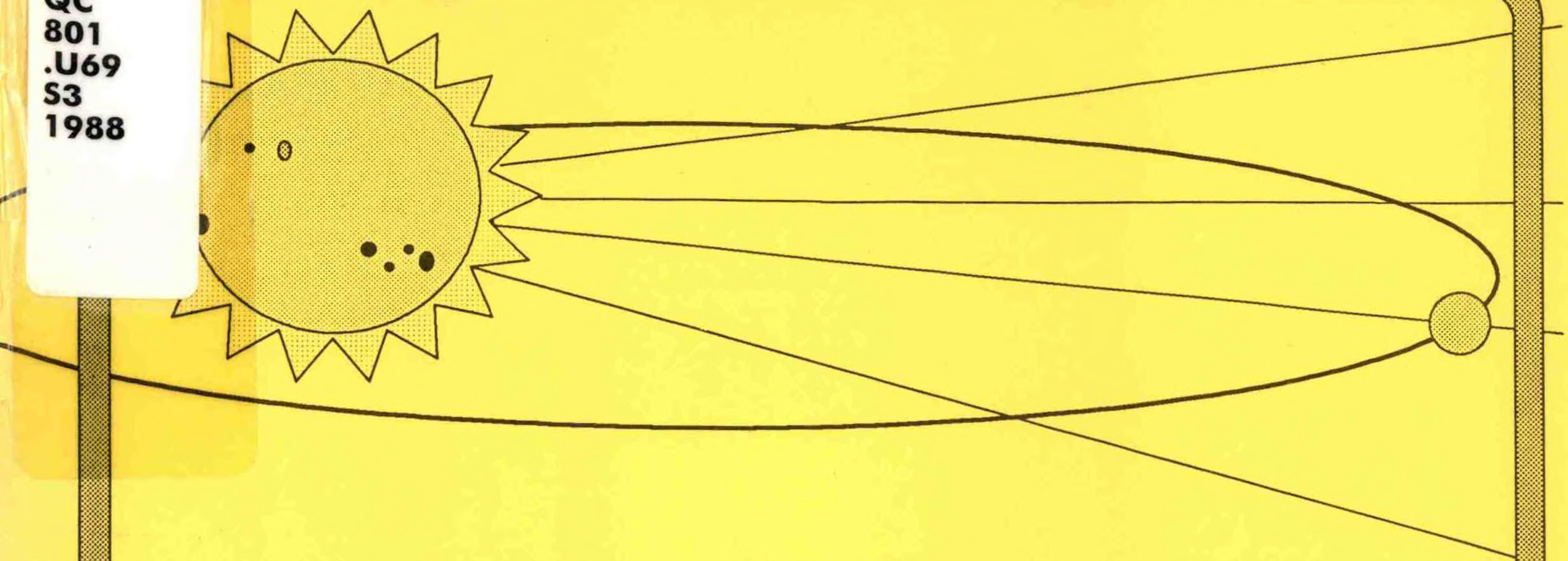

SPACE ENVIRONMENT LABORATORY

ANNUAL REPORT

FY 1988

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Environmental Research Laboratories
Space Environment Laboratory

SPACE ENVIRONMENT LABORATORY

ANNUAL REPORT – FY 1988
October 1, 1987, to September 30, 1988

Ernest Hildner, Director
Space Environment Laboratory
Boulder, Colorado

January 1989

DEPARTMENT OF COMMERCE ★ UNITED STATES OF AMERICA ★

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Department of Commerce

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FOREWORD

The Space Environment Laboratory (SEL) of the National Oceanic and Atmospheric Administration (NOAA's) Environmental Research Laboratories (ERL) has been providing real-time space environment data and forecasts for more than 20 years. The beginning of FY 1987 (October 1986) also marked the start of Solar Cycle 22, the third cycle for which SEL has provided services. In addition to its service activities, SEL has been a leading research laboratory, first in ionospheric physics and later in space physics.

Since 1982, research and development within SEL have been focused on the understanding of space environment disturbances, and on developing new operational tools to improve the real-time service activities.

The physical system of concern is very large, extending from the Sun through the interplanetary medium to Earth's magnetosphere, ionosphere, and upper atmosphere. Thus, to provide the optimum space environment services to the broad community of government agencies, industry, and private citizens, real-time data on solar activity, interplanetary disturbances, and Earth's magnetosphere are required. The observations, analysis tools, and models must encompass a wide set of phenomena occurring in this large system.

Obviously this is a larger task than can be undertaken by any single group. Consequently we have developed an extensive cooperative effort, involving several agencies and research organizations, that enhances our ability to provide space environment services and supporting research and development. SEL is the lead civilian agency for providing real-time services. It works hand in hand with the U.S. Air Force (USAF), to the extent that the Space Environment Services Center in Boulder is staffed with SEL personnel and a small group from USAF. Both NOAA and USAF also provide major components of the real-time sensors.

The fact that SEL couples a real-time, 24-hour/day, 7-day/week service with its research and development activities sets the Laboratory uniquely apart from other components of NOAA's Office of Oceanic and Atmospheric Research.

This Annual Report documents some of the major activities undertaken in FY 1987. The reader is reminded that space environment disturbances are pseudo-cyclical in their characteristics, having about an 11-year period commensurate with the 11-year sunspot cycle. The advances in systems and research documented here will stand SEL in good stead during the next several years, as disturbances reach their peak levels with sunspot maximum. However, there are many areas still needing improvement, some of which are discussed in this report.

GLOSSARY

A-Index – A linear magnetic index derived from the K-index.

AE Index – An auroral-zone magnetic index measuring, at any time, the total excursion of the horizontal component between the station showing the largest positive bay and the station with the largest negative bay.

CCD – Charge-Coupled Device.

CIRES – Cooperative Institute for Research in Environmental Sciences, University of Colorado and NOAA.

CME – Coronal Mass Ejection.

DCE – Despin Control Electronics.

ERL – Environmental Research Laboratories, NOAA.

ESA – European Space Agency.

FY – Fiscal Year.

GOES – Geostationary Operational Environmental Satellite, operated by NOAA.

H-alpha – A red spectral line of hydrogen.

IGM – Interplanetary Global Model.

IMP – Interplanetary Monitoring Platform spacecraft.

IPS – InterPlanetary Scintillations of extra-galactic radio sources.

K-Index – A pseudo-logarithmic magnetic index based on the greatest change of a magnetic-field component during a specified 3-hour period.

MHD – MagnetoHydroDynamic.

MRAO – Mullard Radio Astronomy Laboratory.

NASA – National Aeronautics and Space Administration.

NESDIS – National Environmental Satellite, Data, and Information Service, NOAA.

NOAA – National Oceanic and Atmospheric Administration; also, polar orbiting environmental satellites operated by NOAA.

OMEGA – Global, very-low-frequency radio navigation network.

RAL – Rutherford-Appleton Laboratory, England.

RSTN – Radio Solar Telescope Network.

SEL – Space Environment Laboratory, NOAA/ERL.

SELDADS – Space Environment Laboratory Data Acquisition and Display System.

SELSIS – Space Environment Laboratory Solar Imaging System.

SEM – Space Environment Monitor.

SOHO – Solar Heliospheric Observatory.

SOLWIND – Proposed interplanetary probe for measuring solar-wind parameters.

SOON – Solar Observing Optical Network.

SESC – Space Environment Services Center.

Skylab – Manned NASA spacecraft mission of 1973–1974, equipped with a solar observatory.

SXI – Solar X-ray Imager.

TED – Total Energy Detector.

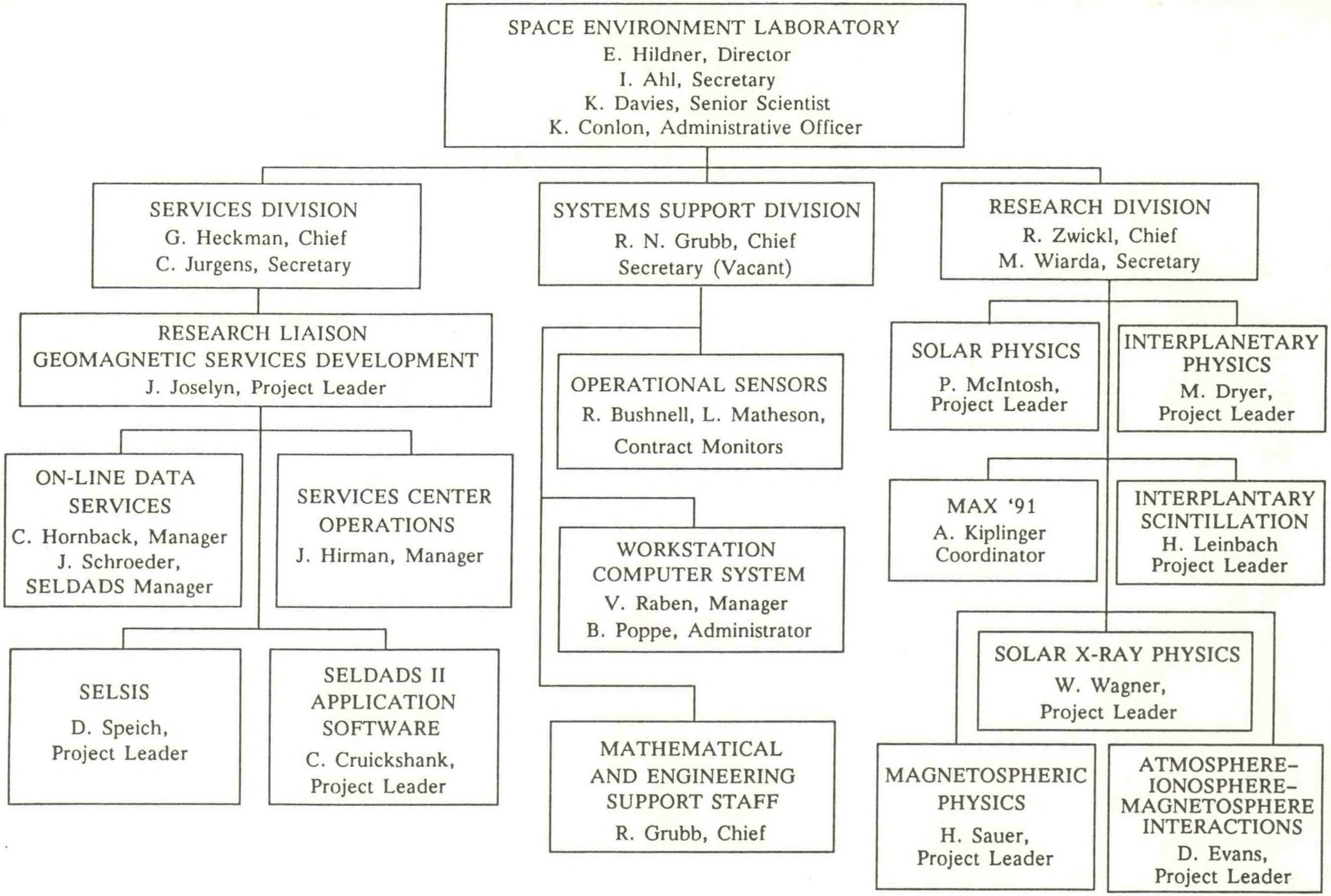
THEO – Computer–based expert forecaster named for THEOphrastus, an ancient astronomer.

TIROS – Television and InfraRed Observation Satellite, operated by NOAA.

USAF – United States Air Force.

WWV – A standard-time-and-frequency radio station in Fort Collins, Colorado, operated by the National Bureau of Standards.

Contents



Space Environment Laboratory Organizational Chart (as of October 1, 1988)

SPACE ENVIRONMENT LABORATORY

Annual Report—FY 1988

INTRODUCTION

As directed in the United States National Space Policy, issued by President Reagan on 5 January 1988, "NOAA will gather data, conduct research, and make predictions about the Earth's environment." The Space Environment Laboratory (SEL) is NOAA's organization to carry out this charge for the near-Earth space environment. SEL is unique in ERL in that it provides an around-the-clock service of real-time monitoring, forecasts, and warnings of solar and space disturbances and, at the same time, conducts research to support and improve the service activities.

SEL is composed of three divisions: Space Environment Services, Research, and Systems Support. Space environment services are provided by the Nation's center for solar-terrestrial services, the Space Environment Services Center. Operated jointly by SEL and the U.S. Air Force Air Weather Service (AWS) in Boulder, Colo., SESC provides monitoring and forecasting services to meet a wide variety of civilian, military, commercial, and Federal agency requirements. These requirements are set out in a new, 5-year National Plan issued by the Federal Coordinator for Meteorological Services and Supporting Research. As solar activity rises toward the maximum of the current cycle, now expected to occur in the first half of FY 1990, the demand for SEL's services is rising rapidly. Figure 1 shows the occurrence of various types of activity compared to the sunspot cycle.

Research and development in the most general sense are carried out in all three divisions. The Research Division carries out research with the dual objectives of improving our understanding of the effects of solar and magnetospheric disturbances on human activities and improving our capabilities to forecast and analyze these events. Research Division staff also serve as the responsible scientists for the real-time detector systems that support the Laboratory's space environment services. The Systems Support Division plans, develops, and provides instrument and data systems. Activities in the Services Division also include the development and implementation of forecasting algorithms, new products, software and systems requirements, forecast verification, and user services.

Activities of SEL are directed toward understanding, monitoring, and forecasting solar and geomagnetic events that have undesirable, harmful, and costly effects on activities on and near Earth, and that may even be health or life threatening. SEL activities encompass real-time collection of solar-terrestrial data; real-time environmental analysis; dissemination of indices and activity summaries; issuance of forecasts, alerts, and warnings of adverse solar-terrestrial conditions; archiving and processing of global data from satellites and observatories; and development of a better understanding of the behavior of the solar-terrestrial environment to yield significant service improvements.

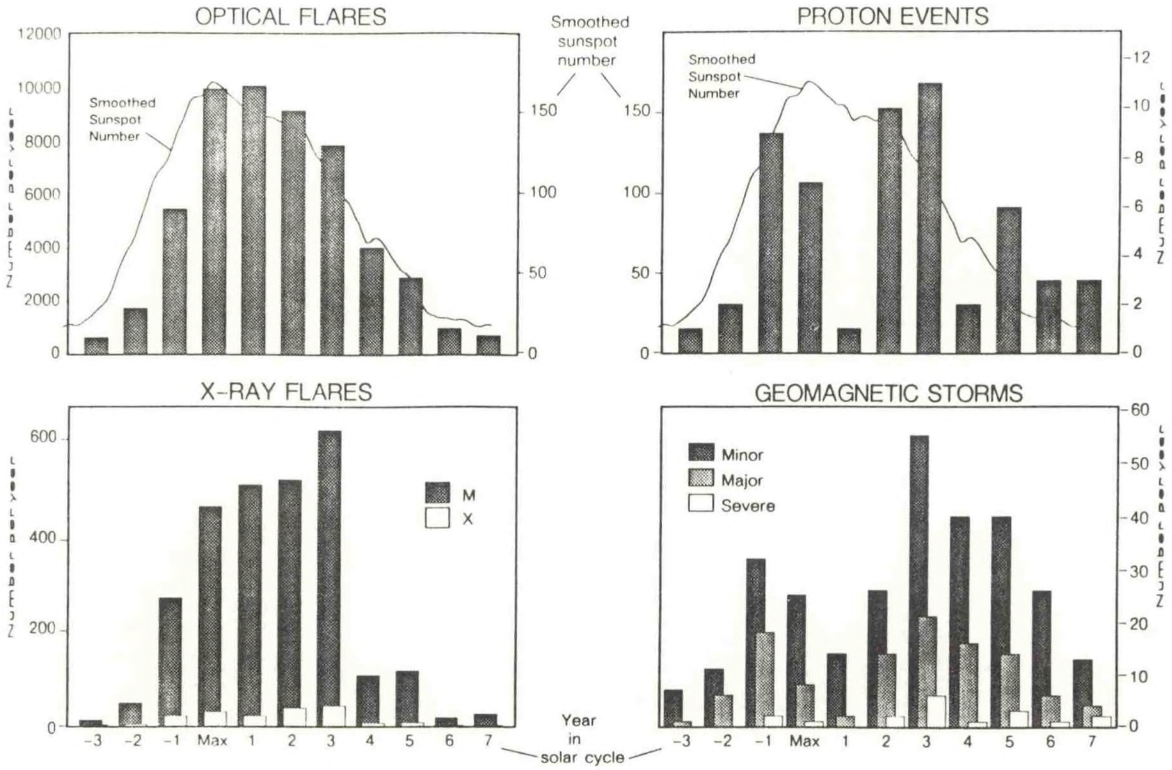


Figure 1. The annual rate of occurrence for optical solar flares, proton events, x-ray flares, and geomagnetic storms observed in Solar Cycle 21 (which began in 1976), compared to the smoothed sunspot number for the same cycle. The new solar cycle that began in 1986 is still rising toward maximum.

Rapid variations in the Sun's output, including solar flares and gigantic ejections of solar mass, and also the slower variations associated with the growth and decay of sunspot cycles, affect activities on Earth. Sometimes the effects are beneficial, but more often they are undesirable, harmful, and costly, and, under special circumstances, may even be health or life threatening. Activities such as these may be affected:

- Satellite operations
  - Orbital variation and lifetime
  - Command and control anomalies
  - Ground-spacecraft communication problems
- Man-in-space
  - Radiation exposure
- Navigation system errors
  - International aviation
  - Ships and submarines
- Scientific research programs
- High-altitude polar flights
  - Radiation exposure

- High-frequency communication problems
  - Intercontinental aviation
  - Ships
  - Military
  - International broadcast
- Remote surveillance degradation
  - Over-the-horizon radar
  - Space-based optical surveillance
- Long-line network interference
  - Transmission lines
  - Pipelines
- Geophysical exploration
  - Magnetic mapping errors
  - Telluric analysis
  - Archaeological studies

Three problems have stood in the way of major improvements in solar-terrestrial services: (1) a lack of adequate measurements to know accurately what is happening in that environment; (2) a lack of sufficient understanding of the physical processes to permit accurate modeling or forecasting of the environment; and (3) the inability, until recently, of data systems to handle the volume of data needed to carry out the services. The programs of all three SEL divisions are designed to solve these problems.

SPACE ENVIRONMENT SERVICES

The Space Environment Services Center (SESC), the national space weather service, operates 24 hours a day, 7 days a week, to maintain up-to-the-minute watch on storms and disturbances in the solar-terrestrial environment. It receives observations from other Federal agencies as well as public and foreign institutes. The data are sent in real time to SESC, where they are used to monitor key variations in solar activity and solar radiation and the effects on Earth's environment. Indices are compiled, activity is summarized, and forecasts are made. These products are issued to programs whose activities are affected by such variations in space weather. SESC also functions as the World Warning Agency for the International Ursigram and World Days Service (IUWDS), operated under the aegis of the International Council of Scientific Unions, to provide international exchange of space weather data and daily forecasts. In this role, SESC exchanges data with similar centers in Regional Warning Centers around the world.

Prediction of the space environment, particularly forecasts of solar and geomagnetic events and background levels, is a key activity in providing space weather service. With the needs of forecasters in mind, a first chapter of a forecaster's manual was compiled in FY 1988 in the form of charts, graphs, and tables taken from published studies.

Energetic electrons at geosynchronous orbit are a source of operating errors and anomalies to satellites that must operate in that environment. To improve service to these users, arrangements were made in FY 1988 with the USAF Global Weather Central to gain data and analysis assistance.

Solar activity occurs in 11-year cycles. A new cycle began in late 1986. This cycle, as measured by sunspot numbers, has risen faster than any of the past cycles in an observation record that dates back to 1848 (Figure 2). The rapid rise has excited interest among users of space environment services, most notably those organizations required to project the lifetimes of satellites several years into the future. The increased level of solar radiation heats the atmosphere and increases atmospheric drag on satellites. The result is a slowing of the satellite along its orbit so that it falls back to Earth much sooner than it would otherwise. Lifetimes of low-Earth-orbit satellites may be reduced by more than 50 percent.

Reviews of the accuracy and outcome of solar cycle predictions were published and briefings provided to government advisory committees and officials on the rise of the new cycle. A prediction for the remainder of Solar Cycle 22 was made using one of the more widely known methods (Figure 3).

As a strategy to gain and focus the attention of scientific colleagues, SEL acquired the support of the Solar Maximum Mission Principal Investigators and held a workshop on Solar Events and their Influence on the Interplanetary Medium (SEIIM). This workshop was planned to promote scientific collaboration and a vigorous exchange of ideas; over 3 days, the 76 attendees discussed topics of energy storage and release on the Sun in relationship to coronal mass ejections and observed features in the interplanetary medium. The meeting resulted in the identification of specific research topics in solar and interplanetary relationships that will be actively pursued.

The *SESC Glossary of Solar-Terrestrial Terms* was first published in 1984 to help standardize terminology used by SESC personnel and to assist customers and visitors in understanding the very specific (and possibly unfamiliar) words and phrases common to daily SESC operations. The document proved very popular, and the original 1,200 copies were completely distributed by the end of 1987. In response to suggestions the Glossary was revised before the latest printing in FY 1988, with changes including 92 new entries and an appendix of scientific units.

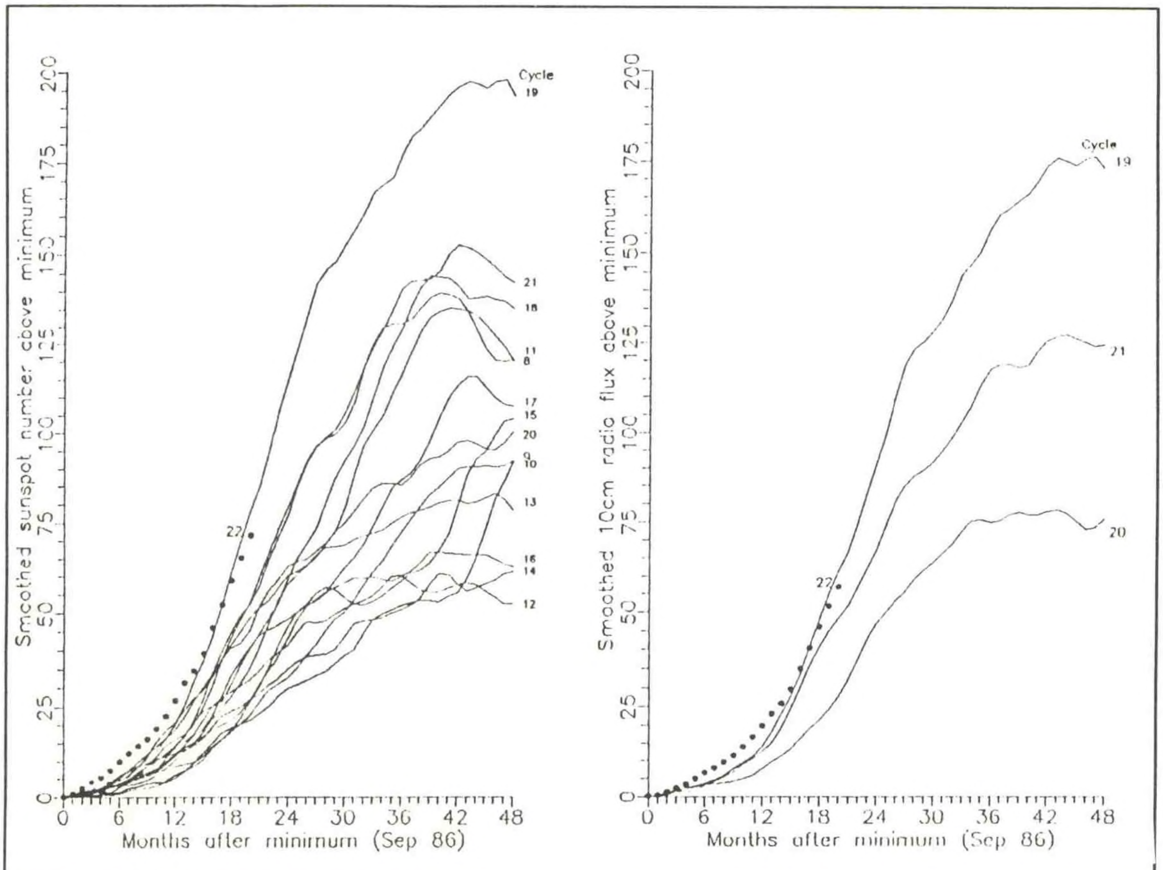


Figure 2. The early rise of Solar Cycle 22 compared to previous cycles.

The *Preliminary Report and Forecast of Solar Geophysical Activity* weekly publication was upgraded to include more current information on solar-terrestrial activity (Figure 4). Though this publication was formerly provided free of charge, a subscription fee was charged in 1988.

SPACE ENVIRONMENT DATA COLLECTION

Solar Electronic Observing Network

AWS operates a network of solar optical and radio telescopes called the Solar Observing Optical Network (SOON) and the Radio Solar Telescope Network (RSTN) at several longitudes around the world to maintain a continuous watch for solar activity and to provide many of the synoptic observations used in forecasting activity. The staffs of SOON and RSTN (more than 50 total) are supplied mostly by USAF and by Australia, through the Learmonth Solar Observatory. The SOON and RSTN observations are provided to SESC in real time for use in the forecast operation. To maintain a liaison between the Learmonth Observatory and SESC requirements, NOAA provides an observer to help staff that Observatory. This position was maintained in FY 1988 by an officer of the NOAA Commissioned Corps who is trained and experienced in solar observing. SOON images from Holloman and Learmonth Solar Observatories are obtained in near-real time at SESC (see the Section on SELSIS). Other coded data from all the SOON and RSTN locations are integrated into the Space Environment Laboratory Data Acquisition and Display System (SELDADS).

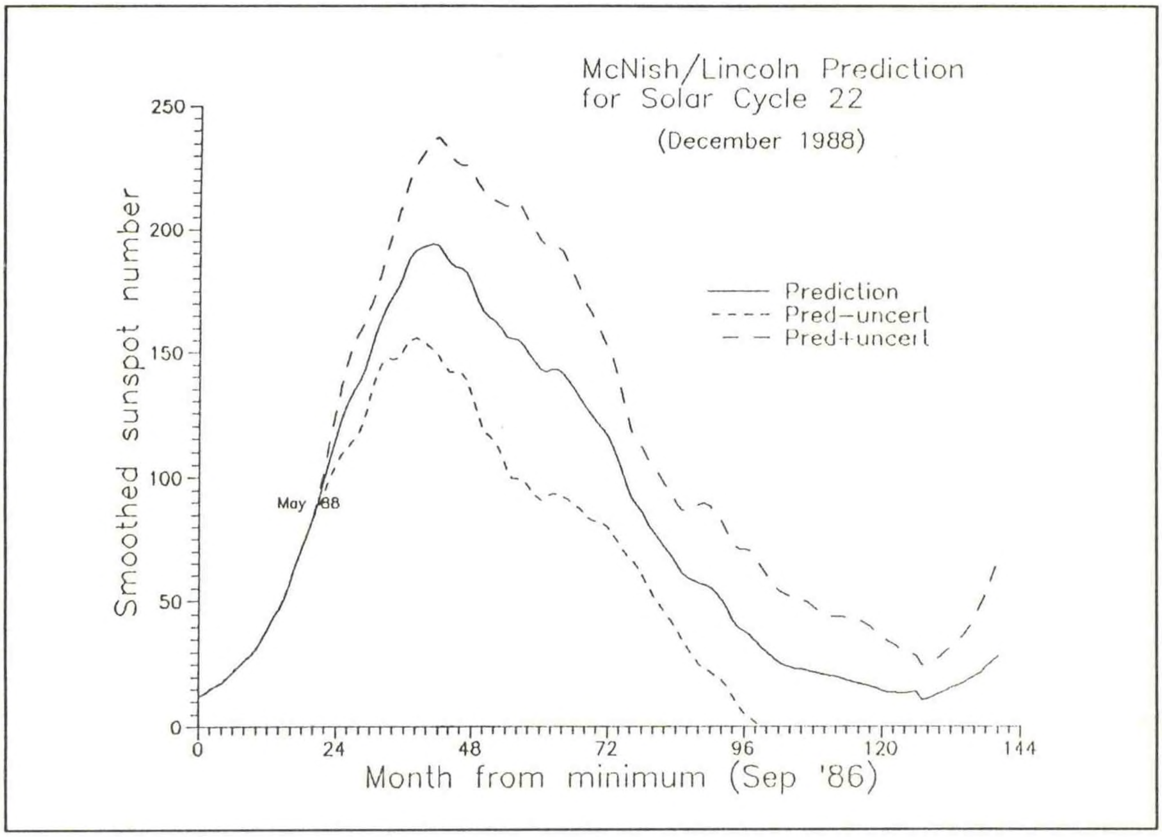


Figure 3. A prediction for the remainder of Solar Cycle 22.

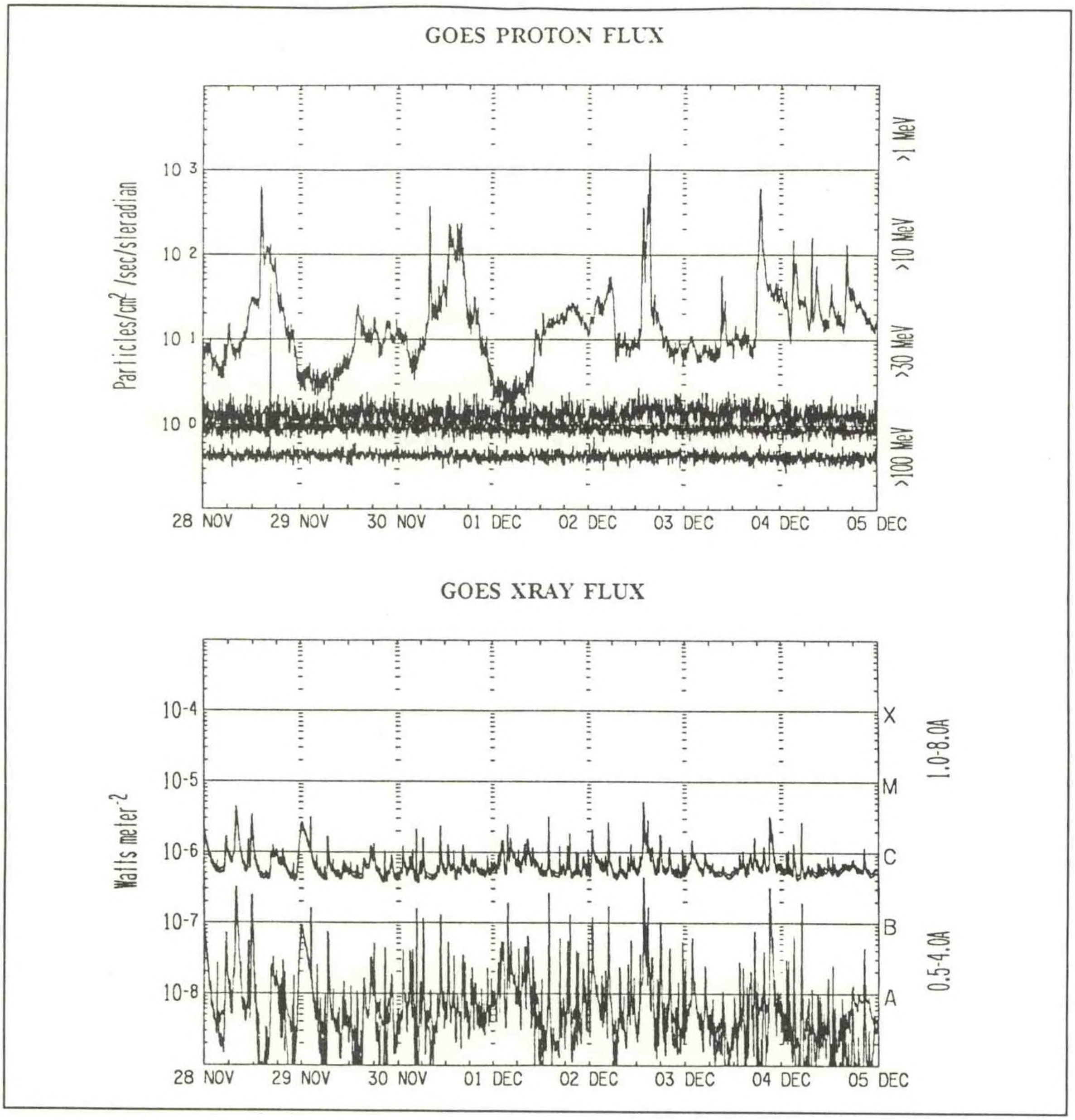


Figure 4. Sample of the plots of solar x-ray and proton data from the weekly ***Preliminary Report and Forecast of Solar Geophysical Data.***

Culgoora Observatory

The Culgoora, Australia, Solar Observatory is operated by the Australian Government to meet its operational requirements for solar observations. To maintain access to the data, and to keep the data responsive to U.S. needs, a NOAA Commissioned Corps officer was stationed at Culgoora throughout FY 1988.

Kitt Peak Observatory

Solar Magnetic field and solar helium observations made at the National Solar Observatory at Kitt Peak (NSO/KP) are critical for both research and real-time forecast services. NOAA, NASA, and the National Science Foundation cooperate in staffing the Vacuum Tower Telescope at NSO/KP. This arrangement was in effect throughout FY 1988. NSO/KP image data are handled through the SEL Solar Imaging System (See the section on SELSIS).

Boulder Observatory

SEL's Boulder Solar Observatory is operated by part-time and work-study personnel. Weather permitting, the Observatory provides daily H-alpha prints to SESC and outside users, a daily sunspot drawing and a sunspot message included in the SELDADS data base, real-time H-alpha video to the SESC Forecast Center, and image data handled through SELSIS.

Some data outages have been experienced because an upgrade and refurbishment of the telescope optics and electronics has been ongoing through FY 1988. This has included rebuilding the declination drive assembly; installing a new video camera; and ordering and purchasing stepping motors, gears, an H-alpha filter controller, and power supplies.

GOES Space Environment Monitors

Space Environment Monitors (SEMs) on the GOES satellites provide primary data for the detection and classification of solar flares and, combined with the SOON/RSTN data, for the prediction of effects at Earth. They also provide the primary data on energetic solar particles reaching Earth and make possible the prediction of radiation and ionospheric effects. A continuous flow of GOES SEM data is critical for SESC operations.

NOAA/TIROS Space Environment Monitors

SEMs on the NOAA polar-orbiting satellites provide information on energetic particle fluxes that pose a radiation hazard in the polar cap regions. In addition, they provide information on the total energy being carried into the atmosphere at high latitudes by particles precipitating from Earth's outer magnetic field. The most recent satellite in the series, NOAA–10, was launched 17 September 1986. A problem with its Total Energy Detector (TED) has grown progressively worse and seriously degrades the usefulness of that data. The remainder of the SEM is working nominally.

Remote Geophysical Observing Network (RGON)

Information on the variation of the geomagnetic field at various locations on Earth's surface is a requirement for SESC operations. A part of that data base is collected, using the GOES data collection platform system, from a network of magnetometers and riometers operated in remote locations.

A major addition to the network is in progress, but completion will not occur until FY 1989. This addition, made through cooperation between the U.S. Geological Survey (USGS) and USAF, will initially add three new magnetometer data streams in near-real time from the United Kingdom and will lead the way to a global near-real-time network. At the same time, new data analysis techniques being developed by USGS will result in improved magnetometer data products. SESC will acquire data from the additional magnetometers via land line from USGS in Golden, Colorado.

Field Site Operation

Two field sites are part of the collection operation. The High-Latitude Monitoring Station (HLMS) at Anchorage, Alaska, is operated jointly by NOAA and USAF to collect data from the high latitudes where many solar-terrestrial disturbances are concentrated. Data collected at

HLMS are given preliminary processing and then transferred to SELDADS at Boulder. A new communication system was implemented in FY 1988 to improve the accuracy and reliability of data from the Thule polar cap monitoring station.

Table Mountain Observatory (TMO) near Boulder receives GOES signals and preprocesses them for relay to SELDADS. TMO is also the location of several sensor systems including a USGS magnetometer. Operations for FY 1988 at Table Mountain gave priority to GOES data reception and magnetometer operation.

SOLAR FLARE FORECASTING AND ANALYSIS

A great need of space environment services is the ability to forecast solar flares a few hours before they occur. In the absence of a full understanding of the physics of flares, forecasts have been based on recognizing certain characteristics of structures on the surface of the Sun whose presence or absence increases or decreases the probability of a solar flare. One promising method of flare forecasting research is based on measuring the energy stored in the magnetic field of solar active regions. Shearing motions of adjacent magnetic fields with opposing polarities has been identified as a potential source of this energy. With AWS and the Air Force Geophysics Laboratory, SEL organized a small workshop to define a project with the objectives of developing and testing methods of measuring shear in an operational environment and using the measurements to construct a forecasting algorithm. Displays for forecasters were developed for SELDADS, and parameters for a flare forecast verification data base were identified.

GEOMAGNETIC SERVICES DEVELOPMENT

Disturbances of the geomagnetic field interest a large and diverse population, ranging from those casually interested in auroral displays (rare at the latitudes where most U.S. citizens live), through operators of communication systems adversely affected by rapid changes in the geomagnetic field, to international consortia of scientists conducting sophisticated research programs. Physical systems affected include radio communication networks and military radars, satellite instrumentation, and power lines and pipelines. Data used by geophysical exploration teams are also affected by geomagnetic disturbances.

During FY 1988, the Geomagnetic Services Development project concentrated on revamping the SELDADS geomagnetic menus and designing and implementing new geomagnetic plots and listings. The terminology used to describe geomagnetic activity was standardized in SESC products. Geomagnetic climatological studies continued and were extended to a similar study of the median behavior of the 10.7-cm solar flux observations (Figure 5). Forecast of the the 10.7-cm solar flux is another SESC product. With the assistance of the ERL Environmental Sciences Group, a plan to develop systematic forecast methodology and verification was drafted. This plan will ultimately supply the answers to such questions as "Which SESC data inputs appear to be the most important for each forecast product and which seem superfluous"? and "Where should training and research resources be focused to improve forecast products"? As a critical prelude to this effort, a forecast verification data base was designed and implemented; the data base is augmented with each day's information.

As a step toward improved prediction of geomagnetic activity, the group participated in an SEL-sponsored workshop on Solar Events and Their Influence on the Interplanetary Medium. The goal of that workshop was an improved basic understanding of the interplanetary response to solar stimuli.

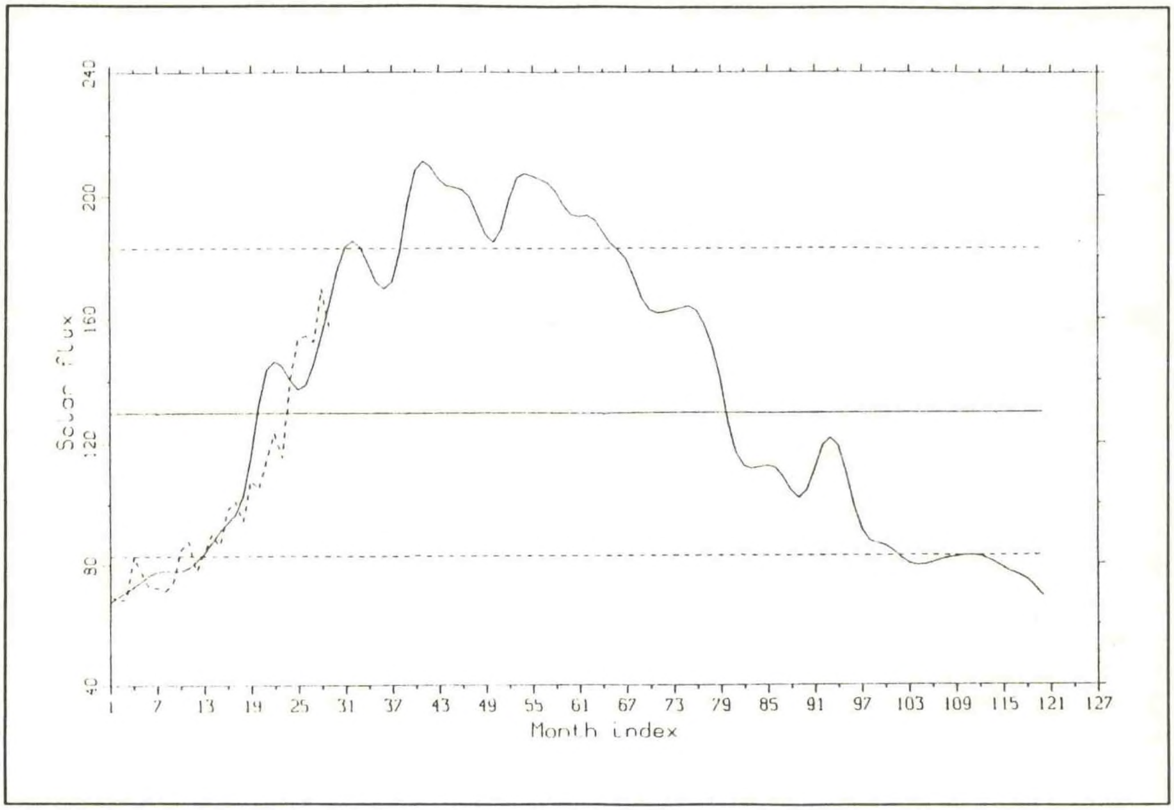


Figure 5. The composite 10-cm flux cycle and the monthly averages for Solar Cycle 22 through November 1988. The horizontal lines show the median and quartile cut points of the composite model.

RESEARCH

IONOSPHERIC RADIO

The objective of SEL's ionospheric radio work is to disseminate knowledge of the ionosphere, especially its variability, so as to increase user understanding of the propagation medium. Radio waves undergo reflection or transmission through the ionosphere, absorption, scattering, focusing, and fluctuations (or fading) of amplitude, phase, frequency, and polarization. The ionosphere is produced primarily by ionizing radiation from the quiet Sun but undergoes considerable modification by bursts of solar x-rays, proton events, magnetospherically energized electrons, and magnetospheric electric fields. An understanding of ionospheric effects, and methods of reacting to them, is essential to an efficient use of the radio spectrum from about 1 kHz to over 1,000 MHz.

During FY 1988 work was completed on the typescript of a book, entitled *Ionospheric Radio*, which replaces *Ionospheric Radio Propagation*, published by the National Bureau of Standards in 1965. The book consists of the following 14 chapters: (1) "Characteristics of Wave propagation;" (2) "Solar-Terrestrial Relationships;" (3) "Magnetoionic Theory;" (4) "Radio Soundings of the Ionosphere;" (5) "Ionospheric Morphology;" (6) "Oblique Propagation;" (7) "Amplitude, Phase, and Frequency;" (8) "Earth-Space Propagation;" (9) "Ionospheric Disturbances;" (10) "Low, Very low, and Extremely Low Frequencies;" (11) "Medium Frequencies;" (12) "High-

Frequency Propagation Predictions;" (13) "Propagation of Very High Frequencies;" and (14) "Ionospheric Modification."

SUDDEN IONOSPHERIC DISTURBANCES

The ionosphere is subjected to a variety of disturbances that adversely affect human activities. One such sudden ionospheric disturbance (SID) usually occurs simultaneously with solar phenomena such as flares and/or x-ray bursts. During a large x-ray burst, the electron densities at a given height, e.g., 70 km, may increase by a factor of 10 to 100. This results in short-wave fadeouts (SWF) on high radio frequencies and very-low-frequency sudden phase advances (SPA) that affect navigation.

The long-term occurrence of SIDs has a pronounced ≈ 11-year cycle, as seen in Figure 6 in the case of SWFs that approximately follow the solar radio noise flux. The durations of SIDs vary from a minute or so to over 2 hours. The average duration is about 20 minutes. Not all large SIDs are accompanied by flares and x-ray enhancements. These cannot be ascribed to "false alarms." Research is underway to determine whether these SIDs are caused by enhancements in solar radiation not associated with flares or x-rays. One such spectral line is the Lyman-alpha line, largely responsible for the quiet D-region.

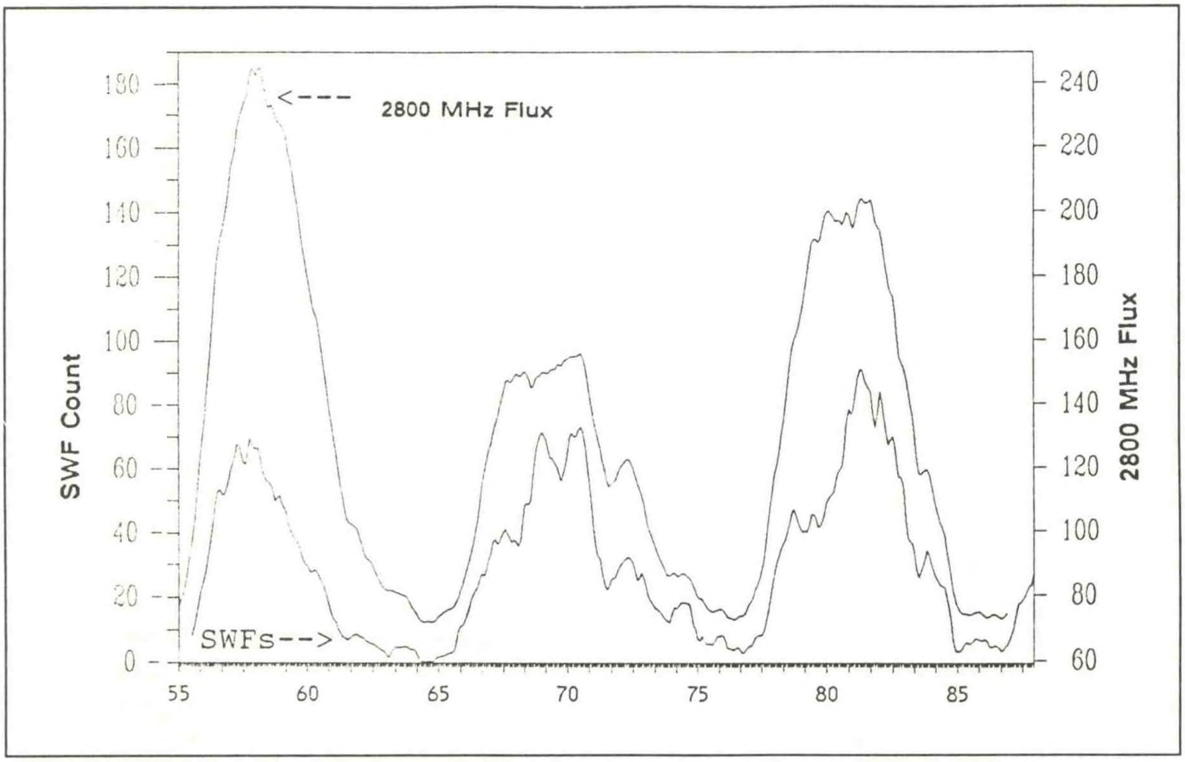


Figure 6. Twelve-month smoothed values of the monthly occurrences of short-wave fadeouts and the corresponding values of the smoothed monthly values of 2,800 MHz solar radio flux.

ATMOSPHERIC-IONOSPHERIC-MAGNETOSPHERIC INTERACTIONS

The objectives of research in the Atmospheric-Magnetospheric-Ionospheric Interactions are to understand the transfer of energy (in the form of both electrical and mechanical energy) from the magnetosphere into the upper atmosphere and to understand and characterize the various possible consequences in the Earth's ionosphere and upper atmosphere.

The Total Energy Detector (TED) instrument aboard the TIROS/NOAA polar-orbiting satellites measures the energy deposition into the upper atmosphere from precipitating auroral particles. Such energy deposition heats the atmosphere, causing it to expand to higher altitudes where the increased neutral densities give rise to atmospheric drag sensed by satellites. The ionosphere is also greatly influenced by this form of energy input, particularly at high latitudes during nighttime. For these reasons the TED data are useful as input to models of the upper atmosphere and ionosphere which are sensitive to the energy input from auroral processes.

Two major studies illustrating these uses of the TIROS/NOAA TED observations were completed during FY 1988. The first was done in collaboration with the Laboratory for Atmospheric and Space Physics at the University of Colorado at Boulder. Researchers in that Laboratory performed measurements from the Solar Mesospheric Explorer (SME) satellite of the concentration of nitric oxide in the upper atmosphere. This trace chemical changes the radiative properties of the upper atmosphere and participates in a catalytic chemical reaction which destroys ozone. Nitric oxide is produced in the upper atmosphere from ionization of molecular nitrogen by both solar ultra-violet radiation and the impact of auroral energy electrons. Measurements from the SME satellite showed large enhancements in nitric oxide densities above 100 km altitude over Canada during a period of auroral activity in September 1984. Because of the long time constants associated with the nitric oxide production and loss processes, these enhancements represented the effects of auroral particle precipitation at that location over the previous 12 hours. That precipitation, a parameter required in order to model the production and loss of nitric oxide for comparison with the observations, was not monitored by either Canadian ground stations or by the SME satellite. Both the NOAA-6 and NOAA-7 satellites were operating during that time and were providing continuous monitoring of auroral activity conditions. The knowledge of the intensity and extent of the auroral precipitation provided by these satellites, together with the statistical patterns of auroral particle precipitation that have been constructed from many years of NOAA observations, allowed the specification of the time history of the auroral particle input to the atmosphere at the proper location over Canada during the September period. This specification was used as an input to a model for the time variations in nitric oxide densities whose results were then compared with the SME observations. This comparison could not have been successfully performed without the monitoring observations from the NOAA satellites.

The second example of work completed in FY 1988 was the adaptation of a two-dimensional thermospheric model to use the specification of heat input from particle precipitation and Joule dissipation provided by the TIROS/NOAA satellites. This work was done in collaboration with visiting researchers from Japan and the United Kingdom. The objective was to develop a method of utilizing the energy budget specification derived from the satellite observations to provide a measure of thermospheric variables such as winds, chemical composition, and exospheric temperatures as a function of time. The modified thermospheric model was tested by using TIROS/NOAA observations made during an extended period in September 1984 to set the time-dependent energy input specification. Figure 7 displays one of the results of this exercise. The bottom curve in this plot shows the auroral activity index obtained from the TIROS/NOAA observations and leading directly to the specification of the heat budget. The curves in the upper panel show (a) the Millstone Hill incoherent scatter radar measurements (line with symbols), (b) the exospheric temperatures modeled for that location assuming that nitric oxide concentrations did not change with auroral activity (dashed line), and (c) the temperatures modeled assuming that nitric oxide concentrations varied according to auroral activity (continuous line). The agreement between model and observations is very good when the variation in nitric oxide is taken into account. This is because nitric oxide radiates efficiently in the infra-red, and, if proper account is

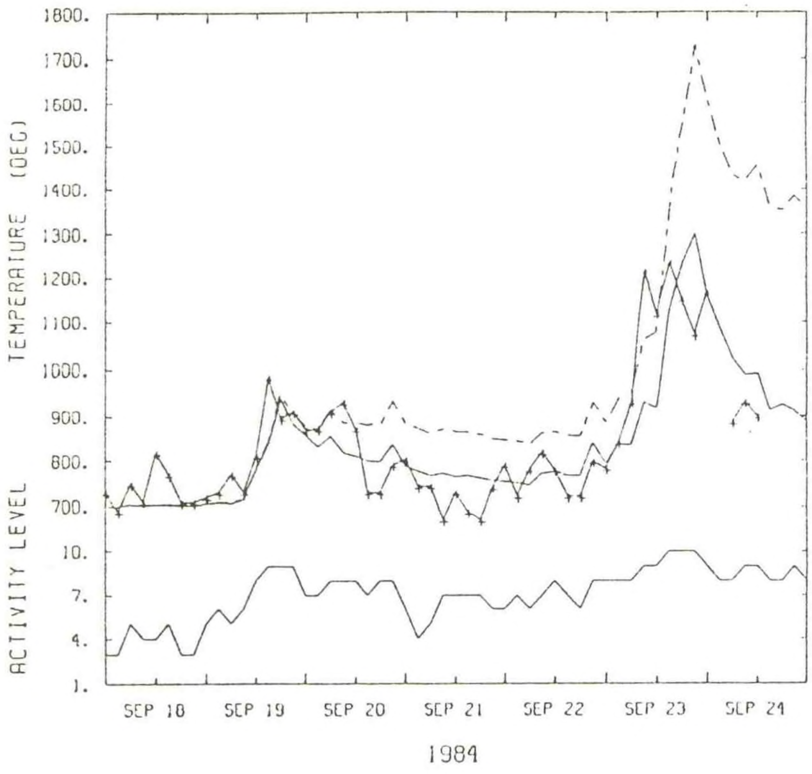


Figure 7. The curve at the bottom of the figure displays the NOAA derived activity index which served to specify the thermospheric heat input for a simulation of the exospheric temperature for a 1-week period of varying activity. The curve with symbols shows the exospheric temperature at 55° latitude, inferred from radar measurements. The dashed curve shows the modeled temperature, assuming no enhancements in NO density; the upper solid curve displays the simulated temperature when NO enhancements are taken into account. The importance of NO in determining the rate of cooling of the thermosphere is clearly shown.

not taken of the nitric oxide enhancements, gross over-estimates will be made of exospheric temperatures and of the time required for those temperatures to decay as activity subsides (dashed line).

In the course of analyzing observations of the energetic particle population measured at middle and low latitudes by a second instrument aboard the TIROS/NOAA satellites, very intense fluxes of energetic electrons were discovered to appear at very low latitudes at the onset of global magnetic storms. The lifetime of this new electron population is very short, the particles being quickly lost to the atmosphere. However, the electron intensities during this short period are very high—in fact competitive with energetic electron intensities observed at auroral latitudes—and should produce observable effects upon the ionosphere. These ionospheric effects, and potential effects upon the low-latitude thermosphere, remain to be studied and assessed.

Unfortunately, as noted earlier in this report, the TED on NOAA-10 developed a malfunction early in the life of that satellite. Careful analysis of this problem has led us to believe that a correction can be introduced into the data processing which will mitigate, but not eliminate, the effects of this malfunction on the observations. Although this correction technique has undergone preliminary testing, and considerable modifications to the archive software have been made during the past year, the technique has not been implemented into the routine processing of NOAA-10 data. Consequently, SEL has been without this valuable data set since spring of 1987. The launch of a new satellite in the TIROS/NOAA series, which will carry the TED, is not scheduled until late 1989.

MAGNETOSPHERIC PHYSICS

The objective of the Magnetospheric Physics Project is an improved understanding of the dynamics of processes by which material and energy are transported from the solar wind into the magnetosphere, stored there, and eventually dissipated into Earth's atmosphere. Both applications and research are pursued to improve the quality and utility of the Laboratory's products and services.

Data Support Activities

To help insure the quality of the data, the oversight and evaluation of operational energetic particle and magnetometer data obtained from GOES and NOAA/TIROS monitoring instruments continue.

The coordinated geomagnetic data base comprising geostationary magnetic field, geomagnetic activity, and solar wind parameters has been extended to include the three years, 1979–1981. Software developed previously has been applied to produce empirical models of the quiet-day (climatological) diurnal and seasonal variations of the geostationary magnetic field that provide the basis for disturbance evaluation and for the further development of physical models of the geostationary environment. Because of increased interest in long–term fluences of energetic particles at geostationary orbit, a detailed analysis of the proton contaminant response of the GOES electron detectors has been completed. An algorithm has been developed to make a principal correction in real time for more accurate determinations of the energetic electron fluxes at geostationary orbit.

Data Analysis Studies

A study of all observed solar wind compressions of the magnetosphere to within geostationary orbit (6.6 earth radii) occurring between 1978 and 1986 has been completed. These events are clearly associated with major geomagnetic storm periods which are preceded by geomagnetic storm sudden commencements. The analysis has further indicated that such compressions are all associated with a southward turning of the interplanetary magnetic field, and it permits an estimate to be obtained for the relative efficacy of the solar wind pressure and interplanetary magnetic field in changing the size of the magnetosphere.

Statistical analysis of the relationship of solar wind pressure changes to changes in the magnitude of the geostationary magnetic field as observed by the GOES satellites indicates a potential for using the GOES real-time measurements to crudely infer the solar wind dynamic pressure remotely. Such inference of solar wind parameters is of significance because of the current lack of in-situ measurement of solar wind properties responsible for subsequent geomagnetic disturbances.

A study of the relationship at Earth between solar x-ray fluxes and the peak proton fluxes of associated solar cosmic ray events has enabled improvement of a predictive algorithm over that currently in use. The current algorithm has a correlation coefficient between predicted and observed peak proton fluxes of only .2. The proposed algorithm yields a significantly improved correlation coefficient of .56 when applied to 40 solar cosmic ray events observed during the years 1976–1986.

A survey of one year's energetic ion data from the ISEE–1 satellite is nearly complete. The characteristics of the observed ion flows at the magnetopause correlate well with the detailed properties of the solar wind. These ions serve as remote probes of the magnetopause structure. Such observations provide information on solar wind coupling to the magnetosphere, energization processes, and the crucial role of the solar wind magnetic field in these processes.

Theoretical Studies

Geomagnetic substorms are thought to originate in the geomagnetic tail. It is known that stored magnetic energy is released during substorms, but details of the release mechanism are controversial. In one model, a near-Earth magnetic neutral line forms, magnetic reconnection is initiated, and a plasmoid is ejected downstream. However, it is difficult to observe the neutral line directly because a crossing of it by a satellite would be extremely fortuitous.

We have studied particle orbits in a model of the tail current sheet including a neutral line. We find a unique signature of the presence of a neutral line in the shape of the resulting energetic particle distributions. The particles may therefore serve to remotely sense the existence of such a neutral line, without the satellite passing directly through it. We will search observations of energetic particle distributions in the geomagnetic tail for evidence of the signature found in the model distributions.

INTERPLANETARY PHYSICS

The objective of the Interplanetary Physics Project is to improve forecasts of the occurrence, duration, and severity of geomagnetic storms. The strategy to accomplish this goal is (1) to develop methods of monitoring disturbances from their generation at the Sun through their travel toward Earth, and (2) to develop, test, and implement physically based, numerical, magnetohydrodynamic (MHD) models that would be driven by real-time solar observations and checked by monitoring interplanetary and near-Earth observations using in-situ and remote-sensing techniques.

Tests of 2 ½ -Dimensional Interplanetary Global Model (IGM)

We continued in FY 1988 to study the interplanetary manifestations of solar activity during the major solar flares and major geomagnetic storms in early February 1986 (at solar minimum), in collaboration with Japanese and English colleagues. The IGM was used to generate the expected (synthetic) profile of Doppler noise due to variations in solar wind mass flux along the telemetry ray path to the *Sakigake* spacecraft situated at 0.84 AU, 57° W of Earth. This synthetic profile compared quite closely with the rather sparsely observed Doppler noise profile. The IGM was also used, guided by after-the-fact acquisition of in-situ solar wind velocity data from the *Giotto* spacecraft at 0.77 AU (51° W), to generate a synthetic solar wind speed history. To achieve good agreement between synthetic and observed histories, sustained (10–20 h) high-speed flow from several of the February 1986 solar flaring regions had to be assumed, thereby altering our physical understanding of solar activity output of energy and momentum.

A parametric study was initiated using a wide range of spatial and temporal scales (initial shock velocities at the Sun between 1000 and 3000 km/s and initial spatial, heliolongitudinal widths from 18° to 54°) of the MHD input parameters for flare-generated or eruptive prominence-generated shock waves. We found that long-lasting, sustained energy and momentum inputs (as indicated above) were required to produce fast forward MHD shocks whose momentum fluxes maximized to the west of the pulse's original central meridian. If this physical explanation were correct, it would explain a recent statistical study (University of Maryland) of the large-scale structures of more than 100 experimentally observed shock waves. Our parametric study also demonstrated the deceleration profiles of the shocks within the range noted above. More rapid deceleration occurred for the initially fastest shocks; the slower shocks also decelerated, but at a slower rate due to the convective effect of the background solar wind over which they were "riding." This family of deceleration profiles has also been observed (Jet Propulsion Laboratory) by remote sensing (radio astronomical) of spacecraft telemetry signals that were intercepted by solar-generated shock waves.

We have been working with colleagues in Czechoslovakia, U.S.S.R., and Spain on studies that incorporate our 2½-D IGM. These studies involve associating energetic particle observations (*Prognoz* 10, VEGA 1, VEGA 2, and ISEE-3) with specific forms of solar activity and with approaching interplanetary shocks and their magnetic topologies. The parametric study noted above was of indispensable help in this study.

Development of Three-Dimensional Interplanetary Global Model (3-D IGM)

Two numerical experiments were conducted with the 3-D IGM, and results were presented at the Committee on Space Research (COSPAR) meeting in July 1988 in Finland. The first experiment incorporated the passive insertion of a simulated solar-generated, spherical plasmoid into a heliospheric solar wind that incorporated a unipolar interplanetary magnetic field. The plasmoid survived transit to Earth's orbit, while increasing in size owing to its higher thermal and magnetic pressure relative to the surrounding plasma. In addition there was some distortion into an ellipsoid-like shape, favoring a tilt toward the east, as a result of magnetic tension and pressure forces. We are continuing to experiment with various forms of plasma flow and interplanetary magnetic field line (IMF) visualization. Figure 8 shows a 3-D depiction of the IMF field lines that lie, initially, in the solar equatorial plane. Their deformation and draping around the passively inserted plasmoid are clearly seen at two separate times en route to 1 astronomical unit (AU). The second experiment incorporated a simulated solar-flare-generated shock wave that propagated in a heliospheric solar wind containing an embedded flat current sheet. Reconnection and formation of a plasmoid at the current sheet's opposite-directed interplanetary magnetic field lines were observed. We believe that this reconnection took place as a result of numerical diffusion that mimicked the tearing mode instability, which would occur in a realistic plasma containing finite resistivity.

We are expanding these two experiments. In the first case (injection of an already-formed, solar-generated plasmoid), we made preliminary calculations of the flow around and within a plasmoid that is injected with twice the background solar wind velocity (250km/s) at the lower boundary (18 solar radii) of the computational domain. In the second case (in-situ formation of an interplanetary plasmoid by a shock wave's propagation along the heliospheric current sheet), we made additional calculations with a single, faster shock wave (2000 km/s, compared to the initial case of two shock waves). We plan to examine the heliolongitudinal extent of the plasmoid as well as the ability of the density structure to produce a large-scale, synthetic, interplanetary image that SEL expects to obtain from the interplanetary scintillation (IPS) technique described below.

Interplanetary Scintillations (IPS) of Distant Radio Sources

SEL staff members met with colleagues from the United States, England, Japan, and India at an Indo-U.S. Workshop on IPS and Solar Activity, in Udaipur and Ahmedabad, India, 1–5 February 1988. The objective was to outline plans for both the Anglo-U.S. and Indo-U.S. IPS projects. The importance of interplanetary imaging by means of the scintillation technique, its possible effect on geomagnetic storm prediction as well as on space plasma research, and numerical modeling with the 3-D IGM, were the major research areas discussed. The ability to generate

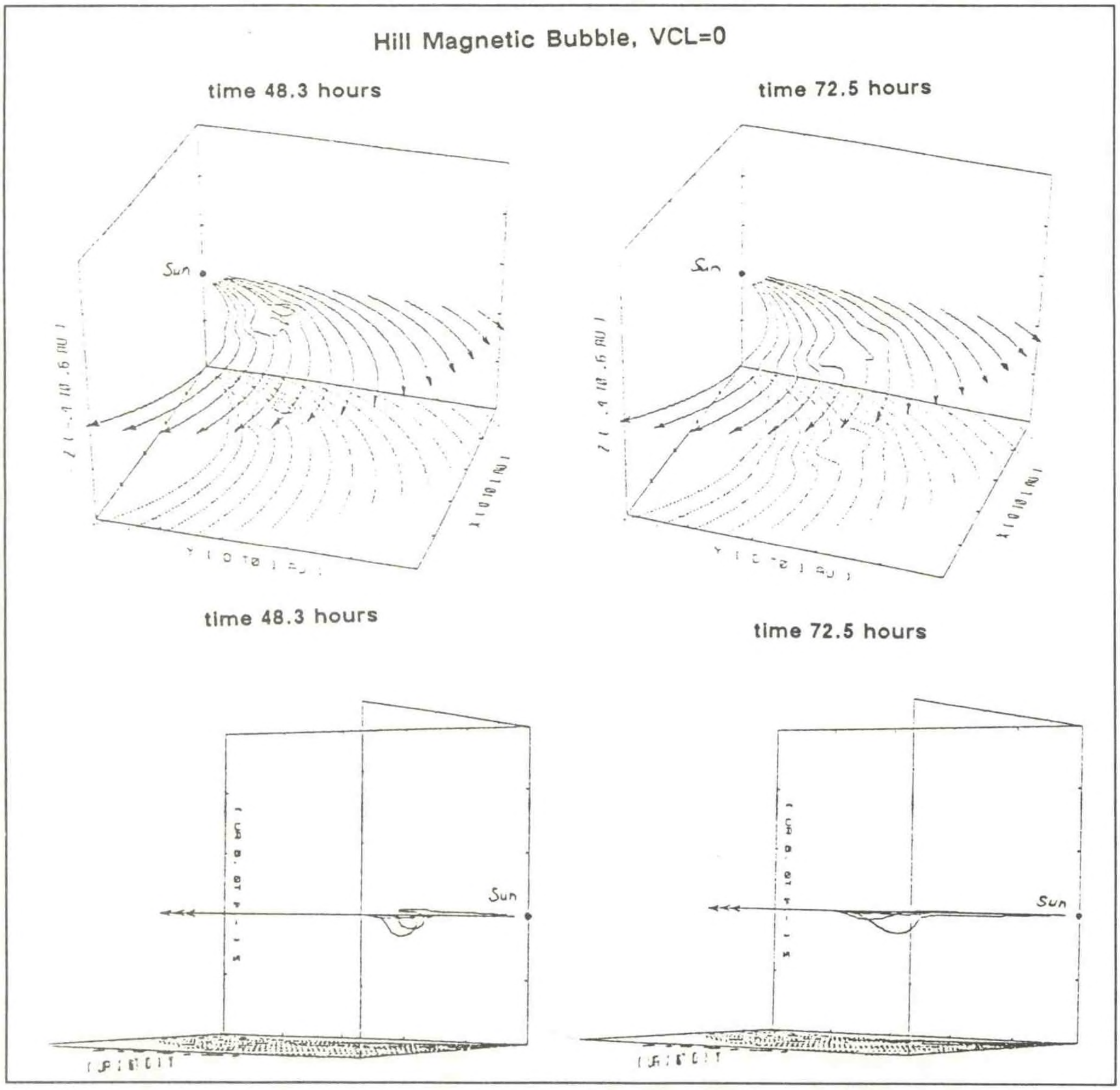


Figure 8. In this figure, we show the interplanetary magnetic field (IMF) lines as they are deformed and draped around a plasmoid (or "magnetic cloud") created at the Sun and passively convected outward through the solar wind plasma. The dashed lines on the lower side of the 3-D box (at t = 48.3 h and 72.5 h after the plasmoid leaves the Sun) are projections of the IMF, all of which were originally chosen, for this visualization, to be in the Sun's equatorial plane. Deflection of the IMF out of this plane is seen, especially at the earlier time. Other views, edge-on to this equatorial position, confirm this visualization. The lower panels dramatically demonstrate the draping of the IMF around the plasmoid. This deflection is an essential element for the forecasting of southward IMF polarities associated with geomagnetic activity. In the upper panels, the observer is located at 8 astronomical units (AU), and at a solar co-heliolatitudinal angle of 60° and a solar heliolongitudinal angle of 20°, measured from the left side of the box. In the lower panels, the observer is located, again at 8 AU, at a 90° co-latitude and a 115° heliolongitude.

synthetic IPS image maps based on the 3-D IGM developed at SEL, and the usefulness of these synthetic maps in interpreting IPS observations, were examined in some detail. Problems associated with cable refurbishment at the ongoing enlargement project for the Thaltej telescope near Ahmedabad, computer shielding, image software, training of younger Indian staff members at the Physical Research Laboratory, refurbishment of the Cambridge University telescope, and the role of IPS maps of solar wind velocities from Toyokawa, Japan, were among the subjects explored. Progress toward all of these goals has taken place since this Workshop was held.

Practical uses of IPS maps are anticipated. The Mullard Radio Astronomical Observatory group has shown that all-sky maps of the relative interplanetary scintillations (IPS) of small-diameter radio sources can be used to delineate the passage of solar wind disturbances from 0.5 AU to 1 AU and beyond. The group has further shown that all major geomagnetic storms during the period of August 1978 to September 1989 were preceded by IPS events. Starting with the IPS observations, an SEL study has found that about one-third of all the observed IPS events probably did not intercept Earth, and less than half of the remainder resulted in major magnetic activity. It is clear that much work remains to be done before a real-time prediction scheme can be implemented. This will call for further research on the use of the maps, both retrospectively and in a simulated operational mode.

SOLAR PHYSICS

The Solar Physics Project studies the nature of solar activity, its origins, and its evolution, to provide the new fundamental knowledge needed for improving predictions of solar-terrestrial disturbances.

Observations of the Solar Cycle

The number of sunspots appearing on the Sun waxes and wanes almost periodically (about every 11 years). Alternating sunspot cycles have opposite magnetic polarity, so a complete cycle is about 22 years. In September 1986 a new sunspot cycle began its rise from minimum; by FY 1988 observations led some to predict that the coming solar cycle maximum would equal the strongest solar cycle on record and that the maximum would occur in 1989 (2 years earlier than previously predicted).

SEL synoptic charts of the global distribution of solar magnetic fields showed in 1987–88 that the present large-scale structure on the Sun appears to have originated with the formation of a few especially strong sunspot regions that were outstanding in their production of x-ray solar flares.

Coronal holes are large areas in the solar atmosphere that are dark in x-rays and have magnetic field lines open to interplanetary space. These features are the sources of high-speed streams of solar wind, which can cause disturbances in Earth's magnetic field when the streams encounter Earth. Our displays of the coronal hole data extracted from the H-alpha synoptic charts for 1976–1986 (Solar Cycle 21) showed that equatorial coronal holes existed throughout the solar cycle. The area of coronal holes near the solar equator underwent a periodic variation during 1982–1985 in unison with the variation in radio intensity of the Sun.

Long-lived, large-scale patterns of magnetic fields were used to determine rotation rates. Patterns at any given latitude usually drift with respect to one another, indicating that rotation rates are specific to individual patterns. Some patterns pass through others, suggesting that their magnetic fields do not diffuse into one another but rather that the weak magnetic fields in these patterns must be renewed on time scales short with respect to the lifetime of the patterns. This observation is not predicted with the prevailing kinematic theory of the solar cycle, which explains large-scale magnetic fields as the result of the diffusion of sunspot magnetic fields (Figure 9).

The three strongest-flaring sunspot groups of Solar Cycle 21 occurred at the time of an anomaly in the rotation rate of equatorial patterns in the magnetic fields. A possible explanation is that the nature of the global solar circulation determines the outbreak of severe flare activity; thus the outbreaks might be predictable from flow observations.

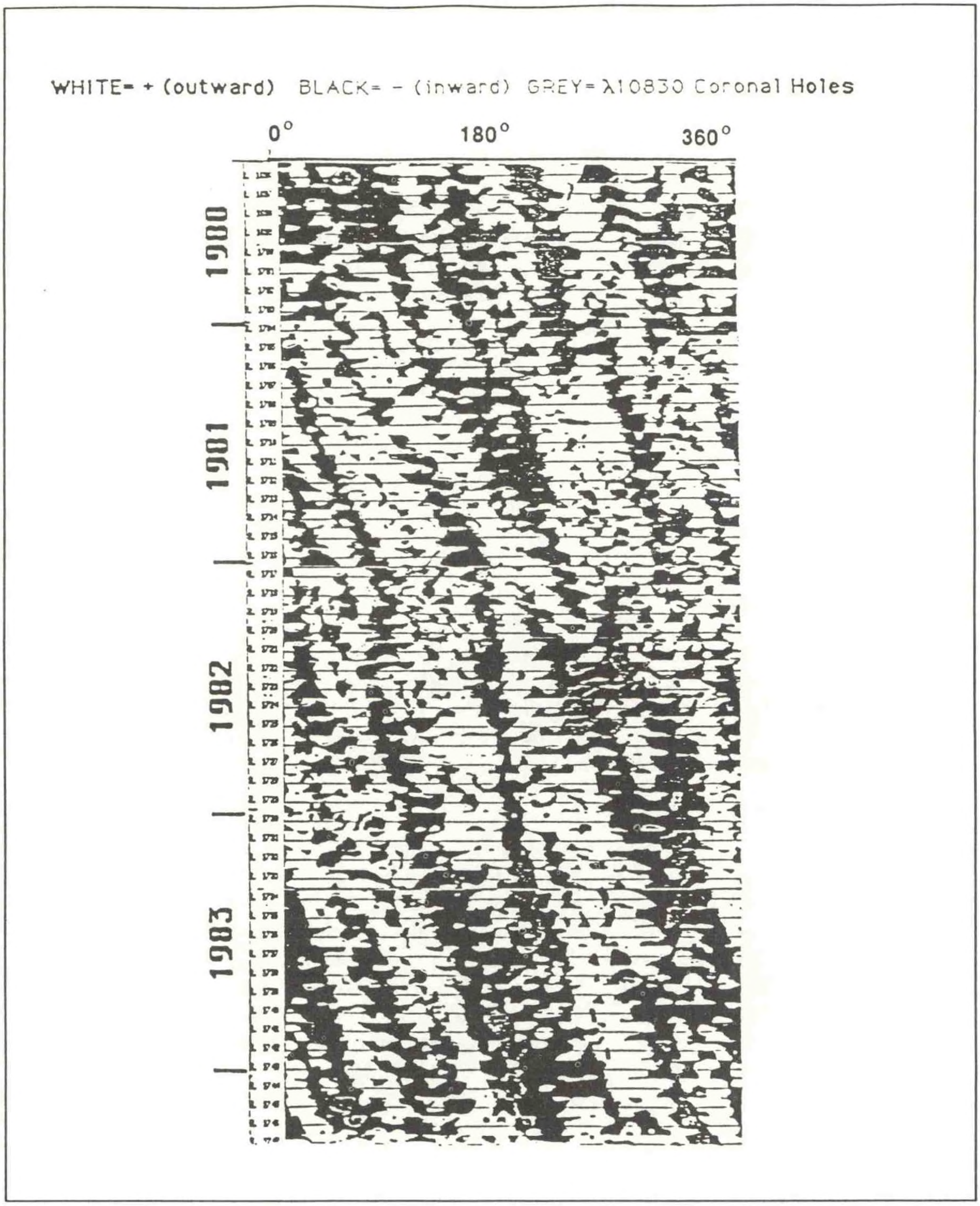


Figure 9. Narrow zones of latitude centered on the solar equator (N08–S08) have been extracted from Hα synoptic charts, rotation by rotation, and stacked in sequence to show the systematic motions and evolutions of large-scale patterns of magnetic polarity. Black represents negative polarity, and white is positive polarity. Solar longitude runs from left to right. In 1982, two narrow patterns at left deviated (decelerated) from the normal rate of rotation for magnetic fields at the equator. Embedded in the left of these two patterns were some of the strongest active regions of the solar cycle.

Model of the Solar Cycle

Collaboration with scientists at Lewis and Clark College and the University of Sydney (Australia) continued to develop a new model of the solar cycle. The model attempts to explain recent observations suggesting that the solar cycle begins with magnetic emergence near the solar poles shortly after sunspot maximum and progresses to the solar equator over a period of at least 18 years. During the 18 years, the newer cycle is manifest as weak activity at high latitudes and the older cycle is seen as sunspots nearer the solar equator.

Solar Mapping

Software developed in FY 1988 is providing faster and more accurate mapping of solar data. This has permitted the continuation of the synoptic chart database to the present time without undue reliance on time-intensive work by an expert solar observer. Beginning in FY 1988, laser-printed, shaded versions of the synoptic charts were published monthly in *Solar-Geophysical Data*. This new format facilitates perception of long-term, large-scale evolution of solar features.

Collaboration with NASA Marshall Spaceflight Center resulted in the conversion of the bit-map archive of charts to a digital time series suitable for detailed numerical analysis.

Sunspot Classification

The McIntosh Sunspot Classification, developed within SEL, was the topic of a seminar held in Beijing, China, in December 1987. The seminar concluded with the adoption of the classification, a modification of the Zurich classification system, for sunspot observations listed in the Chinese solar-geophysical data publication.

Amateur astronomical organizations in Canada, Germany, and the United States have requested permission to publish articles promoting the use of the McIntosh Sunspot Classification by their observers for reporting solar observations.

SEL Spectroheliograph

The SEL spectroheliograph was used to obtain monochromatic digital images of the Sun using a linear charge-coupled detector (CCD).

Hydrogen-alpha and calcium images of the active Sun were obtained to supplement images available from other observatories. Plages visible in the calcium images map regions of vertical magnetic field very well, even to the extent that the plage intensity is correlated with the magnetic field strength.

PC software and hardware became available to allow the alternate display of two images in a "blinking" mode, for comparison of any two of three images. Blinking has been used, for example, to locate H-alpha and calcium plage elements relative to sunspots.

SOLAR X-RAY PHYSICS

The objective of the Solar X-Ray Physics Project is to improve medium- and long-term solar activity predictions and to understand the structure and evolution of the solar corona. Analysis of x-ray wavelengths is used to improve forecasts of solar disturbances that originate in that highest level of the solar atmosphere (or, at the base of the interplanetary medium). During FY 1988 the activities of the project concentrated on the following.

Solar X-Ray Imager

The Solar X-Ray Imagers (SXI) will represent a major new improvement in SEL monitoring and research capabilities. SXI will give continuous real-time, full-disk monitoring [illegible] arc-second pixel size in the 8–20 and 20–60 angstrom x-ray bands plus 255–300 angstrom in the extreme ultraviolet. Plans detailed in last year's report are proceeding according to schedule. The procurement process has proceeded, with the intent to select and subcontract with a vendor in October 1989, looking toward the first launch of a SXI in late 1992. SEL is providing technical assistance and consultation, coordinated with the USAF, to NOAA/NESDIS and NASA/GSFC (the SXI procurement agent).

Solar X-Ray Studies

During the past year a unique opportunity was discovered for deriving spatially resolved properties of the Sun from the disk-integrating X-Ray Sensors on GOES. On 22 October 1987 the Moon passed between the Sun and GOES 6 while a small flare was in progress. Analysis of the 1–8 angstrom and 0.5–4 angstrom x-ray emissions and of the solar panel currents revealed four discrete x-ray sources (Figure 10). The temperature and emission measure of the flare were then derived, assuming that either the entire solar flux or just the increase above the quiescent flux is due to the flare. Neither of these two assumptions is ideal. This study may lead to a new method for determining the fraction of the quiescent x-ray flux that arises from the plasma that flares, and thereby improve our determinations of flare properties (Figure 11).

An x-ray flux intercomparison was made between the GOES ion chamber sensor and the Soviet Prognoz spacecraft proportional counter instrument. Collaboration in this effort was provided by several Czechoslovak scientists. In addition, empirical flare models developed in the Solar X-Ray Physics Project and at Ondrejov Observatory were surveyed to determine the value of further joint work and cooperation.

A statistical study of all the major x-ray flares during Solar Cycle 21 revealed two phenomena (Figure 12). The distribution of flares' maximum emission measures (assuming isothermal flaring volume) with maximum fluxes was found to be constrained. Also, a skewed heliocentric latitude distribution of flare occurrences was discovered that changed with phase of the solar cycle.

The time-integrated, high-energy particle fluence on a spacecraft in the polar cap is a function of the intensity and duration of the interplanetary proton flux and the varying integrity of the geomagnetic field. Long-duration x-ray events in the solar corona provide advance notice of times of enhanced proton flux and lowered integrity of the field. An informal program of data gathering is being exercised currently during solar proton events.

The GOES data on daily background 1–8 angstrom x-ray flux was collected for the entire Solar Cycle 21 (Figure 13).The annually smoothed background fluxes varied by a factor of 85 from solar maximum to minimum. Interestingly, this smoothed flux reaches a peak later in the cycle than any other activity index. The quiescent x-ray flux from our G2 dwarf star is of importance in several stellar and solar-terrestrial specialties. This work was done as part of the World-wide Ionospheric-Thermospheric Study. Spectral line data from the X-Ray Polychromator instrument on the Solar Maximum Mission spacecraft were used in several detailed investigations of thermal flare properties.

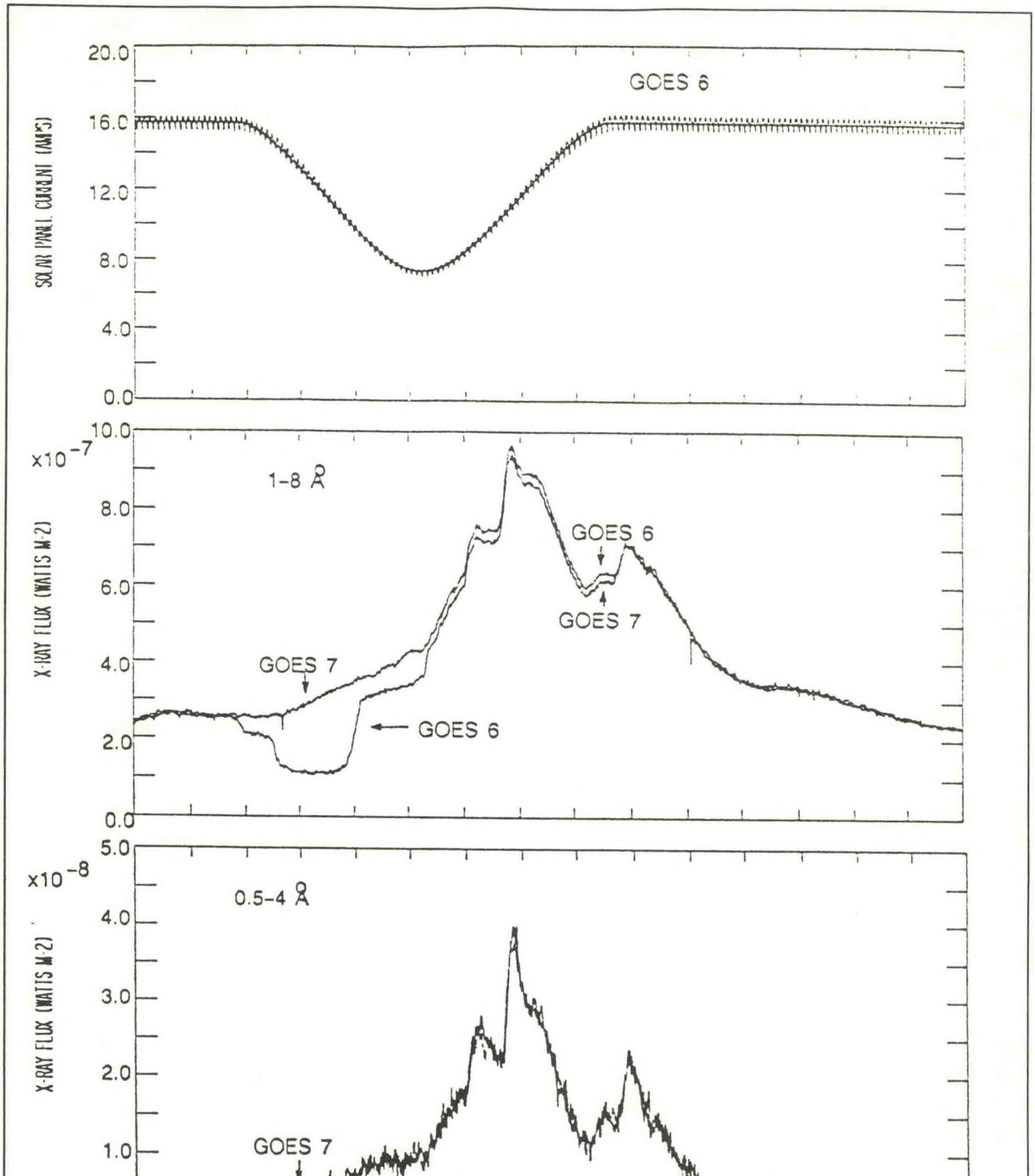


Figure 10. Solar panel current and the low-energy (1-8 angstrom) and high-energy (0.5-4 angstrom) x-ray fluxes observed by the GOES satellites. The solar panel current demonstrates that a solar eclipse occurred from 1055 to 1128 UT. The oscillations are caused by aliasing of the 100-rpm spin and -3 s sampling rate on cutouts in the solar panels. The large drop in the GOES-6 x-ray flux from 1058 to 1106 UT is the eclipse of the flare. The eclipse of a second x-ray source is visible in the 1-8 angstrom sensor from 1055 to 1112 UT.

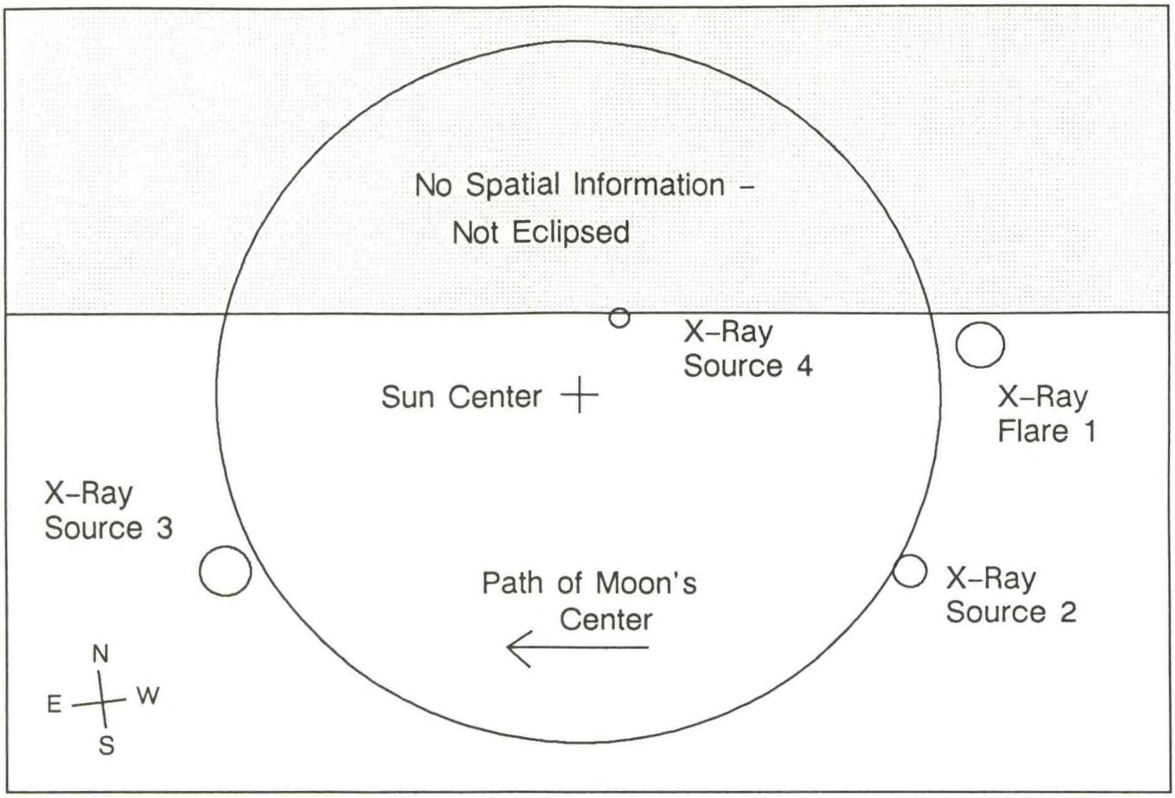


Figure 11. Size and location of x-ray sources during the 1987 October 22, ~1100 UT flare observed by the GOES satellites as derived from models of the solar panel current and x-ray fluxes.

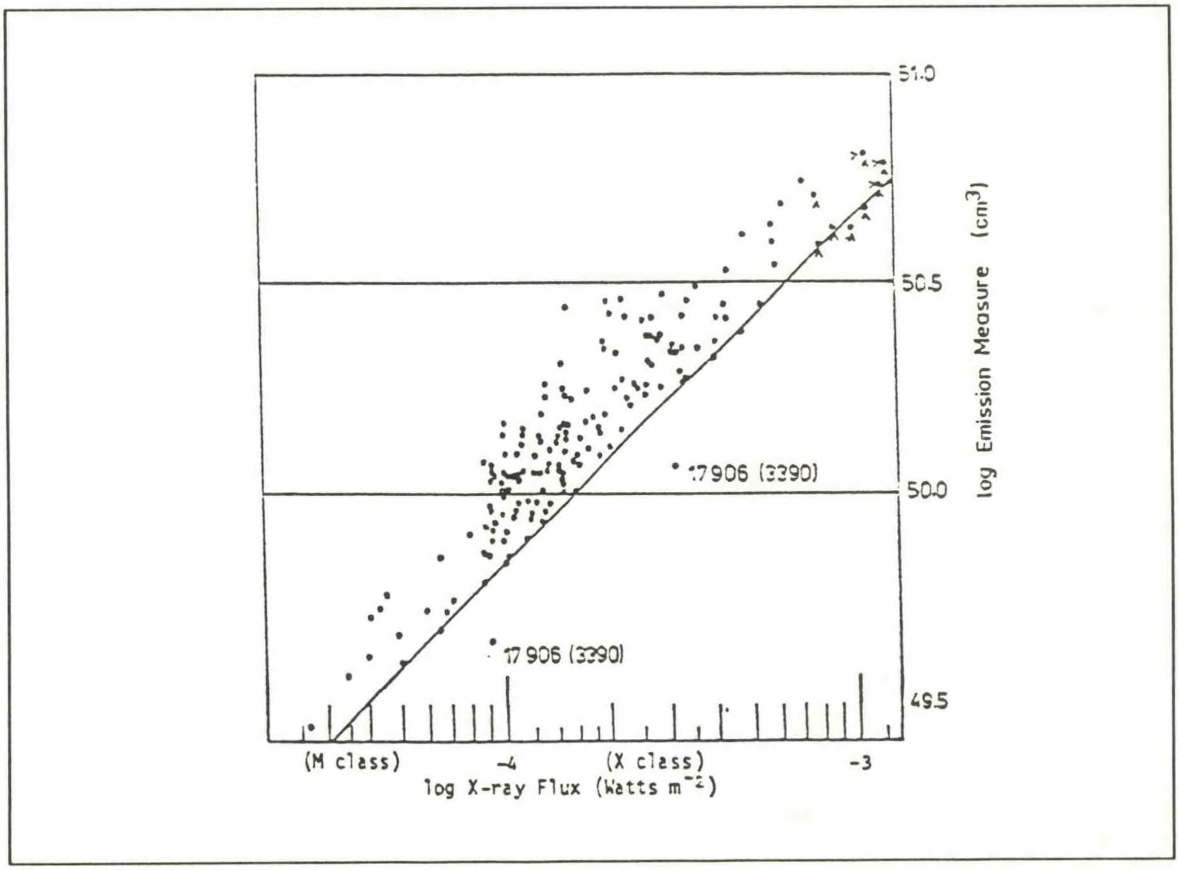


Figure 12. Maximum flare emission measure was found to correlate with maximum 1-8 angstrom x-ray flux. The sloping solid line emphasizes the linear character of the lower boundary of this distribution. The two outlying data points represent two flares with anomalously high temperatures and anomalously low emission measures which occurred in the same active region on October 12, 1981.

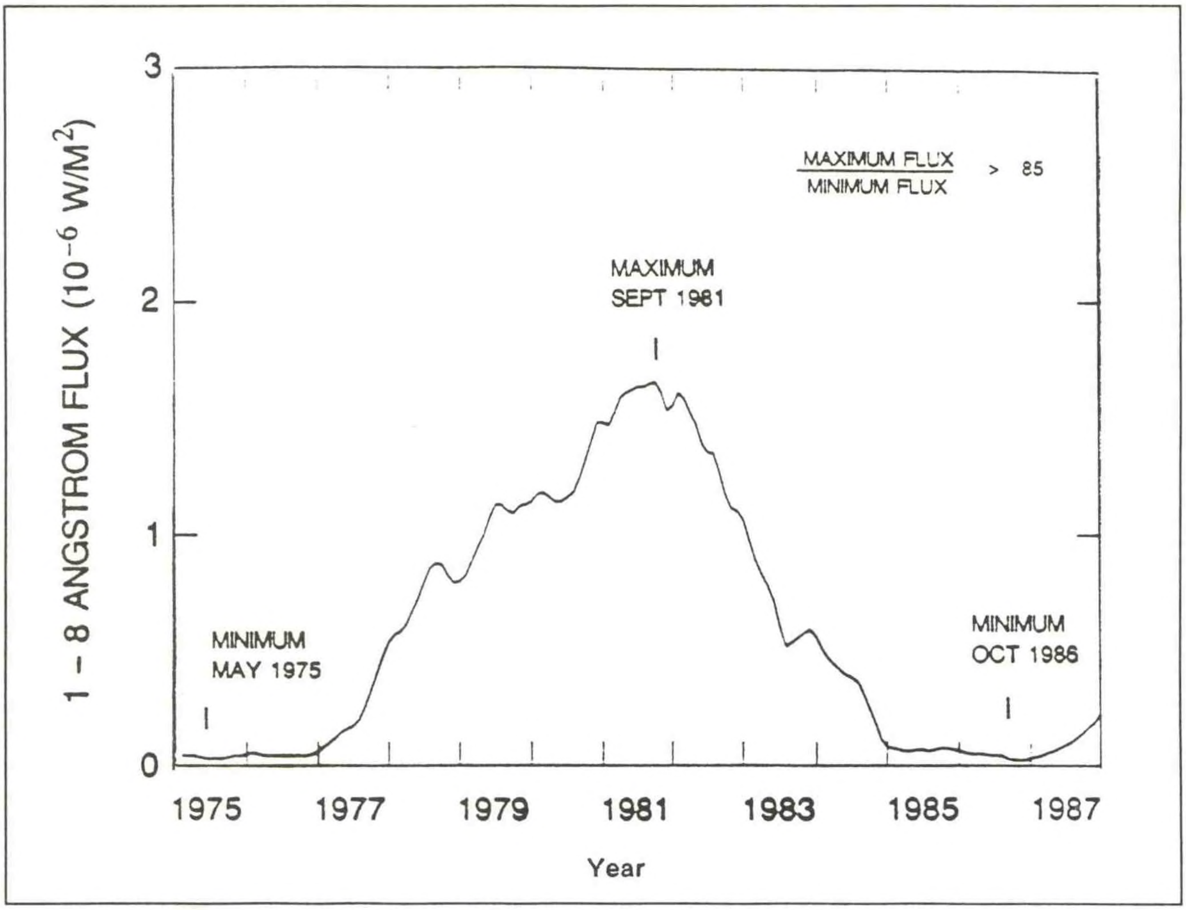


Figure 13. The Solar Cycle 21 variation in daily background 1-8 angstrom x-ray flux was found to show a strikingly high amplitude. This flux, which affects D-region ionization, lags behind all other solar activity indices by months to years.

Space Sensor

In addition to the SXI for which the Project faces major new services and science responsibilities, several other space-based instruments receive attention from the Project. The next-generation GOES X-ray sensor development continues under the monitoring of the Responsible Scientist in the Solar X-Ray Physics Project. Launch of this first of the non-spinning sensors should occur in the 1989–90 period.

Members of the Project served as Co-Investigators on a number of NASA-ESA space science mission experiments or proposed experiments. The U.S.-European Solar Heliospheric Observatory (SOHO) will be launched to the L1 libration point in 1995. The mission planners during this year have selected the Wide Field White Light and Spectroscopic Coronagraph (LASCO), a triplet of three instruments for observing the corona and mass ejections, the source of solar X-ray emission. Two separate Harvard-Smithsonian teams chose Co-Investigators from the Solar X-Ray Physics Project in proposing extreme ultraviolet telescopes—one for the Earth Observing System (the polar platform), the other for the NASA Small Explorer program. Finally, a variety of methods of satisfying the operationally critical forecaster needs for solar wind in-situ data from the L1 libration point were pursued.

DEVELOPMENT

SPACE ENVIRONMENT DATA SYSTEMS

SEL Data Acquisition and Display System (SELDADS)

SELDADS organizationally mirrors the functions of SESC. It is remarkable in the diversity of data that it receives as input and just as remarkable in the diversity of functions that it performs on the data as they move through the system, forming a variety of products. The data processed vary greatly in format, time resolution, and transmission media. Types of data include text, summary codes, raw digital streams, continuous data, irregular data, occasional data, data in order of time observed, and data randomly mixed in time of observation (Figure 14).

Data received by SELDADS are first processed to common units and formats. Events (disturbances) in the space environment are identified on separate data streams, and then consensus events are formed by combining the event reports from different sensors (e.g., telescopes and satellites). Consensus events then become parts of environmental summaries for distribution to users. As the data move through the system, forecasters extract other information, look at plots and lists, edit events, check indices, and enter forecasts back into the system. At the end, new products have been derived, which are sent out as summaries, alerts, and forecasts. Typically, after a piece of data enters the system it is sent out again as part of at least one product within 24 hours.

Each process in the system is complex and often is handled in stand-alone computers elsewhere. As a communications processor, SELDADS receives more than 1400 data sets via half a

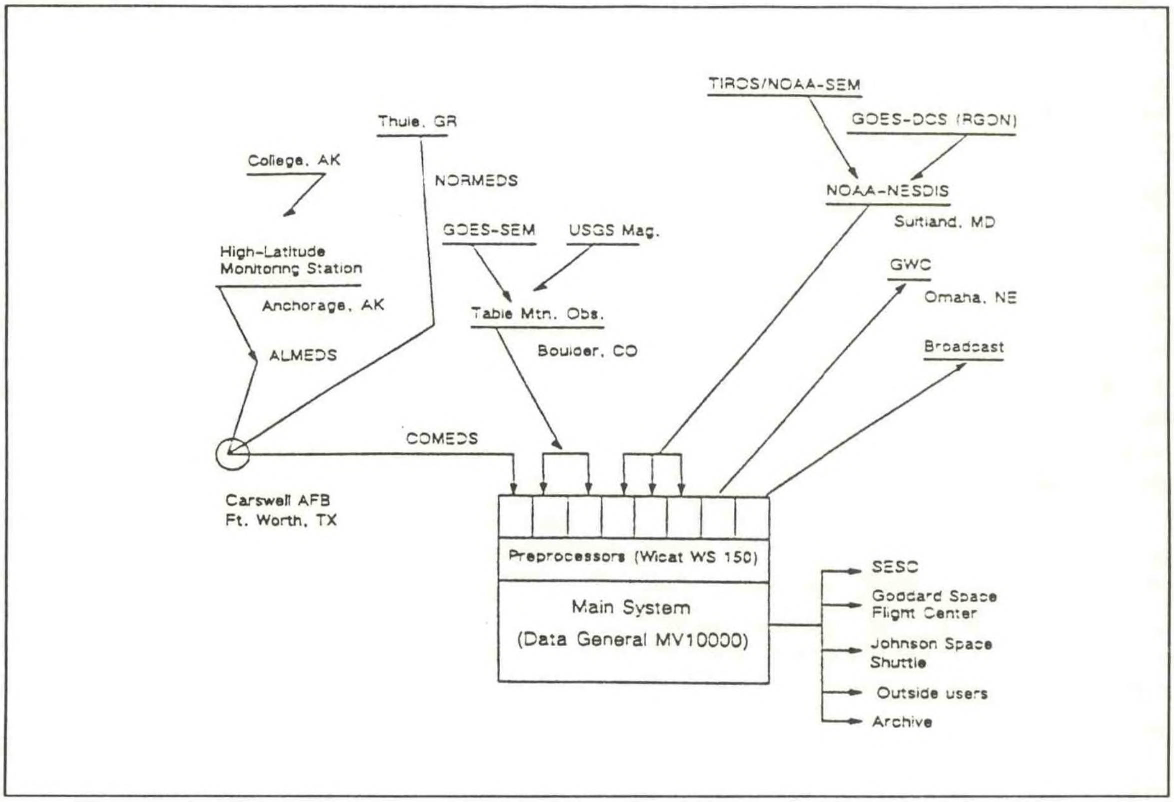


Figure 14. GOES block diagram.

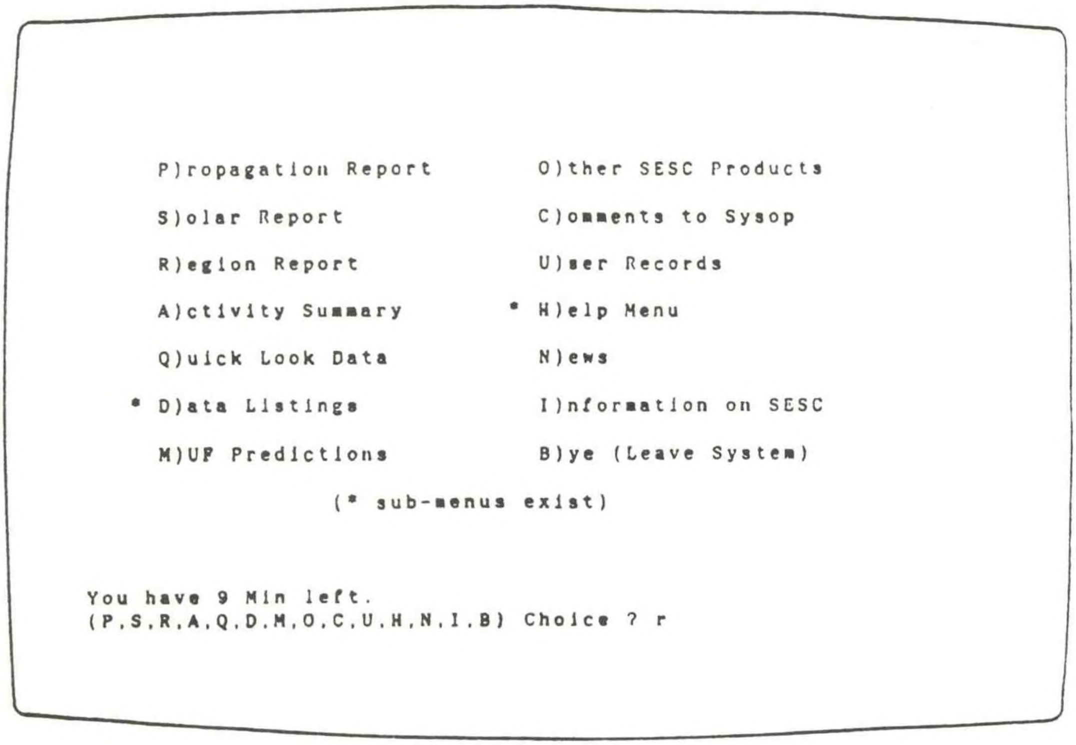


Figure 15. Bulletin Board Menu

dozen major data networks and distributes the products back over another half-dozen networks. Many products are in text form but will also be processed by computers as either text or code and must meet the requirements of both.

SELDADS accomplishments during FY 1988 included further development of forecasting analysis displays for solar and geomagnetic activity; compilation and publication of a comprehensive report describing the system; implementation of a forecast verification database; development of software for use in analyzing the effects of the space environment on satellite operations; implementation of generalized list and plot routines; revision of the database software to speed system operation; development of a comprehensive set of routines for real-time monitoring of the status of system operations and users, to achieve optimal system loading and detection of unauthorized use of the system; and implementation of modern, standardized interfaces for several of the connections with external data sources and recipients.

Electronic Bulletin Board

To facilitate user access to solar-terrestrial data, indices, and forecasts, an electronic Bulletin Board was initiated as an experimental service (Figure 15). The Board makes available the once-daily solar forecast and the 6-hourly HF propagation forecasts to users with a PC or terminal equipped with a modem. Those users dial into the system by public telephone (303–497–5000). The Board has about 1,500 registered users, handles 25–100 calls per day (depending on solar activity), and has had over 16,000 calls since its inception in January 1987. During FY 1988, the radio propagation forecast services offered through the Board operated with very few problems, and the number of users increased as solar activity increased and awareness of the Board grew. Updating of forecasts and data is entirely automatic and does not require operator supervision.

SEL Solar Imaging System (SELSIS)

SELSIS is a digital image acquisition, transmission, processing, and display system designed to handle the image-processing needs of SESC operations and SEL research. It is being implemented in stages. In FY 1988 the interim version of SELSIS replaced the analog wirephoto system of image transmission. The interim system gathers and processes approximately 300 images a month from the regularly contributing observatories in New Mexico, Colorado, Arizona, and Australia. Processing consists of correcting spatial and gray-scale aberrations. The imagery is then hardcopied and visually analyzed by the SESC forecaster as an input to solar and geomagnetic predictions. The quality of the data is high and is adequate for most research purposes.

A significant milestone was achieved with the final documentation of SELSIS requirements. This extensive work contains SELSIS requirements for SESC, SEL research, USAF, and World Data Center-A (NGDC). Three phases of requirements are addressed: (1) the operational interim system; (2) the projected system, which will generate operational products and provide research image processing; and (3) the future system, which will process SXI data.

NASA's Solar Maximum Mission operations and research personnel continue to receive all SELSIS imagery. At NASA's request and with its financial assistance, a MicroVAX computer was purchased to make SELSIS images available through the Space Physics Analysis Network (SPAN). Other government and research institutions have requested that SELSIS images be available on SPAN and other communication networks.

OPERATIONAL SATELLITE INSTRUMENTATION

Data from operational Space Environment Monitors (SEMs), which are carried on the NOAA/TIROS and GOES spacecraft, are essential to the operation of SESC. Instruments normally are provided by contractors to NASA, which acts in turn to supply NOAA with the entire operational satellite. SEL sets the requirements for the SEM system and assists with the technical supervision of the instrument contractor. SEL also repairs and recalibrates instruments awaiting flight.

No new GOES or NOAA spacecraft were launched during FY 1988. Routine checks continued on the quality of data supplied to SESC and archived with the National Geophysical Data Center.

The contract was awarded for the Space Environment Monitor (SEM) systems for the TIROS-K, -L, and -M spacecraft, which will fly in the early 1990s, Work commenced on 1 January 1988. The System Concept Review was held in May, attended by NOAA, NASA, and contractor staff. The preliminary Design Review, which marks the completion of the design and breadboarding of the system, will be held in early 1989.

The GOES I-M program was supported by participation in the Critical Design Reviews for the spacecraft system and for the individual SEM instruments. Attention has continued to be focused on avoiding spacecraft interference to the magnetometer system as well as on maintaining the capability for adding the Solar X-Ray Imager to the SEM instrument complement when funding becomes available under the joint USAF-NOAA agreement.

The search continued for the cause of the spurious data encountered from the TED instrument on NOAA-10. It is suspected that the cause was a deterioration of the coating on the electrostatic analyzer plates used to suppress UV light scattering. New plates with an improved coating are being manufactured for the instruments that have not yet been launched.

SEL SCIENTIFIC WORKSTATION SYSTEM

Six new workstations were added to the system early in FY 1988. SEL now has 16 workstations and two file servers. A number of PCs have also been equipped with network adapters to enable them to use the network as a file server. The system is a major resource to SEL staff for interactive scientific computing and for desktop publishing.

EXPERT SYSTEM AND OBJECT-ORIENTED PROGRAMMING

In close collaboration with members of SEL's research staff, work continued on the development of the Scientist's Workbench System. This is intended to provide a uniform environment for the analysis and correlation of scientific data from disparate data bases. The tools developed are immediately tested and have been put to work on actual projects leading to publications. The basic framework and user interface are now largely complete.

THEO, named after Theophrastus, the first recorded observer of sunspots, is a rule-based expert system to forecast the probability of solar flares using, initially, the topological classification of sunspot regions as observed in white light. The system became available to forecasters as an operational tool. It was developed at SEL in collaboration with the University of Colorado at Boulder (CU) Computer Science and Psychology Departments.

During FY 1988 THEO's rule base was expanded to include information that can be obtained from maps of the sunspot region as observed in hydrogen-alpha light. The database system for THEO has been extensively revised, to eliminate errors caused by the commercial database manager software. Work at CU during FY 1988 extended the verification of the system's performance and began development of a promising self-learning, neural-net implementation of the system.

WIDE-AREA NETWORKING

Wide-area computer networking is becoming increasingly important to SEL as a means of communication between cooperating scientists and institutions, disseminating SEL data, and acquiring data from other institutions and data centers. SEL now has links to the UUCP (Units-to-Units CoPy) network, the BITNET, and the NASA SPAN (Space Physics Analysis Network). Access to SPAN is through a dedicated connection provided by NASA. This initially had to be hosted by a NBS VAX 11-780 computer because of the proprietary protocols used. Dial-in access was required by SEL systems. This arrangement has now been enhanced by NASA and SEL's provision of a microVAX II system which is connected both to SPAN and to the Ethernet network. This permits much more flexible and direct use of this worldwide network from both the SEL Workstation and SELDADS computer systems, as well as better access by NASA Goddard Space Flight Center to the SELSIS imagery. Work is under way to unify the electronic mail systems involved and prepare for a direct connection to the group of networks known as Internet.

INTERPLANETARY SCINTILLATION OBSERVATIONS

Work has begun to reactivate the 3.6-hectare array at the Mullard Radio Astronomy Observatory (MRAO) of Cambridge University, England. Research at MRAO has shown that density disturbances in the solar wind caused by coronal mass ejections can be monitored by using this antenna to observe the scintillation of a large number of extragalactic radio sources. This sometimes makes it possible to predict whether a disturbance will reach Earth and when it will arrive. Data from this system show promise of significantly improving our ability to predict geomagnetic disturbances caused by the arrival of solar-wind density disturbances.

A joint plan was agreed upon by the management of MRAO, ERL, Rutherford Appleton Laboratory (RAL), and the British Antarctic Survey (BAS). Funds have been provided by SEL for the physical renovation of the antenna, and SEL is developing a data acquisition computer system for real-time operation. RAL is assisting in the renovation of the receiving system, and

BAS is providing funding for staff to operate the system. The array is expected to start operating at some time in 1989.

Collaboration is also continuing with the group that is constructing a similar observing system at the Physical Research Laboratory in Ahmedabad, India, with Indo-U.S. funding. The groundwork has been laid for testing data communications with Ahmedabad early in 1989.

SPACE ENVIRONMENT LABORATORY PERSONNEL—FY 1988

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Addendum

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Bornmann, P. L., "Solar Flare Properties Derived From an Eclipse Observed By the GOES X-Ray Sensors," 172nd Meeting of the American Astronomical Society, Kansas City, Missouri, June 5–9, 1988.

Bornmann, P. L., "The Sun as a Star: X-Ray Spatial Information Derived From the Disk-Integrated GOES Sensors," IAU Colloquium No. 104, Solar and Stellar Flares, Stanford University, California, August 15–19, 1988.

Combs, L. E., "Solar Activity and How it Affects the Earth," Westview Elementary School, Northglen, Colorado, February 25, 1988.

Combs, L. E., "Solar Activity and How it Affects the Earth," Angevine Middle School, Lafayette, Colorado, September 26, 1988.

Davies, K., "Mapping of FoF2," US–URSI Commission G, Propagation Medium Modeling Session, Boulder, Colorado, January 5–8, 1988.

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Davies, K., "Studies of Transient Effects in the Ionosphere," Seminar at the University of Electrocommunications, Tokyo, Japan, June 3, 1988.

Dryer, M., "Interplanetary Physics: MHD Numerical Experiments," Seminar, Department of Physics, University of Alberta, Edmonton, Alberta, Canada, April 7–8, 1988.

Dryer, M., "Photospheric Shear-Induced Non-Equilibrium and Arch-Filament Eruption/Coronal Mass Ejection," American Geophysical Union Spring Meeting, Baltimore, Maryland, May 16–20, 1988.

Dryer, M., "Three-Dimensional MHD Simulation of an Interplanetary Plasmoid Produced by Pressure-Gradient-Caused Reconnection at the Heliospheric Current Sheet," COSPAR XXVIII Meeting, Espoo, Finland, July 18–29, 1988.

Evans, D. S., "Modeling the Distribution of Auroral Electrons Above Pulsating Auroras," SEL Seminar, Boulder, Colorado, February 18, 1988.

Heckman, G. R., "Evaluating the Early Rise of Solar Cycle 22," NASA Review Panel Meeting, Huntsville, Alabama, February 17, 1988.

Heckman, G. R., "Use of Precursor Methods in the Prediction of Maximum Sunspot Number for Solar Cycle 22," NASA Review Panel Meeting, Huntsville, Alabama, February 17, 1988.

Heckman, G. R., "Predictions of Solar Cycle 22 and the Problem of Falling Satellites," SEL/SESC Lecture, Boulder, Colorado, March 2, 1988.

Heckman, G. R., "Real-Time Atmospheric Density Models Using Indices From the Space Environment Services Center," Atmospheric Neutral Density Specialist Conference, Colorado Springs, Colorado, March 22, 1988.

Heckman, G. R., "A Review of Solar Proton Event Forecasts for Space Mission Operations," Space Radiation Dose Modeling Workshop, Houston, Texas, May 23, 1988

Heckman, G. R., "Solar Proton Event Forecasts for Exploration Class Space Missions," Workshop to Define Requirements for Radiation Shielding on Exploration Class Space Missions, Houston, Texas, May 26, 1988.

Heckman, G. R., "Strategies for Dealing with Solar Particle Events in Missions Beyond the Magnetosphere," COSPAR XXVII, , Espoo, Finland, July 23, 1988.

Hirman, J. W., "The Mission of the Space Environment Services Center," Technical Consultant visit, San Vito Observatory, San Vito, Italy, October 7, 1987.

Hirman, J. W., "Solar Activity, Terrestrial Effects, and Users," Technical Consultant visit, San Vito Observatory, San Vito, Italy, October 8, 1987.

Hirman, J. W., "Solar Cycle 22 Prediction and its Impact," Technical Consultant visit, San Vito Observatory, San Vito, Italy, October 8, 1987.

Hirman, J. W., "San Vito Observatory Data and SESC Needs," Technical Consultant visit, San Vito Observatory, San Vito, Italy, October 8, 1987.

Hirman, J. W., "Solar Proton Event Forecasts," NATO Advanced Study Institute, Terrestrial Space Radiation and its Biological Effects, Corfu, Greece, October 15, 1987.

Joselyn, J. A., "Geomagnetic Climatology," SEL/SESC Lecture, Boulder, Colorado, October 14, 1987.

Joselyn, J. A., "The Geomagnetic Activity Outlook for 1987–1997 (Cycle 22)," Workshop on Atmospheric Density and Aerodynamic Drag Models for Air Force Operations, Air Force Geophysics Laboratory, Massachusetts, October 23, 1987.

Joselyn, J. A., "Introduction to the Sun," Hillcrest Elementary School, Thornton, Colorado, November 4, 1987.

Joselyn, J. A., "Solar Weather—Why Do We Care?," Mountain Shadows Montessori School, Boulder, Colorado, February 16, 1988.

Joselyn, J. A., "Solar Weather—Why Do We Care?," Rotary Club, Deming, New Mexico, March 3, 1988.

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Joselyn, J. A., "The Impact of Spacecraft Environment on Space Science," SEL/SESC Lecture, Boulder, Colorado, September 20, 1988.

Leinbach, F. H., "Neutron Monitors," SEL/SESC Lecture, Boulder, Colorado, April 13, 1988.

Kunches, J. M., "Solar Flares," Ashley Elementary School, Lakewood, Colorado, December 7, 1988.

Kunches, J. M., "The Sun and Solar Activity," Sabin Elementary School, Lakewood, Colorado, February 18, 1988.

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McIntosh, P. S., "Cycle 22," SEL/SESC Lecture, Boulder, Colorado, March 23, 1988.

Osherovich, V. A., "North-South Asymmetry in the Solar Corona Prior to Solar Minimum 1986," SEL Seminar, Boulder, Colorado, April 26, 1988.

Poppe, B. B., "A New Image for System Administrators," April '88 Conference, Apollo DOMAIN Users' Society, Special Interest Group in System Administration, San Diego, California, April 25, 1988.

Poppe, B. B., "Who is the user?," SEL/SESC Lecture, Boulder, Colorado, September 28, 1988.

Sargent, H. H., III, "The SEL Public Bulletin Board System," SEL/SESC Lecture, Boulder, Colorado, April 20, 1988.

Smith, J. B., "Flare Onset at Sites of Maximum Magnetic Shear," American Astronomical Society/Solar Physics Division Annual Meeting, Kansas City, Missouri, June 7, 1988.

Speiser, T. W., "Adiabatic Motion of Charged Particles in the Magnetosphere," SEL/SESC Lecture, Boulder, Colorado, March 9, 1988.

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St. Cyr, O. C., K. T. Strong, D. M. Speich, and R. Murphy, "A Catalogue of the Soon H-Alpha Patrol Films: A New Resource for Solar Physics," IAU, San Francisco, California, December 10, 1987.

Tappin, S. J., "Discussion of IPS G-Map Observations," SEL Seminar, Boulder, Colorado, March 9, 1988.

Wagner, W. J., "Operational Solar X-Ray Imagers (SXI) on NOAA's Geostationary Meteorological Satellites," Tokyo Astronomical Observatory, Tokyo, Japan, October 2, 1987.

Wagner, W. J., "Solar Events and Their Influence on the Interplanetary Medium," COSPAR XXVIII Meeting, Espoo, Finland, July 25, 1988.

Wagner, W. J., "Observations of 1–8 Angstrom Solar X-Ray Variability During Solar Cycle 21," COSPAR XXVIII Meeting, Espoo, Finland, July 27, 1988.

Zwickl, R. D., "A Study of Fluctuations in the Solar Wind Density and Their Impact on IPS Measurements," SEL Seminar, Boulder, Colorado, September 15, 1988.

Zwickl, R. D., "Relativistic Magnetospheric Electrons: Their Origin and Possible Influence on Middle Atmospheric Processes," January 8, 1988.

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