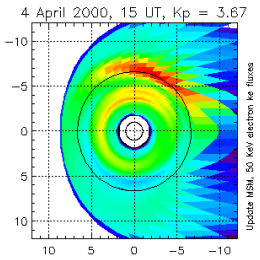
Welcome to Space Environment Center

Six Themes in SEC Activities

1. **Augment Operations**

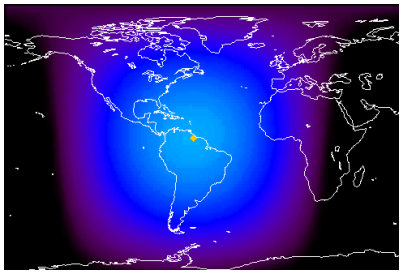
2. **Acquire and Use New Data**



3. **Utilize Numerical Models**

4. **Foster a Space Weather Services Industry**

5. **Modernize Data Handling and Information Dissemination**



6. **Develop New Ionospheric Products**

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 Oceanic and Atmospheric 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) at SEC operates the national and world warning centers for space weather that can affect people and electronic equipment. and provides real-time monitoring and forecasting of solar and geophysical events to customers. The 55th 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.

The Space Environment Center also conducts research in solar-terrestrial physics, develops techniques for forecasting solar and geophysical disturbances, transitions academic research (including numerical models) into operations, and prepares data to be archived by the NOAA National Geophysical Data Center. It often provides advice on solar-terrestrial phenomena and their adverse effects to government agencies and industry. 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, 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 at SEC.

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Augment Operations

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

SWO is manned 24 hours a day, 7 days a week, maintaining an up-to-the-minute watch for storms and disturbances in the solar-terrestrial environment. Forecasters are on duty from 6 a.m. to 2 a.m. MT, and are on-call for the other 4 hours. Solar Technicians are on duty 24 hours a day. Forecasters analyze the more than 1400 near-real-time space weather data sets, garnered 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 real-time alerts and warnings. Staff members are also stationed at solar observatories in the U.S. and Australia and these observers collect and analyze solar observations and forward real- time reports and data to SWO.

Space weather customers are users, operators, managers, design engineers, and researchers working on systems affected or influenced by space weather. Customers include a diverse spectrum of military, government, vendors, 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. The NASA Space Radiation Analysis Group needs current and predicted space weather information to assess crew and payload radiation levels during NASA manned missions. Satellite operators need advisories of severe space weather that may harm their spacecraft. Radio operators need space weather indices for predicting radio propagation. Vendors, who provide tailored space weather services, need information to meet their users' needs.

To better understand user needs and improve services, SEC routinely solicits input and feedback from the community. This information is used to develop and 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 attributes are routinely monitored through formal quality control, verification programs, and user feedback.

Service improvements (1998-1999)

Many aspects of space weather follow the 11-year sunspot cycle. The current solar cycle, Cycle 23, started in 1996, and several periods of major activity have occurred this cycle. These events not only exercised SEC operational systems, but also 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 at SEC:

- Continued to refine the utility of the data from the ESA/NASA SOHO and ACE spacecraft.
- Expanded space weather products on the NOAA Weather Wire service.
- Developed the NOAA Space Weather Scales and implemented products to reflect the scales' categories.
- Improved data display and information dissemination systems.
- Initiated improved warnings using solar wind data.
- Initiated first physics model, the Magnetospheric Specification Model (MSM).
- Initiated plain-language space weather bulletins.

As a recognition of SEC's Space Weather Operations accomplishments, the SWO team won the Vice President's Hammer Award for rapid transition of research results into operations.

Prospective Look at Space Weather Services

Space weather is maturing as a discipline and a service. Scientific studies are being directed at improving space weather specifications and forecasts. As new research results evolve, appropriate models and data need to be integrated into Space Weather Operations to improve products for users. Changing technology is driving the need for new and improved products and service, and the general public is now becoming more aware of space weather and its effects, so major changes are expected in SWO over the next couple years:

- Text products will be made more understandable to the user (using the NOAA Space Weather Scales, for example).
- Plain language alerts, warnings, and watches of space weather will be issued.
- Space weather products will be integrated into the National Weather Service suite of services, including delivery systems.
- Current routine test products (Predictive Magnetospheric Particles and Fields Model and the Predictive *Kp* Model) will be made operational for general use.
- Real-time solar images, including X-ray images from GOES and Hα images from the USAF ISOON telescopes, will become available.
- New models, including ionospheric models, will be made available as routine test products.
- Verification and other quality factors for space weather forecasts will be made available.
- Users should be able to acquire, view, and display data seamlessly from SEC and National Geophysical Data Center.
- More tailored space weather products will become available from SEC partners and vendors.

The Space Weather Operations center is a busy place when there is space weather activity. The command center is a popular tour stop for visitors to the NOAA building (the David Skaggs Research Center) in Boulder, Colo.

Acquire and Use New Data

Many new satellites and sensors have begun to fill previous gaps in space environment data. The benefits will be great for forecasters, customers, and modelers. These satellites are sending a variety of information— images as well as environmental sensor data—to ground stations and then to SEC for use in operations.

Satellite	Orbit	Type of Information	Status
ACE	L1	Solar Wind Monitor	Current
GOES	Geosyn	Space Environment Monitors	Current
POES	Polar	Space Environment Monitors	Current
SOHO	L1	Solar Images	Current
SXI on GOES	Geosyn	Solar Images	Future
NPOESS	Polar	Space Environment Monitors	Future

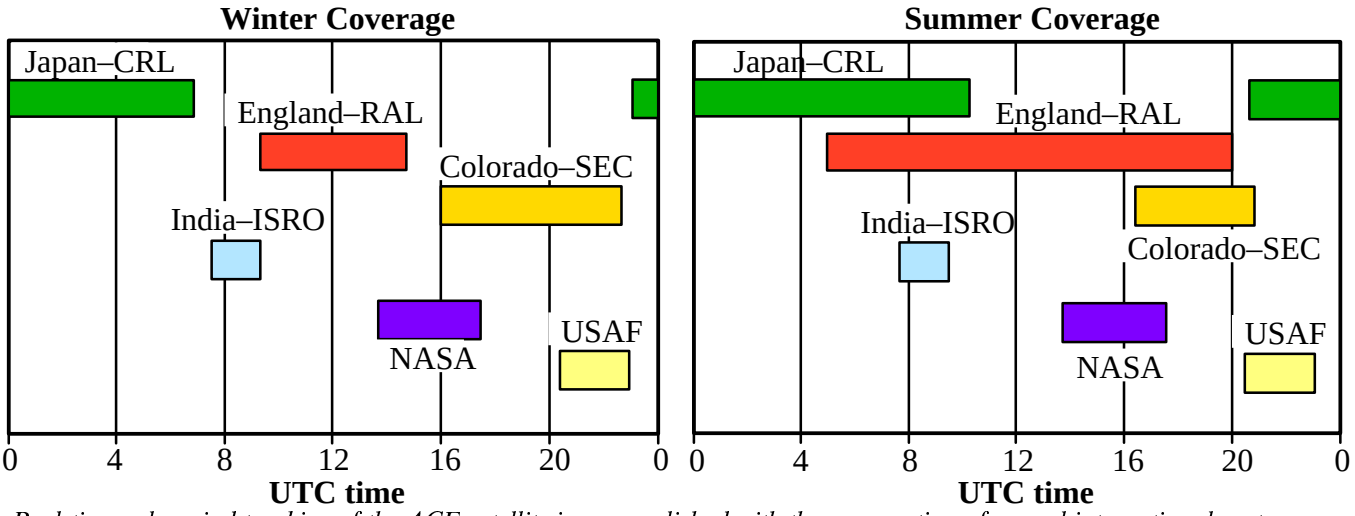
Real-Time Solar Wind Data from ACE

The Advanced Composition Explorer (ACE) satellite was launched by NASA into an orbit 1.5 million km (about 1 million miles) from Earth. The flow of continuous Real-Time Solar Wind (RTSW) data from ACE began on January 21, 1998. As the program became operational, SEC coordinated the efforts to piece together a system to receive the RTSW data continuously using ground systems located around the world. Data are sent to SEC where they are processed and used in Space Weather Operations less than 5 minutes after the time of broadcast from the satellite. World-wide tracking network partnerships, including CRL in Japan, RAL in England, and CNES in France, compliment the USAF and NASA stations. The SEC RTSW team was awarded the Department of Commerce gold medal award for acquiring and making available this valuable data stream.

These data enabled new SEC alerts and warnings of impending major geomagnetic activity with about an hour lead time. Data from the ACE satellite has meant the difference between a best guess and a sure thing in anticipating disturbances to the near-Earth environment. If a major geomagnetic storm occurs, it can cause dramatic changes in the geomagnetic field of Earth, leading to problems in delicate technological systems on satellites, in power grids, and in navigational systems. This critical data set is expected to last the lifetime of the ACE mission, or another 5 years.

Geostationary Operational Environmental Satellite (GOES)

Two NOAA GOES satellites, which routinely take the familiar weather pictures found on the nightly news, are stationed over the east and west coasts of the United States. These satellites also have space environment monitors (SEMs) on them that supply critical data to the space weather community. Designs for new satellites and their instrumentation are developed years before launch, and participation in the definition of the instruments is an important part of SEC work.



Real-time solar wind tracking of the ACE satellite is accomplished with the cooperation of several international partners. ACE orbits close to the sight-line of the Sun, so the ability to track it varies with the season.

In January 1998, Hughes Space and Communications Company was awarded the contract for the next-generation GOES spacecraft. The first of these satellites is to be ready in 2002. The GOES payload includes a Space Environment Monitor (SEM) instruments package that makes measurements used to provide advisories and forecasts of conditions on the Sun and in the near-Earth space environment.

The next-generation GOES satellites will have capabilities similar to the current series, but will include some significant improvements:

- The range of measured energetic particles will be extended to lower energies that affect spacecraft charging.
- A new instrument for measuring solar Extreme Ultraviolet will be added that is important for specifying ionospheric conditions that affect communication and navigation systems.
- Two improved Solar X-ray Imagers, developed by Lockheed Martin Missiles and Space, will be on the next- generation GOES.

GOES provides a broad range of energetic particle measurements that have become a staple for space weather specification. Data from GOES are key parameters in the NASA International Solar Terrestrial Physics Program (ISTP) data sets and are among the most widely used by the national and international scientific and forecasting communities.

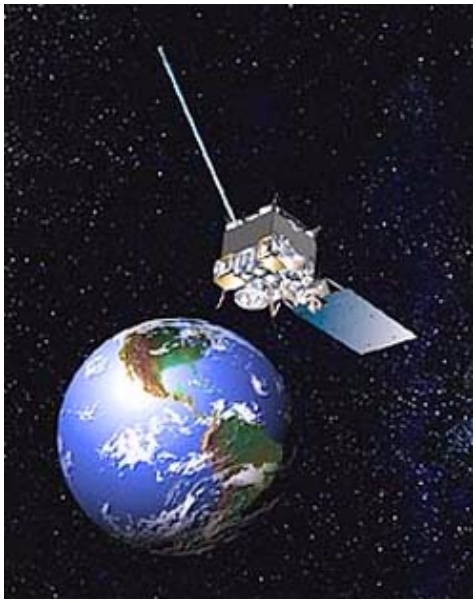
The GOES X-ray Sensor (XRS) data have recently been used in new ways for forecasting and specifying conditions. A proton event forecast, based on the x-rays, provides forecasters with better tools to issue warning of hazardous conditions during human spaceflight, and to conditions that can affect sensitive electronics in space. Another model based on XRS data specifies ionospheric conditions that affect HF communications.

Members of the NOAA GOES NO/PQ Team won the Department of Commerce Gold Medal for Leadership on the GOES NO/PQ Program in December 1999.

Polar Operational Environmental Satellites (POES)

The POES spacecraft fly in low-altitude polar orbits. They were originally referred to as the NOAA/TIROS spacecraft, and the first was launched in 1960. It was not until the early 1970's that these polar orbiting spacecraft carried sensors to monitor the space environment.

GOES NO/PQ series spacecraft



The most recent POES satellite launched (NOAA-15) is the first to have the new Space Environment Monitor (SEM2) with more energy channels covering a wider range of particle energies. It is now the primary POES monitor of the near-earth space environment.

Every alternate POES spacecraft also carries the Solar Backscatter Ultraviolet Sounding Spectral Radiometer (SBUV). This key solar UV radiation measurement is one of the longest records of solar chromospheric activity, spanning nearly 22 years.

The next POES satellite is expected to launch in the second half of 2000, and it will carry both the SEM2 and an improved SBUV instrument. In addition to overseeing the design and construction of the new SEM2 instruments, SEC has been the primary contract monitor for construction of nearly identical space environment monitors for the European polar orbiting meteorological satellites (METOP). Once the METOP satellites are launched, the data will be available to SEC to augment the POES SEM data that is now received.

Utilization of SOHO Data

The Space Environment Center continues to utilize the NASA SOHO Ultraviolet and Coronagraph imagery to monitor solar coronal mass ejections (CMEs) directed toward Earth. NASA Goddard Space Flight Center scientists routinely notify SEC of potential Earth-directed CMEs during normal working hours. SEC requested and

received software to make the suite of SOHO data available to SEC forecasters whenever the spacecraft is tracked. Included in the software package is the ability to run "difference" images so that faint features, such as Earth-directed halo CMEs, can be discerned. With suitable training in interpretation of SOHO data, SEC forecasters can now make their own determination, at any time, of the geoeffectiveness of real-time coronal mass ejections.

SEC continues to participate in empirical studies with SOHO scientists to develop better forecast methods as the experience with CMEs grows. Formal verification has not been done on forecasts that use SOHO data, but all forecasters feel their current forecasts are far superior to those from the last solar cycle when SOHO data were not available. The Vice President's Hammer Award was received for making these data useful.

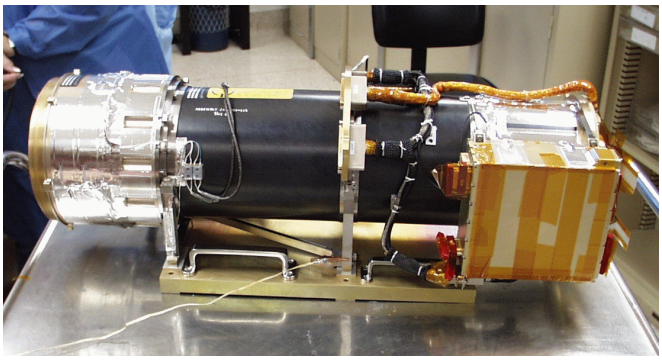
Solar X-Ray Imager (SXI)

SEC's SXI will be a new monitor of dynamic solar events that disturb space weather. It will be able to detect, in detail, solar coronal holes, flares and other transient phenomena, which will lead to better forecasting. Work on SXI progressed significantly during 1998 and 1999. The first of a series of such instruments that will monitor soft x-ray emissions from the Sun, SXI is slated be launched aboard GOES-M in mid-2001. The prototype instrument was tested and completed at Marshall Space Flight Center in 1998, and the instrument has been undergoing integration with the GOES spacecraft. The ground data system needed to handle the one-per-minute image load involves both hardware and software elements, and work on this large task has been a major activity. Concurrently, SEC scientists have been engaged in monitoring and advising on the design and construction phases of the second and subsequent SXI instruments now being built by Lockheed Martin Solar Astrophysics Laboratory.

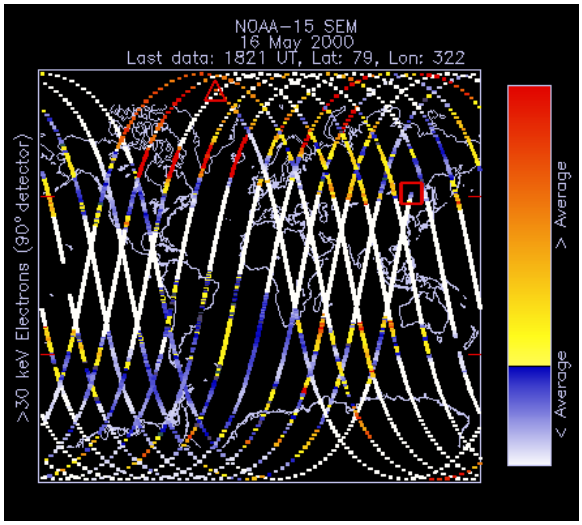
National Polar Orbiting Operational Environmental Satellite System (NPOESS)

A new generation of polar orbiting satellites is being developed to replace the present series of NOAA POES satellites. The present series of POES satellites is expected to last until 2008, as are the Defense Department DMSP satellites, so the first NPOESS satellite will not launch for several years. NPOESS will combine the requirements of the NOAA POES and DMSP satellites to create a joint satellite system to meet the needs of both the civilian and military communities well beyond 2010.

SEC participated on the NPOESS requirements definition teams to make sure that customer needs would be met. NPOESS includes requirements from both of the existing POES and DMSP systems as well as improvements and upgrades based on more stringent future needs. The specifications were sent out to industry for suggestions and responses. These responses have been reviewed and work is proceeding on updating NPOESS requirements.



The newest solar x-ray imager (SXI) under construction at Lockheed. The first SXI will fly on the GOES-M spacecraft in mid-2001.



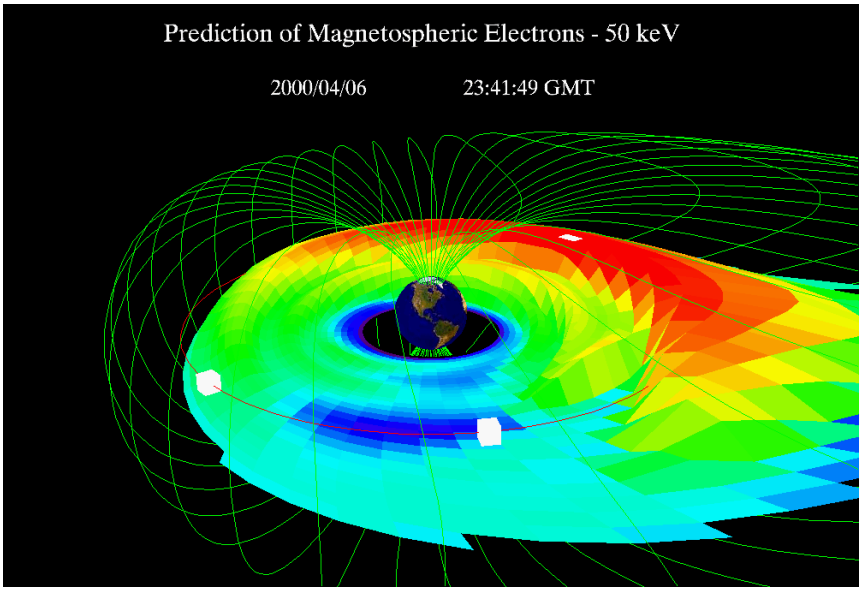
Each orbit of the NOAA-12 spacecraft is noted with the measured flux of electrons. Red levels would be dangerous to astronauts during extra-vehicular activity.

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. In order to provide continuous quantitative assessment and prediction of the geospace environment, numerical models must be used because of the extreme undersampling of the diverse, coupled regions of space. Future operational models, together with forecaster expertise, will greatly improve the quality of products for our users.

SEC is conducting multiple research efforts to enhance the value and availability of numerical models. In one role, SEC staff perform basic research, developing and improving models of the space environment.

SEC is also involved in various collaborative activities to develop numerical models and further their validation and availability for operational use. SEC is a consortium member of the Community Coordinated Modeling Center (CCMC), along with NASA, U.S. Air Force, and the National Science Foundation. The CCMC is a facility designed to develop and test coupled models of the space environment. The CCMC will both advance basic research and foster the development of robust, validated models that will be available for the SEC and USAF Rapid Prototyping Centers.



Predicted flux of 50 keV electrons within Earth's magnetosphere (red indicating high flux levels and blue indicating low levels). Representative magnetic field lines are indicated by the green lines. Geosynchronous satellites are shown as white cubes.

Rapid Prototyping Center

Research and development within SEC and throughout the world is improving our ability to specify and to forecast conditions in the space environment. From these continual advances, SEC must be able to choose the most valuable models and (or) data to improve space environment services, and be capable of implementing them efficiently into space weather operations. The Rapid Prototyping Center (RPC) is viewed as one important route toward enabling this capability.

The RPC is intended to expedite testing and transitioning new models and data into operational use. Efforts to establish the RPC have made considerable progress over the past 2 years. Milestones that have been achieved include: the graduation to operational status of the Magnetospheric Specification Model (MSM); the routine generation of test-product predictions of magnetospheric electron radiation using MSM; the establishment of a software and hardware framework to ingest, test, and graduate new models and data into operations; and the establishment of processes for software development and for model selection and graduation. With the experience gained from the initial models, much of the foundation of the RPC is now in place, and more rapid progress will be achieved on future models and data streams. As examples, both the Solar X-ray Imager project and the Imager for Magnetopause-to-Aurora Global Exploration satellite project benefit from the software and the hardware infrastructure developed for the RPC. The RPC development effort was initially supported by Sterling Software, Inc. through a Cooperative Research and Development Agreement.

A large number of numerical models and data streams are now available for space weather use. An important function of the RPC is to evaluate objectively and prioritize the potential model candidates. To accomplish this, a process has been initiated to evaluate each candidate based on three main factors: the strategic importance, the operational significance, and the implementation readiness. This evaluation will serve as the basis to determine the priority order for entry into the RPC, taking into account the estimated cost for transition and maintenance of the model and the

availability of resources. The candidates that are under consideration at present cover the full expanse of the space environment, from the Sun to the upper atmosphere.

Solar and Solar-Wind Modeling

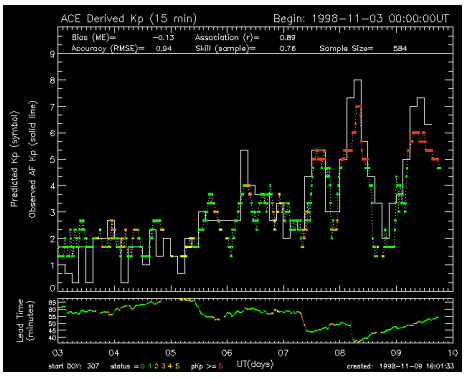
Solar and solar-wind modeling at SEC involves a variety of observations of the Sun and of the interplanetary medium used to understand solar processes and the transport of solar material to Earth and beyond.

- Models are used by SEC forecasters to predict the energetic proton fluxes resulting from solar flares.
- The Wang-Sheeley model, which provides a map of the global solar-wind flow, provides several day's warning of recurrent high-speed streams and sector boundary crossings. The model utilizes daily updated observations of the solar surface magnetic field.
- Another semi-empirical model has been brought on-line to provide an hour's advance notice of magnetic cloud structures about to impact Earth. The model uses ACE real-time data from L1 orbit as input.
- A probability model has been constructed on the basis of over 20 years of historical records, relating SEP incidence to observed flare temperature and flare intensity, extending the alert period before the onset of solar radiation storms.

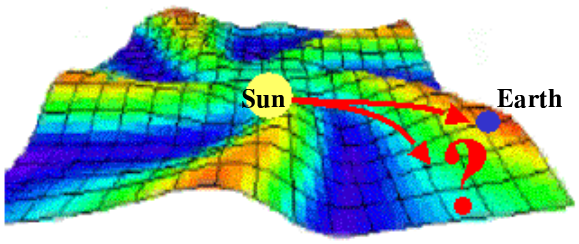
Magnetosphere Modeling

Modeling of the magnetosphere is an important element of SEC operations. Magnetosphere models give numerical guidance for conditions that affect on-orbit spacecraft, human activity in space, and ground-based activities; they also provide inputs to other models.

- Planetary geomagnetic activity index *Kp* is being predicted routinely using a neural-network algorithm. This model uses the real-time solar wind data obtained by the ACE spacecraft, and generates a prediction of *Kp* every 15 minutes.
- The Magnetospheric Specification Model (MSM) predicts the electron and ion flux levels within the magnetosphere, and is available in both a now-cast and a forecast mode. The nowcast mode is driven by the estimated *Kp* index produced by the U.S. Air Force using ground magnetometer data received in near real- time. The forecast mode uses the neural-network predictions of *Kp*, mentioned above, to produce a 1- to 2-hour prediction of the particle fluxes.
- Predictions of the daily fluence of relativistic electrons in the magnetosphere give 1-, 2- and 3-day warnings for conditions that can damage spacecraft. This model uses a linear prediction filter technique to predict the relativistic electron fluence based on measurements of the solar wind speed made by the ACE spacecraft.
- Another mode of operation being tested uses as input the predicted solar wind speed calculated from the technique mentioned above. At present this yields predicted electron fluence up to 8 days in advance.



The predictions of Kp *using the real-time ACE measurements are used as input to a model that gives approximately a 1-hour lead time for predictions of geomagnetic activity.*



Modeled solar wind speeds between the Sun and Earth show possible trajectories of disturbances emanating from the Sun (red arrows).

Foster a Space Weather Services Industry

SEC is constantly working to provide excellent customer service to its many and varied customers. Service provided by industry enhances all space weather services and benefits the customers. SEC would like for vendors to provide tailored customer services, while SEC focuses on improving generic, environmental nowcasting and forecasting services. Vendor-provided tailored services are vital to improving service, as SEC finds less and less time to meet individual user needs.

SEC took bold steps to enable vendor services development in the last 2 years by clarifying its own activities and offering partnerships to vendors.

Vendor Workshops

In 1998 and 1999, SEC held three vendor workshops (one at each Space Weather Week conference and one in the fall of 1999) where SEC and vendors discussed their respective roles and developed a working plan for fostering new products and services. The result of these meetings is the policy outlined below.

Essentials of the SEC Vendor Policy

SEC Strategic Activities—These are the activities that SEC regards as fundamentally its responsibility:

- Provide the Nation's official space weather alerts, warnings and watches.
- Synthesize a picture of the space environment.
- Forecast space weather.
- Provide services to the public.
- Conduct basic research.
- Conduct applied research.
- Foster a vendor industry.
- Provide support for government agencies.

Expectations for Working with Vendors—Vendors are expected to create products tailored[1] to specific end users; SEC will not compete with vendors in the area of tailored products.

SEC has a duty to describe the environment, but SEC can't model the environment at *all* cadences and *all* resolutions; SEC will supply certain products and not others, creating an opportunity for vendors. How SEC defines its duty to describe the environment must, because of sheer volume of work, be limited and prioritized based on an estimation of the importance to users.

SEC will release all public data and model outputs that SEC uses and when there is a user need. Except with prior agreement, SEC will not re-distribute vendor-owned product information.

SEC must have control of any model used to prepare SEC-issued operational products. Value-added products[2] based on that model's output would be the best they can be. Control of the model also means that SEC can choose to not issue a product if the quality is poor.

The Value of the Partnerships—Vendors and SEC contribute scientific and user expertise to any product development, giving assurance that the jointly developed products are firmly based on the best possible science.

SEC will provide reliable data access for its partner.

Vendors and SEC will collaborate on model development. In current partnerships, either the vendor has brought the model to SEC for further development, implementation, and validation or SEC has acquired the model for collaborative implementation.

Most importantly, customer services are improved or expanded by the joint efforts of SEC and the vendors.

Active Partnerships

Two formal types of partnerships used by SEC are the SBIR and the CRADA. SEC currently has two active partners:

Small Business Innovative Research—A Small Business Innovative Research grant (SBIR) Phase II was awarded to Northwest Research Associates, Inc., to develop a distributed computing system that would provide specific products to individual users and distribute data and products to a network of users.

Cooperative Research and Development Agreement—The Cooperative Research and Development Agreement (CRADA)[3] was written to be signed in 2000 with a new vendor partner, Federal Data Corporation, for development of a solar irradiance model.

1. A "Tailored Product" is space weather information that relates to specific customer hardware, environmental parameters, or local weather that is not routinely forecast or nowcast by SEC.
2. A "Value Added Product" is a product that may be derived from SEC products but has some other information or added benefit.
3. The CRADA with Sterling Software, SEC's first such agreements, produced tremendous benefit for the RPC (see page 7).

Modernize Data Handling and Information Dissemination

Data is at the heart of SEC, so data quality, reliability, timeliness and accessibility are of paramount importance. There is an ongoing effort at SEC to maintain and upgrade data handling and distribution systems. For example, access to data sources has been increased due to the changing method of acquiring and formatting the data.

SEC is responsible for all phases of real-time data: ingest, processing, display, analysis, validation, storage, dissemination and archiving. During the past 2 years our primary improvements have been in the areas of data display and dissemination.

Improvements in Data Display and Dissemination

The Information Dissemination System (IDS) is a migration towards a modern, framework-based, distributed object architecture. It provides a variety of interface options for data storage and client applications, on a variety of platforms. It is characterized by the following:

- Extensibility, expandability and supportability.
- Object-oriented design and implementation.
- Reliance on industry standards, such as CORBA (Common Object Request Broker Architecture).

Currently, all of the types of data stored by the data management system are available through the IDS system.

A primary client for the IDS system is the new Data Display System (DDS). This is the replacement system for the real-time monitors and call-up display systems used by SWO and many of SEC's partners. The DDS provides:

- Platform independence.
- Improved maintainability.
- Object-oriented design and implementation.

Phase I of the data display implementation was made available at the end of 1999. Real-time monitors are being phased into the SWO operations.

Efforts are underway to expand the use of the NOAA Weather Wire as part of the effort to integrate SEC's activities more closely with the National Weather Service (NWS). Improved connectivity through the NWS is now under development.

Product Generation and the Outside User System

The Outside User System (OUS) has become SEC's primary customer support mechanism. More data and products are reaching an increasing customer base and new data and products are made available in a more timely and efficient manner. Modernization of these systems has stressed improved reliability, redundancy for critical applications and more efficient use of resources.

Major improvements in the dissemination of SEC information have occurred:

- Major web re-design (not yet implemented).
- More efficient uses of new machines, which separated the product generation system from the Internet servers.
- Availability of new graphical products.
- New space environment measurements.

Data Storage and Access

Real-time space environment data is a national resource. To preserve and protect that resource, a major undertaking has begun to replace the custom Data Management System with a commercial off-the-shelf database system within the next 2 years. Requirements have been written and include:

- Improved reliability.
- Improved maintainability.
- Use of industry standards for data access.
- Implementation of sophisticated database administrator tools.

Proof of concept testing is in progress using an existing relational database to ensure the ability of the system to handle the real-time storage requirements.

Develop New Ionospheric Products

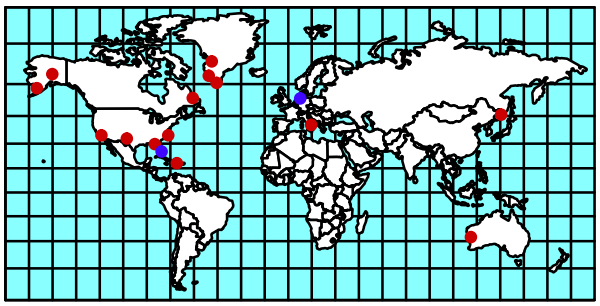
The ionosphere is a crucial part of the near-Earth environment, and its variability has a major impact on customers in the areas of communication and navigation. Over the past year some important new developments in ionospheric services have been made. These include the implementation of a new ionospheric product, improvements in data acquisition, and continued development of empirical and physical models.

New Product

The new ionospheric product introduced in 1999 targets the high frequency (HF) radio propagation community, and addresses the operational impact of x-ray flux on radio communications. The product provides a specification of absorption of HF-radio waves by the D-region, from the ionizing affect of solar flares, and is driven by GOES observations of the intensity of solar x-rays. During a flare the increased absorption can narrow, or even close, the window of usable frequencies. The product contains a global frequency map, an attenuation bar graph, and an estimated recovery clock. The global frequency map graphically illustrates the Highest Affected Frequency (HAF) as a function of latitude and longitude. This new product (see below) has been monitored for use and accuracy in the last 6 months of 1999.

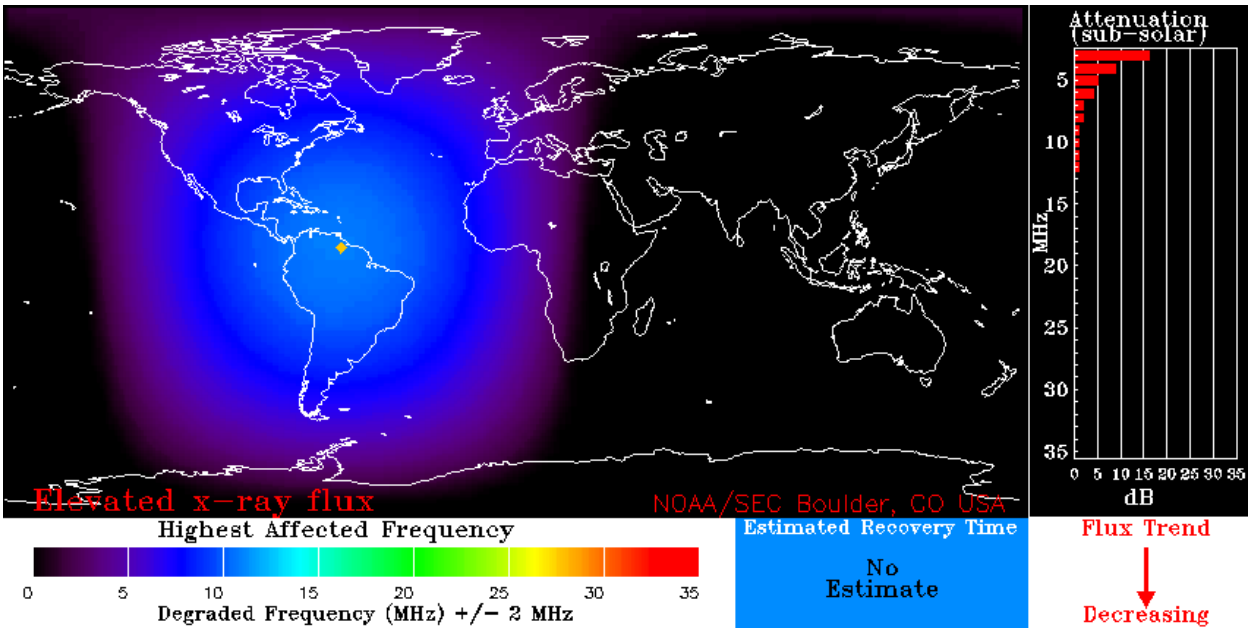
New Data

Another major advance in the ionospheric area has been a radical change in the acquisition of digital ionosonde data. The original method relied on a temperamental network link that restricted the volume, timeliness, and reliability of data. The new method utilizes direct transmission of data from the U.S. Air Force Digital Ionospheric Sensing System (DISS) to SEC. Several of the DISS sites have already been connected, and have already demonstrated the increased reliability of the new network links for data transfer.



DISS stations reporting ionospheric data are located around the world (red dots). The network is growing and several more stations are planned (purple).

The new system also enables many new ionospheric parameters to be made available to the users, and the



Global frequency map illustrates expected disturbances to HF radio wave propagation as a function of latitude and longitude.

Outside User System dissemination system has been upgraded to take advantage of these new capabilities. Data from the DISS sites, and from a number of other locations, are available in near real-time (within 15 minutes). SEC scientists in-house are planning to use this new data stream for developing new ionospheric products in the future. The data acquisition method has been coordinated with our NOAA partners in NGDC to ensure a seamless interface with recent data (within 1 month) available through SEC, and the historical data from the National Geophysical Data Center.

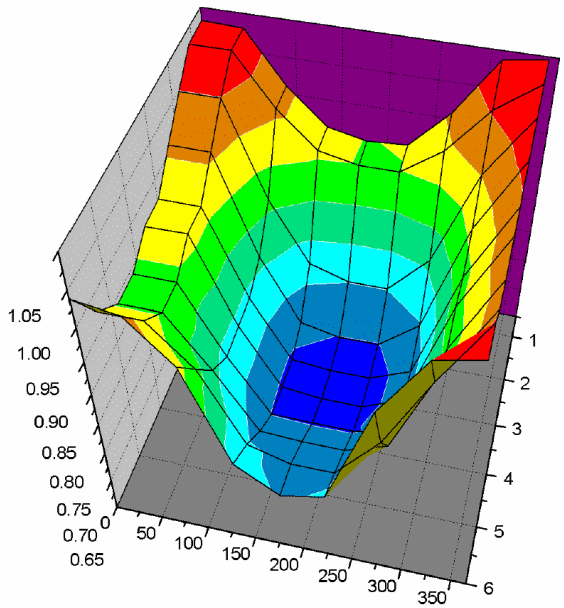
New Models

Research at SEC has led to fundamental advances in our understanding of the response of the ionosphere to geomagnetic storms, and is providing the foundations for ionospheric products for the future. Building on this new understanding, SEC scientists have developed a fast empirical storm-time ionospheric correction model.

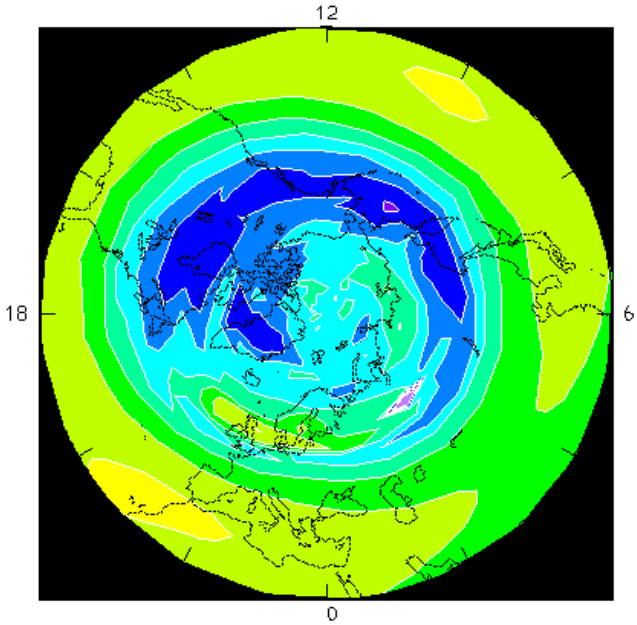
The model predicts the departure of the ionospheric *F*-region peak density from the climatological monthly mean or from an appropriate quiet-time reference model such as the International Reference Ionosphere. The magnitude and direction of the correction is based on the strength of the storm, as measured by *Ap*, and is a function of latitude, season, and local time. The model is particularly successful in capturing the ionospheric storm negative phase in summer mid-latitudes, where it describes more than 50 percent of the increase in variability during a storm. A real-time implementation of this ionospheric correction model is planned for the future and will be driven by the SWO prediction of the geomagnetic field, (for example, *Ap* index). A specification of ionospheric change has application for frequency management by the HF radio propagation users.

Providing a real-time simulation of the ionosphere for operational use requires a physical model, like the Coupled Thermosphere and Ionosphere Model (CTIM). This is a much more computationally demanding task than the model described above. Validation of a 50-day interval to test the accuracy of the model predictions clearly showed the scientific value of using physical models, but the operational value was much more difficult to quantify.

A more promising approach will undoubtedly require the optimal combination of model and data using assimilation techniques. This process has been used in the meteorological weather community for many years but is only just beginning in the space sciences. SEC scientists are currently involved in an ionospheric data assimilation effort under the Multi-Disciplinary University Research Initiative. Developing and applying these data assimilation techniques is one of the challenges for the future, and will undoubtedly provide the foundations for better ionospheric specification and forecasting products.



Empirical Ionospheric Storm-Time Correction Model output shows filtered Ap *(y) versus foF2 ratio (z) for all the days of the year (x).*



Ionospheric Variability Map showing deviation from normal conditions using a numerical model (CTIM).

Foundations of SEC

Research and Development

The unique nature of SEC, an organization that brings together 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 products and operations.

Within the Research and Development (R&D) Division, the staff contribute in three general areas:

- The science staff members conduct research in their areas of expertise, while computer programmers develop sophisticated code in standard languages.
- R&D supports programmatic activities, like the Responsible Scientist, Project Leader, and Development Leader for a new proposed product. R & D staff also have responsibilities for many of the satellite, sensor, and modeling activities discussed earlier.
- R&D staff provide expertise when SEC is called upon to answer user questions.

Research

The research mission of the Division emphasizes theoretical and experimental research studies directed at understanding the fundamental physical processes responsible for and causing:

- The observed energy release in the form of electromagnetic and particle radiation near the solar surface.
- The propagation of solar energy through the corona and out into the interplanetary medium.
- The transfer of energy from the near-Earth interplanetary medium into Earth's local space environment.
- The behavior and subsequent effects of this energy within the magnetosphere, the ionosphere, and the upper-atmosphere regions.

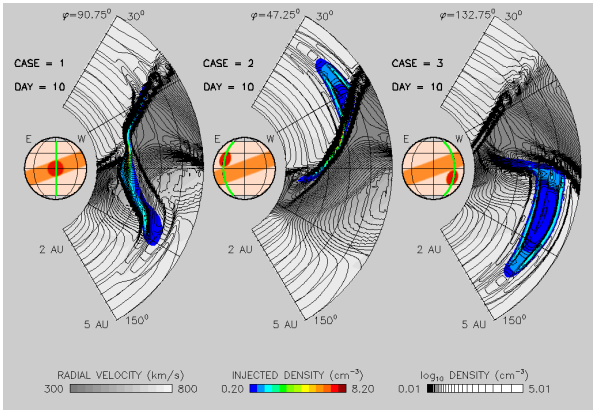
Research Satellite Missions

Research satellite missions provide unique opportunities to fill gaps or be prototypes for much-needed observations that can be used for space weather operations and future services. The NASA ACE is one such mission. The Hard X-Ray Spectrometer instrument is the result of a collaboration between scientists at SEC and the Astronomical Institute of the Czech Academy of Sciences. With support from NOAA, the U.S. Air, NASA, the instrument was flown and has the primary objective of determining the efficacy of predicting proton storms.

IMAGE is the NASA Imager for Magnetopause-to-Aurora Global Exploration satellite. IMAGE will provide SEC with real-time images of the northern hemisphere auroral oval, as well as other potentially valuable magnetospheric diagnostics.

Modeling

R&D staff are involved in numerous research projects. Highlights of recent results include models of the propagation of solar disturbances from the Sun to the Earth, studies on understanding the source of relativistic electrons in Earth's magnetosphere, models of the response of the ionosphere to geomagnetic storms, and further development of two ionospheric models. Data assimilation techniques that were developed earlier for numerical weather models are being applied to the ionosphere by researchers from SEC, Utah State University, and the University of Colorado, under a Multi-Disciplinary University Research Initiative sponsored by the Office of Naval Research and the Air Force Office of Scientific Research.



Model results of a coronal mass ejection propagating from Sun to Earth.

Computers and systems

SEC supports a variety of computer systems for a variety of uses including data handling, Space Weather Operations center, and customer and internal SEC access. There is an increasing emphasis on the use of PC's, because of low-cost, off-the-shelf solutions, and connectivity.

Highlights of the past 2 years include the move to the David Skaggs Research Center (DSRC), surviving Y2K, and upgrading system security.

The Move

The move from the NIST building to the DSRC was a major undertaking given the SEC objectives to minimize data loss, operational impact, and customer impact.

Through the establishment of dual operations centers, redundant critical systems, and phased-in system moves, these goals were accomplished with little or no loss of data and no impact on customer service.

SEC's primary ground station and solar observatory were relocated as part of the move and a third antenna system (funded by Forecast Systems Laboratory) was added to the ground station to enable tracking three satellites simultaneously. Currently, this antenna is supporting ACE tracking. The observatory telescope and control/automation systems are being refurbished and upgraded, and images from the observatory will be available in 2000.

Table Mountain Observatory

SEC continues to maintain an unmanned field site at Table Mountain Observatory (TMO) north of Boulder. This facility provides SEC with backup satellite tracking and is the only real-time source of ground-based magnetometer data. Recent improvements to TMO include roof replacement, lightning protection, a new magnetometer, and a dedicated T1 network connection to the DSRC, paid for with NOAA maintenance funds.

Y2K

A major effort by SEC ensured its code and systems were Y2K compliant. All SEC operational computer systems were reviewed and tested for Y2K compliance, and necessary modifications and upgrades were made. The systems survived the Y2K roll-over with almost no negative consequences.

Security

As SEC's computer systems have become more complex and sophisticated, and others' systems have been hacked, system security has become a major concern. To address this issue, SEC has formed an Information Technology (IT) security team to provide local expertise on IT issues. The team works on these tasks:

- Develop an SEC IT security plan and guidelines.
- Advise SEC management and staff on IT security issues.
- Protect SEC assets from loss, damage, misuse and corruption.
- Respond to DOC/NOAA/OAR requests and requirements.

Information Technology (IT) Architecture

SEC is in the process of developing an IT architecture that will provide a framework for change and growth. The primary goals of the architecture are:

- To allow SEC to take advantage of new technologies, but in such a way as to optimize the long-term management.
- To better utilize limited IT resources.

Partnerships

Military

Over the past year, the space weather functions of the military have undergone a significant realignment and will continue to evolve through the next 2 years. As part of a larger effort to "re-engineer" Air Force Weather, space weather operations were moved from Air Force Space Command to the Air Force Weather Agency (AFWA). The vision of this realignment was to provide the customer with a single source for "mud to sun"

weather support. The biggest impact of this change is that space forecasting functions currently located at Schriever AFB, Colorado Springs, Colo., are in the process of being moved to Offutt AFB, Omaha, Neb. By consolidating, military space weather support will be able to leverage the extensive computer infrastructure and expertise available at Offutt AFB, leading to more rapid model and product development.

Upgrades to the Air Force worldwide network of solar observatories have also been ongoing. A new Solar Radio Spectrometer improves upon older instrumentation used to identify radio sweeps and noise storms. The Improved Solar Observing Optical Network telescope is still under development, with the first installation planned for 2001 at Holloman AFB, N. Mex.

NOAA Corps

NOAA Corps commissioned officers augment the permanent civilian staff at SEC. The NOAA Corps officer billets are filled on a rotating basis, for typical assignment durations of about 3 years. SEC has a present allocation of four NOAA Corps officer billets.

Billets at SWO now include a Project Manager for Space Weather Operations and two Space Environment Forecaster positions. The previous Culgoora, Australia, billet was transferred to SWO in Boulder, following automation of the Culgoora facility. The USAF site at Learmonth, Australia, retains a Solar Analyst/Liaison Officer position.

Besides their important contribution to SEC staffing needs, NOAA Corps officers also provide SEC with a uniquely flexible personnel resource, and make valuable contributions to intra- and inter-agency liaison efforts on behalf of the SEC mission.

International Space Environment Service

International Space Environment Service (ISES) is a permanent service under the auspices of the International Union of Radio Science (URSI) in association with the International Astronomical Union and the International Union of Geodesy and Geophysics.

The purpose of ISES is to facilitate near-real-time international monitoring and prediction of the space environment, by

- Rapid exchange of space environment information.
- Standardization of the methodology for space environment observations and data reduction.
- Uniform publication of observations and statistics.
- Standardized space environment products and services to assist users and reduce the impact of space weather on human activities.

ISES also sponsors meetings and establishes working groups to improve space weather services and to promote the understanding of space weather and its effects for users, researchers, the media, and the general public. ISES members play an active role in the transition of scientific results into operational environments.

There currently are nine ISES Regional Warning Centers (RWCs), representing the major areas of the world. The RWCs are responsible for collecting space environment data from their geographical area, and providing timely, free, exchange of data, information, and techniques with other RWCs. They also provide near-real-time space weather forecasts and warning services for local users, assist the public in understanding space weather, and assist users in space-weather-related activities. SEC is the RWC for this hemisphere (outside of Canada) and also performs the function of World Warning Agency for the ISES.

National Space Weather Program

The National Space Weather Program (NSWP) emerged in October 1994 from the efforts of several U.S. government agencies to prepare the country to deal with the vulnerabilities of our technological world to space weather. Through the Office of the Federal Coordinator for Meteorological Services and Supporting Research these agencies drew up the goals of the NSWP, documented in the National Space Weather Program Strategic Plan. The specific direction of the federal government space weather efforts was outlined in the first National Space Weather Program Implementation Plan in 1997.

The second edition of the National Space Weather Program Implementation Plan is now completed. The document includes achievements during the first years of the program, and discusses plans for continuing research, development of new observations for research and operational space weather forecasting, and a set of operational models aimed at meeting user requirements. It has been developed concurrently with the National Security Space Architect's Space Weather Architecture. SEC was involved in all facets of development of the update.

Space Weather Week

The organizers of the 1998 User Conference and the Research-to-Operations Workshop, held at different times in Boulder, decided that the two successful meetings would be strengthened by combining the groups in 1999. Thus Space Weather Week was born where users and researchers now come together and discuss their joint needs and interests.

Space Weather Week 1999 split the week for the two conferences, with a 2–day overlap. Generally the users attended the first half of the week and the researchers the second. Results were favorable, and Space Weather Week 2000 will to integrate the activities with concurrent sessions during the week.

From the research side, Space Weather Week tried to motivate space weather research and to direct that research toward user priorities. Based on user needs and on the availability of research models, Space Weather Week 1999 included a "Prediction Challenge" specifically designed to evaluate existing models and obtain guidance for models that would be candidates for entering the Rapid Prototyping Center (RPC) and for potential transition into operational use.

On the user side, the conference gave a unique chance to experience the space weather community in these ways:

- Learn about space weather, particularly as it relates to their own systems.
- Network with vendors and other users.
- Request development or improved services.

Feedback from users has been critical in guiding efforts at serving SEC customers.

NOAA Space Weather Scales

A new, clear way to communicate with users and the general public about space weather was introduced in 1999, the NOAA Space Weather Scales. Like a Richter scale for space weather, the scales describe three different events:

- Geomagnetic Storms—disturbances in the geomagnetic field caused by gusts in the solar wind that blows by Earth.
- Solar Radiation Storms—elevated levels of radiation when the numbers of energetic particles increase.
- Radio Blackouts—disturbances of the ionosphere caused by x-ray emissions from the Sun.

As the NOAA Space Weather Scales will make both internal communication and interfacing with the public easier, and will increase awareness of the field. They are becoming widely accepted in the space weather community.

Education for all

A new video about the Sun and SEC has proved useful in K-12 schools as an introduction to space weather. The video has won several awards in the video industry and is popular with visitors and media as well as with students. It is also available in Spanish.

The animation used in the video of a CME (coronal mass ejection) stands by itself as a tool for scientific talks and media briefings. Designed to show one aspect of the Sun's emissions interacting with the Earth's magnetosphere, the animation illustrates a CME traveling to Earth on the solar wind and distorting the magnetic field of the Earth, with particles flowing into the upper atmosphere and producing the aurora around the pole.

Media "Discover" Space Weather

SEC schedules two TV crews per month on average, sees major stories about space weather every few months, and gets calls every week for interviews and background information.

Fueling much of this interest were two press briefings, in the fall of 1998 and 1999, and presentations to Broadcast Meteorologists at two of their annual January meetings. The attention shows the success of this type of outreach.

NOAA Scales

Vision of SEC in Five Years

There are some things SEC can be sure will occur and be achieved in the next 5 years. Space weather services will improve as more data and better models come online; partnerships of all kinds will become more important; the need for space weather services will grow; and carefully selected research and development will lead to improvements. SEC plans to do the following:

Better describe the space environment

- Higher skill, accuracy, and timeliness.
- Better organization in our products.
- Improved terminology.
- Improvements in the observations and models that go into the products.
- Specific services tailored by vendors.

Make space weather products part of a seamless National Weather Service suite

NWS field offices will be providing support and coordination with local emergency managers.

Move data streams and models into operations through the Rapid Prototyping Center

Numerical model output that forecasts conditions and extrapolates from sparse measurements will be available for various phenomena:

- Auroral currents.
- Earth's energetic electron belts.
- Sudden increases in solar particle events from CMEs.
- Solar wind, both the background and that resulting from solar coronal mass ejections.
- Disturbances in the ionosphere.
- Spectrum of EUV output of the Sun.
- The first large-scale Sun-to-Earth numerical models.

Develop and utilize assimilative space weather models

Modern techniques of data assimilation used in terrestrial weather modeling allow diverse observations to be assimilated into a single model to provide the most accurate description of the environment. SEC will:

- Develop and implement advanced assimilation techniques for processing ionospheric data.
- Apply similar techniques to other space weather data.

Use new observations

New images and data will be available to forecasters as well as to researchers and the public. The data will flow from new NOAA, NASA and USAF sensors:

- Solar images made with the SXI on GOES-M, showing all flares and coronal holes.
- Automatic feature recognition in images at several wavelengths.
- Solar EUV monitored at GOES.
- Magnetospheric energetic particle fluxes from GOES at intermediate energy ranges.
- A three-dimensional view of solar activity away from the Sun-Earth line.
- Solar-wind measurements from Triana, and possibly, a NOAA-USAF Geostorms.
- Auroral electrojet location and intensity in real time.
- Helioseismology to see inside the Sun.

Strengthen partnerships nationally and internationally

National Space Weather Program partners will provide data, modeling and research in these ways: USAF for data acquisition, product generation, and modeling; NASA for data and modeling, including "Living with a Star;" NSF for research and modeling; and CIRES for research.

Commercial vendors will be providing space weather services to customers and working with SEC to suggest needs-based research and product development.

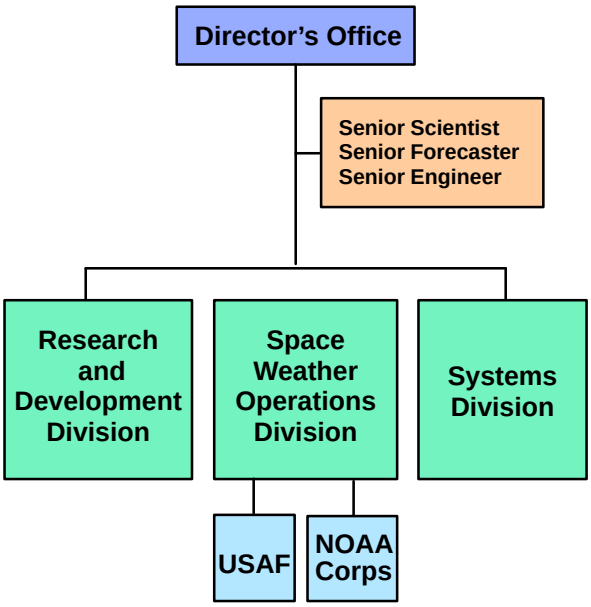
International Space Environment Service, through the Regional Warning Centers, will provide data acquisition and product generation.

Modernize internal data handling and provision to users

The flow of data and information from SEC will satisfy internal and external needs through:

- Replaced database.
- Improved data and model output distribution.
- Present new information on the SEC Web site.

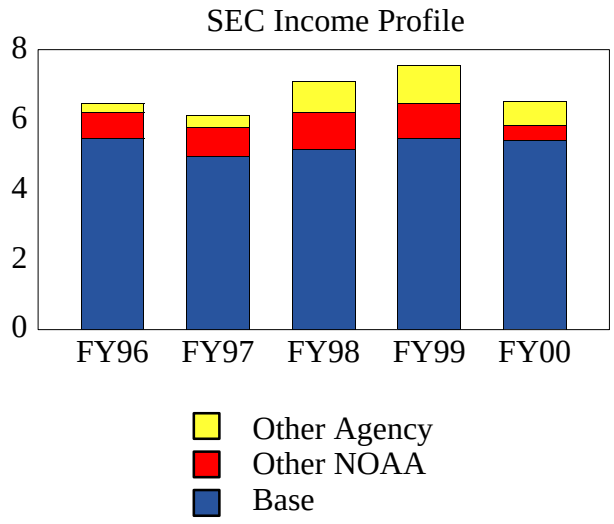
Facts about SEC

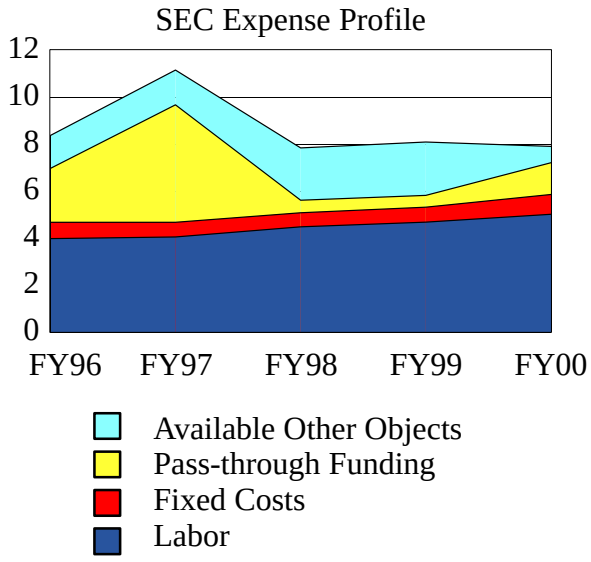


Center Organization—SEC continues to operate within a streamlined structure that minimizes organizational levels. Staff is encouraged to work across organizational boundaries supporting the multitude of projects conducted by the Center.

Funding—The major source of funding at SEC is by direct appropriation from Congress; supplementing this base funding we receive a nominal amount from special NOAA programs and from other agency sponsors. While our base appropriation has increased slightly during the past 2 years, the increase has not been able to make up for the erosion of funds due to inflation and mandated salary adjustments.

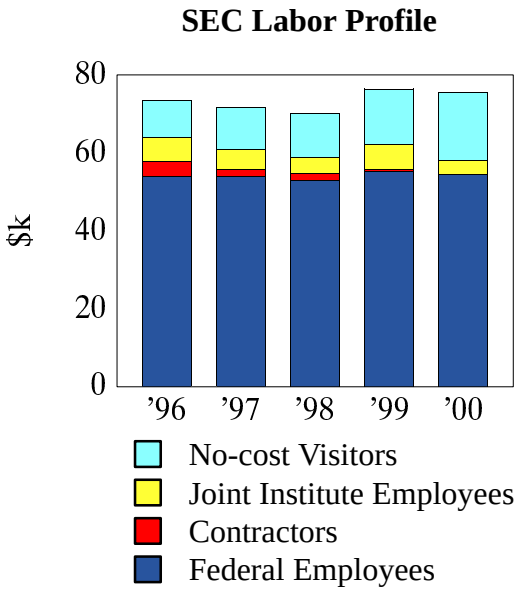
Beginning in 2000, SEC is realigning its internal financial systems to allow greater accountability of our expenses. All spending will be tracked directly back to the SEC theme that the work is supporting. Tracked themes include Space Sciences Research, Space-Based Sensors, Planning and Future Projects, Ground-Based installations, Data Ingest Processing and Verification, Products and Services, and Forecast Center Operations. We anticipate a greatly enhanced ability to produce usable and reliable management reports.





Personnel

Personnel—SEC continues to benefit from a wide range of Joint Institute employees, visitors, and various special guest workers. SEC has been able to continue its high level of research, development, and operational activities through the addition of this non-federal staff.



EEO and Diversity—The Space Environment Center is committed to the principles of Equal Employment Opportunity and Diversity. SEC enjoys a broad representation of different cultures through our many international employees and visitors. To foster greater diversity in the space weather and space physics fields, SEC has devoted resources to the development of educational materials for elementary, junior and high schools. The Space Environment Center also introduces college students to space science through employment in the University of Colorado work-study program.

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 professional organizations, interest groups, and members of numerous organizing committees of meetings. A few examples of SEC staff critical roles follow:

- Co-chair of the National Space Weather Program's governing Committee on Space Weather.
- Secretary for ISES and a member of the ISES Directing Board.
- Secretary-General of the International Association of Geomagnetism and Aeronomy (IAGA).
- Secretary-General of the International Union of Geodesy and Geophysics (IUGG).
- Fellow of CIRES.
- Chairman of SHINE.
- Member of the NASA Solar Dynamics Observatory mission concept team.
- Several members of the NASA Living with a Star project teams.
- Member of the National Solar Observatory SOLIS advisory group.
- Chair of the COSPAR (Committee on Space Research) Panel on Space Weather.
- Secretary of the American Geophysical Union's Space Physics and Aeronomy-Solar Magnetospheric Section.
- Member of the NSF Geospace Environment Modeling (GEM) Steering Committee.
- Member of the NSF Geospace Global Circulation Model (GGCM) Steering Committee.
- Member of the SCOSTEP S-RAMP Committee on Space Weather.
- Member of the National Solar Observatory Users' Committee.
- Member of the Science Advisory Committee for the International Arctic Research Center in Fairbanks, Alaska.
- Chair of the Common Spaces Committee of the David Skaggs Research Center. The Committee won a Department of Commerce Bronze Medal Award for their work.

Space Environment Center Staff and Associates

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Lewis, Dave	3170
Masten, Bob	5716
Prendergast, Kelly	5697
Raben, Vi Hill	5691
Sayler, Steve	3959
St. Marie, Pete	5045
Wolf, Carol, *Sec'y*	5828

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Doggett, Kent	3317
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Hirman, Joe, *Chief*	5688
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Miller, Warren	3749
Nelson, Gayle	3990
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Recely, Frank	3204
Schweitzer, Mike	6570
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Williamson, Court	5153

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Smithtro, Chris, Capt	5999

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Detman, Tom	5394
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Garcia, Howard	3916
Greer, Sue	5418
Hill, Steve	3283
Matheson, Lorne	3164
Muckle, Alex	3966
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Onsager, Terry	5613
Pizzo, Vic	6608
Puga, Larry	5763
Sahm, Susan	5884
Singer, Howard, *Chief*	6959
Smith, Zdenka	3473
Vierick, Rodney	7348

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Arge, Nick CIRES	7394
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Sauer, Herb Ret-NOAA	3681
Speiser, Ted Ret-Univ of Colo.	3284
Williamson, Zach CIRES	----

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Crumly, Mike	3313
Deitemeyer, Pat, *Sec'y*	7583
Garcia, Nancy	3314
Grubb, Dick	3284
Heckman, Gary	5687
Hildner, Ernie, *Director*	3311
Poppe, Barbara	3992
Zwickl, Ron, *Asst. Director*	3029

GUEST WORKERS

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Joselyn, JoAnn IUGG	5147

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Ananthakrishnan, S., M. Tokumaru, M. Kojima, V. Balasubramanian, P. Janardhan, P. K. Manoharan, and **M. Dryer**, Study of Solar Wind Transients Using IPS, in *Solar Wind 9: Proc. 9th International Solar Wind Conference*, (S. Habbal, R. Esser, J.V. Hollweg, and P.A. Isenberg, Eds.), **471**, 321–324, American Institute of Physics, Woodbury, NY, (1999).

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