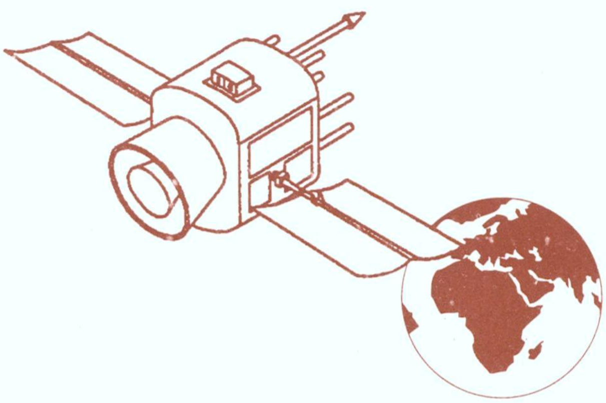
DEPARTMENT OF COMMERCE/ National Oceanic and Atmospheric Administration

OFCM

OFFICE OF THE FEDERAL COORDINATOR FOR
METEOROLOGICAL SERVICES AND SUPPORTING RESEARCH

National Plan for Space Environment Services and Supporting Research 1993-1997

FCM-P10-1993



Washington, DC
August 1993

THE FEDERAL COMMITTEE FOR METEOROLOGICAL SERVICES AND SUPPORTING RESEARCH (FCMSSR)

DR. D. JAMES BAKER, Chairman
Department of Commerce

VACANT
Department of Agriculture

CAPT BRADLEY SMITH, USN
Department of Defense

DR. ARISTIDES PATRINOS
Department of Energy

DR. DEBRA KNOPMAN
Department of the Interior

VACANT
Department of State

MR. E. T. HARRIS
Department of Transportation

DR. JEFFREY PAYNE
Office of Management and Budget

MR. RICHARD W. KRIMM
Federal Emergency Management Agency

VACANT
National Aeronautics and Space Administration

DR. ROBERT W. CORELL
National Science Foundation

MR. WILLIAM G. LAYNOR
National Transportation Safety Board

DR. THEMIS P. SPEIS
U.S. Nuclear Regulatory Commission

MR. H. MATTHEW BILLS
Environmental Protection Agency

MR. JULIAN M. WRIGHT, JR.
Federal Coordinator

MR. JAMES B. HARRISON, Executive Secretary
Office of the Federal Coordinator for
Meteorological Services and Supporting Research

THE INTERDEPARTMENTAL COMMITTEE FOR METEOROLOGICAL SERVICES AND SUPPORTING RESEARCH (ICMSSR)

MR. JULIAN M. WRIGHT, JR., Chairman
Federal Coordinator

DR. NORTON D. STROMMEN
Department of Agriculture

MR. ROBERT C. LANDIS
Department of Commerce

CAPT BRADLEY SMITH, USN
Department of Defense

DR. HARRY MOSES
Department of Energy

MR. LEWIS T. MOORE
Department of the Interior

MR. JEFFREY MACLURE
Department of State

MR. RICHARD HEUWINKEL
Federal Aviation Administration
Department of Transportation

MR. FRANCIS SCHIERMEIER
Environmental Protection Agency

MR. RICHARD W. KRIMM
Federal Emergency Management Agency

DR. SHELBY TILFORD
National Aeronautics and Space Administration

DR. RICHARD S. GREENFIELD
National Science Foundation

MR. JAMES SKEEN
National Transportation Safety Board

MR. ROBERT A. KORNASIEWICZ
U.S. Nuclear Regulatory Commission

DR. JEFFREY PAYNE
Office of Management and Budget

MR. JAMES B. HARRISON, Executive Secretary
Office of the Federal Coordinator for
Meteorological Services and Supporting Research

FEDERAL COORDINATOR
FOR
METEOROLOGICAL SERVICES AND SUPPORTING RESEARCH

6010 Executive Boulevard, Suite 900
Rockville, Maryland 20852

NATIONAL PLAN FOR SPACE ENVIRONMENT SERVICES AND SUPPORTING RESEARCH

1993-1997

FCM-P10-1993
Washington, D.C.
August 1993

CHANGE AND REVIEW LOG

Use this page to record changes and notices of reviews.

Change Number	Page Numbers	Date Posted	Initial
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Changes are indicated by a vertical line in the margin next to the change.

Review Date	Comments	Initial

FOREWORD

The National Space Environment Forecast and Warning Program supports Federal agencies and public users concerned with the impact of the space environment upon human life and the effective, economic operation of modern technical systems. From a variety of Earth- and space-based sensor systems, the program provides real-time data concerning the solar-terrestrial environment. Forecasts of the time of terrestrial impact of significant solar events and warnings of solar events which threaten human life or operation of modern systems are also key products of the space environment program.

The past solar maximum highlighted the importance of this interagency program, as society becomes increasingly dependent upon highly technical communications, transportation, information processing, and defense systems which are vulnerable to terrestrial responses to solar events. This Federal plan describes the components of the multi-agency effort aimed at informing the Federal agencies and public users about the state of the solar-terrestrial environment. The plan outlines agency requirements for data, forecasts, and warnings, and details efforts by DOC, DOD, NASA, and other agencies to satisfy those requirements with current operational support and supporting research.

This plan was prepared from information provided by the member Federal agencies of the Committee for Space Environment Forecasting. I wish to express appreciation to the agencies for their efforts in preparing and submitting the material necessary to maintain this plan. I also wish to express appreciation to a supporting contractor, Science Applications International Corporation, for helping to put the plan together.

Julian M. Wright, Jr.
Federal Coordinator for
Meteorological Services and
Supporting Research

EXECUTIVE SUMMARY

The term "space environment" refers to the complex system including the Sun, interplanetary space, and the Earth's magnetosphere, ionosphere, and upper atmosphere. Solar disturbances, including violent, short-lived phenomena such as solar flares, and longer-term variations in solar energy output, produce effects in the Earth environment which can interfere with the efficient operation of modern technological systems and produce radiation potentially harmful to exposed humans. Space environment services are primarily concerned with observing those phenomena and their effects, forecasting the time of their impact upon the Earth, and warning of those events which threaten human life or the operation of vulnerable systems vital to the national economy or national defense.

This National Plan for Space Environment Services and Supporting Research is based on the fact that no single agency has the resources, mission, authority, and responsibility to meet all national requirements for space environment services. It is only through the coordinated activities of many agencies and the scientific community in many nations that a national service is possible. This Plan establishes the Federal agencies' roles in that coordinated endeavor.

As a foundation for development of the Plan, the document first summarizes requirements for space environment services by each concerned Federal agency. These requirements range from a need for descriptions of geomagnetic disturbances to allow the Department of Agriculture to adjust snow depth measurements, to synoptic observations of solar-terrestrial variations used by the National Oceanic and Atmospheric Administration in evaluating causes of climate change. The Department of Defense requires support for highly technological communications, surveillance, and warning systems which operate in the Earth's upper atmosphere and near-Earth space. The Department of Energy requires information about geomagnetic disturbances which may affect electrical power distribution grids, and NASA requires warnings of solar flare energetic particle events which may threaten the safety of astronauts in orbit and other space systems operating beyond the protection of the Earth's atmosphere. Other Federal agencies have equally diverse and challenging requirements for space environment services, and non-Federal agencies also have requirements for similar services to support commercial and research activities.

All these Federal and public-service requirements are satisfied by a national space environment service composed of five coordinated centers: (1) the Space Environment Services Center (SESC), to meet common service needs of Federal agencies and public users; (2) the National Geophysical Data Center (NGDC), to meet the needs for international data exchanges and archival data for retrospective analysis; (3) the Air Force Space Forecast Center (AFSFC), to meet the needs of Department of Defense (DOD) users, (4) the USAF Environmental Technical Applications Center (USAFETAC), to conduct DOD tailored studies, and (5) the U.S. Geological Survey National Geomagnetic Information Center (NGIC), to meet the real-time and long-term geomagnetic data needs of Federal and public users.

The first requirement for space environment service is, of course, observational data concerning the state of the Sun and the solar-terrestrial environment. The USAF and NOAA monitor the Sun with ground-based optical and radio telescopes located around the world. Similarly, the USAF, NOAA, NASA, and the USGS monitor the state of the Earth's geomagnetic field and ionosphere at ground-based observatories. Agencies of the governments of Canada and Australia also contribute to the real-time monitoring effort.

The operational environmental satellites of NOAA and DOD, and the NASA research satellites monitor solar variations which are not detectable from the ground because of atmospheric shielding. These satellites monitor solar X-rays, energetic solar particle emissions, the Earth's magnetic field, atmospheric energy deposition from magnetospheric electrons and protons, the effect of solar particles which may cause radiation damage to satellite systems, and disturbances of the Earth's magnetic field. In addition, NASA satellites observe the solar wind, the interplanetary magnetic field, and other significant solar disturbances.

The data collected by ground-based and satellite-borne observation systems are transmitted by data collection networks managed by the Departments of Commerce and Defense. These networks not only permit the rapid exchange of data between the national centers, but also allow for rapid international data exchange. At the Space Environment Services Center, the Space Environment Laboratory Data Acquisition and Display System (SELDADS) integrates the data streams from a variety of sources into a database and provides preprocessed, formatted information for real-time alerts, warning notices, forecasts, and summaries. This database is also accessible by the Air Force to support Department of Defense programs. The U.S. space environment service obtains data from international sources through participation in the International Ursigram and World Days Service (IUWDS).

In order to meet their responsibilities to Federal agencies and public users, the Departments of Commerce and Defense jointly operate the Space Environment Services Center (SESC), at Boulder, Colorado. This center, jointly manned by NOAA and USAF personnel, operates and maintains a national real-time space environment database to accept and integrate observational data from all sources, to provide operational support and services in the space and geophysical environment, as required by Federal agencies, and to serve as the U.S. Government's focal point for international data exchange programs. In addition to the SESC, NOAA operates the World Data Center-A for Solar-Terrestrial Physics, in order to maintain access to comprehensive international data available on a slower time scale than real-time. The USAF Air Weather Service operates the AFSFC and USAFETAC to meet unique, often classified, Department of Defense requirements.

Supporting research that requires or uses space environmental data is carried on or sponsored in several of the agencies with requirements for providing and using space environmental services, including DOD, NOAA, NASA, DOE, USGS and NSF. Such research supports the systems used by these agencies and the specific solar-terrestrial research in universities and research centers, much of which has direct application to the improvement of services.

Agency plans for improvements to the space environment services system include the deployment of new systems already proven to provide improved service capabilities, research to increase understanding of the space environment and its effects on terrestrial systems, and development of new observing sensors. The agencies are planning ambitious programs for the next five years, and in most cases, these programs are jointly supported by several agencies. All are complementary and supportive of the general objective of understanding and predicting the near-Earth space environment.

TABLE OF CONTENTS

CHANGE AND REVIEW LOG iii

FOREWORD iv

LIST OF FIGURES AND TABLES xiv

EXECUTIVE SUMMARY v

CHAPTER 1. PURPOSE AND OBJECTIVES 1-1

CHAPTER 2. REQUIREMENTS FOR SPACE ENVIRONMENT SERVICES 2-1

2.1 SOLAR VARIATIONS 2-1
2.1.1 Forecasting Solar Variations 2-1
2.1.2 Distribution of Data and Forecasts 2-2
2.1.3 Supplying Archival Data 2-2

2.2 GOVERNMENT AGENCY REQUIREMENTS 2-2
2.2.1 Department of Agriculture (USDA) Requirements 2-2
2.2.2 Department of Commerce (DOC) Requirements 2-2
2.2.3 Department of Defense (DOD) Requirements 2-3
2.2.4 Department of Energy (DOE) Requirements 2-3
2.2.5 Department of the Interior (DOI) Requirements 2-3
2.2.6 Department of Transportation (DOT) Requirements 2-3
2.2.7 National Aeronautics and Space Administration (NASA) Requirements . 2-4
2.2.8 National Science Foundation (NSF) Requirements 2-4
2.2.9 U.S. Information Agency (USIA) Requirements 2-4

2.3 NONGOVERNMENT AGENCY REQUIREMENTS 2-4

CHAPTER 3. STRUCTURE OF THE PLAN 3-1

CHAPTER 4. OPERATIONAL SPACE ENVIRONMENT SERVICES 4-1

4.1 GROUND-BASED OBSERVATIONS 4-1
4.1.1 Solar Optical Observations 4-1
4.1.2 Solar Radio Observations 4-1
4.1.3 Geomagnetic Field Observations 4-4
4.1.4 Ionospheric Observations 4-6
4.1.5 Specialized Ground-Based Quick-Time Observations 4-7

4.2 SATELLITE OBSERVATIONS 4-7
4.2.1 Solar X-Ray Observations 4-8
4.2.2 Energetic Particle Flux 4-8
4.2.3 Atmospheric Heating From Magnetospheric Electron and Proton Precipitation 4-8
4.2.4 Geomagnetic Field Observations 4-9

4.2.5 Solar Wind (Interplanetary Plasma and Interplanetary Magnetic Field) Observations 4-10
4.2.6 Magnetospheric Plasma Measurements 4-10

4.3 DATA COLLECTION NETWORKS 4-11
4.3.1 U.S. Air Force (USAF) Data Collection 4-11
4.3.2 National Oceanic and Atmospheric Administration (NOAA) Data Collection 4-11
4.3.3 U.S. Geological Survey (USGS) Data Collection 4-11
4.3.4 National Oceanic and Atmospheric Administration (NOAA) Responsibilities for SELDADS 4-12

4.4 ACQUISITION OF SPACE ENVIRONMENT OBSERVATIONS THROUGH INTERNATIONAL DATA EXCHANGE 4-12
4.4.1 DOC Responsibilities as the World Warning Agency 4-13
4.4.2 DOC Responsibilities as World Data Center-A for Solar-Terrestrial Physics 4-13
4.4.3 Participating International Observing Stations 4-13

4.5 SPACE ENVIRONMENT SERVICES CENTER (SESC) 4-14
4.5.1 Interdepartmental Agreements 4-14
4.5.2 NOAA-USAF Cooperative Operation of SESC 4-14
4.5.3 Joint Staffing of SESC 4-15
4.5.4 Separation of Civil and Defense Uses of Space Environment Data 4-15
4.5.5 DOC Responsibility for Operation and Maintenance of SELDADS 4-16
4.5.6 Responsibility for Operation of a Space Environment Forecasting Program 4-16
4.5.7 SESC Services to the National Economy 4-18
4.5.7.1 Satellite-related Activities Requiring SESC Services 4-18
4.5.7.2 Industrial Activities Requiring SESC Services 4-18
4.5.7.3 Navigation Systems Requiring SESC Services 4-19
4.5.7.4 Research Activities Requiring SESC Services 4-19
4.5.7.5 Geophysical Resource Activities Requiring SESC Services . . 4-20
4.5.8 SESC Support Services to Federal Agencies 4-20
4.5.8.1 Support to the Department of Agriculture 4-20
4.5.8.2 Support to the Department of Commerce 4-20
4.5.8.3 Support to the Department of Defense 4-20
4.5.8.4 Support to the Department of Energy 4-21
4.5.8.5 Support to the Department of the Interior 4-21
4.5.8.6 Support to the Department of Transportation 4-21
4.5.8.7 Support to National Aeronautics and Space Administration (NASA) 4-22
4.5.8.8 Support to the National Science Foundation 4-23
4.5.8.9 Support to the U.S. Information Agency 4-23

4.6 **OPERATION OF THE SOLAR-TERRESTRIAL PHYSICS DIVISION OF THE NATIONAL GEOPHYSICAL DATA CENTER (WORLD DATA CENTER-A FOR SOLAR-TERRESTRIAL PHYSICS)** 4-23
4.6.1 The Complementary Roles of SESC and NGDC 4-23
4.6.2 Inter-Agency and Intra-Departmental Agreements 4-24
4.6.3 Solar and Upper Atmosphere Data Collection and Distribution 4-24
4.6.4 Ionospheric Data Collection and Distribution 4-24
4.6.5 Geomagnetic Data Collection and Distribution 4-25
4.6.6 Specialized Data Collection and Analysis Services 4-25

4.7 **AIR FORCE SPACE FORECAST CENTER (AFSFC)** 4-26
4.7.1 Interdepartmental Agreements 4-26
4.7.2 Mission and Organization of the AFSFC 4-26
4.7.3 AFSFC Data Sources 4-27
4.7.3.1 Solar Data 4-27
4.7.3.2 Ionospheric Data 4-27
4.7.3.3 Geophysical Data 4-27
4.7.4 AFSFC Forecast and Warning Services 4-27
4.7.4.1 Requests for Support 4-27
4.7.4.2 State-of-the-Art 4-28
4.7.4.3 Solar Flare Forecasting 4-28
4.7.4.4 Forecasting Ionospheric Variability 4-28
4.7.4.5 Forecasting Magnetospheric and Neutral Density Parameters 4-28
4.7.5 Space Environmental Sensors Managed or Used by AFSFC 4-28
4.7.5.1 Solar Optical Telescopes 4-28
4.7.5.2 Solar Radio Telescopes 4-29
4.7.5.3 Ionospheric Sounders (Ionosondes) 4-29
4.7.5.4 Polarimeters 4-29
4.7.5.5 Magnetometers 4-29
4.7.5.6 Relative Ionospheric Opacity Meters (Riometers) 4-30
4.7.5.7 Neutron Monitor 4-30
4.7.5.8 Satellite Observations 4-30
4.7.6 AFSFC Services 4-30
4.7.7 Space Environmental Impacts on Military Activities 4-31
4.7.7.1 Satellite Control and Tracking 4-31
4.7.7.1.1 Drag Errors 4-31
4.7.7.1.2 Bearing and Range Errors 4-31
4.7.7.2 Satellite Anomalies 4-31
4.7.7.2.1 Spacecraft Charging 4-31
4.7.7.2.2 Single Event Upsets (SEUs) 4-31
4.7.7.2.3 Satellite Disorientation 4-32
4.7.7.3 Manned Spaceflight 4-32
4.7.7.4 Communications Systems 4-32
4.7.7.4.1 HF Systems 4-32
4.7.7.4.2 Satellite Communications 4-32
4.7.7.5 Radar Systems 4-32
4.7.7.5.1 Auroral and Polar Cap Interference 4-32

4.7.7.5.2 Ionospheric Errors 4-33
4.7.7.6 Over-the-Horizon Backscatter Radar 4-33
4.7.8 Future Improvements in AFSFC Support 4-33
4.7.8.1 Digital Ionospheric Sounding System (DISS) 4-33
4.7.8.2 Transionospheric Sensing System (TISS) 4-33
4.7.8.3 Solar Electro-optical Observing Network (SEON) Upgrade 4-33
4.7.8.3.1 SEON Upgrade Phase I 4-33
4.7.8.3.2 SEON Upgrade Phase II 4-34
4.7.8.4 Space Environmental Technology Transition (SETT) Models 4-34
4.7.8.4.1 Magnetospheric Models 4-35
4.7.8.4.2 Ionospheric Models 4-35
4.7.8.4.3 Neutral Atmosphere Model 4-35
4.7.8.4.4 Integrated Space Environmental Models (ISEM) . . 4-35
4.7.8.4.5 Coupling Model and Executive Routine 4-36

4.8 USAF ENVIRONMENTAL TECHNICAL APPLICATIONS CENTER (USAFETAC) 4-36
4.8.1 The Complementary Roles of AFSFC and USAFETAC 4-36
4.8.2 Data Collected through the AFSFC 4-36
4.8.3 Data Collected through National Geophysical Data Center (NGDC) 4-37
4.8.4 Space Environment Models 4-37

4.9 INTERAGENCY COORDINATION AND REPORTING REQUIREMENTS 4-37

CHAPTER 5. CURRENT SUPPORTING RESEARCH 5-1

5.1 DEPARTMENT OF DEFENSE CURRENT RESEARCH 5-1
5.1.1 U.S. Air Force 5-1
5.1.1.1 Solar Research 5-2
5.1.1.2 Space Research 5-2
5.1.2 U.S. Navy 5-3
5.1.3 U.S. Army 5-3

5.2 DEPARTMENT OF ENERGY CURRENT RESEARCH 5-3

5.3 NASA CURRENT RESEARCH 5-4
5.3.1 Space Physics Division 5-4
5.3.2 Satellite Measurements 5-5

5.4 NOAA CURRENT RESEARCH 5-7
5.4.1 Space Environment Laboratory 5-7
5.4.1.1 Space Environment Monitoring Sensors on the GOES and NOAA Satellites 5-7
5.4.1.2 Research on Solar Activity 5-8

5.4.1.3 Research on Interplanetary Propagation of Disturbances 5-8
5.4.1.4 Research on Geospace Processes and Effects 5-8
5.4.1.5 Research on Space Influences on the Terrestrial Environment 5-9
5.4.2 Aeronomy Laboratory 5-9
5.4.3 Air Resources Laboratory 5-9

5.5 DEPARTMENT OF INTERIOR CURRENT RESEARCH 5-9

5.6 NATIONAL SCIENCE FOUNDATION CURRENT RESEARCH 5-10

CHAPTER 6. FIVE-YEAR PLAN 6-1

6.1 AGENCY PLANS TO IMPROVE SERVICES 6-1
6.1.1 Department of Defense Plans--Services 6-1
6.1.2 Department of Energy Plans--Services 6-3
6.1.3 Department of Commerce Plans--Services 6-4
6.1.3.1 Solar X-ray Imager/EUV Imager 6-4
6.1.3.2 Space Environment Laboratory Solar Image System 6-4
6.1.3.3 Space Environment Laboratory Data Acquisition and Display System - III (SELDADS III) 6-4
6.1.3.4 Geomagnetic Forecasts in Probabalistic Format 6-5
6.1.3.5 Verification Reports 6-5
6.1.3.6 Customer Services 6-5
6.1.4 Department of the Interior Plans--Services 6-5

6.2 AGENCY PLANS FOR SUPPORTING RESEARCH 6-6
6.2.1 Overview of Planned Agency Research Programs 6-6
6.2.2 Department of Defense Plans--Research 6-7
6.2.2.1 USAF-Supported Research 6-7
6.2.2.2 USN-Supported Research 6-8
6.2.3 Department of Energy Plans--Research 6-10
6.2.4 Department of Transportation Plans--Research 6-10
6.2.5 Department of the Interior Plans--Research 6-11
6.2.6 NASA Plans--Research 6-11
6.2.6.1 International Solar-Terrestrial Physics/Global Geospace Science (ISTP/GGS) 6-11
6.2.6.1.1 Geotail 6-12
6.2.6.1.2 Wind 6-12
6.2.6.1.3 Polar 6-12
6.2.6.1.4 Solar and Heliospheric Observatory (SOHO) 6-13
6.2.6.1.5 Cluster 6-13
6.2.6.2 Fast Auroral Snapshot Explorer (FAST) 6-14
6.2.6.3 Advanced Composition Explorer (ACE) 6-14
6.2.6.4 Spartan 201 6-15
6.2.6.5 Atmospheric Laboratory for Applications and Science (ATLAS) 6-15
6.2.7 Department of Commerce Plans--Research 6-15
6.2.7.1 National Geophysical Data Center (NGDC) 6-15

6.2.7.2 Space Environment Laboratory (SEL) 6-16
6.2.8 NSF Plans--Research 6-18

CHAPTER 7. LONG-TERM PLANS 7-1

7.1 DEPARTMENT OF COMMERCE LONG-TERM PLANS 7-1

7.2 USAF LONG-TERM PLANS 7-2
7.2.1 Follow-on to the Space Environmental Technology Transition (SETT) Program 7-2
7.2.2 AFSFC Computer System Replacement 7-2

7.3 NASA LONG-TERM PLANS 7-2
7.3.1 Thermosphere-Ionosphere-Mesosphere Energetic and Dynamics Mission . 7-2
7.3.2 High Energy Solar Physics Mission 7-3
7.3.3 Mechanisms of Solar Variability Program 7-3
7.3.4 Galactic Origin and the Acceleration Limit Program 7-3
7.3.5 Global Solar Mission 7-4
7.3.6 Inner Magnetosphere Imager Mission 7-4
7.3.7 Solar Probe Mission 7-4

7.4 NSF LONG-TERM PLANS 7-4

7.5 USGS LONG-TERM PLANS 7-5

CHAPTER 8. RELATIONSHIP OF PROGRAM TO GLOBAL CHANGE 8-1

8.1 DEPARTMENT OF COMMERCE RELATIONSHIP TO GLOBAL CHANGE 8-1

8.2 USGS RELATIONSHIP TO GLOBAL CHANGE 8-2
8.2.1 Geomagnetism and Global Change 8-2

APPENDIX A: ACRONYMS AND ABBREVIATIONS A-1

APPENDIX B: LIST OF SUPPORTING DOCUMENTATION B-1

APPENDIX C: TERMS OF REFERENCE OF THE COMMITTEE FOR SPACE ENVIRONMENT FORECASTING C-1

APPENDIX D: SELECTED BIBLIOGRAPHY D-1

APPENDIX E: ACCOMPLISHMENTS E-1

E.1 USAF ACCOMPLISHMENTS E-1
E.1.1 First Digital Ionospheric Sounding System (DISS) Fielded, 1987 .... E-1

E.1.2 Solar Electro-optical Observing Network (SEON) Digital Image Processing System (DIPS), 1988 . . . . E-1
E.1.3 Desert Shield/Desert Storm Support, Aug 90-Mar 91 . . . . E-1
E.1.4 SEON Upgrade Phase I (SEON I) Contract Award, Nov 90 . . . . . . E-1
E.1.5 Transionospheric Sensing System (TISS) Prototype Contract Awarded, Sep 91 . . . . E-1
E.1.6 Air Force Space Forecast Center (AFSFC) Initial Operating Capability, Jun 92 . . . . E-1
E.1.7 AWS Switched to the INTERNET Magnetometer Network, Jun 92 E-2
E.1.8 Space Environmental Technical Transition (SETT) Operational Software Development Contract Awarded, Sep 92 . . . . E-2
E.1.9 AFSFC Achieved Full Operating Capability, Oct 92 . . . . E-2

LIST OF FIGURES AND TABLES

Figures

4-1 Solar Observing Network 4-2

4-2 Magnetometer Observing Network 4-3

Tables

4-1 Solar Telescope Network 4-4

4-2 Geomagnetic Observation Stations 4-5

4-3 Ionospheric Observing System 4-6

4-4 Satellite Observations of Solar X-Rays 4-8

4-5 Satellite Observations of Energetic Particles 4-8

4-6 Satellite Observations of Magnetospheric Electron and Proton Precipitation Events . . 4-9

4-7 Satellite Observations of the Geomagnetic Field 4-10

4-8 Satellite Observations of Magnetospheric Plasma 4-10

4-9 Sources and Distribution of Space Environment Products 4-17

CHAPTER 1

PURPOSE AND OBJECTIVES

The National Space Environment Forecast and Warning Program is an interdepartmental effort to provide Federal agencies and a wide range of public users with real-time space environment data, forecasts of the time of terrestrial impact of significant variations in solar energy output, and warnings of solar events threatening to human life or to continued effective and/or economical operation of modern technological systems. Data and information for these purposes are deposited in archival formats with NOAA's National Geophysical Data Center for retrospective access.

Interdepartmental cooperation, coupled with international scientific cooperation and data exchanges, is the essential basis for effective system operation. It also achieves economy and efficiency in the operation of a national space environmental service center. Worldwide ground observation networks, augmented by satellite-based instrument systems, worldwide data collection, and integration of various data streams into a common real-time database constitute the minimum basis for preparing and distributing general forecasts and special warnings. No single nation, and no single Federal agency, could provide space environmental forecast services by its own efforts except through massive programs in place of the currently existing international data exchange and cooperative interdepartmental efforts. Continuation of the present scientific program and supporting research is the basis for this plan.

This National Plan for Space Environment Services and Supporting Research provides a cost-effective basis for implementing international arrangements and interdepartmental agreements of the Departments of Commerce, Energy, Defense, Interior, State, and Transportation, the National Aeronautics and Space Administration, and the National Science Foundation, for provision of forecasts, warnings, and other common national services.

This plan is sponsored and maintained by the Committee for Space Environment Forecasting, Interdepartmental Committee for Meteorological Services and Supporting Research. The objectives of the plan are these:

- Provide policy and interagency planning guidance.
- Summarize national user requirements and coordinated agency support for space environment services.
- Review current and programmed activities of participating agencies to avoid duplication in programs.
- Provide the focus for U.S. participation in the international cooperative space environment data exchange program.

CHAPTER 2

REQUIREMENTS FOR SPACE ENVIRONMENT SERVICES

2.1 <u>**Solar Variations**</u>. One environmental problem confronting the service program is the specification and forecasting of solar emissions. The total emission of the Sun, including matter, radiation, and magnetic fields, constitutes the driving function that produces terrestrial disturbances. The time scale for variations ranges from minutes, for solar flares, to years for the background extreme ultraviolet radiation.

Violent solar disturbances, such as solar flares, as well as the longer term and more benign solar variations, produce a wide range of effects in the Earth's environment, in radiation potentially damaging to exposed humans, and in the operations of modern technological systems. The term "space environment," as used in this document, is a general term for a large system including the Sun, interplanetary space, and the Earth's magnetosphere, ionosphere, and upper atmosphere. Space environmental services are primarily concerned with disturbances in this complex environment, ranging from activity on the Sun and propagation of solar disturbances to the Earth, to the reactions resulting from this energy input into the terrestrial system. Each domain of the space environment, including energetic particles, the interplanetary magnetic field, the geomagnetic field, the ionosphere, and the neutral upper atmosphere, is affected in a variety of ways on differing time scales. Satisfying various needs requires a wide range of observations of each portion of the space environment. However, the products and services from these observations, including forecasts or alerts, to support a particular technical system (for example, the operation of communication satellites) are applicable and useful to others, such as national defense surveillance systems. The ability of the common service program to meet a range of user needs is enhanced by developing standardized indices, classifications of events, and common formats for alerts.

2.1.1 Forecasting Solar Variations. Advance knowledge of solar variations is essential to a multitude of activities and interests. Advance knowledge of the magnitude of the longer term solar variations is necessary in the design and operational planning of many technological systems. For example, planning a satellite mission requires predictions of the ultraviolet radiance of the Sun, because of its effects on the density of the upper atmosphere, and subsequent effect on the lifetime of the satellite.

Emerging results from current research indicate that middle- to long-term variations in the Sun's radiation are more complex than previously understood. Effects on the terrestrial environment may be pervasive and may be linked to such phenomena as climate variation.

The consequences of the short-lived but violent disturbances on the Sun (such as solar flares) are usually more dramatic because they are sudden and involve great amounts of energy. Usually, the first indication of such a disturbance on the Sun is an intense burst of X-rays arriving at the Earth. These X-rays can produce an interruption in radio communication circuits which can be easily misinterpreted as, for instance, a malfunction in the equipment.

Often, very energetic charged particles from the Sun will arrive at the Earth some minutes to hours after a solar disturbance. These particles produce radiation hazards to astronauts working in space and to commercial aviation passengers and crews on high latitude, high altitude flights. They can directly damage circuits and sensors and cause spacecraft charging that interrupts command and control of satellites. These particles can also produce severe long-lived disturbances in the polar ionosphere, thus affecting radio propagation, from very-low-frequency navigation signals to microwave radar. Again, degraded performance resulting from these disturbances can render a system useless for some time.

Solar outbursts are often accompanied by the explosive ejection of plasma and shock waves from the Sun into the interplanetary medium. After one to three days this enhanced solar wind reaches the Earth. The interaction between the streaming particles, the interplanetary magnetic field, and the Earth's magnetic field can produce many adverse effects upon modern technological systems, sometimes lasting for several days. The impact of solar wind disturbances on the Earth can result in strong perturbations of the Earth's magnetic field due to ionospheric and magnetospheric current systems. These perturbations can induce strong currents which cause system degradation in transmission lines and pipe lines. Increased precipitation of energetic particles in the polar regions during magnetic storms can disrupt ionospheric communications. An increase in ultraviolet light resulting from normal solar activity causes the atmosphere to expand and increase the drag on low-to-medium altitude satellites.

2.1.2 Distribution of Data and Forecasts. Products and services have been developed to disseminate space environment data and forecasts. They include direct notification to individuals, radio and satellite broadcasts, and printed publications.

Agency activities that are affected by space environment variations fall into a few general categories that cut across agency lines. The resulting requirements for services to support affected operations within government agencies are paralleled by similar requirements outside the government so that a common set of services can meet both types of requirements. Both government and non-government requirements are summarized in Sections 2.2 and 2.3.

2.1.3 Supplying Archival Data. Research into each domain of the space environment and validation of short and long-term forecasts of effects of solar activity are dependent upon access to archival data by scientists in the government, universities, and industry. Because there are national needs for global data, the archives must be based on national and international sources of data, combining real-time data with data collected from other sources.

2.2 Government Agency Requirements

2.2.1 Department of Agriculture (USDA) Requirements. The Department of Agriculture (USDA) requires descriptions of geomagnetic disturbances, to make adjustments to snow depth measurements in telemetry programs operated by the Soil Conservation Service.

2.2.2 Department of Commerce (DOC) Requirements. Environmental research programs of the National Oceanic and Atmospheric Administration (NOAA) require predictions and descriptions of solar and geomagnetic activity, to plan and carry out experiments to measure atmospheric phenomena that are affected by such activity. NOAA climate research programs require synoptic observations of solar-terrestrial variations as part of the long-term database used to evaluate the importance of such variations in affecting climatic changes. NOAA survey ships use navigation satellites whose positional accuracy depends on services provided to the operators of those satellites.

2.2.3 Department of Defense (DOD) Requirements. The Department of Defense (DOD) requires support for electromagnetic communications, surveillance, and warning systems that operate in or through the upper atmosphere and the near-space environment. Air Weather Service (AWS) is the agency within the U.S. Air Force (USAF) responsible for this type of support to DOD users, providing the following services:

- Forecast and specification of electron and ion concentration, irregularities, and electric field variability.
- Forecast and specification of coronal mass ejections, solar flares, and solar particle events.
- Forecast and specification of magnetospheric fields and energy particle variability.
- Forecast and specification of neutral atmospheric density variability.
- Warning of events which threaten human life or operations of vulnerable systems vital to the national defense.

2.2.4 Department of Energy (DOE) Requirements. The Department of Energy (DOE) requires forecasts and specifications of the solar-terrestrial environment to support the planning and execution of general purpose research programs investigating the solar-terrestrial environment, specific research aimed at improving the prediction of solar-terrestrial disturbances, research and operational support related to the use of satellites for the monitoring of nuclear explosions, and the operation of high-frequency radar reconnaissance systems.

The Federal Power Administration requires information regarding geomagnetic disturbances for use in monitoring the operation of power system grids. Increased predictive capabilities would be of value in power system management.

2.2.5 Department of the Interior (DOI) Requirements. The U.S. Geological Survey operates a worldwide network of 13 geomagnetic observatories. Data from these observatories and from the larger INTERMAGNET network are collected via satellite and computer links and provided in real-time to the USAF Space Forecast Center through the NOAA/USAF Space Environment Services Center (SESC). The USGS, in turn, requires alerts and forecasts of solar activity from SESC for planning observatory operations and geophysical surveys.

2.2.6 Department of Transportation (DOT) Requirements. The Federal Aviation Administration (FAA) requires forecasts and specifications of solar and geomagnetic disturbances to diagnose and limit the effects of interference with FAA communication systems and to ensure the safety of personnel in high-altitude, high-latitude aircraft from excessive radiation doses produced by solar activity.

The United States Coast Guard requires continual information regarding the state of the ionosphere, to fulfill its responsibility for operation of the OMEGA and LORAN navigation systems.

2.2.7 National Aeronautics and Space Administration (NASA) Requirements. NASA requires forecasts, alerts, and advisories of solar flare energetic particle events that impair or threaten astronauts and systems operating beyond the protection of the Earth's lower atmosphere. NASA also requires solar and geomagnetic information to determine upper atmospheric densities. NASA requires forecasts, alerts, and magnetic field specifications and indices, to carry out the operation of satellites and shuttle payloads designed for research into space and terrestrial environments. Such monitoring activity is also complementary to NASA space research efforts focusing on missions and campaigns, which often depend on such baseline data.

2.2.8 National Science Foundation (NSF) Requirements. The National Science Foundation (NSF) maintains a diverse program of solar-terrestrial research funded by several divisions (Atmosphere, Astronomy, and Polar Programs) that mainly support university investigators. The primary aim of this work is to understand the variable output of the Sun and the resulting effect on the terrestrial environment and the upper atmosphere. In many cases this requires information on the Sun and near-Earth space, which is supplied by the NOAA Space Environment Laboratory or the NOAA National Geophysical Data Center.

2.2.9 U.S. Information Agency (USIA) Requirements. The U.S. Information Agency requires alerts of solar flares and geomagnetic storms, to manage broadcast frequencies to achieve maximum propagation benefits.

2.3 Nongovernment Agency Requirements. Nongovernment operations using space environment services include the following:

- Satellite operations for communications and navigation require predictions and alerts of anomalies that will effect them. Long-line communications, power distribution networks, and pipelines require specification of the geomagnetic field to prevent system degradation.

- The management and development of natural resources and geophysical exploration require advance knowledge of geomagnetic disturbances, to plan and execute surveying and mapping activities.

- University and commercial research programs studying the solar-terrestrial environment and the effects of space environment disturbances on technical and biological systems require forecasts and descriptions of variations in the ambient environment.

CHAPTER 3

STRUCTURE OF THE PLAN

This National Plan for Space Environment Services and Supporting Research is structured in four primary parts: (1) operational space environmental services, (2) current supporting research, (3) 5-year plan, and (4) long-term plans.

The existing cost-effective interagency-coordinated space environmental services and supporting research activities set forth in Chapters 4 and 5 are recognized as the essential basis for a national service in accordance with Office of Management and Budget (OMB) Circular A-62. Circular A-62 established a mission responsibility for the Department of Commerce to provide common services where it is cost effective and avoids duplication of programs. This concept was developed over several years through coordinated interagency planning under the auspices of the Federal Coordinator for Meteorological Services and Supporting Research and the Federal Council for Science and Technology (see Appendix B) to meet three stringent requirements: (1) avoidance of duplicative programs, separately funded in several agencies; (2) provision of common services to all Federal agencies and public users; (3) specialized space environmental services to meet the needs of the Department of Defense.

Responsible agencies have a national space environment structure in place to satisfy Federal and public service user requirements. The primary components include: (1) the joint NOAA-USAF Space Environment Services Center, to meet common service needs of all Federal agencies and public users; (2) the NOAA National Geophysical Data Center, to meet the needs for international data exchanges and archival data for retrospective analysis; (3) the U.S. Air Force Space Forecast Center, to meet the special needs of the Department of Defense (DOD) users; (4) the USAF Environmental Technical Applications Center (USAFETAC), to conduct DOD-tailored studies; and (5) the U.S. Geological Survey National Geomagnetic Information Center (NGIC), to meet the real-time and long-term geomagnetic data needs of Federal and public users.

A unique national data and information base, maintained by the centers, consists of four coordinated data systems: a real- or quick-time Data Acquisition and Display System (SELDADS) operated by the Space Environment Laboratory, an Astrogeophysical Database (AGDB) operated by the AFSFC and USAFETAC, an archival World Data Center for Solar-Terrestrial Physics operated by the National Geophysical Data Center and a real-time (on line) and archival global geomagnetic database operated by the USGS National Geomagnetic Information Center. The centers, together with the observing systems or networks operated or funded by the National Science Foundation; the Departments of Commerce, Defense, Energy, and the Interior; and the National Aeronautics and Space Administration constitute the source of operational space environment services.

Chapter 6 focuses on the 5-year planning (1993-1997) by interested agencies to improve space environment services through improved observations, better data access, improved understanding of the solar-terrestrial processes through the results of supporting research, and an improved archival system for more effective support to retrospective research. It is recognized that many of the system objectives in Chapter 6 will require one or more decades to accomplish; however, this plan is limited in specifics to the next 5-year period. This plan will build on agency accomplishments (Appendix E) to develop a long-term plan beyond the 5-year period, as described in Chapter 7.

CHAPTER 4

OPERATIONAL SPACE ENVIRONMENT SERVICES

4.1 <u>Ground-Based Observations</u>. The USAF and the National Oceanic and Atmospheric Administration (NOAA) monitor the Sun with ground-based optical and radio telescopes to predict and detect significant solar disturbances and to provide basic data for space environmental forecasts. To provide continuous solar observations, the ground-based observatories must be spread across the globe.

The National Aeronautics and Space Administration (NASA), NOAA, USAF, and U.S. Geological Survey (USGS), conduct ground-based magnetometer and ionospheric sounding observations to specify geomagnetic and ionospheric conditions and to detect disturbances in the ambient environment.

Figures 4-1 and 4-2 show the real-time solar observing and ground-based magnetometer networks.

4.1.1 Solar Optical Observations. Optical observations with solar telescopes provide information on the state and structures of the solar photosphere and chromosphere, including the presence of active regions and the global distribution of solar magnetic fields. The goal is to identify regions of high potential for solar flares, filaments and prominences with high probability of eruption, and coronal holes (sources of high-speed solar wind).

Table 4-1 lists the operating agencies for the network of solar optical telescopes and locations of the observing stations.

4.1.2 Solar Radio Observations. U.S. Air Force and NOAA solar radio telescope observations monitor solar radio bursts in order to detect the acceleration of energetic electrons, and the passage of shock waves through the solar corona. These observations lead directly to energetic particle warnings and geomagnetic storm warnings provided to DOD and civilian user agencies. The Government of Australia (GOA), through cooperative agreements and the National Research Council of Canada, provide additional observations.

Table 4-1 also lists the operating agencies for the network of radio solar telescopes and locations of observing stations.

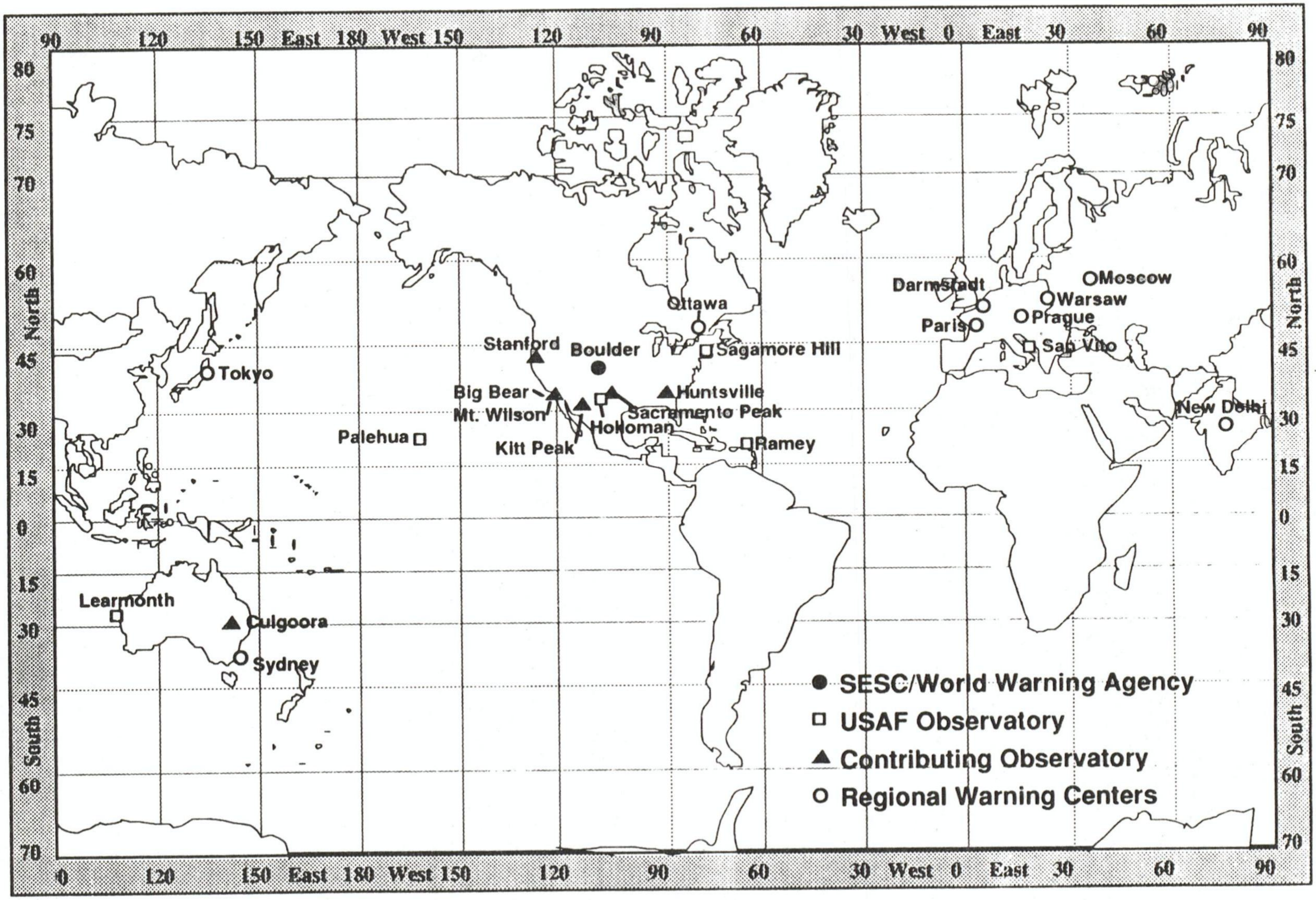


Figure 4-1. Solar Observing Network

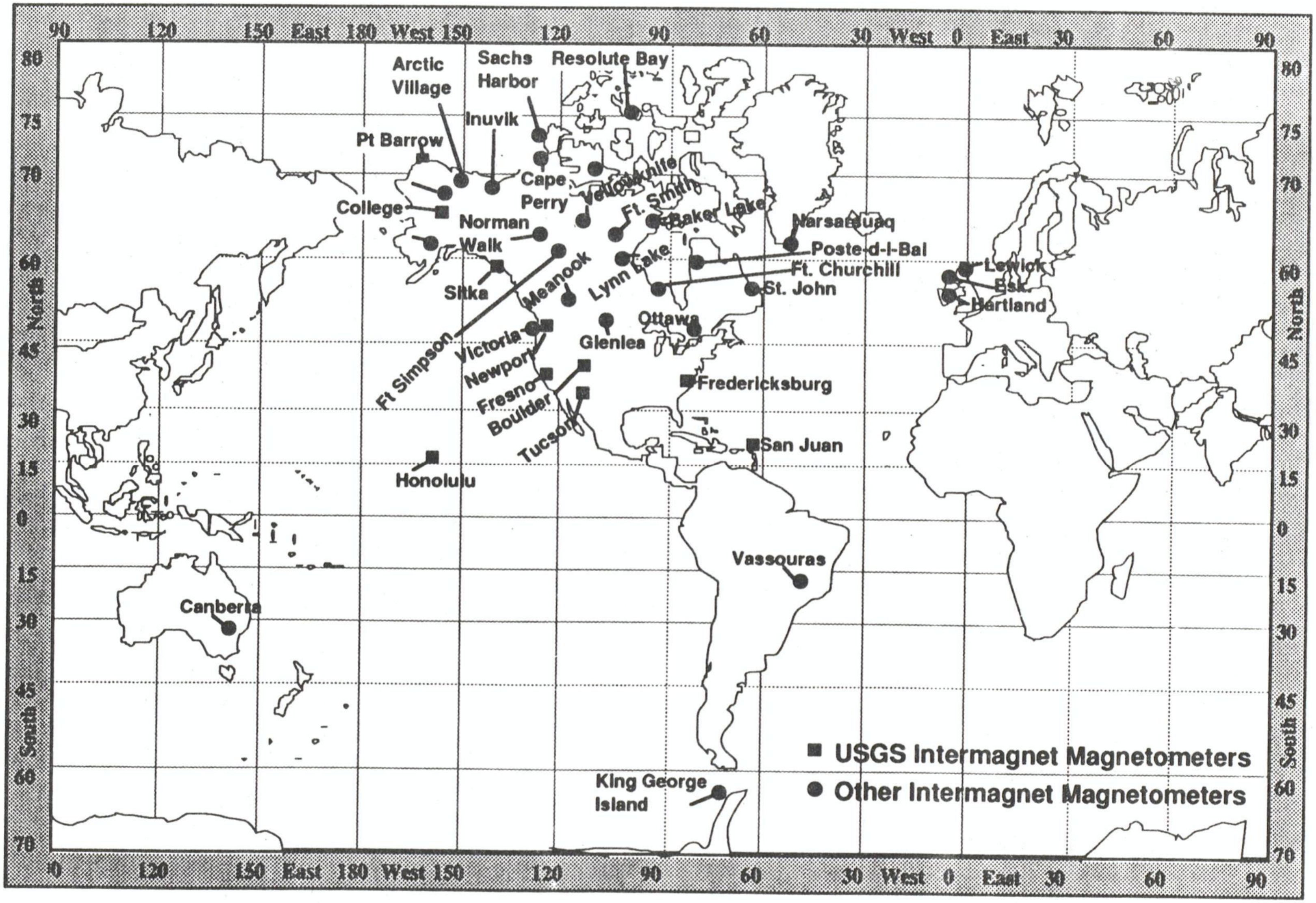


Figure 4-2. Magnetometer Observing Network

Table 4-1. Solar Telescope Network

System	Location	Operating (or Funding) Agency
Radio Solar Telescope Network (RSTN)	Sagamore Hill, MA San Vito, Italy Palehua, HI Learmonth, Australia	USAF USAF USAF USAF, GOA, NOAA
Radio solar telescope	Penticton, Canada Fleurs, Australia Culgoora, Australia	Government of Canada National Research Council GOA GOA, NOAA
Solar Observing Optical Network (SOON)	Holloman AFB, NM Palehua, HI San Vito, Italy Ramey, PR Learmonth, Australia	USAF USAF USAF USAF USAF, GOA, NOAA
Kitt Peak Observatory	National Solar Observatories, AZ	NSF, NOAA, NASA
Sacramento Peak Observatory	National Solar Observatories, NM	NSF, USAF
Culgoora Solar Observatory	Culgoora, Australia	GOA, NOAA
MSFC Observatory	Marshall Space Flight Center, AL	NASA
Mt. Wilson	Pasadena, CA	University of California at Los Angeles

4.1.3 Geomagnetic Field Observations. USAF, NOAA, USGS, and the National Science Foundation (NSF), through a grant to the University of Alaska, monitor geomagnetic parameters which describe the effects of the solar wind on the Earth's magnetosphere.

Table 4-2 lists the stations and operating agencies for the Intermagnet observing stations whose data are available in real-time.

Table 4-2. Geomagnetic Observation Stations

System	Location(s)	Operating Agency
Geomagnetic observatories (supplying data through Intermagnet and other means)	Boulder, CO	USGS
	Anchorage, AK	NOAA
	College, AK	USGS
	Sachs Harbor, Canada	University of Alaska
	Cape Parry, Canada	University of Alaska
	Inuvik, Canada	University of Alaska
	Arctic Village, AK	University of Alaska
	Fort Yukon, AK	University of Alaska
	Pt. Barrow, AK	USGS
	Talkeetna, AK	University of Alaska
	Narsarsuaq, Greenland	University of Alaska
	San Juan, P.R.	USGS
	Tucson, AZ	USGS
	Honolulu, HI	USGS
	Resolute Bay, Canada	Geological Survey of Canada, Geophysics Division
	St. Johns, Canada	Geological Survey of Canada, Geophysics Division
	Poste de la Baline, Canada	Geological Survey of Canada, Geophysics Division
	Ottawa, Canada	Geological Survey of Canada, Geophysics Division
	Fredericksburg, VA	USGS
	Sitka, AK	USGS
	Victoria, Canada	Geological Survey of Canada, Geophysics Division
	Newport, WA	USGS
	Fresno, CA	USGS
	Yellowknife, Canada	Geological Survey of Canada, Geophysics Division
	Meanook, Canada	Geological Survey of Canada, Geophysics Division
	Cambridge Bay, Canada	Geological Survey of Canada, Geophysics Division
	Baker Lake, Canada	Geological Survey of Canada, Geophysics Division
	Ft. Churchill, Canada	Geological Survey of Canada, Geophysics Division
	Glenlea, Canada	Geological Survey of Canada, Geophysics Division
	King George Is, Antarctica	Korean Geological Survey

Table 4-2. Geomagnetic Observation Stations (Continued)

System	Location(s)	Operating Agency
	Hartland, United Kingdom	British Geological Survey (BGS)
	Eskdalemuir, United Kingdom	British Geological Survey (BGS)
	Lerwick, United Kingdom	British Geological Survey (BGS)
	Vassouras, Brazil	Observatorio Nacional do Brasil
	Canberra, Australia	Australian Geological Survey Organization

4.1.4 Ionospheric Observations. USAF and NOAA conduct observations of the ionosphere with ionosondes, polarimeters, and riometers. The USAF is developing an automated Digital Ionospheric Sounding System (DISS) network which has 13 operational locations so far. Table 4-3 lists the locations and operating agencies for these sensor systems. The USAF plans to install six additional DISS sites in Korea, Alaska, United Kingdom, Europe, Hawaii, and an additional Pacific site in the mid to late 1990s.

Table 4-3. Ionospheric Observing System

System	Locations	Operating Agency
Ionosondes	Nicosia, Cyprus	USAF
	Taiwan, ROC	USAF
	Manila, Philippines	USAF
	Resolute Bay, Canada	Government of Canada
	Churchill, Canada	Government of Canada
	Boulder, CO	NOAA (USAF funded)
	Maui, HI	NOAA (USAF funded)
Digital Ionosondes (DISS)	College, AK	USAF
	Vandenburg AFB, CA	USAF
	Dyess AFB, TX	USAF
	Eglin AFB, FL	USAF
	Wallops Island, VA	USAF
	Learmonth, Australia	USAF
	Bermuda	USAF
	Argentia, Canada	USAF
	Goose Bay, Canada	USAF
	Quanaq, Greenland	USAF
	Sondrestrom, Greenland	USAF

Table 4-3. Ionospheric Observing System (Continued)

System	Locations	Operating Agency
	Narsarsuaq, Greenland	USAF
	Ramey, Puerto Rico	USAF
Polarimeters	Ramey, Puerto Rico	USAF
	Patrick AFB, FL	USAF
	Palehua, HI	USAF
	Shemya, AK	USAF
	Osan, Korea	USAF
	Ching Li, Taiwan	USAF
	Anchorage, AK	USAF, NOAA
	Boulder, CO	NOAA
Riometers-- High Latitude	Thule, Greenland	USAF, NOAA
	Anchorage, AK	NOAA/USAF
	College, AK	USGS
	Fort Yukon, AK	Univ of Alaska
	Talkeetna, AK	Univ of Alaska
	Arctic Village, AK	Univ of Alaska
	Cape Parry, AK	Univ of Alaska
	Sachs Harbor, AK	Univ of Alaska

4.1.5 Specialized Ground-Based Quick-Time Observations. The USAF conducts neutron monitoring at Thule, Greenland, for detection of very high-energy particle radiation events. Specialized interplanetary scintillation observations are conducted through the cooperation of the University of California at San Diego.

4.2 Satellite Observations. The NOAA and DOD operational environmental satellites monitor solar variations not detectable from the ground. They also monitor in situ magnetospheric variations. Wherever possible, space environmental observation systems are placed on existing or planned operational satellites. NASA designs and deploys space environmental observation systems on NASA research satellites, supplying the data in real-time, supporting both research and operational services whenever feasible.

NOAA and DOD satellites monitor solar X-rays, energetic solar particle emissions, and the Earth's magnetic and electric fields. Within the magnetosphere, satellites monitor low-energy charged particles, which produce the aurora and high-energy charged particles, which may cause radiation damage to sensitive satellite systems. Observations of the solar wind, the interplanetary magnetic field, and other significant solar disturbances are conducted by NASA satellites of opportunity. Measurements of the neutral atmosphere, the ionosphere, and possibly interplanetary space are planned for the near future.

4.2.1 Solar X-Ray Observations. Using Geostationary Operational Environmental Satellites (GOES), NOAA monitors solar X-ray emissions (see Table 4.4). Solar X-ray observations provide a valuable measure of the energetics of solar disturbances, particularly solar flares.

Table 4-4. Satellite Observations of Solar X-Rays

Sensor	Satellite	Operating Agency
Whole-Sun X-ray Sensor	GOES	NOAA

4.2.2 Energetic Particle Flux. NOAA, USAF, and the DOE take satellite observations of energetic particle flux. Solar emissions of high energy protons, electrons, and alpha particles may cause radiation damage to satellite systems and health hazards to astronauts in space. The same particles also cause outages on high-frequency (HF) radio circuits at polar latitudes and errors in very-low-frequency (VLF) navigation systems (see Table 4-5).

Table 4-5. Satellite Observations of Energetic Particles

Sensor	Satellite	Operating Agency
Energetic particle sensors	GOES	NOAA
Energetic particle sensors	NOAA/TIROS	NOAA
Energetic particle sensors	DMSP	USAF
Energetic particle sensors	DOD satellites	USAF/DOE

4.2.3 Atmospheric Heating From Magnetospheric Electron and Proton Precipitation. DOC monitors total auroral particle energy deposition from the NOAA/TIROS polar orbiting satellites. DOD DMSP satellites detect direct energy deposition from precipitation of magnetospheric electrons and ions within the auroral zone, in situ electric and magnetic fields, electron and ion densities and temperatures, and global scale optical auroral images. From these measurements, the joule energy deposition can also be determined (see Table 4-6).

Table 4-6. Satellite Observations of Magnetospheric Electron and Proton Precipitation Events

Sensor	Satellite	Operating Agency
Precipitating particle sensors	DMSP	USAF
In situ plasma and electric field sensors	DMSP	USAF
Magnetic field sensor	DMSP	USAF
Auroral imager	DMSP	USAF
Total particle energy sensor	NOAA/TIROS	NOAA

The current series of Defense Meteorological Satellite Program (DMSP) vehicles fly the following ionospheric and magnetospheric sensors:

A. Ionospheric Plasma, Plasma Drift, and Scintillation Monitor (SSI/ES-2). The SSI/ES-2 measures ambient electron and ion concentration and their temperatures at the satellite location as well as variations in the ion concentration which cause radio scintillations. Combined with other sensor data in global models, the SSI/ES-2 defines the ambient electric field, the cross polar-cap electric potential drop, and high-latitude heating of the ionosphere. These data support a variety of HF and UHF communication missions, atmospheric drag calculations, and improved satellite operations.

B. Precipitating Electron/Ion Spectrometer (SSJ/4). The SSJ/4 detects and analyzes electrons and ions that precipitate into the atmosphere, producing the auroral display. This sensor supports those missions that need to know the state of the high latitude and polar ionosphere such as communications, surveillance, and detection systems that propagate energy off and through the ionosphere. SSJ/4 data supports spacecraft anomaly analysis.

C. Fluxgate Magnetometer (SSM). The SSM measures disturbances in the Earth's magnetic field, the tilt of the auroral mid-latitude boundary, and the base of the magnetosphere. Together with the SSI/ES-2 and the SSJ/4, the SSM specifies heating and electron density profiles in the high-latitude ionosphere. SSM data supports spacecraft anomaly analysis.

4.2.4 Geomagnetic Field Observations. DOC and USAF use GOES and DMSP observations of the geomagnetic field variations to monitor the effects of solar disturbances on the Earth's magnetosphere (see Table 4-7).

Table 4-7. Satellite Observations of the Geomagnetic Field

Sensor	Satellite	Operating Agency
Magnetometer	GOES	NOAA
Magnetometer	DMSP	USAF

4.2.5 Solar Wind (Interplanetary Plasma and Interplanetary Magnetic Field) Observations. The interplanetary plasma (solar wind) and its magnetic field, are the most important elements not measured by the current system of space environment sensors. Forecasts of disturbances in the terrestrial environment are based on observations of solar activity. The disturbances propagate outward from the Sun on the solar wind and when properly directed, interact with the Earth's magnetic field. These disturbances, which affect the largest number of users of the space environmental services, are difficult to forecast because a large number have no observable solar signature from an Earth-based solar observatory and are therefore often a surprise when they suddenly appear at the Earth. In other cases, disturbances are seen leaving the Sun but never materialize at the Earth.

A satellite monitoring the plasma and magnetic field of the solar wind would provide short-term confirmation that the disturbances are nearing the Earth. The observations would also diagnose disturbances once they begin, so that the lifetime and effect of the disturbance can be better predicted. Such a satellite would also be the best source of solar wind data needed to drive new operational models such as those described in Chapter 6. Monitoring of energetic particles in the solar wind would provide observations that are uncontaminated by particles produced by near-Earth processes. The possibility of obtaining real-time solar wind and interplanetary magnetic field data from cooperative NASA/NOAA/USAF programs is under investigation; however, no specific commitments have been made.

4.2.6 Magnetospheric Plasma Measurements. Satellite observations of plasma parameters in the geostationary region provide a direct measurement of local spacecraft surface charging and deep dielectric conditions. Spacecraft charging may result in the formation of large differential voltage potentials on spacecraft surfaces. Subsequent discharge currents may be detrimental to electronic components (see Table 4-8).

Table 4-8. Satellite Observations of Magnetospheric Plasma

Sensor	Satellite	Operating Agency
Particle Spectrometer	DOD satellites	USAF/DOE

4.3 Data Collection Networks. The combined communications and data collection networks of DOC, DOD, DOI, and INTERMAGNET collect real-time data from the various observing systems and transmit these data to the Space Environment Services Center (SESC), operated jointly by USAF and NOAA at Boulder, Colorado and to the Air Force Space Forecast Center (AFSFC) at Falcon AFB, Colorado.

SESC integrates the data from various observation systems into the computer-based Space Environment Laboratory Data Acquisition and Display System (SELDADS). SELDADS also provides preprocessed, formatted information for real-time alerts and working notices, and preparation of forecasts and summaries. AFSFC accesses SELDADS by computer-to-computer link and maintains an astrogeophysical database to provide space environment services in support of DOD programs.

Another SESC data collection network, the Space Environment Laboratory Solar Imaging System (SELSIS) provides a database of solar images in digital format. SELSIS receives, processes, and stores solar images in near-real-time from USAF and civilian solar observatories and spacecraft of opportunity. Data are used to assist in analyzing and forecasting solar activity.

4.3.1 U.S. Air Force (USAF) Data Collection. USAF provides communication lines to collect data from its own satellites, observatories, and monitoring stations and to transmit these data to AFSFC and to the Space Environment Services Center (SESC) at Boulder, Colorado. In addition, a dedicated network handles magnetometer and riometer data collected at high latitudes in Anchorage, Alaska and Thule AFB, Greenland. NOAA and the USAF cooperate to maintain and operate a computer processing and relay system to assist in collection of this data. The USAF collects required data from NOAA by means of a dedicated, high-speed data link from Boulder, CO to Falcon AFB handling real-time GOES Space Environment Monitor data. Other data from NOAA are collected over a teletype link between SESC and AFSFC.

4.3.2 National Oceanic and Atmospheric Administration (NOAA) Data Collection. Communication links are provided by NOAA to collect data from NOAA satellites, observatories, and monitoring stations for delivery to SESC. SESC maintains a broad and unclassified space environment database accessible in real-time by SESC forecasters and Federal agencies. NOAA also provides data collection from the Remote Geophysical Observing Network (magnetometer network), using the data collection system on the GOES satellites. A Memorandum of Understanding between the National Environmental Satellite, Data, and Information Service (NESDIS) and SEL, signed in 1981, continues to support such collection. Data from the GOES and NOAA/TIROS Space Environmental Monitor and Energetic Particle instrument systems are relayed from NESDIS, at Suitland, Maryland, to Boulder. NOAA receives required data from USAF through the Automated Weather Network (AWN) at Carswell AFB. NOAA provides a dedicated voice line to connect SESC, the USAF Space Forecast Center, Holloman AFB Solar Observatory, Sacramento Peak Observatory, Falcon AFB, and the NORAD Cheyenne Mountain Warning Center (see Section 4.4).

4.3.3 U.S. Geological Survey (USGS) Data Collection. The USGS operates 13 U.S. geomagnetic observatories worldwide (three in Alaska, one on Guam, one in San Juan, Puerto Rico, one in Honolulu, HI, and seven in the lower 48 states). Data from these observatories are received in real-time and near-real-time at the USGS National Geomagnetic Information Center (NGIC) via satellite, computer, and telephone links. NGIC is also an INTERMAGNET Geomagnetic Information Node ("GIN") and, thus, receives data from a global network of geomagnetic observatories. INTERMAGNET means International Real-Time Magnetic Observatory Network. Under the INTERMAGNET program, data from a global network of geomagnetic observatories is transmitted via real-time and near-real-time satellite and computer links to four GIN's (Golden, CO, USA; Ottawa, Canada; Paris, France; and Edinburgh, Scotland).

One-minute geomagnetic data from selected U.S. and INTERMAGNET observatories are sent in real-time via dedicated phone line to NOAA/SESC to be used in preparation of products for AFSFC and other users. Geomagnetic observatory data from the USGS and INTERMAGNET networks are available on-line, on floppy disk, and on yearly CD-ROM's. Archival data from the USGS network are provided yearly on CD-ROM to NOAA/NGDC.

4.3.4 National Oceanic and Atmospheric Administration (NOAA) Responsibilities for SELDADS. The Department of Commerce, through the NOAA Space Environment Laboratory (SEL), is responsible for operating and maintaining SELDADS to process and integrate data streams from all publicly available space environment observing systems of DOC, DOD, DOE, DOI, and NSF, as well as international data exchange programs. The SELDADS database incorporates real-time data from domestic and international sources including NOAA and USAF (See Sections 4.1 and 4.2). SESC employs equipment and procedures to update the database routinely and rapidly and to respond to requests, using computer and communication devices. DOC is responsible for procuring, operating, and maintaining equipment and procedures to update the database routinely and rapidly 24 hours per day to meet the data needs of SESC forecasters and all other users of the national space environment service program. DOC makes this database accessible to all Federal agencies as a common service. DOC is responsible for maintaining and, when necessary, updating and replacing computer equipment and associated software needed to operate this unique national space environment data system.

4.4 Acquisition of Space Environment Observations Through International Data Exchange. The national space environment services program requires acquisition in real-time of space environment data that are accessible through international data exchange agreements. Such access is assisted by an international warning system and a prompt solar and geophysical data exchange program designated the International Ursigram and World Days Service (IUWDS). Through participation in the IUWDS, the United States obtains data that would not otherwise be available.

The IUWDS is a Permanent Service of the International Council of Scientific Unions (ICSU) acting through the International Union of Radio Science in association with the International Astronomical Union and the International Union of Geodesy and Geophysics. IUWDS data exchange is accomplished through regional warning centers, which collect the necessary data from observing facilities in their portions of the world, exchange the data with the other centers one or more times per day, and then redistribute the foreign data to users within their regions. To facilitate the daily data exchange, one regional warning center, SESC in Boulder, Colorado is designated the world warning agency for the IUWDS. The associated Regional Warning Centers are as follows:

- Paris, France
- Ottawa, Canada
- Tokyo, Japan
- Sydney, Australia
- Moscow, Russia
- Delhi, India

- Darmstadt, Germany
- Warsaw, Poland
- Prague, Czech Republic
- Beijing, China

The IUWDS is oriented toward quick-time data exchange. A parallel program exchanges solar-geophysical data for archival and research activities in the cooperating nations through the system of World Data Centers (WDC). In the United States, WDC-A for Solar-Terrestrial Physics (STP) is operated by NOAA in conjunction with the national STP archival program of NGDC. WDC-A for Rockets and Satellites is operated by NASA as part of the National Space Science Data Center. The WDC program is operated in accordance with guidelines of the International Council of Scientific Unions as spelled out in the Fourth Consolidated Guide to International Data Exchange Through the World Data Centers (June 1979). Within their respective regions, World Data Centers coordinate the collection of data, facilitate international exchange of data, and archive data for use by scientists within their respective regions. The United States participates in this international data exchange through the U.S. World Data Center Coordination Office in the National Academy of Sciences.

4.4.1 DOC Responsibilities as the World Warning Agency. DOC operates the World Warning Agency to acquire data and issue alerts concerning significant space environment events. DOC acquires all data exchanged daily in the IUWDS program and has a major role in planning and executing data exchanges. As the U.S. focal point, DOC collects data desired by other Federal agencies and provides information about the status of desired data to other agencies. DOC exchanges with other nations data collected by U.S. space environment observing programs.

To maintain access to international real-time data, DOC fulfills its World Warning Agency functions: issuing a daily consensus forecast and summaries of solar and geomagnetic data according to the international codes, maintaining the current official set of synoptic codes for solar and geophysical data and publishing revisions and corrections for the codes as needed, collecting and exchanging data for the United States and the Western Hemisphere, collecting all daily advisories from other regional warning centers, reporting on its activities to proper national and international organizations, and serving as the Secretary for Ursigrams.

4.4.2 DOC Responsibilities as World Data Center-A for Solar-Terrestrial Physics. In order to maintain access to the more comprehensive and verified international data available on a time scale slower than real- or quick-time, DOC fulfills the functions of a World Data Center in accordance with the ICSU Guide to International Data Exchange Through the World Data Centers and various ad hoc arrangements with other WDCs and sources of data. These functions include acquiring, cataloging, reformatting as appropriate, and disseminating data to domestic and foreign users. In support of the IUWDS, NOAA/NGDC serves as the Secretary for World Days and prepares and circulates the International Geophysical Calendar to coordinate synoptic observations that cannot be made continuously, yet are of value when taken in conjunction with other types of observations.

4.4.3 Participating International Observing Stations. The IUWDS cooperating stations and the types of sensors operated are listed in the companion volume of background documentation (see Appendix B). The corresponding list of other stations and institutions cooperating in data exchange through the WDC system, numbering in the thousands, is available in the catalogs and inventories of WDC-A for STP and has been published in NGDC's UAG Reports and in the MONSEE

Directory of Solar-Terrestrial Physics Monitoring Stations, published cooperatively by DOD's Phillips Laboratory Geophysical Directorate and WDC-A for STP.

4.5 Space Environment Services Center (SESC). The Department of Commerce operates the SESC with support of the DOD in accordance with established agreements.

4.5.1 Interdepartmental Agreements. In a memorandum dated June 20, 1968, the Federal Council for Science and Technology promulgated guidelines to the Federal agencies establishing the Department of Commerce's National Oceanic and Atmospheric Administration (then known as ESSA) as the single agency to be "responsible for providing or arranging for the provision of such services as are necessary to meet the generally recognized common needs of the Nation in the space disturbance forecasting field." The same document states that the Department of Defense, specifically the Air Weather Service of the USAF, has "the mission and responsibility to provide, or arrange for the provision of such tailored space environmental observing and forecasting services as are necessary to meet unique military requirements in support of programs dealing with national security."

NOAA and the USAF have separate, distinct, statutory roles in providing space environmental data, operational support, supporting research, data archival, and forecast and warning services to the civil community, DOD, and other Federal agencies. To carry out those roles NOAA and the USAF have established separate memoranda of agreement.

- **USAF-NOAA Memorandum of Agreement for Cooperative Space Environmental Support Activities** lays out the responsibilities for operation of SESC located at the NOAA Space Environment Laboratory (SEL) in Boulder, Colorado

- **NASA-USAF-NOAA-USN-USA Memorandum of Agreement for Environmental Support for Space Transportation System** (STS) sets up support to the NASA STS.

- **USAF-NOAA Support Agreement for Joint Operation of the High Latitude Monitoring Station** (HLMS) arranges operations of the HLMS, in Anchorage, Alaska.

- **USAF-NOAA Memorandum of Agreement for Cooperative Manning of the Learmonth, Australia, Solar Observing Optical Network (SOON) Facility** establishes the NOAA manpower support to the joint USAF-Government of Australia observatory at Learmonth.

- **International Ursigram and World Days Service Agreement for International Data Exchange** designates SESC the World Warning Agency for space environment and geophysical alerts, forecasts, and summaries.

4.5.2 NOAA-USAF Cooperative Operation of SESC. SESC functions as a national center for space environment and geophysical services and supporting research to meet the common needs of Federal agencies and public users. The SESC operates and maintains a national real-time space environment database to accept and integrate observational data from all sources; to provide operational support and services in the space and geophysical environment as required by NOAA, DOD, NASA, the Department of Transportation (DOT), and other Federal agencies; to provide services to public users in support of the national economy; and to serve as the U.S. Government focal point for international data exchange programs. The Director of NOAA's Environmental Research Laboratories (ERL) and the Director of SEL (reporting to the ERL Director) are delegated authority and responsibility for operation of a national Space Environment Services Center (SESC).

The understanding between NOAA and the USAF regarding the cooperative operation of SESC is summarized as follows:

- USAF and NOAA contributions follow distinct statutory roles in providing environmental data, alerts, and warning services.

- AFSFC operates the worldwide Solar Observing Optical Network (SOON) and Radio Solar Telescope Network (RSTN) and transmits the resulting data in real-time to SESC through the USAF Automated Weather Network.

- SESC and AFSFC provide cooperative support and backup for each other in accordance with existing agreements.

- SESC and AFSFC conduct separate space environment support activities and they freely exchange unclassified data and products of mutual interest.

- AFSFC provides tailored forecasts, alerts, warnings, and other services to DOD agencies as directed by USAF. SESC provides real-time alerts and daily forecasts as common services to other Federal agencies and public users.

4.5.3 Joint Staffing of SESC. USAF assigns personnel to AFSFC, Operating Location A (OL-A), collocated with SESC, to assist in the operations of SESC and to participate in activities of mutual interest and benefit to AFSFC and SESC. The Officer-in-Charge of AFSFC, OL-A performs operational and technical liaison duties, participates in the planning and use of new data sets and supervises applied research projects. The second officer assigned to OL-A, the Technique Development Officer, evaluates and develops forecast techniques and coordinates technology transition efforts. Two noncommissioned officers are integrated with the NOAA forecast staff to assist directly in SESC operations, and to help develop forecasting and training aids to improve customer support.

4.5.4 Separation of Civil and Defense Uses of Space Environment Data. NOAA, USAF, NASA, DOT, DOE, and NSF recognize common interests in space environment observing and forecasting. Aware of the need for prudent employment of available resources and the avoidance of duplication in providing these services and support for agency mission responsibilities, the cooperating departments have sought to satisfy the need for a common service program under the provisions of OMB Circular A-62.

SESC provides centralized space environment support to non-DOD government users, such as NASA, and the general public, such as the commercial airline industry; while AFSFC provides unique and classified centralized support to DOD users. To avoid duplication the two centers share responsibilities to produce certain space environment database, warning, and forecast products as delineated in Table 4-9.

4.5.5 DOC Responsibility for Operation and Maintenance of SELDADS. DOC procures, operates, and maintains SELDADS as the national system for collection, integration, and distribution of solar-geophysical data received in real-time from ground-based observatories and satellite sensors. Data entering SELDADS are converted, if necessary, to engineering units, quality controlled, tested for significant solar-geophysical events, and stored for later access and archival. Collection, processing, monitoring, and storage of the data occur continuously, 24 hours per day, 7 days per week. The primary users of this database are the SESC forecasters. Displays and interactive analyses of the data are used by SESC to provide alerts, forecasts, and data summaries to a user community consisting of industrial and research organizations, and Government agencies in the United States and abroad. Data are provided to meet the operational requirements of the Department of Defense and other national users. DOC is responsible for designing, operating, and maintaining all required system hardware and software and for procuring system upgrades and replacements as necessary to ensure adequacy and responsiveness of the database to the national space environment services program. Summary data are transferred from SELDADS, after about one month, for inclusion in NOAA's National Geophysical Data Center WDC-A archives.

4.5.6 Responsibility for Operation of a Space Environment Forecasting Program. The USAF Air Weather Service (AWS) provides basic and specialized support to military electromagnetic communications, surveillance, and warning systems that operate in or through, or use the upper atmosphere and near space. AWS, through AFSFC, provides the following major technical services to DOD users:

- Forecasts and specification of ionospheric variations and high frequency propagation conditions.
- Forecasts and specification of solar flare and solar particle events.
- Forecasts and specification of the magnetospheric variations.
- Forecasts and specification of upper atmospheric density variations.
- Compilation and distribution of geomagnetic and solar indices.

USAF operates and funds a variety of ground-based and space-based solar-geophysical sensors (see Tables 4-1 to 4-8). DOD provides rapid notification to system operators of conditions that could degrade system performance and to all levels within the military chain of command for decision assistance. AFSFC provides operational space environment support and USAFETAC provides space climatological support to DOD users. AFSFC Pamphlet 105-4 describes the principal USAF space environment products.

Table 4-9. Sources and Distribution of Space Environment Products

Product	Producer	Distribution
Daily solar-geophysical forecast	SESC	SESC to civilian users AFSFC to DOD users
Daily solar-geophysical activity summary	SESC	SESC to civilian users AFSFC to DOD users
Daily solar image collection requirement report	SESC	SESC to DOD users
Daily solar region summary	SESC	SESC to civilian users AFSFC to DOD users
Daily solar coronal disturbance report	SESC	SESC to civilian users AFSFC to DOD users
General purpose solar-geophysical disturbance alerts	SESC	SESC to civilian users AFSFC to DOD users
Tailored alerts for DOD applications	AFSFC	AFSFC to DOD users
Daily HF propagation forecasts	AFSFC	AFSFC to DOD users SESC to civilian users
Preliminary report and forecast (weekly)	SESC	SESC to all users
27-day outlook	SESC	SESC to civilian users AFSFC to DOD users
10-year solar cycle forecast	SESC	SESC to civilian users AFSFC to DOD users
General purpose database (SELDADS)	SESC	SESC to all users
Event Status notification	AFSFC	AFSFC to DOD users
Satellite Anomaly Post Analysis	AFSFC/SESC	AFSFC to DOD users SESC to civilian users

4.5.7 SESC Services to the National Economy. SESC makes available, for public use and national benefit, the forecasts, alerts, and data supplied to other Government agencies. The services are distributed as widely as possible at minimum cost to the U.S. Government, using single-point to multi-point capabilities such as WWV time-and-frequency radio broadcasts, relays over secondary teletype systems operated by other government and private networks, call-up telephone recordings, low-cost computer access, satellite broadcasts, and the U.S. Postal Service.

4.5.7.1 Satellite-related Activities Requiring SESC Services. Satellite operations are affected adversely by variable solar ultraviolet and X-ray emissions, by energetic particle fluxes, and by atmospheric density changes resulting from geomagnetic disturbances. The effects may be very costly to civilian satellite operators and may include the necessity to replace satellites prematurely.

A. Prediction of Orbital Variation. Commercial companies planning or carrying out satellite operations plan payload configuration, fuel loading, and orbital height by considering variable atmospheric drag through use of models driven by medium- to long-term solar activity predictions. (Many of these companies are contractors for various government agencies.)

B. Control of Spin Axis Alignment. Many commercial communication satellites use the Earth's magnetic field for reference in spin axis alignment systems. Geomagnetic storms disrupt these systems and could lead to loss of control of the satellite. Operating companies use geomagnetic storm alerts to deactivate alignment systems.

C. Diagnosis and Correction of Command and Control Problems. Energetic proton events and geomagnetic storms may induce stray currents in satellite systems and interrupt command data streams. Operating companies use alerts for rapid diagnosis of anomalies before engaging in more extensive and expensive diagnostic routines.

During the vernal and autumnal equinoxes, downlink telemetry from geosynchronous satellites can be garbled when large flares occur and the Sun is within the field of view of the ground antenna. Satellite controllers and cable company operators use SESC alerts and warnings to notify customers of potential outages.

High energy particles from large solar flares cause single event upsets in satellite microelectronics causing changes in onboard programming, detector noise, and irreparable physical damage. Additionally, large fluxes of energetic particles result in permanently reduced output from satellite solar cells. Satellite operators and engineers monitor the space environment to assess the effects of its variations upon spacecraft operations and to take appropriate mitigating actions.

Ionospherically propagated radio transmissions may be critically affected by solar activity and geomagnetic storms. Short-wave radio operators use predicted solar and geomagnetic indices to select times and frequencies for propagation. These users include amateur radio operators who provide public services such as disaster communications, eye bank networks, communications between overseas personnel and home, and communications for search and rescue in remote areas such as Alaska. Commercial shipping and aviation radio make extensive use of solar-geomagnetic predictions to maintain operational communications.

4.5.7.2 Industrial Activities Requiring SESC Services. Electromagnetic induction during geomagnetic storms affects the following industrial activities:

A. **Operation of Power Systems.** Electric power companies use geomagnetic alerts to diagnose electric power transmission grid system effects including the operation of transformers and protective systems. Accurate geomagnetic forecasts allow power system operators to increase their operating margins and avoid outages during geomagnetic storms. Geomagnetic alerts allow accurate diagnosis of system problems without lost time. Companies in geomagnetically vulnerable areas adjust power loads during periods of predicted high activity to minimize adverse system effects.

B. **Operation of Telephone Long-Lines.** Operators of long-distance telephone lines and transoceanic cable systems correlate geomagnetic alerts with system anomalies and often can avoid more extensive diagnosis of lowered system capacity.

C. **Protection of Oil and Gas Pipelines.** Pipeline operators avoid electrolytic effects of geomagnetic storm currents within pipelines by applying protective biases. Correct application of the protection depends on knowledge of the current level of geomagnetic activity.

4.5.7.3 Navigation Systems Requiring SESC Services. Modern navigation systems such as LORAN-C and Omega, use the ionosphere to reflect their signals back to users on Earth. The reflection height varies depending on the level of solar flare and geomagnetic activity. At times, when activity is very high, these systems are unusable. For instance, disturbed ionospheric conditions degrade the accuracy of the Global Positioning System (GPS). In extreme cases, especially during the solar maximum period, ionospheric irregularities of electron concentration, can garble GPS signals. SESC predicts and monitors conditions that can hamper the proper function of these systems.

4.5.7.4 Research Activities Requiring SESC Services. Success of costly federal and civilian research programs in solar-terrestrial sciences may be enhanced by use of timely space environment forecast services.

A. **Operation of Research Satellites.** Universities, research foundations, and commercial research groups schedule operating modes and data rates on research satellites by using predictions and alerts of disturbances that change the environment being measured.

B. **Rocket Launches for Solar, Geomagnetic, Ionospheric, and Neutral Atmospheric Research.** Research rockets are used extensively by non-Government research groups to study the effects of variable solar output on the upper atmosphere. Launches are scheduled and final countdowns carried out using space environment predictions and alerts.

C. **Balloon Launches for Solar and Atmospheric Research.** Balloons are used to carry research instruments such as solar gamma ray detectors, ozone sensors, and electric field monitors above the lower atmosphere. Flights are scheduled using space environment predictions and alerts.

D. **Operation of Observatories and Other Ground-Based Research Facilities.** Universities and research institutes that operate facilities for solar research and remote atmospheric sounding change to high data rates or special modes during periods of high solar activity. Forecasts and alerts are used to initiate these modes. Longer-term forecasts are used to schedule certain programs during desired periods of specific types of solar activity or quiet periods.

4.5.7.5 Geophysical Resource Activities Requiring SESC Services. Economically important activities in the management and development of natural resources and geophysical exploration require quiescent conditions in the Earth's magnetic field. Advance knowledge of geomagnetic disturbances is essential for effective surveying and mapping activities.

A. Geophysical Exploration and Mapping. One technique for mapping crustal structures in large areas uses airborne magnetometers to measure local variations in the geomagnetic field. During geomagnetic disturbances, the external variations from solar sources mask the crustal effects and surveys are useless. Surveyors from universities and private industry use alerts and short-term forecasts to schedule surveys.

B. Seismic Research. High-sensitivity magnetometers are used in seismic research and earthquake prediction research. Space environment forecasts are used to help assess the quality of the data.

C. Archeological Surveying. Construction and dredging activities must comply with legislation for preserving or surveying archaeologically significant sites. Magnetic surveys used in searches for hidden and buried sites depend on geomagnetic predictions.

4.5.8 SESC Support Services to Federal Agencies.

4.5.8.1 Support to the Department of Agriculture. SESC provides forecast alerts, indices, and data to the Department of Agriculture to assist in its Soil Conservation program. Telemetry from snow depth monitors is adversely affected by geomagnetic activity. SESC notifications and data allow the Department of Agriculture to assess the quality of its data.

4.5.8.2 Support to the Department of Commerce. SESC provides alerts, predictions, and data for NOAA atmospheric research programs. SESC also provides geomagnetic disturbance information to NOAA research vessels and field parties conducting geophysical surveys and supports NOAA users of satellite and radio navigation systems by providing geomagnetic indices and predictions to the operators of the navigation systems.

NOAA's Space Environment Laboratory conducts continuous review and quality control to achieve archive-quality, solar-terrestrial data for placement in the National Geophysical Data Center. The data to be archived are those collected in SELDADS and include space environment monitor data from the GOES and NOAA/TIROS satellites.

4.5.8.3 Support to the Department of Defense (DOD). In accordance with existing mutual support and backup agreements, AFSFC, OL-A personnel arrange certain specific support to DOD activities, within the existing capabilities of SESC.

A. Air Force Space Forecast Center (AFSFC). AFSFC achieved full operating capability in October 1992. Operational space environmental support within DOD transitioned to AFSFC from the Air Force Global Weather Central. SESC provides solar-geophysical analyses and forecasts to AFSFC based on DOD needs.

SESC will also serve as a contingency backup center for AFSFC space environmental support in case of outages of 10 minutes or more. AFSFC, in turn, serves as a contingency backup center for SESC. Procedures are included in a contingency backup plan. The plan is reviewed and updated annually as part of the USAF-NOAA Memorandum of Agreement for Cooperative Space Environmental Support Activities.

B. Naval Satellite Operations Center (NAVSOC), Point Mugu, CA. SESC provides predicted and observed geomagnetic and solar indices to the Naval Satellite Operations Center (NAVSOC) to enable NAVSOC control of the Navy Navigation Satellite System (NNSS) to meet fleet accuracy specifications. Content and frequency of support are coordinated between NAVSOC and SESC.

C. Naval Space Surveillance Center, Dahlgren, VA. SESC provides predicted and observed geomagnetic and solar indices on a daily basis to the Naval Space Surveillance Center (NAVSPASUR) for its mission of artificial satellite detection and motion in support of the United States Fleet and certain allied maritime forces, and its mission as a backup computational facility for the NORAD Space Defense Operations Center (SPADOC) Computation Center.

D. Naval Research and Development, San Diego, CA. SESC provides real-time continuous solar X-ray data as well as additional solar and geomagnetic indices including forecast and alerts as required for Naval Research and Development (NRaD) of the Navy Command and Control Ocean Surveillance Center (NCCOSC) support of Navy radio communication systems.

E. Office of Naval Research and the Naval Research Laboratory, Washington, D.C. SESC provides solar-terrestrial data as required to the Office of Naval Research to support research and development of naval systems affected by the space environment, especially communication systems, and investigations of satellite operational anomalies.

4.5.8.4 Support to the Department of Energy. SESC provides data, alerts, analyses, and forecasts to DOE programs requiring knowledge of the current state of the solar-terrestrial environment and conducts research into that environment. Content and format of the support will come from SESC standard services and will be determined on a program-by-program basis.

4.5.8.5 Support to the Department of the Interior. SESC provides forecasts and alerts of geomagnetic disturbances to USGS for use in geophysical mapping done as part of the USGS role of natural resource management and development. Specific support content and format are determined on a case-by-case basis, using the standard set of SESC indices, forecasts, and alerts.

4.5.8.6 Support to the Department of Transportation

A. U.S. Coast Guard. The U.S. Coast Guard (USCG) is responsible for the operation and maintenance of the OMEGA and LORAN-C navigation systems. These systems provide for accurate navigation by aircraft, ships, and land-based vehicles. The proper function of these systems can be affected both by solar flares and geomagnetic storms, and data from SESC in the form of the satellite broadcast as well as conversations with forecasters is necessary to diagnose a problem when it occurs with these systems.

The USCG is also in the process of becoming the point-of-contact for civilian use of the Global Positioning System (GPS). This state-of-the-art navigation system is also prone to errors when the ionosphere is disturbed, and users may consult with SESC at times they find to be problematic.

B. National Airspace System. SESC provides support to enable the FAA and its contractors to take these actions:

- Diagnose the causes of communication outages and limit the effects of interferences with FAA communication systems.

- Ensure the protection of personnel in high-latitude, high-altitude (above 35,000 feet) aircraft operations from excessive radiation caused by cosmic rays, auroral X-rays, and solar protons. Ten mr/h or more is considered excessive.

4.5.8.7 Support to National Aeronautics and Space Administration (NASA).

A. Manned Space Flight. SESC provides forecasts, alerts, and advisories of solar flare and energetic particle events during pre-launch, final countdown, and on-orbit phases of Space Transportation System flights. The information, from ground- and satellite-based sources, is provided to the Spaceflight Radiation Analysis Group (SRAG) at NASA's Johnson Space Center, through the SESC. It contains information related to any enhancement of natural radiation in the space environment. Specific content, format, and timing of support are coordinated with SRAG, using the Flight Rules Document specific to each mission.

SESC provides the solar and geomagnetic information required for assessing on-orbit atmospheric drag in trajectory calculations and real-time updates. The support includes predictions, event alerts and standard indices for use in atmospheric density models. The data are provided from SESC through the SRAG during each mission. The specific content and format are coordinated prior to each mission by SESC, SRAG, and the Johnson Space Center Mission Planning and Analysis Division.

SESC provides support services for specific payloads as defined in applicable flight requirement documents. Support for solar-terrestrial research payloads is defined on a flight-by-flight basis. SESC coordinates, as necessary, with AFSFC to obtain such additional space environment information from DOD sources as security classification permits for NASA space flight operations. AFSFC provides support to NASA as requested. Support to DOD-controlled missions is provided by the USAF Air Weather Service and other DOD sources.

B. Solar-Terrestrial Research Programs. SESC provides predictions, analyses, alerts, and data to NASA solar-terrestrial research programs that require knowledge of the current state of the solar-terrestrial environment. The programs supported include scientific satellite operation and control, environmental research rocket launches, Space Transportation System scientific payloads, and supporting ground-based observations. The support content and format are arranged on a flight-by-flight basis.

If the support encompasses special services from SESC, those are provided on a cost-reimbursable basis. Specifically, SESC will continue to provide support on a reimbursable basis for experiment operations centers such as that being planned for the Solar and Heliospheric Observatory (SOHO) mission. The SOHO program office at Goddard Space Flight Center will coordinate the service.

SESC assists and advises NASA in long-range scheduling of space programs that are dependent on the phase of the 11-year solar cycle.

4.5.8.8 Support to the National Science Foundation. SESC provides forecasts, alerts, indices, analyses, and data to research programs funded by the National Science Foundation. The support is negotiated on a case-by-case basis. If the service consists of other than standard products, it is provided on a reimbursable basis. The most important on-going commitment is to the magnetometer network initially funded by NSF, NOAA, and USGS under the International Magnetospheric Study. This network has proved invaluable and can be expected to operate into the next century. The data collection is subject to the Memorandum of Agreement mentioned in Section 4.3.2, between NOAA/NESDIS and NOAA/SEL. NOAA plays a key role in the acquisition and dissemination of the data through the GOES data collection platform systems and through SELDADS.

4.5.8.9 Support to the U.S. Information Agency (USIA). SESC provides alerts of solar flares and geomagnetic storms to USIA for radio frequency management.

4.6 Operation of the Solar-Terrestrial Physics Division of the National Geophysical Data Center (World Data Center-A For Solar-Terrestrial Physics). The NOAA National Geophysical Data Center (NGDC) collects, processes, archives, and disseminates data related to the origin of solar disturbances, the propagation of their effects through interplanetary space, their interaction with near-Earth space, and their impacts on the Earth's geophysical environment. NGDC is the U.S. national repository for solar-terrestrial monitoring data collected by NOAA, by USAF and other government agencies, and by universities and private institutions. NGDC operates WDC-A for STP, in coordination with the U.S. National Academy of Sciences.

International data are received by WDC-A for STP either directly from responsible institutions in each country or as copies of data collected at other World Data Centers (Moscow, United Kingdom, and Japan). The basis for the routine exchange of data among World Data Centers is the Fourth Consolidated Guide to International Data Exchange Through the World Data Centers (revised June 1979), published by the International Council of Scientific Unions' Panel on World Data Centers.

4.6.1 The Complementary Roles of SESC and NGDC. Data and information collected for the purpose of forecasting solar activity and its effects on the space environment or for providing alerts of solar-terrestrial events in progress must be quickly available for real-time or quick-time analysis and dissemination. SESC provides such availability. On the other hand, verification of space environment forecasts and warnings depends upon retrospective access to the "complete" data and information available from national and international sources. Also, development of forecasting techniques is often based on supporting research using comprehensive data sets. NGDC archives supply data for these purposes.

NGDC archives support research being conducted in the retrospective mode on the following: continuous flow of nonradiant energy from the Sun and the origin of solar disturbances; the often violent transfer of particles, fields, and radiation into space; propagation of these through the interplanetary medium; coupling of these with the Earth's protective magnetospheric envelope; storage of energy in near-Earth space and its transfer to lower altitudes; and the effects in all domains upon human systems and natural phenomena. Such research is necessary not only to validate and improve solar activity forecasts and alerts but also to provide a basis for improving our understanding of the physics governing the space environment. The need for such understanding increases as society becomes technologically more complex. More operational satellites are deployed for communications, weather monitoring, and defense surveillance; increasingly susceptible large-energy distribution systems are emplaced; the importance of navigation and communications at sea increases; and more technologically complex electronic systems are used for industrial and national security purposes.

4.6.2 Inter-Agency and Intra-Departmental Agreements. Memoranda of agreement have been negotiated between the USAF AWS and the National Geophysical Data Center (formerly of the Environmental Data and Information Service) covering the archival and distribution of auroral imagery and precipitating particle data from the DMSP satellites and the archival of solar activity data collected by the ground-based SOON and RSTN networks (cited as items 13-15 in Appendix B).

Under a Memorandum of Agreement between USGS and NOAA/NGDC, archival geomagnetic data are provided by USGS from the entire U.S. network of magnetic observatories and supplementary recording sites. NGDC provides access to these data for USGS and other users. Copies are provided to other World Data Centers by WDC-A for STP, to meet the need for international access to such data (see item 16 cited in Appendix B).

In accordance with the NOAA Satellite Archiving Plan (cited as item 17 in Appendix B), SESC provides these archival data to NGDC: digital and analog data from the GOES Space Environment Monitoring Platforms (solar X-rays, energetic particles, and magnetic field variations); energetic particle data from the NOAA/TIROS satellites.

Through SELDADS, NGDC obtains prompt summary data relating to solar activity and the space environment for publication in the monthly Solar-Geophysical Data reports.

Under contracts with the Air Force, NOAA/NGDC operates ionosondes at College, Alaska and Maui, Hawaii. The University of Alaska Geophysical Institute operates the ionosonde at College, Alaska under the direction of NGDC. The Air Force plans to replace the Maui, Hawaii contract with an AWS-operated ionosonde in 1994.

In recognition of the importance of retrospective solar-terrestrial data services provided by NOAA and the benefits to other agencies, the Department of Defense provides staff and funding resources to NGDC. NOAA/ERL/SEL assists in financially supporting university groups that supply solar data and analysis services to the space environment services program.

4.6.3 Solar and Upper Atmosphere Data Collection and Distribution. There is a continuing flow of solar and related data into NGDC, including summary plots, tables, data tapes, and solar imagery from SELDADS and SESC. This is complemented by a flow of data from other Government agencies, universities, and the private sector, and from foreign countries and other World Data Centers. This data stream is received, processed, merged, archived, and retrieved upon request. Selected types of data are prepared for routine publication in the monthly <u>Solar-Geophysical Data</u> reports (see Appendix A of these reports).

4.6.4 Ionospheric Data Collection and Distribution. Ionospheric data are used extensively in planning high-frequency (HF) communications and are also relevant to satellite communications.

They are primary or collateral data in a wide variety of space environment research problems. The major source of ionospheric data collected is from systematic soundings by HF multi-frequency radars (ionosondes) obtained by a world network of some 150 stations. These include the USAF-operated or supported stations listed in Table 4-3. Also, about 15 digital ionosondes are operated by similar groups in foreign countries.

NGDC provides ionospheric data services through the cooperation of DOD, NOAA, DOE, NSF, and other agencies making data available to NGDC. In wide demand are 6-month predictions of applicable HF propagation frequencies. The predictions of ionospheric "climatology" take into account predictions of solar activity and data collected from the world network of ionosondes for the last 40 years. These predictions are generated using programs developed by DOC.

4.6.5 Geomagnetic Data Collection and Distribution. Streams of charged particles, called the solar wind, are emitted by the Sun at all times. In combination with the solar magnetic field, which spreads through interplanetary space, the solar wind interacts with the Earth's geomagnetic field to form a tear-drop-shaped "magnetosphere" with a tail that extends hundreds of Earth-radii away from the Sun. As a result of complex electromagnetic interactions, electrical currents flow on the surface of the magnetosphere, across the magnetotail, and downward toward the Earth along geomagnetic field lines until they encounter the upper atmosphere where they produce aurorae, X-rays, and heating of the neutral atmosphere. These currents flow through the ionosphere and return along field lines to join with belts of charged particles in space above the equator. Wherever an electric current flows, there is simultaneously an associated magnetic field. During solar activity such as flares or when coronal holes are sweeping past alignment with the Earth, great enhancements in the solar wind collide with the magnetosphere and produce large magnetic disturbances recorded at approximately 200 observatories around the world. Special temporary arrays of magnetometers are operated to supplement the standard sites for campaigns and during prolonged intervals such as the International Magnetospheric Study. Satellite-borne magnetometers directly record in situ changes in the space environment.

Because disturbances in the quiet pattern of the geomagnetic field are diagnostic of solar disturbances that impact the Earth, the most-used products derived from magnetic variations are activity indices (indicators of magnetic disturbance). Each is descriptive of certain types of magnetic disturbance and certain regions of the Earth. These are used extensively in supporting research leading to improved understanding of space environment processes and mechanisms and in forecast technique development.

USGS-NGIC collects and distributes real-time digital geomagnetic data (1-minute values) from the U.S. and the INTERMAGNET observatory networks. These are provided in real-time (or near-real-time) to NOAA/SESC for SELDADS and in archival form, later, to NOAA/NGDC.

Geomagnetic variation data from a few sites are quickly available through SELDADS and are used to estimate global indices for many applications. Data from almost 400 ground-based magnetic observatories worldwide are archived by NOAA/NGDC. Availability of critical data is expedited, but converting analog records to digital formats and deriving the index often require months to years. This task is becoming easier as more observatories are adopting digital recording.

4.6.6 Specialized Data Collection and Analysis Services. NGDC archives and disseminates these specialized solar-terrestrial data: USAF satellite-recorded auroral imagery, precipitating electrons and bremsstrahlung X-rays, solar optical and digital data from the USAF Solar Observing Optical Network (SOON), and solar radio emissions recorded by the USAF Radio Solar Telescope Network (RSTN).

In response to Department of Commerce Order 25-5B (NGDC "shall provide data-information services in all scientific and technical areas involving ...the space environment, solar activity and other areas of solar-terrestrial physics..." and shall "prepare systematic and special data products and perform data-related research studies to enhance the utility of the service to the users..."), NGDC staff and visiting scientists perform data analyses. Results are quality control of archived data, development of new data products, and creation of new techniques for data analysis. Special data reports are compiled and published by NGDC for selected space environment events.

4.7 Air Force Space Forecast Center (AFSFC). The Air Force Space Forecast Center (AFSFC) is operated by the USAF Air Weather Service (AWS) to serve the needs of the Department of Defense (DOD) and other Federal agencies as determined by existing agreements. Indirectly, through its joint operations at the Space Environment Services Center, the AFSFC also serves the private and academic sectors.

4.7.1 Interdepartmental Agreements. As stated in section 4.5.1, the DOD, specifically the AWS of the USAF, has "the mission and responsibility to provide, or arrange for the provision of such tailored space environmental observing and forecasting services as are necessary to meet unique military requirements in support of programs dealing with national security".

To implement this responsibility, AWS and the AFSFC have entered into a number of agreements and contracts to obtain the observational solar, ionospheric, and geophysical data required to support a worldwide space environmental forecast and warning service. In many cases, these agreements and contracts also provide for the maintenance and supply of the geophysical sensors.

4.7.2 Mission and Organization of the AFSFC. The AWS mission includes specifying and forecasting the condition of the near-Earth space environment. This environment may impact many DOD systems, including communication (both ground-based and satellite), radar, and surveillance systems. The AWS's AFSFC, a component of the Space Environmental Support System (SESS), provides both broad and mission-tailored support in many areas. These areas include: solar flare activity, ionospheric variability, energetic particle events, geomagnetic and solar indices required to determine atmospheric density variations, and post analysis of operational system problems to determine if the space environment was a contributing factor. Customer support includes real-time notification of solar and geophysical events, forecasts with lead times ranging from hours to months, products tailored to specific user requirements, and detailed post-analysis studies.

The AFSFC is staffed by USAF military and civil service employees. The forecast center itself, located at Falcon AFB, Colorado, serves as the DOD's only space environmental forecast and warning center, providing round-the-clock, worldwide mission support to the DOD and other Federal agencies which can be adversely impacted by disturbances in the near-Earth environment. AFSFC Pamphlet 105-3 describes space environmental effects on DOD systems, while AFSFC Pamphlet 105-4 describes the products generated by the AFSFC to meet these requirements. A number of products are jointly issued by the AFSFC and the National Oceanic and Atmospheric Administration's (NOAA) Space Environment Services Center (SESC) at Boulder, Colorado.

The AFSFC has seven direct subordinate units. One is the Air Force contingent (AFSFC Operating Location A) at SESC. The other six units are USAF Solar Electro-optical Observing Network (SEON) observatories located at Sagamore Hill, Massachusetts; Ramey, Puerto Rico; Holloman AFB, New Mexico; Palehua, Hawaii; San Vito, Italy; and Learmonth, Australia. This network of solar optical and radio observatories maintains near continuous monitoring of solar activity using the Solar Observing Optical Network (SOON) telescope (AN/FMQ-7), Radio Solar Telescope Network (RSTN) telescope (AN/FRR-95), and their associated computer subsystems.

4.7.3 AFSFC Data Sources. The AFSFC receives solar, ionospheric, and geophysical data from worldwide networks of space environment sensors.

4.7.3.1 Solar Data. The SOON telescope gathers standardized photospheric, chromospheric, and coronal data in either computer assisted ("automatic") or non-computer ("semiautomatic") mode. The system provides the capability to observe, analyze, and report such solar phenomena as flares, sunspots, magnetic fields, and disk and limb activity. The primary wavelength of light used to analyze solar activity is the Hydrogen-alpha (H-alpha) wavelength at 6562.8 Angstroms, however, other spectral wavelengths are used for specific functions.

The RSTN telescopes gather standardized solar radio data in either computer assisted or non-computer ("manual") mode. The RSTN system produces discrete (fixed) frequency radio observations at 245, 410, 610, 1415, 2695, 4995, 8800, and 15400 MHz using Radio Interference Measuring Sets (RIMS). The RSTN system also produces swept frequency spectral radio observations over a continuous band of frequencies using the Swept Frequency Interferometric Radiometer (SFIR).

Solar X-ray and energetic particle data are routinely received from the Geostationary Operational Environmental Satellites (GOES) through the NOAA/SESC forecast center. Additional energetic particle data are received from a series of DOD geostationary satellites.

4.7.3.2 Ionospheric Data. The AFSFC receives data from a worldwide (primarily northern hemisphere) network of ionosondes (which provide electron density profiles) and polarimeters (which provide total electron content data). AWS is currently deploying a network of automated ionosondes, the Digital Ionospheric Sounding System (DISS). The Air Force plans to replace the polarimeter network with the Transionospheric Sensing System (TISS) which will use signals from the Global Positioning Satellite (GPS) to determine total electron content.

4.7.3.3 Geophysical Data. Auroral electron precipitation and visual data are available from the Defense Meteorological Satellite Program (DMSP) satellites, which are sun-synchronous, polar orbiting at an altitude of 840 km. Magnetospheric data are obtained from GOES geosynchronous magnetic field measurements provided through the NOAA/SESC forecast center. Ground-based geomagnetic data are available from a network of automated magnetometers owned and operated by the U.S. Geological Survey.

4.7.4 AFSFC Forecast and Warning Services.

4.7.4.1 Requests for Support. AFSFC operations personnel can coordinate immediate support requirements 24 hours/day (DSN 560-6313, Commercial 719-550-6313). Routine requests for support should be submitted through the AFSFC's administrative staff (DSN 560-6322/2208, Commercial 719-550-6322/2208) at AFSFC/DOM, 715 Kepler Ave, Ste 60, Falcon AFB, CO 80912-7160.

4.7.4.2 State-of-the-Art. The state-of-the-art in accurately forecasting solar and geophysical events is limited. However, rapid event notification provides warning to operators of conditions that could degrade the performance of their systems. Typical types of notification include: solar X-ray events which may disrupt high frequency (HF) communications on sunlit paths, solar radio bursts which may disrupt communication systems and/or cause interference on radar systems, solar proton events which can produce radiation hazards to satellites and spacecraft, ionospheric disturbances which can degrade HF and satellite communication systems, and geomagnetic disturbances which can affect the orbital parameters of low altitude satellites or cause spacecraft charging near geostationary altitudes.

4.7.4.3 Solar Flare Forecasting. The USAF optical (SOON) and radio (RSTN) observatory networks were specifically designed to provide consistent, rapid flare observations and data for short-term solar flare forecasting. Solar flares are the primary source of solar X-ray and radio wave bursts, as well as high energy particle emissions.

4.7.4.4 Forecasting Ionospheric Variability. The state of the ionosphere is monitored to provide a variety of notifications and forecasts of irregularities that can affect performance of ionospheric dependent systems. These services consist of real-time and long-range forecasts, along with specification and forecasting of electron density profiles and total electron content. Large scale fields of parameters such as foF2 are also available. As one of its routine general-use products, the AFSFC provides real-time specification and forecast of HF propagation conditions every six hours.

4.7.4.5 Forecasting Magnetospheric and Neutral Density Parameters. Magnetospheric monitoring is accomplished using real-time particle data from the GOES and DOD geostationary satellites. Variation of the magnetosphere is also monitored using ground-based magnetometers, which provide 3-hour ap and 24-hour Ap indices. These indices are indicators of the influx of energy into the upper atmosphere due to energetic particle bombardment, and are a prime input for atmospheric density models. Another prime density model input is the 10.7 cm (2800 MHz) solar radio flux (F10), which correlates with the influx of energy into the atmosphere due to solar X-ray and extreme ultraviolet radiations. F10 observations are received daily from a standard observatory (the Dominion Radio Astrophysical Observatory) at Penticton, British Columbia, Canada.

4.7.5 Space Environmental Sensors Managed or Used by the AFSFC.

4.7.5.1 Solar Optical Telescopes. The Solar Observing Optical Network (SOON) telescope (AN/FMQ-7) gathers standardized photospheric, chromospheric, and coronal data; including information on solar magnetic fields. The SOON consists of five solar optical observatories geographically positioned to allow a 24-hour per day optical observation of the Sun (weather permitting). The SOON monitors and reports real-time solar activity (e.g., flares, loops, eruptive prominences, and disappearing filaments) which are visible in the Hydrogen-alpha (H-alpha) wavelength (6563 Angstroms (A)). It is also used to analyze other H-alpha phenomena such as plages, and quiescent prominences and filaments; to analyze sunspots in white (integrated) light; and to analyze the solar magnetic field structure using the SOON spectrograph system. The four major elements of each AN/FMQ-7 are the telescope with birefringent filter (automatic tracking and light acquisition from 3900 A to 10850 A), the videometer (automatic flare detection within one minute of occurrence when flare area exceeds 10 millionths of the solar hemisphere and brightness is 160 percent over quiet background Sun), the spectrograph subsystem (multispectral line and magnetic field analysis), and the computer processing subsystem (automatic data processing and archival).

4.7.5.2 Solar Radio Telescopes. The Radio Solar Telescope Network (RSTN) telescopes (AN/FRR-95) gather standardized solar radio data. The RSTN consists of four solar radio telescope systems geographically positioned to observe solar radio frequencies on a 24-hour per day basis. The AN/FRR-95 automatically monitors and collects data on eight discrete frequencies using Radio Interference Monitoring Sets (RIMS) and three radio antennas. The 28-foot antenna receives 245, 410, and 610 MHz. The 8-foot antenna receives 1415, 2695, 4995, and 8800 MHz. The 3-foot antenna receives 15400 MHz. These data are analyzed for the presence of particular radio wave patterns indicating solar activity. The AN/FRR-95 system also uses a Swept Frequency Interferometric Radiometer (SFIR) to monitor and collect data over a continuous range of frequencies in the Very High Frequency (VHF) band. The band is currently limited to the 25-75 MHz ranges, but an upgraded SFIR planned for installation at each site will expand that range to 30-250 MHz. Radio bursts in the VHF band are produced by particle streams moving through the solar atmosphere, and provide strong indications of energetic particles leaving the Sun. A computer performs automatic data processing and archival.

4.7.5.3 Ionospheric Sounders (Ionosondes). Data from vertical incidence ionospheric sounders are very important in determining radio propagation conditions in all frequency bands. These devices measure ionospheric parameters (primarily free electron density vs. altitude) up to the maximum level of ionization (F-layer) directly above the sounder. Short pulses of radio energy are transmitted, usually at vertical incidence, at frequencies from about 1 to 20 MHz over about a 5 minute cycle. Delay time between pulse transmission and echo reception is recorded as a function of frequency. Such a plot is known as an ionogram. The ionogram can also be labelled with "virtual height" and free electron density. Virtual height is the apparent altitude of reflection assuming pulses travel at light speed. The Air Force has access to data from several dozen sounders located worldwide, and is in the process of installing a network of automated Digital Ionospheric Sounder System (DISS) instruments (AN/FMQ-12) at critical locations. Ionospheric models use the data obtained from these geographically separated sounders to "fill in the gaps" and produce a global, 3-dimensional specification of the ionosphere's structure.

4.7.5.4 Polarimeters. Polarimeters measure total electron content (TEC) of the ionosphere along a path through the ionosphere from the ground-based instrument to an orbiting reference satellite by monitoring the Faraday rotation, or polarization twist, of a linearly polarized VHF radio wave transmitted from the satellite. TEC data are used to adjust for errors in satellite range and bearing measured by ground-based radars. Polarimeters will be replaced by Transionospheric Sensing System (TISS) instruments, which use signals from Global Positioning System (GPS) satellites.

4.7.5.5 Magnetometers. Magnetometers measure the strength and orientation of the geomagnetic field as observed at a particular point on, or near, the Earth's surface. Although magnetometers are sometimes flown on satellites, most are ground-based. Until mid-1992, the AWS's Air Force Global Weather Central (AFGWC) used a network of five northern hemisphere sites to produce 3-hourly geomagnetic indices. When the Air Force Space Forecast Center became operational in mid 1992, it started using a larger network of automated magnetometers owned and operated by the U.S. Geological Survey, which produce hourly geomagnetic indices. The magnetic indices derived provide a near-real-time indicator of the average planetary geomagnetic activity. The data are used for, among other things, analysis of satellite drag and for evaluating ionospheric radio propagation conditions.

4.7.5.6 Relative Ionospheric Opacity Meters (Riometers). These instruments record the strength of High Frequency (HF) "cosmic radio noise" (i.e., radio waves emanating from extraterrestrial sources) received at the Earth's surface. A decrease in power represents an increase in ionospheric opacity or absorption. Riometers can detect ionospheric disturbances such as: Short Wave Fades (SWF), Auroral Zone Absorption (AZA), and Polar Cap Absorption (PCA) events.

4.7.5.7 Neutron Monitor. An instrument used for ground-based detection of secondary neutrons produced during collisions between cosmic rays and atmospheric molecules or atoms. It provides an indirect measure of the cosmic ray flux encountered by the Earth, whether from solar or non-solar (i.e., "galactic") sources. The most interesting event detected by a neutron monitor is a Ground Level Event (GLE), which is a sudden increase in secondary neutrons produced by collisions between solar cosmic rays and atmospheric gases. GLEs are important as an indicator that a very energetic solar flare has occurred, and a Polar Cap Absorption event and geomagnetic storm are almost certain to follow.

4.7.5.8 Satellite Observations. Satellite sensors provide early warning of changes in the near-Earth environment. In particular, AFSFC and SESC receive near-continuous data from two major satellite networks, the Defense Meteorological Satellite Program (DMSP) and Geosynchronous Operational Environmental Satellite (GOES). DMSP satellites are in low altitude polar orbits, and provide visual aurora, low energy particle, and ionospheric parameter data. GOES satellites are in geostationary orbits, and provide solar X-ray, energetic particle, and magnetometer data. From time to time, other satellites provide useful solar-geophysical data on a temporary basis. For example, in the early 1980s, ISEE-3 provided real-time solar wind, interplanetary magnetic field, and X-ray data from its position 930,000 miles from Earth toward the Sun. Another example was Sky Lab, which provided a capability to image the Sun at ultraviolet and X-ray wavelengths.

4.7.6 AFSFC Services. The AFSFC provides timely, accurate solar and geophysical alerts, analyses, forecasts, and environmental specifications directly to DOD and other Federal agencies, as well as through the SESC. AFSFC Pamphlet 105-4 describes all space environment analysis and forecast products available from the AFSFC. Most of these products can be received by teletype (over the Automated Weather Network, AWN) and/or by AUTODIN. Additional specialized products can be arranged.

The AFSFC serves as a contingency backup center for the SESC. The SESC, in turn, serves as a contingency backup center for the AFSFC. Contingency procedures are contained in a plan that is included as part of the USAF-NOAA Memorandum of Agreement for Cooperative Space Environmental Support Activities. The AFSFC provides support to meet all areas of space environmental impacts discussed below.

4.7.7 Space Environmental Impacts on Military Activities.

4.7.7.1 Satellite Control and Tracking.

4.7.7.1.1 Drag Errors. Changes in solar electromagnetic and particle radiation cause atmospheric density variations, which affect the drag force on satellites, especially those in low altitude polar orbits. Predicted satellite positions will be in error, unless one accounts for solar-geophysical conditions. The two indices most often used in satellite drag computations are: the 10.7 cm solar radio flux, which is related to the amount of ultraviolet energy the Sun is pumping into the Earth's upper atmosphere; and the ap geomagnetic index, which is a measure of how much energy is being added to the upper atmosphere through particle bombardment.

4.7.7.1.2 Bearing and Range Errors. Ionospheric conditions can cause sufficient refraction, scattering, and retardation of an Ultra or Super High Frequency (UHF, SHF) signal to introduce significant errors in a satellite's measured position. A bearing (or direction) error is caused by signal refraction, while a range (or distance) error is caused by both a signal retardation (slower wave speed) and the longer path length of the refracted signal. Satellite trackers can compensate for these errors by using predictions or observations of ionospheric characteristics along the signal path.

4.7.7.2 Satellite Anomalies. Solar radiation and the Earth's Van Allen radiation belts pose significant hazards to spacecraft. Changes in the radiation environment are associated with solar activity and geomagnetic disturbances.

4.7.7.2.1 Spacecraft Charging. Spacecraft charging occurs when there is a variation in the electrostatic potential of the spacecraft (on the exterior surface or deep within the vehicle) with respect to the surrounding space environment. Although any vehicle operating above a few hundred kilometers is susceptible, geosynchronous satellites and low polar orbiting satellites are most likely to experience charging problems. Although the build-up of large static charges may confuse or blind certain sensors, the real danger lies in the subsequent discharge. Damage of sensitive electronics is possible depending on the degree of "hardening" of the spacecraft. Discharges have been known to cause the following problems:

- Spurious electronic switching (sensors or recorders go on/off without being instructed).
- Breakdown of vehicle thermal coatings.
- Amplifier and solar cell degradations.
- Degradation of optical sensors.

4.7.7.2.2 Single Event Upsets (SEUs). SEUs are bit flips in digital micro-electronic memory circuits. SEUs can cause loss of stored data, damage to software, disruption of the central processing unit, unplanned command and control events, and failure of computer components. SEUs are caused by the direct ionization of silicon material by a high energy ion passing through it. These particles may be galactic cosmic rays, solar cosmic rays from very energetic flares, or protons trapped in the Van Allen radiation belts.

4.7.7.2.3 **Satellite Disorientation.** Many space systems rely on electro-optical sensors to maintain their orientation in space. These sensors lock on to certain patterns in the background stars and use them to achieve precise pointing accuracy. These sensors are vulnerable to cosmic rays and high energy protons, which can produce flashes of light as they impact the sensors. Gradual sensor degradation can also occur under constant radiation exposure. These problems occur most frequently during periods of high solar activity and geomagnetic disturbances.

4.7.7.3 **Manned Spaceflight.** High levels of solar radiation, due to large solar flares, can be a threat to man in space. Particles having extremely high energy may pass through the human body with no serious effects. Particles which are stopped by human tissue pose the most danger, since this radiation can ionize atoms within a person's body and result in cell damage. Crew members are particularly susceptible to radiation effects when their vehicle is in a high inclination, high altitude orbit. When outside the protective effect of the Earth's magnetic field, radiation from a single intense flare could be fatal.

4.7.7.4 **Communication Systems.**

4.7.7.4.1 **HF Systems.** The normal propagation methods are by refraction in the ionospheric F-layer for single hops, and by reflection between the ground and the ionosphere for multiple hops. X-rays from solar flares can increase signal absorption in the lower ionosphere (D-layer). The amount of signal loss depends upon flare intensity, location of the HF path relative to the Sun, and design characteristics of the system. For any given ionospheric conditions there is a range of usable frequencies. The Maximum Usable Frequency (MUF) and the Lowest Usable Frequency (LUF) vary with solar activity, season, and time of day. Frequencies that are too high pass through the ionosphere into space, while frequencies that are too low are absorbed in the lower ionosphere.

4.7.7.4.2 **Satellite Communications.** Satellite communication (SATCOM) systems use Very, Ultra, Super, and Extremely High Frequency (VHF, UHF, SHF, and EHF) bands to mitigate the ionospheric effects inherent in HF communications systems. However, these systems are not entirely immune to the environment; both solar activity and geomagnetic disturbances can significantly degrade system effectiveness. Two problem areas are scintillation and solar radio burst interference. Scintillation is a rapid, usually random variation in signal amplitude and phase. It is the result of abrupt variations in ionospheric electron density along the signal path. Solar radio bursts can produce interference on radio and radar systems. If the Sun is in the reception field of the receive antenna, solar radio bursts may cause Radio Frequency Interference (RFI) in the receiver.

4.7.7.5 **Radar Systems.** The DOD relies on many types of long range radar systems to accomplish the missile warning/space surveillance mission (PAVE PAWS, BMEWS, etc). Since the energy from these systems must pass through the ionosphere, variations and perturbations in the ionosphere can produce a number of problems.

4.7.7.5.1 **Auroral and Polar Cap Interference.** Auroral and polar cap interference and clutter are serious problems for radar looking toward the North. The ionospheric irregularities associated with the auroral E-layer, F-region auroral blobs, and polar cap patches of ionization can act as a scatterer of radar energy causing large Doppler shifted returns. Intense radar interference can black out large areas of geographical coverage, mask target returns, and produce false targets.

4.7.7.5.2 Ionospheric Errors. Changes in the amplitude and phase of received radar pulses can influence target cross section measurements. Range errors result from the slightly lower speed of radar waves as they traverse the ionosphere. Azimuth and elevation angle errors are introduced by refraction of the energy in the ionosphere. These problems tend to follow the ionosphere's diurnal, seasonal, and solar cycle variability. Errors approaching 100% can occur during major geomagnetic storms.

4.7.7.6 Over-the-Horizon Backscatter Radar. The Over-the-Horizon Backscatter (OTH-B) radar uses HF refraction through the ionosphere to detect targets at distances up to 2000 miles. Radar operators need to be aware of existing and expected ionospheric conditions over a wide geographical area. Otherwise, improper frequency selection will reduce target detection performance, or incorrect estimation of ionospheric layer heights will give unacceptable range errors.

4.7.8 Future Improvements in AFSFC Support. The AFSFC is in the process of enhancing its ability to observe the space environment, analyze data, and model the near Earth environment.

4.7.8.1 Digital Ionospheric Sounding System (DISS). The DISS (AN/FMQ-12) is a network of automated ionosondes currently being fielded by the Air Force at critical locations around the globe. These sounders differ from current ionosondes primarily in their ability to use an on-site computer to analyze ionospheric sounding observations and transmit the analysis real-time to forecast and warning centers. Remote terminal access will allow the AFSFC to reset sounding parameters, and to examine observational returns in detail when needed.

4.7.8.2 Transionospheric Sensing System (TISS). TISS will replace the current aging, unsupportable polarimeter network. There is a potential for additional TISS capabilities and more ground sites to support valid requirements.

4.7.8.3 Solar Electro-optical Observing Network (SEON) Upgrade. An upgrade/replacement program was approved in 1987 to maintain and improve the capabilities of the six observatories in the USAF Solar Electro-optical Observing Network (SEON). The SEON Upgrade/Replacement program is divided into two phases. Phase I completes the efforts to satisfy SEON needs by upgrading the capabilities of the SEON to observe solar radio bursts, solar flares, and the Sun's magnetic field. Phase II upgrades and replaces logistically unsupportable components of the existing system. Phase I is well underway and first article installation is expected at the Palehua Solar Observatory by early 1993. Phase II is still in the feasibility evaluation stage.

4.7.8.3.1 SEON Upgrade Phase I. A contract to implement Phase I was awarded in November 1990. The Phase I upgrade is intended to replace the current aging, unsupportable computer system at the USAF solar observatories. At the same time, all the operating software will be rewritten in Ada. Identical Digital Equipment Corporation Microvax workstations will be installed for both the optical (SOON) and radio (RSTN) telescope systems. Workstations and peripherals will be linked via an ethernet, and will be capable of real-time backup for each other. Dedicated front-end processors for telescope control, SFIR, and fixed frequencies will be linked via the ethernet.

The Phase I upgrade will also involve some observing equipment enhancements. Enhancements to the SOON system include two charge-coupled-device (CCD) cameras to replace the Minicon cameras on the H-alpha and spectrograph light paths. The videometer function will be accomplished by a dedicated processor. Enhancements to the RSTN system include a completely new automated SFIR with an expanded 30-250 MHz sweep capability. The digital output from the 5207 Lock-in Amplifiers will be used, thus eliminating the Phoenix A/D converter. Finally, an uninterruptible power system (UPS) will be provided for both the RSTN and SOON systems.

4.7.8.3.2 SEON Upgrade Phase II. The Phase II upgrade is intended to improve solar observations by adding new capabilities through acquisition and fielding of advanced technology equipment and observing techniques.

The major improvement for the SOON system is the procurement of vector magnetographs (VMGs). An unsatisfied requirement exists to improve the ability of the AFSFC and SESC to forecast solar flare activity by improving the data provided by the SOON telescope. The VMG will provide a true vector field representation for both the longitudinal and transverse components of the Sun's magnetic field. This will make it possible for sites to isolate and measure high magnetic shear zones with strong flare potential and should reduce flare false alarm rates. Plans are to develop a separate, stand-alone optical telescope with sufficient computing power to handle the large volume of data required for useful analysis.

The major improvement for the RSTN system is the procurement of Solar Radio Burst Locators (SRBLs). SRBLs will permit radio mapping of active regions on the solar disk. Determination of solar disk location is crucial to accurate forecasting of solar flare impacts in the near-Earth environment. However, current radio telescopes can not specify disk locations, so we depend on optical observations for this information. A SRBL capability would not be affected by atmospheric obstructions (clouds, haze, etc.) which currently limit optical observations, and so would allow uninterrupted determination of disk locations. The method for acquiring spatial radio data has not yet been finalized, although several techniques are under review.

4.7.8.4 Space Environmental Technology Transition (SETT) Models. The SETT Models program involves the transition of a suite of prototype scientific models into operational models capable of interfacing with the real-time databases within the AFSFC operating environment. These models will specify and forecast the space environment from the Sun to the Earth's upper atmosphere. In addition, new applications software will be developed to retrieve model output and allow forecasters to effectively use the data for operational customer support. The research-grade models are undergoing advanced development by Air Force Materiel Command contracted universities and civilian laboratories. The contract for transitioning the SETT models to the AFSFC operating environment was awarded in September 1992. The new software will take advantage of high-tech commercial off-the-shelf (COTS) software packages to reduce development costs, while still providing detailed graphical displays of the complex space environment.

Ten space environmental models are being developed in an orderly, phased fashion, which means the transition process and operational software development will also be phased. The transition process is expected to be completed by 1998. Follow-on space models are planned to improve model output accuracy by replacing parameterization techniques with first principle physics schemes wherever possible. The currently planned suite of ten models include: two magnetospheric models, three ionospheric models, one neutral atmosphere model, two interplanetary models, a coupling model, and an executive routine.

4.7.8.4.1 Magnetospheric Models. The magnetospheric models will enable the AFSFC to provide specification and forecasts of the following: charged particle population and geomagnetic field line geometry in the near-Earth region, energy fluxes and characteristic energies of precipitating energetic electrons, and global electric fields mapped into the ionosphere and neutral atmosphere.

A. Magnetospheric Specification Model (MSM) was designed as part of a suite of models that model the propagation of a solar disturbance from the sun, through interplanetary space, through the magnetosphere, and into the upper atmosphere. The primary purpose of the MSM is to provide electric fields for the ionospheric model. As a spin-off, the MSM provides a basic capability for post-analysis of satellite anomalies by specifying low-energy charged particle fluxes that cause surface charging on spacecraft and satellites.

B. Magnetospheric Specification and Forecast Model (MSFM) was designed to extend the specification model capability to include short-range forecasting to support the ionospheric forecast model. The MSFM concentrates on increasing accuracy, increasing spatial coverage to include more of the magnetosphere, and establishing a significant magnetospheric forecast capability (0-3 hours).

4.7.8.4.2 Ionospheric Models. The new ionospheric models will enable the AFSFC to provide real-time ionospheric specification and forecasts of electron density profiles, total electron content (TEC), critical frequencies, and ionospheric scintillation parameters.

A. Parameterized Real-time Ionospheric Specification Model (PRISM) is a global ionospheric specification model that will use near-real-time data from both ground-based and space-based sources to provide accurate specification of electron density profiles and TEC.

B. Ionospheric Forecast Model (IFM) is a 3-dimensional, time-dependent model that will use PRISM as input to produce global ionospheric forecasts.

C. Wide Band Scintillation Model (WBMOD) models the effects of ionospheric plasma density irregularities on transionospheric radio frequency propagation. It provides specifications and predictions of the worldwide occurrence and behavior of the plasma density irregularities, and uses these to estimate the levels of ionospheric scintillation that the irregularities will cause on transionospheric propagation channels.

4.7.8.4.3 Neutral Atmosphere Model. The Vector Spherical Harmonic Model (VSH) will specify and predict global neutral particle densities, winds, and temperatures from 90 to 1500 km in the atmosphere. The primary objective of VSH is to reduce the average error in density specification to 5% in the region below 500 km.

4.7.8.4.4 Integrated Space Environmental Models (ISEM). These models include two interplanetary models, as well as an integrated software system that links all the space environmental models together and an executive routine.

A. Solar Wind Transport Model (SWT) will predict the effect of the solar wind and interplanetary magnetic field on the Earth's magnetosphere.

B. Interplanetary Shock Propagation Model (ISP) will provide an early warning (1-4 days) of geomagnetic storms resulting from solar flares.

4.7.8.4.5 Coupling Model and Executive Routine. A model coupling effort will link the interplanetary, magnetospheric, ionospheric, and neutral atmosphere models together with physically-based, self-consistent interfaces. Coupling will allow output from PRISM to be used as input by VSH, etc., resulting in more accurate customer support. Finally, an Executive Routine will provide a single framework to coordinate and facilitate the execution of all the regional space models using scientific expertise and decision making capability within the program. This will increase the consistency of the outputs, optimize run times, and decrease the workload of forecasters.

4.8 <u>USAF Environmental Technical Applications Center (USAFETAC)</u>. USAFETAC at Scott Air Force Base (AFB), Illinois is an Air Force controlled and manned organization assigned to the Air Weather Service. After collecting, storing, and archiving space environmental observations, USAFETAC summarizes, analyzes, and applies information from the resulting Space Environmental Support System (SESS) climatic database and other sources for Department of Defense (DOD) and other US. Government agency customers.

At USAFETAC Operating Location A (OL-A) in Asheville, North Carolina, civilian technicians create and maintain the Air Force's computerized SESS climatic database from space environmental data received through the AFSFC from observing sites around the world and from satellites in space. After quality-controlling these observations, OL-A preserves the data as a permanent climatological record.

At Scott AFB, Air Force space environmental analysts use the SESS climatic database, along with the information resources of the Air Weather Service Technical Library (AWSTL), to prepare environmental studies and analyses for DOD and other clients upon request. Tailored application of information in the database ranges from answers to simple requests for climatological probabilities to the latest in environmental simulation studies.

4.8.1 The Complementary Roles of AFSFC and USAFETAC. AFSFC provides real-time SESS support for DOD and other Federal agency customers. This support includes the forecasting of solar activity and its effects on DOD systems, providing warning of solar-terrestrial events when they occur, providing an assessment of the probability that past and present DOD system anomalies where caused by the space environment, and transmitting SESS data collected in real-time to USAFETAC for archival.

USAFETAC provides archived SESS observations to AFSFC for use in assessing past DOD system anomalies. The results of climatological studies done by USAFETAC provide verification of the accuracy of SESS models and forecasting techniques used by the AFSFC. USAFETAC climatological studies also provide guidance to DOD agencies in planning for future surveillance, communications, and radar systems and testing systems in development.

4.8.2 Data Collected through the AFSFC. The SESS climatic database at USAFETAC contains reports from solar optical and radio observing sites, ionosonde observations, geomagnetic indices and magnetometer reports, x-ray and energetic particle data reported by geostationary satellites, plasma density and energetic particle data reported by DMSP satellites, and unclassified reports of satellite anomalies. This database extends back to December 1981 for most types of data, and back to January 1976 for a limited number of data types.

4.8.3 Data Collected through National Geophysical Data Center (NGDC). USAFETAC receives special SESS data sets from NGDC on CD-ROM. These data sets include solar and ionosonde observations taken prior to 1976, geomagnetic indices not reported in real-time, and energetic particle and magnetometer data from GOES. These data sets are used to extend the USAFETAC SESS climatic database further into the past when doing climatological studies.

4.8.4 Space Environment Models. USAFETAC uses operational and research space environment models. These models include:

- Wide-Band Scintillation Model (WBMOD), which specifies ionospheric scintillation.
- IONCAST, which calculates the effect of the ionosphere on HF communications.
- International Reference Ionosphere (IRI), a research model.
- Global Reference Atmosphere Model (GRAM), which specifies the neutral atmosphere.

In addition to the SESS climatology database, USAFETAC has a series of models to provide space environment climatology for data-sparse areas. USAFETAC is also acquiring a suite of new technology SESS models under the Space Environmental Technology Transfer (SETT) contract. The SETT contract includes:

- Ionospheric models--the Parameterized Real-time Ionospheric Specification Model (PRISM), the Ionospheric Forecast Model (IFM), and an upgraded WBMOD.
- Neutral Atmospheric Model--the Vector Spherical Harmonics (VSH) model.
- Magnetospheric Models--MSM and MSFM.
- Integrated Space Environmental Models (ISEM)--Solar Wind Transport Model (SWT), Interplanetary Shock Propagation Model (ISP), a model coupling routine, and an executive routine.

4.9 <u>Interagency Coordination and Reporting Requirements</u>. The agencies (listed in Chapter 1) conduct a continuing systematic review of current and planned activities to meet their mission requirements for space environment services and supporting research. The agencies coordinate matters affecting more than one member agency to assure maximum collaboration of current and future activities consistent with effective and economical accomplishment of mission requirements. Annually, the agencies summarize space environment activities in the Federal Plan for Meteorological Services and Supporting Research in the section entitled "Other Specialized Services." In addition, individual scientists in the various agencies continually coordinate their research efforts on a less formal basis.

Coordination is the principal function of the Committee for Space Environment Forecasting (CSEF) (see Appendix C). To facilitate coordination and maintenance of this plan, agencies report to the chairman of the Committee as follows:

A. Changes in activities or plans that affect other agencies are reported on a continuing basis and as they occur.

B. Annual reports, in accordance with the requirements of the OFCM include the following:

- Changes in requirements for space environment services.
- Changes in currently operating space environment observation sensors and associated data systems.
- Changes in current services and supporting research.
- Changes in standard space environment products provided for interagency use.
- Cooperative programs in space environment observations, services, and supporting research.
- Memoranda of Agreement and other formal documents relating to cooperative space environment programs.
- Plans for future observing sensors and associated data systems.

CHAPTER 5

CURRENT SUPPORTING RESEARCH

The primary functions of space environment services are to provide accurate forecasts of significant disturbances, and adequate real-time observations from which the consequences of the disturbances can be analyzed, so that remedial actions can be taken by the users. Additional responsibilities include providing data summaries and maintaining an archival database of information on disturbances.

The physical system is complex. It begins at the Sun and includes the Earth's magnetosphere, ionosphere, and atmosphere. Monitoring systems give an incomplete picture of the nature of disturbances at the Sun, their propagation to the Earth, and their effect at the Earth. The physical understanding and modeling of various parts of the system are not adequate. For these reasons, improving the timeliness and accuracy of alerts, warnings, and forecasts depends on supporting research to provide a deeper physical understanding of the sources of disturbances throughout the entire system.

Supporting research that requires or uses environmental data is carried on or sponsored in several of the agencies with requirements for providing and using space environmental services, including DOD, NOAA, NASA, DOE, DOI, and NSF. Such research supports the systems used by these agencies, and the specific solar-terrestrial research in universities and research centers, much of which has direct spin-off toward improvement of services.

5.1 Department of Defense Current Research. The DOD conducts and supports research on space environmental effects on military systems. This research is related to DOD functions such as command and control, communications, detection and surveillance systems, satellite operations, interceptor operations, and battle planning. It is DOD policy that unclassified results of DOD-sponsored research be released into the public domain.

5.1.1 U.S. Air Force. The Air Force Materiel Command (AFMC) conducts and supports research and technique development efforts relating to the space environment. The Air Force Office of Scientific Research (AFOSR) is the focal point for all basic research activities in the USAF. AFOSR supports research on solar-terrestrial effects through contracts and grants in addition to basic in-house research.

Under AFMC, the Air Force Phillips Laboratory/Geophysics Division (PL/GP) is the lead USAF laboratory for conducting space environmental research. Its programs are highly coordinated with those of other USAF and DOD elements. The PL/GP research program includes basic research, exploratory development and advanced development efforts. Two of its programs relate to the space environment:

- Space Effects on Air Force Systems.

- Ionospheric Effects on Air Force Systems.

5.1.1.1 Solar Research. PL/GP is engaged in solar research in the following areas:

A. Solar Flares. Solar flare research is concentrated on improvement of the database relating to the onset and characteristics of solar flares, especially in relation to the magnetic field configuration in their immediate vicinity and the conditions of the plasma in the flare region. The purpose of this work is to develop better models of flares and to improve the basis for making predictions regarding their onset and severity.

B. Coronal Mass Ejections (CME). These are the events that cause geomagnetic storms. Work in this area includes modeling CME structures as they appear on the Sun, and observations of CMEs as they leave the Sun and move out through the solar corona and the interplanetary medium.

C. Solar Variability. Objectives include the study of the variations of the solar magnetic field in relation to active regions on the Sun and the propagation of the magnetic field in the interplanetary region and its relation to disturbances at the Earth. Also the solar visible and UV radiance are being studied on all time scales to establish their relation to solar activity and to provide a base for studying variations in the chemistry of the middle atmosphere and possible effects on tropospheric weather.

5.1.1.2. Space Research. PL/GP has the following objectives in space research:

- Develop methods to understand and mitigate the effects of the hazardous space environment on space-borne systems as well as ground-based and airborne systems.
- Design and develop space sensors required to characterize and specify the space environment for systems designers and operators.
- Conduct space test to validate space sensors, models and codes. Conduct laboratory simulation experiments of relevant space physics phenomena to validate in situ measurements and predict phenomena where no in situ measurements have been made.
- Design methods to provide the earliest warning of hazardous solar energy fluxes.
- Develop sophisticated interplanetary magnetosphere, ionosphere and thermosphere specification and forecast models.
- Develop an integrated Space Environment model for forecasting hazards to space systems.
- Develop phenomenological models of high voltage ionization and breakdown in space, along with conducting NRL Space Chamber experiments to test hardware components and mission concepts, as

well as development of flight instruments for this high voltage environment.

- Build improved models of the static and dynamic behavior of the Earth's radiation belts for improved satellite design and space operations.

5.1.2 U.S. Navy. The Navy has a vital interest in the space environment because of strong dependence on space and radio communication systems, which are affected by the whole range of solar emissions. The type and strength of these emissions are essential factors for assessment of communication performance and long-range planning for optimum use of scarce resources.

The Navy conducts and supports research on the space environment through the Office of Naval Research (ONR) and the various system commands. The research is supported through contracts and grants in addition to basic in-house research conducted by the Naval Research Laboratory (NRL) and various Navy centers for research and development, notably the Naval Research and Development (NRaD) of the Navy Command and Control Ocean Surveillance Center (NCCOSC). All Navy research programs are coordinated with other DOD elements.

5.1.3 U.S. Army. The space environment greatly affects the DOD Army research and development of ballistic missile defense ground-based elements.

The ground entry points (GEP) receive space environment information. They pass this information to the Command Center Element (C^2E) which is responsible for battle management/ command, communication, and control (BM/C^3) and battle planning for the ground-based elements. The C^2E relays this information to ground-based interceptor (GBI) and ground-based surveillance and tracking system (GSTS).

The GBI is an interceptor designed to destroy reentry vehicles (RVs) in space before they reenter the Earth's atmosphere. Not only does GBI fly at extremely high speeds in a space environment, it also can use a seeker through a window in its nose to select the proper target in space, and/or receive in-flight target updates (IFTUs) which it uses to correct its flight path for an intercept. The GSTS is a ground-launched space sensor which also operates in space. Once on station, it scans above the horizon for threats incoming to the United States and relays this information back down to the C^2E for battle management/planning. Operations from hard Earth, stars, zodiacal light, aurora, and angles to the Sun and Moon effect the capability of GSTS. Because these systems operate in space to defend our lives, it is easy to see how space environment information is crucial to U.S. Army defense systems.

5.2 <u>Department of Energy Current Research</u>. The Department of Energy through its Los Alamos National Laboratory (LANL), its Pacific Northwest Laboratories (PNL), and some university grantees, conducts research into the processes affecting the near-Earth environment. Many results from this effort have been instrumental in improving Space Environment Services Center products. Los Alamos maintains an extensive, computer-based satellite data archive as well as experimental and theoretical expertise. Both are being applied to most of the outstanding problems of the SESC. PNL has an extensive data archive of ground-based optical observations of mid-latitude auroral phenomena and an active network of auroral photometers in the U.S. and Canada. Areas of expertise at both laboratories include atmospheric and real-time forecasting. At LANL, research topics include energy coupling mechanisms (involving the solar wind/magnetosphere interface, particle precipitation into the ionosphere, and atmospheric modeling) and use of high frequency radar to probe the ionosphere. PNL conducts fundamental research in particle precipitation into the ionosphere and modeling of the atmospheric response. Both laboratories maintain links to many international and national research groups (e.g., the LANL link to the University of California Institute for Geophysics and Planetary Physics) that provide great depth of expertise. Heretofore, LANL has been largely independent in space environment work, but, since the establishment of its new ESS (Earth and Space Sciences Division), it has been able to seek cooperative arrangements and to assume responsibilities in supporting space environmental services.

5.3 NASA Current Research

5.3.1 Space Physics Division. The NASA Space Physics Division of the Office of Space Science and Applications endeavors to understand the generation, transport, and interaction of plasmas, electromagnetic fields, and energetic particles throughout the solar system. The Division supports investigations of the origin, evolution, and interaction of particulate matter and electromagnetic fields in a wide variety of space plasmas, including the energy flow and particle transport from the solar surface through the geospace environment to the Earth's upper atmosphere. The goals of the Space Physics Division include:

- Solar Physics - the Sun as a star, as an influence on Earth, and as the dominant source of energy, plasma, and energetic particles in the solar system.
- Heliospheric Physics - cosmic ray, solar wind, and plasma-field interactions throughout the heliosphere and nearby interstellar medium.
- Magnetospheric Physics - the study of magnetospheres and their interaction with space plasma media. Research efforts include planetary magnetospheres and satellite-plasma interactions.
- Ionospheric and Upper Atmospheric Physics - the formation, structure, and dynamics of planetary ionospheres, thermospheres, and mesospheres, and aurora and atmosphere-ionosphere-magnetosphere coupling.
- Solar-Terrestrial Physics - studies of energy flow within the solar system from the solar surface through the geospace environment to the Earth's upper atmosphere.
- Plasma Processes in Space.

The Space Physics Division is organized into discipline branches corresponding to the following scientific areas:

A. Cosmic and Heliospheric Physics. This branch studies the origin and evolution of galactic cosmic rays and solar-system material, acceleration processes, galactic confinement processes, and the transport of energy, plasmas, and magnetic fields in the heliosphere and beyond.

Also studied are the wave-particle and plasma-field interactions of the solar wind, including interplanetary shocks.

B. Solar Physics. This branch studies the interior, photosphere, chromosphere, transition region, and corona of the Sun, including the generation, storage, and release of solar flare energy. The Solar Physics branch pursues research in nuclear processes, atomic and molecular collisions, magnetohydrodynamics, magnetically confined plasmas, and comparative stellar studies. Helioseismology and studies of solar activity constitute major components of the program.

C. Magnetospheric Physics. This branch studies the global structure and microphysical dynamics of magnetospheres, and the interactions of magnetospheres and other obstacles with space plasmas. Research emphases are on planetary magnetospheres, satellite-plasma interactions, and cometary environments.

D. Ionospheric, Thermospheric, and Mesospheric Physics. This branch studies the upper atmospheres, ionospheres, and auroral processes of the Earth and other planets, including current-generation and critical-velocity phenomena. The Ionospheric, Thermospheric, and Mesospheric Physics branch aims to understand the formation, structure, coupling, and dynamics of these systems.

5.3.2 Satellite Measurements. Observations, theory, modeling, simulations, laboratory studies, interactive data analysis, instrument development, and active experiments are all important aspects of the space physics research program. Observations are made from a variety of platforms including the Earth itself, high-altitude balloons, sounding rockets, Earth-orbiting satellites, crewed orbital platforms such as the Space Transportation System, and interplanetary spacecraft. Currently operational satellite missions are:

A. International Sun-Earth Explorer/International Cometary Explorer (ICE) was launched in 1978 into a halo orbit 235 Re on the Sun side of the Earth. ICE presently leads the Earth in an interplanetary cruise orbit about the Sun. ICE provides information on solar wind plasma and magnetic conditions, investigating the properties of magnetic fields, plasma, flare energetic particles, IP shocks, type II & III radio bursts, and galactic cosmic rays. Hourly-averaged solar wind density, speed, and temperature data are available from the NSSDC up to about the time of the Comet Giacobini-Zinner encounter.

B. Interplanetary Monitoring Platform (IMP-8), launched in 1973, orbits the Earth at a distance of between 30-40 Re. IMP-8 provides solar wind parameters as input for magnetospheric studies and as a 1 AU baseline for deep space studies, including solar cycle variations, magnetospheric boundary and magnetotail phenomena. As part of the Global Geospace Science (GGS) program, the primary mission objective of IMP-8 is to perform detailed and near-continuous studies of the interplanetary environment for orbital periods comparable to several rotations of the active solar regions. IMP-8 magnetometer data at 15 second resolution and plasma data at 1-2 minute resolution are available at the NSSDC along with hourly averages with overall solar wind data coverage at about the 40% level.

C. Pioneer 10 and 11 were launched in 1972 and 1973 respectively into solar system escape trajectories. As of January 1991, Pioneer 10 was at a heliocentric radius of 50.4 AU, travelling at about 2.7 AU per year towards the tail region of the heliosphere in a direction opposite to that of the Sun's motion through the galaxy. At the same time, Pioneer 11 was at 32 AU from the Sun, travelling in the direction of the heliosphere's bow shock at about 2.5 AU per year. Over the next decade these two spacecraft will search for the heliospheric boundary with interstellar space, study the large scale electrodynamic structure of the solar plasma and magnetic field, measure the intensity and composition of galactic cosmic radiation to include the study of the radial gradient of cosmic ray intensity and its dependence on solar activity, and to search for gravitational radiation.

D. Voyager 1 and 2, both launched in 1977, are travelling on solar system escape trajectories at the rate of 3.5 and 3.4 AU per year respectively. Voyager 1 had reached a heliocentric distance of 44 AU by January 1991, on a trajectory that rises above the ecliptic plane at 35.5°. Voyager 2 was at 34 AU at the same time, on an even steeper trajectory that descends below the ecliptic plane at 47.5°. The Voyager Interstellar Mission, which includes both spacecraft, has the objectives of characterizing the solar wind with distance from the Sun, observing and characterizing the Sun's magnetic field reversal, searching for low-energy cosmic rays, characterizing particle acceleration mechanisms in the interplanetary medium, searching for evidence of interstellar hydrogen and helium and an interstellar wind, and locating the heliospheric/interstellar boundary.

E. Ulysses, a joint NASA/ESA mission, was launched in 1990 on an ecliptic trajectory to Jupiter. There it will use the planet's gravitational field to achieve a high inclination orbit over the Sun's poles at a distance of 1.28 by 5 AU. The Ulysses mission will investigate, as a function of solar latitude, the properties of the solar corona, the solar wind, the structure of the Sun-wind interaction, the heliospheric magnetic field, solar and non-solar cosmic rays, and solar radio bursts and plasma waves. During the Jupiter fly-by phase the mission will also make measurements of the Jovian magnetosphere.

F. Yohkoh, launched into a 527 by 806 km orbit in 1991, is a Japanese program designed to answer many questions in solar flare physics that have been raised by the highly successful Hinotori and SMM missions, and includes the United States and the United Kingdom as participating partners. The primary objectives of the Yohkoh mission are to obtain simultaneous images of solar flares with high time and spatial resolutions in both the hard and soft x-rays in order that the full morphology of the flare can be observed with sufficient precision to reveal the underlying physical processes. The U.S.-Japan Soft X-Ray Telescope (SXT) images the solar corona in soft x-rays, with high time and high spatial resolution, to reveal properties of the global coronal magnetic fields. The SXT measures variations of photospheric brightness with modest spatial resolution for studies of solar irradiance and global oscillations.

G. Solar Anomalous Magnetospheric Particle Experiment (SAMPEX). This mission was launched from Vandenberg AFB in July 1992, close to the solar activity cycle maximum. The spacecraft samples particles and cosmic rays while pointing in a generally zenith direction, especially over the poles. The mission has monitored at least one major solar flare event and several smaller to moderate solar flare events.

The SAMPEX satellite will carry out energetic-particle studies of outstanding questions in the fields of space-plasma physics, solar physics, heliospheric physics, cosmic-ray physics, and middle-atmospheric physics. It will measure the composition of solar energetic particles, anomalous cosmic rays, and galactic cosmic rays. The designed mission lifetime of at least three years will allow the solar studies to be carried out from immediately after the peak of the solar maximum into the declining phase of the activity cycle. In particular it will be able to accomplish the following objectives:

- Measure the dependence of fluxes on the declining solar activity cycle.
- Determine flux levels and local time dependence of precipitating electrons during the declining solar cycle.

5.4 <u>NOAA Current Research</u>. Research for improvement of space environment services is conducted in NOAA's Space Environment Laboratory. Some research projects within the National Geophysical Data Center, Aeronomy Laboratory, and Air Resources Laboratory also pertain to the space environment.

5.4.1 Space Environment Laboratory. The Space Environment Laboratory (SEL) consists of two Divisions: the Research and Development Division, and the Services Division. SEL research emphasizes theoretical and experimental studies directed toward the fundamental physical processes responsible for the following:

- Observed energy release in the form of electromagnetic and particle radiation near the solar surface;
- Propagation of this energy through the corona and out into the interplanetary medium;
- Transfer of this energy from the near-Earth interplanetary medium into the local space environment;
- Behavior and subsequent effects of this energy within the magnetosphere, ionosphere, and upper-atmosphere regions. SEL also defines the requirements for the space environment monitors on the Geostationary Operational Environmental Satellite (GOES) series of NOAA satellites, and the NOAA series of polar-orbiting satellites.

5.4.1.1 Space Environment Monitoring Sensors on the GOES and NOAA Satellites. The Space Environment Monitors (SEM) onboard GOES provide real-time data critical to the mission of the Space Environment Services Center. Each SEM is composed of 4 separate sensor systems: two energetic particle sensors, a magnetometer, and a solar soft X-ray detector. The energetic particle sensors provide information on the presence and intensity of solar particle events necessary to issue alerts and estimates of the consequences of such events. The solar X-ray sensor allows the identification of the onset of a solar flare and provides information on the intensity of that flare. The magnetometer provides information about the intensity of geomagnetic disturbances, especially the arrival of solar wind shocks at the Earth, substorm occurrences, and instances when the magnetopause nears the Earth under the influence of unusual solar wind conditions. The data are telemetered directly to SEL, utilized in real-time, and subsequently carefully checked and formatted for research and archive purposes.

The monitors onboard the polar-orbiting NOAA satellites are composed of 3 separate sensor systems: a Total Energy Detector (TED) which monitors the energy deposition in the upper atmosphere by auroral particles from the magnetosphere, a set of solid-state detector telescopes which monitor the intensities and extent of the particles in the Earth's radiation zones, and a set of omnidirection solid state detectors which monitor the intensities and locations of energetic solar particle events as these particles enter the atmosphere. The observations by the TED detectors are used to provide quantitative information on the intensities of geomagnetic disturbances, especially the effects of those disturbances on the ionosphere and upper atmosphere. Data from the solid state detector systems supplement the TED observations in assessing magnetic disturbances and are useful in analyzing the potential environmental causes of malfunctions in satellite instrumentation and operations. The omnidirectional solid state detectors quantify the solar particle fluxes entering the atmosphere and the effects of those particles on the ionosphere's D-layer and the chemistry of the stratosphere and mesosphere. These data are telemetered to NOAA tracking stations and transferred to SEL by dedicated telephone line from Suitland, Maryland. After being utilized to provide near real-time estimates of the intensity of geomagnetic disturbances and the extent of solar particle influxes, the data are carefully checked and archived for research purposes. At this time, the primary research uses of these data are for the SEL program of determining the ionospheric and atmospheric responses to energetic particle forms of energy input.

5.4.1.2 Research on Solar Activity. As routine products, the SESC issues probability forecasts of major flare activity and energetic solar proton events for each of the next three days, and the outlook for flare activity and energetic protons for the next 4 weeks. Another product is the expected value of the solar flux at 10.7 cm for each of the next 27 days. The SESC also issues forecasts of geomagnetic activity that depend on observations and interpretations of solar phenomenology. However, despite best efforts, skill levels are less than required by SESC users. Research efforts are directed toward investigating solar processes including the analysis of large-scale phenomena on the Sun; the structural and dynamical aspects of solar active regions related to the occurrence of solar flares; and studies of solar irradiance variations. Solar images are important to both services and research. The Space Environment Laboratory Solar Imaging System (SELSIS) is being developed to display, analyze and integrate digital solar images in several wavelengths to discern the causes and consequences of solar activity.

5.4.1.3 Research on Interplanetary Propagation of Disturbances. The solar wind that impinges on Earth originates from coronal holes, coronal mass ejections, and possibly from the above quiet coronal regions such as the heliospheric current sheet. The plasma from each of these sources interacts and evolves as it propagates toward the heliopause. For example, shock waves can form and decay. A theoretical understanding of the physics that drives the solar wind, and promotes the structures observed in the interplanetary medium remains elusive. However, magnetohydrodynamic models of the solar wind from a near-Sun 'source surface' out to several AU have been devised at SEL. These models describe the spatial and temporal evolution of disturbances as they approach Earth, thereby forecasting the onset time, magnitude and duration of geomagnetic activity. Research centers on extending these models to three-dimensional geometries, and finding the best observational inputs to initialize the models.

5.4.1.4 Research on Geospace Processes and Effects. The physics regarding the coupling of energy from the solar wind into the magnetosphere, and the subsequent dissipation of the acquired energy, continue to be major areas of scientific research. During episodes of geomagnetic storms, those capital investments of communication and research satellites at geosynchronous altitudes, and navigation and surveillance satellites at low Earth altitudes are at risk. On the ground, induced currents in power lines, pipelines and train tracks can result in costly operational degradations and failures. Research into sensing and understanding the geomagnetic field from the ground out to the magnetopause are a primary SEL concern. Geospace research also includes the sensing and behavior of energetic particle populations, both trapped and extraterrestrial. Work is focussed on strategies for evaluating, modeling and forecasting the state of disturbance of the ground-based geomagnetic field, and the near-Earth space environment.

5.4.1.5 Research on Space Influences on the Terrestrial Environment. Operational data gathered from a number of sensors onboard satellites measure the energy input to the top of the atmosphere in the forms of energetic photons arriving directly from the Sun, of energetic particles from the galaxy and from the Sun, and energetic particles and electrical energy transfer as a result of magnetospheric processes. These forms of energy input are largely responsible for major perturbations in the Earth's ionosphere and atmosphere above 100 km altitude. Such disturbances dramatically change the densities, temperatures, and chemical composition of the upper atmosphere thus affecting the operations of low Earth orbiting satellites. The disturbances also alter the nature of the Earth's ionosphere causing significant degradation in radio communication and navigation systems, occasionally to the point of producing short wave blackouts. Electrical current flow in the ionosphere during such disturbances not only produces the geomagnetic fluctuations that are the main symptom of a geomagnetic storm, but also intense heating of the neutral atmosphere. The research objectives in this program are to utilize the observations to obtain more quantitative and physical measures of the intensity of geomagnetic disturbances, to better understand the origins of these forms of energy inputs, and to investigate and assess the responses and consequences to the Earth's ionosphere and atmosphere of those inputs.

5.4.2 Aeronomy Laboratory. Research in the Aeronomy Laboratory relevant to the near-Earth space environment and the upper atmosphere includes these studies:

- Radar studies of atmospheric winds to heights of 100 km, including measurements at auroral latitudes.
- Studies of the effect of energetic solar particles on the upper atmospheric ozone concentrations.

5.4.3 Air Resources Laboratory. Research in the Air Resources Laboratory includes a study on the influence of long-term variability of solar radiation on climate.

5.5 Department of Interior Current Research. The U.S. Geological Service (USGS) measures the Earth's magnetic field at appropriate locations throughout the world and conducts research into the nature of the global field including the source, characteristics, methods of characterizing, and rate of change on all time scales. Current areas of research include the following:

- Modeling of ionospheric source fields.
- Large-scale induction studies as well as magnetotelluric and magnetovariation studies of crust and mantle resistivity.

- Core-mantle boundary sources of secular variation.

- Modeling of main field from satellite and ground magnetic data.

- Measurement and study of magnetohydrodynamic waves and field line resonances in the Earth's magnetosphere and ionosphere.

- Studies of electromagnetic (EM) effects of tectonic stress and of EM earthquake precursors.

5.6 __National Science Foundation Current Research__. The National Science Foundation supports basic research in solar-terrestrial sciences through the Atmospheric Sciences Division of the Geosciences Directorate. The Upper Atmospheric Research Section within the Atmospheric Sciences Division consists of four discipline programs covering physical processes at the sun's surface, the heliosphere, magnetosphere, thermosphere, and ionosphere. The results of this research have been applied to the development and operation of ground-based space environment monitoring instrumentation, the development of ionospheric, thermospheric and magnetospheric specification models, and to the analysis of post-event databases. The worldwide array of NSF-sponsored instruments, observatories and facilities provide vital ground-based measurements in coordination with DOD, DOC, and NASA space missions. The four discipline programs are described below:

- **Solar-Terrestrial Physics**: This program supports research into processes by which energy in diverse forms is generated by the sun, transported to Earth, and ultimately deposited in the terrestrial environment. At the sun, major topics include the solar dynamo, the 11-year variation, magnetic flux emergence, solar flares, and activity. Transportation of energy includes coronal mass ejections, heating the solar wind, and interactions of the solar wind with cosmic rays. In the atmosphere, relevant topics include photochemistry in response to UV changes, solar "constant" changes, and climatic impacts. In particular, the SunRISE program examines the climatic consequences of varying solar radiation.

- **Magnetospheric Physics**: This program supports research in various magnetospheric regions including the magnetopause, ring current, magnetotail, auroral zone, and solar wind/magnetosphere coupling. The magnetosphere is the domain of geospace where charged particle motion is dominated by Earth's magnetic field. Principle tools used are MHD, kinetic theory, nonlinear dynamics, and simulations. Observational programs include magnetometers, radars, riometers, and other ground-based instrumentation, particularly in support of space-based measurements. The Geospace Environment Modeling (GEM) program coordinates and focuses research related to developing a global model of the geospace environment, from the solar wind to the upper atmosphere.

- **Aeronomy**: The program supports studies of upper and middle atmosphere phenomena such as ionization, recombination, chemical reaction, photoemission and transport. Topics include the transport of energy, momentum, and mass in the mesosphere-thermosphere-ionosphere system and the coupling of this global system to the stratosphere below and magnetosphere above. Plasma processes associated with phenomena in the ionosphere are studied as well. This program includes the Coupled Energetics and Dynamics of Atmospheric Regions (CEDAR) initiative which is an element of the Global Change program.

- **Upper Atmosphere Facilities**: This program supports the operation, maintenance, and scientific research tasks associated with the nation's four large incoherent scatter radar facilities. The Sondrestrom Radar in Greenland, the Millstone Hill Radar in Massachusetts, the Arecibo Observatory in Puerto Rico, and The Jicamarca Radio Observatory in Peru make up a meridional chain of four radars that routinely perform diagnostic experiments to study Earth's ionosphere and thermosphere. Each of the four facilities has been a focal point for other ground-based instrumentation such as lidars, interferometers, HF radars, etc. For a period of at least 24 hours each month all four radars are operated simultaneously as part of the URSI-organized World Day experiments.

CHAPTER 6

FIVE-YEAR PLAN

Chapters 4 and 5 have detailed the interagency needs and the existing cooperative system for providing services to meet these requirements. Present services meet the minimum requirements for some users, but substantial improvements are needed; capabilities are falling increasingly short of requirements. Plans to meet the increased requirements include new observing systems to provide more complete and reliable measurements of the space environment, use of research results to improve forecasting and warning services, and upgrading of data and communication systems to improve the use of observations already available. For planning purposes, the improvements can be divided into (1) new systems already proven to provide improved service capabilities, (2) research to increase understanding of the space environment and its effects on terrestrial systems, and (3) observing sensors still in development.

Agency plans for programs to improve services are outlined in the following sections. The Committee for Space Environment Forecasting will work to assure maximum interagency coordination of activities, consistent with effective and economical accomplishment of mission requirements.

6.1 Agency Plans To Improve Services

6.1.1 Department of Defense Plans--Services. The U.S. Air Force will plan for and acquire systems needed to provide space environmental data that satisfy national security needs. The following major programs are planned:

A. Ionospheric Sensing (IONS). The Air Force seeks capabilities to measure and accurately specify the ionospheric total electron content (TEC), ionospheric scintillation, and profiles of electron density in the ionosphere. One portion of IONS, the Transionospheric Sensing System (TISS) program, will be fielded by 1995 and will include 5 automated ground-based sensors to replace and upgrade the current polarimeter network. TISS will monitor L-band ultra-high frequency (UHF) transmission from the Global Positioning System (GPS) satellites to determine TEC and scintillation parameters and report these data in real-time to the AFSFC.

B. Space Environmental Monitoring (SEM). The Air Force Statement of Operational Need for Space Environmental Monitoring was signed in 1987. The SEM initiative calls for continuous space-based observations of solar electromagnetic and particulate radiation, the interplanetary magnetic field vector, and charged particle densities of the near-Earth space environment. SEM will provide for sensors on various satellites in several different orbits. The first step in SEM implementation is the joint NOAA/USAF effort to fly solar X-ray imagers aboard GOES-Next satellites in the late 1990s (see Section 6.1.3 for details). A libration point satellite to measure solar wind parameters is the next important step to take, but funding for this effort is not yet available.

C. Magnetometer Network. The Air Force will contract for real-time magnetometer data from the USGS, rather than acquire its own upgraded network of geomagnetic sensors. The USGS network and its services are described in Section 6.1.4.

D. Solar Electro-optical Observing Network (SEON). To meet DOD and national user requirements into the early 21st century, the Air Force will upgrade SEON in two phases. Phase I will replace unsupportable SEON equipment allowing AWS to sustain its current solar monitoring capability. It will also provide documented, structured software for the SEON system. Installation of Phase I replacement and upgrade equipment will be complete by the mid-1990s.

SEON Phase II will upgrade capability at the observatories. The Radio telescope, which can detect solar radio events but can't determine the specific source location on the solar disk will be able to resolve the location of radio emission sources. This information is an essential factor in forecasting the influx of high energy particles in the near-Earth environment. Advanced development may be required to accurately specify small-scale solar magnetic fields via a vector magnetograph. Solar magnetic field specification will greatly enhance forecaster ability to predict the timing of solar flares and associated high energy particle emissions, geomagnetic storms, and ionospheric disturbances. The SEON Phase I and Phase II upgrade is discussed in more detail in paragraph 4.7.8.3.

E. Space Environment Sensors on DMSP Spacecraft. By 1999, DMSP spacecraft will include two new sensors. One is the Ultraviolet Spectrographic Imager (SSUSI), a nadir pointing telescope measuring ultraviolet (UV) radiation from the Earth's atmosphere and ionosphere. The data will determine the auroral oval location and provide data to help specify characteristics of the ionosphere, including electron density profiles, neutral densities, and low altitude electric fields. The other new sensor, the Ultraviolet Limb Imager (SSULI), is a spectrograph measuring extreme and far UV radiation from the Earth's limb which provides ion density and neutral density profiles.

F. Space Environmental Technology Transition (SETT). In conjunction with the expanded real-time data sources and increased computer capabilities of the AFSFC, the Air Force is developing specification and forecast models to meet user requirements and improve support. The models discussed below in paragraphs G, H, I, and J will be implemented by AFSFC between now and 1999. SETT is discussed in more detail in paragraph 4.7.8.4.

G. Ionospheric Models (IM). AFSFC is responsible for providing analyses and forecasts of the portion of the Earth's upper atmosphere which affects the propagation of radio waves. This support is important to a wide variety of DOD agencies using systems which operate through or in the ionosphere. These agencies require an accurate specification of the state of the ionosphere, and AWS supports this requirement by forecasting and analyzing conditions in the near-Earth space environment. The IM program includes the transition of research techniques and models into standardized, documented operational computer code; and implementation at the AFSFC for use by AFSFC for post-analysis applications. The IM program consists of three components:

- Parameterized Real-time Ionospheric Specification Model (PRISM), which replaces and upgrades currently-used ionospheric models.

- Wide Band Ionospheric Scintillation Model (WBMOD) upgrade, a refinement of the existing model.

- Ionospheric Forecast Model, which will use PRISM to produce global ionospheric forecasts.

H. Neutral Atmospheric Model (NAM). AWS customers require a computer model providing global atmospheric density and winds from 90-1500 km. The model will be used to support a variety of functions, including satellite drag, reentry vehicle accuracy, and decoy discrimination. The program consists of a Vector Spherical Harmonic (VSH) model which supports Air Force Space Command (AFSPACECOM) neutral density and neutral wind forecast requirements.

I. Magnetospheric Models (MM). AFSFC forecasts disturbances in the Earth's magnetosphere which can cause anomalies on board DOD spacecraft. Presently, AFSFC relies on manual analyses and forecasts using available data. These magnetospheric models support spacecraft operators using two components:

- Magnetospheric Specification Model (MSM) provides basic post-analysis of satellite anomalies and runs on a minicomputer.

- Magnetospheric Specification and Forecast Model (MSFM) is a follow-on to the MSM and improves accuracy of magnetospheric specification, increases spatial coverage, and establishes a significant 1 to 3-hour magnetospheric forecast capability.

J. Integrated Space Environmental Models (ISEM). This effort develops and transitions interplanetary research techniques and models into standardized, documented operational computer code for use at AFSFC, linking AFSFC space environmental models together. ISEM consists of three major components:

- Interplanetary models: the Solar Wind Transport (SWT) model, which will predict the effect of the solar wind and interplanetary magnetic field on the Earth's magnetosphere; and the Interplanetary Shock Propagation (ISP) model, which will predict geomagnetic storms from 1 to 5 days in advance.

- Model coupling links the major regional interplanetary, magnetospheric, ionospheric, and neutral atmospheric models together with physically-based interfaces allowing the output of one model to be used by another.

- Executive routine provides a single framework to coordinate execution of all regional space models using scientific expertise and decision-making capability within the program. It will optimize operation of the models and control quality of results.

6.1.2 Department of Energy Plans--Services. The Los Alamos National Laboratory has established a real-time data link for the acquisition of data from instruments provided by the DOE to several DOE/USAF programs. Algorithms are in place at Los Alamos to analyze these data; the reduced data are now used routinely to assess spacecraft anomalies and will eventually be available through NASA for space environment studies.

6.1.3 Department of Commerce Plans--Services. SESC will continue to improve its capabilities to provide specification of the current space environment and quantitative forecasts and warnings through the following programs:

6.1.3.1 Solar X-ray Imager/EUV Imager. A memorandum of understanding between USAF and NOAA provides for shared resources to procure and launch a series of Solar X-ray Imagers (SXI) on the GOES-NEXT block of satellites. The telescopes will provide real-time images of the Sun in X-ray and EUV wavelengths once per minute. Data from SXI will impact two major service areas: prediction of hazardous energetic proton events at the Earth and forecasting of geomagnetic storms caused by coronal holes and coronal mass ejections directed at the Earth.

A. X-ray Imager. The use of X-ray images will greatly enhance the ability to observe the structure of the upper solar atmosphere, in comparison to present ground-based images of the Sun. Flares that occur beyond the visible limb of the Sun, or disk flares occurring at times when ground-based observatories are covered by clouds, will always be detected by SXI in its fully sunlit geostationary orbit. Real-time processing and display of the SXI images will be implemented for use in the SESC and the AFSFC. Techniques will be developed to incorporate the improved observations into forecast products. Images will be archived in the National Geophysical Data Center.

B. EUV Imager. As a result of a Small Business Innovation Research grant, a preliminary design for a reliable, solid-state EUV flux sensor has been completed. Such an operational sensor would provide a measurement of the solar radiant flux that causes day-to-day variation in neutral atmospheric and ionospheric density. Funding has not been obtained for the additional cost of the EUV sensor. Indices will be developed for the whole-Sun EUV radiation that controls radio propagation and atmospheric drag on satellites. Presently, surrogate data in the visible or radio regions of the solar spectrum must be used.

6.1.3.2 Space Environment Laboratory Solar Image System. The Space Environment Laboratory Solar Image System (SELSIS) is being developed to collect images of the Sun from ground-based observatories including the AWS Solar Electro-optical Observing Network (SEON). The ability to process solar images in several wavelengths from various observatories to achieve consistent size, orientation, and contrast range is a complex problem that will be undertaken in the next phase of SELSIS. Once these problems have been solved, the system will be further developed to achieve the capability to overlay various images, to combine them into synoptic maps with objective identification and measurement of features. The ultimate goal is the use of the system in daily objective forecast mapping and analyses in place of the current manual methods of analysis. The system will be upwardly expandable to handle the SXI images described in the preceding section. The image system will link SESC, the AFSFC and the National Geophysical Data Center. Improvements based on experience gained using advanced feature identification and image processing packages will also be incorporated into the operational image processing system. These packages are the commercial spin-off of research and development work done by the Department of Defense in feature recognition.

6.1.3.3 Space Environment Laboratory Data Acquisition and Display System - III (SELDADS III). SELDADS II has been an extremely successful system, providing real-time support to the SESC and its customers since 1986. However, the system is aging and the demands on its resources are increasing. The preprocessor/real-time monitor upgrade, which is currently in progress, will replace the most precarious subsystems. Planning is proceeding for the evolutionary replacement of the MV10000 and the user subsystems within the next few years. The goals of the next generation of SELDADS is to replace ten-year-old equipment and provide improved access to data and products for SESC users and forecasters. Ability to analyze and display all the data in the SELDADS in contemporary graphics will be highlighted, including new data streams from the GOES Solar X-ray Imagers and solar wind satellites. The system is planned to allow evolutionary replacement using modern concepts of distributed systems and open industry and government standards. Targeted system changes include the following: integration of image display and analysis into SELDADS; better verification feedback to forecasters; increased informational content in products; advanced data presentation and analysis techniques; improved data access; modernization of product distribution.

6.1.3.4 Geomagnetic Forecasts in Probabalistic Format. Geomagnetic storms affect satellite command and control systems, electric power distribution networks, defense and reconnaissance system operation, navigation systems, and radio propagation conditions. Users from government agencies and the public sector use forecasts and alerts of geomagnetic storms. They form the largest contingent of customers for services provided by the NOAA Space Environment Laboratory through its Space Environment Services Center. Standard forecasts of geomagnetic activity are for specific values (e.g., the A-index for tomorrow will be 40) and provide no information to users on the range of probable values nor the confidence or likelihood of the forecast value actually occurring. A format has been developed and is being implemented that will provide additional information to users. The forecasts are cast in the form of the probability of occurrence of three levels of geomagnetic activity ranging from quiet through average conditions to storms. Implementation requires the development and installation of new software in the SELDADS. This will provide the forecaster with climatological background, supporting verification software, and an interface for generating the product, and distribution of the product to users. Further customer education will be part of the implementation process.

6.1.3.5 Verification Reports. Using consultants from the university and meteorological community, an advanced, comprehensive forecast verification system has been developed for the standard SESC products. The system is currently used to provide on-line feedback to forecasters on their recent forecasting results. The system will be expanded to provide periodic (probably annual) reports of SESC forecasts using various measures that illustrate the relationship between forecasts and the actual occurrence of the phenomena being forecast. These reports will be oriented toward users and management needs to evaluate the factors that influence forecasts and the expected utility of forecasts in various situations.

6.1.3.6 Customer Services. An SEL Customer Focus Group has been established. The purpose is to identify customers and their needs and improve communications between SESC and the user community. Objectives will be to establish a database of users and user profiles, design an SEL customer newsletter, and prepare educational material for distribution to users. A User Group, composed of current users of SESC services, will be created. Input from this group will influence the content of SESC products, newsletters and conferences. A Customer Relations group will be set up to develop a marketing plan to reach a more diverse user community composed of government, industry and the public. The efforts of these groups will result in improved services to existing customers and increased visibility of SEL to potential users.

6.1.4 Department of the Interior Plans--Services. The USGS is providing one-minute geomagnetic data from a global network at intervals of 12 minutes (or 1 hour in the case of UK observatories) to NOAA/SESC for use by the USAF Space Forecast Center. The data is initially received at the USGS National Geomagnetic Information Center via satellite and computer links from the U.S. and INTERMAGNET observatory networks.

Plans call for placing automatic observatory systems reporting in real- or near-real-time via satellite at five additional U.S. magnetic observatories, as well as in India, Brazil, Europe, and Russia. These new observatories will permit real-time (1 hour) calculation of Dst and AE indices. Table 4-2 lists the stations to be included initially.

6.2 Agency Plans For Supporting Research

6.2.1 Overview of Planned Agency Research Programs. Like meteorology and oceanography, solar-terrestrial science is an environmental discipline. As in these other fields, its main goal is to understand the physics and chemistry of the environment well enough to be able to determine what properties of the system are predictable deterministically, and to be able to predict their statistical characteristics. In meteorology, the deterministic and stochastic phenomena are called weather and climate, respectively. Viewed as an environmental discipline, the goal of solar-terrestrial research is therefore to understand the physics and chemistry of the solar-terrestrial system well enough to be able to formulate a set of equations that, if properly initialized, predict the deterministic properties of the system, and exhibit the stochastic properties with the correct statistical characteristics.

Another way to state the ultimate goal of solar-terrestrial research is to say that it aims at the development of a global magnetospheric circulation model (GMCM) that takes continuous upstream solar wind parameters as input and gives all magnetosphere-ionosphere-thermosphere quantities of interest continuously as output. Such a global model could be used in a forecast-weather mode or in a simulation-climate mode. The above preamble gives the guiding principles behind a new NSF program entitled Geospace Environment Modelling (GEM). However, it could equally well describe the scientific goals of all the agency research programs in this area. NASA has already approved the International Solar-Terrestrial Program (ISTP) which will supply much of the in situ data to tackle these problems. ISTP itself is collaborative with Europe and Japan as well as DOD. Other NASA spacecraft such as Upper Atmosphere Research Satellite (UARS) will provide remote sensing of atmospheric responses to solar inputs. DOD will continue to support missions such as Combined Chemical Release and Radiation Effects on Satellites (CRRES) whose objective was to improve definition of the near-Earth space environment. This was done with a view to measuring the radiation which degrades spacecraft performance and helps create the hazardous space environment. NOAA's growing effort in "spacecraft anomalies" is highlighting the vulnerability of NASA/DOD operations in space.

The variable solar input to the solar/terrestrial system is a major cause of space weather. Thus, observation and prediction of solar activity are important. A major program, MAX 91, is an ongoing joint NASA/NSF/NOAA venture in the 1991-1995 time period. This program uses ground-based and balloon platforms to capitalize on spacecraft opportunities represented by Yohkoh, and continuing projects such as the Gamma Ray Observatory and NOAA's new GOES X-Ray Imager.

Remote sensing from the ground is an integral part of assessing the effect of space weather on the terrestrial atmosphere. NSF is supporting a major new thrust in this area under the program Coupled Energetics and Dynamics of Atmospheric Regions (CEDAR). This involves the application of the latest technology of radar and optical observations. Complementary efforts will be undertaken by NRL in two programs, Atmosphere and Ionosphere Remote Sensing (AIRS) and Coordinated Study of Terrestrially Important Phenomena (COSTIP). The principal objectives of AIRS is remote sensing and modeling of the upper atmosphere. It will include a joint space experiment called the Remote Atmospheric and Ionospheric Detection System (RAIDS) with USAF support, to be launched on TIROS/NOAA in 1993. COSTIP aims at the long-range prediction of solar-induced terrestrial disturbances including geomagnetic storms. As such, it is closely allied to NOAA's mission in space weather forecasting.

The agencies are planning ambitious programs in the next five years. In most cases they are jointly supported by several agencies. All are complementary and supportive of the general objective of understanding and predicting the near-Earth space environment.

6.2.2 Department of Defense Plans--Research. The Director of Defense Research and Engineering in the Office of the Secretary of Defense oversees the research activities of the Services to avoid duplication and optimize the benefits to the DOD.

6.2.2.1 USAF-Supported Research. Solar/magnetosphere/ionosphere/atmosphere interactions research includes studies conducted by PL/GP of solar emissions; the interplanetary medium; and the magnetosphere, ionosphere, and upper atmosphere. The following paragraphs describe these research areas in more detail:

A. Solar Emissions. PL/GP will conduct solar research directed toward solar activity forecasting, coordinated with complementary NOAA, NASA, and NSF research programs. The PL/GP Solar Research Branch at Sacramento Peak Observatory, NM will conduct research directed toward improving probability forecasts of solar activity ranging from long-range (7-45 days) "outlooks" to short-range (minutes to 24 hours) predictions, and advise the AWS on the specific solar parameters that should be monitored to improve the forecasting of solar-induced environmental disturbances.

B. Interplanetary Medium. Research continues on the effects of solar-flare-initiated phenomena including potentially hazardous energetic particle emission and shocks propagating through the interplanetary medium. The objective of this research is to improve forecasts of a specific solar-initiated phenomenon's arrival at the Earth and the magnitude and duration of the terrestrial effects. This research activity is coordinated with NOAA/ERL.

PL/GP will also advise AWS on specific parameters in the interplanetary medium that should be monitored for predicting the magnitude and duration of solar flare-initiated disturbances that perturb the aerospace environment.

C. Magnetospheric research:

- Studies plasmas, particles, electric and magnetic field configurations during quiet and disturbed solar-terrestrial conditions.
- Develops global understanding of the physics of magnetic storms and substorms.

- Improves definition of the environment in which USAF spacecraft operate and the hazards associated with operations within this environment, including the spacecraft-charging phenomenon.

- Determines dynamics and injection mechanisms of energetic particles in the Earth's radiation belts, that degrade DOD space assets.

D. Ionosphere. PL/GP will conduct research to improve capabilities to use and predict the state of the ionosphere as an electromagnetic propagation medium in the following areas:

- Ionospheric scintillations at VHF, UHF, and Super High Frequency (SHF) bands; improve the forecasting of ionospheric scintillations and ionospheric clutter at HF; and HF ranging for communication and surveillance fences using HF radars.

- Interaction of the magnetosphere with the polar ionosphere.

- Behavior of the total electron content/time-delay over the entire world; applications to current and proposed USAF systems; and improved correction for the time-delay produced by the total electron content encountered along a path from target to observer.

- Ionospheric error on the extended range of space defense radars and deep space surveillance radar systems.

E. Upper Atmosphere. PL/GP will continue research into improved predictions of the state of the upper atmosphere, both following a perturbation, such as a solar-flare-initiated disturbance, as well as in conditions of typical daily variability. The purpose of this research is to minimize the effects of such density perturbations on USAF space vehicle operations.

Research is also needed to develop dynamic models of upper atmospheric density, composition, chemistry, and dynamics; and to determine the effect of energetic particle, ultraviolet, and X-ray radiation impinging on the upper atmosphere.

6.2.2.2 USN-Supported Research. Research required on the solar-terrestrial environment includes investigations of the Sun, the interplanetary medium, the magnetosphere and the upper and middle atmosphere.

A. Solar Radiation. The Naval Research Laboratory (NRL) and the Office of Naval Research (ONR) will conduct solar research directed toward understanding and predicting phenomena that have important effects on the Earth. The ONR program focuses on obtaining magnetic field measurements and using them in a variety of research and forecasting projects. The

NRL program involves theoretical, observational, and numerical studies of the Sun's radiative and particle emissions, including solar flares, coronal mass ejections, coronal holes, and ultraviolet flux variability. The research program is partially supported by NASA.

B. Interplanetary Medium. NRL will conduct research on the transition of the solar corona into the interplanetary medium with interest in both the recurrent effects of high-speed streams from coronal holes and the transient effects of shock waves and energetic particles generated by coronal mass ejections. The object of this research is to improve forecasts of the arrival of these solar-initiated disturbances at the Earth and ongoing conditions in the Earth's space environment.

C. Magnetosphere. NRL will conduct a program of theory and experiment to elucidate the properties of the magnetosphere, especially as it relates to the high-latitude ionosphere, small-scale fluctuations, wave phenomena and particle acceleration. NRL also has a program for investigating the heavy ion component of the cosmic rays in the vicinity of the Earth which are the principal cause of heavy upsets in electronic circuits.

D. Upper Atmosphere. NRL is developing satellite observation techniques in the ultraviolet radiation domain to sense remotely the upper atmosphere and obtain global measurements of the electron density of the E-region of the ionosphere. The program is partially supported by the USAF Space and Missile Center.

E. Middle Atmosphere. NRL is conducting basic research remote sensing techniques for the middle atmosphere, with the principal objectives of measuring the electron density of the D-region of the ionosphere and parameters that affect the climate.

F. ELF/VLF/LF Systems. Long-wavelength communication systems provide the bulk of the Navy's fleet broadcast to its submarine forces. These long-wave systems operate within the Earth-ionosphere waveguide, which makes them sensitive to ionospheric disturbances such as those described as sudden phase anomalies (SPAs) and polar cap absorption (PCA) events and also to the appearance of sporadic layers in the ionosphere. These phenomena cause sudden and long-lasting reductions in signal strength.

The differences in ionospheric structure between the middle and polar latitudes also have strong influences on long-wave propagation. The boundary between these latitudes fluctuates with solar activity and season. The connection between these fluctuations and solar emissions is not yet fully understood, and further research is being conducted. The ionosphere varies in structure hourly. This variation is not connected directly to well-defined ionospheric disturbances such as SPAs. However, it contributes to fluctuations in the signal strength of long-wave systems. There is inadequate knowledge of the overall signal statistics for many critical long-wave systems, particularly in the Low Frequency bands. Research is being directed to correct this deficiency.

G. HF Systems. The Navy is experiencing a resurgence of interest in HF (2-30 MHz) propagation systems for tactical and strategic communications. HF is also finding new uses in direction finding (HFDF) and over-the-horizon radar systems (OTHR). However, radio propagation at these frequencies is more sensitive to ionospheric disturbances than at long-wave frequencies. A different part of the ionosphere is responsible for the propagation at these frequencies, and the propagation mechanism is different than at long-wave frequencies. Therefore, different problems exist at HF. These frequencies are affected by SPAs and PCAs; however, they are also strongly affected by X-ray and solar proton events. In addition, there is the less dramatic moment-to-moment variation which manifests itself as shifts in the maximum usable frequency, Doppler shifting (flutter fading), and changes in the direction and/or time of arrival. The Navy is developing a set of powerful propagation assessment tools based on real-time solar and ionospheric databases and computer driven semi-empirical ionospheric propagation models. The solar data are augmented by real-time data from ionosondes and time-of-arrival data. These propagation assessment tools are also being simplified wherever possible, to provide portable propagation assessment capabilities. The continuing improvement of these portable systems will rely on the availability of solar and ionospheric data which must be correlated with HF measurements and propagation analysis. Success will depend a great deal upon the availability of real-time ionospheric assessment data. Other uses for these HF assessment programs will be in the area of frequency management.

H. Satellite Systems. Satellite communication and navigation systems are an increasingly important asset to the Navy. These systems involve transionospheric propagation and, consequently, are sensitive to ionospheric disturbances. Of particular importance are the effects of geomagnetic field-aligned irregularities which cause scintillation of satellite signals on both the up- and down-links. Research is being conducted toward understanding the mechanisms responsible for the onset of scintillation. In spite of nearly 40 years of research in the area of ionospheric irregularities, these mechanisms are not yet identified. The research is directed toward consideration of solar and ionospheric sensing of parameters needed to identify the probable occurrence of scintillation and the expected duration and severity of the outages.

The propagation prediction models being developed for satellite links will be coordinated with the HF models so that rapid re-allocation of communication links can be implemented. Ultimately, the propagation prediction models will depend on real-time and long-range ionospheric disturbance forecasting.

6.2.3 Department of Energy Plans--Research. At both its National Laboratories and at academic institutions, the Department of Energy conducts research applicable to the problem of predicting the near-Earth space environment. Los Alamos National Laboratory will continue its research studies of the near-Earth space environment using data from instruments on satellites used to verify the limited nuclear test ban treaty. This effort characterizes the plasmas and energetic particles of the terrestrial magnetosphere, identifies the natural temporal variations of these charged particles, and attempts to determine the processes whereby these particles are energized and transported within the magnetosphere. At the Pacific Northwest Laboratory, coordinated observations of mid-latitude auroral phenomena, obtained via ground-based optical photometers and cameras, will continue to be used to study particle transport and energetics in the near-Earth space environment. Extensive interactions with satellite experimenters, in the form of coordinated studies, are the base for PNL's approach to the analysis of mid-latitude ionospheric and magnetospheric phenomena. Researchers at the University of Alaska are modeling magnetospheric interactions and those at the University of Arizona are measuring changes in the solar diameter.

6.2.4 Department of Transportation Plans--Research. The data from sensors normally monitored (and reported by the SESC) are well correlated with data from OMEGA monitors as far as PCA onset is concerned, but very poorly correlated in terms of magnitude over the duration of the event. To address this discrepancy, the Coast Guard will conduct a joint study with the Space

Environment Laboratory (NOAA) that involves comparison of OMEGA data with data from TIROS or other polar-orbiting satellites.

6.2.5 Department of the Interior Plans--Research. U.S. Geological Survey research based on the data available from the real-time global network will encompass:

- Statistical studies and comparisons of the new, real-time range index, real-time Dst, real-time AE, and whether they represent after-the-fact Kp, Dst, and AE indices, as well as selected magnetic effects.
- Modeling of ionospheric source fields as well as ionospheric parameters in cooperation with NOAA scientists.
- Modeling of mantle conductivity and core mantle sources of secular variation.
- Modeling of magnetic field line resonances and their relationships to ionospheric and magnetospheric parameters.
- Induction and magnetotelluric studies of the Earth's crust.
- Study and measurement of electromagnetic effects of tectonic stress.
- Continued development of advanced magnetic sensors and systems.

6.2.6 NASA Plans--Research. NASA will conduct approved research missions to provide basic understanding of the Earth's environment (atmosphere, ionosphere, magnetosphere), of the Sun and the interplanetary medium, and of their interactions.

6.2.6.1 International Solar-Terrestrial Physics/Global Geospace Science (ISTP/GGS). The implementation of a major international program in solar and space physics began in FY 1987 with participation by NASA, the Japanese Institute for Space and Astronautical Science (ISAS), and the European Space Agency (ESA). The U.S. contribution to this overall effort is referred to as NASA's International Solar-Terrestrial Physics (ISTP) Program. A systematic deployment of a group of satellites is planned for the early- to mid-1990s by these agencies. This constellation will provide measurements and test models for the study of the interior of the Sun (helioseismology), the origin of the solar wind through coronal diagnostics, the cause and effect relations of the flow of energy in the Earth's key magnetospheric source and storage regions, and the microphysics of plasma interactions utilizing the Earth's magnetosphere as a laboratory. ISAS is providing the Geotail mission to monitor the Earth's tail storage region, while NASA will provide the Wind mission to monitor the solar wind input and the Polar mission to monitor the ionospheric source region. These three missions, in conjunction with the NASA/DOD Combined Chemical Release and Radiation Effects on Satellites (CRRES) mission flown in 1990 in the equatorial storage region, form the Global Geospace Science (GGS) ensemble. The ESA Solar and Heliospheric Observatory (SOHO) will be launched to study solar seismology and coronal diagnostics at the Earth-Sun L-1 Lagrangian point, while another ESA mission, Cluster, will provide three-dimensional measurements of magnetospheric properties.

6.2.6.1.1 Geotail. Launched on July 24, 1992, Geotail is a collaborative project being undertaken by ISAS and NASA as part of the Collaborative Solar-Terrestrial Research (COSTR) program. The primary objective is to study the dynamics of the Earth's magnetotail over a wide range of distances extending from the near-Earth region (8 Re) to the distant tail (220 Re). Geotail will spend at least 18 months in the deep tail, in a double-lunar-swingby orbit, with a nine-month overlap with the period when Wind and Polar are also in orbit collecting data. After the double-lunar-swingby phase, Geotail will undergo an orbit change to enable observations in the near tail region. During the near-tail phase, the spacecraft will be kept in the plasma sheet as long as possible at the time of solstice. In support of the GGS program, the mission will address transport, storage, and conversion of energy in the tail with a comprehensive instrumentation package for the following:

- Magnetic fields
- Electric fields
- Low-energy charged particles
- Energetic particles
- Plasma waves

6.2.6.1.2 Wind. The spacecraft will be launched into the double-lunar-swingby orbit. In this orbit, the line of apsides is held close to the Earth-Sun line throughout the year by means of lunar swingby maneuvers. Data obtained during these passes will be useful for the solar wind input function in support of space physics missions. After the lunar swingby orbit phase, Wind may be inserted into a small L1 halo orbit. In this position it will provide optimum interplanetary measurements on a continuous basis. The mission objectives are as follows:

- Determine the solar wind input properties for magnetospheric and ionospheric studies as part of the ISTP program.

- Determine the magnetospheric output.

- Investigate basic plasma processes in the solar wind.

- Provide baseline observations for global heliospheric studies.

The Wind satellite will specifically measure and investigate magnetic fields, energetic particles, radio and plasma waves, solar wind plasma, hot plasma composition, and cosmic gamma-rays.

6.2.6.1.3 Polar. Scheduled for 1994, Polar will be the second launch of two NASA spacecraft in the GGS initiative, which is part of the ISTP project. In support of the GGS program, with Wind and Geotail overlapping, Polar will be placed in a 90° inclination orbit with an apogee of 8-10 Re and a perigee of about 2 Re. The perigee radius will be increased to the maximum allowed by the spacecraft final mass and capability of the onboard propulsion system. This will maximize coverage of the low-altitude auroral acceleration region. The apogee may be lowered several years after launch. In this orbit Polar will provide coverage of the day-side cusps region at high latitudes and the southern hemisphere polar cusps at low altitudes, as well as global imaging of the northern auroral zone. The objectives of the Polar mission are to:

- Characterize the energy input to the ionosphere.

- Determine the role of the ionosphere in substorm phenomena.

- Measure complete plasma, energetic particles, and fields in the polar regions.

- Determine characteristics of ionospheric plasma outflow.

- Provide global multispectral auroral images of the footprint of the magnetospheric energy deposition into the ionosphere and upper atmosphere.

6.2.6.1.4 Solar and Heliospheric Observatory (SOHO). This mission is a joint venture of ESA and NASA within the framework of the Solar-Terrestrial Science Program (STSP), and will participate in the ISTP project. The SOHO spacecraft is baselined for a 1995 launch using an Atlas Centaur launch vehicle. From a parking orbit it will be accelerated into a trajectory towards the L1 Lagrangian point, a position of balanced gravitational force that exists at a distance of 1.5 million km along the Earth/Sun line. The "cruise" phase to L1 will take some 4 months, during which time the experiments will remain dormant. Since halo orbits around the L1 point are highly unstable, regular maneuvers of the spacecraft will be needed to maintain the orbit. The lifetime of the satellite is nominally 2 years, but will be extendable to 6 years. The objectives of the SOHO mission are:

- The study and understanding of the formation of the solar corona; in particular, its heating mechanism and its expansion into the solar wind. SOHO will accomplish this by remote sensing of the solar atmosphere with high resolution coronagraphs and spectrometers and by in situ measurements of the composition of the resulting particles in the solar wind.

- The study of the solar interior structure and dynamics, from core to the photosphere, by helioseismological methods, and the measurement of solar irradiance variations.

- To fulfill these objectives, the payload will contain instruments dedicated to: high resolution coronal observations, in situ measurements of the solar wind, solar irradiance monitoring, and helioseismology.

6.2.6.1.5 Cluster. A joint NASA/ESA venture scheduled for launch in 1995, Cluster will consist of four identically-instrumented spacecraft launched by ESA into a 4 Re x 22 Re elliptical polar orbit as part of the STSP and ISTP programs. The orbit will pass through the northern cusp region, and cross the day-side magnetopause at lower latitudes. The apogee should be large enough to cross the bowshock, and the fully developed magnetotail should be crossed at distances larger than 12 Re.

The four spacecraft will be injected into a standard Geosynchronous Transfer Orbit (GTO), then transferred into a polar orbit via single lunar flyby, double lunar flyby, or direct injection selected such as to allow the exploration of the bowshock, the magnetopause, the day-side cusp, and the geomagnetic tail current sheet.

The objective of this mission is to perform three-dimensional studies of the microphysical properties of different plasma states in the Earth's magnetosphere and solar wind. The Cluster satellite will specifically investigate the following:

- Magnetic fields
- Electric fields
- Plasma wave
- Plasma RF soundings
- Energetic ion and electron distributions
- Hot plasma ion and electron distributions

6.2.6.2 Fast Auroral Snapshot Explorer (FAST). This mission will be launched on a Pegasus-class vehicle in 1994. This investigation of auroral processes expands upon a wide range of plasma phenomena discovered on previous satellite and sounding rocket missions. Its high resolution measurements will greatly extend the observational capability of sounding rockets and should make a significant contribution to understanding the basic physics of auroral particle acceleration. The FAST spacecraft will operate in the natural plasma laboratory above the Earth's auroral zones. This domain of the upper atmosphere is where the neutral atmosphere contacts the plasma-dominated solar system environment of Earth. Energy and matter flow through this region, exciting the upper atmosphere into luminous displays controlled by electrical and magnetic forces.

The FAST instruments will contain new sensors capable of detecting the flows of various types of matter, electrons, protons, and other ions, with greater sensitivity, discrimination, and much faster sampling than previously possible. Other sensors will measure the electrical and magnetic forces and simultaneously correlate these forces with their effects on the electrons and ions at altitudes of 300 km to 3500 km, the source region for much of the energy that appears as auroral light emitted at about 100 km. These observations will be complemented by data from other spacecraft at higher altitudes, which will be observing fields and particles and photographing the aurora from above, thus placing FAST observations in global context. At the same time, auroral observatories and geomagnetic stations on the ground will provide measurements on how the energetic processes that FAST observes affect the Earth.

To carry out its mission, FAST will use a high resolution set of coordinated instruments that will examine the electrodynamic causes of intricately complex auroral displays. Of special importance will be an attempt to reveal how electrical and magnetic forces guide and accelerate electrons, protons, and other ions in the auroral regions.

6.2.6.3 Advanced Composition Explorer (ACE). The prime objective of this mission is to determine and compare the elemental and isotopic composition of several distinct samples of matter, including the solar corona, the interplanetary medium, the local interstellar medium, and galactic matter. This objective is approached by performing comprehensive and coordinated determinations of the elemental and isotopic composition of energetic nuclei accelerated at the Sun, in interplanetary space, and from galactic sources. These observations would span five decades in energy, from solar wind (several hundred MeV per nucleon) to galactic cosmic rays (1 keV per nucleon) and would cover the element range from 1H to 40Zr. The comparison of these samples of matter would be used to study the origin and subsequent evolution of both solar system and galactic material by isolating the effects of fundamental processes that include nucleosynthesis, charged and neutral-particle separation, bulk plasma acceleration, and the acceleration of suprathermal and high energy particles.

The ACE study payload includes six high-resolution spectrometers, each designed to provide optimum charge, mass, or charge-state resolution in a particular energy range, and each having a geometry factor optimized for the expected flux levels, so as to provide a collecting power factor of 10 to 1000 times greater than previous versions of planned experiments. The flux dynamic range of these instruments will be sufficient to perform measurements under all solar wind flow conditions and during both large and small solar particle events. Magnetic field, solar wind electrons, and solar flare electrons will also be measured.

6.2.6.4 Spartan 201. Spartan 201 is the next step (prior to SOHO) in understanding the heating and acceleration of the solar wind. Spartan 201 was launched in spring 1993, deployed from the space shuttle's bay and retrieved 40 hours later. This Spartan flight acquired observations of longer duration than those available from a sounding rocket. These measurements of the Sun's corona will determine the electron temperature and flow speeds of higher stages of ionization. Weak photon fluxes preclude sounding rocket measurements of these quantities.

Spartan 201 serves as a prototype for important aspects of the Ultraviolet Coronagraph-Spectrometer and Large Field Spectrograph Coronagraph on the Solar and Heliospheric Observatory (SOHO). Spartan 201 represents the primary source of data on solar wind generation and coronal heating for a focus of the international SOHO science preparations.

6.2.6.5 Atmospheric Laboratory for Applications and Science (ATLAS). This mission was first launched on the space shuttle in 1992. It used two Spacelab pallets and an igloo to accommodate a core payload of solar and atmospheric monitoring instruments plus reflights of some Spacelab investigations. The orbiter orientation was either inertially-fixed so that selected instruments were pointed at the Sun, or nadir-pointed for observations of the Earth's atmosphere. The orbit had solar occultations so that absorptions in the solar spectrum caused by trace molecules in the atmosphere were detected by the ATMOS infrared spectrometer. ATLAS-2 flew on the space shuttle in spring 1993, with a complement of six instruments mounted on a single Spacelab pallet.

The science objectives of these missions, which will be reflown at several-year intervals, are to measure long-term changes in the total energy radiated by the Sun, to determine the variability in the solar spectrum, and to measure the global distribution of key molecular species in the middle atmosphere. Such measurements are needed because even small changes in the Sun's total irradiance or its spectral distribution can have a significant impact on the Earth's climate and environment. Additional objectives are to differentiate man-made from natural perturbations of the Earth's atmosphere and to provide absolute calibrations for solar monitoring instruments on free-flying spacecraft.

6.2.7 Department of Commerce Plans--Research

6.2.7.1 National Geophysical Data Center (NGDC). The NGDC will provide data and data-analysis facilities, computer programs, scientific participation. and advice in cooperative research projects with scientists from other Federal agencies or academia, on a reimbursable basis.

These projects will use the special data analysis capabilities of NGDC, particularly in the treatment of multi-station geomagnetic variations data, in the derivation and application of magnetic activity indices, in the calculation of true-height profiles of the ionosphere, and in case studies of space environment events from all types of solar-terrestrial data sources.

6.2.7.2 Space Environment Laboratory (SEL). Space environment services are based on observing and understanding a very large and complex system. Disturbances begin at the Sun and end with a variety of possible geophysical effects. To support and improve the services requires an extraordinary range of scientific expertise, and more resources than any single organization can muster. The approach taken by SEL is to focus on those areas that bear most directly on forecasting disturbances and assessing their consequences. In the next 5 years, SEL research will be tied to some exciting new observations.

A. Wind/SWIM Measurements. A critical physical solar wind parameter in the coupling process to the magnetosphere has been identified. That parameter is the southward component of the interplanetary magnetic field, a quantity not presently deducible from solar observations. Through the Wind/SWIM NASA spacecraft, SEL will cooperate with the USAF to acquire in situ solar wind data near the L1 libration point. Further, a major effort to acquire dedicated L1 observations is in progress. Development projects and models that use real-time solar wind data to improve services will be initiated.

B. Solar X-ray Telescope. This sensor is being designed, and will be included on a future GOES. Processing and using the images that are expected from this instrument will require considerable planning, but copious benefits for both services and research are expected as we begin to monitor this extremely important layer of the solar atmosphere.

C. Geomagnetic Observatories. The INTERMAGNET consortium of ground-based geomagnetic observatories is expanding rapidly. There are more than 30 observatories now reporting data in near-real-time, and that number could more than double in the next five years with the special addition of stations in critical (and heretofore inaccessible) longitudes. These additions will allow the calculation of global magnetic indices. These indices measure geophysical characteristics important to drive models of the magnetosphere and ionosphere. Processing and interpreting the data from this global network will be a non-trivial task.

In addition to receiving and integrating new data, increased SEL effort will be placed on synergistic studies of the data from all of their own space environment monitors, as well as key parameter data available from NASA and DOD satellites. To do this, an SEL scientific database must be designed and implemented. Finally, close scientific liaison with the solar-terrestrial physics community will be required to foster the transfer of worldwide research results into improved services.

D. Solar Activity. Research has demonstrated that an understanding of the global morphology of magnetic fields on the Sun may lead to improved forecasting of major solar activity. SEL will continue to develop global mapping techniques, aided by manipulation of digital solar images.

E. Interplanetary Propagation of Disturbances. Progress continues on quantitative models to describe the propagation of disturbances through interplanetary space. Studies will continue to address in detail how well the models can work, given available or planned input data. Additional work is required to understand the influence of small-scale solar wind structures on the magnitude of disturbances induced in the Earth's space environment.

F. Effects of Disturbances at the Earth. To improve the real-time assessment of disturbances, a number of research tasks are being addressed over the long-term to contribute to the ability to evaluate disturbances quantitatively in near-real-time. Many studies use data from the operational satellites as the primary input. The high-priority studies are the following:

- Temporal and spatial variations of the cutoff latitudes of energetic solar particles.
- Geographical and temporal distributions of energy input into the upper atmosphere.
- Temporal and geographical distributions of geomagnetic activity.
- Studies of environmental conditions at synchronous satellite orbits, as they affect satellite systems.

G. Solar X-ray Imager (SXI) Project. Subjects of research to be performed using the SXI include the following:

- Long-term studies of solar flares and activity and the long-term evolution of solar structures, especially in the lower corona.
- The structure and evolution of coronal holes and the variable geoeffectiveness of these holes through the solar cycle.
- Coronal mass ejections as solar phenomena, and as the source of geomagnetic storms and energetic proton events.
- The nature and relative contribution of X-ray bright points to solar energy dissipation.
- EUV energy input to the terrestrial atmosphere.

H. MAX 91 Coordinated Flare Observations. MAX 91 is a program approved by the United States and international governing bodies that provides for coordinated observations of solar flares, their energy source, energy release, transport in the interplanetary space, and effects at the Earth. The observations are made by satellites, balloons, and ground-based sensors. Maximum benefit from the observations is gained by coordinating the timing, cadence, and pointing targets of the observations to ensure maximum scientific return from limited resources. The program, has a national and international coordinator working in SEL and using the observations and communication facilities of SESC in accomplishing the objectives. The program began in 1991; 4 years of observations will be followed by 3 years of data analysis.

I. Solar Influences on the Terrestrial Environment. A new branch, Solar Influences on the Terrestrial Environment (SITE), has been established in the Research and Development Division. The research in this branch will emphasize the responses of the ionosphere and atmosphere to energy inputs in the form of Joule heating (electrical currents in the ionosphere), energetic particle precipitation, and ultra-violet and extreme ultra-violet radiation from the Sun. Research will also be conducted to better understand the origins of these energy inputs which are associated with solar and magnetospheric processes. This research will make use of the observations of the near-Earth particle populations provided by the SEM onboard the TIROS/NOAA satellites as well as solar ultra-violet observations made by the SBUV instruments onboard the TIROS/NOAA and NIMBUS satellites. Given quantitative specifications of these forms of energy inputs to the atmosphere, the atmospheric and ionospheric responses will be assessed by theoretical modeling.

J. Research Activities in the Solar Influences Area of the National Climate and Global Change Program. The Space Environment Laboratory has accepted the responsibility for formulating a NOAA-wide plan for research in the area of "Solar Influences" upon climate and global change. The research program will initially concentrate upon determining the immediate chemical, electrical, and dynamical responses of the upper atmosphere to energy inputs from above in the form of particles and energetic photons from the Sun. The research is expected to evolve toward the study of secondary and tertiary atmospheric responses that may have consequences to the behavior of the lower atmosphere. To this end, a long-term database utilizing historical particle and ultraviolet observations from satellites will be constructed. This database will serve as the fundamental resource for assessing the immediate atmospheric responses to these inputs.

6.2.8 NSF Plans--Research. NSF plans to continue to support a broad-based program in solar-terrestrial research. One of the major thrusts during the next five years will be establishment of an observatory in the northern polar cap. It is known that the solar wind interaction with Earth's polar cap regions influences the behavior of the entire global structure of our atmosphere. Due to the scarcity of observations at the highest latitudes of the globe, the Earth's polar regions currently represent the most conspicuous gap in our understanding. A new upper atmospheric observatory, located within the northern polar cap, will be able to determine the characteristics and variability of the crucial terrestrial parameters, while satellite observations record the variations in the solar wind. Two global change programs, CEDAR and GEM, are directly aimed at the study of energy transfer mechanisms in the solar-terrestrial system and will greatly benefit from the availability of the Polar Cap Observatory. In addition, the new facility will benefit the international Solar-Terrestrial Energy Program (STEP), and many long-term NASA programs.

CHAPTER 7

LONG-TERM PLANS

7.1 **Department of Commerce Long-Term Plans**. The long-term emphasis of the Space Environment Laboratory is toward improved ability to measure, forecast, and characterize the near-Earth space environment.

The Space Environment Laboratory plans to continue to pursue solar wind monitoring through all possible avenues. Accurate geomagnetic forecasts have the highest potential payoff to users of space environment forecasts across the nation, yet these forecasts are the least reliable now produced. Current understanding and anticipation of advanced research indicates the only reliable method for obtaining accurate forecasts is with a solar wind monitoring satellite standing sentry between the Sun and the Earth. Cooperation with other federal agencies, the public sector, and other countries will include work with the NASA and the USAF on the upcoming Wind/SWIM satellite programs to obtain partial real-time solar wind data for at least a few years. A tentative agreement has also been reached with NASA for real-time access to the ACE satellite solar wind data that would follow the Wind/SWIM program, but the agreement depends on Department of Commerce funding to cover the costs of real-time data access. Cooperation is being pursued with several foreign organizations to obtain the worldwide tracking network necessary to obtain ACE data in real-time. In the longer term, SEL is pursuing a concept that requires a permanent, operational solar wind sentry after the ACE satellite is gone near the turn of the millennia.

The large quantity of space environment data flowing through the Space Environment Laboratory as part of its forecast program, and the uniqueness of the long-term space radiation monitoring provided by the Space Environment Monitors on the GOES and NOAA satellites, place SEL in a position to gain greater understanding of the range of variation of radiation in the Earth's near-space environment, both in the short and long-term. SEL expects to maintain, and, where useful, expand its effort to create and distribute a reliable, well-calibrated set of data that can:

- Be used for more accurate characterization of the near-Earth environment,
- Better describe this environment in terms of usable parameters,
- Develop improved forecast techniques,
- Make the data useful for other environmental studies such as climate and global change.

The availability of continuous images of the Sun in X-rays offers the opportunity for research and development to improve space environment forecasts well after the turn of the century. SEL anticipates major emphasis in this area for the next decade and beyond as a wealth of new data becomes available from the GOES X-ray Imager.

Long-range national plans for future space exploration missions to the Moon and Mars are not likely to grow significantly for several years given the state of the national economy. In anticipation of these missions eventually being flown, and given the Space Environment Laboratory expertise in forecasting the solar radiation hazard to astronauts, SEL will maintain a small effort to improve the quality of radiation hazard forecasts. These forecasts will benefit current and near-term users including those involved in manned and unmanned space and satellite operations.

7.2 USAF Long-Term Plans. National space policy states that the United States will conduct those activities in space that are necessary to national defense. In an era when regional threats may emerge with little or no warning, U.S. forces must be capable of responding with speed, agility, and flexibility anywhere in the world. The DOD recognizes the unique advantages which space systems provide--fresh and timely intelligence and early warning of hostile action, in-place communications, multispectral imagery, precise navigation and weather data. Space assets are force multipliers, complementing and enhancing the capabilities of terrestrial forces. Exploitation of space will be increasingly important to the Nation and, particularly to achieve national security goals.

The Air Force has responsibility to provide operational space environment support to DOD space-based and land-based systems. Research efforts, acquisition programs, and the real-time warning and forecast infrastructure all focus on supporting DOD (and National) space policy and objectives. The space environment models under development and the AFSFC anticipated the increased emphasis on space resources and the need for environmental support. However, as a science, the study of the space environment is in its infancy and there is a constant need to improve models and computing capability.

7.2.1 Follow-on to the Space Environmental Technology Transition (SETT) Program. The follow-on program will develop and transition algorithms to upgrade or replace current and near-term replacement (SETT) space models with improved accuracy and coverage, responding as accurately as possible to customer requirements.

7.2.2 AFSFC Computer System Replacement. The AFSFC computer system will be replaced in the late 1990s as the current system becomes unsupportable. Improved computer technology available during the 1990s will allow space models to run more efficiently at AFSFC.

7.3 NASA Long-Term Plans. The Space Physics Division of NASA's Office of Space Science is developing long-range plans for a number of research mission concepts.

7.3.1 Thermosphere-Ionosphere-Mesosphere Energetic and Dynamics Mission. The Thermosphere-Ionosphere-Mesosphere Energetic and Dynamics (TIMED) mission, a possible 1995 new start, will carry out the first exploratory and comprehensive space-borne investigation of the physical and chemical processes acting within and upon the coupled mesosphere-lower thermosphere-ionosphere (MLTI) system between 60 and 180 km above the Earth's surface. A configuration of two identical spacecraft in different orbits is required to provide the complementary and extensive coverage of MLTI parameters in latitude, altitude, local time, and season. The slowly changing orbit of TIMED-H will provide essentially full global coverage, while the rapidly precessing orbit of TIMED-L will provide full diurnal coverage each month at middle and low latitude.

The TIMED mission will be an exploratory mission to characterize and understand the interplay of composition, energetics, radiation, and dynamics of the MLTI regions. It will complement the NASA UARS (stratospheric) and International Solar-Terrestrial Physics (solar wind and magnetospheric) missions and contribute to the international Solar-Terrestrial Energy Program. The TIMED mission will also contribute to the study of anthropogenically-induced changes in the atmosphere, and to the understanding of variations of methane and carbon dioxide levels, which may be important harbingers of global change.

7.3.2 High Energy Solar Physics Mission. The High Energy Solar Physics (HESP) mission, proposed for launch in 2000 for the next solar maximum, is essential for understanding the most fundamental processes of solar flares, including the impulsive release of energy stored in unstable magnetic configurations, efficient acceleration of particles to high energies, rapid transport of energy, and the subsequent heating of the ambient solar atmosphere.

The strawman HESP payload consists of a single instrument, an imaging spectrometer for high energy emission. This instrument responds to photons over the entire energy region from 2 keV to more than 200 MeV and neutrons from 20 MeV to more than 1 GeV. The experiment will have the following unique capabilities for solar flare observations: high energy resolution spectroscopy, high angular resolution gamma-ray imaging of solar flares, high angular and time resolution hard X-ray imaging, imaging of energetic neutrons and high resolution X-ray and gamma-ray imaging spectroscopy. With such a powerful new instrument, the HESP mission is expected to locate the regions of particle acceleration and energy release, characterize in great detail the accelerated particle distributions as functions of both space and time, follow the subsequent transport of energy through the plasma, and thereby identify the operative physical mechanisms.

7.3.3 Mechanisms of Solar Variability Program. The purpose of the Mechanisms of Solar Variability (MSV) program is to achieve greater understanding of the physical causes of variations in photon, magnetic and corpuscular emissions from the Sun. Variations in solar photon and corpuscular radiation affect the earth's upper atmosphere. Variations in total solar output are a possible significant perturber of tropospheric climate. MSV would enhance our understanding of the causes of solar variability through high-angle-resolution observations of the interaction of solar surface magnetic fields and convection motions, as well as related x-ray, UV, and visual brightness variations. The MSV program would complement national programs aimed at monitoring integrated solar outputs, and contribute to the better understanding and predictive capability of global solar variability.

The first phase of the MSV program, MSV-O, will use multiple flights of a 1-m class solar balloon-borne telescope, and coordinated rocket flights to obtain UV and x-ray observations.

7.3.4 Galactic Origin and the Acceleration Limit Program. Describing the processes by which galactic cosmic rays achieve their enormous energies remains a fundamental objective of space physics. The Galactic Origin and the Acceleration Limit (GOAL) program would provide a direct test of the hypothesis that most of the galactic cosmic rays are accelerated by the blast waves from supernovae, through the processes observed in the heliosphere shock waves. GOAL would test this theory by measuring the composition of cosmic rays at energies from 1013 to 1015 eV, reaching beyond the energy to which supernova remnants are currently believed capable of accelerating cosmic ray protons.

To achieve the factor of about 30 increase in collecting power that is required for this study, GOAL would use NASA's new long duration balloon capability to make a series of flights of detectors with proven technology. In addition to providing a test of the standard model for cosmic ray origin and acceleration, these composition measurements would overlap with ground-based air-shower measurements from 1014 to 1015 eV, providing a normalization, and thereby allowing air shower studies to be used to deduce the composition at still higher energies, beyond the so-called "knee" in the cosmic ray energy spectrum.

7.3.5 Global Solar Mission. The Global Solar Mission (GSM) mission encompasses a number of possible concepts at this time. One such scenario would consist of a single spacecraft in a solar polar orbit and three spacecraft in ecliptic solar orbits. The objectives of the GSM are to observe the Sun and solar wind globally. The GSM mission would allow the study of the solar magnetic activity cycle over a variety of spatial and thermal regions and study the role of the Sun in shaping the structure and dynamic of the heliosphere. Proposed measurements include polar magnetic fields, high latitude differential rotation, pole-equator temperature differences, solar wind particle and fields, coronal streams and mass ejections from above the ecliptic, and helioseismology p-modes in the absence of rotational splitting from the pole.

7.3.6 Inner Magnetosphere Imager Mission. The Inner Magnetosphere Imager (IMI) mission would obtain simultaneously the first global images of the Earth's magnetosphere and its component regions, such as magnetospheric ring current system, plasmasphere, and auroral regions. The synthesis of three decades of in situ magnetospheric measurements has revealed a tantalizing but crude picture of the global magnetosphere: tantalizing because of the brief glimpses provided of the magnetospheric configuration, and crude because these glimpses are based on measurements widely separated in space and time. To progress scientifically in understanding the global magnetosphere and how local processes combine to form the whole, it is necessary, and technically feasible, to render visible the previously invisible magnetosphere. This would be done with instruments on an orbiting platform that measure ultraviolet emissions and energetic neutral atoms. The IMI images will provide a new window to the plasma universe, and the impact of this new global perspective will be felt in all space science disciplines in which plasma physics is important.

7.3.7 Solar Probe Mission. The purpose of the proposed Solar Probe mission is to explore a region near the Sun that has never previously been directly investigated, using an in situ experiment package that will return information that cannot be returned remotely. The Solar Probe will rely on a Jupiter gravity assist to enter into an orbit that has a perihelion of 4 solar radii, and aphelion of 5 AU and an inclination of 90 degrees. The primary focus of the mission is to obtain data on the structure and dynamics of the outer solar atmosphere and the origin of the solar wind. This region remains an unknown link that couples the solar output to the terrestrial environment. The first in situ measurement of coronal particles and fields will help discrimination among many current models of the structure and dynamics of the outer corona and solar wind. In addition, observation of the development of turbulence, nonlinear wave processes, plasma heating and particle acceleration in the corona and solar wind will provide data in a plasma parameter space that has not been obtained in terrestrial laboratories or in previous space missions.

7.4 NSF Long-Term Plans. The Solar-Terrestrial Energy Program (STEP) is an international program involving approximately 4500 scientists in 42 countries to coordinate both ground-based and space-based solar-terrestrial research in the 1990's. The NSF-STEP program has been formulated to provide a scientific focus and internationally-based framework for several solar-terrestrial research activities specifically related to the ground-based components of on-going and future space programs. NSF-supported ground-based instrumentation will enable basic research in micro-, meso-, and macro-scale physics that will be critical in defining, focusing, and coordinating space-based observations.

Thus, NSF-STEP promises to be an important catalyst for basic research in solar-terrestrial science, leveraging through STEP an international investment of several billion dollars over the coming decade.

7.5 USGS Long-Term Plans. U.S. Geological Survey plans to continue global real-time networking of the world's geomagnetic observatories through INTERMAGNET. USGS will use global geomagnetic data sets to extensively study the solid Earth, the magnetosphere, and the ionosphere. USGS also plans to organize an international effort to fill the need for geomagnetic data in the broad ocean areas. This plan calls for placing geomagnetic observatories with good base line control on the ocean bottom and on ocean islands.

CHAPTER 8

RELATIONSHIP OF PROGRAM TO GLOBAL CHANGE

8.1 Department of Commerce Relationship to Global Change. A national plan that addresses the general problem of global change has been cast in terms of seven broad topics. Each of these topics in the U.S. Global Change Research Program (USGCRP) is significant to the understanding of either the causes or the consequences of global change. The topics are also intertwined so that no single one can be addressed in isolation from the others. However, to provide guidance in the relative allocation of resources and effort, these broad topic areas have been ordered in priority, ranging from "Climate and Hydrologic Systems" downward to "Solar Influences."

The Sun's output of photons, solar wind plasma, and energetic particles varies on time scales from minutes to millennia. The relative changes in total solar irradiance are small, while larger relative changes occur in the flux of UV photons penetrating to below 40 km in the atmosphere and in the fluxes of MeV particles penetrating to 20 km. The variable solar wind modulates MeV-GeV galactic cosmic rays that penetrate to the Earth's surface. The solar wind's interaction with the magnetosphere also generates electric fields in the middle and high-latitude ionosphere which couple, in turn, to the global electrical circuit.

Claims are often made that changes in weather and climate (as measured, for example, by the strength and pattern of the global atmospheric circulation) are correlated with manifestations of solar variability; e.g., solar flares, sunspot numbers, solar wind magnetic fields, or ^{14}C production rates. Such correlations have been made over time scales of days to millennia. The inferred magnitudes of the global atmospheric responses to such solar variations are significant in comparison to the projected warming effects of increasing greenhouse gas concentrations. The inferred amplitudes of regional changes in the atmosphere may be large enough to have important consequences for agriculture and energy utilization.

The United States Global Change Research Program (USGCRP) recommends and seeks to coordinate a broad-based research program addressing global change. This program includes geological, oceanic, biological, and atmospheric changes brought about by both natural and anthropogenic causes. The influence of the changing Sun has been identified as one agent of global change, and the National Research Council has produced a report on that subject. The research recommended in that report includes investigations of changes in the middle atmosphere, in ozone, and in the thermosphere-ionosphere-magnetosphere system brought about by variations in several types of solar inputs. Contributions to the program include work by NASA, NSF, DOD, and NOAA.

NSF currently provides support for global change research in the RISE, GEM and CEDAR programs. RISE (Radiative Inputs of the Sun to Earth) is concerned with solar-photon forcing of the atmosphere, and emphasizes total-solar-irradiance effects. GEM (Geo-space Environment Modeling) is concerned with solar wind-magnetosphere interactions, but not with the lower atmosphere consequences such as mapping the magnetospheric electric fields to the troposphere. CEDAR (Coupled Energetics and Dynamics of Atmospheric Regions) is concerned with coupling between the upper and middle atmosphere, but it has no component addressing the lower atmosphere and climate change. The Middle Atmosphere Research Initiative (MARI) has been proposed to improve the understanding of the composition and structure of the middle atmosphere, which is determined by complex relationships among the chemical, dynamical, and radiation properties. NASA funds research on the Sun and near-Earth space, and in its Earth Science and Applications Division is performing basic research on stratospheric and tropospheric processes. NASA has committed resources to long-term monitoring of total solar irradiance, and to the monitoring and modeling of atmospheric ozone content. The DOD also funds research on near-Earth space and the atmosphere, where such changes are relevant to military applications.

The NOAA program in Climate and Global Change is called Atmospheric Response to the Changing Sun and will focus on describing the transfer of energy from the magnetosphere to the lower atmosphere. An example is the mapping of magnetospheric electric fields to the troposphere. The NOAA program takes advantage of NOAA's long-term monitoring efforts with the NOAA and GOES satellites.

8.2 USGS Relationship to Global Change. The Global Change and Climate History Program (GCHP) of the U.S. Geological Survey (USGS) Global Change Research Program seeks to accomplish the following objectives:

- Document the natural variability and rates of climate change on all timescales;
- Document and assess the consequences of climate change on terrestrial and marine environments;
- Improve the scientific basis for understanding the causes of climate change;
- Develop and improve methods for reconstructing past climates and environments from the geologic record;
- Provide paleoenvironment datasets for testing model simulations;
- Improve our understanding of the links between climate variation and surficial processes;
- Improve our understanding of biogeochemical cycles on local to global scales;
- Document and understand the role of volcanic emissions in global change.

To accomplish these objectives, the GCHP Program is organized into the following 7 task elements:

- Paleoclimate Research
- Cold Regions Research
- Climates of Arid/Semi-Arid Regions
- Biogeochemical Dynamics
- Volcano Emissions
- Sea Level Change
- Geomagnetism/Climate Interactions

8.2.1 Geomagnetism and Global Change. Global change processes have strong expression in the geomagnetic field on a broad time scale from 10^6 to 10^{-3} years.

- 10^6-10^4 years: Sea level changes linked to geomagnetic field reversals.

- 10^3 years: Earth's magnetic field has decreased by a factor of 2 in the last 2000 years. (Implications for climate, cosmic radiation, field reversals in 4000 AD?)

- 10^1 years: Global temperature patterns - quasi-biennial oscillation (QBO) correlate with 11 year geomagnetic activity and 10 cm solar flux cycle (Labitske 1986).

- 10^1-10^0 years: Core-mantle coupling "geomagnetic jerk" of 1969-1970.

- 10^0-10^{-3} years: Electromagnetic coupling between magnetosphere/ionosphere and thermosphere/atmosphere. Earth's ring current changed for 2 months by magnetic storm of February 1986.

APPENDIX A

ACRONYMS AND ABBREVIATIONS

ACE	Advanced Composition Explorer
A/D	Analog-to-Digital signal converters
AE	Auroral Electrojet
AFB	Air Force Base
AFGWC	Air Force Global Weather Central
AFMC	Air Force Materiel Command
AFOSR	Air Force Office of Scientific Research
AFSFC	Air Force Space Forecast Center
AFSPACECOM	Air Force Space Command
AGDB	Astrogeophysical Database (AFSFC)
AN/FMQ-7	Solar Observing Optical Network (SOON) telescope
AN/FRR-95	Radio Solar Telescope Network (RSTN) telescope
AN/FMQ-12	Digital Ionospheric Sounder System (DISS) instruments
ap index	Mean 3-hour planetary magnetic activity index
Ap index	Daily global planetary geomagnetic index
AUTODIN	Automated Digital Network
AWN	Automated Weather Network
AWS	Air Weather Service
AWSTL	Air Weather Service Technical Library
AZA	Auroral Zone Absorption
BGS	British Geological Survey
BM/C^3	Battle Management/Command, Communication, and Control
BMEWS	Ballistic Missile Early Warning System
C^{2}E	Command Center Element
CCD	Charge-coupled-device
CD-ROM	Compact Disk-Read Only Memory
CEDAR	Coupled Energetics and Dynamics of Atmospheric Regions
CME	Coronal Mass Ejection
COSTIP	Coordinated Study of Terrestrially Important Phenomena
COSTR	Collaborative Solar-Terrestrial Research
COTS	Commercial-off-the-shelf
CRRES	Combined Chemical Release and Radiation Effects on Satellites
CSEF	Committee for Space Environment Forecasting
DIPS	Digital Image Processing System
DISS	Digital Ionospheric Sounding System
D-layer	Daytime region of the Earth's lower ionosphere
DMSP	Defense Meteorological Satellite Program
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior

DOT	Department of Transportation
Dst	Storm Time Index
EHF	Extremely High Frequency
EOS	Earth Observing System
ERL	Environmental Research Laboratories
ESSA	Environmental Science Services Administration
ESA	European Space Agency
EUV	Extreme Ultraviolet
FAA	Federal Aviation Administration
FAST	Fast Auroral Snapshot Explorer
F-layer	Upper region of the Earth's ionosphere
F10	Solar radio flux at 10.7cm wavelength (2800 MHz)
foF2	Maximum HF frequency reflected by the upper ionosphere
GBI	Ground Based Interceptor
GCHP	Global Change and Climate History Program
GEM	Geospace Environment Modeling
GEP	Ground Entry Points
GGS	Global Geospace Science
GIN	Geomagnetic Information Node
GLE	Ground-Level Event
GMCM	Global Magnetospheric Circulation Model
GOA	Government of Australia
GOAL	Galactic Origin and the Acceleration Limit Program
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GRAM	Global Reference Atmosphere Model
GSA	General Services Administration
GSFC	Goddard Space Flight Center
GSM	Global Solar Mission
GSTS	Ground-based Surveillance Tracking System
GTO	Geosynchronous Transfer Orbit
H-alpha	Hydrogen-alpha spectral line (6562.8 Angstroms)
HESP	High Energy Solar Physics
HF	High Frequency
HFDF	High Frequency Direction Finding
HLMS	High Latitude Monitoring Station
HLISM	High Latitude Ionospheric Specification Model
ICE	International Cometary Explorer
ICSU	International Council of Scientific Unions
IFM	Ionospheric Forecast Model
IFTUs	In-Flight Target Updates
IM	Ionospheric Models
IMI	Inner Magnetosphere Imager
IMP	Interplanetary Monitoring Platform
INTERMAGNET	International Real-Time Magnetic Observatory Network
INTERNET	Communications network
IONCAST	Ionospheric effects on HF communications model
IONS	Ionospheric Sensing

IRI	International Reference Ionosphere
ISAS	Institute for Space and Astronautical Science
ISEM	Integrated Space Environmental Models
ISP	Interplanetary Shock Propagation Model
ISTP	International Solar-Terrestrial Physics
IUWDS	International Ursigram and World Days Service
LANL	Los Alamos National Laboratory
LORAN	Long-Range Navigation System
LUF	Lowest Usable Frequency
MM	Magnetospheric Models
MSFM	Magnetospheric Specification and Forecast Model
MSM	Magnetospheric Specification Model
MSV	Mechanisms of Solar Variability
MUF	Maximum Usable Frequency
NAM	Neutral Atmospheric Model
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NAVSOC	Naval Satellite Operations Center
NESDIS	National Environmental Satellite, Data, and Information Service
NESS	National Environmental Satellite Service
NGDC	National Geophysical Data Center
NGIC	National Geomagnetic Information Center
NNSS	Navy Navigation Satellite System
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Air Defense Command
NRaD	Navy Research and Development
NRL	Naval Research Lab
NSF	National Science Foundation
OFCM	Office of the Federal Coordinator for Meteorological Services and Supporting Research
OL-A	Operating Location-A (Asheville, NC)
OMB	Office of Management and Budget
ONR	Office of Naval Research
OTH-B	Over-the-Horizon Backscatter radar
OTHR	Over-The-Horizon Radar
PAVE PAWS	Sea-Launched Ballistic Missile early warning radar
PCA	Polar Cap Absorption
PIMS	Plasma Interactions Monitoring System
PL/GP	Air Force Phillips Laboratory/Geophysics Division
PNL	Pacific Northwest Laboratories
PRISM	Parameterized Real-time Ionospheric Specification Model
RAIDS	Remote Atmospheric and Ionospheric Detection System
RFI	Radio Frequency Interference
RGON	Remote Geophysical Observing Network
RIMS	Radio Interference Measuring Set
RISE	Radiative Inputs of the Sun to Earth
RSTN	Radio Solar Telescope Network
RV	Reentry Vehicle

SAMPEX	Solar Anomalous Magnetospheric Particle Experiment
SATCOM	Satellite Communications
SEON	Solar Electro-optical Observing Network (USAF)
SEL	Space Environment Laboratory (NOAA)
SELDADS	SEL Data Acquisition and Display System
SELSIS	Space Environment Laboratory Solar Image System
SEM	Space Environment Monitoring
SESC	Space Environment Services Center
SESS	Space Environmental Support System
SETT	Space Environmental Technology Transition
SEU	Single Event Upset
SFIR	Swept Frequency Interferometric Radiometer
SHF	Super High Frequency
SID	Sudden Ionospheric Disturbance
SITE	Solar Influences on the Terrestrial Environment
SMM	Solar Maximum Mission
SOHO	Solar and Heliospheric Observatory
SOON	Solar Observing Optical Network (USAF)
SPA	Sudden Phase Anomaly
SPADOC	Space Defense Operation Center
SPAN	Space Plasma Analysis Network (NASA)
SRAG	Spaceflight Radiation Analysis Group (NASA)
SRBL	Solar Radio Burst Locators
SSI/ES-2	Ionospheric Plasma Drift/Scintillation Monitor (DMSP Sensor)
SSJ/4	Precipitating Electron/Ion Spectrometer (DMSP Sensor)
SSM	Fluxgate Magnetometer (DMSP Sensor)
SSULI	Ultraviolet Limb Imager (DMSP Sensor)
SSUSI	Ultraviolet Spectrographic Imager (DMSP Sensor)
S/T	Solar-Terrestrial
STEP	Solar-Terrestrial Energy Program
STP	Solar-Terrestrial Physics
SWIM	Solar Wind Interplanetary Monitor
SWT	Solar Wind Transport
SXI	Solar X-ray Imager
TEC	Total Electron Content
TED	Total Energy Detectors
TIMED	Thermosphere-Ionosphere-Mesosphere Energetic and Dynamics Mission
TIROS	Television and Infrared Observation Satellite
TISS	Transionospheric Sensing System
TSS	Tethered Satellite System
UARS	Upper Atmosphere Research Satellite
UHF	Ultra-high Frequency
UK	United Kingdom
UPS	Uninterruptible Power Supply
USA	U.S. Army
USAF	U.S. Air Force
USAFETAC	USAF Environmental Technical Applications Center
USCG	U.S. Coast Guard

USDA	Department of Agriculture
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
USIA	U.S. Information Agency
USN	U.S. Navy
VHF	Very High Frequency
VLF	Very Low Frequency
VMG	Vector Magnetograph
VSH	Vector Spherical Harmonic Model
WBMOD	Wide Band Ionospheric Scintillation Model
WDC-A for STP	World Data Center-A for Solar-Terrestrial Physics (NOAA)
WISP	Waves in Space Plasma

APPENDIX B

LIST OF SUPPORTING DOCUMENTATION

1. USAF-NOAA Memorandum of Agreement for Cooperative Space Environmental Support Activities

2. USAF-NOAA-USN-USA Memorandum of Agreement for Environmental Support for Space Transportation System

3. USAF-NOAA Support Agreement for Joint Operation of the High Latitude Monitoring Station (HLMS)

4. USAF-NOAA Memorandum of Agreement for Cooperative Manning of the Learmonth, Australia, Solar Observing Optical Network (SOON) Facility

5. NOAA-USAF Memorandum of Understanding for the Solar X-ray Imager on GOES

6. Arrangement Concerning Collaborative Observations between NOAA and the Department of Science, Government of Australia, on Solar Radio and Optical Emissions at Culgoora Observatory, New South Wales

7. Stations that contribute data to the International Ursigram and World Days Service, Agreement data exchange

8. NASA Shuttle Operations Program Requirements Document--Space Environment Services

9. NASA-NOAA Memorandum of Understanding for Providing and Using ISEE-3 Spacecraft Data

10. Los Alamos-USAF Letter of Agreement concerning the use and dissemination of energetic particle data

11. Excerpt from DOC Organization Order 25-5B (solar-terrestrial services)

12. Excerpts from Guide to International Data Exchange Through the World Data Centers

13. USAF AWS-NOAA EDIS Memorandum of Agreement for DMSP Data Archiving

14. USAF AWS-NOAA EDIS Memorandum of Agreement for SEON Data Archiving

15. USAF AWS-NOAA EDIS Memorandum of Agreement for RSTN Data Archiving

16. USGS-NOAA Memorandum of Agreement for Geomagnetic Data

17. NOAA Satellite Archiving Plan

18. Navigation and Communication Systems in the FAA National Airspace System Subject to Solar-Terrestrial Disturbances

19. LORAN Transmitter and Receiver Locations of the USCG

APPENDIX C

TERMS OF REFERENCE OF THE COMMITTEE FOR SPACE ENVIRONMENT FORECASTING

TERMS OF REFERENCE
FOR
INTERDEPARTMENTAL COMMITTEE
FOR
METEOROLOGICAL SERVICES AND SUPPORTING RESEARCH (ICMSSR)

COMMITTEE FOR SPACE ENVIRONMENT FORECASTING (CSEF)

1. PURPOSE

The Committee for Space Environment Forecasting shall be the principal means for conducting detailed business for the ICMSSR in the areas of integration of current and future solar-terrestrial services. It shall be responsible for:

a. Collecting and consolidating user requirements within its assigned areas.

b. Developing those parts of proposed Federal Plans for Meteorological Services within its assigned areas for efficient utilization of resources to meet valid user requirements.

c. Conducting a continuing, systematic review of current and programmed activities within its assigned areas and recommending changes in Federal Plans to more efficiently utilize resources in meeting valid user requirements.

d. Reporting periodically on the implementation of those parts of Federal Plans within its assigned areas.

e. Coordinating matters within assigned areas affecting more than one member agency to assure maximum collaboration of current and future activities consistent with effective and economical accomplishments of mission requirements.

f. Considering other matters as directed by the ICMSSR.

2. MEMBERSHIP

a. The Committee for Space Environment Forecasting shall consist of permanent representatives designated by the following agencies of the U.S. Government and chaired by the representative of the Department of Commerce:

Department of Commerce
Department of Defense
Department of Energy
Department of Interior
Federal Aviation Administration
National Aeronautics and Space Administration
National Science Foundation

b. Additional agencies of the U.S. Government may participate as members when matters under consideration are of concern to them. Subject to the concurrence of the members, public and industrial organizations having a substantial interest in specific matters may be invited by the Chairman to participate in discussions of these matters.

c. A permanent secretary shall be provided by the Federal Coordinator for Meteorological Services and Supporting Research (hereinafter called Federal Coordinator).

d. Each agency shall designate an alternate. Such designation and changes thereto shall be made by memorandum to the Chairman.

3. RULES OF PROCEDURE

a. Meetings shall be called by the Chairman or at the request of one or more members and shall normally be convened in facilities provided by the Federal Coordinator. Meetings shall be held with sufficient frequency to assure prompt handling of committee business.

b. Decisions by the Committee shall be on the basis of agreement by all members whose agency is or will be a party to actions pursuant to the decision. Members may abstain from voting without prejudice to the decisions of the Committee. Any member may reserve his position pending agency clearance or instructions. Decisions may be reached in formal session or by approval on an individual basis of papers circulated among the members by the Chairman.

c. If all members whose agency is or will be a party to actions pursuant to a decision are unable to reach agreement on the item, the opposing views, fully documented, will be promptly forwarded by the Chairman to the ICMSSR.

d. Agreements reached by the Committee shall be implemented by member agencies without further action, except:

(1) When the agreement is in response to an item referred to the Committee by the ICMSSR, the Chairman will consult the Chairman of the ICMSSR to determine whether ICMSSR review is required.

(2) When the agreement involves a substantial deviation from the approved Federal Plan, review by the ICMSSR will be required.

(3) When the agreement involves or relates to programs or functions under the purview of another committee, concurrence by such committee will be required.

(4) When any member requests that the agreement be approved by the ICMSSR, review by the ICMSSR will be required.

e. Items for consideration by the Committee shall be presented through the Executive Secretary of the Committee.

f. Agenda and Record of Actions of meetings of the Committee shall be prepared and disseminated to members, the ICMSSR and the Federal Coordinator by the Executive Secretary of the Committee. The record of comment and positions taken on agenda items by agency members will be cleared by telephone with the respective members prior to publishing of the Record of Actions. Complete records of the committee and working groups shall be maintained in the office of the Federal Coordinator.

g. The Committee may establish additional rules of procedure for conduct of business; however, the establishment of additional groups must have prior approval of the ICMSSR.

h. Amendments to these Terms of Reference will be made by the ICMSSR.

APPENDIX D

SELECTED BIBLIOGRAPHY

TOPIC - The Sun/Solar Activity

Bray, R.J., and R.E. Loughead, Sunspots, John Wiley and Sons, Inc., New York, 1965.

Eddy, J., A New Sun. The Solar Results from Skylab, NASA SP-402, 1979.

Gibson, E.G., The Quiet Sun, NASA SP-303, 1973.

Giovonelli, R., Secrets of the Sun. Columbia Univ. Press, 1984.

Kuiper, The Sun, University of Chicago Press, 1953.

Nicolson, I., The Sun, Rand-McNally and Company, 1982.

Noyes, R.W., The Sun, Our Star, Harvard University Press, 1982.

Priest, E.R. (ed.), Solar Flare Magnetohydrodynamics, (The Fluid Mechanics of Astrophysics and Geophysics, Vol. 1), Gordon and Breach Science Publishers, New York, 1981.

Sturrock, P.A., ed., Solar Flares, a Monograph From Skylab Workshop II, Colorado Associated University Press, 1976.

Svestka, Z., Solar Flares, Volume 8, Geophysics and Astrophysics Monographs, D. Reidel Publishing Co., Dordrecht, Holland, 1976.

White, O.R., Solar Output and Its Variation, Colorado Associated University Press, Boulder, Colorado, 1977.

Zirin, H., Astrophysics of the Sun, Cambridge University Press, New York, 1988.

TOPIC - The Geomagnetic Field

Chapman, S., and J. Bartels, Geomagnetism, International Series of Monographs on Physics, Vols. I and II, Oxford University Press, London, England, 1940.

Campbell, W.H., Beginning Geomagnetism Lectures.

Mayaud, P.N., Derivation, Meaning, and Use of Geomagnetic Indices, Geophysical Monograph 22, American Geophysical Union, Washington, D.C., 1980.

Parkinson, W.D., Introduction to Geomagnetism, Scottish Academic Press Ltd., Edinburgh, Scotland, 1983.

TOPIC - The Magnetosphere/Ionosphere

Brekke, A., and A. Egeland, The Northern Lights, Springer Verlag, 1983.

Brier, H.S., and W.I. Orr, VHF Handbook for Radio Amateurs, Radio Publication Inc., 1974.

Chamberlain, J.W., Physics of the Aurora and Airglow, International Geophysics Series, Vol. II, Academic Press, New York, 1961.

Davies, K., Ionospheric Radio, Peter Peregrinus Ltd., London, United Kingdom, 1990.

Eather, R.H., Majestic Lights, American Geophysical Union, Washington, D.C., 1980.

Gassman, G.J., The Effect of Disturbances of Solar Origin on Communications, Pergamon Press, 1963.

Lanzerotti, L.J., (ed.) Impacts of Ionospheric/Magnetospheric Process on Terrestrial Science and Technology, in Solar System Plasma Physics, Vol. III, North Holland Publishing Co., 1979.

Massey, H.S.W., and R.L.F. Boyd, The Upper Atmosphere, Chapter 9, Benham and Company Limited, 1959.

McCormac, B., and A. Omholt, Atmospheric Emissions, Van Nostrand Reinhold Company, 1969.

Pope, J.H., and R.H. Grubb, Effects of Solar Disturbances on Radio Communication With Aircraft, NOAA Technical Report ERL 233-SEL 22 Available Through the Government Printing Office.

Ratcliffe, J.A., An Introduction to the Ionosphere and Magnetosphere, Cambridge University Press, London, England, 1972.

Saveskie, P.N., Radio Propagation Handbook, Tab Books, Inc., Blue Ridge Summit, Pennsylvania, USA, 17214, 1980.

The Radio Amateurs Handbook, American Radio Relay League, Newington Connecticut, USA, 06111, 1992.

TOPIC - Energetic Particles

Barish, R.J., Understanding In-Flight Radiation, In-Flight Radiation Services Inc., New York, 1989.

Beir, V., Health Effects of Exposure to Low Levels of Ionizing Radiation, National Academy Press, Washington, D.C., 1990.

Breneman, H.H., and E.C. Stone, Solar Coronal and Photospheric Abundances from Solar Energetic Particle Measurements, *Astrophys. J. Lett.*, 299:L57 1985.

Feynman, J., T.P. Armstrong, L. Dao-Gibner, and S. Silverman, New Interplanetary Proton Fluence Model, *J. Spacecraft and Rockets*, 27:403, 190.

Feynman, J., and S. Gabriel, eds., Proceedings of the JPL Workshop in the Interplanetary Charged Particle Environment, NASA JPL Publication 88-28, Jet Propulsion Laboratory, Pasadena, California, 1988.

Hamilton, D.C., Radial Transport of Energetic Solar Flare Particles from 1 to 6 AU, *J. Geophys. Res.*, 82:2159, 1977.

Kahler, S.W., The Role of the Big Flare Syndrome in Correlations of Solar Energetic Protons and Associated Microwave Parameters, *J. Geophys. Res.*, 87:34

Lanzerotti, L.J., Solar System Plasma Physics, North Holland Publishing Company, New York, 1979.

McGuire, R.E., T.T. Von Rosenvinge, and F.B. McDonald, The Composition of Solar Energetic Particles, *Astrophys. J.*, 301:938, 1986.

Shea, M.A., and D.F. Smart, A Summary of Major Solar Proton Events, *Solar Phys.*, 127:297, 1990.

Shea, M.A., and D.F. Smart, History of energetic solar protons for the past three solar cycles including Cycle 22 update, in Biological Effects and Physics of Solar and Galactic Cosmic Radiation, Swenberg, C.E., Horneck, G., and Stassinpoulos, E.G., ed., Plenum Press, New York, 1992 (in Press).

Smart, D.F., and M.A. Shea, Predicting and modeling solar flare generated proton fluxes in the inner heliosphere, in Biological Effects and Physics of Solar and Galactic Cosmic Radiation, C.E. Swenberg, G. Horneck, and E.G. Stassinpoulos, ed., Plenum Press, New York, 1992 (in press).

Svestka, Z., and P. Simon, eds., Catalog of Solar Particle Events 1955-1969, D. Reidel Publishing Co., Dordrecht, Holland, 1975.

Van Hollebeke, M.A.I., L.S. Ma Sung, and F.B. McDonald, The Variation of Solar Proton Energy Spectra and Size Distribution with Heliolongitude, *Sol. Phys.*, 41:189, 1975.

Zirker, J.B., Coronal Holes and High Speed Wind Streams, Colorado Associated University Press, Boulder, Colorado, 1977.

_______ Health Effects of Low Level Ionizing Radiation, Physics Today, August, 1991.

ADDITIONAL READINGS

Akasofu, S.I., and S. Chapman, Solar-Terrestrial Physics, Oxford University Press, London, 1972.

Allen, C.W., Astrophysical Quantities, Third Ed., The Athlone Press, London, England, 1973.

Brown, S., All About Telescopes, Edmund Scientific Co. Barrington, NJ, 1967.

Bruzek, A., and J. Durrant, Illustrated Glossary for Solar and Solar-Terrestrial Physics, Astrophysics and Space Science Library, Vol. 69, D. Reidel Publishing Co., Boston, MA, 1977.

Donnelly, R.F., (ed.) Solar-Terrestrial Predictions, Proceedings of a Workshop at Boulder, Colorado, U.S. Dept. of Commerce, NOAA/ERL, U.S. Government Printing Office, 1979.

Garrett, H.B. and C.P. Pike, (ed.) Space Systems and Their Interaction with Earth's Space Environment, American Institute of Aeronautics and Astronautics, New York, 1980.

Gauthreax, Jr., S.A., Animal Migration, Orientation and Navigation, Chapter 5, Academic Press, New York, 1980.

Gilliland, J.M., Solar-Terrestrial Physics: A Glossary of Terms and Abbreviations, Royal Aircraft Establishment Technical Report 67158, Ministry of Technology, Farnborough, Hants., 1967.

Gnevyshev, M.N., and A.I. Ol', Editors, Effects of Solar Activity on the Earth's Atmosphere and Biosphere, Israel Program for Scientific Translations, Keter Publishing House Jereusalem Ltd. 1977.

Harding, R., Survival in Space, Routledge, New York, 1989.

Hargreaves, J.K., The Solar-Terrestrial Environment, Cambridge University Press, Cambridge, UK 1992.

Hess, W.T., Introduction to Space Science, Gordon and Breach Science Publishers, New York.

Herman, J.R., and R.A. Goldberg, Sun, Weather and Climate, NASA SP-426, U.S. Government Printing Office, 1978.

Johnson, N.L. and D.S. McKnight, Artificial Space Debris, Orbit Book Co., 1987.

Jursa, A.S., (ed.) Handbook of Geophysics and the Space Environment, Air Force Geophysics Laboratory, Air Force Systems Command, USAF, 1985.

Kundu, M.R., and T.E. Gergely, eds., Radio Physics of the Sun, IAU Symposium No. 86, International Astronomical Union, D. Reidel Publishing Co., Boston, MA, 1980.

Mangis, S.J., Introduction to Solar-Terrestrial Phenomena and The Space Environment Services Center, U.S. Government Printing Office, Washington, DC, 1975.

McCormac, B.M., (ed.) Weather and Climate Responses to Solar Variations, Colorado Associated University Press, Boulder, Colorado, 1983.

McKinnon, J.A., August 1972 Solar Activity and Related Geophysical Effects, NOAA Technical Memorandum ERL SEL-22, U.S. Government Printing Office, 1972.

Reviews of Geophysics (Contributions in Solar-Planetary Relationships), 25, No. 3, 1987.

Reviews of Geophysics, 1991 Supplement, (Contributions in Solar-Planetary Relationships), 1991.

Workshop on Satellite Drag (Proceedings), NOAA, Space Environment Laboratory, Boulder, Colorado, May 1982.

Roth, G.D., (ed.) Astronomy: A Handbook; Sky Publishing Corporation, Cambridge, MA, 1975.

Simon, P.A., M.A. Shea, and G. Heckman, (ed.) Solar-Terrestrial Predictions, Proceedings of a Workshop at Meudon, France, U.S. Dept. of Commerce, NOAA, U.S. Government Printing Office, 1986.

Thompson, R.J., D.J. Cole, P.J. Wilkenson, M.A. Shea, D. Smart, and G. Heckman, (ed.), Solar-Terrestrial Predictions, Proceedings of a Workshop at Leura, Australia, U.S. Dept. of Commerce, NOAA, U.S. Government Printing Office, 1990.

The International System of Units (SI), NBS Special Publication 330, 1986.

Anonymous, Space Environment Services Center Products and Services User Guide, Space Environment Laboratory Special Report, 1993, available from SESC, NOAA R/E/SE, 325 Broadway, Boulder, CO 80303.

Anonymous, Introduction to the Space Environment, Space Environment Laboratory Special Report, 1993, available from SESC, NOAA R/E/SE, 325 Broadway, Boulder, CO 80303.

APPENDIX E

ACCOMPLISHMENTS

E.1 USAF Accomplishments

E.1.1 First Digital Ionospheric Sounding System (DISS) Fielded, 1987. DISS, the first automated system to provide near-real-time data, provides critical ionospheric information to the Over-the-Horizon Backscatter radar ensuring accurate detection and correlation of target aircraft. DISS data will also be used to make real-time corrections to ionospheric model outputs, improving support to ionospheric customers.

E.1.2 Solar Electro-optical Observing Network (SEON) Digital Image Processing System (DIPS), 1988. DIPS replaced unsupportable equipment previously used to store solar images, overlay graphic displays on the stored images, and replay sequences of the stored images. DIPS is fielded at each SOON observatory in the SEON and ensures solar analysts have timely and accurate images of solar activity. This data results in improved timeliness and accuracy of solar and geophysical forecasts issued by AFSFC and SESC.

E.1.3 Desert Shield/Desert Storm Support, Aug 90-Mar 91. Air Force Global Weather Central (AFGWC) provided important space environmental support during DESERT SHIELD/DESERT STORM. High frequency radio propagation path forecasts were provided to stateside and deployed communications commands to help them optimize the use of HF radio for transcontinental and tactical communications. The 389 daily planning forecasts, provided to HF frequency managers, helped USCENTCOM prevent communications bottle-necks on transcontinental HF circuits. Approximately 3,970 short wave fade advisories, radio noise, and geomagnetic storm warnings were transmitted, helping HF communications operators compensate for frequent interruptions caused by the space environment. AFGWC helped resolve 141 satellite control anomalies in the AFSATCOM, NATO SATCOM, and GPS systems increasing the accuracy and availability of three-dimensional navigational data and communication for tactical units.

E.1.4 SEON Upgrade Phase I (SEON I) Contract Award, Nov 90. SEON I replaces unsupportable equipment at the solar observatories, ensuring the availability of critical solar observations. These observations serve as the foundation of AFSFC and SESC solar and geophysical forecasts.

E.1.5 Transionospheric Sensing System (TISS) Prototype Contract Awarded, Sep 91. TISS will replace an unsupportable polarimeter network for providing total electron measurements. TISS data will be used to improve support to space and missile early warning surveillance radars and will be used as near-real-time inputs to ionospheric models.

E.1.6 Air Force Space Forecast Center (AFSFC) Initial Operating Capability, Jun 92. AFSFC assumed part of the space environmental support provided by the Air Force Global Weather

Central (AFGWC). This was a key milestone in the establishment of AFSFC as the focal point for space environmental support to the Department of Defense (DOD).

E.1.7 AWS Switched to the INTERNET Magnetometer Network, Jun 92. Using INTERNET allows AWS to save maintenance costs by disbanding its own five-station network. INTERNET allows access to a twelve-site network, with the potential of adding even more sites. Because of its larger size, INTERNET data results in better global representations of magnetic disturbances, resulting in improved support to ionospheric and space customers.

E.1.8 Space Environmental Technology Transition (SETT) Operational Software Development Contract Awarded, Sep 92. This contract facilitates the installation of a new, more accurate generation of space models at AFSFC and USAFETAC along with the development of graphics applications algorithms used to translate model outputs into customer products. These models will, for the first time, use near-real-time observations of the space environment to make the model output more accurate. Some SETT models will improve upon models already operational at AFSFC (i.e., the ionospheric specification models) while other models will provide capabilities currently unavailable (i.e., ionospheric forecast, magnetospheric specification, and magnetospheric forecast models).

E.1.9 AFSFC Achieved Full Operating Capability, Oct 92. AFSFC assumed all space environmental support from AFGWC, becoming the focal point of space environmental support to the DOD. This high-tech facility has its own computer system dedicated to receiving and processing space environmental data and running space environmental models. AFSFC is the source of both classified and unclassified space environmental support for the DOD.

Durothum Becton

R 11/22/93

P 11/29/93

COMMITTEE FOR SPACE ENVIRONMENT FORECASTIN

DR. ERNEST HILDNER, Chairman
Department of Commerce

MAJ WILLOW CLIFFSWALLOW
Department of Defense
United States Air Force

DR. WILLIAM LUTH
Department of Energy

MR. JOHN D. WOOD
Department of the Interior

DR. ARTHUR W. GREEN, JR.
Department of the Interior

DR. GEORGE L
National Aeronautics and

DR. RICHA
National Sc

MR. JAMES B. HAR
Office of the
for Meteorol
Suppor