957). As the subject matured and completed a transition from an exploratory phase to one of incipient quantitative understanding, it became evident that an increased scientific yield could only be achieved through greatly increased coordination of observations and data analysis. Unfortunately, however, research on the upper atmosphere and near-earth space in the polar regions is planned and funded in a rather fragmented and piecemeal fashion, often without any overall coordination except for informal post facto communication among the scientists themselves.

To analyze this situation and formulate appropriate recommendations, the Polar Research Board (PRB) established at its Spring 1981 meeting the Ad Hoc Committee on the Upper Atmosphere and Near-Earth Space. The charge given to this committee is as follows: (i) to apprise the PRB of relevant polar aspects contained in recent studies carried out by the Academy on upper atmosphere and near-earth space; (ii) to make specific and detailed recommendations on upper-atmosphere research in the Arctic and Antarctic regions in support of, or in addition to, recommendations made by recent or concurrent Academy studies; (iii) to identify related logistic and policy issues on which specific

PRB action is desirable; (iv) to contribute to upcoming proposals for the establishment of a National Arctic Research Policy; (v) to act as scientific liaison on upper-atmosphere matters with the Scientific Committee on Antarctic Research (SCAR), Middle Atmosphere Program (MAP), and other international programs; (vi) to advise the PRB on any other matter related to upper-atmosphere and near-earth space research in the polar regions.

The present report addresses points (i) and (ii) above.

This study was made possible by a grant from the Andrew W. Mellon Foundation to the National Academy of Sciences.

Juan G. Roederer, Chairman
Ad Hoc Committee on the
Upper Atmosphere and Near-
Earth Space

Contents

1
Introduction and Summary of Recommendations

The purpose of this report is twofold: (1) to review recent studies published by the National Academy of Sciences on the upper atmosphere and near-earth space and extract and synthesize statements and recommendations therein relevant to research in the polar regions; (2) to elaborate and expand on these statements and recommendations and their rationales, formulate new ones specifically addressed to polar science, and consider policy issues that are believed to be important for furthering basic and applied studies of the polar upper atmosphere and near-earth space during the coming years.

The recommendations given below are more detailed and more numerous than is customary for Academy reports. The reason lies in the special circumstances given by the charge to our Committee: to address specific issues of upper-atmosphere and near-earth space research at high latitudes and to complement or expand in detail pertinent recommendations formulated in previous studies. The rationale for these recommendations is given in Chapter 6 of this report.

1.1 RECOMMENDATIONS ON BASIC RESEARCH IN SPACE PLASMAS

(a) Magnetosphere-Ionosphere Coupling

We recommend sustained experimental and theoretical efforts to understand the processes of magnetosphere-ionosphere coupling and energy transfer in high magnetic latitude and polar regions.

(b) Plasma Studies in the Auroral Ionosphere

We recommend the study of basic plasma processes in the polar regions using recently developed modification techniques, such as chemical releases, particle beam injections, and electro-magnetic wave injections at very low frequencies and high frequencies. Such experiments should be coordinated with similar experiments at lower latitudes to aid in understanding the complex physical processes occurring in the polar upper atmosphere.

(c) Cusp Studies

We recommend continued development and strengthening of investigations of the magnetospheric cusp and dayside aurora both at Svalbard and South Pole Station, as well as long-term support for the very-high-latitude incoherent-scatter radar installation at Søndre Strømfjord, Greenland.

(d) Prediction of Auroral and Magnetic Perturbations

We recommend a coordinated effort to improve the prediction capability of auroral activity and ionospheric and magnetic perturbations at high latitude by determining quantitatively the relationships between solar-wind parameters and occurrence, type, intensity, and space and time evolution of auroral and other high-latitude magnetospheric perturbations and by studying the responsible physical processes.

1.2 RECOMMENDATIONS ON BASIC RESEARCH IN NEUTRAL-ATMOSPHERE PHYSICS

(a) Neutral Upper Atmosphere

We endorse U.S. participation in the Middle Atmosphere Program (MAP) and recommend increased emphasis on studies of the composition and dynamical characteristics of the middle and upper atmosphere (including the stratosphere) in the polar regions. Areas of special interest that represent major gaps in our knowledge of global atmospheric properties are the degree of dynamical coupling between different altitude regimes, the influence of small-scale dynamics, and the difference in chemical composition between the polar and midlatitude atmospheres.

(b) Solar Activity Effects on the Polar Atmosphere

We recommend an increased effort in the study of the physical links between solar activity and atmospheric behavior in the polar regions, especially concerning two aspects: (1) the links between solar-flare particle energy deposition, formation of odd-nitrogen and odd-hydrogen compounds, and their effect on stratospheric ozone; (2) the global ionosphere-atmosphere electric-field configuration, its modification from above by ionospheric conductivity changes and from below by tropospheric electric storms. Another objective of this research should be the critical examination of the possible connection of these phenomena with polar climate.

1.3 RECOMMENDATIONS ON RESEARCH RELEVANT TO APPLIED FIELDS AND OTHER DISCIPLINES

(a) Ionospheric Inhomogeneities

We support a research program aimed at understanding the physical mechanisms that cause the formation of high-latitude ionospheric irregularities. A more complete understanding of the processes involved will ultimately lead to an ability to predict ionospheric conditions and their interference with communications and defense systems.

(b) Electromagnetic and Particle Radiation Background at High Latitudes

We support a broadly based research program to obtain a data base on the background intensity, frequency distribution, and time variations of the natural electromagnetic radiation at high latitudes. Similarly, the fluxes of the energetic particle populations on high-latitude magnetic field lines should be measured over a time period long enough to establish the important diurnal, seasonal, and solar cycle variations.

(c) Geomagnetic Influences on Ground-Based Systems

We endorse the continued evaluation of the influences of geomagnetic variations and disturbances on ground-based technological systems, in order to make available to systems designers the most up-to-date understanding of the geophysical environment necessary to achieve an improved capability of avoiding interferences and outages of geomagnetic origin.

(d) Astronomical and Solar Research

We recommend the continued effective use of the unique atmospheric, geomagnetic, and/or seasonal characteristics of the polar regions for astronomical and solar research objectives.

1.4 RECOMMENDATIONS ON POLICY ISSUES

(a) Coordination of Polar Programs in Upper-Atmosphere and Near-Earth Space Research

We recommend that a mechanism for coordinating polar programs in upper-atmosphere and space research be established as part of an overall national coordination of programs in Arctic research. The responsibility for coordinating polar-upper-atmosphere research, including logistic aspects where necessary, should be assigned to some agency that conducts or supports programs in the polar regions and that has, or can build, effective contacts with the National Science Foundation, Department of Defense, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, Department of Energy, and other appropriate agencies. As a minimum effort, some designated group should maintain a central information exchange on the polar programs of all agencies, their schedules, objectives, and expected results.

(b) Research in Svalbard

We recommend that the United States strengthen its upper-atmosphere research program conducted at Svalbard. In implementing this recommendation the United States would be exercising its rights as a signatory of the Svalbard Treaty in support of scientific research by U.S. investigators in the Svalbard Archipelago.

(c) The Role of SCAR in Upper-Atmosphere and Near-Earth Space Research

We recommend that the United States urge SCAR that scientific representatives of interested member nations be brought together at the earliest possible time to review existing upper-atmosphere and near-earth space programs in Antarctica and to develop plans for the future.

2
The Polar Upper Atmosphere and Near-Earth Space: An Overview

The upper atmosphere at high latitudes has rightly been called "earth's window to outer space." Many geophysical effects displayed there are direct manifestations of phenomena occurring in deep space that thus become available to "remote sensing" through this window in the polar regions. Even the deep-space medium itself--solar-wind plasma--enters in the form of a narrow beam through this window to interact with the upper atmosphere at high latitude in the so-called cusp regions. The polar regions of the earth are thus important areas for the study of space and its effects on our environment.

The reason for this circumstance is that a vast portion of the earth's magnetic-field envelope, or magnetosphere, is electrically connected to the polar regions (Figure 1). Processes occurring in the outer reaches of the magnetosphere often map back to the earth along magnetic field lines, which converge as they approach the earth at high latitudes. This geometry results in a spatial focusing action of magnetospheric disturbance, with the consequence that effects associated with extended regions of the magnetosphere can, in many cases, be sampled in narrow latitudinal intervals at low altitudes. These effects can be readily observed in terms of motions of atmospheric ions, electrons and neutral gas, selective optical and x-ray emissions, magnetic perturbations, temperature changes, variations in the spatial distributions of plasma, radio emissions, and the onset of plasma turbulence. The aurora is the most conspicuous (and magnificent) high-latitude manifestation of magnetospheric activity. Caused by

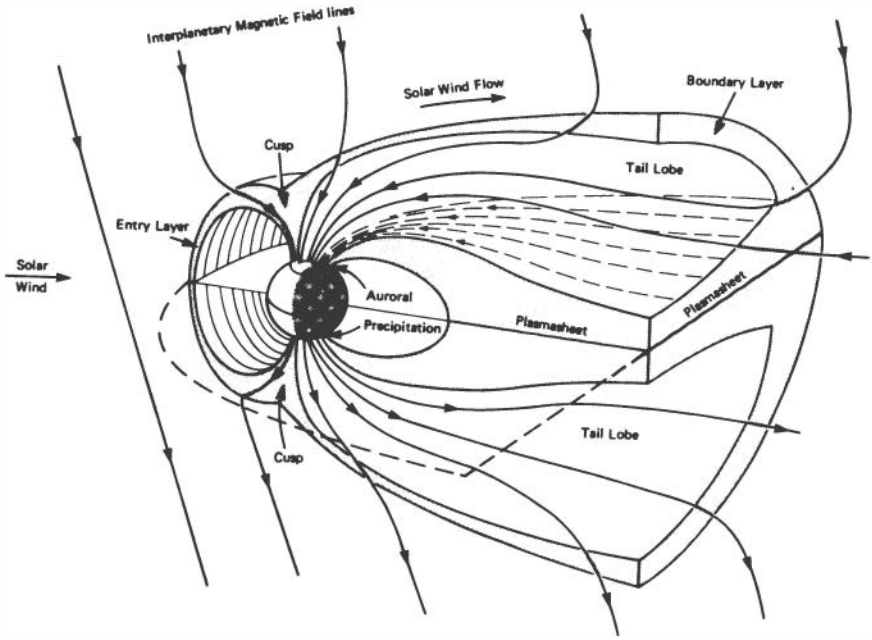

FIGURE 1 Sketch of the earth's magnetic-field envelope, or magnetosphere, and its connection to the polar regions (not to scale). Relevant plasma regions and sample magnetic field lines connecting the polar cap to the interplanetary field are shown.

optical emissions from atoms excited by energetic electrons and ions precipitating from the magnetosphere, the aurora is a "live TV show" of energy conversion processes occurring far out in space.

Far from being a passive energy absorber, the high-latitude ionosphere exerts an important feedback action on the magnetospheric and atmospheric regions to which it is linked, acting as an energy and momentum modulator, as a source of particles, and as a source of important perturbations to the underlying neutral atmosphere. In particular, the polar ionosphere plays a principal role in the global electric circuitry of the entire magnetosphere-atmosphere system: for the magnetosphere it is a "cold," and "resistive," lower boundary; for the neutral atmosphere, instead, it is a comparatively "hot" and "conductive" upper boundary. In the former role the ionosphere is a dumping ground of magnetospheric energy; in the latter role, it is a source of perturbations that propagate from the polar regions to lower latitudes.

There are many peculiar features of midlatitude upper-atmosphere behavior whose origin can be traced to high-latitude processes. Transport of energy away from the high-latitude regions is a significant aspect of the meridional circulation in the thermosphere, with consequent effects on winds, gas composition, and temperatures. In addition, rapid onsets or changes in the level of auroral activity are responsible for large-scale thermospheric waves that propagate equatorward. Such waves carry substantial energy and are readily detectable through the ionospheric perturbations that result. Finally, another feature of the high-latitude upper atmosphere is the presence of exotic atomic and molecular species created through particle bombardment and the enhanced rates of chemical reaction associated with it.

A significant feature of the polar "window to outer space" is that it affords the study of many deep-space phenomena from ground and from balloon and rocket altitudes. The polar region as a whole thus becomes a "space platform," a sort of "slow-motion satellite in a 1-earth-radius orbit." The advantage of passing relatively slowly through the various ionospheric projections of the magnetospheric regions offers important opportunities for detecting temporal and spatial variations, which are often missed or are difficult to interpret from satellite observations. Satellites, of course, are necessary for the collection of in situ measurements (as opposed to remote-sensing observations from ground), and they are essential for the study of mechanisms in space-regulating energy, momentum and mass transfer from the solar wind to the magnetosphere, and the subsequent deposition into the atmosphere.

The upper atmosphere and near-earth space in the polar regions, especially in the Arctic, play important roles in the applied fields of communications and defense. Many natural high-altitude perturbations are known to interfere, often seriously, with man-made systems at high latitude. For example, the background of electromagnetic radiation at all frequencies provides a lower limit to the noise level of any communications system. In the polar regions, this background can at times and in certain frequency ranges (e.g., extremely low frequency) be higher than at lower latitudes. Of special concern are the high background levels that the aurora can induce in the optical and infrared sensors used by detection and surveillance spacecraft and the ionospheric irregularities in polar regions. The latter can modify electromagnetic waves, thereby affecting communications with satellite systems and affecting the utilization of over-the-horizon detection radars for defense against transpolar bomber attack. Electric currents induced during large geomagnetic storms in long conductors such as telephone cables, power lines, and pipelines can cause failure or serious damage. It is clear that a better, more quantitative understanding of the polar upper atmosphere will lead to an improved capability for predicting natural perturbations and their interference with man-made systems.

3
The Regions of Interest

It is necessary to clarify what is meant by "polar" in relation to the upper atmosphere and near-earth space. Because of the tilt of the earth's magnetic axis, and the eccentricity of the magnetic dipole, magnetic coordinates do not coincide with geographic coordinates. Phenomena controlled by the near-earth space magnetic field can thus be "polar" and yet occur at lower geographic latitudes for certain longitudinal sectors (e.g., in eastern Canada, where the geomagnetic latitude is 11° higher than the geographic latitude). Phenomena controlled by the outer magnetosphere, on the other hand, are locked to a frame of reference fixed to the earth-sun line, exhibiting a local time dependence when viewed from the rotating earth. In this way, a ground observatory will, during the course of a day, sweep across the projections of several relevant magnetospheric boundaries, sampling a variety of particle and field environments. Finally, atmosphere-controlled phenomena will vary with geographic coordinates (and the time) of the point in question. A typical example of an important phenomenon subjected to all three types of control is the production by the aurora and transport of nitric oxide (NO) in the upper atmosphere. As a result, in a certain longitude interval and at certain local times, aurorally produced NO can be fed into the midlatitude upper-atmospheric wind system and distributed over a wide range of longitudes.

We shall use the following definition: A <u>polar</u> phenomenon is one occurring at a location, or on a magnetic field line linked to a location, whose magnetic invariant latitude (Λ) <u>or</u> geographic latitude (λ)

is greater than about 60° in absolute value (Figure 2). The value of 60° invariant latitude (approximately 60° geomagnetic latitude) is a reasonable boundary separating polar magnetospheric phenomena from midlatitude phenomena because it represents the average equatorward limit of auroral occurrence at midnight during magnetically active times. It could be argued that the preceding definition extends the area of incumbency of the Polar Research Board to regions that cannot be classified as polar from a traditional, i.e., climatic or logistic, point of view (Figure 2). However, it should be noted that any such "non-traditional" region (e.g., Roberval, Province Quebec, Canada) will be connected magnetically to a conjugate area in the opposite hemisphere whose geographic latitude is polar in the traditional sense (in this example, Siple Station, Antarctica).

Important geographic areas for polar studies of the upper atmosphere and near-earth space, relevant to U.S. research interests, include Alaska, Northern and Eastern Canada, Greenland, Svalbard, Northern Scandinavia, and Antarctica.

<u>Alaska</u> is the only high-latitude region under U.S. sovereignty. A cluster of important upper-atmosphere research centers with observatory complexes and a sounding rocket range lie at the southern edge of the auroral zone; the auroral oval passes over them at local magnetic midnight hours during moderate and intense auroral activity. Of obvious importance in this area are all defense-related aspects of upper-atmosphere and near-earth space studies. <u>Northern Canada</u> lies most of the time inside the region of "open" magnetic field lines of the polar cap, with several observation sites and rocket launch facilities often used by American investigators. The "Alaska IMS magnetometer chain," an extensive array of stations with real-time data-transmission capability set up for the International Magnetospheric Study, stretches from Alaska through Northern Canada into Greenland.

<u>Greenland</u> has been selected for the future emplacement of the incoherent-scatter radar currently at Chatanika, Alaska. The site, near Søndre Strømfjord, will place the radar under the polar cusp during local noon. The cusp is a spatially limited region of the upper atmosphere in which solar-wind plasma, funneled toward the polar region by the earth's magnetic field,

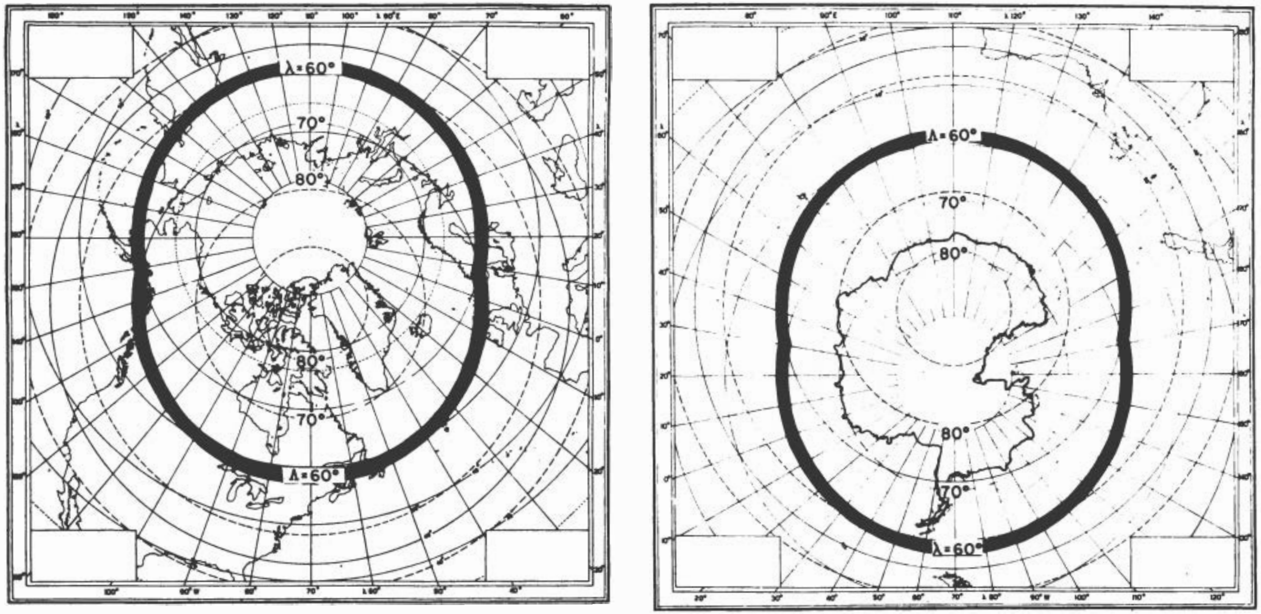

FIGURE 2: The regions enclosed by the heavy curves are considered "high latitude" or "polar" from an upper-atmosphere and near-earth space point of view. λ is the geographic latitude; Λ is the invariant latitude (approximately equal to the geomagnetic latitude).

comes in direct contact with the atmosphere (see Figure 1). Svalbard (Spitsbergen) has particular importance for polar-cusp studies, especially for related optical observations. Because of the tilt in the earth's magnetic field the geographic latitude of the atmospheric spot "illuminated" by the cusp as the earth rotates underneath varies from 66° to 80° in the northern hemisphere. Since the cusp is always located at local magnetic noon, optical studies of the cusp aurora are possible only in winter in a certain longitudinal sector, where the geographic latitude of the cusp approaches 80°. Svalbard is the only land mass in the northern hemisphere satisfying this condition. Northern Scandinavia has important upper-atmosphere research facilities operated by European consortia, which also are, or will be, available to U.S. users. This area lies magnetically in a similar configuration to central Alaska but almost opposite to it in local time. This configuration makes Northern Scandinavia most valuable for simultaneous, coordinated measurements to determine noon-midnight or dawn-dusk asymmetries of high-latitude upper-atmosphere and magnetosphere phenomena.

The importance of Antarctica for upper-atmosphere research is obvious, but the high cost of logistics makes it necessary to justify explicitly on scientific grounds why a given scientific question must be pursued there rather than in more readily accessible regions of the Arctic or Subarctic. Typical experiments that need Antarctic locations include those that require simultaneous observations at magnetically conjugate points, very large antenna arrays laid out on an ice sheet, low electromagnetic noise level, or that focus on the study of global properties and north-south asymmetries. The South Pole Station is unique for optical cusp studies because of a particular conjunction of geographic and geomagnetic aspects at that point.

Because of the three-dimensional nature of the phenomena affecting the polar upper atmosphere, near-earth space is a region of fundamental interest, and satellites and sounding rockets are essential research tools. This research requires not only low-altitude polar-orbiting satellites but also spacecraft in orbits that cut across the distant regions of the magnetosphere and magnetotail that are magnetically linked to the polar regions (Figure 1). Indeed, during the past decade it became evident that the ionosphere-magnetosphere must be studied as one integral system of mutually interacting plasmas and fields, none of which can be considered in isolation (International Magnetospheric Study, 1976-1979).

4

Agencies and Committees Involved in Polar-Upper-Atmosphere and Near-Earth Space Research

The study of the polar upper atmosphere and near-earth space belongs to the discipline of solar-terrestrial physics (STP). STP has become a discipline in its own right, concerned mainly with (a) the variable components of solar energy emissions including UV and x-rays, the solar wind and solar-flare particles; (b) the generation of these emissions on the sun; (c) their propagation through space; and (d) their interactions with, and effects on, the earth's environment.

STP, an outcome of the space age, has on one hand expanded the frontiers of geophysics far beyond our planet and on the other brought the field of astrophysics into the reach of *in situ* measurement and experimentation. As such, the scientific content of STP cuts across traditional disciplinary boundaries, involving a variety of scientific and technical constituencies. To this day, however, many geophysical and astrophysical organizations have not yet been able to adjust fully to this new development. Although an important part of the U.S. space program has been dedicated to STP projects and there is substantial NSF and other agencies' support of STP research, this discipline often appears either fragmented or under-represented in important policy-making or advisory committees, and it has yet to gain the visibility it deserves in the popular science press. This observation applies to the study of the polar upper atmosphere, a discipline that is under-represented in the Polar Research Board and that has a rather low visibility in the Scientific Committee on Antarctic Research (SCAR), in spite of the large number of scientists involved in such research, the substantial financial commitments, and the considerable scientific knowledge generated since the IGY.

In the U.S. National Academy of Sciences, polar-upper-atmosphere research programs are dealt with implicitly by the Space Science Board and its Committee on Solar and Space Physics, the Geophysics Research Board and its Committee on Solar-Terrestrial Research, and, explicitly but somewhat marginally, by the Polar Research Board. In the National Science Foundation, polar research in upper-atmosphere physics is funded by the Atmospheric Sciences Program and by the Division of Polar Programs. Other organizations dealing with this field include National Aeronautics and Space Administration, Air Force Geophysics Laboratory, Air Force Office of Scientific Research, Defense Nuclear Agency, Office of Naval Research, National Oceanic and Atmospheric Administration, as well as several industrial laboratories. At the international level there is yet another group of organizations directly or indirectly concerned with research on the polar upper atmosphere and near-earth space: Scientific Committee on Antarctic Research, Scientific Committee on Solar-Terrestrial Physics, Committee on Space Research, International Association of Geomagnetism and Aeronomy, International Association of Meteorology and Atmospheric Physics, and Union Radio Scientifique Internationale.

5 Recent Studies and Recommendations Impacting on Polar-Upper-Atmosphere Research

In recent years several studies were conducted on STP research by the National Research Council, by *ad hoc* groups, and by international bodies. All emphasize the importance of coordinated observations at high latitudes and make strong recommendations on this matter. From these studies it emerges clearly that the polar regions of the earth are unique in a geophysical sense and that many of the current problems in STP require a thorough understanding of the phenomena above the earth's polar regions.

The following studies have been selected for the purpose of extracting relevant statements and recommendations on the polar upper atmosphere and near-earth space: (1) *Space Plasma Physics: The Study of Solar-System Plasmas* (NAS, 1978); (2) *Solar-System Space Physics in the 1980's: A Research Strategy* (NAS, 1980); (3) *Upper-Atmosphere Research in the 1980's: Ground-Based, Airborne, and Rocket Techniques* (NAS, 1979); (4) *The Middle Atmosphere Program: Prospects for U.S. Participation* (NAS, 1980); and (5) *Solar-Terrestrial Research for the 1980's* (NAS, 1981).

5.1 SPACE PLASMA PHYSICS: THE STUDY OF SOLAR-SYSTEM PLASMAS

This study, mainly oriented toward identifying physical processes that need to be understood, defines six basic problems, two of which can be addressed by research at high latitudes. These two are acceleration of energetic charged particles and particle confinement and transport.

In the Panel Overview on Solar-System Magnetohydrodynamics, the principal concern is with understanding the basic plasma-physical processes involved, and four main research tasks are enumerated. One focuses on the problem of "Plasma and Energy Storage and Release Mechanisms in the Earth's Magnetospheric Tail." In addition to the obvious spacecraft measurements required for this work, coordinated polar-cap and auroral-zone measurements are called for, as these observations reveal the dumping of magnetospheric particles into the atmosphere. Another task deals with "Atmosphere-Ionosphere-Magnetosphere Interactions." Here the polar atmosphere plays a dominant role as the switchyard for the major electric-current networks encompassing the entire magnetosphere. Research specified for this task includes satellite missions to study the field-aligned currents, together with ground-based monitoring of the atmosphere and ionosphere. The reverse problem, namely, the generation of the polar wind and the high-latitude upward acceleration of ions, is also noted. One chapter describes the impact of magnetospheric processes on the upper atmosphere, focusing on high latitudes, where these interactions primarily occur.

Another chapter of this report, "Solar-System Plasma Processes," deals with the processes themselves rather than the descriptive structure of the sun, interplanetary space, and the magnetosphere. This approach leads to problem-oriented research projects and experiments that seek an understanding of the underlying forces. In describing the status of ionospheric physics, the radiation belts, plasma waves, field-aligned currents, and parallel electric fields, the authors note that polar-region research is needed for the following topics: (a) ionospheric turbulence (which can be understood by studying auroral-zone irregularities); (b) radiation belts (wave-particle experiments similar to those done by the Siple transmitter are called for); (c) plasma waves and auroral kilometric radiation (with much of the most important research to be done from satellites); and (d) Birkeland currents and parallel electric fields (this topic centering on the auroral zone and requiring spacecraft <u>and</u> ground instrumentation).

5.2 SOLAR-SYSTEM SPACE PHYSICS IN THE 1980's

This report describes solar-system plasma physics, evaluates the status of that field of research, and makes a series of recommendations for future programs. Throughout the report the polar regions of the earth are emphasized; even in the historical introduction, interest in the aurora is brought out as one of the first manifestations of solar-terrestrial physics. In the Status and Objectives chapter of the report, the importance of the polar region is mentioned in the following ways: (a) The lack of stability in the geomagnetic tail leads to energy deposit in the polar atmosphere, (b) High-latitude field lines contain acceleration regions for injecting particles into the atmosphere or for directing ionospheric ions out into the magnetosphere, (c) The earth's atmosphere on a worldwide basis shows effects caused by the electric and magnetic interactions in the polar thermosphere and mesosphere.

In the chapter that includes a detailed research strategy in magnetospheric physics, projects such as the Dynamic Explorer satellite program, now in operation, are emphasized. One of the principal features of that mission is to measure the field-aligned currents in the polar regions, simultaneously with high-altitude auroral imaging. This mission is a step toward the simultaneous measurements called for in six critical regions, namely, the upstream solar wind, the geomagnetic tail, above one polar cap, the auroral oval, the equatorial magnetosphere, and from the ground.

In the section on Rockets, Balloons, and Ground-Based Facilities, a principal goal for which these observations are needed is to obtain the auroral energy budget and associated atmospheric effects. This work will have to be done largely in the polar regions.

In summarizing the problems facing magnetospheric and ionospheric physics, the report outlines four tasks that must be undertaken. These tasks are (1) study of the magnetopause; (2) storage and release of energy in the geomagnetic tail; (3) origin and fate of magnetospheric plasmas; and (4) electrodynamic coupling between the magnetosphere, ionosphere, and atmosphere. In the last three tasks the polar region is fully involved. Storage and release of energy in the tail requires measurements at auroral latitudes, and the fate of magnetospheric plasma is influenced by loss at high latitudes. The sources of magnetospheric plasma include ions escaping from the high-latitude atmosphere. Electrodynamic coupling of the solar wind to the neutral atmosphere proceeds through a series of steps involving such processes as currents and electric fields imposed on the polar ionosphere.

5.3 UPPER-ATMOSPHERE RESEARCH IN THE 1980's: GROUND-BASED, AIRBORNE, AND ROCKET TECHNIQUES; AND THE MIDDLE ATMOSPHERE PROGRAM: PROSPECTS FOR U.S. PARTICIPATION

The polar regions are extremely important from the point of view of the middle and upper atmosphere. The middle atmosphere (i.e., the stratosphere and mesosphere, occupying roughly the altitude range from 10 to 100 km) is dominated by photochemistry, and its general circulation is driven by solar heating of ozone and cooling by carbon dioxide. The recent upsurge of interest in man's potential impact on the ozone layer led to a great increase in middle-atmosphere research, and the need to perform cooperative studies on an international basis has led to the development of the Middle Atmosphere Program (MAP), an international effort that will take place during 1982-1985.

One by-product of the increase in middle-atmosphere research has been the realization of the importance of the polar regions and of the sparse data base that exists for high latitudes in general. Observations of middle-atmosphere properties in the polar regions are in an unsatisfactory condition. While a certain amount of information can be obtained by remote sensing from satellites, the satellites themselves are generally not in polar orbits, and the techniques they use often need sunlight and are not applicable to the polar night. In this situation, the only satisfactory way to build up the required data base is through direct in situ measurements by balloon and rocket techniques and through remote sensing from the ground, including radar and lidar measurements.

Most of the theoretical predictions of middle-atmosphere behavior that have been made have been based on calculations using one-dimensional models that simulate average global conditions. No fully satisfactory photochemical model for the polar middle atmosphere has yet been produced, yet the chemical processes that take place there may play a determining role in global composition and dynamics.

Both documents emphasize the need for maintaining an adequate global network of launch facilities for balloons and rockets; this need is especially great in the polar regions, where the conditions to be studied are unique and logistic problems are severe. Facilities do exist, e.g., at Poker Flat (Alaska), Churchill (Canada), and Siple and McMurdo (Antarctica), and every effort should be made to maintain and improve them and to make the scientific community aware of their potential usefulness. Additional facilities, possibly on a temporary basis for the duration of MAP, would be desirable at even higher latitudes in the Arctic, where conditions may be significantly different from those in Antarctica. The high and intensely cold continental ice cap of Antarctica has a dominating influence on dynamical motions throughout the depth of the atmosphere, and hence also on chemical composition. The warmer oceanic Arctic Basin, surrounded by continental land masses, has an entirely different dynamical regime and requires study in its own right.

Radar has proven to be an extremely important technique for investigating the motions of the lower and middle atmosphere (mesosphere-stratosphere-troposphere (MST) radars) and of the upper atmosphere and ionosphere (incoherent-scatter radars). The latter technique is now well established, and a high-latitude incoherent-scatter radar will soon exist at Søndre Strømfjord, Greenland (replacing the radar at Chatanika, Alaska), and near Tromsø, Norway (EISCAT).
The MST radar technique is a more recent development and is just beginning to be applied to high-latitude studies with a facility at Poker Flat, Alaska. The need for MST radar installations at higher latitudes in the Arctic, and in Antarctica, has not yet been established but should be studied.

The ionsphere itself continues to have great practical importance in the polar regions. The advent of communications satellites in synchronous orbits operating at frequencies well above those used for ionospheric propagation largely removed the need for ionospheric radio communications at middle latitudes. At high latitudes, however, there are serious problems in receiving signals from satellites in equatorial orbits, and the requirement for communications via ionospheric propagation remains. The use of ionospherically propagated radio waves for communications has in fact increased in recent years. Since the ionosphere in the polar regions is much more variable than at lower latitudes, forecasting of ionospheric behavior at high latitudes remains a substantial and important challenge that will require continuing accumulation of data, possibly from unmanned automatic stations.

5.4 SOLAR-TERRESTRIAL RESEARCH FOR THE 1980's

This study integrates the science recommendations of the reports described in sections 5.1 - 5.3 above and provides additional information on ground-based, balloon, and rocket techniques; on national considerations for management of STP research; on theory; and on applications and societal impacts. Throughout the earth-related aspects of STP, the report emphasizes the importance of research in the polar regions.

In its scientific chapters, the report focuses on the solar-terrestrial system as an intricate "machine" of solar-energy generation, transfer, and dissipation and emphasizes the need to concentrate during the present decade on quantitative studies of significant coupling and trigger mechanisms and feedback processes. The report points out that research of practical concern includes the study of chains of processes that have end results important to life, the study of effects on communication and technological activities, and the study of the impact of STP processes on the scientific understanding of other, non-STP-related natural phenomena. In this context, the report points out that it would be dangerous to downgrade or totally ignore the study of any of the elements in the solar-terrestrial system. The earth has not been inhabited long enough to see the system go through more than a tiny fraction of its possible excursions. Human and industrial activity are tampering with the controls of Spaceship Earth even before we know completely how the system works. That is why intensive, basic scientific study of the whole interactive solar-terrestrial system is so relevant to an understanding of societal impacts and deserves a commensurate priority among those scientific disciplines that promise practical benefit.

Three major recommendations of the study deal with the polar regions. They, and their respective rationales, are as follows:

1. The study recommends a coordinated scientific effort to understand the magnetosphere-ionosphere-atmosphere energy-transfer processes in magnetic-field-line regions that pass through the auroral zone, polar caps, and the geomagnetic tail. This recommendation addresses the need for a deeper insight into the physical mechanisms governing the effect of entry of solar-wind plasma, hydromagnetic waves, and solar energetic particles into the magnetosphere-ionosphere system.
2. The study recommends a coordinated scientific effort to understand the global coupling of the magnetosphere-ionosphere-atmosphere system. The ionosphere exerts important feedback effects on the magnetospheric regions to which it is linked, plays an active role as a major sink of magnetospheric energy, and is the source of important perturbations that propagate to lower latitudes. Pursuit of this recommendation will thus require coordinated research on a global scale.
3. The study recommends an effort to determine the effects on the chemistry and energetics of the middle atmosphere of both (a) exchange processes with the troposphere and thermosphere and (b) solar variability. Possible changes in chemical composition that are due to solar variability could perturb radiative and dynamic processes of the middle atmosphere, and this possibility needs to be explored. The middle atmosphere is also affected by exchange processes from the troposphere below and with the thermosphere above that must be considered in any attempt to understand the region. Perturbations (e.g., to ozone concentrations) may be made through human, natural, or solar activity that could affect the earth's climate.

Regarding the implementation of these recommendations, the study mentions the following of relevance to polar regions:

(i) Integrated Station Arrays and Unmanned Stations. The next decade should feature the continued development of more effective low-power data-acquisition and preprocessing systems for use in remote regions like Antarctica, where, up to now, it has been almost impossible to set up arrays with optimum station spacing. These arrays should involve remote unmanned observatories, possibly powered with energy extracted from the local environment. To monitor continually the magnetospheric energy dissipated in the near-earth environment, a chain of observatories like that in the Alaskan sector should be connected for near-real-time data acquisition to key stations in the Scandinavian sector to achieve a transpolar configuration.

(ii) Coherent-Scatter Radar. Results from the currently operating STARE system in Scandinavia have provided important new views of the distribution of the electric field near the aurora. The economy of this technique should foster its development at several locations in the auroral zone, extending in longitude to yield an instantaneous view of plasma convection and the quasi-DC and transient electric fields.

(iii) Incoherent-Scatter Radar. An incoherent-scatter radar at very high latitude will be established in order to observe the energy and momentum input into the atmosphere from the cusp and dynamic processes in the polar cap. The appropriate upgrading of the existing subauroral latitude radars is an important part of this plan.

(iv) Atmospheric (MST and ST) Radars. The mesosphere-stratosphere-troposphere (MST) and stratosphere-troposphere (ST) radar capabilities should be exploited to gain a better understanding of the importance of small-scale motions in the overall dynamics of the middle atmosphere. Studies should also be undertaken to examine the potential scientific return of a more extensive network of MST and ST radars.

(v) Optical Measurements. Optical measurements of natural atomic or molecular emissions can be very cost-effective and should therefore take advantage of recent developments in detector technology. The widely used photographic all-sky cameras should be replaced with electronic monochromatic imagers (e.g., image tube or charged-coupled diode arrays). High-spectral-resolution systems are needed for the observation of the daytime auroras at those northern hemisphere sites where adverse solar illumination is encountered. High-throughput spectrophotometric facilities are required to monitor the low level of optical emissions from the metastable atmospheric species.

(vi) Balloons. A major new development in ballooning technology involves superpressure balloons, which have been used recently in the southern hemisphere for long-duration flights concerned with middle-atmosphere objectives. At present there is no well-defined routine for obtaining launch support for superpressure balloon payloads. Consideration should be given to treating balloon launch opportunities similar to satellite opportunities, with scientific teams chosen from individually submitted proposals for specific mission objectives.

(vii) Sounding Rockets. "Cause-and-effect" experiments that use rocket platforms for both active portions of the experiment and for diagnostic instrumentation will likely become important facets of suborbital research technology in the 1980's. There is a clear need for rocket platforms capable of probing the important auroral acceleration zone above about 3000-km altitude from appropriately located launch sites. Multirocket experiments for electric-field measurements at lower altitudes below the acceleration region will also be necessary.

(viii) Active Experiments. Major radio-frequency heating transmitters operating in a continuous-wave mode are being built at midlatitudes near the European incoherent-scatter facility. There is laboratory evidence that experiments using high-power density, pulsed plasma-wave excitation can lead to caviton formation, particle energization, and nonlinear interactions in the high-latitude ionosphere. Multiple shaped-charged ion injections conducted simultaneously at different points in the neighborhood of an auroral arc should be carried out to provide information on the nature of parallel electric fields responsible for auroral particle acceleration above auroral arcs.

6
Recommendations on Research and Policy Issues

The recommendations from previous studies as described in the preceding section, especially those contained in the recent study of Solar-Terrestrial Research for the 1980's, address quite well the outstanding problems and opportunities for research in the polar regions. In this chapter we elaborate on several of these recommendations that pertain to polar research and their relationales, formulate new ones specifically addressed to polar science, and consider some policy issues that we believe are important for the study of the polar upper atmosphere and near-earth space in future years.

6.1 RECOMMENDATIONS ON BASIC RESEARCH IN SPACE PLASMAS

(a) Magnetosphere-Ionosphere Coupling

We recommend sustained experimental and theoretical efforts to understand the process of magnetosphere-ionosphere coupling and energy transfer in high-magnetic-latitude and polar regions.

This recommendation is in essence an endorsement of a recommendation from the study, Solar-Terrestrial Physics for the 1980's, which points out the need for deeper insight into the physical mechanisms governing the entry of solar-wind plasma, hydromagnetic waves, and solar energetic particles into the magnetosphere-ionosphere system. Understanding the high-latitude ionospheric electric currents and their variations is a key part of this objective. Pursuit of this recommendation requires careful coordination between research groups as well as appropriate siting and/or relocation of existing and new instrumentation with respect to present or planned fixed facilities, such as the Poker Flat Rocket Range and the new types of coherent- and incoherent-scatter radars in North America and Greenland. Suitably located observatory networks, with modern instrumentation for a complete diagnostic capability of electromagnetic phenomena over a broad (DC-vlf) frequency range, are required. The "mesh" spacing between similar instruments in such networks will vary appropriately with the instrument type. High-altitude and long-duration balloon flights of appropriate instrumentation, particularly in the southern polar regions where political complications are nearly nonexistent, will be particularly important aspects of these investigations.

(b) Plasma Studies in the Auroral Ionosphere

We recommend the study of basic plasma processes in the polar regions using recently developed modification techniques, such as chemical releases, particle-beam injections, and electromagnetic wave injections at vlf and hf. Such experiments should be coordinated with similar experiments at lower latitudes to aid in understanding the complex physical processes occurring in the polar upper atmosphere.

Interaction between energetic charged particles and electromagnetic fields plays a key role in the dynamics of the upper atmosphere and near-earth space. Auroral particles are observed to be accelerated to high energy through dc electric fields parallel to the magnetic field. Motion of the plasma across magnetic field lines, on the other hand, is driven by the perpendicular component of the electric field. The origin of these electric fields is not yet fully understood. A program of coordinated measurements from ground and space is needed to define the parallel currents, conductivities, electric fields, and plasma instabilities associated with this quasi-static electric circuit.

Electromagnetic waves can interact with energetic particles through various resonances, causing wave growth and particle scattering. Effects of such interaction include the generation of remarkably intense radio waves and the precipitation into the ionosphere of significant fluxes of energetic particles. One example is the structured radio emission known as auroral kilometric radiation (AKR). Another is the broadband vlf hiss that correlates well with visible aurora. Still another is the quasi-coherent vlf radio emission known as polar chorus, thought to be generated on auroral field lines and which can be triggered by signals from ground sources, such as lightning discharges. Each of these nonthermal radio-wave emissions has been attributed to interaction with streams of auroral electrons, but none has been explained in terms of known radiation mechanisms. Hence their study is of fundamental importance to plasma physics as well as to an understanding of the high-latitude upper atmosphere. Requirements for further advances in our understanding of these natural phenomena include coordinated measurements of particles and waves using a variety of detectors located at high-latitude ground stations and on balloons, rockets, and satellites.

Modification experiments have the great advantage that the initial perturbations are known *a priori*. They offer exciting new approaches to the study of the high-latitude ionosphere and magnetosphere. Current techniques include the injection of chemicals, particle beams, and electromagnetic waves and are being employed over a wide range of latitudes. They are especially interesting at high latitudes, where the input of energy from natural sources is high. For example, to launch vlf/elf waves in the ionosphere by the hf heating technique requires the presence of a direct current, such as the polar electrojet. This current is then varied through absorption of some of the energy of the waves whose intensity is modulated at the desired vlf/elf frequency. On the other hand, the auroral ionosphere offers unique opportunities to study short-term nonlinear plasma effects caused by intense hf waves. The strong density gradients and lower resonance heights, the available free energy provided by auroral electron beams, and the possibility to transmit the high-power hf pulses in a direction parallel to the magnetic field lines represent configurations of particular interest. Finally, using rockets or satellites, particle beams can be injected into the polar ionosphere to study beam-plasma interactions, and the background plasma concentration can be either raised or lowered through the release of appropriate chemicals.

With the aid of these powerful techniques the study of the ionospheric plasma begins to approach laboratory-style experimentation in which the parameters are known and controllable, with the advantage of a wall-free environment. Many of the results have important practical applications, especially in the area of electromagnetic communication systems at high latitudes.

(c) Cusp Studies

We recommend continued development and strengthening of investigations of the magnetospheric cusp and dayside aurora both at Svalbard and at South Pole Station, as well as long-term support for the very-high-latitude incoherent-scatter radar installation at Søndre Strømfjord, Greenland.

Studies of the magnetospheric cusp, where particles and waves from interplanetary space penetrate deep into the magnetosphere to altitudes as low as the ionosphere, can only be carried out from the polar regions. The Svalbard, Søndre Strømfjord, and South Pole stations represent ideal locations for investigation of the cusp in the northern and southern polar regions. Studies at South Pole Station should concentrate on optical and other appropriate geophysical measurements, making use of the exceptionally good atmospheric viewing conditions and the long southern night at that location. Optical and other geophysical investigations at Svalbard, conducted in a concentrated interval around the December solstice, can be especially fruitful in conjunction with geophysical studies made simultaneously along the Alaskan magnetometer array. As recommended in Solar-Terrestrial Research for the 1980's, the planned radar investigations in Greenland can be considerably augmented and enhanced if appropriate complementary ground-based instrumentation is installed for coordinated measurements with radar experiments.

(d) Prediction of Auroral and Magnetic Perturbations

We recommend a coordinated effort to improve the prediction capability of auroral activity and ionospheric and magnetic perturbations at high latitude by determining quantitatively the relationships between solar-wind parameters and the occurrence, type, intensity, and space and time evolution of auroral and other high-latitude magnetospheric perturbations and by studying the responsible physical processes.

In recent years, evidence has been accumulated indicating that near-earth magnetospheric perturbations are controlled by a combination of large-scale solar-wind parameters involving the magnetic-field magnitude and direction, the bulk speed and, perhaps, the density.

To a considerable extent, this control appears to be exerted in near real time, indicating the action of a dynamic process that regulates energy transfer from the solar wind to the magnetosphere, followed almost immediately by the deposition of part of this energy in the high-latitude upper atmosphere. It is unknown as yet what fraction of the transferred energy is deposited at once, what fraction is stored in the magnetospheric tail and released only later, and what fraction is returned to the solar wind without ever affecting near-earth space.

Quantitative knowledge of the correlation between solar-wind behavior and magnetospheric response and the identification of the responsible physical mechanisms will lead to an improved quantitative prediction capability of solar-wind disturbance effects on the polar ionosphere and upper atmosphere. Preliminary tests have shown that a 1-hour lead time is possible for a prediction capability. The prediction of the detailed nature and time evolution of magnetic storms and substorms is of fundamental importance for the operation of early-warning defense systems, communications systems at high latitudes and powerline grids during peak load situations. An important spinoff of this study may be a greatly improved method of using ground-based monitoring networks to infer solar-wind conditions in a quantitative manner.

This study will require continued data acquisition of relevant solar-wind parameters from a spacecraft parked near the Lagrangian point upstream of the earth's magnetosphere, monitoring of magnetic perturbations by the worldwide high-latitude magnetometer network and systematic optical recording of auroral activity at key stations. Because of hemispheric differences in the polar current system configuration, simultaneous, coordinated observations in both polar regions are necessary.

6.2 RECOMMENDATIONS ON BASIC RESEARCH IN NEUTRAL ATMOSPHERE PHYSICS

(a) Neutral Upper Atmosphere

We endorse U.S. participation in the Middle Atmosphere Program (MAP) and recommend increased emphasis on studies of the composition and dynamical characteristics of the middle and upper atmosphere (including the stratosphere) in the polar regions. Areas of special interest that represent major gaps in our knowledge of global atmospheric properties are the degree of dynamical coupling between different altitude regimes, the influence of small-scale dynamics, and the difference in chemical composition between the polar and mid-latitude atmospheres.

Our information on the composition and dynamical characteristics of the neutral upper and middle atmosphere in the polar regions rests on a sparse data base. Enough is known, however, to be certain that there are major chemical differences between the polar and mid-latitude atmospheres. These are caused by different types of energetic-particle ionization (discussed in Recommendation (d) above) and by the greatly different conditions of solar illumination. The absence of sunlight during the polar winter as well as its continual presence during the summer cause the concentrations of many chemically active species to be significantly different from those typical of middle latitudes.

In the middle atmosphere (10-100 km), the large-scale circulation is driven by meridional temperature gradients, and these are largely determined by the distribution of ozone and of sunlight. Since the ozone concentration is affected by many of the other minor chemical species, the dynamical properties of the polar middle atmosphere are also unique, forming the core of an intense westerly polar vortex during the winter months and of a weaker easterly regime during the summer.

(b) Solar Activity Effects on the Polar Atmosphere

We recommend an increased effort in the study of the physical links between solar activity and atmospheric behavior in the polar regions, especially concerning two aspects: (1) the links between solar-flare particle energy deposition and formation of odd-nitrogen and odd-hydrogen compounds and their effect on stratospheric ozone; (2) the global ionosphere-atmosphere electric-field configuration, its modification from above by ionospheric conductivity changes and from below by tropospheric electric storms. Another objective of this research should be the critical examination of the possible connection of these phenomena with polar climate.

Direct solar radiation is less intense in the polar regions, and the importance of heat transported from lower latitudes through atmospheric and oceanic currents is therefore enhanced. In addition, the upper atmosphere itself is more subject to influences of solar activity in the polar regions. Under these circumstances, any possible effect of upper-atmospheric processes on climate would be expected to have more influence in the polar regions than at lower latitudes. Thus, if there is a connection between solar activity and the weather and climate of the lower atmosphere, it may be most evident at high latitudes.

For example, intense solar flares give rise to fluxes of energetic particles that arrive in the vicinity of the earth within a few hours of the flare. The geomagnetic field deflects these particles away from the middle and low latitudes of the earth but allows entry into the atmosphere in the polar regions. Because of their high energy, substantial fluxes of the particles often penetrate into the stratosphere, where the ionization they produce leads to the formation of odd-nitrogen and odd-hydrogen compounds that can efficiently catalyze the chemical destruction of stratospheric ozone. Since ozone is the principal source of heating for the middle atmosphere, and since there is some degree of dynamical coupling between the middle and lower atmospheres, there is a possible connection between such solar-particle events and polar climate.

Another chain of interaction mechanisms between near-earth space and the atmosphere at high latitudes is given by the global electric conductivity of the polar ionosphere on one hand and by highly localized conductivity increases in thunderstorm systems on the other. In addition, the conductivity of the clear-weather atmosphere to altitudes of a few tens of meters above the ground is determined by the galactic cosmic-ray flux; near the ground level, natural radioactivity is the determining factor. It is believed that the main driving mechanisms of these electric circuits are the solar-wind dynamo and resulting plasma motions in the magnetosphere and windshears in tropospheric thunderstorms. It is not known whether these are independently operating mechanisms or whether some interaction exists, mediated by the overall global electric-field configuration.

These studies will require a combination of techniques, including remote sensing from satellites and ground-based optical methods and direct air sampling and field measurements by balloon and rocketborne instrumentation.

6.3 RECOMMENDATIONS ON RESEARCH RELEVANT TO APPLIED FIELDS AND OTHER DISCIPLINES

(a) Ionospheric Inhomogeneities

We support a research program aimed at understanding the physical mechanisms that cause the formation of high-latitude ionospheric irregularities. A more complete understanding of the processes involved will ultimately lead to an ability to predict ionospheric conditions and their interference with communications and defense systems.

The polar ionosphere exhibits a variety of inhomogeneities with wavelengths ranging from tens of centimeters to tens of kilometers. The largest-scale structures result from the nonuniform precipitation of energetic particles associated with aurora, while a variety of plasma instabilities lead to the generation of smaller-scale features. The principal practical effect of ionospheric irregularities is to scatter or otherwise modify electromagnetic waves passing through the ionized medium. Communications with satellite systems at high latitude, even at gigahertz frequencies, are affected by fading and scintillation. Partial solutions include the use of higher transmitting power and/or reduced data rates, although the effects cannot be completely overcome.

The Arctic ionosphere and upper atmosphere exert an important influence on communications and defense systems. At latitudes above about 70°, communication via geostationary satellites becomes difficult or impossible as the line of sight to these satellites goes below the horizon. Thus, in these regions, there has been continued use of hf (3-30 MHz) radio communication that depends on reflections from the ionosphere. The disturbances to the ionosphere associated with auroral displays and geomagnetic activity make it difficult to forecast the optimum useful frequency and can cause severe and sometimes total interruption of hf circuits. Similar effects arise from solar-flare particles incident on the polar-cap ionosphere. At the lowest frequency (75 Hz) proposed for communications in the elf range, ionization encompassing the entire polar cap must be considered, as such enhanced ionization will influence the earth-ionosphere cavity and alter the signal amplitude at distant receiving stations.

The irregular behavior of the ionosphere at these high latitudes also makes it difficult to utilize over-the-horizon detection (OHD) radars, which operate at hf and depend on ionospheric reflections. Despite the difficulty, the U.S. Air Force is pursuing such a system and has a particular need to be able to characterize the ionosphere in real time. Better predictions and methods for making real-time measurements can result from research conducted in the auroral region.

(b) Electromagnetic and Particle Radiation Background at High Latitudes

We support a broadly based research program to obtain a data base on the background intensity, frequency distribution, and time variations of the natural electromagnetic radiation at high latitudes. Similarly, the fluxes of the energetic particle populations on high-latitude magnetic field lines should be measured over a time period long enough to establish the important diurnal-, seasonal- and solar-cycle variations.

The natural background of electromagnetic radiation at all frequencies in the polar regions provides a lower limit to the noise level of any communication system. Establishing these noise levels and understanding their variations is important in sizing communication systems, both military and civilian. Because of the unique characteristics of the polar ionosphere and its current systems, these noise levels cannot be derived from experience at lower latitudes, and polar research programs must be conducted to obtain these data. Furthermore, there is a large asymmetry between the Arctic and Antarctic with respect to noise levels and hence measurements in both polar regions are required.

A number of important military and civilian programs now routinely use satellites and have become dependent on the availability of reliable, long-lived spacecraft. These programs include communications, meteorological data gathering, navigation and global surveillance for military as well as for commercial purposes. Spacecraft systems are affected by the space environment, which may either injure sensitive components or produce unwanted background effects. Degradation of solar cells by radiation is a well-known example; a less-well-known but important effect is the electrical charging and subsequent arcing of spacecraft surfaces exposed to high-temperature plasmas. These conditions exist only on high-latitude field lines and occur sporadically when new injections of plasma are made from the outer magnetosphere or when ionospheric plasma is accelerated upward along auroral field lines. As satellite instrumentation becomes more sophisticated, previously overlooked effects such as the electrostatic charging of surfaces can become troublesome, so the investigation of environmental influences on satellite equipment is a continuing task needed for spacecraft technology.

At high latitudes an additional concern is the high background levels that aurora and airglow can induce in the visible light, ultraviolet, and infrared sensors used by detection and surveillance spacecraft. These sensors can be confused by auroral arcs, and thus the Department of Defense is attempting to characterize the atmospheric emission at many wavelengths and to understand how it varies over a wide range of conditions.

Most environmental effects can be alleviated by design modifications. For example, solar-cell damage can be compensated for by specifying a larger solar array than is initially needed, and radiation damage to electronics can be reduced by additional shielding. Unwanted backgrounds can often be reduced by sensor modifications or by clever software methods to discriminate against the unwanted signals. However, all of these techniques increase program costs and require a detailed knowledge of the phenomena being circumvented. Any uncertainty in the phenomena (such as the intensity of trapped radiation) forces the designer to more conservative choices, and these compromises add to the program cost. Because many of the environmental factors of importance are complex and vary with location, as well as on a daily, seasonal, and solar-cycle time scale, obtaining an adequate description of the space environment requires a substantial research commitment over a long time period. However, the economic benefits associated with optimum spacecraft designs are so large that such efforts are justified. As stated previously, the polar region is a unique window through which space processes can be investigated. Hence, upper-atmosphere and space research in the polar regions has an important impact on the efforts to utilize space technology for practical purposes.

(c) Geomagnetic Influences on Ground-Based Systems

We endorse the continued evaluation of the influences of geomagnetic variations and disturbances on ground-based technological systems, in order to make available to systems designers the most up-to-date understanding of the geophysical environment necessary to achieve an improved capability of avoiding interferences and outages of geomagnetic origin.

The influences of geomagnetic disturbances on ground-based systems arise from currents flowing in the earth's ionosphere. These currents are produced by magnetospheric processes such as magnetic substorms, hydromagnetic waves and magnetic-field-aligned currents and are most pronounced at auroral latitudes. These ionospheric currents in turn produce variable magnetic fields at the surface of the earth, which induce currents in the earth itself and in long conductors such as telephone cables, power lines and pipelines on the surface and beneath the surface of earth. In the majority of situations, the induced currents are of little consequence to the system. For example, pipelines are designed with cathodic protection to minimize the corrosion impact, and the induced fluctations in communication cables produce no problems for noise or integrity in the systems.

However, during times of significant magnetic storms the induced currents can become very large and produce damage or failure in communication and power systems. For example, they can cause the shutdown of a communication cable powering system. If the induced currents that flow through the secondary winding of power control systems are excessive, they can cause burnouts and failures of protective relay devices. In the auroral zone, induced currents in pipelines can affect pipeline control electronics and the monitoring procedure for corrosion effects.

Although the possibility of such induced currents from geomagnetic processes has been realized for over a century, new systems must always be evaluated for their susceptibility to geomagnetically induced currents.

This can oftentimes be a difficult task to accomplish, either analytically or experimentally. In addition, the scale sizes of many geomagnetic disturbances are still imperfectly known, and present understanding is not yet at the point where the scale sizes of most disturbances can be predicted reliably. Nature continues occasionally to conspire in presenting new aspects of geomagnetic disturbances so that it remains necessary to continue the evaluation of both existing and new technological systems in the context of evolving knowledge of geophysical processes.

(d) Astronomical and Solar Research

We recommend the continued effective use of the unique atmospheric, geomagnetic, and seasonal characteristics of the polar regions for astronomical and solar research objectives.

This recommendation, although not specifically pertaining to upper-atmosphere research, is formulated here because certain geophysical and geomagnetic conditions in the polar regions also make them quite appropriate locations for some solar and astronomical investigations. Solar and galactic cosmic-ray research has been conducted to good advantage in these locations for many years. The good atmospheric conditions for astronomical investigations at the South Pole have been recognized for a long time, but the difficult human observing conditions and the severe requirements on telescope characteristics have slowed the development of such research at this station. The South Pole Station location also offers astronomical advantages in terms of exceptionally long, uninterrupted intervals of observing time (both sunlight and darkness) and low atmospheric water-vapor content (of particular importance for infrared observations). The long intervals of uninterrupted visibility of the sun have been used recently to excellent advantage in investigations of normal modes of solar oscillation. Unambiguous detection of these modes is of basic significance in understanding the energy transport process from the nuclear burning in the interior to the radiation emission at the surface.

The asymptotic directions of arrival for galactic and solar cosmic rays traveling through the earth's magnetic field and measured at McMurdo, Antarctica, and Thule, Greenland, are nearly perpendicular to the ecliptic plane. These are the only two existent stations with such characteristics; most other monitoring stations have asymptotic arrival directions close to ecliptic. Several research groups have used the neutron monitor measurements made at these stations to investigate the heliospheric asymmetries in the solar and galactic cosmic-ray fluxes near earth. Such investigations have provided new insights into the modulation of cosmic rays by interplanetary shock waves and the interplanetary magnetic field.

6.4 RECOMMENDATIONS ON POLICY ISSUES

(a) Coordination of Polar Programs in Upper-Atmosphere and Near-Earth Space Research

We recommend that a mechanism for coordinating polar programs in upper-atmosphere and space research be established as part of an overall national coordination of programs in Arctic research. The responsibility for coordinating polar-upper-atmosphere research, including logistic aspects where necessary, should be assigned to some agency that conducts or supports programs in the polar region and that has, or can build, effective contacts with the National Science Foundation, Department of Defense, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, Department of Energy, and other involved agencies. As a minimum effort, some designated group should maintain a central information exchange on the polar programs of all agencies, their schedules, objectives, and expected results.

It is well recognized (see Chapter 5) that geophysical research programs, particularly those involving global phenomena, often require simultaneous measurements at various locations with a variety of instruments. In addition, interpretation of measurements and theoretical advances require data from a multitude of sources obtained on a global scale. National and international programs such as the International Geophysical Year and the International Magnetospheric Study achieved much of their success by intelligent scheduling of individual experiments and by the pooling of data. Considerable additional value could be derived from current U.S. polar research programs in upper-atmosphere and near-earth space physics if more effective coordination could be made of the activities that are sponsored by the various agencies and are now conducted independently.

In this regard, the polar programs in upper atmosphere and near-earth space are one facet of the overall U.S. solar-terrestrial physics program. It has been noted (Report to the Committee on Atmosphere and Oceans Policy Review Group on the Need for a National Coordinated Solar-Terrestrial Program in the 1980's, October 1979, Williams, D.J.) that the present and planned solar-terrestrial programs are conducted independently by various sponsoring agencies and have only informal cooperation. The polar programs with their mixture of commercial, military, and scientific motivations exemplify this diversity of objectives and lack of effective coordination. Agencies currently active in high-altitude polar research include the military agencies Office of Naval Research, Defense Advanced Research Projects Agency, Air Force Office of Scientific Research, Defense Nuclear Agency, Air Force Geophysics Laboratory, as well as civilian sponsors such as Department of Energy, National Science Foundation, and National Aeronautics and Space Administration. The research programs vary in scope from single-point measurements to campaigns involving many rocket launches and simultaneous ground and satellite measurements. The objectives run the gamut from basic research to evaluating the impact of aurora on a specific communication system.

Perhaps the most serious problem in promoting cooperative high-latitude research programs in the United States is the lack of contact between the Department of Defense (DOD) and civilian programs. A DOD project usually has a primary military mission, and this objective can often be completed without recourse to other data. Hence, the military sponsor usually does not need to contact other groups or to share data in order to achieve the program objectives. However, in addition to the primary mission, a DOD program frequently collects data of great scientific interest, and these data can be lost to the scientific community unless they are recognized as valuable and arrangements are made to exploit them. Even more serious is the loss of science stemming from the lack in coordination during the planning and data-taking phases. By scheduling various military and civilian programs to be active at the same time, all programs would benefit with little, if any, increase in cost. A prime example of this situation is the almost continuous presence of polar-orbiting DOD satellites carrying auroral instrumentation. Managers of ground-based, rocket, and balloon programs conducted by civilian agencies are often unaware of this resource and these programs are carried out with no plans to utilize the satellite data.

The principal difficulty in achieving the required coordination is the lack of readily available information on the polar programs sponsored by the various agencies. Sometimes the principal investigators organize an informal group to schedule joint data-gathering time intervals. However, if the DOD program is not directed by a scientist who is aware of, and interested in, the geophysical aspects of the project, the program may run to completion without the scientific community learning of it. It should be noted that in most cases the geophysical data can be extracted and published even if the primary purpose of the mission or the experiment is classified.

In the context of program coordination, it also should be noted that there is no national policy for Arctic and Subarctic research, nor is there a comprehensive, interdisciplinary, national program for the conduct of Arctic and Subarctic research. This lack of national direction and coordination has led to a piecemeal attrition of federal support to research facilities, lack of long-range planning, failure to reciprocate in international scientific exchanges concerning the Arctic, and uneven attention to, and support of, the various scientific disciplines in the Arctic. In contrast, research efforts in Antarctica benefit from a strong national program for research in that region. Closely related to this lack of a national Arctic Science Policy is the need for coordination of research efforts in the Arctic and Subarctic at both the state (Alaska) and local levels. State and local coordination would enhance cost-effectiveness, lessen duplication of effort, and expose research gaps. All of this is in sharp contrast with the Soviet Union, which has a large, coordinated program of Arctic research, of which upper-atmosphere and near-earth space research are important components.

The coordination of polar programs in upper-atmosphere and near-earth space research should be established as part of an overall national coordination of programs in solar-terrestrial physics. A newsletter describing current and planned experiments, the principal investigators, sponsors, and contractors should be distributed on a regular basis. The agency charged with this function should be especially concerned with the inclusion of various DOD programs in its listings. It is not envisaged that the coordinating group would sponsor research, although it could well be located in an agency that supports such activities.

(b) Research in Svalbard

We recommend that the United States strengthen its upper-atmosphere research program conducted at Svalbard. In implementing this recommendation the United States would be exercising its rights as a signatory of the Svalbard Treaty in support of scientific research by U.S. investigators in the Svalbard Archipelago.

In Chapter 3 we pointed out the importance of Svalbard because of its special geographic-geomagnetic position. There is an urgent need for increased understanding and support on the part of the U.S. Department of State of the needs and concern of U.S. scientists conducting research programs in Svalbard.

The Government of Svalbard is unique in the world. The Treaty of Svalbard (treaty of 9 February 1920 and Act of 17 July 1925 relating to Spitsbergen) appointed Norway as sovereign, but all the signatories are allowed free access to the archipelago. Article 5 of the treaty declares that an agreement is to be negotiated on the conditions for carrying out scientific research in Svalbard. However, such an agreement has not yet been drafted.

U.S. upper-atmosphere research on Svalbard is currently limited to a joint program that includes the operation of an optical auroral observatory located in the easily accessible Longyearbyen area on land owned by the Store Norske Coal Company. A U.S. proposal to conduct sounding-rocket experiments from Svalbard jointly with Norwegian groups is under consideration. Such a program would be invaluable for cusp studies (see Section 6.1. (c)) and could not be conducted as cost-effectively from any of the other areas located in geographic-geomagnetic locations similar to Svalbard. There are numerous other ground, balloon, and rocket-based experiments that would also benefit greatly from the use of a facility on Svalbard. It is, therefore, important that the appropriate diplomatic steps be initiated to make Svalbard easily accessible to U.S. researchers for a variety of polar research programs.

(c) The Role of the Scientific Committee on Antarctic Research (ICSU) in Upper-Atmosphere and Near-Earth Space Research

We recommend the United States urge the Scientific Committee on Antarctic Research (ICSU) that scientific representatives of interested member nations be brought together at the earliest possible time to review existing upper-atmosphere and near-earth space programs in Antarctica and to develop plans for the future.

Research in the Antarctic on the upper atmosphere and near-earth space is global in scope, covering all longitudes and a wide range of geomagnetic latitudes and altitudes. At the international level the promotion and coordination of the research has tended to be focused in the appropriate international unions, principally the International Association of Geomagnetism and Aeronomy, International Association of Meteorology and Atmospheric Physics, Union Radio Scientifique Internationale and various special committees such as the Scientific Committee on Solar-Terrestrial Physics and the Committee on Space Research. As a result, the role of SCAR in upper-atmosphere physics has been less critical than in some other Antarctic disciplines, such as marine biology and glaciology. For example, the last meeting of the Working Group on Upper-Atmosphere Physics was held in 1974 at Jackson Hole, Wyoming.

However, times are changing. Increasingly, research in this discipline depends on coordinated measurements, often made at widely spaced observatories belonging to different nations. These observatories require extensive and costly support. People and equipment must be delivered to remote sites using ships and aircraft. Communications must be maintained among Antarctic sites and home laboratories, using hf radio and satellite links. Arrangements must be made for data exchange and publication. With the rapidly increasing expense of field operations, it is essential that programs be well planned and that costs be distributed equitably among the participating parties.

Thus it appears that SCAR could usefully increase its contribution to upper-atmosphere and near-earth-science research in Antarctica by providing more opportunities for participating nations to develop coordinated programs of mutual interest within the framework of the Antarctic Treaty and to share in the provision of logistic requirements.