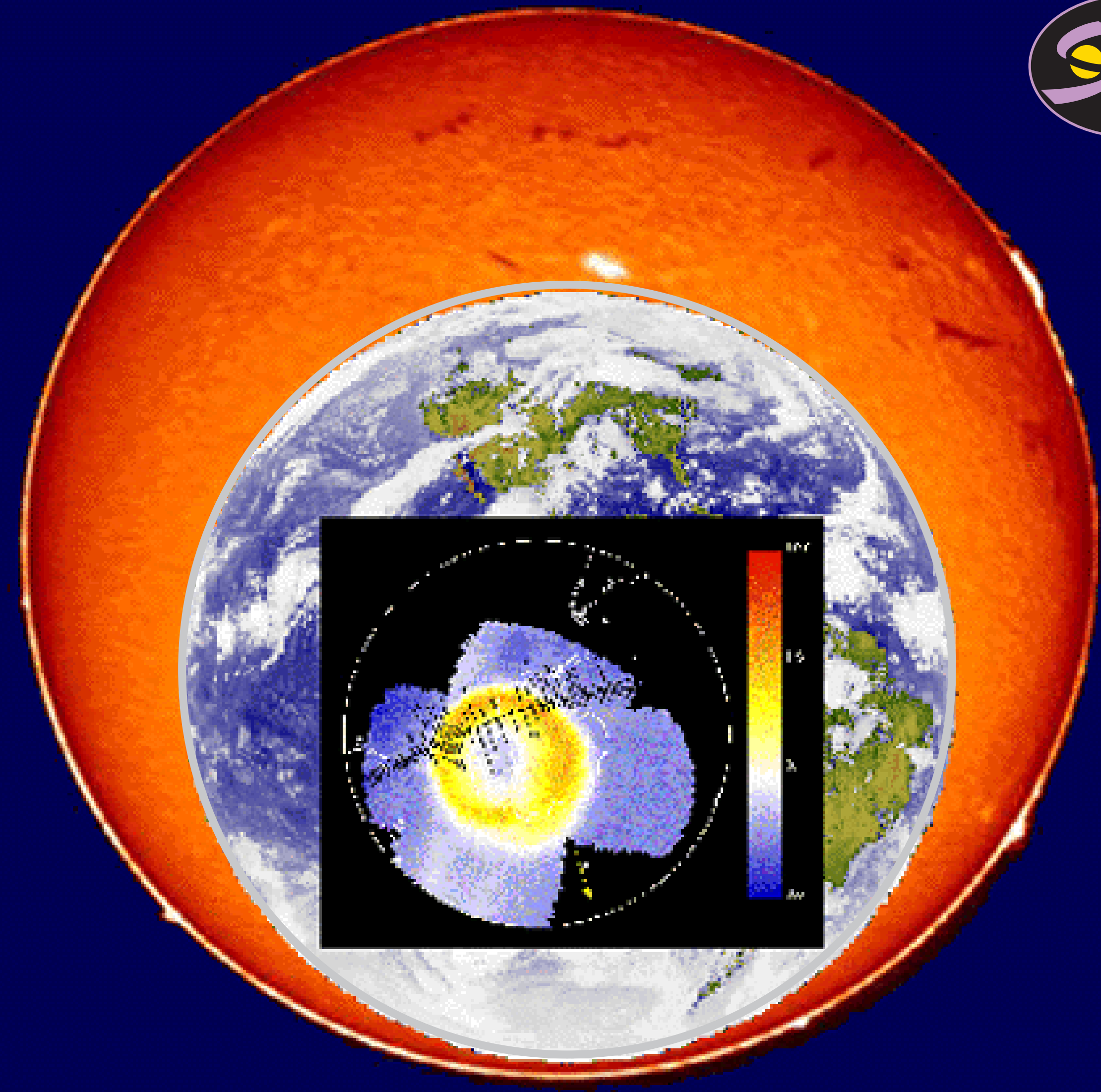


Space Environment Center 1996–1997

U.S. Department of Commerce

National Oceanic and Atmospheric Administration

Environmental Research Laboratories
National Centers for Environmental Prediction

January 1998

As the Sun sets behind the mountains of Boulder, Colo., our telescope captures an enthusiastic SEC worker in silhouette.

Cover: Our sun, the driver of our space weather, influences Earth in many ways, one of which is to cause aurora. The inset map shows the auroral oval, as revealed in measurements of energetic particle precipitation along the track of a NOAA spacecraft orbiting over the north pole on a moderately active day. Auroral plots like these—and others—are produced daily and posted on SEC's Web site: **http://sec.noaa.gov**

SEC's Mission

The Space Environment Center is the Nation's official source of space weather alerts and warnings. The Center continually monitors and forecasts Earth's space environment; provides accurate, reliable, and useful solar-terrestrial information; and leads programs to improve services.

To serve the Nation and reduce adverse effects of space weather disturbances on human activities:

- SEC synthesizes and disseminates information about past, present, and future conditions in the space environment for space weather users and private industry vendors; we prepare the data we acquire for the national archive.
- SEC leads in development and implementation of programs in solar-terrestrial physics and space environment services by conducting research and developing techniques that improve monitoring and forecasting.
- SEC uses its expertise to advise and educate those who operate systems affected by disturbances in the space environment and those who have a general interest in our science.

A Message from the Director

The accomplishments highlighted in this report occurred during a time of solar activity minimum; our plans should be seen in the context of the approaching maximum of solar and geomagnetic activity. At the same time activity is rising, there is a considerable increase in the number of spacecraft and other systems vulnerable to space environment events. Space Environment Center (SEC) has selected five major themes (noted on the next page) that are discussed in detail in the first half of this report.

Media and popular interest in space weather are higher now than they were at a comparable time in the previous solar cycle. SEC staffers will continue their efforts to educate potential customers and the public about space weather and its effects on man-made systems.

The year 1996 saw the National Space Weather Program Implementation Plan published, providing a guide for inter-agency activities that will lead to improved services for space weather customers. SEC completed its triennial review where the reviewers gave critical and helpful advice and affirmed that SEC is on the right track overall. A number of new hires (especially in the Research and Development Division) strengthened the Center.

The year 1997 was marked by several successful partnerships: the Advanced Composition Explorer (ACE) Real-Time Solar-Wind effort, the delivery of the Solar X-ray Imager to the spacecraft integrator, and a Cooperative Research and Development Agreement (CRADA) are all detailed in this report. SEC was also reorganized into a structure that recognizes how major activities are actually carried out.

It appears (currently) that SEC will experience very slight growth in FY98 and FY99. The pace of change for SEC's activities will accelerate as SEC attempts to better serve its customers and to better understand the space environment. New data, new models, new understanding, new services, and a variety of opportunities lie ahead, and the excitement is building toward solar activity maximum.

Dr. Ernest Hildner, Director

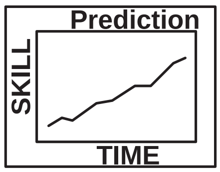
Space Environment Center
325 Broadway
Boulder, CO 80303
303–497–3311, Fax 303–497–3645
ehildner@sec.noaa.gov

Space Environment Center

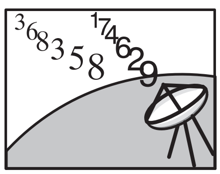
Welcome to Space Environment Center

Themes in SEC Activities

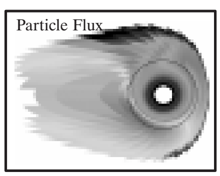
Augment Operations



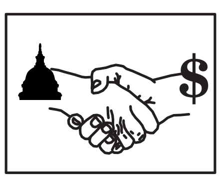
Acquire and Use New Data



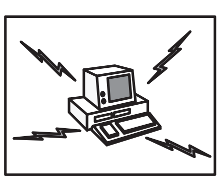
Utilize Numerical Models



Foster a Space Weather Services Industry



Modernize Data Handling and Information Dissemination



Who we are and what we do

The Space Environment Center (SEC) occupies a central position in the space weather community. A component of the NOAA Environmental Research Laboratories in Boulder, Colo., SEC is also one of the National Centers for Environmental Prediction of the NOAA National Weather Service.

The Space Weather Operations (SWO) Division at SEC operates the national and world warning center for disturbances in the space environment that can affect people and electronic equipment. The 55^{th} Space Weather Squadron of the U.S. Air Force in Colorado Springs, Colo., provides services to U. S. military customers, and works closely with SWO. SWO is jointly operated by NOAA civilian employees, uniformed NOAA Corps staff, and U.S. Air Force personnel.

SEC also conducts research in solar-terrestrial physics, develops techniques for forecasting solar and geophysical disturbances, transitions academic research—including numerical models—into operations, provides real-time monitoring and forecasting of solar and geophysical events to customers, and prepares data to be archived by NOAA National Geophysical Data Center. It often provides advice on solar-terrestrial phenomena, and their adverse effects to government agencies and industry associations. Research scientists at SEC are working toward a better understanding of the Sun-Earth connection by studying solar electromagnetic, particle, magnetic-field, and plasma emissions and the processes that affect the space environment around Earth.

Cooperative ventures also abound at SEC, as graduate students, post-doctoral students, visiting scientists, Cooperative Institute fellows from the University of Colorado, contractors, and private-sector partners all contribute to the vibrant atmosphere of SEC.

Contents

Solar Cycle 23

The Background Tapestry for Space Weather Services

The near-Earth space environment responds directly to the general level of activity on the Sun. During solar minimum, the neutral atmosphere settles down to its smallest scale-height, and geomagnetic disturbances are few and occur months apart. During times of maximum solar activity, the scale-height of the neutral atmosphere expands so that the density at satellites in low Earth orbit is at least double that at minimum, the magnetopause is more frequently pushed inside geosynchronous orbit (about 6.6 Earth radii), and geomagnetic storms occur several times each month. The scale of these effects correlates with the overall magnitude of the solar cycle, as measured either by smoothed sunspot number or the 10.7-cm solar radio flux. Because of these cyclic effects, predictions of solar and geomagnetic activity are of interest to people involved in a variety of activities, including the operation of low-Earth orbiting satellites, electric power transmission grids, geophysical exploration, and high-frequency radio communications and radars. More specifically, the height of Earth's upper atmosphere (and thus the drag on satellites in low Earth orbit) is dependent on the intensity of short-wavelength solar radiation and the level of geomagnetic activity. Knowledge of the profile and magnitude of the next solar and geomagnetic cycle is then crucial, for example, in logistical planning for reboosting the Hubble Space Telescope, and for assembly of the International Space Station.

The general trend in recent solar and geomagnetic activity cycles (Figure 1) is toward larger amplitude sunspot cycles; Cycle 19 was the largest in recorded history (smoothed sunspot number maximum of 201 in March, 1958), and Cycle 22 was the third largest (smoothed maximum of 159 in July, 1989). Cycles 21 and 22 both showed annual averages of geomagnetic activity that were large in comparison with most cycles in the record of *aa* indices (Figure 1). The dramatic variability from one cycle to the next in these sunspot and geomagnetic records shows the difficulty in making empirical predictions of both types of activity. The issue is further complicated by the lack of a successful quantitative, theoretical model of the Sun's magnetic cycle.

In September 1996, before the end of Solar Cycle 22, an international panel of 12 scientists met at Space Environment Center, thanks to financial support from NASA, to consider 28 collected predictions of the profile and amplitude of Cycle 23 solar and geomagnetic activity. The panel's consensus prediction is shown in Figure 2, and is based on a determination that the onset of Solar Cycle 23 began in October 1996. Figure 2 also shows the progress of the current solar cycle through May 1997. Solar Cycle 23 is predicted to reach a maxi-

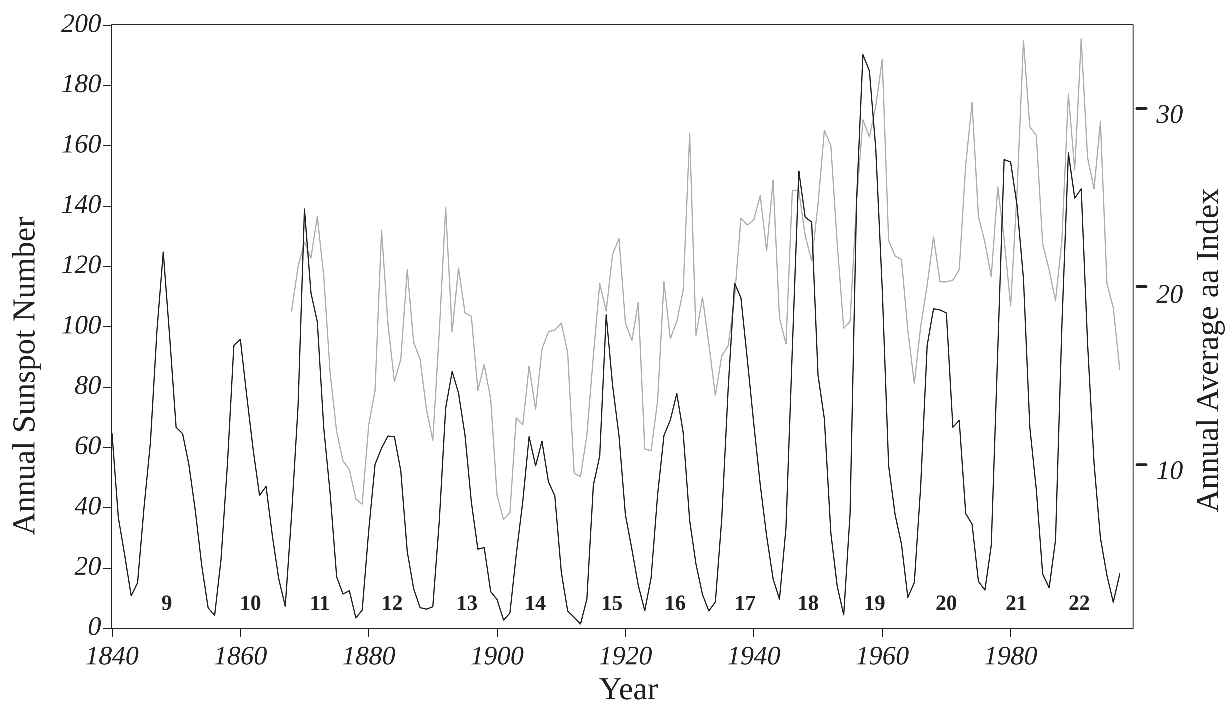


Figure 1. Annual sunspot numbers, 1840−1997 (black line; cycles are labeled with their associated numbers), and annual average aa *geomagnetic index, 1868−1997 (grey line).*

mum smoothed monthly sunspot number near 160 (between the values of 130 and 190) in March, 2000 (between June 1999 and January 2001). The corresponding prediction for the 10.7-cm solar flux is approximately 205 solar flux units* (between 175 and 235 sfu). This projects a solar cycle which is comparable to the last two cycles, but which is unlikely to exceed Cycle 19, the largest cycle on record.

Because many of the technological effects of solar activity depend on resulting disturbances of the geomagnetic field, the panel also pioneered a prediction of the approximate total number and annual number of significant geomagnetic disturbances expected during Cycle 23. Two types of forecasts were investigated: a climatological approach based on the 128-year record of the *aa* index, and a precursor approach that used the counts of disturbed days based on the *Ap* index, an index which has been archived since 1932. The two indices are similar since both are based on the daily summaries of the 3-hourly *K* indices derived at a network of geomagnetic observatories. The *aa* index is based on the observations at two nearly antipodal observatories (Canberra, Australia, and Hartland, United Kingdom), and is expressed in nanoteslas (nT). The *Ap* index, expressed in units of 2 nT, is derived from a larger network of geomagnetic stations that includes the *aa* observatories. A quantitative comparison of the two indices reveals that the conversion between them is on the order of $Ap \approx 0.8\ aa$. This conversion factor is taken into account in the results presented in Table 1. Both methods predict that the level of upcoming geomagnetic activity will be near the levels experienced in Cycle 22, and imply high levels of activity during the years 1999–2005.

* Solar flux units, (sfu) = 10^{-22} W/m^2

Table 1: Expected total numbers of disturbances during all of Cycle 23.

Geomagnetic Index and Threshold	Number of occurrences predicted by each approach: Precursor	Climatology
Ap ≥25; aa≥31	595	932
Ap ≥40; aa ≥50	228	301
Ap ≥50; aa≥62	133	153
Ap ≥80; aa≥100	44	29
Ap ≥100; aa≥125	23	18
Ap ≥200; aa≥250	2	2

Ap is expressed in units of 2 nT; *aa* is in units of nT.

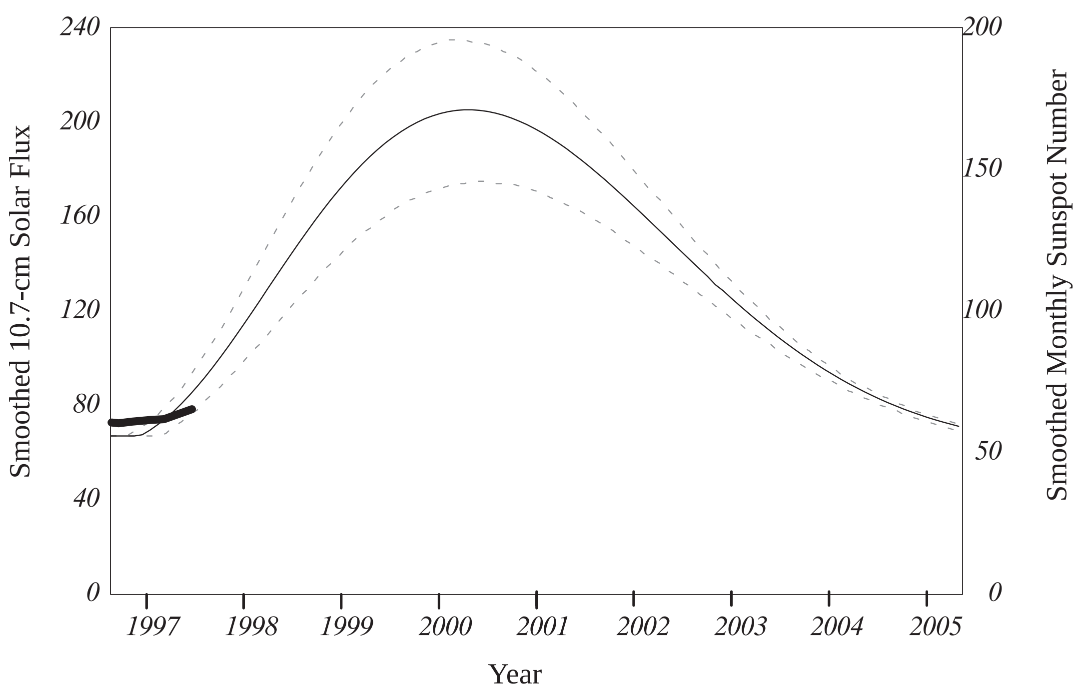
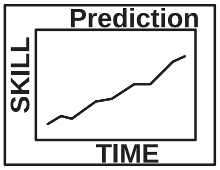


Figure 2: The estimated Cycle 23 profile of smoothed 10.7-cm solar flux and sunspot number, with lower and upper limits as dashed lines. Actual 13-month running-mean smoothed data values are plotted through May 1997 (thick line).



Augment Operations

Severe space weather events—variations of electromagnetic fields and energetic particles—can have adverse effects on human activities. Increased reliance on technology has increased our susceptibility to severe space weather. The Space Weather Operations (SWO) center at SEC provides real-time space weather services. This center, staffed by NOAA civil servants and uniformed members of the NOAA Corps and the U.S. Air Force (USAF), synthesizes a characterization on the current state of the space environment, predicts solar-terrestrial conditions, and disseminates information including timely notification of space weather disturbances. This information helps operators of affected systems take action to reduce the impact of space weather, to plan activities sensitive to solar-terrestrial conditions, and to diagnose system problems.

SWO operates 24 hours a day, 7 days a week, maintaining an up-to-the-minute watch on storms and disturbances in the solar-terrestrial environment. Forecasters are currently on duty from 8 a.m. to 6 p.m. MST, while the Solar Technicians are on-site 24 hours per day. Forecasters synthesize the more than 1400 near-real-time space weather data sets at SEC to form a coherent picture of the space environment, develop space weather products and predictions, and help users analyze space weather related problems. Solar Technicians monitor the space environment, ensure continuous computer and communications operations, respond to user requests, disseminate products, and issue the real-time alerts and warnings. In addition, staff are stationed at solar observatories in the U.S. and Australia. These observers collect and analyze solar observations and forward real-time reports and data to SWO.

The primary purpose of SWO is to provide real-time and predictive assistance to operators, managers, users, design engineers and researchers working on systems affected or influenced by space weather. Customers include a diverse spectrum of military, government, private industry and the general public. Forecasts and real-time information are of vital importance to users and owners of satellites, communication companies, navigation systems, power and pipe lines, and high altitude/high latitude aircraft. Customers range from the NASA Space Radiation Analysis Group, which needs current and predicted space weather information to assess crew and payload radiation levels during NASA Space Shuttle missions, to satellite operators who need advisories of severe space weather which may harm their spacecraft, to radio operators who need space weather indices for predicting radio propagation.

To better understand and improve user needs, SEC routinely solicits input and feedback from users. This information is used to improve space weather products and services. Products are disseminated through several different delivery systems. Accuracy and timeliness are the most critical requirements placed on the service. These are routinely monitored through formal quality control and verification programs.

The Space Weather Operations center is staffed with a forecaster and a solar technician, and is staffed 24 hours a day.

Service improvements (1996–1997)

Many aspects of space weather follow the 11-year sunspot cycle. The new solar cycle, Cycle 23, started in 1996 and several periods of major activity have already occurred. These events not only exercised SEC operational systems but were a wake-up call to our users. In addition to maintaining continuous real-time services for the past 2 years, several significant service improvements were made:

- Completed the migration of operational software to new platforms (OFF the MV).
- Updated services standards for customer (printed in *User Notes*).
- Integrated observations into operations from the ESA/NASA SOHO spacecraft.
- Commenced and maintained broadcast of space weather products on the NOAA Weather Wire service.
- Added near-real-time data from NOAA spacecraft data to our suite of Web products.
- Expanded the dissemination of the Alerts service to include e-mail, fax, weather wire, and pager service.
- Shifted from mailed paper copies to an electronic version of the "Weekly" available on our Web site.
- Initiated a new product, alerts for energetic electron events.
- Participated with users to help prepare them for the anticipated increase of activity during solar cycle 23.

Service plans (1998–1999)

Forecaster Staffing Plan for SWO

Forecaster staffing in SWO will change in 1998. This change is necessitated by the rise of Cycle 23, as well as the utilization of the new Advanced Composition Explorer (ACE) data and the Magnetospheric Specification Model (MSM); these will be supported by full forecaster staffing. The three steps to reach the goal of full staffing are as follows:

Step 1—increase forecaster staffing from one 10-hour shift to two 10-hour shifts per day.

The work load will be split between the two shifts, with the additional task of appraising the routine test products from the three-hourly runs of the MSM, on-going analysis of the ACE solar wind data, and making the decision to issue appropriate warnings (March 1998).

Step 2—increase forecaster staffing to three 8-hour shifts.

Added duties will commence with official issuance of MSM model output, and will require a more detailed forecaster appraisal before each issuance. ACE data will also be used more extensively for watches and warnings, and forecast amendments will be issued (September 1998).

Step 3—supplement the three forecaster shifts with a Senior Duty Forecaster.

Increased solar and geophysical activity, more external interactions, new data sets at a high cadence, and the implementation of models through the RPC, will all require increased time and attention (as resources allow).

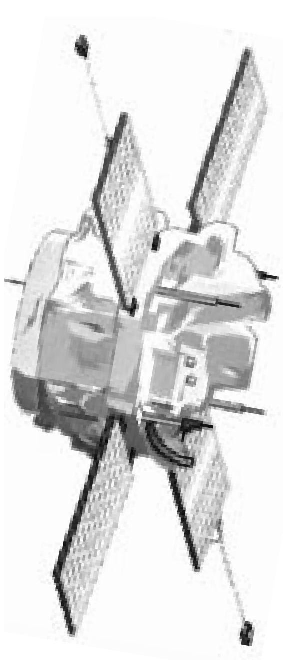
Major changes planned in SWO starting in 1998:

- Expand forecaster service to 24 hours per day, as mentioned above.
- Integrate continuous real-time solar wind data into operations and services.
- Expand alert service to include geomagnetic storm warnings.
- Initiate a Space Weather Bulletin service.
- Provide forecaster with outputs from physical based models via the SEC RPC.
- Expand products to include outputs of models, such as the MSM.
- Conduct a third User Conference (April 1998).
- Upgrade solar image analysis.
- Prepare for ingest and utilization of the modified Air Force SEON system and GOES Solar X-ray Imager.
- Expand our products and delivery systems to handle new data, products, and services.
- Provide for expansion of space weather third-party-vendor service.

Acquire and Use New Data

Advanced Composition Explorer (ACE)

Real-time solar-wind data from NASA's Advanced Composition Explorer (ACE) satellite has nearly become a reality. The data will enable SEC to formulate and issue alerts and warnings of impending major geomagnetic activity, providing better service for the majority of SEC's customers. Because it takes a disturbance in the solar wind about an hour to travel from where ACE is, near the L1 point to Earth, telemetry from ACE will allow alerts of imminent, severe geomagnetic storms to be issued about one hour in advance of their onset. Data from the ACE satellite and its array of instruments will mean the difference between a best guess and a sure thing in detecting disturbances to the space environment.



The ACE satellite was launched in August 1997, by NASA, to an orbit one million miles from Earth toward the Sun. It orbits around the Lagrange L1 point, the point along the Sun-Earth line where inward and outward forces balance, allowing a spacecraft to orbit there with relatively little expenditure of station-keeping fuel. Among other measurements, it will measure the isotopic and ionic composition of escaping particles from the Sun and take background measurements of the interplanetary magnetic field and the solar wind.

The USAF and a contractor's dedicated antenna Satellite Control Network (AFSCN) has agreed to collect ACE data for approximately 20 hours per day. This partnership with the Air Force will be beneficial for SEC, the Space Weather Squadron, and researchers around the world.

If a major geomagnetic storm occurs, it can cause fluctuations in Earth's geomagnetic field severe enough to upset delicate technological systems on satellites, affect power companies, and degrade navigational systems. ACE will broadcast its Real-Time Solar-Wind (RTSW) data continuously; the ACE mission is expected to last for at least 3 years, and RTSW will be collected and transferred to SEC by USAF, the Japanese Communications Research Laboratory, Rutherford-Appleton Labs in the UK, and NASA antennas.

Solar X-ray Imager (SXI)

Images of the Sun in x-rays provide valuable information about solar conditions that affect Space Weather. The new satellite-based Solar X-ray Imager, SXI, will provide continuous monitoring of the Sun, without the regular outages experienced by research instruments in low-Earth orbit.

X-ray images show the morphology of solar active regions, and whether the region is reaching a level of complexity that is expected to produce flares. Unlike ground based images, x-ray images also show activity beyond the solar limbs. This gives advance warning of up to three days of active regions that will be rotating onto the solar disk. Beyond-the-limb x-ray information is also used to determine locations of flares that do not have an optical counterpart, approximately 20 percent of all x-ray flares. Without flare location, forecasters have little information to determine whether the flare occurred beyond the west limb and is therefore likely to result in energetic particles at Earth. X-ray images also give clear indications of coronal holes, regions of very weak emission that are the sources of the high-speed solar wind.

The first SXI—a USAF/NASA/NOAA partnership— is expected to launch on the GOES-M satellite in early 2000. SEC identified critical areas in the design, monitored the performance of the instrument, and analyzed test data. SEC is currently developing algorithms that will be used to process the images.

This SXI is the first in a series of NOAA- and USAF-funded instruments that will continuously monitor the Sun. The contract for the follow-on SXI instruments, which will have a ten-fold improvement in sensitivity, was awarded to Lockheed-Martin Advanced Technology Center in June 1997.

Solar and Heliospheric Observatory (SOHO)

In 1996, SEC began using near real-time data from the NASA/ESA Extreme-Ultraviolet Imaging Telescope (EIT). These images provide backup for the coronal hole data received from the National Solar Observatory.

Also, SOHO's Large-Angle Spectrographic Coronagraph (LASCO) has provided critically important reports of Earth-directed "halo" coronal mass ejections (CMEs). These observations are unavailable from any other source. Over 25 halo CMEs were reported in 1997, and all but one of them have resulted in geomagnetic disturbances here at Earth. Without these observations, SEC would not have predicted disturbances for the majority of the events, due to the lack of classical predictors. This state-of-the-art research being used in operational forecasting, while unusual, is remarkably beneficial.

Geostationary Operational Environmental Satellite (GOES)

The new generation of staring (as opposed to spinning) GOES spacecraft was initiated with GOES–8, –9, and –10. The Space Environment Monitor (SEM) instruments aboard GOES include magnetometers, an X-Ray Sensor (XRS), and an Energetic Particle Sensor package. Improvements over previous GOES spacecraft include extending the dynamic range of the XRS and the addition of two energetic electron channels. The new XRS provides the ability to assess the peak energy of some of the most important solar flares. The energetic electron flux measurements are important for maintaining reliable and efficient operation of defense, navigation, and communication satellites.

GOES magnetometer and particle data are provided to the NASA International Solar Terrestrial Physics Program (ISTP) and are among the ISTP data sets most widely used by the national and international scientific communities.

NOAA is in the process of procuring new GOES satellites (beginning with GOES N) to be ready around 2002 when the current series is expected to reach the end of its useful lifetime. SEM improvements for the new series include extending the range of energetic particle measurements, a new instrument for measuring solar extreme ultraviolet, and an SXI, as discussed on the previous page.

Polar Operational Environmental Satellite (POES)

NOAA-9, NOAA-12, and NOAA-14 are the most recent POES-series satellites to fly in one of two low-altitude polar orbits. (These satellites are often referred to as the NOAA/TIROS spacecraft). NOAA-K, to be renamed NOAA-15 in orbit, will be launched in May 1998.

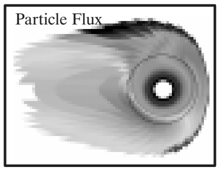
These spacecraft provide data to SEC through the SEM and the Solar Backscatter Ultraviolet Sounding Spectral Radiometer (SBUV) instruments. The information on energetic particles and solar radiation is then made available to NASA, USAF, and a variety of commercial and research customers. SEC has specified and overseen the development of the new version of the SEM instrument being built by Panametrics Corp.

The SBUV instrument is primarily used by SEC to obtain frequent measurements of the solar radiation falling on the atmosphere in ultraviolet wavelengths. Short- and long-term measures of the variability of the Sun can be determined using these measurements. One measurement (the MgII core-to-wing ratio) has been shown to be an excellent proxy for solar ultraviolet radiation, and the ratio is supplied to researchers around the world to be used for studies of ozone variability, stratospheric dynamics, and solar variability research. The measurement maintained by SEC is a nearly continuous record of solar variability that extends back 20 years to 1978, and is one of the longest continuous records of solar radiation. The next launch of an SBUV instrument will be on NOAA-L late in 1999.

National Polar Orbiting Operational Environmental Satellite System (NPOESS)

After the launch of the last of the scheduled NOAA POES satellites (NOAA-N) sometime in 2002, a new generation of satellites called the National Polar Orbiting Operational Environmental Satellite System (NPOESS) will be implemented. This series of spacecraft will replace not only the NOAA POES satellites but also the Department of Defense DMSP satellites. The operational requirements of both NOAA and the Department of Defense have been combined into a single set of satellite requirements. SEC has participated in all levels of the process of requirements identification.

The present design will include the functions of both the DMSP and NOAA satellites, and several additional functions have been improved or added to the design requirements list. The NPOESS series of spacecraft is designed to carry the NOAA POES system well beyond the year 2010.



Utilize Numerical Modeling

Unlike terrestrial weather conditions that are monitored routinely at thousands of locations around the world, the conditions in space are monitored by only a handful of space-based and ground-based facilities. Space weather forecasters are required to specify and to predict conditions in space using a minimum of guidance from actual measurements. The extreme undersampling of the diverse, coupled regions of space demands that numerical models be utilized to provide continuous quantitative assessment and prediction of the geospace environment. Future operational models, together with forecaster expertise, will make possible a more accurate and comprehensive set of products to better serve our nation's needs.

Extensive research, modeling, and monitoring efforts directed at understanding the space environment have produced a broad spectrum of data and model resources. Most recently, an interagency initiative, the National Space Weather Program, has built on our existing resources to produce quantitative predictive models of the space environment.

SEC serves a dual role in making available operational numerical models. In one capacity, SEC staff members perform basic research, developing and improving numerical models of the space environment. This research includes modeling processes at the Sun and in the solar wind, and modeling the effects of these processes on the near-Earth environment, including the magnetosphere and the ionosphere.

Another critical role of SEC is to take mature numerical models and data products developed elsewhere and make their outputs available (operationally) to the broad user communities. The extensive model and data resources that exist and that are being developed, together with our increasing need to monitor and to predict the space environment, present an imperative to transition these resources into operational use in a manner that most efficiently serves national needs. Models and data streams that are candidates for operational use need to be critically evaluated through a competitive process to insure the earliest utilization of the best and most useful models. The transition from research to operations will be accomplished at SEC's RPC, where staff will work directly with modelers, data providers, service providers, and end users to test and develop products. The close interaction between SEC and the broad user community will also focus future research and development efforts funded by various government agencies, specifically through the National Space Weather Program.

Rapid Prototyping Center

The National Space Weather Program Implementation Plan, 1997, states that a critical requirement for success is the application of the numerical models developed under the program as operational tools in the nation's forecast centers. The RPC is a facility to expedite testing and transitioning of these new models and data into operational use. The first elements of the RPC are being designed and implemented with substantial support from Sterling Software, Inc., through a Cooperative Research and Development Agreement (CRADA).

The operational models and data products made possible through the RPC will provide the basis for improved forecasts and for tailored space weather products. The output will be available to a broad user community, including SWO, the USAF 55th Space Weather Squadron, commercial space weather concerns, and the research community.

The RPC is being designed to fulfill our modeling and monitoring needs as we approach the next solar maximum and beyond. Routine test products will be released early in 1998, and fully operational products are expected by mid-1998. By combining existing real-time data, future data sources such as ACE and SXI, local computer systems, and external computer systems such as those available through the National Centers for Environmental Prediction, SEC plans to transition one to four models or data streams into operations per year. This will transform our prediction and specification capabilities and allow us to better meet the challenges of our nation's expanding utilization of space as we enter the 21st century. Not incidentally, provision of the output of space weather models to the public will foster a space weather services industry, as noted in the next section of this report.

Solar-Wind Modeling

Solar-wind modeling at SEC involves using observations of the Sun and of the interplanetary medium to understand solar processes and the transport of solar material to Earth and beyond. Various empirical and numerical techniques are used to investigate the dynamics of the Sun and of interplanetary space. A semi-empirical algorithm is used by SEC forecasters to predict the energetic proton fluxes resulting from solar flares. Also related to solar flare activity, numerical algorithms are used to estimate the time of arrival at Earth of interplanetary shock waves that could induce enhanced geomagnetic activity. Large-scale three–dimensional simulations of the interplanetary plasma are used to investigate the propagation of solar disturbances, emphasizing the conditions that are most likely to have important consequences in Earth's environment.

With funding provided by the Office of Naval Research, SEC has undertaken to bring into routine operations the Wang and Sheeley model of the steady, global solar-wind flow and to make the output of the model available to the user community on a regular basis. The model uses solar-photospheric magnetic-field measurements to predict the flow speed and magnetic polarity at Earth. This information will see wide-spread use by the scientific and operations communities, since it provides the most complete overview of the global interplanetary environment on a near-real-time basis.

The original research-grade model code has been thoroughly rewritten, streamlined, and automated. The most important improvement to the original model is that the magnetic observations are input daily. For the first time, a rigorous validation study of the accuracy of the forecasts has also been undertaken to provide a statistical basis for application of the predictions and to provide a meaningful measure of future improvements to the model. Several improvements to the model are planned for implementation in 1998.

Magnetosphere Modeling

Modeling of the magnetosphere has important benefit to SEC operations, both in giving numerical guidance for conditions that affect on-orbit spacecraft and in providing inputs to other models. SEC modeling efforts have been directed at predicting various geomagnetic indices, quantifying the mass transport between the solar wind and the magnetosphere, predicting relativistic electron fluxes at geosynchronous orbit, and modeling the electron and ion plasma throughout the inner magnetosphere.

The first numerical model being implemented through the RPC is the Magnetospheric Specification Model (MSM), developed at Rice University with USAF funding. Under the CRADA agreement, Sterling Software is implementing the MSM with re-usable object-oriented software, laying the groundwork for the transition of other physical models. Using near-real-time geomagnetic indices as input, the MSM computes time-dependent electron and ion particle fluxes in the inner magnetosphere. The output will provide forecasters and external users with a near-real-time picture of the magnetospheric plasma that is relevant to satellite operations and to the understanding of satellite anomalies.

Ionosphere Modeling

Physical models are valuable tools for unraveling the complexities of the ionospheric response to geomagnetic storms. It is now clear how the coupling with the neutral atmosphere controls the seasonal and local-time dependence of the ionospheric variability during storms; an effort is now underway at SEC to determine how this new understanding can be shifted to operational use.

Two approaches are being used to model the ionosphere. The Coupled Thermosphere-Ionosphere Model (CTIM), uses all the complex processes and inherently time-dependent responses in its computation. The CTIM has been running daily for 9 months to provide the validation required before it can be an operational tool. The essential physics of the storm-time ionosphere has also been described in an empirical algorithm. The algorithm captures the major response of the ionosphere to geomagnetic storms in a manner that does not require intense computations.

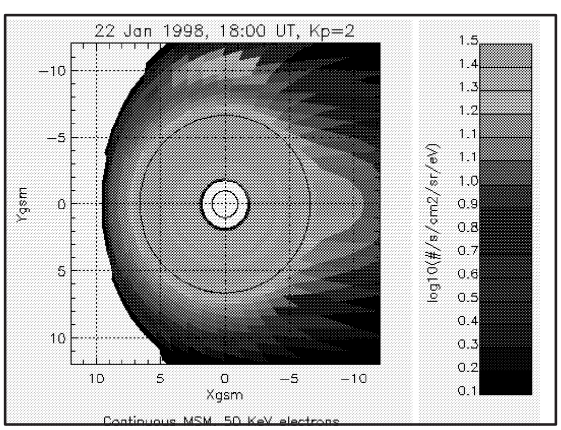
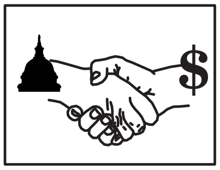


*Illustration of the Magnetospheric Specification Model Output calculated at the 50 keV electron flux level in the equatorial plane of Earth's magnetosphere. This model is run every 3 hours using as input the most recent provisional geomagnetic index (*Kp*). The outer circle, with radius 6.6 Earth radii, indicates the location of geosynchronous orbit. The particle fluxes are known to cause spacecraft charging that can lead to anomalous behavior in system electronics.*



Foster a Space Weather Services Industry

In the last 2 years, SEC has followed the guidance of the National Weather Service, NOAA, and the Department of Commerce to foster private-sector development of space weather services.

SEC must balance its obligation to provide services to the public with its obligation to promote private-sector services that would extend products to users for a fee. While maintaining our role as the sole official source of space weather warnings, we have worked to encourage the start-up of a space weather industry by holding meetings and workshops with vendors and entering into two work agreements with private companies related to supporting a space weather industry.

Vendor Workshops

In 1997, we held two workshops with vendors where we discussed the roles of SEC and of vendors, defined a policy for dissemination of products, and generally delineated services areas between private and public sectors. From those meetings a policy was written and published, and a third meeting is scheduled for April 1998.

Cooperative Research and Development Agreement

A Cooperative Research and Development Agreement (CRADA) was signed in June 1997, with Sterling Software, Inc. This agreement represents the first public-private partnering to provide space weather services.

The high level of resources and commitment shown by Sterling Software in helping SEC develop an RPC has contributed to the timely development of model output that will be the basis of new, private sector services. The first model to be implemented is the MSM (described in the previous section), which was developed by Rice University with USAF support, and it is expected to be running routinely by the middle of 1998. The CRADA is in place until June 1999 and could be continued as long as the partnership is worthwhile to both SEC and Sterling.

The CRADA is intended to be mutually beneficial, and SEC appreciates that it will be a great help to all space weather users, and to SEC's customers in particular. The results of model runs will be freely available to *all* our users.

Small Business Innovative Research Grant

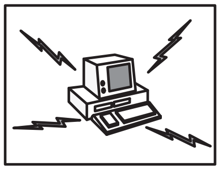
It is useful to consider space weather as an analog to meteorological weather in developing a space weather industry. (The National Weather Service supports a private industry that uses the data and services generated by the Weather Service.)

A Small Business Innovative Research grant (SBIR) was awarded to Northwest Research Associates, Inc., to develop private industry products and data distribution that result in the opportunity for businesses to provide space weather services. Northwest Research Associates' effort is aimed at developing a distributed computing system that would provide specific products to individual users and distribute data and products to a network of users.

The successful completion of this grant will lead to a proposal for a Phase II grant, where the design and prototype will be developed into a working system.

Expectations for a Space Weather Industry

As we continue to work with vendors, both in dissemination and in developing novel products, we expect that a small but profitable private sector will share the load of servicing the high-tech community and the nation with important safeguards against disturbances in the space environment.



Modernize Data Handling and Information Dissemination

In 1996, SEC moved its operational system from obsolete, unsupportable hardware to more modern platforms. While the incremental improvements resulted in a more widely distributed system with greatly enhanced reliability and functionality over its predecessor, they failed to address several critical requirements. The solution-based distributed architecture will become increasingly difficult to support as SEC systems grow to meet new requirements.

To meet our growing requirements, SEC is currently embarking on three new simultaneous development projects to upgrade its operational system architecture. These projects, the Information Dissemination System (IDS), the Data Display System (DDS), and the Data Simulation System (DSS), are designed to be extendable and expandable to meet present and future demands and requirements of existing and new users.

Information Dissemination System (IDS)

Of the three projects, the IDS is the primary system that will enable SEC to move to a modern object-oriented distributed architecture, where any number of clients and servers can use one system. This will result in fewer interfaces to maintain, making it inherently easier to maintain.

The IDS will employ software bus technology based on the Common Object Request Broker Architecture (CORBA) standard to meet its principal goals. IDS interface definitions will be available via CORBA-compliant Interface Definition Language. Any customer or third-party vendor can then develop applications with custom access to existing and future SEC data without direct SEC involvement.

Perhaps the most significant advantage of the IDS is that it will allow users to automatically and transparently access older data through IDS client applications regardless of where those data reside.

Data Display System (DDS)

The Data Display System will replace several distinctively separate systems used to display real-time and call-up data and plots. The DDS will acquire data as an IDS client and will provide data displays to both SWO and SEC partners and customers.

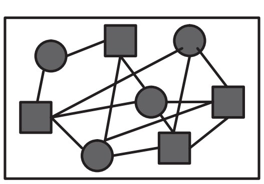
The DDS will have both user interface and display components, interfaced through a CORBA software bus. The DDS will acquire the required data through the IDS and render the data displays, but will be capable of functioning over very low bandwidth TCP/IP connections.

Data Simulation System (DSS)

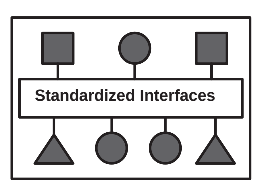
The Data Simulation System is intended to train and test staff, systems, and algorithms. The DDS will be capable of supplying historical data from any real data source available through the IDS as though they were being measured in real time; the data will be available to authorized clients in the same format and cadence as the current, actual data counterpart, but time-tagged to the simulation exercise clock. This is sometimes called a “delayed real-time” simulation. The DDS will use CORBA-compliant software and interfaces that mirror real-time operations.

Initially SEC plans to assemble the information for a dozen selected events of interest for simulations on CD-ROMs. Additional events can be added to the available selection.

The first prototype build of the IDS is due the first quarter of 1998, with the first production build of all three projects due the second quarter of 1998. Incremental builds will add functionality and performance every three to four months throughout the development phase of the projects. All three projects will be fully functional, and enter into the maintenance phase of their life cycles, by the year 2000.



The existing system (left) requires many-to-many interfaces. The IDS (right) will use standardized interfaces. Different shapes symbolize databases, data sources, and various users inside and outside SEC.



Foundations of SEC

Partnerships

SEC works in cooperation with many other organizations. These partnerships allow leveraging of SEC resources far beyond what could be achieved alone. The impact of these partnerships reaches into current space weather services, the development of improved services, the transition of improvements into services, and applied research and development.

The Space Weather Operations of SEC are a joint operation of NOAA and USAF, providing joint products, with forecaster staffing from both organizations. NOAA and USAF share observations that include the GOES Space Environment Monitor, the Solar X-ray Imager, and the Solar Electronic Observing Network (SEON). USAF, SEC, and the U.S. Geological Survey are cooperating to improve access to real-time geomagnetic observations and to improve the quality of real-time, estimated *A*- and *K*-indices.

SEC continues to work with NASA (and USAF) to arrange for real-time data from NASA research missions that will be especially useful for space weather services. The new data section of this report describes observations from the ACE and SOHO missions. Plans for future collaboration include real-time images from the NASA IMAGE satellite (providing a quick look from high over the north pole) of auroral activity as it is actually occurring.

SEC and the NASA Space Radiation Analysis Group at Johnson Space Center continue to cooperate in developing improved systems and technology for space radiation support, and for SEC to provide space radiation information for Space Shuttle and Space Station operations. Under the agreement, NASA has supported portions of the SEC data systems.

SEC is cooperating with two commercial companies in Small Business Innovative Research programs aimed at improving space weather services; one is for development of a model for predicting locations of auroral electric current locations, and the other for development of an information system to make space weather information more readily available to third-party vendors.

SEC is participating in the joint USAF-NOAA program to define space environment requirements for the sensors on board the polar orbiting satellites of the future and with the European Space Agency to define the sensors for the European METSAT program.

SEC is also working with the Czech Academy of Sciences' Astronomical Institute and USAF to arrange for a test and proof of concept flight for a hard x-ray spectrometer that would lead to improved solar particle event forecasts.

SEC is working with the Naval Research Labs (NRL), who sponsor post-doctoral staff in SEC to improve, and make ready for operations, geomagnetic forecasting models originally developed by NRL.

In all these partnerships, and others, SEC gains the use of resources far beyond its own baseline funding.

International Space Environment Service

SWO is a Regional Warning Center (RWC) and the World Warning Agency (WWA) of the International Space Environment Service (ISES). The ten Regional Warning Centers of ISES are responsible for providing real-time monitoring and prediction of space weather for the entire globe; each RWC is responsible for providing services in its localized section of the world. SWO, as RWC Boulder, serves the Western hemisphere (except Canada). In addition, as the WWA, SWO acquires and exchanges data between all the RWCs and maintains the international space weather codes used to transmit space weather data. It also issues the international GEOALERT message (a daily consensus forecast and summary of solar and geophysical conditions) and plays a major role in planning and executing international space weather campaigns.

National Space Weather Program

Throughout this report, there are descriptions of SEC activities that are part of the National Space Weather Program (NSWP). The first SEC priority in the NSWP was obtaining real-time solar-wind data from the ACE satellite. The paragraphs on ACE data in the new data section of this report describes the SEC success on this objective. A primary objective of the NSWP is the transition of models from research into operations. A Rapid Prototyping Center was chosen by SEC as the best way to facilitate this transition. User requirements are also a focus of the NSWP, and SEC efforts to establish user requirements are described in the section on user workshops. Finally, developing a set of standard measurements (metrics) to evaluate progress in the NSWP has begun, and SEC staff are active in this effort, including leadership of working groups to determine appropriate standards.

Collaborations at Workshops

User Conference

SEC talks to users of our space weather products and services every day. The phone calls and e-mails give feedback on the various types of information that we disseminate. *User Notes* is a quarterly newsletter that keeps users informed about SEC, provides news of general developments in space weather monitoring, and gives details about related events.

Every 4 years, a User Conference is held at SEC that gives attendees exposure to the broader user community, and an opportunity to collaboratively request changes to services provided by SEC. The next User Conference is scheduled for April 1998.

Industry Workshops

An approach used by SEC staff to learn more about customer needs is to participate in meetings, described below, that cater primarily to users of space weather services. At such meetings, SEC staff are able to relay to users the particular circumstances of space weather for such applications as navigation, space radiation, induced currents, and orbital dynamics.

The Geomagnetically Induced Currents (GIC) Causes and Effects meeting was sponsored by the National Science Foundation (NSF) and held at the Electric Power Research Institute (EPRI) headquarters in Washington, D.C., in October 1996. The meeting established a dialog among power company personnel, EPRI consultants, and government, non-government, and private industry scientists that resulted in defining future activities that can lead to improved space weather services.

The Space Weather Effects on Propagation of Navigation and Communication Signals Workshop, sponsored by NSF and NOAA, was held in Bethesda, MD, in October 1997. Users, data providers, forecasters, and scientists discussed areas of common concern related to the ionosphere, and conditions imposed on navigation and communication systems, principally the Global Positioning System (GPS), by the ionosphere. This workshop was seen as the first in a series of meetings, increasing communication and understanding between users and providers of space weather services.

At the Institute of Navigation GPS-97 meeting in Kansas City in September 1997, SEC staff presented a view of how the increasing solar cycle would impact the burgeoning GPS market during the rise of Solar Cycle 23.

Research and Development Workshops

SEC staff are leading organizers of and participants in these activities:

The Geospace Environment Modeling (GEM) program is an NSF initiative designed to produce a comprehensive model of the interactions of the solar wind with Earth's magnetosphere and ionosphere. One of the SEC mission goals is "to prepare and disseminate forecasts and alerts of conditions in the space environment." The results of GEM activities will support this mission goal and be a part of our participation in the multi-agency National Space Weather Program.

The GEM Working Group 5 Workshop in January 1995 developed into the GEM General Geospace Circulation Model Campaign/SEC Space Weather Workshop in January 1996, and the Space Weather: Research to Operations Workshop in January 1997. These meetings, held at SEC, have been jointly organized by the NSF Division of Atmospheric Sciences, the Air Force Research Laboratory Geophysics Directorate and SEC and have included multi-agency participation. Another meeting is being held in February 1998.

Solar, Heliospheric, and Interplanetary Environment (SHINE) is an affiliation of researchers within the solar, interplanetary, and heliospheric communities, dedicated to promoting enhanced understanding and predictive capabilities for solar disturbances that propagate to Earth. Although it is not an official entity within NSF, SHINE has conducted a number of mini-workshops and has played an active role in providing advice to the agency in matters related to the solar-interplanetary aspects of space weather prediction.

In addition to active participation in the Spring 1998 AGU, SHINE will set up special sessions at the upcoming Solar Wind 9 meeting (October 1998), and is planning to conduct a week-long workshop in conjunction with GEM and CEDAR in 1999.

The most recent Solar-Terrestrial Predictions Workshop was held January 1996 in Hitachi, Japan, and brought together users, researchers, and providers of space weather services. The workshops, held every 4 years, are a powerful forum for proposing improvements to space weather service internationally. New techniques and customer experiences combine to help workshop participants set plans for future collaborations and data sharing.

Computers and systems

Although SEC's planned next-generation operational system, SELDADS 3, was not implemented, major system advances and upgrades were nonetheless realized over the last 2 years. To move SEC operational software off obsolete, non-supportable hardware and software, and make critically needed system improvements, SEC launched an emergency "Off-the-MV" effort. This was an interim solution to address the most critical deficiencies and problems associated with the old SELDADS 2 system. Since this effort was intended to be a quick port of operational components from the MV10000 computer, not a redesign of the whole system, it did not address all the improvements and advances conceived in the SELDADS 3 plan, and the result has been labeled SELDADS 2.5.

Some of the major improvements achieved through the SELDADS 2.5 upgrade include the following:

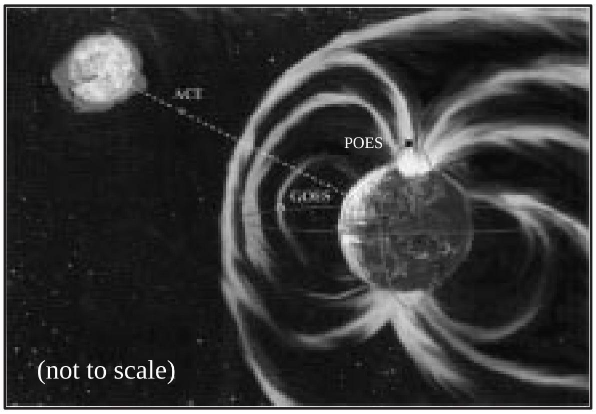
- The elimination of SELDADS dependency on the 15-year-old MV10000 minicomputer and propriety display hardware.
- The replacement of the Satellite Broadcast System by the NWS Weather Wire Service.
- The consolidation of most outside user data accesses through a comprehensive TCP/IP and Web-based Outside User System (OUS).
- The upgrade to a POSIX-compliant preprocessor operating system and the successful porting of the processes used to ingest and process most of the raw data streams received at SEC from various sources.
- The use of commercial off-the-shelf relational databases to issue alerts and products.
- The use of PC hardware and a modern graphical user interface for SWO data input, access, analysis and control operations.
- The upgrade of the hardware and software used to deliver and display SEC data to the USAF 55th Space Weather Squadron.
- The development of a backup for critical 55th Space Weather Squadron products.

In addition to supporting new requirements including the constant effort required to ingest, process, store, retrieve, display and disseminate new data streams, numerous SELDADS 2.x upgrades are being made. These will provide needed additional functionality and improved system robustness. Some current and near-term SELDADS 2.x upgrades include the following:

- The implementation of a dual operational Data Management System and a third developmental system is expected to greatly reduce the risk of data loss due to system failure.
- Dual OUS systems are being developed to share the server load, and maintain operation during system failure.
- GOES ground-station systems were upgraded to provide reliable backup capabilities while tracking three satellites.
- Secondary data processing and other related functions are being redesigned and moved off the DMS systems, and onto the preprocessors, to improve system architecture and performance.
- A new-generation status-monitor system is being implemented to improve the diagnosis and resolution of system and data problems.
- Some deferred functionality like event and alert monitoring is being added.
- Quickly ported code is being cleaned-up and rewritten as time, opportunities, and priorities permit.
- The upgrade of our Local Area Network will move us from 10base2 to modern 10baseT with switching technology.

Although the SELDADS 2.x upgrades have and will result in significant system and performance improvements, the architecture is not compatible with long-term growth and performance requirements needed to support SWO operations and the user community during solar maximum and into the next solar cycle. To meet these new requirements, SEC has started work on three new development projects that together will define the next-generation operational system (described on page 11). These projects represent a major paradigm shift in both our distributed architecture and development methodology. The system will have the ability to meet the demands of the next solar cycle will depend heavily on the success of these efforts

Research and Development



A depiction of the space environment, where measurements from research and operational satellites are used by scientists to attempt to understand the complex interaction of forces that affect the environment near Earth.

The Research and Development Division

The unique nature of SEC, an organization housing research, development, and operations under the same roof, imposes special conditions upon its staff. Throughout SEC, Research and Development personnel work closely with other staff to support all the elements of the SEC mission and to provide a firm research underpinning to our products and operations.

Within the Research and Development (R & D) Division, it is necessary for the staff to contribute in three general areas. First, the science staff members conduct research in their areas of expertise, while other staffers, such as those doing computer programming, develop sophisticated code in languages adopted by the SEC. The second area involves programmatic activities; examples include the role of Responsible Scientist (similar to the concept of a NASA Principal Investigator for a given instrument package), Project Leader, or Development Leader for a new proposed product. R & D staff have responsibilities for may of the activities discussed throughout this report, such as GOES and POES instrumentation and data, ACE data, SXI instrumentation and data, planning for future satellite missions, and various aspects of the RPC and space weather modeling. The third area encompasses the broad area of "expertise," where everyone is called upon to answer users' (customers') questions.

The research mission of the Division emphasizes theoretical and experimental research studies directed to understanding the fundamental physical processes responsible for and causing: 1) the observed energy release in the form of electromagnetic and particle radiation near the solar surface; 2) the propagation of this energy through the corona and out into the interplanetary medium; 3) the transfer of this energy from the near-Earth interplanetary medium into Earth's local space environment; and 4) the behavior and subsequent effects of this energy within the magnetosphere, the ionosphere, and the upper-atmosphere regions.

The reorganization of the R & D Division during 1997 has provided new opportunities for both individual and institutional goals. The broad mission of the Division has been split into three general areas, each covered by a separate group:

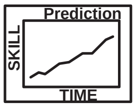
The Solar Terrestrial Models and Theory Group is devoted to basic research into Earth's space environment and the application of this research to space weather operations. The group has staff with expertise from solar physics to Earth's upper atmosphere. The staff maintains close collaborations throughout the research community, publishes regularly in scientific journals, and works directly with the SWO and Systems Divisions to develop state-of-the-art capabilities.

The Solar Terrestrial Instrumentation and Data Group ensures that space environment data are processed, validated, interpreted, and disseminated in an efficient and timely fashion. The group develops analysis tools for working with data from a variety of spacecraft, including the NOAA geosynchronous and polar orbiters, and spacecraft in the solar wind. In addition to enhancing the utility and value of the primary data through research and analysis, the group explores sources of new data and improved monitoring to support SWO.

The Solar Influences and Imaging Group conducts research into understanding processes on the Sun, and the effects of solar activity on the near-Earth space environment. The group leads in the development of techniques to process and interpret both ground-based and space-based solar imagery and has special expertise in solar x-ray imaging. To support SWO, the staff examines both short- and long-term solar influences on human activities in space and on the ground.

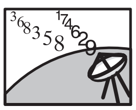
Vision of SEC in Five Years

While the preceding pages discussed the previous 2 years of accomplishments and described project plans, the vision of the Center in 5 years is one of great expectations and innovation.



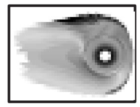
Augment Operations

The Space Weather Operations Center will be staffed 24-hours a day with both a Forecaster and a Solar Technician. The forecast will be updated more than once a day, as will model output and environment parameters in near real time.



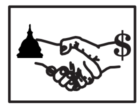
Acquire and Use New Data

Solar-wind data, solar x-ray images, magnetospheric images, and ground magnetometer readings will be available to forecasters as well as to researchers and the public. The new data will flow from revised sensor networks and NASA research missions.



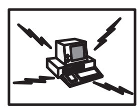
Utilize Numerical Models

Several useful models will see routine use and will be key in improving forecasts and warnings. Models will be transitioned smoothly into operational use as they prove worthy.



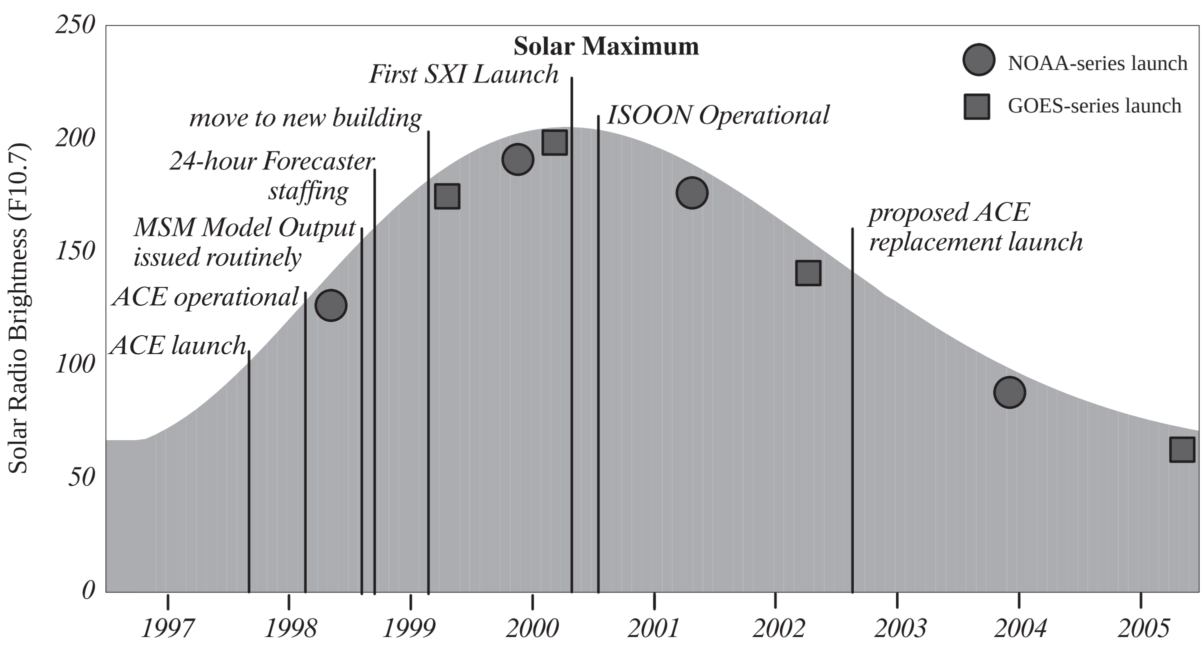
Foster a Space Weather Services Industry

Private industry will be providing space weather services to many customers, and working with SEC to suggest needs-based research and product development.



Modernize Data Handling and information Dissemination

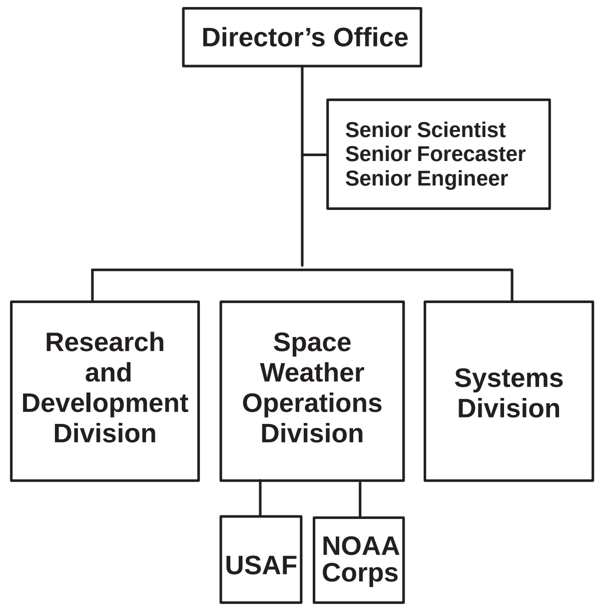
The flow of data and information will be able to satisfy the highest demand customers. Data will flow seamlessly from SEC and NGDC so that customers need not be concerned about the archival source of data.

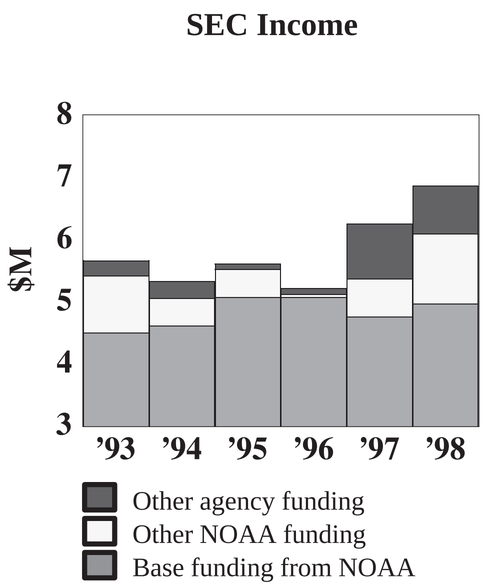


Facts about SEC

Organization and Funding

Center Organization—SEC underwent a major reorganization in 1997; the resulting structure is shown below. This was done to recognize major areas of the lab and to encourage the staff to work across boundaries on projects. The reorganization eliminated a level of management, while freeing senior staff to work on strategic planning, specific projects, and direction of major initiatives.

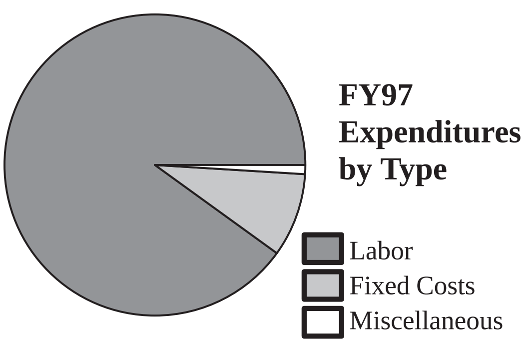




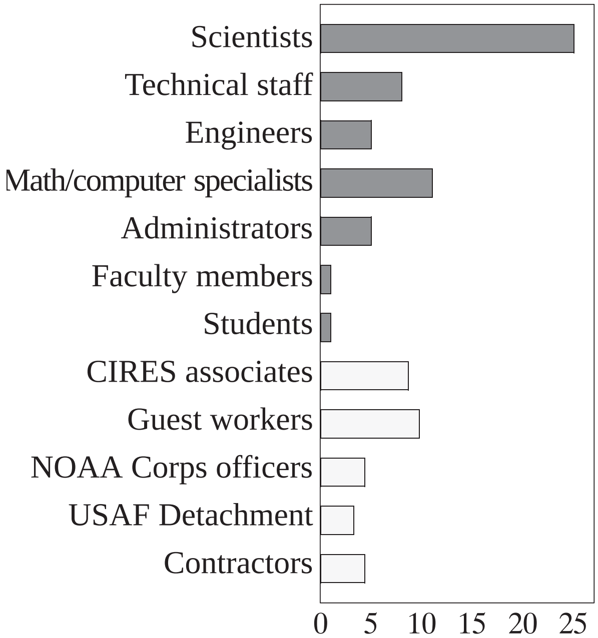
Funding—The major funding base for SEC is direct Congressional appropriation; other-agency projects and NOAA programs provide a small additional amount.

The budget for SEC has grown slightly in recent years, as shown at upper left. However, inflation has eaten away at spending power. In fixed 1993 dollars, our base funding has dropped.

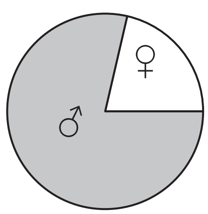
A new computer system was funded by major reprogramming from, and deferral of, other projects in 1995 and 1996. Since then, SEC has been able to hire a few carefully selected staff capable of forwarding the research, operations, and systems efforts.



Staff



A profile of the workforce at SEC. The darker bars constitute the SEC positions that make up the 54.6 Full Time Equivalent civil service staff at the close of FY97. The light bars illustrate other staff employed at SEC.



The Center is committed to EEO and has a diverse staff.

Committee memberships, review boards, planning groups—SEC staff members play critical roles in the space environment community, participating in numerous scientific papers and proposed reviews, and as leaders of scientific organizations, interest groups, and members of scientific organizing committees of meetings too numerous to mention. A few examples follow:

- Pat Bornmann served on the American Astronomical Society Solar Physics Division Nominating Committee, 1997.
- Tim Fuller-Rowell is a Fellow of CIRES.
- Gary Heckman is Secretary for URSIgrams for ISES, and a member of the ISES Steering Committee; he is an editor of the Solar Terrestrial Predictions Proceedings.
- Ernie Hildner is on the National Solar Observatory Users' Committee and the High Altitude Observatory Advisory Committee. He is a member of the National Space Weather Program's governing Committee on Space Weather.
- Joe Hirman is the Deputy Secretary for URSIgrams and a deputy member of the ISES Steering Committee.
- JoAnn Joselyn serves as Secretary-General of the International Association of Geomagnetism and Aeronomy.
- Terry Onsager is a member of NASA's Sun-Earth Connection Advisory Subcommittee, and of the American Geophysical Union Space Physics and Aeronomy Education Committee, NSF GEM working group co-chairman, Associate Editor of the Journal of Geophysical Research (Space Physics), and Associate Editor of Geophysical Research Letters.
- Vic Pizzo is Chairman of SHINE, Liaison for solar-terrestrial physics for the Solar Physics Division of the American Astronomical Society, member of the NASA Science Definition Team for the proposed STEREO Mission, member of the National Solar Observatory SOLIS advisory group, and Associate Editor for the Journal of Geophysical Research (Space Physics).
- Howard Singer is a member of the Steering Committee of the GEM effort; and a member of the NSF Geospace General Circulation Model (GGCM) Steering Committee.
- Ron Zwickl served as Chairperson, National Program Committee of the American Geophysical Union, and a member, Meetings Committee, American Geophysical Union.

Space Environment Center Staff and Associates

(Phone extensions listed below can be used by dialing (303) 497 – extension.)

Systems Division

Abeyta, Jim	5827
Barrett, Bill	6872
Cruickshank, Cheryl	3930
DeFoor, Tom, *Chief*	7575
Finelli, Dave	7409
Husler, Mike	5691
Ito, Dave	3994
Lewis, Dave	3170
Masten, Bob	5716
Prendergast , Kelly	5697
Raben, Vi Hill	5691
Sayler, Steve	3959
Seegrist, Larry	5045
Wolf, Carol	5828

GUEST WORKERS

Andic, Hikmet Univ. Louis Pasteur	5045
Bouwer, Dave Sterling Software	3899
Connelly, Lillian Coop. Ins. Res. Env. Sci.	
Davis, Brad Coop. Ins. Res. Env. Sci.	
Fedrick, Kelvin Coop. Ins. Res. Env. Sci	3968
Gray, Al Coop. Ins. Res. Env. Sci.	3593
Retallack, Bill NOAA	
Springer, Bruce Satellite Data Systems	
Taylor, John Satellite Data Systems	5712
Vickroy, Jim Sterling Software	7435
Vitt, Francis Sterling Software	3845
Wizner, Margerite Satellite Data Systems	

SWO Division

Balch, Chris	5693
Cohen, Norm	7824
Combs, Larry	5299
Curtiss, Candice	3204
Doggett, Kent	3317
Hirman, Joe, *Chief*	5688
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Jong, Jiancun Chinese Academy of Sciences	
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Acknowledgements: The many SEC authors thank Barbara Poppe, and Gary Heckman and Larry Puga for bringing this publication to fruition.