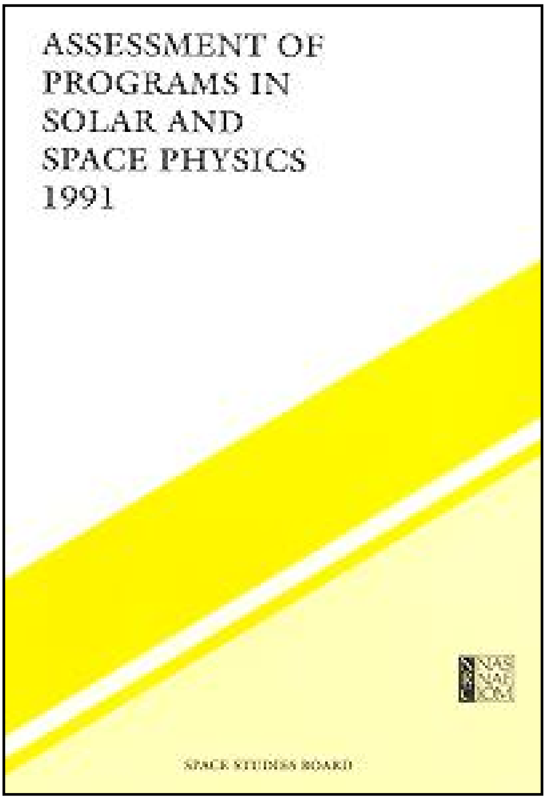
# Assessment of Programs in Solar and Space Physics 1991




Committee on Solar and Space Physics
Space Studies Board
Commission on Physical Sciences, Mathematics, and Applications

Committee on Solar-Terrestrial Research
Board on Atmospheric Sciences and Climate
Commission on Geosciences, Environment, and Resources

National Research Council

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# Assessment of Programs in Solar and Space Physics 1991

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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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# Assessment of Programs in Solar and Space Physics 1991



## Foreword

This report is one in a series written by the standing discipline committees of the Space Studies Board. The purpose of this new series is to assess the status of our nation's space science and applications research programs and to review the responses of the National Aeronautics and Space Administration and other relevant federal agencies to the Board's past recommendations.

It is important, periodically, to take stock of where research disciplines stand. As an advisory body to government, the Space Studies Board should regularly examine the advice it has provided in order to determine its relevance and effectiveness. As a representative of the community of individuals actively engaged in space research and its many applications, the Board has an abiding interest in evaluating the nation's accomplishments and setbacks in space.

In some cases, recurring budget problems and unexpected hardware failures have delayed or otherwise hindered the attainment of recommended objectives. In other cases, space scientists and engineers have achieved outstanding discoveries and new understandings of the Earth, the solar system, and the universe. Although the recent past has seen substantial progress in the nation's civil space program, much remains to be done.

These reports cover the areas of earth science and applications, solar system exploration (and the origins of life), solar and space physics, and space biology and medicine. Where appropriate, these reports also include the status of data management recommendations set forth in the reports of the Space Studies Board's former Committee on Data Management and Computation. The Board has chosen not to assess two major space research disciplines—astronomy and astrophysics, and microgravity research—at this time. Astronomy and astrophysics was recently surveyed in a report under the aegis of the Board on Physics and astronomy, *The Decade of Discovery in Astronomy and Astrophysics* (National Academy Press, Washington, D.C., 1991); the Space Studies Board is currently developing a strategy for the new area of microgravity research.



On completion of the four reports, the Board will summarize the contents of each volume and produce an overview. The Space Studies Board expects to repeat this assessment process approximately every three years, not only for the general benefit of our nation's space research program, but also to assist the Board in determining the need for updating or revising its research strategies and recommendations.

Louis J. Lanzerotti
Chairman, Space Studies Board

# Assessment of Programs in Solar and Space Physics 1991



## Summary

### INTRODUCTION

The Committee on Solar and Space Physics (CSSP) and the Committee on Solar Terrestrial Research (CSTR) are both responsible for providing scientific advice to U.S. government agencies in the overlapping fields of solar physics, space physics, and solar-terrestrial relationships. The CSSP is a subcommittee of and reports to the Space Studies Board (SSB); the CSTR has a similar relationship to the Board on Atmospheric Sciences and Climate (BASC). CSSP and CSTR now function as a single, federated committee reporting to both the SSB and BASC. This assessment report has been written in response to a request by the SSB for an assessment of the way in which prior recommendations of the National Research Council (NRC) are being implemented by the appropriate federal agencies (See Appendix A). The federated committee has expanded the scope of the study beyond that requested by the SSB to include an assessment of responses to NRC reports in solar-terrestrial research that are beyond the space-oriented scope of the SSB. This report was reviewed and approved by the SSB.

### STATUS OF DISCIPLINE

The scientific purview of the CSSP and CSTR covers the disciplines of solar physics, heliospheric physics, cosmic ray physics, magnetospheric physics, middle- and upper-atmosphere physics, solar-terrestrial coupling, and comparative planetary studies. The assessment has two major sections: discipline-specific issues and common issues.



### Discipline-Specific Issues

*Solar Physics*

Good progress has been made in studies of solar irradiance variations, high-energy emissions, and solar magnetism, resulting in part from the Solar Maximum Mission (SMM) and the development of ground-based Stokes polarimeters. Fundamental studies of helioseismology and solar neutrinos are slowly progressing. The principal problem areas are the lack of prospects for space observations of the highest-energy solar phenomena during both the current and the next solar maximum, multiyear gaps in solar irradiance measurements, lack of a funded plan for U.S. participation in the Large Earth-Based Solar Telescope, (LEST), and most critically, the extraordinarily long delay in achieving a new start for the Orbiting Solar Laboratory (OSL). Because of the breadth and importance of its scientific goals, OSL remains the top-priority candidate for a new mission start.

*Heliospheric Physics*

Extremely valuable data on the properties of the outer heliosphere continue to be received from the Pioneer and Voyager spacecraft. With the successful launch of Ulysses, the fist in situ measurements of the three-dimensional structure of the heliosphere will be obtained in 1993-1995. Both Ulysses and Wind (to be launched in 1993) are expected to allow great advances in our knowledge of the abundance and charge state of solar wind ions. Problem areas are the lack of advanced development of technology required for future missions and the decline in support for ground-based radio observations of the solar corona and solar wind.

*Cosmic Ray Physics*

Data returned by the Voyager and Pioneer spacecraft launched, in the 1970s, gave valuable new insights into the modulation of galactic cosmic rays, the nature of anomalous cosmic rays, and the variable abundances of solar energetic particles. Although several other missions and experiments responsive to NRC recommendations were started, many of them were subsequently canceled or postponed indefinitely; others have been stretched out over more than a decade. The augmentation of the Explorer Program has led to the selection of two new cosmic ray missions-the Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX) and the Advanced Composition Explorer (ACE).

*Magnetospheric Physics*

During the 1980s, a number of advances occurred that increased our understanding of magnetospheric physics, including definitive observations that the ionosphere is a major source of magnetospheric particles, initial measurements of the composition and charge state of the ring current, the discovery of plasmoids traveling at high velocity away from the Earth, and the development of new models of the Earth's magnetopause, bow shock, and foreshock regions. The key magnetospheric project, the International Solar-Terrestrial Physics (ISTP) program, has been subject to delays and descoping actions. Deletion of the Equator spacecraft eliminated crucial measurements of the equatorial magnetosphere. NASA is currently trying to develop other ways to obtain those key measurements. The several ISTP elements may, however, be spread out in time to the extent that there will be little of the simultaneity of measurements so vital to accomplishing the ISTP objectives. Although the mission of the recently launched Combined Release and Radiation Effects Satellite (CRRES) is td perform some active magnetospheric experiments, much of the active experiment program has been lost as a major element of magnetospheric research because of budget cuts and delays.



*Middle- and Upper-Atmosphere Physics*

There has been much progress in implementing NRC recommendations in this discipline; the Middle Atmosphere Program (MAP), the Coupling Energetics, and Dynamics of Atmospheric Regions (CEDAR) program, and a series of satellite observations gave a major boost to studies of chemical, dynamical, radiation, and coupling processes. Recent studies of the polar ozone depletion are especially noteworthy, but the ',combination of long delays, such as in Upper Atmosphere Research Satellite (UARS); the lack of a vigorous research program on the effects of solar activity on the middle atmosphere; and some gaps in addressing the global electric circuit problem, has reduced expected progress in some important areas.

*Solar-Terrestrial Coupling*

Progress in solar-terrestrial coupling has been closely related to results in the areas of magnetospheric and atmospheric physics. Those results, mostly tied to programs defined in the 1970s and conducted in the 1980s, have improved our understanding of the solar wind-magnetosphere-ionosphere interactions and resulting dynamics. The programmatic delays from planning to implementation have meant that most of the solar-terrestrial recommendations made through the 1980s will not be acted on until the 1990s. Illustrative of programs that are expected to provide major advances in this area are the ISTP, CEDAR, and Geospace Environmental Modeling (GEM) programs.

*Comparative Planetary Studies*

Observations of planetary magnetospheres and atmospheres continue to be an important element of solar system exploration. The Voyager flybys of Uranus and Neptune added two new planets to the list of objects available for comparative studies of planetary magnetospheres and magnetosphere-ionosphere-atmosphere interactions. But again, major delays (e.g., in the Galileo and CRAF/Cassini missions) and the absence of a U.S. mission to comet Halley have significantly slowed the implementation of recommendations in this area.



## Common Issues

*Program Management*

The recommended establishment oaf a separate Space Physics Division within NASA's Office of Space Science and Applications (OSSA) has been successfully implemented. The recommended reorganization of the solar physics program within NSF is still under consideration. The recommended interagency coordination council for solar terrestrial research was formed, but has not been active since 1987. International coordination has been excellent.

*Data Archiving and Access*

The recommended solar-terrestrial Central Data Catalog and Data Access Network have not been implemented. Although there have been some initial developments in this area, progress has been painfully slow. A great deal needs to be done before the NRC recommendations are met.

*Explorer Program*

The recommendations of an augmentation of the Explorer program and the institution of a two-stage selection process have both been implemented, as has the recommendation for a return to a concept of small, simple missions. The recommended level of an average of one Explorer per year for solar and space physics has not been reached, however, because cost overruns in the current Explorer program continue to cause delays.

*Coordinated Programs and Synoptic Observations*

Several initiatives have responded to recommendations for coordinated programs. Examples include ISTP and CEDAR. To date, there is no national program or policy supporting recommendations for synoptic observations of the fundamental parameters of the solar-terrestrial system. One exception was NASA's successful effort to increase the data return from the IMP-8 spacecraft.

*Research and Analysis*



Even though support and augmentation of the research base have been recommended by virtually every report, the base appears to have eroded. In addition to this major concern, agency responses to other specific recommendations in this area include the following:



1. **Theory and modeling.** NASA's Space Physics Theory Program (previously called the Solar-Terrestrial Theory Program) has been very successful, but there is concern about the steady erosion of average grant sizes in real-year dollars.

2. **Supercomputing.** Recommendations for access to supercomputers for solar-terrestrial research have largely been met. The limiting factor for many scientists is now the lack of the small, inexpensive workstations required to communicate with the supercomputers and to analyze and display their output.

3. **Suborbital and Spartan programs.** After some floundering during the mid-1980s, NASA's balloon program is currently fairly healthy, with the major problem being limited funding for instrument development. The rocket program has declined because funding has not kept up with inflation, active experiments were removed from the program, and funds were diverted to development of the Spartan program (a diversion with which the NRC concurred). The Spartan program effectively ended with the Challenger accident and, in retrospect, the resources expended for the Spartan program adversely affected the rocket-type science program it was meant to help.

*Education*

To date, only a few programs have set aside specific funds to support educational components of their activities. The CEDAR program has shown notable success in this area.

## CONCLUSIONS

In summary, there has been considerable scientific progress during the past decade, with the bulk of the advances stemming from programs started in the 1970s, prior to the NRC recommendations considered in this report. Progress on the NRC recommendations of the 1980s has been generally slow, however, and in some cases nonexistent. Cancellations, long delays, and major programmatic restructuring have been routine. The perception is that initial responses have been positive but that actions in the implementation phases have not been carried through to achieve the goals embodied in the recommendations.

Because of these cancellations, delays, and stretch outs, the scientific goals and most of the specific recommendations for each of the subdisciplines remain valid. There is presently no need for a new set of scientific goals and priorities. The most recent NRC report that set out an implementation plan for solar and space physics was written in 1985. Although parts of that report are now obsolete, the CSSP/CSTR plans to review NASA's Strategic Plan currently under development rather than to develop an implementation strategy of its own at the present time. The federated committee also plans to further examine issues in the agencies' research and analysis programs.

# Assessment of Programs in Solar and Space Physics 1991

## 1 Introduction

The Committee on Solar and Space Physics (CSSP) and the Committee on Solar Terrestrial Research (CSTR) are both responsible for providing scientific advice to U.S. government agencies in the overlapping fields of solar physics, space physics, and solar-terrestrial relations. The CSSP reports to the Space Studies Board (SSB) and the CSTR has a similar relationship to the Board on Atmospheric Sciences and Climate (BASC). Starting in October 1990, CSSP and CSTR began to function as a single, federated committee reporting to both the SSB and BASC. This *assessment report* has been written in response to a request by the SSB for an assessment of the way in which prior recommendations of the National Research Council (NRC) are being implemented by the appropriate federal agencies. The SSB has also requested that the assessment report address the need and time scale for any changes in the existing scientific strategies in the subcommittee's purview. The federated committee expanded the scope of the study beyond that requested by the SSB to include an assessment of responses to NRC reports in solar-terrestrial research that are beyond the traditional space-oriented scope of the SSB but that address the broader interests of CSTR, BASC, and the solar and space physics community.

The scientific purview of the CSSP and CSTR is very broad, ranging from the interior of the Sun, through interplanetary space and planetary magnetospheres to their atmospheres, and out to interstellar space. Much of this research involves the discipline of plasma physics, but there are also strong elements of high energy physics, radiative transfer, and aeronomy. For the purposes of this report, the scientific research is discussed in seven categories: solar physics, heliospheric physics, cosmic ray physics, magnetospheric physics, upper-atmosphere physics, solar-terrestrial coupling, and comparative planetary studies. Other topics that cut across all the subdisciplines are also discussed.

The principal NRC report pertaining to solar and space physics published since 1980 are listed in the bibliography. A list of abbreviations and acronyms follows the bibliography. The users or recipients of the advice given by CSSP and CSTR are diverse; they are listed in Appendix B.

# 2
# Status of Discipline

The assessment of the progress in meeting the objectives for the discipline spelled out in the recent NRC reports is divided into two categories: issues specific to each of the disciplines and issues common to all disciplines concerned.

## DISCIPLINE-SPECIFIC ISSUES

### Solar Physics

The three major aspects involved in scientific studies of the Sun—the Sun as a source of energy for the heliosphere, and in particular, for the Earth; the Sun as a star; and the Sun as a laboratory for the study of basic physical processes—are included in this assessment. The principal scientific goals of the solar physics program are as follows:

- Understanding the physical origin and effects of solar and stellar activity. Solar activity manifests itself in many forms, with time scales ranging from milliseconds to decades, and size scales from sub-arcsecond magnetic flux tubes to coronal streamers and mass ejections extending out to tens of solar radii.

- Using highly resolved observations of solar activity as a "laboratory" for understanding widely applicable astrophysical and plasma processes.

- Understanding the causes of variations in the radiative output of the Sun. The active cavity radiometer irradiance monitor (ACRIM) experiment on the Solar Maximum Mission (SMM) made the surprising discovery that the solar bolometric irradiance varies with the sunspot cycle and with the appearance and dissolution of individual sunspot groups.

- Measuring the internal structure, dynamics, and composition of the Sun. The principal tools for such measurements are helioseismology, the study of solar neutrinos, and the study of the solar activity cycle.



Achieving the first three goals requires synoptic, high-resolution observations of active regions, including small-scale magnetic and flow fields (AMPS, 1983; SSB, 1985b; CPSMR, 1989). Ground-based Stokes polarimeters have been constructed and are beginning to make progress in this area. The critical tool, however, is the Orbiting Solar Laboratory (OSL). OSL is designed to probe the fine-scale (100 to 300 km) structure that drives solar activity. Among the large-scale consequences of small-scale processes are x-ray emission, solar flares, mass ejections, and bolometric luminosity variations. We must look to the Sun, the only highly resolved star, to place stellar x-ray astronomy on a firm physical foundation. The observed magnitude of solar luminosity variations was unanticipated and is a significant scientific problem in its own right. Recent research, however, has shown that solar-type stars occasionally undergo even larger (~l percent) luminosity variations. Because such a variation in the Sun would cause global climate changes on Earth with catastrophic social consequences, understanding the drivers of solar luminosity changes has been given very high priority.

Flying in a fully sunlit orbit and carrying five major instruments to study the full temperature range of the solar atmosphere at high angular resolution, OSL is the most comprehensive and intensive solar physics mission ever developed. The scientific objectives of OSL cannot be achieved by observations from the ground because of the requirements for response in the ultraviolet and x-ray, for a field of view large enough to encompass an entire active solar region, and for continuous observations. While adaptive optics, although a promising but still immature technology, may substantially increase our ground-based viewing capabilities at visible wavelengths, the technique cannot provide, even in theory, diffraction-limited images over the large field of view that OSL's instruments are designed to image. OSL's instrumentation is state-of-the-art yet technically proven. Despite the continuing delays in the implementation of this program, it remains the highest priority new program for solar and space physics.

High-energy aspects of solar activity have been studied at length because of the success of SMM and its repair mission. The impending SOLAR-A Satellite, a Japanese mission using several U.S. instruments, will further expand our knowledge of high-energy solar processes. The Geostationary Operational Environmental Satellite (GOES) program funded by the National Oceanographic and Atmospheric Administration (NOAA) will provide a substantial improvement in routine imaging of solar soft x-ray and ultraviolet emissions; the Solar and Heliospheric Observatory (SOHO) will furnish observations of coronal mass ejections. Unfortunately, no imaging of high-energy x-ray emissions is planned for the next solar maximum.



The Rosner report (CPSMR, 1989) recommended that National Science Foundation (NSF) support activities leading to the definition and siting of a modern telescope system for studying the physics of the Sun at small scales; such a system would obtain data complementary to data from OSL. The report pointed out that one option for pursuing this goal was for substantial U.S. participation in the international consortium for the Large Earth-Based Solar Telescope (LEST). To date, NSF has neither funded U.S. participation in LEST nor pursued any alternative option.



Many past reports have recommended systematic long-term study of the total solar irradiance (the "solar constant") and the solar ultraviolet spectral irradiance (BASC, 1984; SSB, 1985b; CPSMR, 1989). National Aeronautics and Space Administration (NASA) and NSF have reacted positively to these recommendations, but the goal of obtaining long-term, uninterrupted measurements has not been achieved because of program delays. SMM reentered the atmosphere in early 1990, thereby halting the steady stream of ACRIM bolometric irradiance data and making cross calibrations with any future instruments impossible. Several solar variability monitors are included on Upper Atmosphere Research Satellite (LIARS), but there will be at least a two-year gap between the end of ACRIM and the beginning of LIARS measurements. NSF is considering, but has not yet funded, a program of ground-based monitoring of solar variability.

The NRC recommended the establishment of an instrumentation and theory program in helioseismology (BASC, 1984) to study the Sun's global circulation and interior dynamics (SSB, 1985b), and the early completion and operation of a global network of helioseismic observing stations (CPSMR, 1989). In keeping with these recommendations, helioseismology has been relatively well supported and its scientific promise is being realized. For example, the depth and rotation profile of the solar convection zone have been determined. The Global Oscillation Network Group (GONG) project is well under way, although it has been funded well below the proposed profile. Observations continue from the South Pole under the aegis of the polar research program, and space observations will be made from SOHO of the European Space Agency (ESA) with substantial U.S. participation.

Results from the new the Japan-U.S. Kamiokande II experiment suggest already that the solution of the solar neutrino problem requires physics beyond the standard electro-weak theory with zero neutrino masses. A critical test of nonstandard theories will soon be provided by gallium detectors that measure the low-energy neutrinos that directly probe the most energetically important nuclear reactions in the solar core.

In summary, the SMM and the funding of ground-based Stokes polarimeters have led to good progress in studies of irradiance variations, high-energy emissions, and solar magnetism. Helioseismology and solar neutrino studies are also progressing. The principal problem areas are the extraordinarily long delay in achieving a new start for the Orbiting Solar Laboratory, multiyear gaps in irradiance measurements, and lack of a funded plan for U.S. participation in LEST.

## Heliospheric Physics

Heliospheric physics has developed into an independent discipline during the last decade, with its own set of scientific objectives:

- Understanding the basic physical processes that heat the corona and accelerate the solar wind. This objective can be accomplished by in situ measurements, remote measurements of electromagnetic emissions originating in or scattering from the solar wind source regions, and measurements of the chemical and charge composition of the solar wind.

- Understanding the large-scale structure and dynamics of the solar wind. How does the stream structure imposed at the Sun and the global morphology of the heliospheric magnetic-field shape the solar wind and influence its interaction with the local interstellar medium?

- Understanding fundamental microscopic and macroscopic plasma processes, including the evolution of turbulence in the solar wind, the acceleration and transport of energetic particles, and the pickup of ions in the solar wind.

The three-dimensional structure of the heliosphere will be addressed by the Ulysses Mission. After seven years of delay, the Ulysses spacecraft, built by ESA, was successfully launched by NASA in October 1990 and is expected to reach a solar southern latitude of 83° in July 1994 and a similar northern latitude a year later. A key requirement for the success of this mission is the simultaneous measurement of fields and particles in the solar wind near the ecliptic by some combination of Interplanetary Monitoring Platform (IMP-8), International Cometary Explorer (ICE), the wind component of the International Solar-Terrestrial Physics (ISTP) program, Galileo, and perhaps the Soviet Regatta Mission.

The heliospheric elements of the ISTP involve the Wind and SOHO spacecraft. Wind will carry a set of instruments to monitor the interplanetary input to the magnetosphere and will also study the solar wind per se, including microphysical processes such as shock acceleration. Both missions will obtain new data on the elemental abundances and ionization charge states of the solar wind.

Extended missions for the large number of heliospheric spacecraft (Voyagers 1 and 2, Pioneers 10 and 11, ICE, Pioneer Venus Orbiter, IMP-8, Helios 1 and 2) still in full-time or occasional operation have been strongly recommended (BASC, 1981, 1984; SSB, 1985b, 1988b). NASA has responded to these recommendations by increasing the collection of data from IMP-8, which is the only currently active solar-wind monitor near Earth, and has made great efforts to obtain as much data as possible from the Pioneer and Voyager spacecraft that are continuously moving into unexplored regions of the outer heliosphere. There is grave concern, however, that the tracking time available on the Deep Space Network is insufficient to support these spacecraft. efforts to obtain increased funding for coordinated heliospheric studies using existing spacecraft have so far been unsuccessful.



Previous reports also recommended advanced technology development for a number of missions to be implemented after ISTP. The NRC has consistently recommended (SSB, 1980, 1985b, 1988b) a Solar Probe mission that will send a spacecraft into the region where the solar wind is accelerated. The development of a nonablative heat shield to protect the spacecraft and instruments at a distance of only 3 solar radii from the surface of the Sun has not yet been adequately funded despite the fact that the heliospheric community ranks the solar Probe as its highest priority new mission. Heliospheric missions recommended (SSB, 1980, 1985b, 1988b) to follow the Solar Probe would all benefit or be enabled by advanced propulsion (e.g., solar electric or nuclear electric). These missions include the interstellar probe, a 1-astronomical unit solar polar orbiter, and a heliosynchronous orbiter. We believe that such propulsion systems are no closer to reality than they were when the recommendations were first made (SSB, 1980).

In addition to space missions, the NRC has also recommended (BASC, 1981) continued use of interplanetary scintillation (IPS) and radio spectrometric studies of coronal and interplanetary disturbances. The latter work, with the exception of operational U.S. Air Force observations (radio solar telescope network), ahs been discontinued. Recent IPS work has been limited to near-Sun observations and occasional Deep Space Network doppler and phase scintillation studies. To obtain the IPS data that it requires, NOAA has initiated cooperation with other countries.

In summary, the NRC recommendations concerning heliospheric physics are generally being implemented, but with many delays (Ulysses, Wind). On the positive side, outer heliospheric data continue to be received from the Pioneer and Voyager spacecraft. Current concerns include advanced development of technology required for future missions, oversubscription of Deep Space Network tracking support, and the decline in support for ground-based radio observations of the solar corona and solar wind.

## Cosmic Ray Physics

The Field committee report (AMPS, 1983) has provided overall guidance for the cosmic ray program during the 1980s. The scientific goals can be organized under the following objectives:

- The origin and evolution of matter
- Particle acceleration, transport, and interactions



- The role of cosmic rays in galactic processes
- The nature of the interstellar medium

In order to address these objectives, the following measurement goals were identified for the 1980s (BPA, 1982; SSB, 1988c):

- Isotopic composition of nuclei from H to Ni
- Elemental composition of ultraheavy ($Z > 30$) cosmic rays
- Elemental composition and origin of high-energy (,$10^{15}$ Ev) cosmic rays
- Spectra of high-energy electrons, positrons, and antiprotons
- Low-energy cosmic rays in the interstellar medium
- Acceleration, propagation, and composition of solar energetic particles

Some of the highlights of cosmic ray physics in the 1980s were the Voyager and Pioneer observations of the solar modulation of galactic cosmic rays, further study of anomalous cosmic rays, and better understanding of the mass spectrum of solar cosmic rays. At the same time, progress in cosmic ray physics was limited by the cancellation of a Spacelab experiment to study high-energy interactions and of re-flights of two experiments to measure cosmic ray nuclei.

Two new cosmic ray Explorers were selected following the 1988 augmentation to the Explorer budget:

1. The Advanced Composition Explorer (ACE), which will measure the elemental and isotopic composition of H through Ni nuclei over six decades in energy/nucleon, from solar wind to galactic cosmic ray energies.

2. The Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX), which will measure low-energy solar, magnetospheric, and galactic particles from 0.3 to 300 MeV/nucleon from a polar orbit. SAMPEX is the first of a new series of Small Explorers that has been initiated to provide frequent access to space for low-cost, focused experiments.

Several small experiments on "missions of opportunity" were also successfully funded through the Explorer Program. On the negative side, cost overruns in the current Explorer Program will apparently delay the launch of ACE until at least 1997, ten years after it was proposed.



Another major recommendation (BPA, 1982; SSB, 1988c) was the development of a superconducting magnetic spectrometer facility for the Space Station, including instruments to extend particle and antiparticle spectroscopy into the GeV and TeV energy ranges. Such a facility, named Astromag, was selected for flight on the Space Station. In addition, a Heavy Nuclei Collector (HNC), which would measure cosmic ray abundances of the heaviest elements in the periodic table, was conditionally selected for Space Station. Unfortunately, funding for these and all other attached payloads was recently suspended indefinitely. It will, therefore, be necessary to explore other options to accomplish the important objectives of Astromag and HNC.

Recently, the Positron Electron Magnetic Spectrometer (POEMS), was tentatively selected for, and subsequently deleted from, the Earth Observing System (EOS). POEMS would have measured electrons and positrons from the Galaxy and the Sun as well as solar gamma rays and neutrons. Other means must be found to pursue those important objectives.

Also recognized as important (BPA, 1982; SSB, 1988c) were laboratory cross-section measurements to support the interpretation of cosmic ray data. There has been considerable progress in the initiation of new cross-section measurements at the BEVALAC, but this facility is unfortunately scheduled to close in 1994.

The Twenty-First Century report (e.g., SSB, 1988b,c), which had a more distant horizon, recommended the following additions to the cosmic ray program for the years 1995-2015: (1) Interstellar Probe, a mission to traverse the boundary of the heliosphere and to conduct in situ measurements in interstellar space, (2) large detector arrays for very high energy (> $10^{15}$ eV) and ultra-heavy (Z > 30) nuclei, and (3) experiments on polar platforms to measure positrons, antiprotons, and the isotopes of ultra-heavy nuclei. Very little of the advanced technology development required for these missions has been started.

If the recently selected SAMPEX, ACE, Astromag, and HNC missions are indeed flown during the coming decade, we can expect major progress in studies of the elemental and isotopic composition of energetic nuclei from the solar system and galaxy, and in studies of antiprotons, electrons, positrons, and ultra-heavy nuclei, although on a considerably longer schedule than envisioned by the Field committee (AMPS, 1983). Although the cosmic ray program currently scheduled for the 1990s will address in part all of the goals laid out for this subdiscipline for the 1980s, it will not exhaust those goals that remain valid and can be extended in a natural manner to nuclei in the upper two-thirds of the periodic table and to higher energies. There are, however, two areas in which these goals should be supplemented. There has been increasing interest in the interface between astrophysics, particle physics, and cosmology, and in the use of cosmic rays to test new theories in this field. The second area is the investigation of particles accelerated within, or at the boundary of, the heliosphere. The most significant of these is the so-called "anomalous" cosmic ray component, apparently an accelerated sample of the neutral interstellar medium.



In summary, although missions and experiments responsive to NRC recommendations were started, many of them have been cancelled or indefinitely postponed; others have been stretched to more than a decade. While there is now promise of progress during the 1990's from missions such as SAMPEX and ACE, there is also a danger that Astromag and HNC will repeat the cycle of disappointments that characterized the 1980s.

## Magnetospheric Physics

The Kennel report (SSB, 1980) cited six critical regions of the terrestrial magnetosphere that needed to be better understood in order to advance quantitative understanding of the time-dependent exchange of energy and plasma between the solar wind and the magnetosphere, and called for simultaneous studies of plasma processes in those regions. The regions cited were (1) the Earth's extended magnetic tail, (2) the upstream solar wind, (3) the mid-magnetosphere equatorial plane, (4) well above the polar cap, (5) the low-altitude region observable from the ground, and (6) the atmospheric regions. The Friedman-Intriligator report (BASC, 1981) expressed strong agreement with the recommendations of the Kennel report, and made a series of recommendations that emphasized the need to understand the *coupling* between the critical regions, in addition to understanding local processes within each region. Specifically, Friedman-Intriligator recommended programs to study energy and momentum transfer between the solar wind and magnetosphere; energy transfer between the magnetosphere, ionosphere, and atmosphere in magnetic field line regions passing through the auroral zone, polar caps, and geomagnetic tail; and global coupling of the magnetosphere, ionosphere, and atmosphere system.

The decade of the 1980s witnessed both a substantial, steady growth in our understanding of magnetospheric processes and a series of major accomplishments that provided new perspectives on the magnetosphere and its dynamics. The following list, although not complete, is illustrative of the major changes that came about in the 1980s in magnetospheric physics:

- Global auroral imaging provided a remarkable initial step to obtaining a global perspective of magnetospheric processes.



- New observations, notably from Dynamics Explorer (DE) and Active Magnetospheric Particle Tracer Experiment (AMPTE), definitively showed that the ionosphere is a major source of magnetospheric particles.

- The composition and charge state of the ring current were measured for the first time.



- The first measurements of the deep tail were made showing surprising correlations with inner magnetosphere activity and the existence of plasma configurations, called plasmoids, traveling at high velocity away from the Earth.

- New observations demonstrated the importance of magnetospheric boundary layers in the transport of plasma through the magnetosphere and possibly in the dynamics of the magnetosphere.

- The development of a new model of the Earth's bow shock and foreshock regions provided a better understanding of many of the available observations.

Suggested methods for achieving further progress were put forth by the Intriligator report (BASC, 1984) in 1984, and by the Krimigis report (SSB, 1985b) in 1985. The Intriligator report recommended an international solar-terrestrial physics program and an increase in annual solar-terrestrial research funding above 1984 levels. The Krimigis report recommended a coordinated program of multisatellite observations aimed at providing simultaneous information from the six critical regions as recommended in the Kennel report. In essence, this was the ISTP program.

Several concerns stem from the program delays and major program restructuring. For example, the deep-tail and near-equatorial ISTP spacecraft were removed from the NASA program. The Japanese have provided a deep-tail spacecraft, Geotail (which includes NASA-funded instruments), and the Air Force has provided an equatorial spacecraft named the Combined Release and Radiation Effects Satellite (CRRES). Geotail fulfills the need for deep-tail observations, but CRRES does not fulfill the need for observations in the vital equatorial mid-magnetospheric region at altitudes above 6 earth radii. The CSSP/CSTR endorses NASA's current efforts to re-establish those crucial equatorial observations and reaffirms their need in the ISTP science program. A further concern is that the various programs will be spread out in time to the extent that there will be little simultaneity, thereby directly impacting a most important aspect of the earlier recommendations, i.e., the need for simultaneous observations in the key magnetospheric regions. Although ISTP has the highest priority within the magnetospheric community, the Krimigis report also recommended a series of active experiments to study plasma processes in the magnetosphere either by optical observation of tracer gases or by measuring the response of the magnetosphere to artificial disturbances such as injections of waves or energetic particles. Although CRRES is performing some chemical releases, most of the active experiments developed for the Shuttle have been seriously descoped or delayed.



In summary, response to magnetospheric science and implementation recommendations has been positive but slow. The slowness has resulted in programmatic restructuring that has worked against some key aspects of the recommendations, the most serious being the decrease in temporal overlap of the ISTP spacecraft.



## Middle- and Upper-Atmosphere Physics

A comprehensive program investigating the global neutral atmosphere, the characteristics of its distinct altitude regions, long-term and solar-cycle variability, and the coupling and interaction between regions were defined as the focus for research in the 1980s in several NRC reports (SSB, 1980; BASC, 1981, 1984). Specific scientific topics included:

- The effects of variable photon and particle fluxes.
- The significance of forcing from the magnetosphere.
- The energy balance, chemistry, and dynamics of the thermosphere, mesosphere, and stratosphere.
- A better understanding of the global electric circuit.

The NRC reports emphasize continuing observation and analyses combined with a broad range of specific new missions. Increased annual funding, continued support for mission operations and data analysis, technology development, coordinated campaigns, and a continuing suborbital program were to form a basis for studies of the thermosphere, middle atmosphere, and global electric circuit. Support for the Middle Atmosphere Program (MAP), UARS, the Solar Mesosphere Explorer (SME), a middle atmosphere tether mission, and the Shuttle-based Solar Terrestrial Observatory (STO) were recommended.

Significant advances in understanding dynamical, radiative, chemical, and coupling processes were made through participation of U.S. scientists in MAP.

Satellite observations and parallel theoretical efforts have played a central role in facilitating rapid progress. Observations by the Stratospheric and Mesospheric Sounder (SAMS) and the Limb Infrared Monitor of the Stratosphere (LIMS) provided data on atmospheric composition and dynamics on a global scale. SME made global measurements of ozone and other minor constituents in the middle atmosphere, as well as measurements of temperature over a period of several years. Observations of ozone and aerosols from the Stratospheric Aerosol and Gas Experiment (SAGE) and of total ozone content from the Total Ozone Mapping Spectrometer (TOMS) have also played an important role, especially in recent studies of polar ozone depletion. Spacecraft observations have also determined the response of ozone concentrations to 27-day and solar-cycle variations in solar ultraviolet radiation, but the effect on the lower atmosphere remains to be determined. At greater heights, DE has revealed much new information on the dynamics of and coupling between the magnetosphere, ionosphere, and thermosphere.



A partial list of theoretical advances stimulated by these satellite-based observational programs includes an increased understanding of the processes that control the thermal budget and the distribution of minor constituents in the middle atmosphere; the importance of transport by planetary and gravity waves; the interaction among dynamics, photochemistry, cloud microphysics, and radiative transfer in the development of the Antarctic ozone hole; and the formation and redistribution of volcanic aerosols by atmospheric motions, and the possible impact of such aerosols on stratospheric chemistry and ozone depletion.

The funding agencies also have made a concerted effort to support ground- and aircraft-based research on transport and chemistry in the stratosphere. In particular, there has been strong support for investigations of the polar ozone problem. NSF support has also helped focus research on the thermosphere and its coupling to the ionosphere and mesosphere through the program on Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR). Ground-based experiments, with support from various agencies and from CEDAR have revealed a number of important dynamical, radiative, chemical, and coupling processes, as well as their influences on the circulation, structure, and variability of the middle atmosphere. Particularly interesting in this regard have been the insights gained through observational and theoretical efforts addressing relatively small-scale motions, and the extent to which such motions influence the circulation and thermal structure of the middle atmosphere on both small and global scales.

A clearer understanding of the global electrical circuit has been achieved. Progress has been made toward quantifying the relationship between lightning flash rate and the Maxwell current output above thunderstorms and into the global electric circuit. Atmospheric electric fields and ion mobilities have been measured using balloons and rockets. NASA is also supporting work on modeling the global electric circuit and the Lightning Imaging Sensor (LIS) has been selected to fly on the first platform of the Earth Observing System (EOS-A). On the other hand, little or no progress has been made in elucidating how global cloud distributions or pollution in the boundary layer affect the global electric circuit.

In summary, response to many of the recommendations concerning the middle and upper atmosphere has been positive, and great strides have been made in advancing our understanding of the processes and interactions taking place in those regions. However, delays in the implementation of satellite-borne observing systems combined with inattention to some scientific problems have limited the progress anticipated at the time the recommendations were made. Areas of concern include repeated postponements of the launching of UARS, uncertain prospects for the rapid implementation of other, simpler satellite missions in the period between the launching of UARS and that of EOS-A, the lack of a vigorous research program on the effects of solar activity on the middle atmosphere, and the neglect of certain aspects of the global electric circuit problem.



## Solar-Terrestrial Coupling

Since the early 1980s, recommendations in the solar-terrestrial area have focused on the development of a quantitative understanding of the cause-effect chain of events linking solar variations to effects in the Earth's environment. Related studies address of the interplay between solar radiation, the solar corona, solar wind, magnetosphere, ionosphere, and atmosphere. To this end, specific recommendations (see SSB, 1980, 1985b; BASC, 1981, 1984) have been made:

- To provide simultaneous measurements on as many of the links as possible in the coupling of the Sun to the Earth;
- To develop and test increasingly comprehensive models of these processes; and
- To determine the effect of solar luminosity and spectral irradiance variations on weather and climate.

In response to NRC recommendations to study solar wind-magnetosphere-ionosphere coupling at polar latitudes (BASC, 1981), the Chatanika incoherent scatter radar was relocated to Sondrestrom, Greenland. Magnetosphere-ionosphere coupling was a focus of the CEDAR program, and the expanded theory programs led to greatly improved models of the ionosphere and ionosphere-thermosphere coupling. Some specific programs required for implementation of the solar-terrestrial coupling goals have been approved, notably UARS, ISTP, CEDAR, Geospace Environment Modeling (GEM), CRRES, the Solar-Terrestrial Theory Program (STTP), and a revitalization of the Explorer program. Many of these programs remain under development with implementation several years away. Further, some have been descoped owing to budgetary constraints. Therefore, the NRC recommendations formed in the early 1980s are as valid today as then.

Major gaps that still remain in previously recommended scientific studies include solar variability and its impact on weather and climate, and the global electric circuit and its role in the solar-terrestrial coupling process. A further hampering of progress in this area results from a baseline program (e.g., research and analysis, theory, rockets, balloons, and ground-based) that barely has maintained an adequate level of effort and in some areas actually has eroded during the past decade.

In summary, funding agencies have provided a generally positive response to the scientific recommendations forged in solar-terrestrial physics in the early 1980s. This positive response, however, has been negated by delays in implementation, program restructuring, and inattention to a number of recommendations. The net result is that the earlier scientific recommendations remain valid and will not be implemented until more than a decade after their formulation.



### Comparative Planetary Studies

For the past decade, NRC committee reports (e.g., SSB, 1980, 1985b) have underscored the basic importance of comparative studies of planetary magnetospheres and have strongly recommended the inclusion of particle and field instruments on all planetary missions. The spectacular successes of the Voyager mission have dramatically demonstrated the veracity and importance of those recommendations.

Although several new missions (Galileo and CRAF/Cassini) have substantive particles and fields payloads, there is not an appropriate complement of particles and fields instruments on the Mars Observer even though recent USSR Phobos results have shown the existence of a dynamic particles and fields environment around Mars.

Some progress has been made toward understanding the thermospheres of planets other than Earth. The Pioneer-Venus mission has provided much new information on the Venusian thermosphere and ionosphere; unfortunately, our understanding of the thermospheres and ionospheres of other planets is still rather poor.

The cometary plasma and neutral particle environments have been studied, and the major advances have come from the Soviet, European, and Japanese missions to Comet Halley. The major U.S. contribution concerned the cometary plasma environment of Comet Giacobini-Zinner as sampled by the ICE spacecraft-a mission of opportunity with a spacecraft not designed for cometary observations.

In summary, the response to recommendations in this area has been positive. However, major delays (Galileo, CRAF/Cassini), the absence of a U.S. mission to Comet Halley, and the lack of plasma instrumentation on U.S. missions to Mars have slowed progress significantly.



## COMMON ISSUES

## Program Management

The Krimigis report (SSB, 1985b) recommended a reorganization of the NASA Office of Space Science and Applications (OSSA) calling for the establishment of a separate Space Physics Division. This recommendation has been implemented and the resulting strong representation of the discipline of space physics at NASA Headquarters has revitalized the field.



The Rosner Report (CPSMR, 1989) called for restructuring of the solar physics related programs at NSF, noting that the discipline is split between the Divisions of Astronomy and the Division of Atmospheric Sciences. This recommendation is currently under consideration.

Several reports (BASC, 1981, 1984; CPSMR, 1988) recommended paying more attention to interagency coordination of activities in the broad area of solar-terrestrial research. This recommendation has become increasingly important with the initiation of additional projects that draw on resources of several agencies. The Interagency Coordinating Council for Solar-Terrestrial Research (ICCSTR) was established as a mechanism for such consultation in 1984, but it has been inactive since 1987. The charter remains in effect and the committee could be reactivated to serve as a mechanism for interagency coordination. Despite the hiatus in ICCSTR activity, inter-agency consultation and cooperation has been initiated in the area of Global Change, essential to the effective development of this ambitious program.

Coordination of U.S. space programs with the programs of other nations was called for in the Lanzerotti report (SSB, 1984c). One response to this recommendation was the establishment of the Interagency Consultative Group (IACG) that meets regularly to coordinate planning for space missions. In addition, several international unions and scientific committees sponsor major worldwide coordinated efforts in this field. An example is the current Solar Terrestrial Energy Program (STEP) sponsored by the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP).

## Data Archiving and Access

A number of NRC reports (BASC, 1988; CPSMR, 1988; SSB, 1982, 1984a, 1985b, 1986b, 1988a) have recommended increased attention to the acquisition and storage of meaningful data in an accessible and understandable format. They have pointed out that improved data archiving is important not only for its own sake, but also because it facilitates good science. The science must be an integral element of all the archiving efforts. Providing an accessible, well-documented archive of solar-terrestrial data is essential for the future of the science.

The Shea-Williams report (SSB, 1984a) detailed a plan for solar-terrestrial data access. It included the formation of a solar-terrestrial Central Data Catalog and Data Access Network (CDC/DAN) and the establishment of a scientific steering committee for oversight. The report called for all agencies sponsoring solar-terrestrial research projects to configure their data systems to be compatible with the CDC/DAN and recommended that it serve as a clearing house for software. In addition, the report recommended that the funding agencies offer incentives to encourage researchers to provide useful and appropriate data sets and that projects identify resources needed for data archiving at project initiation. Finally, the report recommended the formation of data archival groups consisting of discipline specialists to review archival activities and to help search for useful but non-archived data collections.

The needs discussed in the NRC committee reports remain unfulfilled today. Some progress related to the recommendations has been made: greater emphasis is being placed on the acquisition and storage of meaningful data in an accessible form; program management no longer assumes that its responsibility ends with the data acquisition and initial science analysis; NASA and NSF support networking that aids the transport of smaller data sets; and missions such as ISTP have initiated planning for the data system and archiving objectives early in the mission plans. Unfortunately, the ISTP data distribution system has not lived up to its early promise with respect to compilation and access to reduced data. Although, the CDC/DAN has not been implemented, NASA has organized a group of scientists to address the issues raised in the NRC reports. Since the space physics data system activities are so new, the issues of science oversight, interoperability, and software have not been addressed yet, and no action has been taken by NASA to offer real incentives for solar-terrestrial researchers to provide useful and appropriate data for archiving.

Finally, NASA, in cooperation with several other agencies in the United States, Canada, Europe, and Japan, has developed a master directory to data repositories of geophysical interest. A group of discipline coordinators is charged with verifying the contents of the directory and locating unique but nonarchival data collections. NASA has also appointed an advisory group to consider the problems associated with making data directories and catalogs interoperable.

In summary, the start of the solar-terrestrial data systems is encouraging, but a great deal needs to be done.

## Explorer Program

In 1984 the CSSP became concerned that the capability of the Explorer program was in danger of serious erosion as a result of escalating costs and mission complexity. In an effort to revitalize the Explorer program as a viable research tool, a study was initiated; the resulting report (SSB, 1984b) recommended the following:

- A return to small, simple missions.

- An average of one Explorer per year for solar and space physics, along with augmentation of the Explorer budget if necessary.



- Use of a two-stage selection process based on an Announcement of Opportunity mechanism, with selection for definition, followed, if warranted, by selection for development.

Near this same time frame, strong recommendations for an augmented and revitalized Explorer program were offered by the Astronomy Survey Committee (AMPS, 1983) and the Committee on Space Astronomy and Astrophysics (SSB, 1986a).

Within the past three years all of these recommendations have been addressed to some extent by NASA, beginning with a significant augmentation to the Explorer budget in 1988. A principal result of this budget increase was the establishment of a new Small Explorer (SMEX) program aimed at providing frequent (approximately one launch per year) access to space for low-cost (< $30 million), focused experiments. The first two SMEX missions to be selected are from the Space Physics Division: SAMPEX, scheduled for launch in 1992, and Fast Auroral Snapshot Explorer, scheduled for launch in 1993. In addition, in response to a 1986 call for proposals for an Explorer Concept Study, four new Delta-class Explorer concepts were selected for Phase-A study, including two from space physics.

As the above progress indicates, NASA has been generally responsive to the recommendations from NRC reports, and this important program has indeed been revitalized. Unfortunately, cost overruns in the current Explorer program continue to cause delays, and it now appears that the first of the new Delta-class Explorers will not be launched until more than 10 years after it was proposed.

The overwhelming response of Explorer proposals (more than 40 Delta-class Explorer concepts and more than SO SMEX proposals) confirms the continuing value of these small missions to the space physics community.

## Coordinated Programs and Synoptic Observations

Solar-terrestrial research deals with time-varying phenomena spanning several regions of space and scientific disciplines. Coordinated programs, encompassing observations and theory covering the interrelated areas, are necessary to address these complex research problems adequately. Just as three-dimensional, time-varying magnetospheric characteristics can be addressed by simultaneous equatorial, polar, and tail observations, coordinated measurements of the Earth's polar upper atmosphere and the overlying magnetosphere are needed to determine the linkage between the solar wind and terrestrial upper atmospheric winds. To facilitate coordinated research, the ISTP program was strongly recommended (see BASC, 1984; SSB, 1985b) as was a program of coordinated ground-based campaigns to study the coupling of



atmospheric regions. The program of World Days or SCOSTEP campaigns triggered by specific events was recommended, including incremental funding of $2M per year (BASC, 1984).

Several initiatives have been proposed in response to these needs, including ISTP and CEDAR. Incremental funding for CEDAR has been supported by the Global Change program. NSF has also gone forward with the GEM initiative that consists of coordinated observational campaigns and theoretical studies of specific regions. The first target of the GEM program is the magnetosphere boundary layer.

Synoptic observations of the fundamental parameters that characterize the solar-terrestrial system underlie the wide range of specific investigations in the field. Such studies reveal trends and long-term variability not evident in studies of isolated events (BASC, 1981, 1988). It has been recommended that unmanned spacecraft, space platforms (BASC, 1988), and ground-based facilities (BASC, 1984) provide continuing measurements of solar (including total radiance, spectral, particle, and magnetic field), interplanetary (solar wind particles, magnetic field, and energetic particles), magnetospheric (aurora, current, and electric fields and particles), and thermospheric (circulation, temperature, and energy resources) parameters. Incremental funding in the amount of $4 M/year was recommended. Analysis of historical and archival data sets was also recommended (CPSMR, 1988; BASC, 1988). To date, there is no national program or policy in response to those recommendations. An effort was made, however, to provide additional solar wind and interplanetary magnetic field data from IMP-8, resulting in >50 percent coverage.

## Research and Analysis

The perceived erosion of the base research program is currently receiving a lot of attention by both NASA and NRC committees. This section briefly addresses some of the issues specific to solar and space physics.

### *Theory and Modeling*

A major review of the field of space plasma physics by the SSB in the late



1970s *Space Plasma Physics: The Study of Solar System Plasma*, (National Academy of Sciences, 1978—the Colgate report) emphasized that theory should play a central role in the planned development of space plasma physics. The

SSB research strategy for this field—the Kennel report (SSB, 1980)—reiterated this conclusion and stressed the need for quantitative modeling in every subdiscipline of the field. Subsequent reports (BASC, 1981, 1984; SSB, 1985b) echoed the same theme.



On the positive side, theoretical support is now "built-in" on many flight missions. Those mission-associated theory efforts have the advantage of being closely coupled to observational campaigns and the disadvantage of having to cope with scheduling delays and other upsets that typically accompany flight missions (e.g., CRRES, ISTP).

The establishment of the STTP in 1979 was a very positive response to NRC recommendations. STTP, now called the Space Physics Theory Program (SPTP), was and is intended to support efforts characterized by a "critical mass" of collocated personnel and to provide "attractive and secure opportunities to young theorists.." (STTP Announcement of Opportunity, 1979). The program was started with $2.25 M, with awards up to ~$450K and an average award of ~$200K. The current program supports a larger number of groups with roughly twice the original total funds covering the full scope of the Space Physics Division, but with an average award of ~$275K. This is a good deal less than the original level of support when 11 years of inflation is taken into account. This steady erosion of constant-dollar grant size jeopardizes the "critical mass" feature of the program, and taxes the ability to support senior researchers and still provide the "attractive and secure opportunities to young theorists. . .". NSF, with fewer resources to devote to solar-terrestrial research, has used its re-sources more effectively in supporting theory, with reasonable-sized grants and a reasonable level of commitment to seeing ongoing efforts through to completion.

The NASA Research & Analysis program (now called the Supporting Research & Technology Program) has moved even farther in the direction of offering large numbers of awards of ever-decreasing size. These declines in support are at odds with the recommendation (BASC, 1981) that "As [solar-terrestrial] research matures, the need for theoretical work and modeling grows; an appropriately balanced program must provide for such an effort." This recommendation is certainly still valid. A dramatic strengthening of and recommitment to the original principles of SPTP are needed. NASA's Research and Analysis program is even more in need of reassessment. NSF activities in this area are now heavily constrained by the mandate to support the Global Change program, but the same principles apply.

*Supercomputing*

Supercomputers are especially important for global modeling of the solar corona, the heliosphere, the magnetosphere of the Earth and other planets, and the terrestrial and planetary atmospheres and ionospheres. The Krimigis report (SSB, 1985b) recommended support for a program of computer modeling, including access to supercomputers.

Three major elements are required to undertake modeling on supercomputers: (1) the supercomputer itself, (2) access to the computer via electronic networks, and (3) digestion of the results (including graphics) at the home institution by means of small computers and workstations.



Response to the modeling and supercomputing recommendation has been very good overall. In particular, the response to the three major elements has been as follows.

1. The NSF set up four supercomputing institutions across the country, and the supercomputer facility at the National Center for Atmospheric Research (NCAR) has continued to be supported and upgraded. NASA has supercomputing facilities available at several NASA centers, although for off-site researchers the NASA facilities have been more difficult to use than the NSF centers. The military also has supercomputers on which space science work is done, but access to those facilities is restricted.

2. The NSF Internet and NASA Space Physics Analysis Network (SPAN) electronic networks are available for access to the "national" supercomputers. These networks had problems during their initial phase several years ago, but they have improved greatly.

3. Small machines or workstations of relatively modest cost (<$10,000) are required to analyze and display the output produced by the supercomputers, as well as to initiate communication over the networks with the supercomputer facilities. This linkage is now the limiting factor for many scientists. Requests for funds for small computers are too often frowned upon by agency program directors during times of fiscal constraints.

*Suborbital and Spartan Programs*

The Suborbital program, which includes balloon, rocket, and aircraft payloads, is essential for addressing quick turn-around science objectives, development and testing of new instrumentation, more rapid testing of theoretical ideas, and training students in experimental techniques. The strengthening and augmentation of such projects was strongly endorsed by both the Intriligator and Krimigis committees (BASC, 1984; SSB, 1985b).

During the mid-1980s, the Balloon program floundered because of faulty balloon material. NASA made special efforts to correct that situation, and by 1986-1987, the Balloon program was enjoying great success. Currently, the Balloon program is sized at ~50 flights/year, which is adequate to meet the demand, but some additional funding is required for improved balloon electronics, including more sophisticated location devices (e.g., Global Positioning System (GPS) receivers). The biggest problem is lack of funding to support payload development. Because approximately two-thirds of the proposals are not funded and because of a trend to larger, more expensive payloads, there has been a decline in the frequency of flights in the last few years. An example of the devastating effect of limited funding is the collapse of the balloon component of the MAX'91 Long Duration Program because no funding could be found for the three instruments that had been selected for flight.

Important advances in soft x-ray and extreme ultraviolet imaging of the Sun have been achieved through NASA's Rocket program. Overall, however, the Rocket program declined in the 1980s because inflation was not covered from 1987 through 1989, active experiments were removed from the program, and Rocket program money was spent on development of a fine-pointing capability for the Spartans.

The Spartan program was designed to provide relatively long flights (~40 hours) for rocket-type payloads by using the Shuttle for release and retrieval. The Krimigis report (SSB, 1985b) recommended that some Rocket program funding be used to support the Spartan program. The Spartan program was effectively terminated by the Challenger disaster in 1986. In retrospect, the resources expended for the Spartan program adversely affected the rocket-type science it was meant to help. NRC recommendations to strengthen the Suborbital program are still valid and generally unfulfilled. Education

Recommendations to enhance university participation and to increase graduate student support appear in several NRC reports (e.g., SSB, 1985a; CPSMR, 1989). To date, only a few programs have set aside specific funds to support educational components of their activities. CEDAR is a notable example of support for educational endeavors, with student attendance at their annual workshop increasing from six participants in 1986 to 107 students in 1990.

# 3
# Conclusions

During the past decade, major scientific progress has been made throughout the solar, solar-terrestrial, and space plasma physics disciplines. The bulk of these advances has stemmed from projects and programs started and/or planned in the 1970s, prior to the NRC recommendations considered in this report. With regard to the NRC recommendations of the 1980s, progress has generally been slow at best and in some cases nonexistent. Interminable delays and major programmatic restructuring have been characteristic of agency responses to the NRC recommendations. The perception is that although initial agency responses have been positive, actions in the implementation phases have not been carried through to achieve the goals embodied in the recommendations. For example, entire spacecraft were cut from the UARS, Ulysses, and ISTP projects. The launch of Ulysses was delayed three years by problems with the Shuttle launch capability and another four years as the result of the Challenger accident. The Orbiting solar Laboratory (OSL) still does not have a new start, more than a decade after the basic program was defined (first as the Solar Optical Telescope, later as the High Resolution Solar Observatory, and currently as OSL). Cost overruns have led to delays in the launches of Explorers. Many experiments (e.g., Spartans, active magnetospheric experiments, MAX'91 balloon experiments, and attached payloads for Space Station Freedom) have been selected and then not funded or canceled after significant work had been done. These cycles of first raising then dashing the hopes of the scientific community have had a demoralizing effect.

In view of these stretchouts, the scientific goals and most of the specific recommendations for each of the subdisciplines remain valid. The highest priority scientific questions given in the NRC reports of the 1980s remain at the scientific forefront. Some of the issues have become better focused because of advances in theoretical work and analysis of data resulting from programs initiated in the 1970s.



The role of the NRC committees has traditionally been to develop scientific strategies and measurement goals, but to leave the development of strategic plans for the implementation of the scientific programs to the implementing agencies. An exception to this traditional division of responsibility was the Krimigis report (SSB, 1985b) which laid out an implementation plan for solar and space physics activities beginning in 1985. Parts of that plan are now obsolete. Neither the Global Change Program nor the Space Exploration Initiative were on the scene in 1985. Furthermore, in the post-Challenger environment, the community would no longer endorse a recommendation such as "Enhance current Shuttle/Spacelab programs in this discipline." As another example, the Krimigis report shows no post-ISTP magnetospheric missions except Explorers and Shuttle or Space Station experiments. NASA has now stepped back into its traditional role and has sponsored a series of workshops to develop a new mission strategy for solar and space physics and for their other science disciplines. The CSSP and CSTR intend to review that plan as part of the national program in solar, solar-terrestrial, and space plasma physics for consistency with the NRC science strategies. At this time, CSSP and CSTR do not recommend that the NRC take on the task of updating the mission strategy recommended in the Krimigis report (SSB, 1985b).

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# Abbreviations and Acronyms

| | |
|---|---|
| ACE | Advanced Composition Explorer |
| ACRIM | Active Cavity Radiometer Irradiance Monitor |
| AMPTE | Active Magnetospheric Particle Tracer Experiment |
| AO | Announcement of Opportunity |
| AU | Astronomical Unit |
| BASC | Board on Atmospheric Sciences and Climate |
| CDC/DAN | Central Data Catalog and Data Access Network |
| CEDAR | Coupling, Energetics, and Dynamics of Atmospheric Regions (program) |
| CPSMR | Commission on Physical Sciences, Mathematics, and Resources |
| CRAF | Comet Rendezvous/Asteroid Flyby (mission) |
| CRRES | Combined Release and Radiation Effects Satellite |
| CSSP | Committee on Solar and Space Physics |
| CSTR | Committee on Solar-Terrestrial Research |
| DE | Dynamics Explorer |
| EOS | Earth Observing System |

| | |
|---|---|
| ESA | European Space Agency |
| EUV | Extreme Ultraviolet |
| FAST | Fast Auroral Snapshot Explorer |
| GEM | Geospace Environment Modeling |
| GOES | Geostationary Operational Environmental Satellite |
| GONG | Global Oscillation Network Group |
| GPS | Global Positioning System |
| HNC | Heavy Nuclei Collector |
| IACG | Interagency Consultative Group |
| ICCSTR | Interagency Coordinating Council for Solar-Terrestrial Research |
| ICE | International Cometary Explorer |
| IMP | Interplanetary Monitoring Platform |
| IPS | Interplanetary Scintillation |
| ISTP | International Solar-Terrestrial Physics Program |
| LEST | Large Earth-Based Solar Telescope |
| LIMS | Limb Infrared Monitor of the Stratosphere |
| LIS | Lightning Imaging Sensor |
| MAP | Middle Atmosphere Program |
| NASA | National Aeronautics and Space Administration |
| NCAR | National Center for Atmospheric Research |
| NOAA | National Oceanic and Atmospheric Administration |
| NRC | National Research Council |

| | |
|---|---|
| NSF | National Science Foundation |
| OSL | Orbiting Solar Laboratory |
| OSSA | Office of Space Science and Applications |
| POEMS | Positron Electron Magnetic Spectrometer |
| SAGE | Stratospheric Aerosol and Gas Experiment |
| SAMPEX | Solar, Anomalous, and Magnetospheric Particle Explorer |
| SAMS | Stratospheric and Mesospheric Sounder |
| SCOSTEP | Scientific Committee on Solar Terrestrial Physics |