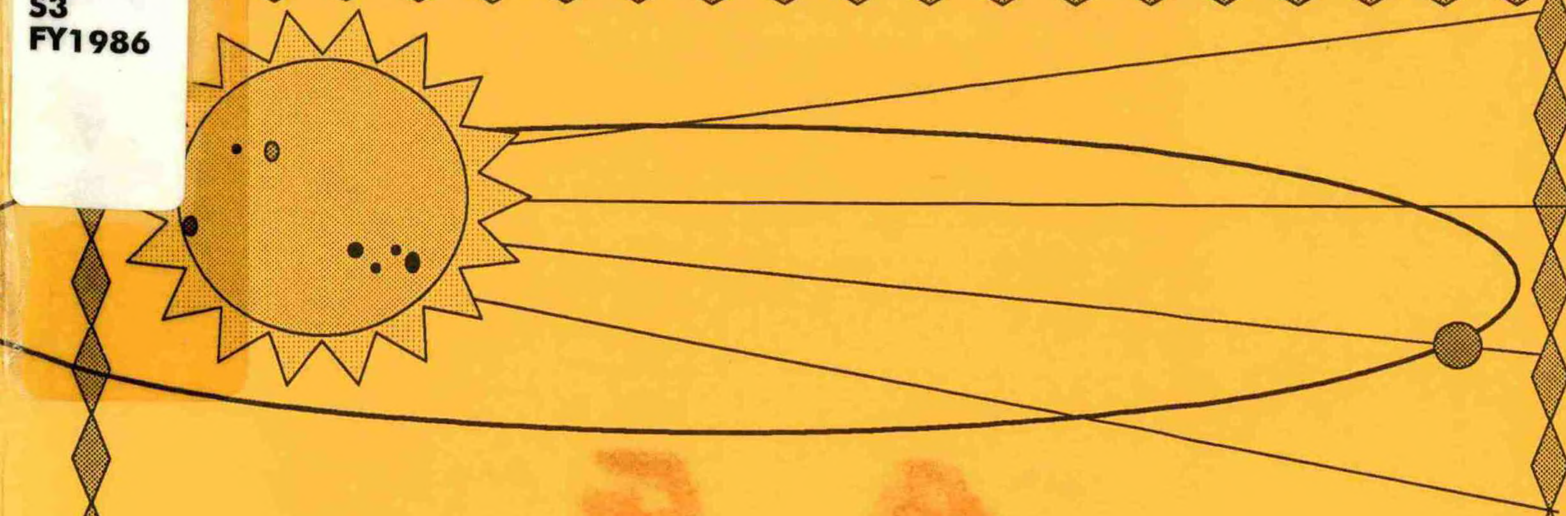

SPACE ENVIRONMENT LABORATORY

ANNUAL REPORT

FY 1986

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

SPACE ENVIRONMENT LABORATORY

ANNUAL REPORT – FY 1986
October 1, 1985, to September 30, 1986

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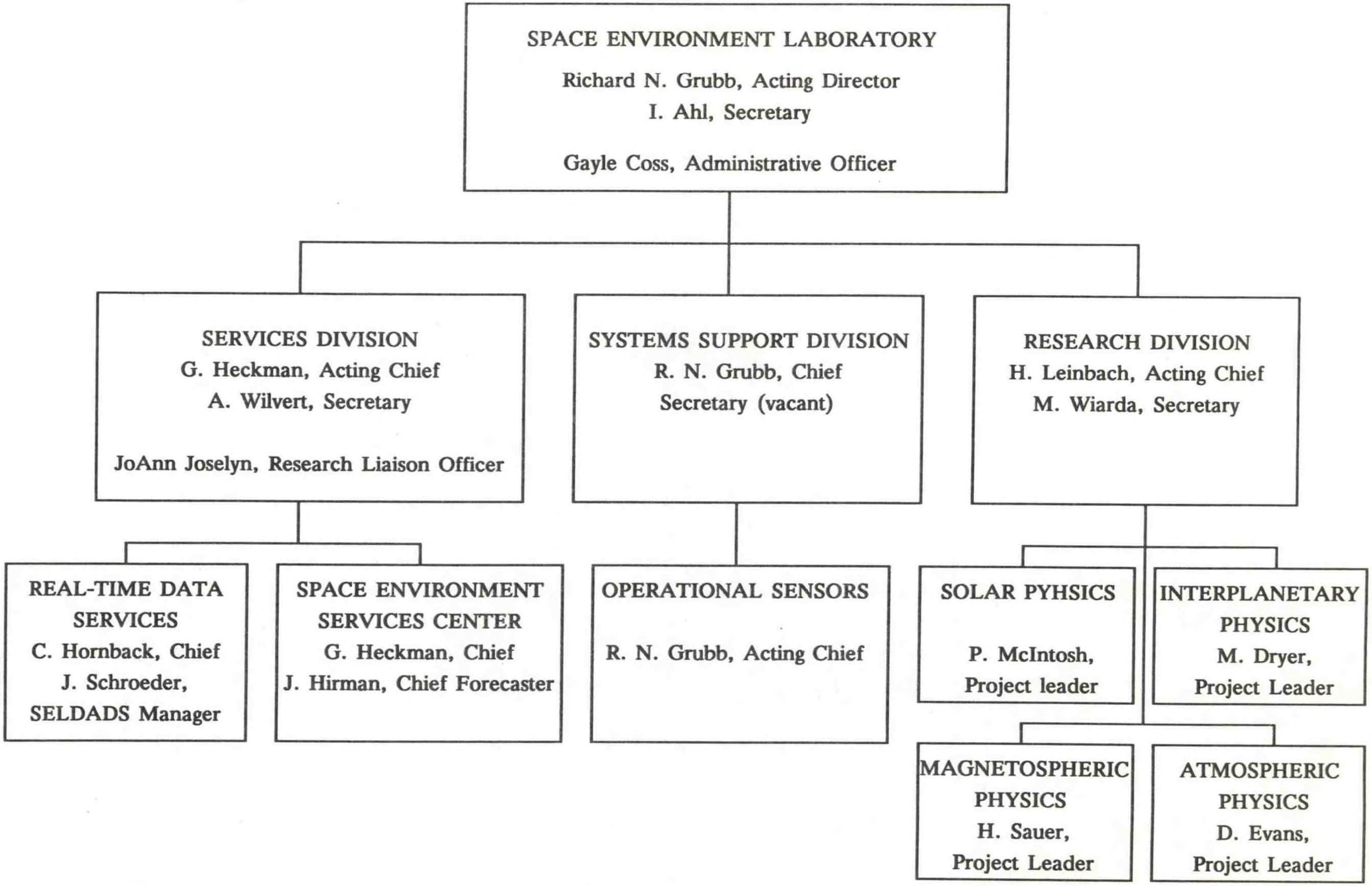

Space Environment Laboratory Organizational Chart (as of September 1, 1986)

SPACE ENVIRONMENT LABORATORY
Annual Report—FY 1986

INTRODUCTION

The Space Environment Laboratory (SEL) is unique within NOAA's Environmental Research Laboratories in providing both real-time services to meet national needs, and research and support activities to improve these services. SEL is a national center for providing around-the-clock forecasts and warnings of solar and space disturbances, an activity that requires a substantial fraction of its resources. The rest of its efforts are devoted to studying and analyzing solar and terrestrial disturbances, and to developing systems to improve monitoring, understanding, forecasting, and analysis of disturbances.

SEL is composed of three Divisions: the Research Division, the Systems Support Division, and the Space Environment Services Division. The three divisions work cooperatively in providing real-time space environment services and conducting the necessary supporting research and development activities.

SEL accomplishments in 1986 are described in this Annual Report. They include these highlights:

- The new SEL Data Acquisition and Display System (SELDADS II) became operational in May 1986 and will replace SELDADS I at the beginning of FY 1987.

- The new color graphics workstation system, which provides for the quantitative interpretation of images acquired through the SEL Solar Imaging System (SELSIS), is being integrated into SESC operation.

- Considerable progress was made in obtaining interagency support for the installation of a Solar X-Ray Imager on the GOES–I through GOES–M satellites. When it flies in the 1990s, this new sensor will provide a major increase in our operational knowledge of the structure and potential activity of the Sun.

- Research within the Laboratory, based on operational measurements of the energy deposited in the upper atmosphere by charged particles at high latitudes, has resulted in a new picture of the way atmospheric density responds to solar activity at heights of 120 km and greater. This is expected to have significant value for predicting atmospheric drag effects on spacecraft and improving our general understanding of upper atmospheric circulation.

- A workshop on "Solar Events and Their Influence on the Interplanetary Medium" was held in September 1986. The workshop was organized by

SEL and funded by NASA. It was successful in fostering interactions among workers in this field that should lead to improved understanding which can be applied to the SEL service.

- Work on a knowledge-based expert system for predicting solar flares on the basis of sunspot classification continued in collaboration with the Psychology and Computer Science Departments of the University of Colorado. The system has been integrated with a historical data base and has proved useful for forecaster training and experimental operational use. In an extended form, using more data, it is expected to be useful as an operational solar forecaster's assistant.

- The management of SEL has been modified to emphasize the interdivisional projects that have specific service-related objectives and to de-emphasize the divisional boundaries. Specific responsibilities have also been assigned within the Research Division for scientific oversight of the operational sensor systems to assure the reliability of the data.

- During May, the Laboratory programs were reviewed by ERL, OAR, and by a panel of outside experts in the solar-terrestrial field including representatives of major users of SESC services in DoD and NASA. This review was part of the normal series of reviews of the Laboratories, which are held at 2 or 3 year intervals. In their reports, the reviewers generally praised the Laboratory work, particularly considering the limited resources available to cover so large a field.

During FY 1986 it became necessary for Harold Leinbach, who had been Acting Director of SEL since February 1982, to step aside because of civil service limitations to temporary appointment. The post of acting director was assumed in March 1986 by Richard Grubb, who is Chief of the System Support Division. During the year, as a result of positive decisions made by the administration, OMB, and NOAA on the future of SEL within NOAA it became possible to proceed with the recruitment of a new permanent Director of the Laboratory. The appointment of Ernest Hildner to this position was approved in September 1986; he will assume the position in November 1986. Dr. Hildner is a Solar Physicist and has most recently held appointments at the High Altitude Observatory of the National Center for Atmospheric Research in Boulder, and NASA's Marshall Space Flight Center in Huntsville, Alabama.

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, and may even be health or life threatening. Many activities may be affected:

- Satellite operations
  - Orbital variation and lifetime (atmospheric heating and density variations)
  - Command and control anomalies (surface and dielectric charging)
  - Ground-spacecraft communication problems (ionospheric scintillation)
- Man-in-Space
  - Radiation exposure (energetic solar protons)
- Navigation (ionospheric disturbance)
  - International aviation
  - Ships and submarines
- Scientific research programs
- High-altitude polar flights
  - Radiation exposure (very energetic solar protons)
- High-frequency communication (ionospheric disturbance)
  - Intercontinental aviation
  - Ships
  - Military
  - International broadcast
- Remote surveillance
  - Over-the-horizon radar (ionospheric disturbance)
  - Space-based optical surveillance (auroral emissions)
- Long-line network communications (induced currents due to geomagnetic field fluctuations)
  - Transmission lines
  - Pipelines
- Geophysical exploration
  - Magnetic mapping (geomagnetic field fluctuation)
  - Telluric analysis (induced ground currents)
  - Archeological studies

In response to the effects on these activities, various agencies of the Federal government have initiated programs for measuring the variations, 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, from observatories and satellites that measure the environment to 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 Air Force Air Weather Service to meet the common needs for space environment services.

SPACE ENVIRONMENT SERVICES CENTER

The center of the nation's solar-terrestrial services is the Space Environment Services Center (SESC) at Boulder, Colorado. The services of SESC are limited to meeting the common needs of the other Federal agencies and, where they coincide, those of the public sector. The users of SESC may need specialized or tailored services, which they produce themselves. On occasion, SESC provides reimbursable, tailored services to meet the needs of other agencies. For example, the NASA Solar Maximum Mission continued in FY 1986 using space science expertise from SESC to develop and carry out a research-oriented observing program devoted to the improved understanding of the nature and source of solar activity such as solar flares.

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

FORECASTS of solar flares, space radiation (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.

DATA and OBSERVATIONS of space environment parameters. The products are distributed by radio broadcasts, computer-to-computer links, teletype networks and satellite broadcasts.

The primary mission of SESC, to provide these products as accurately as possible with continuity and reliability of service, was met in FY 1986. The mission is not simple. The relationships between disturbances on the Sun and the effects at Earth are complex and not fully understood. Activity at favorable locations on the Sun does not always produce terrestrial effects such as geomagnetic storms, yet a nearly continuous background of low geomagnetic activity at the Earth often does not have clear solar antecedents. Measurements of some of the most critical parameters are sparse or missing. Future progress depends on better monitoring instrumentation as well as improved understanding of the phenomena. As a step in improving its ability to deal with the forecast requirements, SEL implemented a replacement for the SESC data processing system (see SEL Data Acquisition and Display System—SELDADS II—below). An essential SESC task during the year was the development of a comprehensive set of operational requirements to be met by the software of the new system. Development was simultaneous with the forecast and analysis operation.

The new software system is designed along the functional lines of the forecasting and environmental analysis as done in the SESC. Menu items are titled and arranged to match the sequential processes that the forecast staff must accomplish to carry out their job. User interfaces are standardized and designed to simplify the forecaster-computer interface and enhance the effort spent on environmental analysis. The new system is also designed to be easily expandable so that new forecast methods can be smoothly integrated with present functions, ensuring that continuous service can be provided at times of future expansion.

In FY 1986, 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 exchange of data and forecasts relative to the space environment.

The 11-year solar cycle neared its minimum in FY 1986. Solar flares and other forms of solar activity are at their lowest level of occurrence since 1976. However, in February 1986 the quiet levels were broken by a series of solar flares, that produced the most intense geomagnetic storm observed since 1960. The activity produced most of the effects listed above, with a particularly large number of satellite operating outages reported. The actual occurrence of solar minimum as measured by the standard sunspot number index may be occurring in the fall of 1986. If not, the minimum is expected to occur in 1987. The time of minimum cannot be definitively established until at least 6 months past its occurrence.

In the coming year, services will be maintained at present levels unless unforeseen circumstances arise. Final integration of SELDADS II into the overall operation, including revised operations procedures, will be a second objective. Third will be the participation in projects with Systems Support and Research Division staff to develop ways of expanding the analysis capabilities of SELDADS II.

SPACE ENVIRONMENT DATA COLLECTION

Solar Electronic Observing Network

The 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 the world to maintain a continuous watch for solar activity and to provide many of the synoptic observations used in forecasting solar activity. Together the SOON and RSTN make up the Solar Electronic Observing Network (SEON). The staffs of SOON and RSTN (more than 50 total) are supplied in the most part by the Air Force and the Learmonth Solar Observatory, Australia. The SOON and RSTN observations are provided to SESC in real time for use in the forecast operation. To maintain a liaison between the SOON and RSTN and the SESC, NOAA provides an experienced observer who helps staff the Learmonth Observatory. This position was maintained in FY 1986 by an officer of the NOAA Commissioned Corps who is trained and experienced in solar observing. SOON images from Holloman Solar Observatory are obtained in near-real time at SESC (see the section on SELSIS). Other data from all the SOON and RSTN locations were integrated into SELDADS II, and include synoptic descriptions of current and potential solar activity as well as real-time flare reports, coded sunspot reports, and solar radio burst summaries.

Plans for the coming year include the initiation of several reports per day from the SOON observatories of a set of solar active region parameters that have been shown to be effective in predicting solar flares. The data are not otherwise available in objective form and will be used in the daily forecasts as well as to provide a data base for future studies to improve the forecasts.

Culgoora Observatory

The Culgoora, Australia, Solar Observatory is operated by the Australian Government to meet operational requirements for solar observations. It is also a data source for SEL. In addition to its regular daily observations, and because it has a radio telescope that exceeds the capability of those at the Air Force RSTN locations, the Culgoora Observatory can be used as a baseline for quality control of the classification and reporting of radio bursts seen by it and the RSTN. Quality control remains important throughout the solar cycle. Experience has shown that in the absence of the cross checking, radio bursts may be misclassified by the RSTN system, leading to the use of incorrect information in the analysis and forecast routines. To maintain access to the data, and to keep the data responsive to U.S. needs, a NOAA Commissioned Corps Officer has been stationed at Culgoora throughout FY 1986. A replacement NOAA Commissioned Corps officer will be recruited in the coming year to replace the officer due to rotate out of the Culgoora position.

Kitt Peak National Observatory

Solar magnetic field and solar helium observations made at the Kitt Peak Observatory are critical for both research and real-time forecast services. The daily magnetograms from Kitt Peak show the direction, strength, and complexity of the magnetic field both in the quiet and the active regions of the Sun. A vacuum tower telescope at Kitt Peak makes consistently high-quality observations of these magnetic fields by observing lines in the solar spectrum that are modified by the effect of the Sun's magnetic field and thus can be used to measure that field remotely. The Kitt Peak magnetograms are one of the highest priority types of synoptic data used in daily solar activity forecasting. The images are transmitted to Boulder as soon as possible after observation through use of the new SEL Solar Imaging System (see the section on SELSIS, p. 32). The solar helium observations at Kitt Peak are used to infer the location of solar corona holes, which are usually the sources of so-called M-region geomagnetic storms that may recur monthly for 6 months or more. The SESC experience in the past year, at a time approaching solar minimum activity levels, has been that the inference of holes from the helium data is subject to increasing problems of identification, which in turn increases the difficulty of accurately forecasting geomagnetic activity. The Solar X-Ray Imager (see p. 28) will be able to identify coronal holes directly and will provide the best defined and most consistent observations of coronal holes. NOAA, NASA, and the National Science Foundation cooperate in staffing the Vacuum Tower Telescope at Kitt Peak. This arrangement was in effect throughout FY 1986. Kitt Peak data are handled through the new SEL Solar Imaging System.

GOES Space Environment Monitor (SEM)

Space Environment Monitors on the Geostationary Operational Environmental Satellites (GOES) provide primary data for the detection and classification of solar flares and, combined with the SOON/RSTN data, for the prediction of resultant effects at Earth. Solar flares are classified according to their intensity as measured by the x-ray sensors on the satellites. The satellites also provide the primary data on energetic solar particles reaching the Earth and make possible the prediction of radiation and ionospheric effects. For example, the primary measurement of solar proton fluxes for manned space operation by NASA is provided by the GOES energetic particle sensors. The long-term data base supplied by the satellites has also been used with increasing frequency in other studies into environmental variations ranging from climate effects, through communication variations, to component failures on satellites.

A continuous flow of GOES SEM data is critical for SESC operation. Such data are provided by a set of tracking systems at the Table Mountain Observatory near Boulder. The data are read out, processed, and transmitted continuously into SELDADS for use by SESC, and are made available to other users requiring the data. The data are also archived in the National Geophysical Data Center of NOAA's National Environmental Satellite, Data, and Information Service (NESDIS). GOES-5 and -6 provided these data during FY 1986. The planned replacement of GOES-5, which has suffered from deteriorating SEM data quality, was lost when GOES-G failed to achieve orbit after launch in May. Displays of the GOES SEM data were completed as some of the earliest display data in SELDADS II in FY 1986.

NOAA/TIROS SEM

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 the Earth's outer magnetic field. Data coverage has been reduced since SEMs have recently been flown only on the even-numbered satellites. The most recent satellite in the series, NOAA-10, was launched on 17 September 1986.

New methods of processing and displaying NOAA data have been under development. These are oriented toward providing useful information regarding the amount and location of energy input into the upper atmosphere as measured by the NOAA Space Environment Monitor. Secondary parameters such as the thermospheric temperature can be calculated using the NOAA data as input to models. The operational problem yet to be solved is to develop methods of checking the computed values in real time. Efforts to develop methods for validation and application of these data to meet user needs will continue, and integration of these into the new SELDADS will be one of the priority tasks in the coming year.

Remote Geophysical Observing Network (RGON)

Information on the variation of the geomagnetic field at various locations above the Earth's surface is a requirement for the services operation. 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 by universities with funding from the National Science Foundation. The data are transmitted by individual radio transmitters from each of the remote magnetometer sites and received by the GOES data collection systems every 16 minutes. The data are relayed by the NESDIS to Boulder where they become a part of the SELDADS data base.

Accomplishments in FY 1986 included the ability to produce real-time stacked plots of these data for the use of the forecast operation as a part of the new SELDADS system. The stacked plots are grouped according to the geographical chains of magnetometers from which they are obtained, and the grouping facilitates the detection and analysis of geomagnetic disturbances as the disturbances spread along the various chains.

Upgrading of data relay hardware to maintain the RGON links in the near future is necessary . The old hardware is becoming unreliable. Discussions are under way with the other agencies involved but plans are not final.

Other Data

Other primary sources of geomagnetic data for the environment services operation are obtained from the Air Force and from the U.S. Geological Survey; both operate magnetometer networks and make the data available in real time. Displays of these data were completed in SELDADS II in FY 1986. Other observatories supplying data in FY 1986 for SESC operations included the Ottawa (Canada) Solar Radio Observatory, Mt. Wilson Observatory, Stanford Solar Observatory, Sacramento Peak Observatory, and the University of California at San Diego Clark Lake Observatory.

Field Site Operation

Two field sites are part of the data collection operation. The High-Latitude Monitoring Station (HLMS) at Anchorage, Alaska, is operated jointly by NOAA and the Air Force to collect data from the high latitudes where many solar-terrestrial disturbances are concentrated. Data collected at HLMS (with magnetometers, riometers, HF receivers, auroral radar) are given preliminary processing and then transferred to the SELDADS at Boulder. Primary activity at HLMS in FY 1986 included development of new computer software and completion of interfaces to utilize more efficient communications systems. Plans have been made to phase out staffing at the High-Latitude Monitoring Station by mid-1990. The Air Force will install a set of sensors that operate remotely with real-time data relay to meet operational needs.

Table Mountain Observatory (TMO) near Boulder receives signals from the GOES satellites and processes them for relay to SELDADS. TMO is also the location of several sensor systems including a magnetometer of the U.S. Geological Survey. Operations for FY 1986 at Table Mountain gave priority to GOES data reception and magnetometer operation. Old data systems were terminated at TMO in 1986 including data from the NASA Interplanetary Cometary Explorer (previously Interplanetary Sun-Earth Explorer —ISEE) and the three-frequency radio telescope that was part of the old NASA Solar Proton Alert Network (SPAN). The old ISEE was no longer located to give useful solar wind data for Earth effects, and the SPAN data have been replaced by newer, expanded equipment in the Air Force Radio Solar Telescope Network (see Solar Electronic Observing Network above.) Early planning has begun, to close the Table Mountain Observatory operation and replace it with GOES ground reception facilities at the main Department of Commerce facilities in Boulder.

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 Services Division and to the Research Division in planning, development, and provision of instrument and data systems.

MAGNETOSPHERIC PHYSICS

The objective of the Magnetospheric Physics Project is an improved understanding of the dynamical processes by which material and energy are coupled from the solar wind into the magnetosphere, thereby modifying the near-Earth environment, and applying this understanding toward improving the quality and utility of the SEL's products and services.

Data And Data Studies

A Personal-Computer-Based GOES Archive

SEL uses instruments on board the GOES series of satellites to monitor the geomagnetic field, and the particle and solar x-ray radiation environment at geosynchronous orbit. The data are used by SESC to provide real-time monitoring and forecasting of the state of the near-Earth environment, and to maintain a source of reliable information to operational and research activities of a variety of users.

A personal-computer-based archive of 5-minute averages of the complete GOES Space Environment Monitor (SEM) data has been created to provide:

(1) maximum transportability of data to and among users,

(2) easy access and manipulation of that data, and

(3) simple plot routines by which the data may be selectively displayed.

Two 5 1/4-inch diskettes are able to contain one month's data from each of the energetic particle, solar x-ray, and magnetometer sensors. The archive system represents a compact and user-friendly medium for the access, analysis, and storage of the SEM data.

Geosynchronous Magnetic Field

The magnetic field in geosynchronous orbit is routinely monitored by instruments aboard the GOES spacecraft. These data are available to the Space Environment Services Center on a real-time basis; however, their full potential has not yet been utilized. Study has suggested that the available real-time data could provide meaningful indices of the level of geomagnetic activity, by examining the relationship between disturbances at geosynchronous altitude and parameters describing the level of ground activity.

Quantitative determination of this relationship requires that a historical data base be established. Creation of such a data base for the calendar year 1983 is nearing completion. The next step in the analysis of these data is the determination of quiet-day models of the geosynchronous field to provide the reference from which activity can be determined. Examination of these data has prompted the following preliminary study.

GOES Magnetopause Crossings

Much geomagnetic activity is associated with the compression and erosion of the magnetopause; during high activity, the magnetopause may be pushed inward to geosynchronous orbit (6.6 Re) or even lower. The magnetometer data base shows a number of instances when the GOES magnetometer has a southward component (a signature of magnetopause crossing) in association with the sudden commencement of high geomagnetic activity, as indicated by the activity parameter AE. Figure 1 shows two cases illustrating this association. Figures 1a and 1b show the magnetopause crossing; the corresponding magnetic activity (AE) is shown in Figures 1c and 1d.

The GOES spacecraft crossed the compressed magnetopause at the times when the measured field went negative as indicated in Figures 1a and 1b. The sudden onset of geomagnetic substorm activity is indicated in Figures 1c and 1d by variations in the magnetic index AE. If the association of the magnetopause crossing with immediate high activity can be placed on a quantitative basis, detection of such crossings by the GOES satellite may provide a useful geomagnetic forecasting tool.

Geomagnetic Cutoffs

Access of energetic particles of solar or galactic origin to the Earth is restricted to regions surrounding the Earth's geomagnetic poles, extending down to some particular magnetic latitude termed the cutoff latitude. This polar access region is roughly circular around the geomagnetic pole, and its size is strongly dependent on conditions of geomagnetic activity. A study has been undertaken to investigate the relationship between the size of this access region,

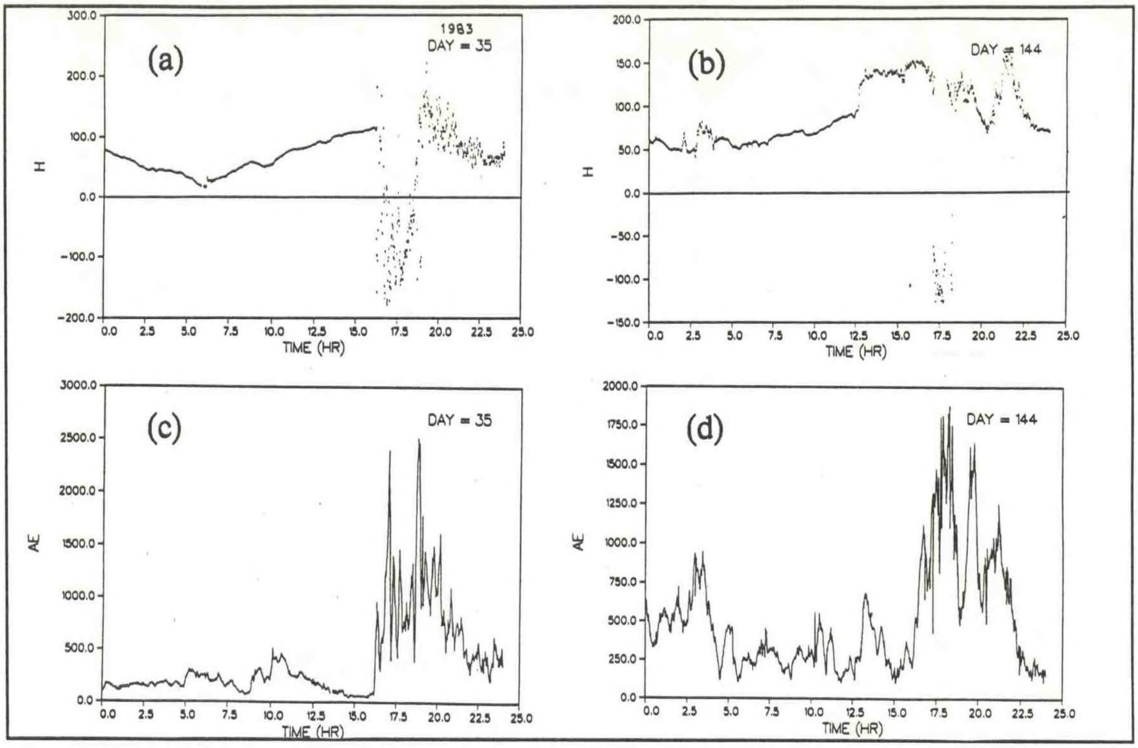

Figure 1.—Magnetic field plots showing magnetopause crossings (a and b), and corresponding magnetic activity (c and d) in terms of the Auroral Electroject Index (AE).

defined by the limiting cutoff latitudes, and parameters describing geomagnetic activity.

The NOAA-6 is a low-altitude (870 km), polar-orbiting satellite that monitors energetic proton fluxes with energies of 80 keV to >80 MeV produced by solar and galactic sources. Energetic particle data have been collected for about 2000 polar passes of the NOAA-6 for periods during 1982-1983 in which substantial fluxes of solar protons were present. A computer procedure was developed to identify the cutoff latitudes for each of these passes, and a data base was constructed that contains these values and associated parameters of geomagnetic activity upon which the position of the cutoff latitude is known to depend. Correlations of the cutoff latitude with these activity parameters have been made. It remains to determine whether an inversion can produce a useful prediction of the global cutoff latitudes from knowledge of appropriate geomagnetic activity parameters.

Theoretical Studies

The regions of pivotal importance in controlling the dynamics of the magnetosphere system are the so-called plasma boundary regions: the magnetotail plasma sheet, its earthward extension, the auroral regions, and the dayside magnetopause (Figure 2).

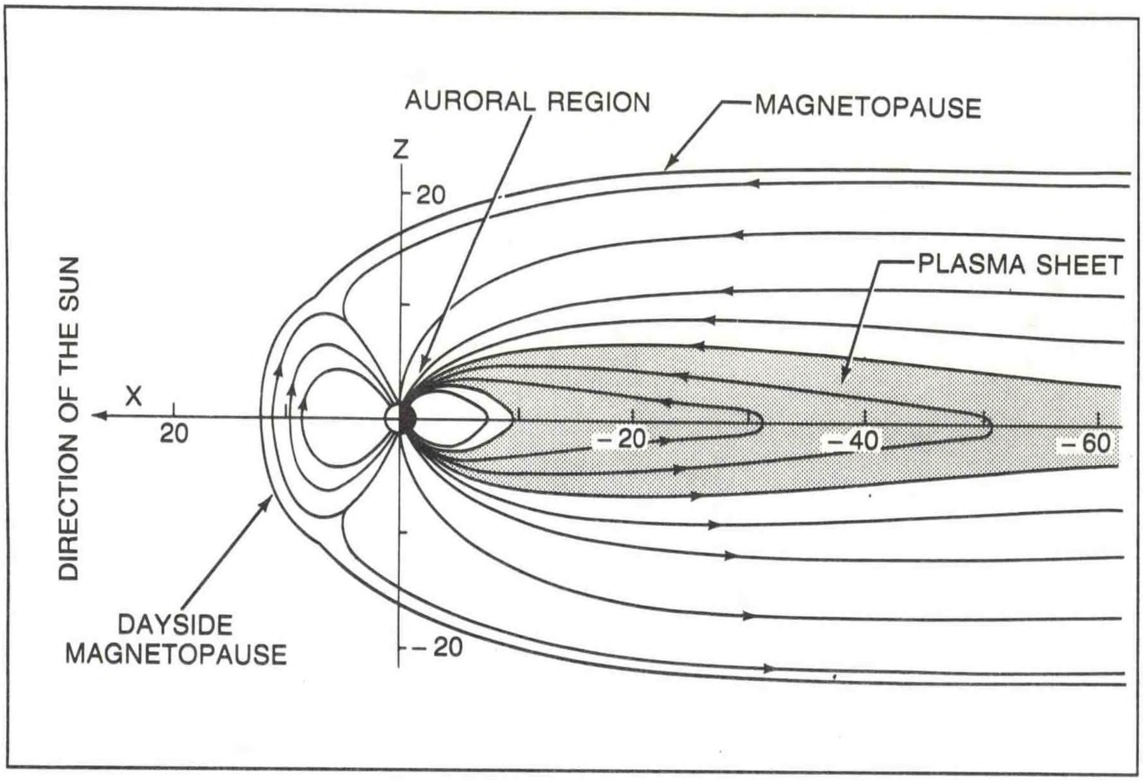

Figure 2.—Schematic illustration of the noon–midnight section of the magnetosphere.

Magnetotail Particle Kinetic 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 important region is an important step toward the long-term goal of understanding the mechanisms behind geomagnetic activity.

Previous SEL studies of single particle orbits in current sheet magnetic fields have proved that this method can reproduce observed particle distributions fairly well. More detailed single particle kinetic calculations near magnetic neutral points have shown the motion to be "chaotic" in many cases; i.e., an infinitesimal perturbation in initial conditions results in a dramatic change in the particle orbit. This stochasticity has the potential to enhance the magnitude of the tearing mode instability, which has been proposed as the magnetotail energization mechanism. Further studies, both analytic and single-particle simulation, of self-consistent currents and fields have been performed for both the current sheet and neutral point models. Current density–electric field relations have also been calculated. These relations show a significant departure from the linear (Ohm's Law) electric field-current relationship fundamental to

MHD fluid theory. Self-consistent electric fields are similar for both models and compare favorably with inferred values of the cross-tail field in the plasma sheet. Further studies of the breakdown of the MHD approximation have begun, and the process of combining these models into a medium-scale single particle model for the plasma sheet has been initiated.

Auroral Region and Boundary Layer Plasma Instabilities

To better understand the interactions of energized plasma sheet particles with accelerated ionospheric ions and several electron populations in the plasma sheet boundary layer and auroral acceleration region, linear, and quasi-linear Vlasov kinetic theory is used. Results for the auroral region indicate that two instabilities can be excited depending on the relative velocity of the O^+ and H^+ ion beams: a non-resonant ion-ion instability at low speeds (low altitudes in the parallel electric field region), and an ion-electron acoustic instability at high speeds (high altitudes). The frequency spectrum of the waves produced is in the range of the observed electrostatic noise in the region. Calculation of particle heating with a particle-in-cell simulation code has begun. In the plasma sheet boundary layer, the convective simulation study is under way. Recently, the quasi-linear diffusion equation for this case has been solved, and calculation of diffusion coefficients is in process. This is to determine whether diffusion of heated boundary layer ions could be a major source of the hot central plasma sheet ion population.

Magnetopause Studies

It is now known that one of the most important parameters of the solar wind for driving magnetospheric dynamics (auroras, magnetic storms, substorms, and so forth) is the southward component (B_Z) of the interplanetary magnetic field (IMF). A recent study involved finding new ways to monitor B_Z from measurements inside the magnetosphere. It is important to know B_Z to be able to predict magnetic storms and related activity. Unfortunately there is no longer an upstream solar wind monitor, since the ISEE–3 satellite was moved.

In this study a large data set was developed involving magnetic measurements at synchronous orbit, at the magnetospheric boundary, and in the solar wind. It was found that a certain class of long period hydromagnetic pulsations (Pc 4) at synchronous orbit is correlated with the occurrence of southward B_Z. If further study confirms this correlation, then these pulsations may be used in conjunction with ground measurements as an indicator of southward B_Z, thus providing a rudimentary remote sensing capability of the interplanetary magnetic field.

ATMOSPHERIC-IONOSPHERIC-MAGNETOSPHERIC INTERACTIONS

The objectives of this project are an improved understanding of the transfer of electrical and mechanical energy from Earth's magnetosphere into the upper atmosphere and a characterization of the possible consequences of this energy input to Earth's ionosphere and upper atmosphere.

Data Acquisition

A major resource for this project is the observations of auroral particle energy inputs to Earth's polar atmosphere that are made continuously by instruments on board the TIROS/NOAA satellites. These data are processed on a routine basis and are used to specify the level of geophysical activity, as inputs to models that characterize the response of the ionosphere and upper atmosphere to changes in the energy input from the magnetosphere, and in correlation with observations made by other satellites and by ground-based facilities. During the last year data were available from only NOAA-6 which was launched in 1979. The instrument on NOAA-6 has degraded over the years, and the usefulness of the data has diminished. This deficiency has been partially rectified with the launch of NOAA-10 in September 1986. The instrument on NOAA-10 is now operating satisfactorily and providing energy flux observations on a regular basis.

Specification of the Thermospheric Heat Budget from TIROS/NOAA Data

The principal parameter derived from the TIROS/NOAA observations is an estimate of the total power deposited into the auroral atmosphere by precipitating auroral particles, a parameter obtained for each satellite transit of the polar regions. This power input describes the level of auroral activity. In the past, patterns of auroral energy input as a function of magnetic latitude and magnetic local time have been created for each level of activity. The TIROS/NOAA observations have also been used to construct analogous ionospheric conductivity patterns, also ordered by auroral activity. During the past year, collaborative work with the Millstone Hill Ionospheric Radar Facility (operated by MIT) has resulted in the construction of preliminary ionospheric level electric field patterns also ordered by the TIROS/NOAA activity parameter. The combination of these electric field patterns with the corresponding ionospheric conductivity patterns yields patterns of Joule (or Ohmic) heat input to the atmosphere as a function of the TIROS/NOAA activity parameter. The combination of the particle energy input and the Joule energy input effectively specifies that portion of the heat budget of the thermosphere that is due to magnetospheric processes. Figure 3 shows this heat budget specification for four levels of activity in the form of the rate of neutral gas temperature increase at 130 km altitude as a function of magnetic latitude and magnetic local time. It is noteworthy that the

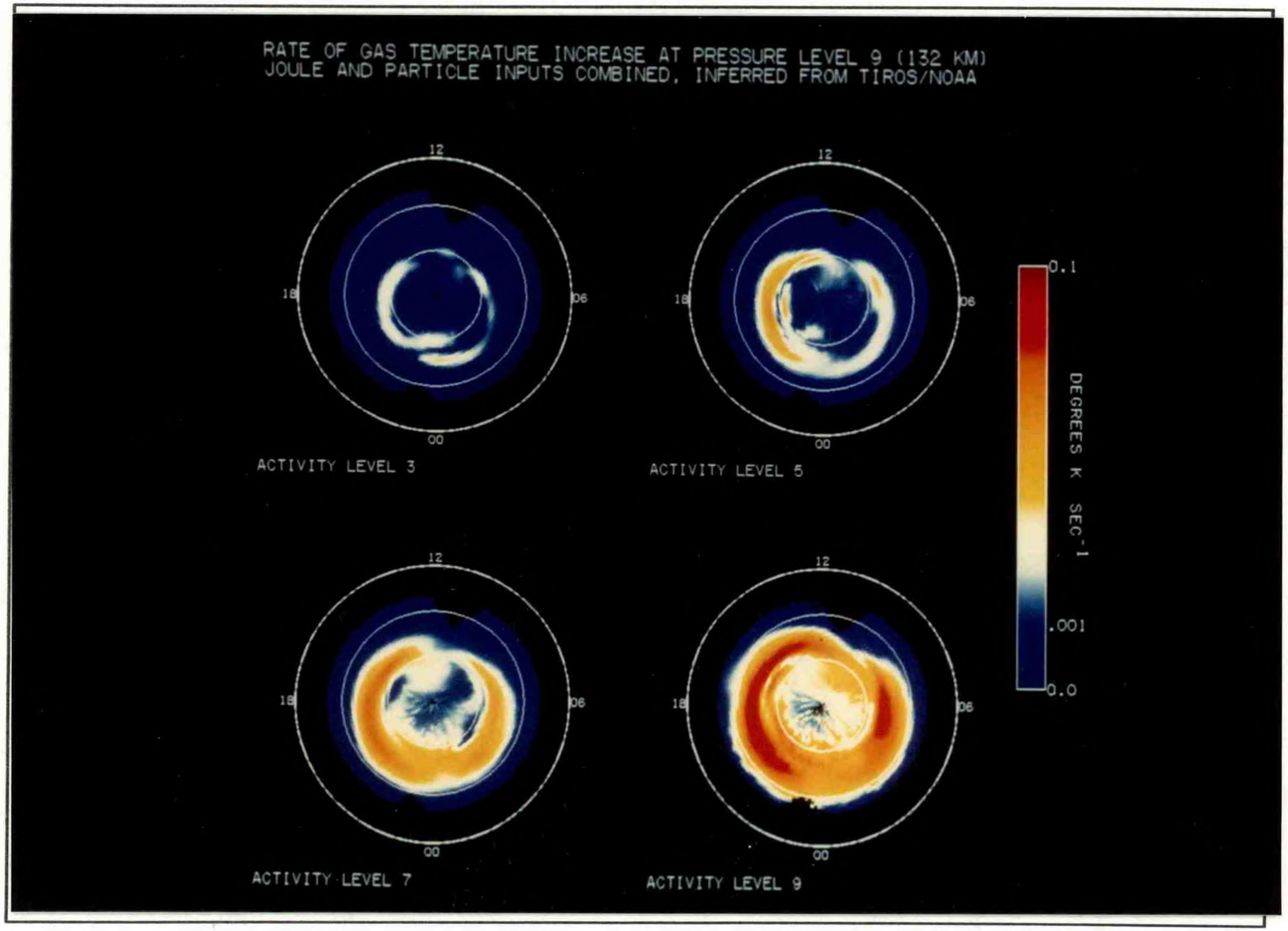

Figure 3.—The global specification of the heat input to the neutral atmosphere at 130 km altitude for four levels of geophysical activity. The specification is expressed in terms of the instantaneous rate of temperature increase on the part of neutral gas. At high activity levels, this rate of temperature increase exceeds by a wide margin that rate provided by absorption of direct solar radiation.

heat input maximizes in the late afternoon hours (about 0.1 kelvin per second at high levels of activity) because satellite drag studies have shown that the atmospheric density perturbation also maximizes in this time sector, a feature not replicated in current atmospheric models.

In cooperation with scientists from University College London and from Japan, a study was conducted using the specification of the thermospheric heat budget derived from the TIROS/NOAA observations as an input to a model that traced the evolution of the thermosphere in response to the time-varying energy input from the magnetosphere. A 7-day period during September 1984 was chosen for this study because of the availability of extensive ground-based observations of the state of the neutral atmosphere at that time. The results of the study were encouraging in that the modeled results, driven by TIROS/NOAA activity parameter, followed the evolution of the exospheric temperature very well.

Other Data Studies and Collaborative Programs

TIROS/NOAA observations were used in a number of other scientific studies in cooperation with researchers from other institutions. A study compared NOAA-6 particle observations obtained during an overpass of Siple Station, Antarctica, with the auroral data from a television imager at that station. The geometry of the pass was ideal and it was expected that excellent agreement between satellite and ground observations would result. In fact, the initial agreement was rather poor. It was only after learning of a 2-second timing error in NOAA-6 data from that epoch and correction for the use of geodetic latitude (as opposed to geocentric latitude) that reasonable agreement was achieved. Even then, the errors associated with tracing the geomagnetic field line from the location of the satellite (where the particles were observed) 750 km downwards to the top of the atmosphere (where the aurora was observed) compromised the quality of the agreement that could be obtained. This study illustrated the extreme difficulty inherent in performing satellite-ground or satellite-satellite correlations of highly structured auroral phenomena, using magnetic field mapping to interconnect the observations.

Correlations between TIROS/NOAA observations and data collected by other satellites continue to be sought in an effort to determine the spatial extent and degree of inter-hemispheric symmetry (as contrasted to strict magnetic conjugacy) in particle precipitation. Work with Aerospace Corporation scientists has shown that similar auroral features can occur simultaneously at very high latitudes in the northern and southern hemispheres. This sort of high latitude symmetry has ramifications for the nature of the magnetosphere at large radial distances.

The signature of pulsating aurora, as it appears in the TIROS/NOAA data, has been defined in the course of a comparison study with x-ray images of the atmosphere that were obtained by Lockheed Research Laboratory scientists from an instrument on board the S-81 spacecraft. Being able to identify precipitating electrons responsible for the pulsating aurora has permitted the construction of electron energy spectra which demonstrate that the time variations causing the visible pulsation are restricted to higher energy electrons but are superimposed upon a nearly steady-state low-energy (<1 keV) background. Lockheed and SEL scientists developed a numerical model was developed which showed that these low-energy electrons could be explained as being backscatter that is being produced from the atmosphere by the time-varying high-energy precipitation. In this fashion, a time-varying and a steady-state component to the precipitation could be explained in a natural manner without invoking ad hoc processes operating in the magnetosphere.

Operational Users and Data Exchanges

TIROS/NOAA observations continue to be made freely available for a variety of scientific uses and in support of operational programs. During the year, data were supplied to the Aerospace Corporation, Lockheed Research Laboratories, SRI International, Geophysics Research Laboratory, University of Maryland, private industry, and several overseas organizations. A special data reduction program was undertaken for NESDIS in connection with the Chernobyl accident.

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 to develop methods of monitoring disturbances as they are generated and as they travel toward the Earth. The development, test, and implementation of physically based, numerical magnetohydrodynamic (MHD) models would be driven by real-time solar observations and checked by spacecraft monitoring of the solar wind plasma and interplanetary magnetic field near Earth.

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

A 3–D, time-dependent MHD model continues to be tested. It is, at present, initiated at 0.01 AU (astronomical units) with representative solar-flare- generated shock wave pulses. The earlier work, limited to a single interplanetary magnetic field (IMF) polarity, was oriented toward check-out of the algorithm and investigation of a large variety of graphic displays that would demonstrate important physical phenomena. Recent work incorporates an initial configuration that consists of a simple, flat, heliospheric current sheet. By introducing one or more pulses at off-ecliptic locations, we can study the latitudinal dependence of the disturbance upon this "canonical" current sheet. Although the model equations incorporate infinite electrical conductivity, there is sufficient numerical diffusion to provide electrical resistivity and allow field line reconnection. The physical basis of this reconnection of the IMF is rooted in the large-scale thermal and magnetic pressure gradients that can drive opposing IMF polarity field lines together, annihilating some magnetic flux in the process.

This progress is illustrated in Figure 4 which shows projections of the IMF onto two meridional planes at four separate times following the introduction of two shock waves. The shocks were introduced with finite heliolongitudinal and heliolatitudinal spatial extents for a finite time representative of typical flares. The peak strength of each shock was located at two southerly latitudes to "mimic" the actual locations of two of the February 1986 solar flares. The figure shows the combined effects of the two flares that were relatively closely spaced in time. The combined propagating shock can be discerned by the curvature in the near-radial projection of the IMF (outward polarity in the northern hemisphere, inward in the southern). IMF reconnection appears at the shock, followed later in time by reconnections of the sunward side of what may be a magnetic cloud (or "bubble") as suggested by *in situ* spacecraft observations (Helios, Imp, and Voyager). This result suggests that generation of geoeffective southward IMF polarities and the associated IMFs may be sensitive to the proximity of the heliospheric current sheet to the sources (such as flares, coronal holes, and eruptive prominences) of interplanetary disturbances. We plan to pursue this 3–D Interplanetary Global Model (IGM) development together with a complementary model for a helmet streamer configuration at the Sun. This latter effort will develop our capability to accept inputs at the base of the corona from solar magnetograms and soft x-ray images. This work is being conducted in collaboration with Tennessee Technological University, Tel-Aviv University, and the University of Alabama in Huntsville.

Test of 2½-Dimensional (2½–D) Interplanetary Global Model

The 2½–D IGM (limited to ecliptic plane studies but with all three components of solar wind velocity and IMF) was successfully transferred, together with vectorization capability, to the Cyber 855/205 as well as to the scientific workstation (Apollo DOMAIN). Some additional color graphics capability was introduced on the Apollo to display physical compressions and rarefactions in the solar wind. We used this IGM to study the simulated interplanetary environment that resulted from six significant solar flares during 3–7 February 1986 near the end of solar cycle 21. The simulation used the available real-time solar data to drive the model, to examine (1) the simulated compound effects of the multiply-interacting disturbances, and (2) the simulated effects of each flare

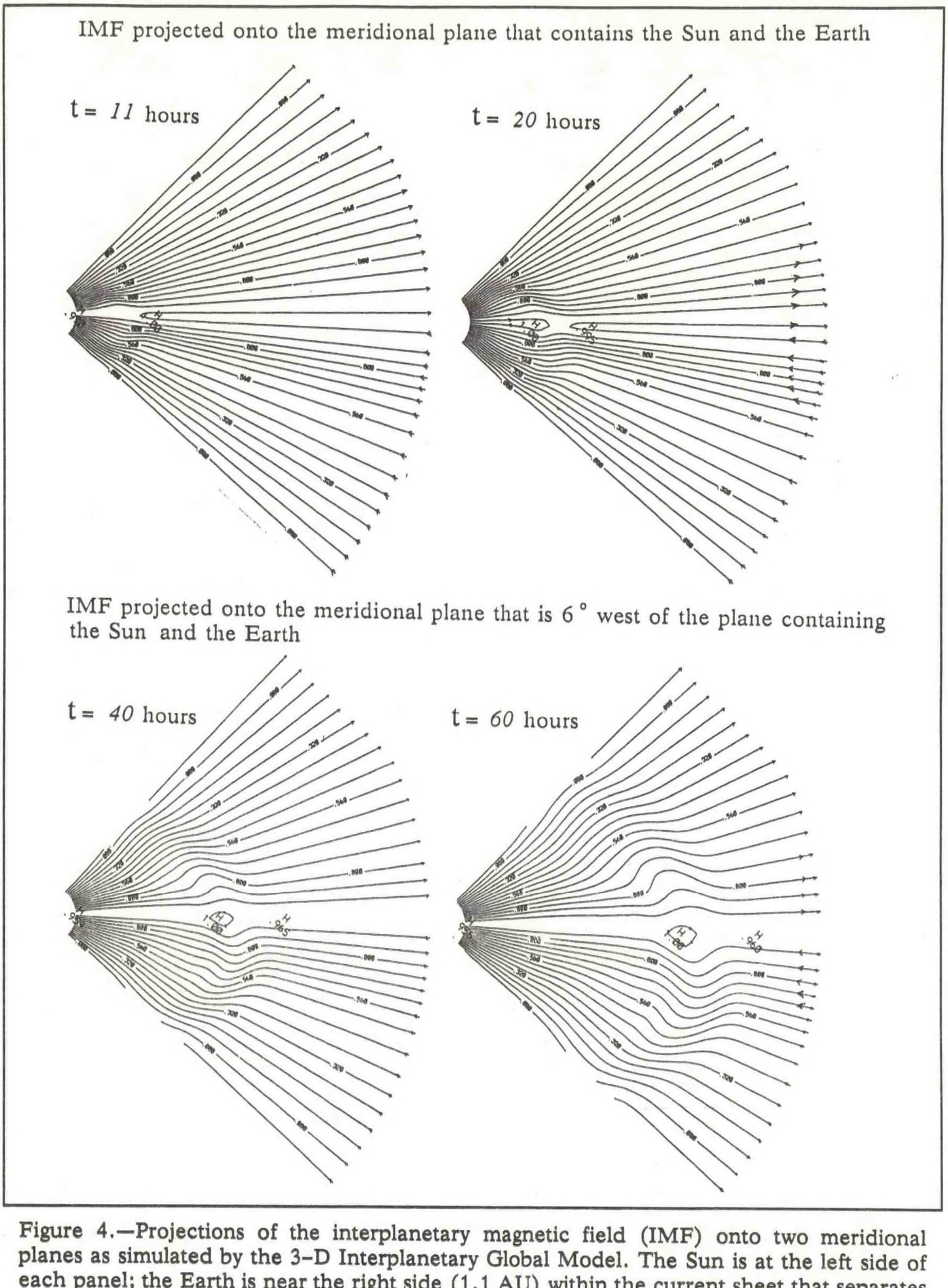

Figure 4.—Projections of the interplanetary magnetic field (IMF) onto two meridional planes as simulated by the 3-D Interplanetary Global Model. The Sun is at the left side of each panel; the Earth is near the right side (1.1 AU) within the current sheet that separates outward polarity (northern hemisphere) from inward polarity (southern hemisphere). Generation of a magnetic cloud (or "bubble") by strong pressure gradients produced by two solar flares in the southern hemisphere is indicated by this simulation.

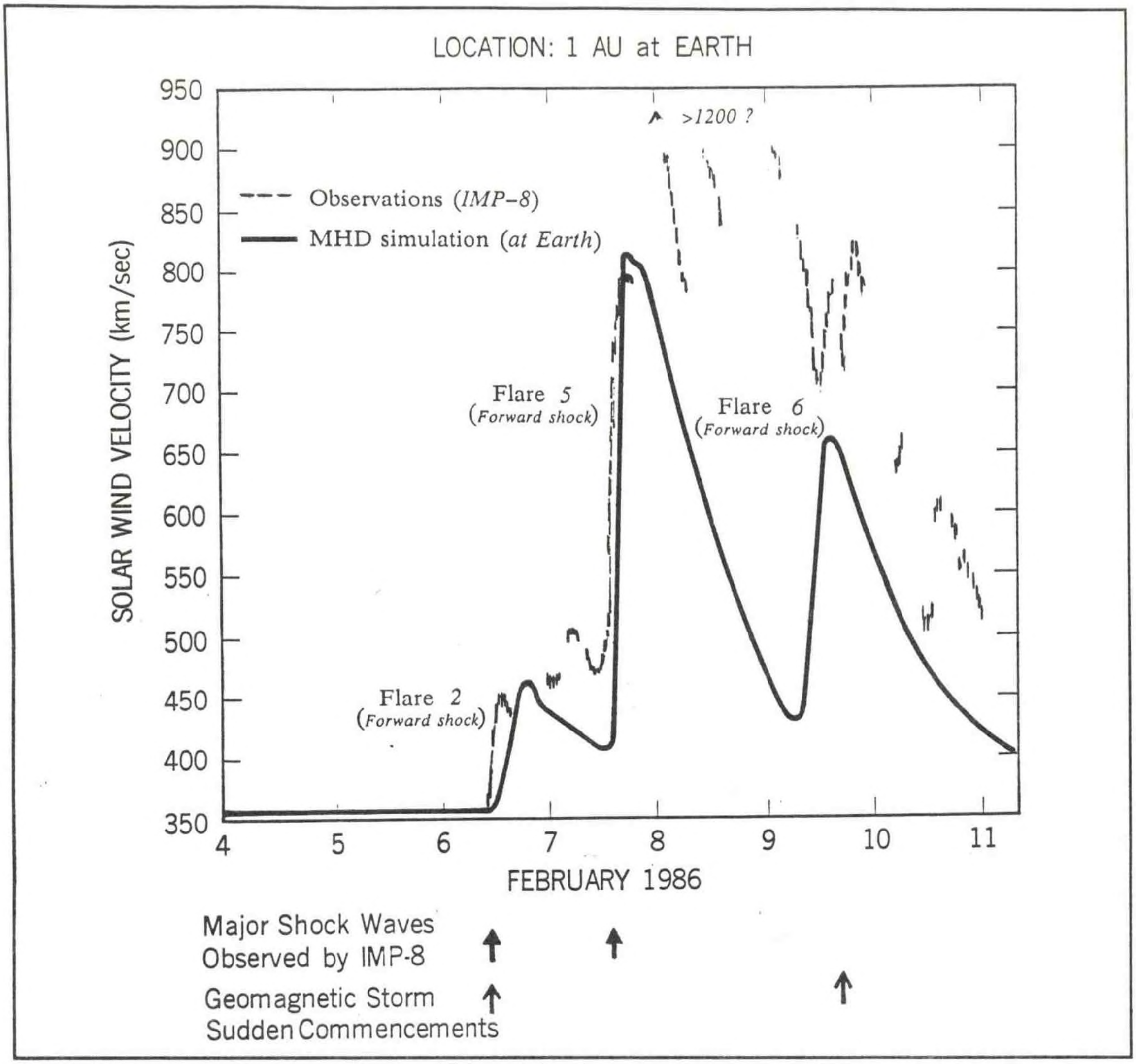

Figure 5.—Comparison of the solar wind velocity at the Earth as simulated by the 2½–D IGM with IMP–8 observations during the February 1986 period of six solar flares and geomagnetic storm activity. The effects of the first and fourth flares were overtaken and combined, respectively, with the two successive flares. Flare 3 was directed mostly 90° to the east of the Earth with insufficient strength to influence the others. The comparison with observations clearly indicate only a partial success of the simulation during the first few days of geomagnetic activity.

alone, propagating in the absence of any of the other flares. This latter procedure was used in the sense of a sensitivity study. For the first case, which is closer to the actual expected global structures, the 2½–D IGM was partially successful in predicting most of the major interplanetary shocks as indicated by preliminary IMP–8 data.

Figure 5 shows the simulated solar wind velocity at Earth as a function of elapsed time from the arrival of the first flare's simulated shock (at 2300 UT on 3 February 1986) at 0.01 AU. This helioradial position is the inner boundary of the computational domain that includes half of the ecliptic plane. The fast forward shocks from the second, fifth, and sixth flares are evident from the sudden sharp increase of velocity. The compressive effects of the first, third, and fourth flares were overtaken and combined with the compressions caused by the other flares. Figure 5 also shows a comparison with IMP–8 data when this spacecraft was outside of Earth's bow shock wave. It is seen that the first two shocks were reasonably well predicted in timing and phasing. However, the actual peak amplitude (perhaps as high as 1200 km/s) was not predicted. Also, the structured decay that possibly included other shocks and a background high-speed stream were not predicted. Although storm sudden commencements (SSCs) were actually detected (as denoted by arrows at the bottom of Figure 5) at the simulated arrival of the second and sixth shocks, the simulation can be considered only partially successful. It is becoming increasingly clear that we require better definition of the input conditions at the Sun and better observations that could drive the 3–D IGM discussed above. This work is being done in collaboration with CIRES, Tel-Aviv University, and the University of Alabama in Huntsville.

Interplanetary Scintillations of Distant Radio Sources

Work was started to evaluate the Interplanetary Scintillations (IPS) radio astronomical technique as a real-time forecasting tool. "All-sky-maps" of the enhanced (reduced) scintillations of several thousand radio galaxies and pulsars, observed from a single station, the Mullard Radio Observatory in Cambridge, England, give daily "images" of plasma density compressions (rarefactions) traveling in the interplanetary medium. Phenomenological model simulations and 3–D IGM simulations (of co-rotating and flare-produced structures) were used to generate maps of expected scintillation. This procedure appears to be a promising one for creating a library of synthetic maps that could be used to interpret the (messier) maps of actual, observed disturbances. We hope to encourage the reactivation of the Cambridge IPS station to further SEL's research and operational mission in this respect.

We have also initiated a collaborative project with three other major IPS observatories (Toyokawa, Japan; Physical Research Laboratory, India; and University of California, San Diego) each of which specializes in cross-correlating the scintillation observations (from a much more limited number of radio sources) from three stations with baselines on the order of 100–200 km. Solar wind velocities, produced by this remote sensing technique, have been used to infer complementary diagnostics for co-rotating and flare/prominence-produced structures in the solar wind. Approval of a Special Foreign Currency contract with the Physical Research Laboratory (Ahmedabad, India) has recently been granted. We anticipate that this collaboration will therefore be extended.

SOLAR PHYSICS PROJECT

This project has chosen to emphasize the large-scale and longer-term aspects of solar activity as an approach to understanding the most fundamental processes that precede and control the solar events that have significant effects on the interplanetary and terrestrial environments. Two requirements in the NOAA solar-terrestrial prediction service drive the choice of emphasis:

(1) need to improve the prediction of the time, location, and intensity of solar flares,

(2) need to predict severe geomagnetic storms.

These two prediction problems are separate, although loosely related. The largest solar flares are sometimes followed by a severe geomagnetic storm, but some of the most severe storms have been associated with unimpressive flares or with ejections of filaments from areas distant from the flaring active regions. The common aspect thought to relate all sources of severe geomagnetic storms is the coronal mass ejection.

The limitations on flare prediction center on lack of understanding of the processes for generating magnetic fields and controlling their emergence through the solar surface. The eruption of magnetic flux occurs in quasi-periodic episodes, as can be seen in the saw-toothed character of the plots of monthly sunspot numbers. Work has shown that the eruption of magnetic flux is often distributed along the boundaries of the pre-existing, large-scale patterns of weak magnetic fields, as if there were giant convective elements determining the location of flux eruption. These large-scale aspects suggest that improvement in predicting flux eruption, and thereby improving flare predictions, may come best from studies of large-scale solar magnetic fields.

The limitations on predicting coronal mass ejections are several. Most of these ejections are accompanied by the disappearance of a large, dark filament easily observed in the Hα spectral line of hydrogen. However, most filament eruptions are not followed by an observable coronal mass ejection, nor by a geomagnetic disturbance. The filaments are the primary markers of the boundaries to the slowly varying, large-scale patterns of solar magnetic fields. That fact has been used to develop Hα synoptic charts. These charts have demonstrated that the formation and evolution of filaments occur in unison with the evolution of the large-scale magnetic fields. Inasmuch as the structure and activity of the corona follow the filament activities, prediction of coronal mass ejections leads, again, to study of the large-scale magnetic fields.

Solar Mapping

The acquisition and display of data on large-scale solar magnetic fields continued as a major component of the project. Computer graphics programming for entry and display of Hα synoptic charts produced significant new tools for research. The completion of computer programs for digitization of the Hα synoptic charts allowed entry of more than 40 charts into the computer database. These data were used in the completion of the graphical display programs and the initial analysis of evolving patterns in large-scale solar magnetic fields. The graphical displays are efficient, menu-driven programs giving the user the choice of viewing individual charts, time-lapse movies of charts, or stack plots of selected latitude intervals from a time series of charts. All these options include a choice between color or black and white versions of the charts. The former permit better visualization of the overlays of many data types while the latter give presentations suitable for publication. The fast, computer-generated graphics are a powerful tool for exploring the complex evolutions and determining the most effective approach to expressing these evolutions in quantitative terms that relate most directly to the prevailing theories of the day.

Figure 6 presents a stack plot derived from the digital database so far entered into the Apollo graphics computer system. This figure displays the equatorial portion of 42 Hα charts from April 1983 to July 1986, showing the orderly movement and evolution of the patterns of magnetic polarity on the solar surface. Black indicates areas of negative (inward-directed) magnetic fields; white indicates positive (outward-directed) fields.

This 3-year period spanned the final, declining years of a solar cycle, with a rapid decrease in sunspot and flare activity midway through 1984. The evolving patterns change in correspondence with this sudden decrease in activity, showing a sudden change from small, rapidly-evolving patterns to large, stable patterns. Such comparisons with other measures of solar activity promise to give fresh insight into the processes that drive the solar cycle and generate the flux eruptions that trigger eruptive events.

Throughout the entire period covered by Figure 6, the major components of the patterns drift at a nearly constant rate with respect to the system of solar longitude adopted for this display. This drift simply reveals the more rapid rotation of the solar equator with respect to the longitude system that was derived from observations of sunspots at higher solar latitudes where the rate of rotation is slower. The polar regions rotate much slower still, producing patterns of magnetic fields that would drift in the direction opposite to what is observed in this figure.

Solar Cycle Workshop

Information gained from these new graphics tools was used in an international workshop on the nature of the solar cycle held at CalTech's Big Bear Solar Observatory in August. Patrick McIntosh, who heads the SEL Solar

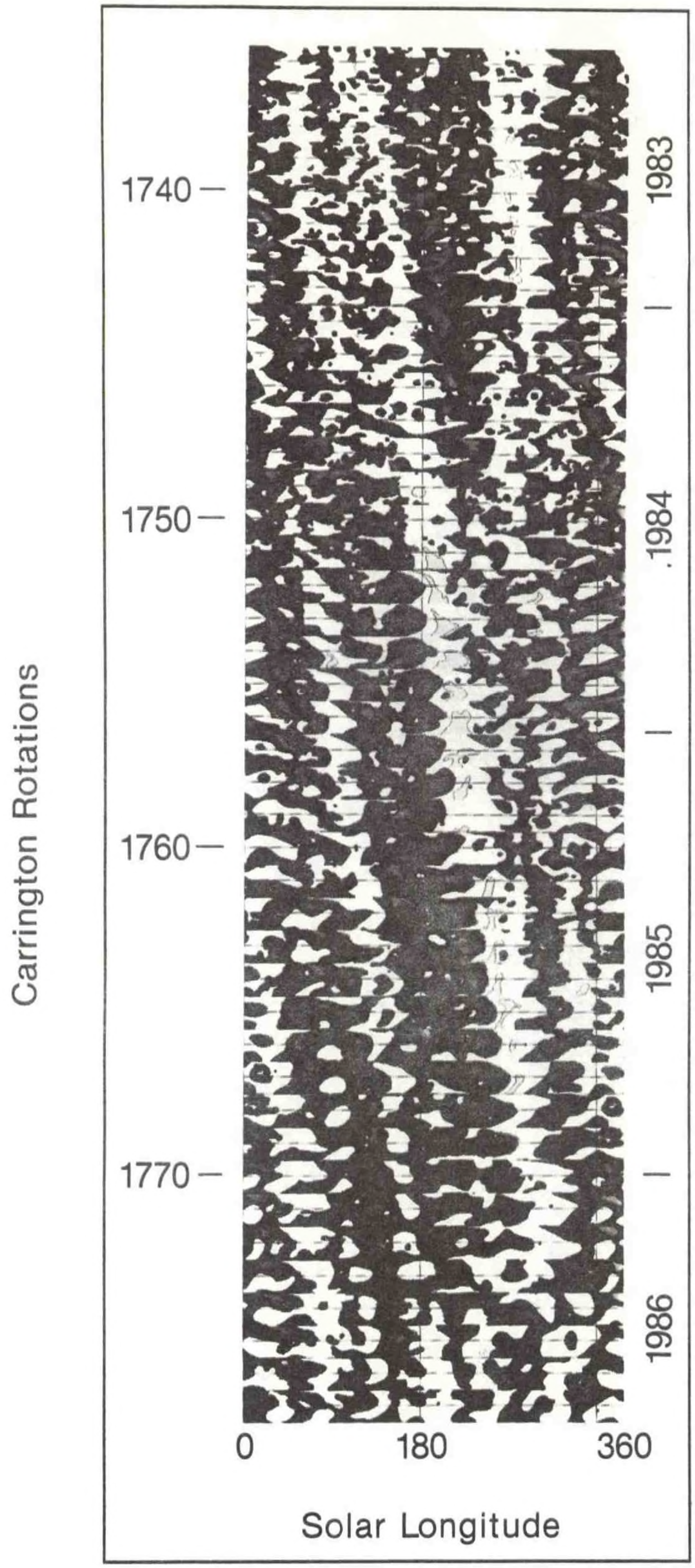

Figure 6.—Stack plot of Hα synoptic charts between latitudes 20° N and 20° S.

Physics Group, was invited to lead the workshop group on large-scale magnetic fields. Observations derived from the SEL Hα synoptic charts stimulated the formation of this workshop. The highly organized and long-lived patterns seen in the 22-year data base of Hα charts may indicate that the prevailing theory of the solar cycle does not explain the basic properties of the solar cycle. There was some agreement that flaring active regions occurred in sequences paralleling the drifting patterns of large-scale magnetic fields on the Hα charts.

Condensed displays of selected latitude zones extracted from the Hα charts revealed a semi-permanent feature that prevailed through most of an 11-year solar cycle. The polar-crown gap, an interruption of the polarity-inversion line at the highest solar altitudes, persists with little variation from one solar maximum to the next. This feature drifts eastward with respect to the lower latitudes where sunspots and flares occur. Some evidence suggests that the polar-crown gap may interact with equatorial features to influence the eruption of flaring active regions. Motion of the polar-crown gap with respect to the location of a great activity complex of 1981–1982 coincided with the beginning and the end of the period of high solar activity at this location. The polar-crown gap aligned with this equatorial longitude when the first great flares occurred, and the enhanced activity continued for 14 months until the polar-crown gap returned to this longitude.

The geometry of the polar-crown neutral line differs between solar minima following even-numbered solar cycles and solar minima following odd-numbered solar cycles. The great, globe-encircling neutral line that includes the polar crowns of both solar hemispheres is more continuous in the southern hemisphere near the end of the odd-numbered solar cycles, presenting an asymmetric distribution to the overlying green-line solar corona. The pattern formed by the polar-crown neutral lines were similar in two hemispheres for the solar minimum of 1976, but have become distinctly different during the 1986 minimum. This periodic asymmetry has been modeled with a combination of a dipole and quadrupole magnetic field in the solar interior.

The torsional oscillations seen in Mt. Wilson Doppler data can also be detected in analysis of the Hα synoptic charts. This is further evidence that the motions of the neutral lines mapped from filaments and chromospheric structures are due to plasma motions and not an independent phenomenon related only to magnetic field evolution. The Hα charts may also reveal meridional flow better than most other solar data. Variations in meridional motion of large-scale, high-latitude neutral lines are correlated with variation in the east-west motion of nearby portions of the same neutral line. Deceleration of the east-west motion is followed one month later by a poleward shift of the adjacent neutral line. Acceleration is followed by motion toward the equator. Proper analysis of the long time-series of Hα charts is expected to illuminate new properties of the global circulation in the solar atmosphere, particularly the components in the meridional direction.

Workshop on Solar Events and Their Influence on the Interplanetary Medium

The Solar Physics Project also contributed to a workshop focusing on the coronal mass ejection and its possible role in producing geomagnetic activity. The Solar Events and their Influence on the Interplanetary Medium (SEIIM) Workshop was held in Estes Park in September.

The group reported that filament eruptions accompanying coronal mass ejections often occur where the underlying neutral line is undergoing a rearrangement, either because of a merger between two large-scale patterns, or a division of a single pattern into two. The filaments near, or over, these changing neutral lines must destabilize and erupt during the process of changing the connection among the segments of neutral line. The study of time series of Hα synoptic charts has revealed instances of rearrangement even when few, if any, filaments mark the neutral lines. These rearrangements may eject coronal material without a visible filament eruption. An outstanding example of rearrangement with five filament eruptions over a period of 4 days was presented to the SEIIM workshop to stimulate interest in this possible source of a significant number of the coronal mass ejections.

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 solar corona. X-ray wavelengths are used to aid forecasts because such photons originate in the corona (i.e., the highest levels) of the solar atmosphere. The corona is also the origin for virtually all the disturbances from the Sun that impact the Earth. In the past year, the Solar X-ray Physics Project secured verbal agreement from the Air Force to procure new x-ray sensors for the GOES-Next series of satellites. The Project has advanced the interpretation of both whole-Sun and imaging x-ray observations, the latter by virtue of work by a National Research Council Fellow who has joined the Project. Work has been focussed on the Solar X-Ray Imager and solar x–ray studies.

Solar X-Ray Imager

Real-time monitoring of the x-ray Sun has been a major solar-terrestrial requirement for both environmental services and supporting observational research. Such data will be obtained by Solar X-Ray Imagers (SXI) on several of the GOES-Next spacecraft, probably beginning in late 1990. The U.S. Air Force has expressed very firm support, which will allow NOAA to obtain the sensors, modify the spacecraft for an SXI, and perform the integration of the instruments. In turn, NOAA is to operate the SXIs, improve predictions, and deliver data to the Air Force Space Forecast Center. Information to be obtained with SXIs is crucial to the operational forecasting of energetic proton events at Earth, geomagnetic storms, and atmospheric heating and ionization by extreme ultraviolet flux. SXI data are also basic to increased understanding of the processes that drive these effects (see Solar X-Ray Studies below).

To assist the development of the SXI sensors and to prepare for the immediate use of their data after launch, an SXI Working Group has been established. Representatives of NOAA/OAR (from SEL), NOAA/NESDIS, the Air Force Geophysics Laboratory, and the Air Force Air Weather Service meet regularly to contribute their individual expertise to this advisory committee and to assure the interests of their organizations. This Working Group will define optimal instrument design, operating modes, and the algorithms to be implemented.

Data from the x-ray telescopes on Skylab have now been used to demonstrate immediate forecasting advantages from SXI. Beyond the obvious aids, SEL has been investigating, for example, the factors that influence the geoeffectiveness of x-ray coronal holes. Likely candidates are the direction of the magnetic field carried up to the magnetopause by the high-speed solar wind streams coming from the hole, the age and sub-Earth area of the hole, and the gradients of coronal density at the margins of the hole (the Venturi shape).

The Solar X-Ray Imager will also image the extreme ultraviolet (EUV) Sun. EUV flux has direct applicability as input to the elaborate computer codes now used (and being designed) for specifying atmospheric heating and ionization (see other sections of this Annual Report). Such data provide the opportunity at last to separate the radiant energy input from that generated by geomagnetic storms.

The SXI will show the location of all potential proton flares. Moreover, the configuration of the hottest flaring loops and overlying coronal structure will also be revealed. The SXI Working Group and the SEL Project scientists are addressing the problem of what x-ray features may correlate with the acceleration of protons and, especially, high-Z energetic heavy ions.

Solar X-Ray Studies

In the areas of interpretation of the currently available x-ray data, the Project welcomed Patricia Bornmann this summer as an NRC Fellow who has research experience with the x-ray polychromator instrument on the Solar Maximum Mission. Bornmann has noted that the link between flares and coronal mass ejections (CME, the cause of many geomagnetic storms) has not been well established. In many cases one is observed without the other; this had been taken as an indication that these were two distinct physical phenomena. However, new research shows that the two phenomena may be manifestations of a similar energy release, the difference in the final result being a function of the environment in which the energy is released.

The current study is based on the published literature regarding the properties of flares and CMEs. Taken together, the evidence suggests a progression from flares without accompanying CMEs, to events with both a flare and a CME, and on to events with only a CME and no reported flare. The cause suggested for this progression of event classes is the strength and complexity of the overlying magnetic field that constrains the disturbance in some events.

The results of the study suggest that the spatial resolution of the SXI may provide a new diagnostic for determining if a region on the solar disk produced a CME. The events that launch CMEs have larger spatial scales than those that do not. Thus, the apparent *size* of the flaring region seen with SXI may indicate a high probability of a CME just as do the time scales of the x-ray emission (as had been previously recognized by SESC forecasters).

The full-Sun GOES x-ray sensors currently in use provide information concerning the physical parameters of flares. The data suggest an attempt to estimate and analyze the local, magnetically contained properties of a flare such as density, volume, mass, total internal energy, and gas pressure from observed time-dependent profiles of electron temperature and emission measure derived from intensity ratios between two continuum soft x-ray channels. A form of the non-equilibrium energy equation that contains the independent variables of length and time is solved by invoking a self-similar formalism that eliminates one independent variable, and by introducing an analytic expression for the observed temperature that eliminates one dependent variable. The resulting energy equation is a Ricotti equation amenable to numerical solution. Solutions are obtained by parametrically adjusting the poorly known (at flare temperatures and densities) constants associated with radiation and conduction. The derived thermal physical properties have been compared with those derived by other investigators using independent methods and instrumentation to validate the method and to evaluate quantitatively the astrophysical constants for radiation and conduction under flaring conditions.

The transfer function for each x-ray sensor ion chamber, used to convert chamber electrical current into x-ray flux, has been found to be highly (solar) temperature dependent for plasma temperatures less than 10^7 K. The temperature dependence is exacerbated by redefining the upper wavelength limit of the shortwave ion chambers from the nominal 4.0 angstroms to a more physically probable value of slightly shorter wavelength. An effort to determine the true effective bandpass was pursued by comparing derived temperatures with independently derived data for the same flares. The effective bandpass is somewhat instrument dependent but resides in the vicinity of 0.5–3.7 angstroms. The investigation will continue and will be formalized into a routine calibration procedure.

Particularized properties of six small-to -moderate flares of February 1986 were used to initiate a magnetohydrodynamic simulation (Dryer, Wu, Han model) of the propagation of shocks into the ambient solar wind for these rapidly occurring events. The principal conclusion is that the geoeffectiveness of a disturbance originating at the Sun is amplified by the repetitious recharging of the solar wind's momentum flux and energy content by rapidly occurring flares (on the additional condition of a southward pointing interplanetary magnetic field). Thus a series of small flares may be more geoeffective than a single large flare.

The Solar X-Ray Physics Project clearly sees its tasks for the coming year. Some of the responsibility for the SXI will be handed over to program people experienced in bringing space sensors to the launch pad. Research will continue into energetic solar processes using the full-disk, X-Ray Sensor, Skylab, and Solar Maximum Mission data. Such investigations will assure the readiness of SEL for SXI data in late 1990.

SPACE ENVIRONMENT DATA SYSTEMS DEVELOPMENT

SEL Data Acquisition and Display System

The SEL Data Acquisition and Display System (SELDADS) is a large, distributed processing system that supports the operation of the SESC. It collects the real-time data into data bases, drives displays for the use of the 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 by the National Geophysical Data Center in NOAA's National Environmental Satellite, Data, and Information Service. The original SELDADS I was initially conceived in the early 1970s and grew piecemeal as the needs expanded. Finally, SELDADS I could not accommodate and display all the real-time data, and system reliability had deteriorated. SELDADS I has been replaced by a new system, designated SELDADS II, over the past 2 years. SELDADS II hardware was delivered in 1984 and a phased program of implementing software has been in process since that time. The application software, the portion of the system that serves the staff of the SESC, was developed on the basis of user requirements after extensive analysis of the steps that occur in the solar-terrestrial analysis and forecast process. (See Space Environment Services Center, above.) Software was developed by members of a

SELDADS II Implementation Project composed of personnel from the SEL Services and Systems Support Divisions, and assisted by staff of the SEL Research Division. Data ingest, database operation, displays, listings, product generation, communication interfaces, and access for external users were completed in FY 1986 to the level that permitted operation to be shifted to the new system.

An interface for outside users of SELDADS, primarily those from other government agencies, was developed and implemented during the past year.

Now that SELDADS II is meeting basic SESC needs, attention will be concentrated on enhancing its capabilities beyond those of SELDADS I. The priorities are (1) completion of some operational tools not included in the original system (processing routines that reduce the time spent in assembling data or other tasks that the machine can assume); (2) display of all real-time data available in the data base; and (3) development of new analysis capabilities such as the ones for geomagnetic and solar forecasting that provide numerical guidance in some form. (See Geomagnetic Forecast Development and Solar Flare Forecasting and Analysis Development, below.)

SEL Solar Imaging System

The SEL Solar Imaging System (SELSIS) is a new digital image-handling system developed by the staff of the SEL Systems Support Division, on the basis of requirements for SESC operations. The system is capable of collecting images from suitably equipped solar observatories, storing the images in an on-line system, processing to correct problems of orientation and sizing of the images, and providing CRT displays and hard copy to the SESC forecasters. The system operated in a developmental mode in FY 1986 and provided images but no processing to both the SESC forecaster and the Solar Maximum Mission Operation Center at the Goddard Space Flight Center. Observatories connected into the system include the Air Force Holloman Solar Observatory and the Kitt Peak National Observatory.

A major effort has been the development of the more competent new central display and processing system for SESC. This is based on a commercial color workstation computer and provides image scaling, rotation, and contouring, as well as a laser printer system for hard copies. The system, with this phase 1 capability, will be installed in SESC early in FY 1987, and the software for phase 2, which includes feature recognition, viewpoint translation, and various multiple data presentations will be developed. If budgeting constraints permit, observatory processors will be installed at the Air Force solar observatory at Ramey AFB in Puerto Rico, Big Bear Observatory in California, and Sacramento Peak Observatory to provide additional data sources.

Operational Satellite Instrumentation Project

Data from operational Space Environment Monitors (SEM), which are carried on the NOAA/TIROS and GOES spacecraft, are essential to the operation of the SESC. The provision of instruments for replacement spacecraft and the development of new or improvement of existing instruments for spacecraft is, therefore, an important supporting activity.

Instruments are normally produced by contractors (or subcontractors) to NASA, which in turn supplies NOAA with the entire operational satellite. SEL sets the requirements for the SEM system and assists with the technical supervision of the instrument contractor. When necessary, SEL also repairs and recalibrates instruments that are awaiting flight.

In FY 1986 the Medium Energy Proton and Electron Detector (MEPED), which was launched on NOAA-10 in September, was checked and requalified before delivery to the spacecraft contractor. The performance of SEM on NOAA-10 will be checked out after the instrument is turned on in FY 1987.

GOES-I and its SEM were lost owing to a failure of the Delta launch vehicle. The existing SEM systems on GOES-5 and -6 are now showing some degradation due to radiation damage to the solid state detectors in the Energetic Particle Sensor (EPS). Steps were taken to correct the data and to minimize the effects of the damage by maintaining detector bias during eclipse periods. The new SEM, which will be launched on GOES-H later in FY 1987, will provide a new system to replace that on GOES-5 which has been in orbit for 5 years.

In February 1986 NASA formally asked the Laboratory to manage the procurement of the three SEM systems, which will be required for the proposed NOAA-K, -L, and -M follow-on spacecraft. A Technical Advisory Committee has been set up and the technical specifications completed. The Source Evaluation Board for the procurement has been appointed and is expected to meet and finalize the Request for Proposals early in FY 1987.

SEL has supported the GOES-Next (I-M) program by taking part in the Preliminary Design Reviews for the new SEM instruments needed for the three-axis stabilized spacecraft. The continuing effort to provide an operational Solar X-Ray Imager as part of the new GOES series was supported with analysis of the proposals for the imager from potential instrument contractors, and the spacecraft contractor's accommodation studies.

Ongoing data quality control is essential if the data from the operational sensors are to be reliable for operational use. Under the SELDADS I system, detailed quality control and evaluations could only be done on the off-line Cyber system, because of the limitations on the real-time processing. With SELDADS II this limitation no longer exists in such an extreme form and a new automated data quality review system is being implemented to run in near-real time on SELDADS II. This system abstracts instrument calibration data and spacecraft housekeeping into a separate engineering file, which will be analyzed daily. Summary outputs will provide data on any apparent changes in instrument performance or significant trends. The system is now in experimental operation on SELDADS II.

TECHNIQUE DEVELOPMENT

Geomagnetic Forecast Development

Approximately two-thirds of the SESC users are primarily concerned with disturbances in the Earth's geomagnetic field. Providing data and forecasts to serve these users is complicated by problems of understanding the complexities of the Sun-Earth connection and in specifying the nature of a geomagnetic disturbance to users in various areas, since the characteristics vary from region to region over the surface of the Earth. An intensive effort to improve the geomagnetic services has been developing over the past 2–3 years. In FY 1986, a focus of the effort was a Workshop on Solar Effects and Their Influence on the Interplanetary Medium funded by NASA and SEL. The Workshop brought together members of the international research community with the goal of establishing the current state of knowledge in linking solar activity to disturbances in the interplanetary medium and identifying areas of research to improve the level of understanding. Ninety-four scientists, including representatives from Argentina, Germany, Japan, France, Scotland, Greece, China, and the United States attended and identified areas of consensus and disagreement with regard to the physical connections between solar flares and other eruptive events, coronal mass ejections, and then interplanetary events. The Workshop will reconvene in March 1988, to determine progress on issues of contention.

Another prospective source of improvement to forecasts is the provision of climatological information on geomagnetic activity to duty forecasters. "Climatology" refers to an analysis of prevailing conditions (typically weather) at specified locations. During FY 1986, several projects on geomagnetic climatology and forecasts were completed under a consulting agreement with John Flueck of NOAA/ERL/ESG and CIRES student Timothy Brown. They first computerized the daily A and 3-hourly geomagnetic K-indices from 1957–1985 for geomagnetic observatories located at Fredericksburg, Virginia, and College, Alaska. (The K-index, an integer from 0 to 9, is a quasi-logarithmic indicator of geomagnetic activity: 0 is very quiet and 9 is severely disturbed; eight K-indices are measured each day in consecutive 3-hourly periods.) Next, they analyzed each data set to produce a matrix and plot of the percent occurrence of the 10 possible K-indices for each 3-hour period during the day. This "climatology" documents the diurnal pattern in magnetic activity at the two locations, and

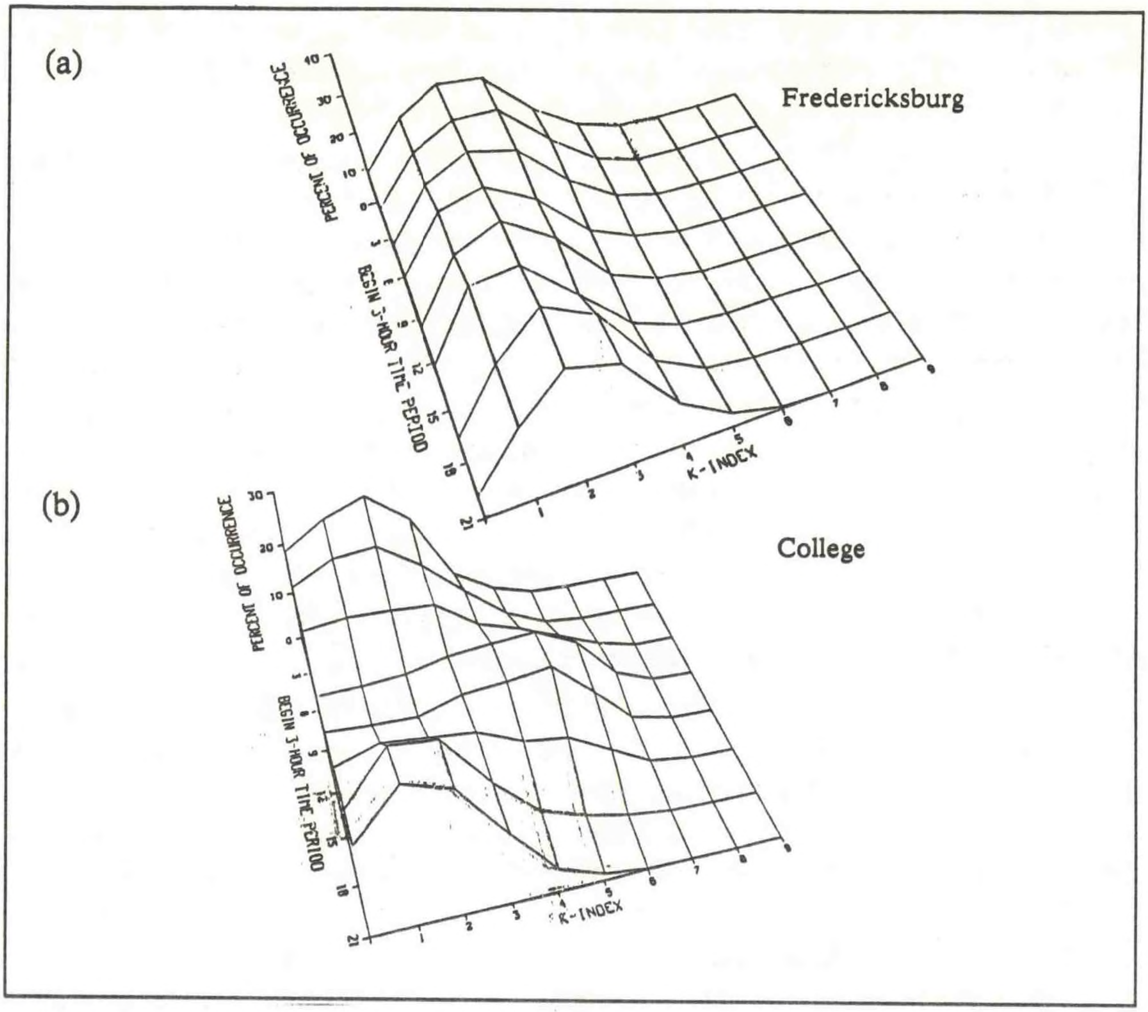

Figure 7.—K-index percent of occurrence for 29 years of K-index data (1957–1985) from Fredericksburg, Virginia (a), and College, Alaska (b). Because average conditions are likely to predominate, climatology is a rudimentary forecast of expected geomagnetic conditions. This analysis shows the most likely level of geomagnetic activity (the K-index) as a function of Universal Time. The apparent vertical axis displays the percent of occurrence for each K-index and each 3-hour period. The values for 0000–0300 UT are plotted at 0 and the values from 2100–2400 UT are plotted at 21. At Fredericksburg, a K-index of 2 is prevalent throughout the day. At College, a distinct average diurnal variation is seen; quiet levels are much more common near 0000 UT; disturbed levels (K's of 5, 6) prevail near 0900–1500 UT.

provides a baseline geomagnetic forecast for general customer use and our own verification purposes. The differences between the climatologies for Fredericksburg, a middle-latitude station (Figure 7a), and College, a high-latitude station (Figure 7b), show that proposed forecasts for College must take into account physical processes that are significantly different from those operable at middle geomagnetic latitudes. Flueck and Brown also produced smoothed "frequency of occurrence" plots for each possible K-index as a function of time that show some unexpected and interesting cyclical patterns. These patterns may be usable in a statistical forecasting scheme of quiet and active periods. As a result of this work, continuing projects have been proposed to refine methods of producing climatic geomagnetic forecasts and forecast verifications, and to investigate alternate descriptions of ground-based and satellite geomagnetic data.

From August 1, 1984, through July 31, 1986, SEL supported Meiqing Gao, a CIRES Professional Research Assistant from the Institute of Geophysics, Academia Sinica, Beijing, P.R. China. She worked primarily with Jo Ann Joselyn of the Space Environment Services Division. During FY 1986, her work concentrated on a comprehensive study of solar flares and geomagnetic storms. The first task was to identify all geomagnetic storms of the current solar cycle through 1984 using Dst data. (The Dst index is an hourly, global geomagnetic index that measures the magnitude of magnetospheric ring current.) The next step was to associate appropriate M- and X-class (peak amplitude) x-ray flares with those storms. Her conclusions, which differ from previous work for a shorter time scale, were that there is no preferred flare heliolongitude for storm occurrence or storm magnitude, and there is no heliolongitude effect in the time delay between flare beginning and storm beginning.

Additional work on the relationship between major (X-class) solar flares and geomagnetic storms was done by the SEL staff. The conclusions were that most of the largest flares of solar cycle 21 did not result in geomagnetic storms. For flares with solar wind data available 1–3 days after the event, three approximately equal categories emerged: a flare-associated disturbance arrived at the Earth with a southward interplanetary magnetic field (IMF) component and a storm ensued; a flare-associated disturbance arrived with a northward IMF and no storm ensued; and no flare-associated interplanetary disturbance arrived at the Earth. An additional finding was that approximately two-thirds of the storms associated with X-class flares had an SSC (sudden storm commencement) signature, which is presumed to be the result of a flare-generated shock propagating in the solar wind, whereas only approximately one-third of the X-class flares not producing a storm produced a shock signature (sudden impulse) at the Earth.

At 1 AU a solar sector boundary (SSB) is recognized as a zone of transition between large-scale sectors of solar wind, each sector characterized by a predominant interplanetary magnetic field pointing roughly either toward or away from the Sun. The boundary is a warped heliospheric current sheet that surrounds the Sun. The solar wind in SSB regions has unique characteristics (slow, dense, cool) and it was conjectured that the SSB presents a barrier, of sorts, in the interplanetary medium. Thus, a study of the effect of the SSB on the magnitude of flare-associated geomagnetic disturbances concluded that geomagnetic disturbances associated with flares on the same side of the current sheet as Earth were larger than those associated with flares on the opposite side. In sharp contrast, a study by Joselyn of large flares not associated with

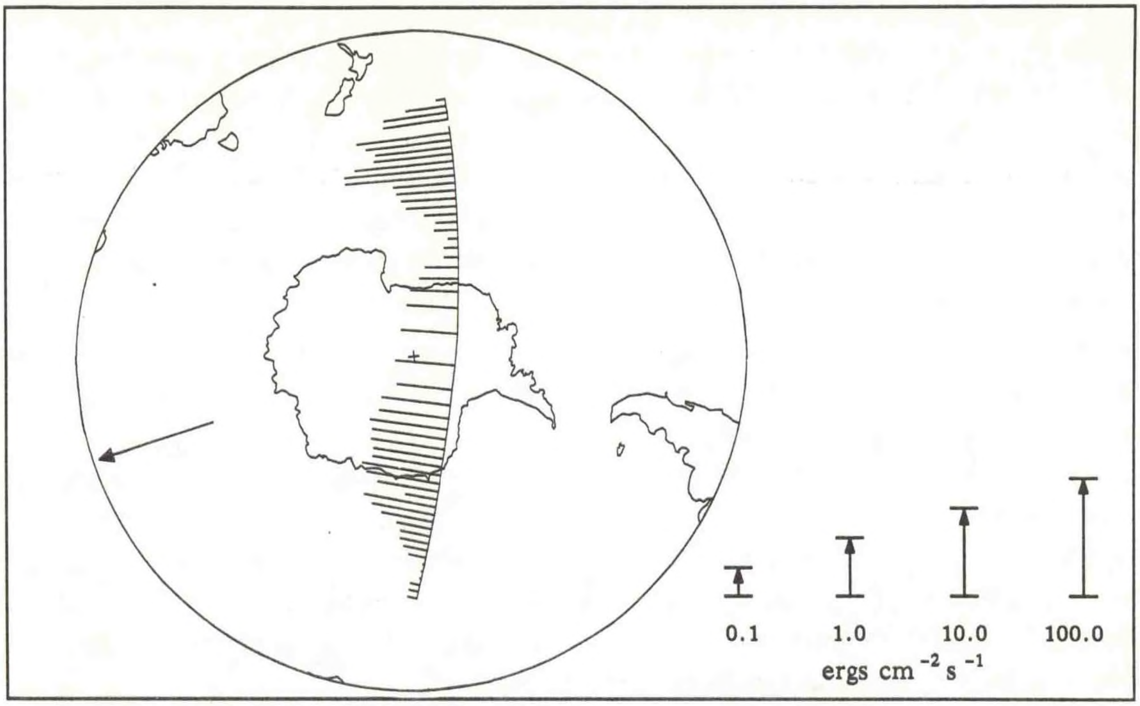

Figure 8.—Southern Hemisphere auroral particle energy influx pass (NOAA-6) started at 0647 UT on April 1981, ended at 0713.

geomagnetic storms showed that the presence of an SSB between the flare site and the Earth was not a factor in explaining the lack of geomagnetic storm effects.

Two projects were initiated to define new analysis and display capabilities for SELDADS II. These will be implemented as part of the program for an expanded SELDADS II that goes beyond previous capabilities for forecasting and analysis. The first is a display of the NOAA polar-orbiting satellite Total Energy Deposition (TED) data. The NOAA precipitating particle data are used to calculate (1) the average energy input in each 1° of magnetic latitude along the satellite track above 45°, (2) the estimated total hemispheric energy input in gigawatts, (3) the Auroral Activity index (a number ranging from 1 to 10 scaled from the total hemispheric input), (4) the geographic latitude of each equatorward auroral boundary, and (5) the Q-index, an algorithm used by the Air Force Global Weather Center as an alternative estimate of the equatorward auroral boundary. The display is illustrated in Figure 8, a map of Earth for a single satellite orbit in geographic coordinates of the South Pole. The map shows the following: an arrow pointing to the Sun (local noon), the satellite track, and the average total energy deposition for each 1° of geomagnetic latitude plotted as a log-scaled line perpendicular to the satellite track (each line is centered in its 1° bin). Visual overhead aurora occurred (assuming dark sky) along the satellite track where precipitating energy flux exceeded 1 erg cm^{-2} s^{-1}. Aurora may be visible to an observer displaced 4°–5° of latitude away from the band of auroral precipitation. There are additional displays that may be superposed on the primary display described above. These include the statistical patterns of energy deposition determined by the Auroral Activity index (which then extrapolates the satellite track data to all longitudes), and an indication of the sunrise-sunset terminator at ionospheric altitudes. Even more displays, such as joule heating or atmospheric density calculations, are under development.

The second project is a geomagnetic analysis procedure, which will first make use of the geomagnetic climatology developed by Flueck and Brown. Forecasters will eventually be guided into probability forecasts of six levels of geomagnetic conditions for two zones of geomagnetic latitude, instead of the A-index forecasts (the A-index is a daily number ranging from 0 to 400) now issued for a middle-latitude station. This change in forecasting format will allow meaningful verification procedures. As guidelines are developed for forecasting geomagnetic activity from solar phenomena (e.g., solar flares or coronal holes), they will be implemented as forecaster advice.

Every two years, the International Union of Radio Science (URSI) produces a "Review of Radio Science" for that biennium. The chairpersons of each of the international URSI commissions invite contributors to their sections of the report. The Review for 1984–86 is in preparation, and Kenneth Harker, Chairman of the U.S. Commission H (Waves in Plasmas), selected Jo Ann Joselyn to write the section on Data Analysis and Image processing for forwarding to the U.S. Committee. After it is edited, the U.S. report will be combined with those of other administrations to produce the final International Review.

Solar Flare Forecasting And Analysis Development

Development activities aimed at improving solar flare forecasts include the Theo expert system (described later) and independent work on developing an index to measure magnetic field "shear," caused by the relative motion of sunspots or other strong magnetic fields in the surface of the Sun. These are believed to be the means of storing energy for solar flares. The work uses the solar magnetograph at NASA's Marshall Space Flight Center, and is being done in cooperation with the U.S. Air Force.

A method of providing numerical guidance for solar flare forecasts was developed in a large study completed previously in cooperation with the Air Force Geophysical Laboratories and the National Bureau of Standards. Implementation of the model in SELDADS II began in FY 1986. The observatories in the Air Force SOON system will compile a set of parameters for each active region on the Sun. The parameters have been tested and shown to be most significant in predicting solar flares. Data from the SOON will be provided to SESC on a regular schedule several times per day. They will be used to drive a numerical model that will provide continuous guidance to the duty forecaster. Tests showed the model to have a forecasting skill approximately equal to that of the regular SESC forecasters while it operated with less-than-ideal data. It is dynamic in that it can be updated regularly with results of the most recent observations and forecasts. The operating version will probably be updated in this manner annually, thus providing guidance adjusted for the phase (or season) of the 11-year solar cycle. Other work will include development of a test for measuring a solar-active region shear index that may be useful in flare predictions.

Radio Propagation Forecast Development

Agreement has been obtained with the National Technical Information Agency for the Space Environment Laboratory to issue a daily propagation "nowcast" and forecast to civilian high-frequency radio users. Arrangements are being made to start issuing this information early in calendar year 1987. To begin, the service will be that prepared for military users by the Global Weather Central of the U.S. Air Force. The response of the ionosphere to a disturbance depends on latitude and local time. Hence the northern hemisphere is divided into five latitude zones and four longitude zones (each 90° wide).

This service consists of simple codes conveying (1) observed conditions and (2) a forecast. The observed conditions are reported on a relative scale by one of three letters, N (normal), U (usable), and W (unusable); the expected conditions are described on a scale from 1 (useless) through 9 (excellent). The report will include a summary of sudden ionospheric disturbances, specifically shortwave fadeouts, during the previous UT day. The report will be made available to the public by means of a microcomputer bulletin board.

Total Electron Content

The total electron content (TEC) along a radio path between a satellite and a ground receiver is an important ionospheric parameter. For example, it determines the excess time delay of radio signals and the angular refraction. The total electron content is obtained from measurements of the Faraday rotation of the electric field of a radio wave. Measurements of TEC at Boulder provide perhaps the most representative ionospheric parameter for the continental United States and have been made at the Table Mountain Observatory for more than 10 years using signals from the GOES-3 geostationary satellite. Over these years there has been deterioration in the receiving equipment. During 1986 some refurbishing of the equipment at TMO was carried out, and the output will be calibrated against similar data obtained in 1974–1975 using carefully calibrated signals from the ATS-6 radio beacon experiment.

Development Of Expert Systems—Theo

Knowledge-based "expert systems" attempt to capture on computer the knowledge of a human expert in a limited domain and make this knowledge available to a user with less experience. Such systems could be valuable as an assistant to a forecaster or for training purposes. SEL has continued to work cooperatively with the Computer Sciences and Psychology Departments of the University of Colorado in Boulder to develop the expert system for sunspot classification and solar flare forecasting, which was started as a pilot project in FY 1985. This system is known as Theo, after Theophrastus, an ancient Greek scholar who is credited with having been the first to observe sunspots. Within SEL this work is a joint effort between the Solar Physics project, and the Systems Support and Services Divisions.

Theo has been integrated with a data base so that previous history is always available to the forecaster, and the structure of the program has been improved. Improvements to the user interface and the ability of the system to explain its logic and data base make the system easy for novice forecasters to use. A default version of the system was developed to make it possible to produce a conservative forecast with incomplete data direct from the computer database without requiring interaction from a user. This enables Theo to run very quickly, giving rapid advice to a forecaster in circumstances when operational activity prevents detailed analysis. The default version produced a complete forecast in less than 5 minutes even on a day with 15 groups of sunspots and many large flares. Work is now under way to extend the verification testing and better understand the differences in performance between Theo and the human expert, which it emulates.

The prototype expert system was deliberately confined to a narrow range of knowledge to facilitate quick completion of the prototype. It was recognized that an operational version of the expert system eventually must use all the data normally analyzed by the real-time forecast system. Expansion of the knowledge base to include observations of the solar chromosphere in the Hα line began. The Hα observations will permit much-improved inference of magnetic topologies in active regions, perhaps simplifying those rules now in Theo that attempt to discover magnetic conditions from sunspots. Preflare situations can involve active regions with few or no sunspots. The expanded knowledge base will handle those situations. The addition of new magnetic flux to an existing active region is an important preflare condition and is clearly discerned with Hα observations. The sunspots are often too subtle in giving early warning of this condition.

The developmental system has been made available within SESC on a workstation computer and has been used for training and demonstration purposes. In principle it is available for experimental operational use, although solar activity has been so low for most of the period that its application has been very limited.

In the near future a more rigorous verification test of Theo's ability, compared with the human expert and with the SESC actual performance, will be completed. This will complete the data needed for publication of the results achieved by the initial prototype system.

Development of Scientific Workstations

With the development of high-performance, 32-bit microprocessors and high-resolution graphics systems, it is now feasible to place a workstation at a scientist's desk to be the single point of contact for all computational and graphical display needs. The local computational capability provides rapid source code editing and debugging. Networking to other workstations and to the DoC mainframe scientific computer system provides the power for major computations and the capability to return the results for graphical display and manipulation.

During FY 1986 the SEL network of workstations was expanded by the delivery of five monochrome workstations, which brought the total number of stations in the network to nine. Seven of these have computational capabilities approximately equal to a VAX 11/780. Network connections were installed to the DoC Cyber mainframe system and to the operational SELDADS system.

The graphics support available to scientific users was enhanced by porting the SEL DPLOT device-independent graphics software to the workstation system. DPLOT makes it much easier for a scientific programmer working in FORTRAN 77 to use the power of the workstation graphics and makes it possible to move graphics applications between the Cyber mainframe, the operational MV10000 SELDADS system, and the workstations, while choosing from a variety of output devices. Applications developed using this package ranged from graphical output of interplanetary disturbance models to verification of SESC forecast performance and display of operational satellite data. Use of the workstations was also applied to development of the knowledge-based expert systems and to magnetospheric modeling.

A commercial software package and laser printer system was added to the workstation system to provide publication-quality text and graphics. A DPLOT driver was developed. The complete system is now employed in SEL for scientific papers, for which it provides mathematical equation support, and also for presentation material and the SESC weekly publication.

If budgeting constraints permit, next year the system will be expanded to make workstations more readily available to a greater number of research and development staff.

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Davies, K., "Scintillation patterns produced by multiple diffracting lenses in the ionosphere," URSI Working Group G-12 International Beacon Satellite Symposium on "Radio Beacon Contributions to the Study of Ionization and Dynamics of the Ionosphere and Corrections to Geodesy," Oulu, Finland, June 9–14, 1986.

Gao, M., "A Study of the Heliolongitudes of Flares Potentially Associated with Major Geomagnetic Disturbances," 1986 Spring AGU Meeting, Baltimore, Maryland, May 19–23, 1986.

Garcia, H. A., "Solar Flares and the Intense Geomagnetic Storm of February 1986," 168th American Astronomical Society Meeting, Ames, Iowa, June 22–26, 1986.

Garcia, H. A., "An Analysis of Flare Properties by Observed Temperature and Emission Measure Profiles," Committee on Space Research (COSPAR) XXVI Plenary Meeting, Toulouse, France, July 1–12, 1986.

Grubb, R. N., "Apollo Domain as a Scientific Researchers Workstation System," Apollo DOMAIN Users' Society Conference, Chicago, Illinois, March 24, 1986.

Grubb, R. N., "Theo—A Solar Flare Forecaster's Assistant: Expert Systems on the Apollo Domain," Apollo DOMAIN Users' Society Conference, Chicago, Illinois, March 25, 1986.

Heckman, G. R., "How Solar Data Are Used by NOAA-SEL in Predictions—What are the Most Critical Data Bases?," Long-Term Observations Panel, Boulder, Colorado, February 25, 1986.

Joselyn, J. A., "Solar Sector Boundaries," SESC Lecture Series, Boulder, Colorado, October 25, 1985.

Joselyn, J. A., "Do Solar Sector Boundaries Influence the Geoeffectiveness of Solar Flares?" 1986 Fall AGU Meeting, San Francisco, California, December 11, 1985.

Joselyn, J. A., "Short-Term Predictions of Geomagnetic Activity," Sixty-Second Annual Meeting of the Southwestern and Rocky Mountain Division of the American Association for the Advancement of Science, Boulder, Colorado, April 3, 1986.

Joselyn, J. A., "Are Homing Pigeons Affected by Geomagnetic Disturbances," Rocky Mountain Flyers Club, April 12, 1986.

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Martin, R. F. Jr., "Chaotic Dynamics Near a Magnetic Neutral Point," 1986 Fall AGU Meeting, San Francisco, California December 10, 1985.

Martin, R. F. Jr., "Numerical Simulation of Magnetospheric Plasma," SEL Lab Review, Boulder, Colorado, May 15, 1986

Martin, R. F. Jr., "Chaotic Dynamics Near a Magnetic Neutral Point," Naval Research Lab, Washington, D.C., May 23, 1986.

Martin, R. F. Jr., "The Magnetosphere and Aurora," Eastern Illinois University, Charleston, Illinois, July 2, 1986.

McIntosh, P. S., "Knowledge Acquisition for the Theo Expert System," Workshop on Artificial Intelligence Research in the Environmental Sciences, Boulder, Colorado, May 28, 1986.

Poppe, B. B., "From Micro to Apollo With Text for Publication," Apollo DOMAIN Users' Society Conference, Chicago, Illinois, March 25, 1986.

Reddy, B. M., "Predictions for Tropospheric Communications," Informal SEL Seminar, Boulder, Colorado, March 19, 1986.

Reddy, B. M., "Ionospheric Research Needed for Future Communications Systems," Informal SEL Seminar, Boulder, Colorado, March 19, 1986.

Wagner, W. J., "Proton Flare Radiation Hazards for Polar Missions and Their Mitigation by Solar X-Ray Imagers," Office of the Command Surgeon, USAF Space Command, Peterson AFB, Colorado, January 13, 1986.

Wagner, W. J., "Solar X-Ray Imagers on GOES I-M: A Technical Convergence of Agencies in Space Environment Services," Directorate of Astrodynamics, HQ USAF Command, Peterson AFB, Colorado, January 13, 1986.

Wu, S. T., "Simulation of Disturbed Solar Wind in Three Dimensions," Symposium on Heliospheric Study, Hamana, Japan, December 4-6, 1985.