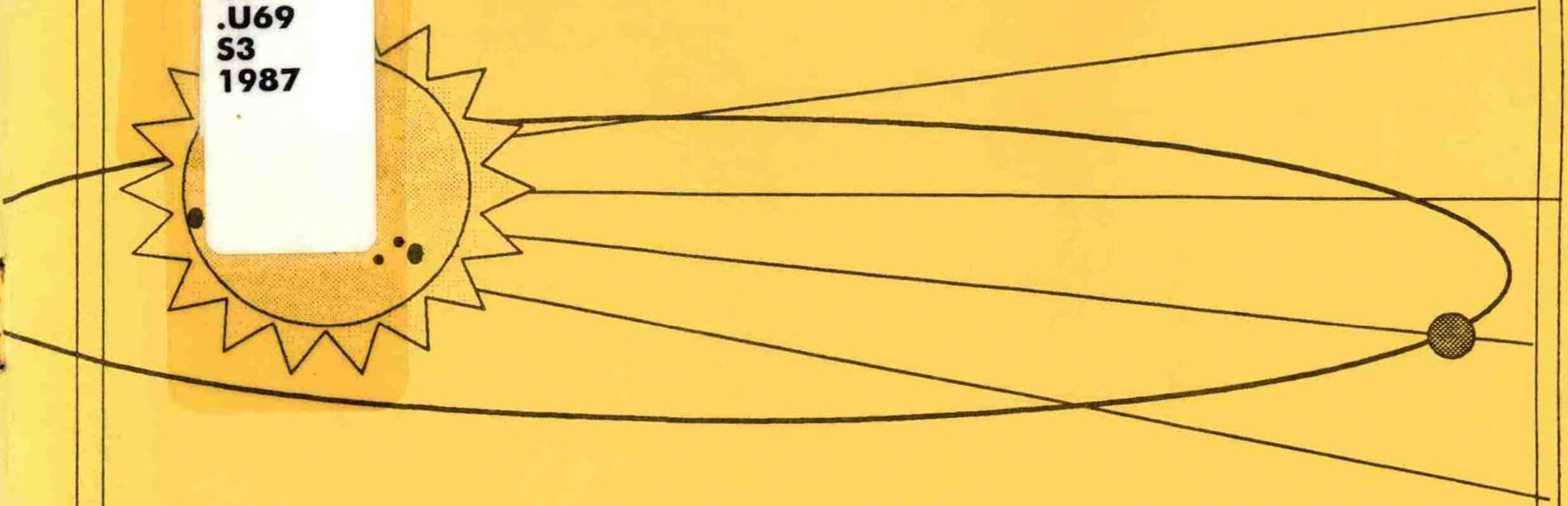

SPACE ENVIRONMENT LABORATORY

ANNUAL REPORT

FY 1987

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

SPACE ENVIRONMENT LABORATORY

ANNUAL REPORT — FY 1987
October 1, 1986, to September 30, 1987

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Space Environment Laboratory
Boulder, Colorado

January 1988

United States
Department of Commerce

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National Oceanic and
Atmospheric Administration

Environmental Research
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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 number 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 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 – Charged 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.

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.

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.

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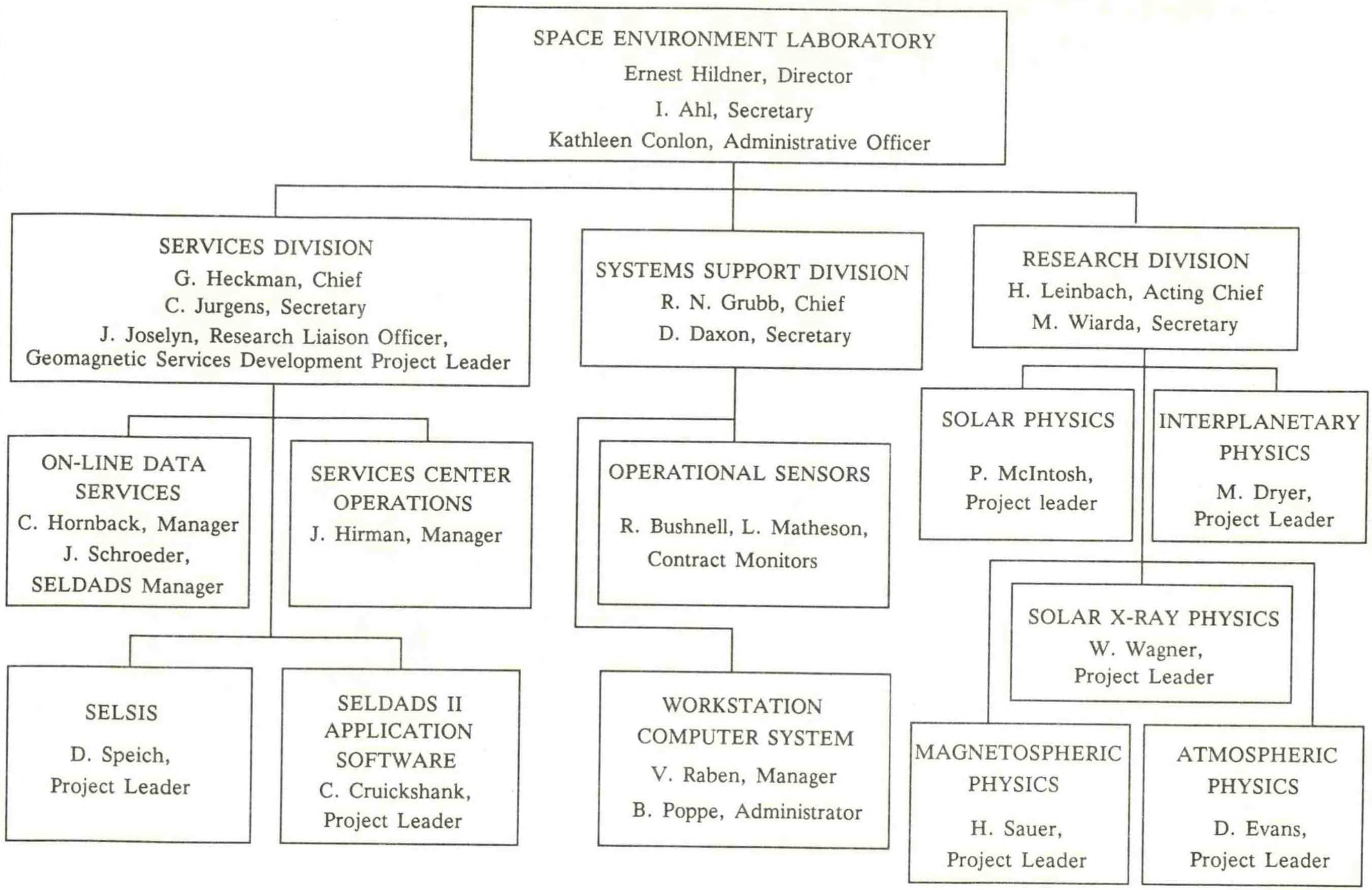

Space Environment Laboratory Organizational Chart (as of October 1, 1987)

SPACE ENVIRONMENT LABORATORY
Annual Report—FY 1987

INTRODUCTION

The NOAA/ERL Space Environment Laboratory is a combined research and real-time services organization specializing in the study, monitoring, and forecasting of solar, interplanetary, magnetospheric, and upper-atmospheric disturbances.

The Laboratory is administratively divided into four groups: the Director's Office, the Research Division, the Space Environment Services Division, and the Systems Support Division. For several years, many of the tasks within SEL have been structured across Division lines. Prime examples are the SELDADS II and SELSIS projects, concerned with systems that support the real-time operations within the Space Environment Services Division. Many of the researchers on those projects also have prime duties as the responsible scientists for various satellite- and ground-based detector systems for obtaining real-time observations to support the Space Environment Services Center (or, informally, the "Forecast Center").

The interests of the Laboratory are of necessity very wide ranging, from disturbances on the Sun to related disturbances in the upper atmosphere. This breadth of coverage presents a challenge to management in maximizing the output of SEL within the constraints of available resources. Cooperative operational and research arrangements with other agencies and institutions are a very large factor in assuring that the Laboratory meets its obligations. Within NOAA, SEL has particularly close association with the National Environmental Satellite, Data, and Information Service (NESDIS). Outside NOAA, the Laboratory has close ties to components of USAF, the National Aeronautics and Space Administration (NASA), and the National Science Foundation, and to various university research groups.

This Annual Report documents the progress of the Laboratory during FY 1987. Many of the projects are ongoing, especially those that provide space environment services. The long-term goal for these projects is to continually improve the scope and usefulness of these services. For the research tasks, a primary long-term goal is to couple new knowledge and techniques to service operations. Success in these endeavors often hinges on the availability of appropriate real-time data; thus, another long-term goal of the Laboratory is to upgrade the real-time monitoring of the Sun-Earth system.

SPACE ENVIRONMENT SERVICES

Rapid variations in the Sun's output, including solar flares and gigantic ejections of solar mass as well as 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. In extreme circumstances they may threaten health or life. Many activities may be affected:

- Satellite operations.
  - Orbital variations and lifetime (atmospheric heating and density variations).
  - Command and control anomalies (surface and dielectric charging).
  - Ground–spacecraft communication problems (ionospheric scintillation and solar radio noise interference).
  - Instrument health (large fluxes of energetic particles).
- Man-in-space and high-altitude polar flights.
  - Radiation exposure (energetic solar protons).
- Navigation by satellites (orbit variations)
  - Ships and submarines.
- Navigation by very-low-frequency OMEGA radio (ionospheric disturbances).
  - International aviation.
  - Ships and submarines.
- High-frequency communications (ionospheric disturbances).
  - Intercontinental aviation.
  - Ships.
  - Military.
  - International broadcast.
- Remote surveillance.
  - Over-the-horizon radar (ionospheric disturbances).
  - Space-based optical surveillance (auroral emissions).
- Long electrical conductors (induced currents due to geomagnetic field fluctuations).
  - Transcontinental cables.
  - Power transmission lines.
  - Pipelines.
- Scientific research programs.
- Geophysical exploration.
  - Magnetic mapping (geomagnetic field fluctuations).
  - Telluric analysis (induced ground currents).
  - Archaeological studies.

In response to the effects on these activities, various agencies of the Federal government have initiated programs for measuring different types of disturbances, summarizing them in the form of standard indices, and predicting disturbances. Although the systems affected vary from agency to agency, the disturbances in the natural environment that produce them are the same. Therefore, the agencies have developed a program of shared resources. These include observatories and satellites that measure the environment; communication networks; and forecast centers that analyze the data, issue indices, and make forecasts. A description of this national program is contained in "The National Plan for Space Environment Services and Supporting

Research, 1983–1987" (NOAA Report FCM–P10–1983). The plan provides for joint operation of a Space Environment Services Center (SESC) by NOAA and the USAF Air Weather Service to meet common needs for space environment services. During FY 1987, the next extension of the plan was drafted.

Space Environment Services Center (SESC)

The center of the nation's solar-terrestrial services is SESC in Boulder, Colorado. The services of SESC are tailored to meet the common needs of the other Federal agencies and, where they coincide, those of the public sector. Users of SESC's products may then produce specialized services for their own use. On occasion SESC provides tailored services, on a reimbursable basis, to meet the needs of other agencies. For example, SESC continued to support NASA's Solar Maximum Mission satellite operations center during FY 1987.

SESC collects and analyzes data, produces indices, and provides forecasts, alerts, and data summaries 7 days a week, 24 hours a day. The products are a standardized set analogous to those issued by the National Weather Service:

- Forecasts of solar flares, space radiation (energetic proton) events, geomagnetic storms, and the slowly varying component of solar radio emissions.
- Alerts of disturbances in progress in the solar-terrestrial environment.
- Indices that summarize current conditions in the solar-terrestrial environment.
- Reports and data summaries of solar, ionospheric, and geomagnetic activity.

These various products are distributed to users by computer-to-computer links, teletype networks, broadcasts on WWV, satellite broadcasts, and through the mail (e.g., by a weekly bulletin).

The primary mission of SESC, to provide these products as accurately as possible with continuity and reliability, was met throughout FY 1987. The mission is complex and difficult. The relationship between solar disturbances and activity at Earth is not fully understood. Even in those cases where empirical or theoretical understanding are available, application to services often is not feasible because of the lack of appropriate real-time data.

An example is in the coupling of solar wind disturbances to Earth. It has been well established by solar wind researchers using space-probe data that coupling is enhanced when the interplanetary magnetic field direction is nearly antiparallel (i.e., southward) relative to Earth's field at the nose of the magnetosphere. Conversely, coupling can be very weak when the interplanetary field direction is parallel to Earth's field. But at the present time we have no way of utilizing this cause-effect relationship in operations because no real-time observations of the near-Earth interplanetary field are made, none of the remote-sensing techniques (such as the interplanetary scintillation methods) provide information on the solar-wind magnetic field, and none of the existing numerical models adequately predict the details of the interplanetary magnetic field.

Although lack of adequate real-time data will continue to plague SESC for some time to come, improvements in existing data systems and analysis techniques during FY 1987 have materially improved the quality of its forecasts and other products. For example, the replacement of the old data-base system by the new SEL Data Acquisition and Display System (SELDADS II) marked a large step forward. On October 1, 1986, SELDADS II became fully operational and the old system was retired from duty. At the beginning of FY 1987, some 90 separate software elements (including data acquisition and analysis packages, real-time graphical displays for the forecaster, and automatic message generation and transmission) were available on SELDADS. By the end of the fiscal year, the total had swelled to 160 operational software elements. All these packages were developed in-house, representing a major workload for a significant number of staff from SESC and the Systems Support Division. SELDADS II has eased time pressures on the forecasters and measurably improved the quality and timeliness of the products issued by SESC.

Figure 1 shows a plot of the solar x-ray flux as measured on the Geostationary Operational Environmental Satellites (GOES) for the period of January 1987 to January 1988. This is one example of the types of real-time and retrospective data plots available to the forecasters. Note how the background flux of solar x-rays increased as the activity of the new cycle increased. At the beginning of the cycle, sunspot activity was low, and many days during each month were without spots. By the summer of 1987, activity was clearly on the increase as measured by the number of sunspot groups, by the level of the 10-cm solar radio flux, and by the background level of solar x-rays.

SESC continued in its role of World Warning Center for the International Ursigram and World Days Service, an organization established by the International Council of Scientific Unions to provide for prompt international exchange of data and forecasts relative to the space environment. The countries actively participating are Canada, Australia, Japan, France, Germany, England, Czechoslovakia, Poland, India, and the USSR.

During FY 1987 a new Satellite Anomaly Analysis service was begun, at the request of the satellite operations community. Many satellites occasionally experience one or more types of

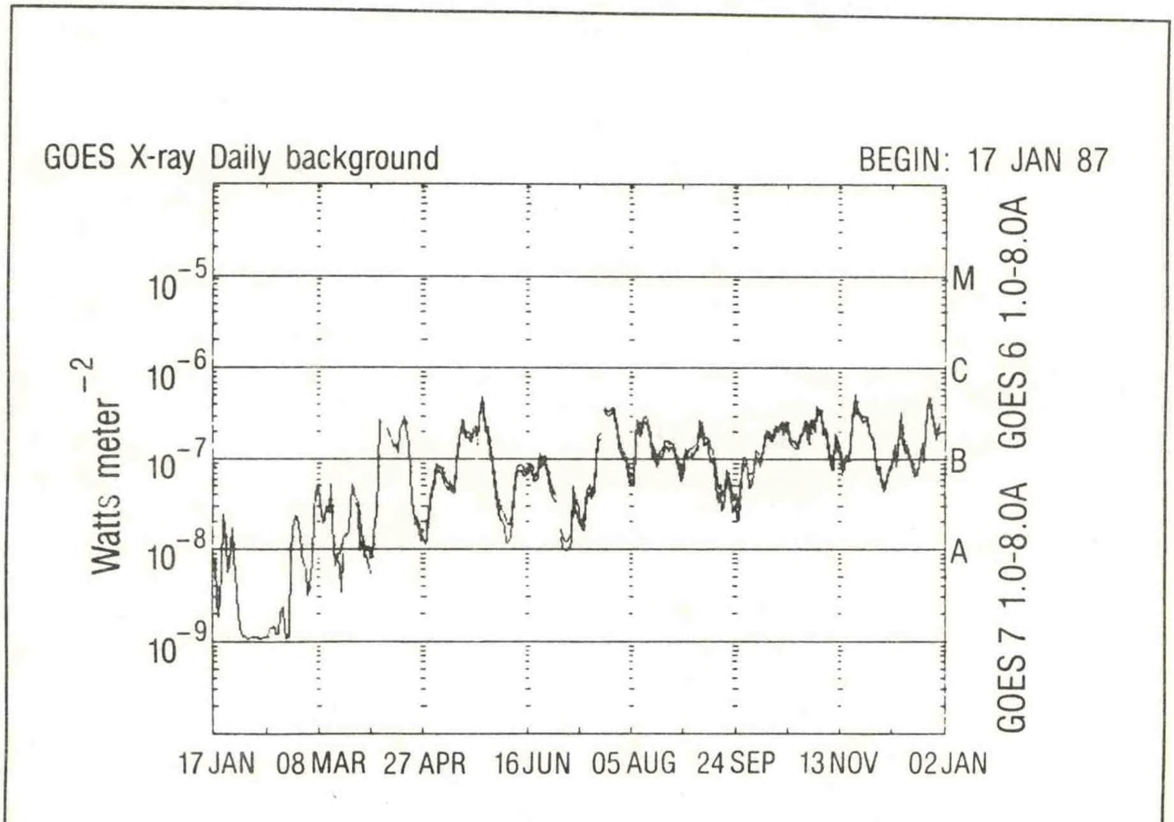

Figure 1. Variation of the 1–8 angstrom solar x-ray flux between January 1987 and January 1988, measured by the GOES satellites. The steady increase shows that the new sunspot cycle, number 22, was well under way before January 1988.

anomalous behavior. A fundamental question is whether such anomalies are strictly the result of internal hardware and/or software problems, or whether (as in the case of energetic charged particles) they are induced by the local environment. With the new service, satellite operators can discuss their operational problems with the SESC staff. The staff then perform an analysis of relevant geophysical data, with the cooperation of USAF personnel, and advise the satellite operators if malfunctions may be related to natural disturbances in the local spacecraft environs.

SPACE ENVIRONMENT DATA COLLECTION

Solar Electronic Observing Network

The U. S. Air Force Air Weather Service 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 Earth. This network maintains a continuous watch for solar activity and provides many of the synoptic observations used in forecasting solar activity. Together, SOON and RSTN make up the Solar Electronic Observing Network. The staffs of SOON and RSTN (totaling more than 50 workers) are supplied primarily by USAF. Some of the staff for SOON/RSTN at the Learmonth Solar Observatory in western Australia are provided by the Australian government. A NOAA Corps officer, assigned to SESC, is also stationed at Learmonth.

The SOON sites at Learmonth and at Holloman Air Force Base, New Mexico, provide near-real-time images a few times each day to SESC. These images, which are transmitted digitally (see the section on SELSIS), include hydrogen-alpha images, continuum-like images of sunspots, and contour magnetic maps of solar active regions. In addition, all the SOON/RSTN sites provide coded data on solar activity to SELDADS and plain-language messages to the forecaster.

Culgoora Observatory

The Culgoora, Australia, Solar Observatory is operated by the Australian government to meet its own operational requirements for solar observations. The Observatory also provides data to SEL. A NOAA Corps officer, detailed to SESC, is stationed at Culgoora to assist with operation of the site and provide liaison with SESC.

National Solar Observatory at Kitt Peak

Some solar observations, such as whole-disk solar magnetograms, require specialized equipment. Since some of this equipment already existed at the Kitt Peak solar research facility in Arizona, NOAA has arranged for transfer of these unique images to Boulder. SESC provides a resident staff member at Kitt Peak, as does NASA; the National Science Foundation provides additional support for the daily synoptic solar observations.

The whole-disk magnetograms provide vital input to forecasting of solar activity. These images show the regions on the Sun's surface where the magnetic field has a component in the direction of the line of sight. Such measurements are possible because of the spectral line splitting and polarization that occur in the presence of a magnetic field (the Zeeman effect).

Solar researchers have shown, time and again, the importance of solar magnetic fields in the dynamics of solar activity. An analysis of the flare potential of an active region (sunspot group) depends not only on the complexity of the arrangement of sunspots as seen in white-light observations, but, more importantly, on the magnetic field topology in the region. The Kitt Peak magnetograms are an important source of that information.

Kitt Peak is also the only observatory routinely supplying synoptic observations of the Sun in the near-infra-red spectral line of neutral helium at 10830 angstroms. Research by solar physicists over the past several years has established that the coronal hole regions on the solar surface have a smaller amount of He 10830 absorption than other parts of the solar surface, and thus appear brighter. Thus the He 10830 images provide one way to detect coronal holes with reasonable but imperfect reliability. Coronal holes are known to be the source regions for very-high-velocity solar wind streams. Such streams are often the sources of the recurrent geomagnetic activity seen particularly in the years just preceding solar minimum. A better way of detecting coronal holes is by obtaining images of the Sun in soft x-rays. SEL's efforts to implement a soft x-ray imager are discussed in the section "Solar X-Ray Imager."

The Kitt Peak images are digitally transmitted to SESC (see the section "SELSIS").

GOES Space Environment Monitor (SEM)

The integrated-flux solar x-ray detectors on the GOES satellites provide primary detection and classification of solar flares. Many studies in recent years have shown that mass ejections with enough energy to impact Earth are often accompanied by long-duration solar x-ray events. Together with optical and radio data from the SOON/RSTN sites, the real-time x-ray data are used for prediction of effects at Earth resulting from solar activity. For many years, SESC has classified solar flares according to the peak solar x-ray flux in the 1–8 angstrom range measured by GOES. This classification has become a standard reference in the solar research community.

GOES satellites also carry a complement of energetic-particle sensors and magnetometers. Some of the SEL research work using these data is discussed below. The particle information is especially useful to the forecasters for two reasons: (1) The detectors are a primary sensor for energetic solar protons, and (2) large increases in the low-energy proton flux of magnetospheric origin empirically correlate very well with moderate-to-strong substorm activity at auroral zone latitudes.

A continuous flow of real-time GOES SEM data is critical for SESC operation. The data are received at SESC's tracking station at Table Mountain Observatory near Boulder. The data are read out, processed, and transmitted continuously into SELDADS for use by SESC; they are then made available through SELDADS to other users. The data are also archived in the National Geophysical Data Center of NESDIS. Until March 1987, GOES–5 and GOES–6 were the two satellites interrogated for their SEM data. In early March, GOES–7 was declared operational; its data replaced those from GOES–5. An improved system for checking the quality of the GOES data was implemented in 1987.

NOAA/TIROS Space Environment Monitors

Besides the data obtained at synchronous orbit by the GOES satellites, data are also obtained with SEMs flown on the NOAA polar-orbiting satellites. These satellites measure energetic particles to detect solar proton events, and also measure the total energy deposited into the upper atmosphere by lower energy auroral electrons. NOAA–10 is the satellite currently used for these purposes. Unfortunately, a degradation in the total energy detector took place during 1987, reducing the quality of NOAA–10's data. This degradation is apparently due to exposure to the space environment; it illustrates the effects that this environment can have on technological systems.

Remote Geophysical Observing Network

Another important set of data for SESC consists of measurements of geomagnetic field variations at both auroral and sub-auroral latitudes and at middle latitudes. The magnetic field data are used to define the real-time magnetic indices. Real-time displays of selected magnetometer data provide the forecaster with important information on the level of magnetic activity at middle- and high-latitude stations.

Some of the magnetometer data, as well as riometer data on high-latitude ionospheric absorption, are collected from a network of remote stations using the GOES data collection platform systems. Many of the sensors are operated by several universities with funding from the National Science Foundation. The data are transmitted by radio transmitters at each of the remote sites and are received by the GOES data collection systems every 12 minutes. The data are relayed by NESDIS, in Maryland, to Boulder, where they become a part of the SELDADS data base.

Other Data Sources

SESC receives other important solar data from non-U.S.-government sources. The Canadian government supplies 10-cm total-solar-flux measurements and east–west fan-beam scans of the Sun on a daily basis. The 10-cm flux measurements were started in 1947 and have become a standard index for solar activity. The east-west scans have proved to be of particular value in forecasting, since the effects of active regions on the 10-cm source regions in the lower corona are visible at the east limb up to 3 days before the region actually transits the limb and becomes visible from Earth in hydrogen-alpha images.

SESC also receives Ca II spectroheliograms and isophote maps of coronal line emission from the National Solar Observatory at Sacramento Peak in New Mexico.

Mt. Wilson Observatory, near Pasadena, California, where George Ellery Hale initiated magnetic-field measurements of sunspots in the early part of this century, supplies SESC with measurements of the magnitude and polarities of all measurable sunspots in each region. These data complement the whole-disk magnetograms from Kitt Peak; they are a vital set of data for forecasting the probability of occurrence of solar flares.

Field Site Operation

SESC and USAF jointly operate the High-Latitude Monitoring Station in Anchorage, Alaska. This site collects and re-transmits several types of data to SELDADS, including an auroral radar at Anchorage, several magnetometers and riometers, and the Thule neutron monitor data. USAF and NOAA are planning to convert this station to fully automatic operation in the future. New computer software was installed at the High-Latitude Monitoring Station in 1987.

SESC also operates Table Mountain Observatory, north of Boulder, as the receiving site for the GOES SEM data transmissions. This observatory is also the location for the U.S. Geological Survey Boulder magnetometer that inputs real-time data to the Forecast Center, where they are graphically displayed.

RESEARCH AND DEVELOPMENT

Research and development in the most general sense are carried out in all three divisions of SEL. The Research Division carries out research in solar-terrestrial relations, 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. Detectors include the Space Environment Monitors on NOAA's geostationary and polar-orbiting satellites, as well as ground-based monitors. The Systems Support Division provides general support to the Space Environment Services Division and to the Research Division in planning, development, and provision of instrument and data systems. The Space Environment Services Division contributes several technique-development projects, including work on new forecasting and verification methods.

SOLAR PHYSICS

The Solar Physics Project studies the nature of solar activity and its origins, to provide new knowledge needed for improving predictions and analysis of solar-terrestrial activity. Work during FY 1987 was divided among

(1) observational studies of the structure and evolution of large-scale forms of solar activity,
(2) expanding the knowledge base of an expert system for solar flare predictions, and
(3) theoretical studies of solar magnetic fields and related solar structures.

Observations of the Solar Cycle

The number of sunspots appearing on the Sun waxes and wanes with an average period of about 11 years. Similarly, other measures of solar activity, such as the integrated flux of 10-cm radio noise from the inner corona, also vary with the same period. Sunspot cycles are counted from the period of minimum number of spots to the next period of minimum number of spots. A distinguishing feature between successive cycles, of great physical significance, is the change in the orientation of the magnetic fields in sunspot groups. Sunspot groups have a bipolar magnetic field configuration such that, if the fields are inward in the leading (westernmost) spots, the fields in the trailing spots will be outward from the surface. This arrangement of polarity is reversed between the northern and southern solar hemispheres. These hemispheric differences reverse in polarity between succeeding cycles. The leading polarity in both hemispheres becomes the trailing polarity in the following cycle. From a perspective of the magnetic-field orientations, the Sun thus exhibits a 22-year cycle.

It was possible in late 1986, for the first time, to announce the occurrence of the time of minimum in the solar cycle during the month it was occurring. Three types of observations showed a close correlation with the time of minimum in two or more of the previous solar cycles, and their use to infer the time of the 1986 minimum demonstrated that the correlations are valid once again.

The first observation was of the relative frequency of "new" cycle versus "old" cycle sunspot groups, using the fact that new cycle groups occur at latitudes greater than 20 degrees whereas the old cycle groups occur near the solar equator. The ratio of new to old groups becomes greater than 1 during the month of solar cycle minimum, and it can be calculated immediately. This ratio suddenly increased to greater than 1 in October 1986. The traditional method for determining solar minimum has been to use the 13-month running mean of monthly observed sunspot numbers; therefore, the minimum could not be determined until almost a year after the time of minimum. Not until mid-1987 was it generally agreed that the smoothed sunspot numbers defined minimum as September 1986.

The second observation used the monthly mean radio flux, observed only since 1947 and covering only $3^1/_2$ solar cycles. An abrupt drop in flux occurred at the same phase in the declining portion of all four cycles of record, and the time between the drop and the subsequent minimum in flux was 3.5 years for the three cycles prior to the present minimum. The precision with which the drop occurred at the same phase for these three cycles prompted the speculation that minimum could be predicted in 1986 on the basis of the observed drop in flux at the end of 1982. The predicted time of minimum agreed with the new/old group ratio to within 1 month.

The third observation is much more vague, but supports the other two predictions. The large-scale patterns of magnetic polarity become ill-defined for the year or more just before the minimum, and then grow distinct as soon as the new cycle is under way. This observation is derived from only two cycles of data and, therefore, is the most speculative predictor of solar minimum. The fact that the patterns suddenly became clearly marked by large filaments and other structures in October 1986 added the final evidence to conclude that September 1986 was the correct month of minimum.

Solar Mapping

The series of H-alpha synoptic charts for each solar rotation, edited for research use, now includes over 23 years of data. This permits intercomparison between two complete 10.5-year solar cycles and between the early stages of three cycles. The two-dimensional, time-dependent patterns give a perspective on the nature of the solar cycle that is observationally independent of, and more detailed than, the history of sunspot observations alone.

To obtain insight about how solar cycles develop and change, the first diagram showing a full 22 years of large-scale solar magnetic field patterns was constructed. Many interesting patterns of evolution were revealed and are now under study. For example, a time-lapse movie of the large-scale magnetic fields, together with coronal holes, revealed vortical motions surrounding sites of strong flare activity. Other discoveries from this work are the periodic variations in the latitudes of filaments near the solar poles, synchronous with waves of magnetic flux moving from equator to pole, and the sudden changes in patterns and rotation rates among large-scale magnetic fields, synchronous with changes in the solar irradiance at radio wavelengths.

Synoptic maps of the large-scale magnetic fields on the Sun are made routinely as information for the forecasters; the final edited maps are published by the National Geophysical Data Center in *Solar-Geophysical Data*. Production of these maps was accelerated through use of new computer-screen dump routines for output to a laser printer.

SOLAR X-RAY PHYSICS

The objective of the Solar X-Ray Physics Project is to improve short- and medium-term solar predictions and to understand the structure and evolution of the x-ray-producing solar corona. Solar x-rays are generated by processes in the solar atmosphere at effective temperatures of at least 1 million degrees. The solar atmosphere over active regions is one source of x-ray emission. An energetic solar flare or a coronal mass ejection can enhance the x-ray flux from the entire Sun by two to three orders of magnitude. SEL has operated real-time x-ray detectors on the GOES satellites since the early 1970s. These data are analyzed to improve forecasts of solar disturbances that originate in the outer solar atmosphere. During FY 1987 the Solar X-Ray Physics Project concentrated on the following tasks.

Solar X-Ray Imager

The addition of a Solar X-Ray Imager (SXI) to the operational Space Environment Monitor on GOES is a high priority for SEL. The SXI will contribute significantly to improvement in predictions of geomagnetic storms, solar extreme ultraviolet flux variations, and solar flare proton events. The operational value of the data from such an SXI has been demonstrated by retrospective analysis of 1973 data from a similar instrument on NASA's Skylab mission.

SEL has formulated plans for installing SXI telescopes on the GOES–K through GOES–M spacecraft; the first launch is expected about 1992. A Memorandum of Agreement signed in FY 1987 provides USAF funding in FY 1990 for one or more SXIs that NOAA will fly on GOES. SXI data and forecasts will be shared by NOAA and USAF. NOAA will use the SXI images to improve current forecasts and to develop improved prediction techniques, and will perform research toward a better understanding of the physical processes at work on the Sun.

Solar X-Ray Studies

An algorithm and a program have been developed for computing the solar plasma temperature and the emission measure from the GOES full-disk x-ray data, measured in two different x-ray bandpasses of about 0.5 to 4, and 1 to 8 angstroms. Analysis of solar plasma temperature and emission measure was completed for each of about 100 flares that occurred during the maximum of the last solar cycle. The analysis algorithms are being modified and improved to better account for energy transfer into and out of the flaring volume. It is hoped that characterizing a flare by its temperature and emission measure will assist predictions of the flare's effects on the interplanetary medium and, in turn, the near-Earth space environment.

In another study, spectral line data from the X-Ray Polychromator experiment on the NASA Solar Maximum Mission spacecraft have been used to show that the assumption of a two-temperature-component flare plasma yields results essentially identical to those of the differential emission measure technique. It is thus possible to conclude that a hot *and* a cool component co-exist in the telescope's field of view, and that this dichotomy is not merely an artifact of the differential emission measure analysis.

The long-duration events observed in x-ray fluxes by GOES are now known to accompany coronal mass ejections (CMEs) from the Sun. Shocks often accompany CMEs, the combination producing energetic proton events and geomagnetic storms at Earth. Research during FY 1987 showed that events detectable from ground-based observatories in the Fe XIV green coronal emission line were incipient CMEs. This result opens the possibility for detailed studies of the magnetic field changes that lead to x-ray long-duration events and CMEs.

SEL personnel served as co-investigators in a proposal for the fabrication and flight of a spaceborne coronagraph on the ESA–NASA Solar Oscillations and Heliospheric Observatory scheduled for launch to the L_1 Libration Point in 1994. Coronal mass ejections directed toward Earth will be studied with this telescope; the real-time detection of such CMEs will probably be used by SESC forecasters in a fashion similar to their use of P78–1 SOLWIND coronagraph data obtained during FY 1985.

INTERPLANETARY PHYSICS

The objective of the Interplanetary Physics Project is to improve forecasts of the occurrence, duration, and severity of geomagnetic storms. The strategy is

(1) to develop methods for monitoring disturbances as they are generated near the Sun and travel toward Earth, and

(2) to develop, test, and implement physically based, numerical magnetohydrodynamic (MHD) models that someday will be driven by real-time solar observations and checked by spacecraft monitoring near Earth.

Test of 2 1/2-Dimensional Interplanetary Global Model (2 1/2-D IGM)

Several major solar flares and a major magnetic storm occurred in February 1986. This complex series of events was selected to test, retrospectively, the predictive capabilities of a 2 1/2-D MHD model of the propagation of solar wind disturbances. The observed times of occurrence of the flares were used as the start times of the simulations, and inferred energy inputs of the flares were based, for example, on the integrated flux of the solar x-rays emitted by these flares. The simulations of the time of arrival of the disturbances at Earth were very reasonable, but the model was less successful in matching the solar-wind-velocity profiles observed at Earth. A consideration of the influence of several coronal holes on the properties of the solar wind between the Sun and Earth did not improve the comparison between the simulation and preliminary solar wind data from the IMP–8 spacecraft in near-Earth interplanetary space.

It was clear that input based on individual flare pulses, each having a rather short temporal duration, was not sufficient to provide a satisfactory simulation of the solar wind disturbances observed near Earth. Therefore a collaboration was started with English and Japanese solar-wind experimentalists flying instruments on the Comet Halley probes, Giotto and Sakigake, located at about 0.77 AU (51 degrees west of Earth) and at 0.84 AU (57 degrees west), respectively. In-situ solar wind velocities for the February 1986 events were obtained from these additional observation points, together with interplanetary Doppler scintillation data from the Sakigake telemetry signals. The scintillation data give path-integrated measurements of the solar wind disturbances between the spacecraft and Earth, complementing the single-point in-situ measurements made at the spacecraft. These data will be used in further simulations that will incorporate the idea that some flares may continue to pump energy into the solar wind over a long (10–24 hour) time scale. As a prelude to this work, a sensitivity study was initiated using a wide range of spatial and temporal scales of the MHD input parameters for flare-generated shock waves.

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

The 3–D IGM code was successfully transferred from the CRAY–1 to the CYBER 855/205 computer. Simulation studies of the reconnection of opposing field lines at an initially flat heliospheric current sheet were conducted; this type of reconnection has possible relevance to the formation of "magnetic clouds" that have been observed by various interplanetary spacecraft. Such magnetic clouds are an important source of major magnetic storms at Earth. In collaboration with colleagues at the University of Alabama/Huntsville and at the Tennessee Technological University, 3-D graphical algorithms were developed in order to visualize these clouds.

In addition, initial tests of a more general, sinusoidal heliospheric current sheet for a steady-state solar wind flow were carried out. The pilot study to extend the inner limit of the 3-D IGM to the base of the corona is continuing as a collaborative effort with CIRES research associates and contractors. Several approaches to improve the initial conditions for the model are under way:

(1) A one-dimensional simulation with all three components of the velocity and magnetic field, using implicit numerical techniques close to the Sun.

(2) A $2^1/_2$-D helmet streamer analysis, including a number of extensions including variable temperature, heat conduction, and appropriate boundary conditions at large distances.

Interplanetary Scintillations (IPS) of Distant Radio Sources

Two collaborative efforts, with English and Indian scientists, are under way to develop real-time systems for measuring the interplanetary scintillations of extra-galactic point radio sources. The English workers have shown that all-sky maps of the scintillation index of several hundred of these sources can be used to infer whether solar wind disturbances are present between the Sun and Earth, and even to predict when such disturbances will reach Earth. Thus the IPS technique, which measures path-integrated disturbances in the solar wind, has an important potential for aiding forecasters.

The Anglo-U.S. IPS project is discussed below under "Development." An Indo-U.S. IPS project was approved, and special foreign-currency rupees were disbursed to Indian colleagues. A major part of the project is to enlarge one of the three IPS radio telescope antenna fields in India to obtain all-sky maps of scintillations, as is done by the English workers. India and England are about $5^1/_2$ hours removed in local time, so that together the two sites would measure the solar wind disturbances several hours apart each day, greatly improving the predictive capabilities over those from a single site's maps. The increased time coverage is vital, since most solar wind disturbances reach Earth only 1 to 3 days after their initial detection by the IPS technique.

Professor Anthony Hewish of Cambridge University, Nobel Laureate, visited SEL in November 1986 to brief the staff on the use of the IPS technique and to discuss the prediction capabilities of the technique. A follow-up study by SEL was made of the relation of IPS events observed in 1978–1979 with near-Earth solar wind measurements as well as terrestrial magnetic disturbances. There is no question that IPS measurements can give a forewarning of major solar wind disturbances arriving at Earth. However, a major factor in determining the magnitude of the coupling of disturbances to Earth is the direction of the interplanetary magnetic field relative to Earth's magnetic field at the sunward boundary of the magnetosphere. No magnetic field information can be inferred from the IPS measurements. So far, MHD modeling is also incapable of predicting the field orientation at Earth in sufficient detail. This is due in part to the difficulty of specifying the initial heliospheric magnetic field topology, particularly close to the Sun.

MHD modeling has, however, demonstrated a potential for the use of its calculated solar wind density structure to generate synthetic all-sky maps of interplanetary scintillations. The right-hand side of Figure 2 shows an example of modeled scintillation indices, which are compared with actual observations in the left diagram made at Cambridge, England, in September

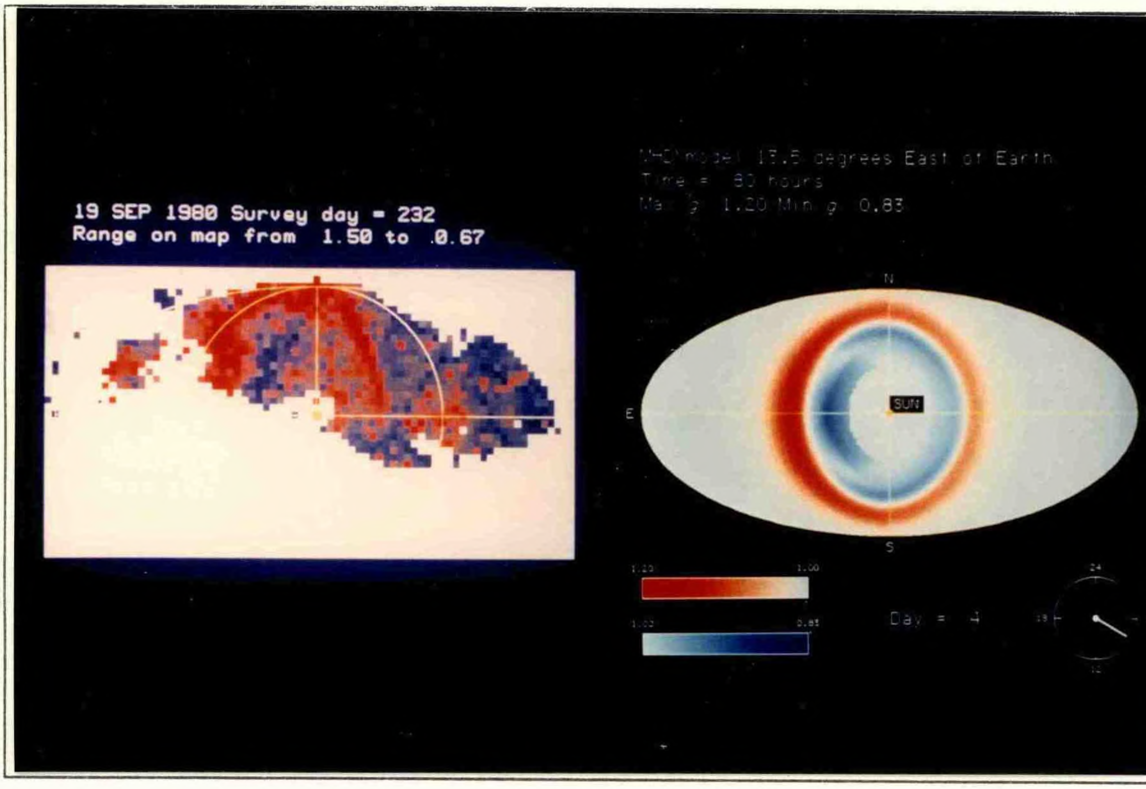

Figure 2. Comparison of an IPS interplanetary image (left) with a "synthetic" image generated from a 3-D MHD, time-dependent model of a solar-flare-generated, bubble-shaped shockwave (right). In the observations on September 19, 1980 (Cambridge, England), the color coding is the ratio $g = m/m_o$, where m is the scintillation index on this date, averaged over several radio sources within each 5° x 5° pixel; m_0 is the same index expected for each source at each elongation from fits made from an entire year's observations. In the model, the center of a flare-generated shock wave is taken at 13.5° east of the Sun-Earth axis, thereby approximating the actual flare's longitude. An integration along the line of sight is made assuming that the local solar wind density structure is responsible for the turbulence that produces the observed scintillation. A synthetic "g-map," similarly color coded, is produced at successive times (here: t = 80 hours after the "flare"). Agreement of the compressions and rarefactions (as provided by the model) is encouraging.

1980. The model assumed that a shock wave was generated by an erupting filament, accompanied by a solar flare located about 15 degrees east of the Sun-Earth axis. According to the model, the enhanced scintillation (coded in red) results from shock-compressed solar wind that was en route to Earth.

MAGNETOSPHERIC PHYSICS

The objective of the Magnetospheric Physics Project is an improved understanding of the dynamic processes by which matter 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 Services

The responsible scientists' roles were continued for the energetic particle detectors on the GOES and NOAA satellites, and for the magnetometers on the GOES satellites.

Design review meetings were held with the vendors that are supplying the Space Environment Monitor (SEM) instruments for the GOES I–M satellites. SEL has proposed to add a three-channel electron spectrometer for the energy range of 500 to 4000 KeV, to replace the single-channel measurement now made. This enhancement will define the electron spectrum in an energy range that can cause spacecraft upsets.

The proposals for the energetic-particle sensors for the NOAA K, L, and M satellites were evaluated. SEL intends to add a 140-MeV channel to the omnidirectional detector, in order to better define the spectrum at the higher ion energies; this is important in assessing radiation hazards at high altitudes.

The personal-computer-based GOES data archive and its associated access and display software were completed, documented, and released for public use. This archive makes the GOES data easily accessible to researchers; it is being incorporated into the National Geophysical Data Center's assemblage of data products, and will henceforth be maintained by that organization.

Data Analysis Studies

At times, gusts in the solar wind impinge on Earth's magnetic field and compress the field; this causes the magnetopause, the boundary between the solar wind and the geomagnetic region, to shift earthward. Normally at a radial distance of 10 to 15 Earth radii sunward of Earth, the magnetopause on rare occasions can move inside the geostationary orbit at 6.6 Earth radii. Between 1978 and 1986, 63 such events were recorded by the GOES satellites. These cases may represent less than half the actual number of such compressions, since a satellite must be on the dayside of Earth to record magnetopause crossings. These extreme cases are being examined for their relation to the level of geomagnetic activity and to explore the potential of such observations as a real-time warning of severe geomagnetic disturbance.

Even during the majority of the time that the magnetopause remains more distant from Earth than 6.6 Earth radii, the strength of the magnetic field at a geosynchronous satellite is an indicator of the degree to which the magnetosphere is being compressed by the solar wind. For example, Figure 3 shows the correlation between the intensity of the field component parallel to Earth's axis, and the solar wind pressure, when the GOES satellites are near the noon meridian. The solar wind pressure is deduced from near-Earth space probe measurements of solar wind velocity and density. In this figure, the solid line represents the dependency based on a simple model (Roederer, J. G., 1970, *Dynamics of Geomagnetically Trapped Radiation*, Springer–Verlag, New York).

The GOES magnetometer data contain a wealth of information about disturbances at the nominal magnetic distance of the satellite of L=6.6. To have a reference level against which to study fluctuations, a study of the field at quiet times has been made. A data base of magnetic field data, along with the auroral AE magnetic index, has been compiled for the years 1979, 1980, 1983, and 1984. Figure 4 shows a Fourier representation of quiet conditions for 1979, using the GOES–2 magnetometer data. In this plot, the total magnitude of the field is plotted as a function of time of year and time of day. The averages were constructed for successive 2-week periods, so that there are 26 biweekly values for the year. As expected, the field is strongest when the satellite is on the dayside of the magnetosphere (dayside compression) and weakest on the midnight side, where the geomagnetic field at L=6.6 is beginning to be stretched into a tail configuration. Significant seasonal variations are apparent as well.

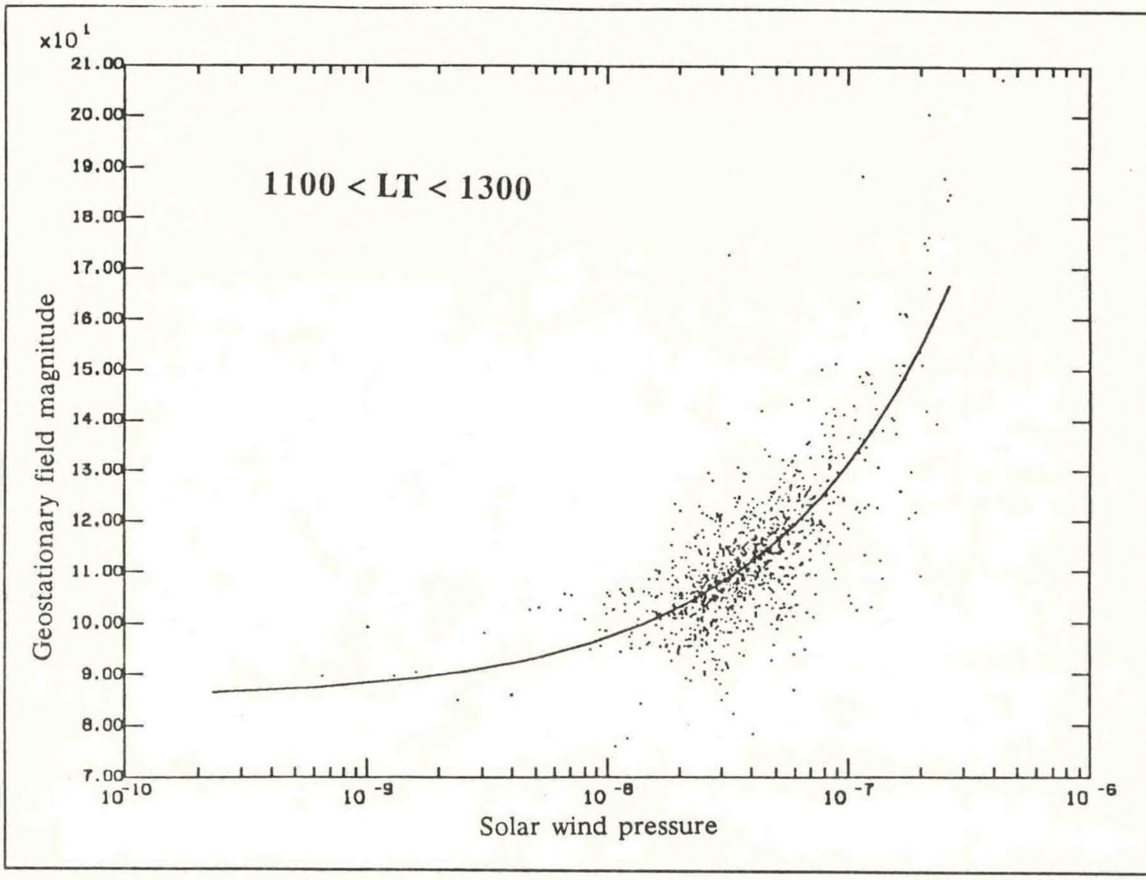

Figure 3. Plot of hourly averages of geostationary field magnitude vs. hourly averages of solar wind pressure (1979). The solid curve is the dependency based on a simple model (e.g., Roederer, 1970).

Theoretical Studies

The magnetotail plasma sheet is generally believed to be an important source of particle energization during magnetic storms and substorms. Energized particles from this region are injected into the plasma sheet boundary layer and the high-latitude auroral region, where they interact with a complex array of particle populations and fields. Developing a physical model of this region is an important step toward the long-term goal of understanding the mechanisms behind geomagnetic activity.

The acceleration of charged particles at a magnetic neutral point or line is a concept central to many magnetospheric substorm models. With simplifying assumptions, one can predict the formation of a neutral point on theoretical grounds. Neutral points also seem to form spontaneously in a wide variety of numerical plasma simulations. However, the observational evidence for such regions is indirect and controversial, often being inferred from tailward streaming ions interpreted as plasmoids.

Recent SEL studies using non-interacting particle simulations have produced a new signature for a magnetic neutral line: a "ridge" in the velocity space distribution function (Figure 5). Previous work in the Laboratory has shown that earthward-streaming beams are the result of ions interacting with the tail current sheet in the absence of a neutral point. The addition of a

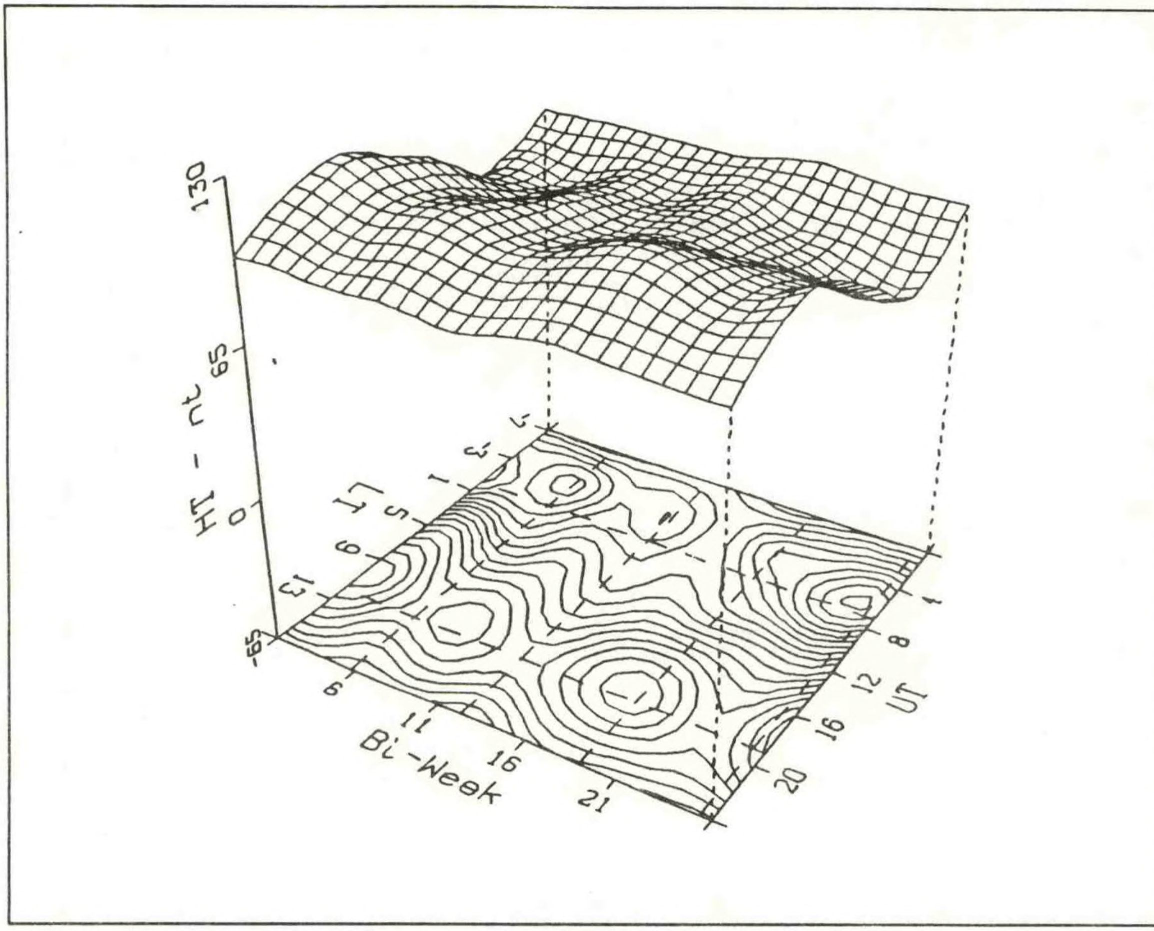

Figure 4. Quiet-day variation of geostationary magnetic field observed by GOES-2 (1979) as a function of local time and season. As expected, the field is strongest at local noon, weakest at local midnight.

neutral line causes the beam to become dispersed, forming a ridge in the distribution function and a drop-off in particle fluxes over the ridge. This predicted signature of a neutral line should be observable in energetic particle data. If so, it should help evaluate the relevance of competing substorm models (e.g., neutral-line vs. boundary-layer models).

Further progress has also been made toward the goal of a medium-scale, single-particle model of the geotail. A study of the macroscopic, quasi-self-consistent properties of steady-state current sheets has begun. The problem of the existence of such non-equilibrium steady-states is being studied with a minimum energy dissipation analysis. A comparison between models with and without neutral lines will show more clearly which physical quantities determine when a current sheet becomes unstable and forms a neutral line. This can then be used as a way of understanding how substorms may be initiated.

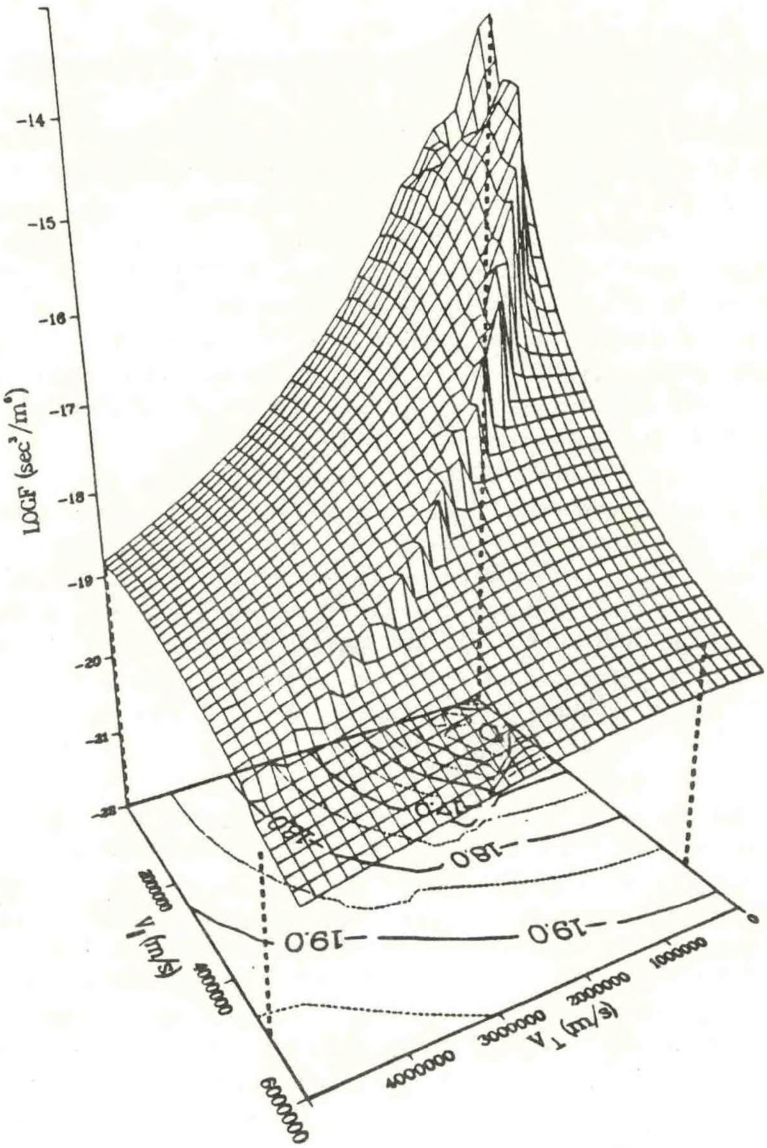

Figure 5. Particle distribution function *F*, derived from neutral line model. *F* is related to particle intensities as a function of energy and pitch angle. The sharp "ridge" feature is formed by energetic ions interacting with a remote neutral line.

MAGNETOSPHERIC-IONOSPHERIC-ATMOSPHERIC INTERACTIONS

The objectives of research in the Atmospheric-Magnetospheric-Ionospheric Interactions Project are to understand the transfer of energy (both electrical and magnetic) from the magnetosphere into the upper atmosphere, and to understand and characterize the various consequences that may arise in Earth's ionosphere and upper atmosphere because of this energy input.

An instrument aboard the TIROS/NOAA polar-orbiting satellites measures total energy deposition due to energetic particles precipitating into the upper atmosphere. Such energy deposition heats the atmosphere, causing it to expand. In turn, the expansion brings about higher densities at satellite altitudes, thus giving rise to variations in the drag experienced by satellites. Total Energy Detector (TED) data are useful as input to models that predict this drag on satellites and the resulting effect on their lifetimes.

Unfortunately, the TED sensor on NOAA–10 developed a problem during FY 1987 and began to exhibit spurious response. Careful examination of the data, and of a duplicate unflown sensor, led to a preliminary explanation for the sensor problem and to an outline of a procedure for mitigating the spurious response. A procedure for correcting the spurious data will allow resumption of the use of TED data to predict atmospheric heating and satellite lifetimes. Laboratory experiments have replicated most of the characteristics of this spurious response. The origin of the problem seems to center around electrical charging of a thin insulating film on the electron analyzer plates, with subsequent field emission of electrons. The fact that the problem occurs only after some time in space points toward chemical changes in the properties of the materials in space, perhaps due to reaction with atomic oxygen at the satellite altitude. Great care must be taken in the choice of materials used in future instruments.

A specification of the average and extreme energetic particle environments at middle- and low-latitude locations around Earth has been created using 2 years of NOAA–6 data. This data base permits an individual observation of energetic-particle intensities to be interpreted as normal or unusual. For example, the high electron intensities observed at middle latitudes over central Russia several hours after the Chernobyl nuclear-reactor accident had, with one exception, been duplicated previously only during times of high magnetic activity. Because magnetic activity was low at the time of the Chernobyl incident, the high intensities are regarded as unusual. This same data base has been helpful in exploring some instances of dramatic, short-lived increases in energetic-particle intensities at low latitudes simultaneous with the onset of large magnetic storms.

SPACE ENVIRONMENT DATA SYSTEMS DEVELOPMENT

SEL Data Acquisition and Display System (SELDADS)

SELDADS is a large, distributed processing system that supports the operation of SESC. It collects the real-time data into data bases, drives displays for the use of SESC staff, is used in producing the standard forecasts and indices, acts as a communications interface, and provides access to the data base for dial-up users. The standard period of retention in the data base is 32 days, after which the data are archived in the National Geophysical Data Center. The original SELDADS I was conceived in the early 1970s and grew intermittently as pieces of hardware became available. SELDADS II hardware was delivered in 1984, and a phased program of implementing software has been in process since that time. SELDADS II has been the operational system since October 1986, when SELDADS I was retired from service.

Accomplishments during FY 1987 included the following:

(1) Completion of operational tools to streamline forecasting staff duties.
(2) Development of generalized plot and list programs to provide a display for the forecaster of most data in the data base.
(3) Automation of the weekly publication, *Preliminary Report and Forecast of Solar Geophysical Data*.
(4) Implementation of new geomagnetic analysis techniques, including numerical guidance.

SEL Solar Imaging System (SELSIS)

SELSIS is a digital image-handling system being developed by the staff of the Systems Support and Space Environment Services Divisions to meet digital image acquisition and processing requirements for both SESC operations and SEL research. A joint project between the Space Environment Services Division and the Systems Support Division was established in FY 1987 to develop future SELSIS requirements and specifications.

SELSIS collected, preprocessed, stored, displayed, and made hard copies of imagery from the four operational observatories that constitute the current SELSIS network. Two new sources of near-real-time imagery were established during FY 1987: SEL's Boulder Observatory and the USAF observatory at Learmonth. These observatories, in addition to those at Holloman Air Force Base and the National Observatory at Kitt Peak, allow better geographic coverage of the Sun from SELSIS-equipped, ground-based observatories.

SELSIS provides the SESC forecasters with digital solar images that are corrected for both spatial and intensity aberrations. These images are used daily for solar activity forecasts and for product generation such as input for solar synoptic maps. SELSIS imagery was also transmitted in near-real time to the Goddard Space Flight Center to support NASA's Solar Maximum Mission operations.

SEL Public Bulletin Board System

The SEL Public Bulletin Board System was developed to explore a popular new technology as a means of achieving widespread dissemination of real-time solar-geophysical indices and text products. The system uses microcomputer hardware and serves anyone who can use a telephone line to link his personal computer with another. Users dial 303–497–5000 to be connected to a personal computer in SEL that acts as a computer-maintained bulletin board for public access. The board provides the most recent values of sunspot number, solar radio flux, geomagnetic A- and K-indices, the daily Solar Forecast, and the USAF 6-hourly HF Radio Propagation Forecast. The system operates unattended 24 hours a day, 7 days a week. User response has been good, with between 25 and 50 accesses per day.

GEOMAGNETIC SERVICES DEVELOPMENT

Approximately two-thirds of the users of SESC products and services need summaries, alerts, and forecasts of disturbances of the geomagnetic field. These customers range from the general public, puzzled by the rare occurrence of auroral forms at low latitudes, to scientists conducting sophisticated research campaigns. However, most geomagnetic customers need help with operational problems such as unusual ionospheric propagation conditions, power or pipeline equipment anomalies, or geophysical exploration field-project planning and data interpretation. Two years ago, a long-range plan to improve SESC geomagnetic services was instituted. That plan includes new SELDADS software to access and plot the existing vector geomagnetic data, practical guides for assessing the state of disturbance of the geomagnetic field, new forecast formats and verification algorithms, and numerical guidance to assist forecasters. These tasks are formidable because the state of scientific knowledge of the causes and effects of geomagnetic disturbances is itself rudimentary, critical solar observations and solar wind measurements are not available, and there is no base of experience upon which to build. Many of the analysis aids we are developing are original; they must undergo redesign and refinement even as they are being adopted.

During FY 1987, significant strides were made in developing the software to access and assess geomagnetic data. As one part of its geomagnetic data files, SELDADS contains vector data for 18 ground-based magnetometers and 2 geosynchronous satellite magnetometers, all at 1-minute resolution. To handle the flood of information from these and planned additional instruments, new summary indices and display techniques are being designed and tested.

Tables of monthly geomagnetic "climatology," the percentage of days in 29 years that each value of the geomagnetic index was observed at Fredericksburg, Virginia, and College, Alaska, were implemented. These tables provide guidance to the forecaster about typical conditions observed during each day, averaged over the past 29 years. Monthly geomagnetic climatology forecasts provide a starting point for making daily forecasts. The climatology can be adopted as is or modified to incorporate effects expected from observed solar activity. Development of verification techniques using climatology and other scoring methods will continue in FY 1988. These will be combined in a system for recording forecasts, observations, and parameters used in making forecasts in a veri ication data base to be designed in FY 1988.

SOLAR FLARE FORECASTING AND ANALYSIS DEVELOPMENT

The accurate forecast of solar flares a few hours before they occur is one of the unmet goals of space environment services. A large amount of research and observation has been put into the task by research groups around the world. In lieu of a full understanding of the physics of flares, a first-step forecasting ability has 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. Forecasts have been limited by the lack of standardized definitions of these characteristics (e.g., sunspot shape and size, magnetic field gradients, etc.) from observatory to observatory, and by sometimes inconsistent application to forecasting. A computer-based "expert system" that can be used for training forecasters and for first-order standardization of forecasts was made operational during the year. A cooperative program with the observatories of the Solar Observing Optical Network (SOON), operated by USAF, provides for consistent methods of measuring the pre-flare characteristics. Part of the new SELDADS hardware (see SELDADS) provides for collectic n of these data into the SELDADS data base. Future work will include the development of displays to allow the forecaster to use the measured characteristics in several forecast models and to evaluate them using dynamic statistical routines such as multivariate discriminant analysis models. Further cooperation with USAF has included work to refine the currently used characteristics into more physically meaningful terms such as shearing in the solar atmosphere and free-energy of the magnetic field, parameters that are believed to be related to solar flare occurrence.

Solar flare forecasts will be included in the planned systematic verification data base of all SESC forecasts.

Development Of Expert Systems—THEO

During FY 1987 a rule-based expert system to predict flare probabilities was put into daily operational use. This program, named THEO for Theophrastus, the first person to report seeing spots on the Sun, uses rules developed over several decades by one expert forecaster. The rules relate the morphology of a sunspot group and the spots in it to the probability of a flare's occurring in the group. The program automatically picks up its input from the SELDADS data base, viz., the characterizations of sunspots that have been communicated to SELDADS by observers. The forecaster can alter the characterizations used in the program if he chooses. THEO gives numerical guidance to the forecaster, but is not intended to and does not supplant the exercise of judgment by the forecaster. THEO is also used as one of several tools for training new forecasters.

Verification studies are made of the forecasts issued by both THEO and the duty forecasters. The results can be used, for example, to refine the rule base used by THEO.

Operational Satellite Instrumentation Project

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 produced by contractors (or subcontractors) 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 TIROS instruments awaiting flight.

GOES-7 was launched successfully in February 1987, and the SEM subsystem was checked out. All the instruments were fully functional except the High Energy Proton and Alpha Detector. The main data output channels of this instrument apparently failed, although the sensor components appeared to be functional and the instrument passed its internal calibration check. The problem is thought to be caused by a shift in the timing of the high-speed coincidence circuit used to separate valid events from background. The remaining instruments, the whole-Sun X-Ray Sensor, the Energetic Particle Sensor, and the Magnetometer, give data agreeing with those from the previous spacecraft. During the later stages of the spacecraft system check-out, a problem occurred with the Despin Control Electronics (DCE). SEL was able to help NESDIS understand the problem by using the magnetometer, which measures Earth's field relative to the spin clock from the DCE, as a diagnostic for the problem.

The SEM on NOAA-10 was activated and tested in October 1986. Both the TED and the Medium Energy Proton and Electron Detector operated nominally at turn-on. Some difficulties with the TED developed later in the year, similar to those experienced late in the life of the TED on NOAA-6. Spurious count outputs were triggered following large auroral electron fluxes; they are thought to be due to a deterioration in the special surface treatment of the electron analyzer plates. A test program is being developed in an attempt to reproduce this problem on the ground and to implement a solution for the next TED due to be launched in 1989.

Work continued on the procurement of new SEM systems for TIROS–K, –L, and –M spacecraft. A final contractor selection is expected early in FY 1988.

The GOES-Next program (Satellites I–M) has been supported by participation in the Preliminary Design Review for the spacecraft and reviews of the subcontractor's designs for the SEM instruments. Considerable attention has been focused on avoiding spacecraft interference problems to the magnetometer and 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 data quality control software for the operational sensors has been placed in routine operation on SELDADS, and routine reports of calibration data and trends are now produced automatically.

SEL Scientific Workstation System

Software is being developed for a "scientists' workbench," which is intended to provide a uniform environment for analysis and correlation of data contained in disparate environmental data bases. By using the techniques of object-oriented programming developed by the Artificial Intelligence community, it should be possible to provide a common set of analysis and display tools that can be used on diverse data without the need for the individual scientist to deal with the complexities of the different data sets or the communications needed to access them.

During FY 1987 one more workstation and a second file server were added to the system. A further five workstations have been ordered, and will be delivered in FY 1988. The graphics and other software tools available to users have been steadily improved during the year. The system integration between the workstation network and the SELDADS system has also been strengthened. This now permits automatic transfer of data from SELDADS to the workstation publication system for the production of the SESC weekly and for the operation of the THEO expert system. The desktop publication system is now being extensively employed by staff throughout SEL to produce both internal operational documentation and scientific and technical reports. Plans have been developed to provide a uniform network environment for both the administrative and technical personal-computer applications, as well as the workstation applications within the Laboratory, and thus to facilitate all aspects of SEL computer use.

Interplanetary Scintillation Observations

Discussions were held with a number of United Kingdom groups, with a view to reactivating the 3.6-hectare antenna array at the Mullard Radio Astronomy Observatory (MRAO) of Cambridge University. Work at MRAO has shown that density disturbances in the solar wind can be monitored, using this array, by observing the scintillation of hundreds of extra-galactic radio sources on a daily basis. The resulting all-sky scintillation maps can be used to predict if a disturbance will reach Earth, and to estimate its time of arrival. Data from this system show promise of significantly improving our ability to predict geomagnetic disturbances caused by the arrival of those disturbances.

A joint plan has been drawn up by SEL, MRAO, and groups at the Rutherford-Appleton Laboratory (RAL) and the British Antarctic Survey. The plan envisages United Kingdom funding for a postdoctoral associate and postgraduate student to operate the array, and a jointly funded SEL, RAL, and MRAO effort to put the array back into service and install a real-time data-processing system.

SEL Spectroheliograph

In 1970 SEL developed a small spectrohelioscope as part of its program to support the Skylab mission. This instrument was used to make visual and photographic solar observations in a variety of spectral lines, including the hydrogen alpha line and the magnesium green lines. It was easy to determine the magnetic polarities of sunspots visually by observing in the wing of a Zeeman-sensitive spectral line, alternating in a blink-comparator fashion between the two senses of circular polarization.

Since 1970, detector technology has made great advances, particularly in the area of Charged Coupled Devices (CCDs) based on the electrical charging of silicon elements when exposed to light. SEL decided about 2 years ago to upgrade the spectrohelioscope by using a linear CCD array as the detector. During FY 1987 this project was successfully completed, and by the end of the fiscal year digital images were being obtained, again in a number of spectral lines of interest in monitoring solar activity. CCD arrays are particularly sensitive in the near-infrared portion of the spectrum, making it easy to obtain spectroheliograms in the infrared calcium triplet of lines near 8500 angstroms. These lines arise from near-ground-state levels of singly ionized calcium; they are particularly useful for detecting plage in active regions. As a general statement, all bright calcium plage regions also correspond to regions with moderate-to-strong vertical components of magnetic field.

The conversion to using a CCD has been an interesting project because of several technical issues. For example, the entrance slit of the monochromator must be curved in order to generate a straight image of the slit on the diode array. The sweeping of the solar image across the entrance slit is accomplished by rotating a square-cross-section prism in front of the slit. To maintain a uniform sweep rate, the rotation rate of the motor must be varied as a function of the angle of incidence of light on the prism. This is accomplished under computer control, in real time, by the same computer that is acquiring the input from the CCD array.

We expect that the spectroheliograph will become increasingly valuable in supplementing the image data available to the forecaster as solar activity continues to intensify.

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* Intermittent Employee
**SEL employment terminated during FY 1987.

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Janet Will	Clerk-Typist

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Larry Combs	Chief Observer
Patricia A. Levine	Physical Science Aide
James Masciarelli, III	Physical Science Technician

RESEARCH DIVISION

Harold Leinbach	Acting Division Chief
Marianne V. Wiarda	Secretary
Thomas Jacobwith**	Clerk-Typist
Joanna Trolinger	Editorial Clerk

Atmosphere-Ionosphere-Magnetosphere Interactions

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Magnetospheric Physics

Herbert H. Sauer	Project Leader
Martha Ness	Physical Science Technician
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Theodore W. Speiser *	Physicist

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Interplanetary Physics

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Zdenka A. Smith	Physicist

Solar Physics

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Randolph Smith	Physical Science Technician

Solar X-Ray Physics

William J. Wagner	Project Leader
Howard Garcia	Physical Scientist

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Janet E. Falcon	Mathematician
Robert Ito	Computer Programmer
Dave Lewis	Physicist
Robert Masten	Electronics Technician
Lorne Matheson	Physicist
Jennifer McLean*	Computer Assistant
Barbara Poppe	Computer Specialist
Vern Raben	Electronics Engineer
William M. Retallack	Computer Programmer
Scott Snowden*	Computer Assistant
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Judith J. Stephenson	Mathematician
John H. Taylor	Electronics Engineer
James Winkleman	Mathematician
Kathleen Withers**	Secretary

NOAA CORPS

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Lt.(jg.) Scott Kuester	Solar Observer, Culgoora, Australia
Lt.(jg.) Daniel Clements**	Space Environment Forecaster
Lt. James R. Gordon**	Solar Observer, Culgoora, Australia
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USAF

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Lt. Robert Bass .... Technique Development Officer
M.Sgt. Norman L. Cohen .... Space Environment Forecaster
Capt. John Holbrook .... Data Quality Officer, Anchorage
Sgt. Mark Maciolek .... Equipment Technician, Anchorage
M.Sgt. Royce Hildebrand** .... Space Environment Forecaster
M.Sgt. Harry Sorg .... Space Environment Forecaster

GUEST WORKERS

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Sami Cuperman .... Physicist—Univ. of Tel Aviv, Israel–CIRES
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Ed Gillis .... Physicist—Univ. of Colo.
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Walther Spjeldvik** .... Physicist—CIRES
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* Intermittent Employee
**SEL employment terminated during FY 1987

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Bornmann, P. L.," Determination of Temperature and Emission Measure From Light Curves of Soft X-Ray Lines," SEL/SESC Lecture, October 10, 1986.

Bornmann, P. L., "Flares to Coronal Mass Ejections: A Proposed Activity Classification," SEL Seminar, October 21, 1986.

Bornmann, P. L., "Flares to Coronal Mass Ejections: A Proposed Activity Classification," NCAR High Altitude Observatory Seminar, December 1, 1986.

Bornmann, P. L., "Flares to Coronal Mass Ejections: A Proposed Activity Classification," NASA/Goddard Space Flight Center Seminar, January 21, 1987.

Bornmann, P. L., "Turbulence as a Contributor to Intermediate Energy Storage During Solar Flares," NASA/Goddard Thermal/Non-Thermal Interactions in Solar Flares Workshop, March 23, 1987.

Bornmann, P. L., "Two-Component Analysis of Soft X-Ray Line Fluxes," NASA/Goddard Thermal/Non-Thermal Interactions in Solar Flares Workshop, March 24, 1987.

Bornmann, P. L., "Review of Basic Radiation Processes," SEL/SESC Lecture, May 6, 1987.

Bornmann, P. L., "Two-Component Analysis of Soft X-Ray Line Fluxes," American Astronomical Society Solar Physics Division Meeting, Honolulu, HI, July 13, 1987.

Cuperman, S., "Effect of Coupled Electron-Proton Thermal Conductivities on the Two Fluid Solutions for the Quiet Solar Wind," Solar Wind VI Conference, Estes Park, CO, August 24, 1987.

Cuperman, S., "Higher Order Fluid Equations for Multicomponent Nonequilibrium Stellar (Plasma) Atmospheres: Consideration of Forces Due to Divergent Magnetic Fields," Solar Wind VI Conference, Estes Park, CO, August 25, 1987.

Cuperman, S., "On the Dispersion of Ion Cyclotron Waves in Magnetized H+–He++ Solar-Wind-Like Plasmas," Solar Wind VI Conference, Estes Park, CO, August 26, 1987

Davies, K., "Ionospheric Propagation Problems During Geomagnetic Storms," SEL/SESC Lecture, May 13, 1987.

Dryer, M., "MHD Simulation of the Interplanetary Environment in the Ecliptic Plane During the 3–9 February 1986 Activity, AGU Fall Meeting, San Francisco, CA, December 10, 1986.

Dryer, M., "Shock Waves: Classifications, Jargon, and Real-Life," SEL/SESC Lecture, April 1, 1987.

Evans, D. S., "Aurorae–Is It a Threat to the Environment?" SEL/SESC Lecture, April 15, 1987.

Evans, D. S., "TIROS/NOAA Total Energy Detector—Specifying the Level of Auroral Activity," SEL/SESC Lecture, April 29, 1987.

Garcia, H. A., "Determination of Flare Physical Properties: An Update," SEL/SESC Lecture, October 24, 1986.

Garcia, H. A., "Thermodynamic Analysis of Flares Using Observed Temperature Profiles," SEL/SESC Lecture, March 18, 1987.

Heckman, G. R, "New Support Capability From Upgraded Space Environmental Monitors from Future GOES and NOAA Satellites," USSPACECOM Meeting, Colorado Springs, CO, August 19, 1987.

Heckman, G. R., "Real Time Satellite Anomaly Service in the Space Environment Services Center (SESC), NESDIS Seminar on Satellite Anomalies," September 15, 1987.

Heckman, G. R., "How Much Solar Activity and Its Terrestrial Effects are Expected the Next 10 Years" (part one), and "Our Prospects for Better Ionospheric Scintillation Forecasts Based on Improved Specification of Geomagnetic Activity" (part two), Space-Based Radar Conference, AFGL, September 17, 1987.

Heckman, G. R., "The History of the Space Environment Services Center," SEL/SESC Lecture, September 23, 1987.

Hildner, E., "CMEs and Their Coupling Into the Interplanetary Medium," SEL/SESC Lecture, March 4, 1987.

Joselyn, J. A., "The Space Environment Services Center: Products and Customers," Informal meeting with AFGL scientists, Bedford, MA, October 30, 1986.

Joselyn, J. A., and W. Wagner, "An Overview of the S.E.I.I.M. Workshop," SEL/SESC Lecture, November 14, 1986.

Joselyn, J. A., "Solar Weather—Why Do We Care?" RMC/SLA January Meeting, Boulder, CO, January 21, 1987.

Joselyn, J. A., "Solar and Geomagnetic Conditions during the SUNDIAL 86 (Sept. 22–Oct. 4) Campaign," SUNDIAL Meeting, San Diego, CA, February 24, 1987.

Joselyn, J. A., and H. H. Sauer, "The Rice University Magnetospheric Model," SEL/SESC Seminar, April 8, 1987.

Joselyn, J. A., "Are Homing Pigeons Affected by Geomagnetic Disturbances?" Rocky Mountain Flyers Club, Lakewood, CO, April 12, 1987.

Joselyn, J. A., "Geomagnetic Climatology," IUGG/IAGA XIX General Assembly, Vancouver, Canada, August 14, 1987.

Joselyn, J. A., "Prediction of Geomagnetic Disturbances," IUGG/IAGA XIX General Assembly, Vancouver, Canada, August 17, 1987.

Joselyn, J. A., "A Study of the Heliolongitudes of Flares Potentially Associated with Major Geomagnetic Disturbances," IUGG/IAGA XIX General Assembly, Vancouver, Canada, August 18, 1987.

Joselyn, J. A., "Helium 10380 Angstom Coronal Holes and Geomagnetic Storms during Solar Cycle 21," IUGG/IAGA XIX General Assembly, Vancouver, Canada, August 18, 1987.

Kunches, J. M., "Operational Uses of the SOON Optical Data," Technical Consultant Visit Seminar, Holloman AFB, NM, October 30, 1986.

Kunches, J. M., "Solar Proton Flares," Dept. of Radiology and Radiation Biology Seminar, Colorado State University, Fort Collins, CO, February 18, 1987.

Martin, R. F. Jr., "Self-Consistent Neutral Point Current and Fields from Single Particle Dynamics," First Huntsville Workshop on Magnetosphere/Ionosphere Plasma Models, Lake Guntersville, AL, October 14, 1986.

Leinbach, H., "A Look at Hewish's IPS Events and Near-Earth Solar Wind Parameters," SEL/SESC Lecture, March 25, 1987.

McIntosh, P. S., "Sunspot Observations Forecasters Should Know About," SEL/SESC Lecture, November 14, 1986.

McIntosh, P. S., "The Polar Crown Filaments Through Two Solar Cycles," Solar Cycle Workshop II, Lake Tahoe, CA, May 11, 1987.

McIntosh, P. S., "Meridional Motions Derived from H-alpha Synoptic Charts," Solar Cycle Workshop II, Lake Tahoe, CA, May 11, 1987.

McIntosh, P. S., "A Video of Six Years of H-alpha Synoptic Charts," Solar Cycle Workshop II, Lake Tahoe, CA, May 12, 1987.

McIntosh, P. S., "X-ray Irradiance and Changes of State of the Large-Scale Solar Magnetic Fields," Solar Cycle Workshop II, Lake Tahoe, CA, May 12, 1987.

McIntosh, P. S., "An Abrupt Drop in 10 cm Radio Flux as an Indicator of Solar Cycle Phase," Solar Cycle Workshop II, Lake Tahoe, CA, May 13, 1987.

McIntosh, P. S., "State of the Solar Cycle," Solar Cycle Workshop II, Lake Tahoe, CA, May 13, 1987.

McIntosh, P. S., "The Magnetic Butterfly Diagram," Solar Cycle Workshop II, Lake Tahoe, CA, May 14, 1987.

McIntosh, P. S., "A New Perspective on Coronal Holes," Sacramento Peak Summer Workshop on Solar and Stellar Coronae, Sunspot, NM, August 17, 1987.

Raben, V. A., "Introduction to Image Processing," Apollo Domain User Group National Conference, San Francisco, CA, September 21, 1987.

Sauer, H. H., "Energetic Particle Behavior at Geostationary Altitudes," SEL/SESC Lecture, December 5, 1986.

Smith, J. B. Jr., "The Evolution of AR4711 (February 1986)—Footpoint Motion, the Photospheric Vector Magnetic Field, and Flare Production," American Astronomical Society Solar Physics Division Meeting, Honolulu, HI, July 13, 1987.

Smith, Z. K., "Comparison and MHD Simulation for the February 1986 Events with Interplanetary Observations by the Spacecraft Sakigake," Symposium on Physical Interpretation of Solar Interplanetary and Cometary Intervals, Huntsville, AL, May 13, 1987.

Smith, Z. K., "A Study of the Temporal and Spatial Evolution of Shocks Within 1 AU," Solar Wind VI Conference, Estes Park, CO, August 26, 1987.

Speich, D., "Operational Interpretation of Data From the Soft X-Ray and Coronograph Data Experiments Aboard SMM," SEL/SESC Lecture, October 31, 1986.

Speich, D., "SELSIS as a Panacea," SEL/SESC Lecture, April 22, 1987.

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