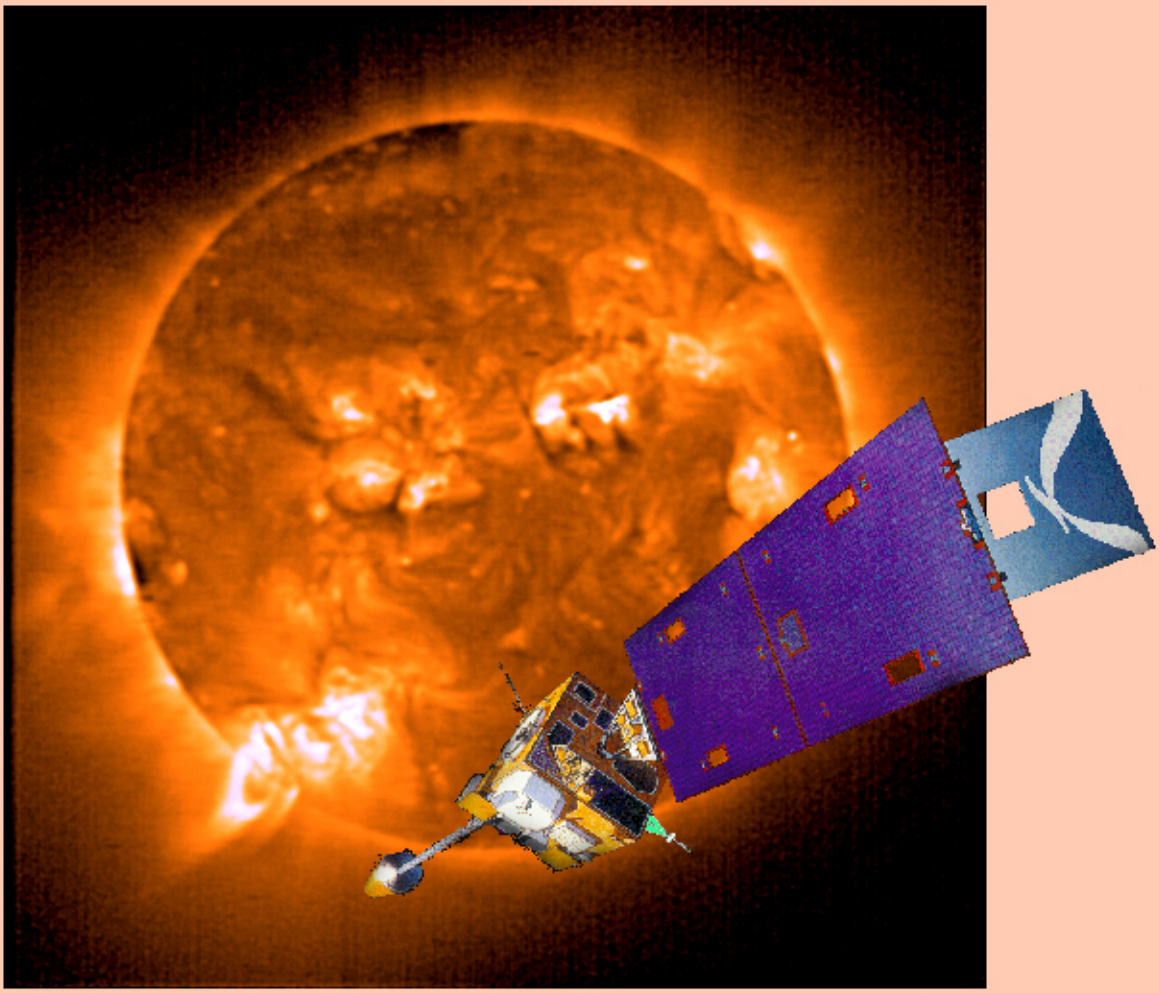
Space Environment Center 2000–2001



U.S. Department of Commerce

National Oceanic and Atmospheric Administration

Office of Oceanic and Atmospheric Research
National Centers for Environmental Prediction

February 2002

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

A Message from the Director

The pace of change is constantly increasing, and nowhere is that more true than for space weather research and services. The last 2 years in the life of Space Environment Center (SEC) have brought innumerable changes, and many will be highlighted in the following pages. Here are just a few of the changes that have occurred at SEC:

- the solar cycle rose, peaked, fell, and threatens to peak again;
- an outside review of our space weather services resulted in a change in the functions and job titles of personnel in the Forecast Center and a reduction in forecaster staffing there;
- four new models were introduced into operations;
- the NOAA Space Weather Scales saw increasing popularity and use;
- the annual Space Weather Week meeting continued to grow and attract new co–sponsorship;
- SEC developed a new 5 year strategic plan;
- our Air Force counterparts moved from Colorado Springs, Colo., to Omaha, Neb.; and
- NOAA's first Solar X–ray Imager was launched and tested.

Whew! One of the most welcome changes is that SEC's gloomy financial picture brightened, somewhat, and we hope that the shrinkage of SEC has ended.

The many accomplishments (both achieved and planned) presented in this report are only possible because of the strong and energetic staff at SEC. Our Cooperative Institute for Research in the Environmental Sciences and U.S. Air Force partners are vital parts of the organization, as are our NOAA Corps officers, long–term guest workers, and vendor partners. Our collaborations with other parts of NOAA and other agencies, often through the National Space Weather Program, have brought us new data, helped us with our research, and influenced national efforts like the NASA Living with a Star Program. Of course, SEC staff plays a significant role in the International Space Environment Service (ISES), and SEC benefits hugely from its membership in ISES.

Homeland security has become a major focus of government efforts and SEC intends to do its part, particularly in the arenas of communications, radio-navigation, and support to the nation's electrical energy industry. We are forging new partnerships, within the government and out, to better understand and predict the ionosphere both over the globe and over specific regions.

In the last 2 years SEC has made great strides, and we look for even more changes in the next 2 years. As the following pages make clear, we are proud of what we have accomplished, and we face the future with optimism and enthusiasm.

Dr. Ernest Hildner, Director

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Space Environment Center

Cover: On September 7, 2001, the new Solar X-ray Imager aboard GOES–12 delivered its first public image; this and subsequent images were immediately put to work in the Nation's space weather services for civilians (NOAA) and the Dept. of Defense (AFWA). For more information, visit our Web site at http://sec.noaa.gov

Welcome to Space Environment Center

GOES-N launches a new era of solar x-ray imaging, culminating over 25 years of inspiration, advocacy, planning and accomplishment.

New Interest in Space Weather Research and Services

In the last few years, there has been a large increase in society's dependence upon systems adversely affected by space weather. Not only do we depend more heavily on systems already in use, new systems and new modes of operation using old systems vulnerable to space weather have proliferated.

- Satellites are becoming smaller and cheaper because of reduced component size and increased computer speeds. Economic competition drives a need to reduce shielding and redundancy, but these changes leave satellites more vulnerable to space weather disturbances.
- U.S. airlines are offering passengers the convenience of non-stop flights over the North Pole to Asian destinations; these flights (and research flights in Antarctica) sometimes experience air traffic control difficulties due to space weather.
- National policy and defense planning have resulted in increased reliance on the use of commercial systems to gather information and move it between the United States and troops and ships in hot spots around the world. However, experiences during severe conditions of the last solar cycle indicates that some users may experience performance failures and degraded results during times of high solar and ionospheric activity.
- The nation is also placing large numbers of astronauts into radiation-vulnerable orbits for unprecedented periods of time during the assembly and operation of the International Space Station.

Our increased need for improved space weather information to insure safety, reliability, and defense are inevitable outcomes of our growing use of space-weather-sensitive systems.

Space Environment Center (SEC) has been keeping up with the changes, responding to new customer needs, research breakthroughs, and the changing face of space weather services. This report is intended to show what has been accomplished in the last 2 years, and what is planned for the next few.

Contents

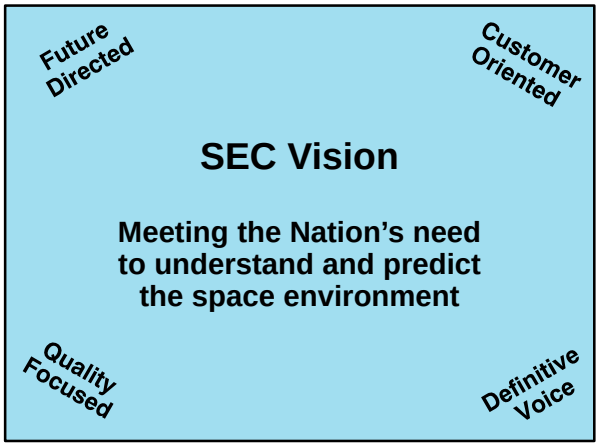
Strategic Planning

In Fiscal Year 2001, SEC undertook extensive strategic planning based on the "balanced scorecard" model (*The Balanced Scorecard*, R.S. Kaplan and D.P. Norton, HBS Press, Boston, 1996). The balanced scorecard requires that management consider and prioritize all the activities necessary to move an organization like SEC into the future. It accommodates several simultaneously important objectives and allows priorities under each objective. Task lists and an annually updated operating plan flows from this framework of priorities.

The activities SEC anticipates in the next 5 years are set against the expected backdrop of customer needs and the increased availability of data and mature models; both will improve services. SEC research activities will lay the groundwork for these improved services. Development and transition will make it possible to utilize the latest internal and external research. SEC will participate in additional efforts with its partners in other federal agencies and with global partners through the International Space Environment Service and bilateral international partnerships.

The Balanced Scorecard

The SEC balanced scorecard captures a broad view of the Center's activities from four Perspectives: External, Internal, Human and Financial. It was also helpful to identify four basic Themes that cut across all of SEC: Data, Operations, Development and Transition, and Research. All of the work done at SEC is captured in the matrix of these Perspectives and Themes, and addresses the total customer base of SEC, in and outside of NOAA.



MISSION

"Serving the Nation's Space Weather Needs."

Space Environment Center

- continually monitors and forecasts Earth's space environment;
- provides accurate, reliable, and useful solar-terrestrial information;
- conducts and leads research and development programs to understand the environment and to improve services;
- advises policy makers and planners;
- plays a leadership role in the space weather community; and
- fosters a space weather services industry.

Space Environment Center is the Nation's official source of space weather alerts and warnings.

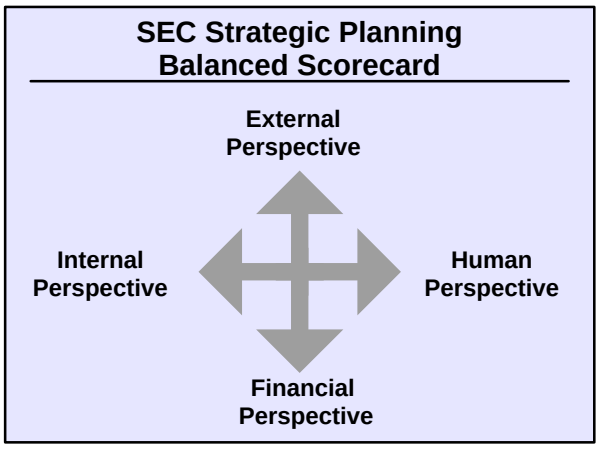
SEC staffers have participated in the data gathering and results, and they will continue to be involved as the strategic planning model is used in successive years to evolve the plan.

Vision and Goals

To fulfill its part of the Strategic Plans of NOAA, NOAA Research, and the National Weather Service and its National Centers for Environmental Prediction, SEC strives to meet the Nation's need to understand and predict the space environment. SEC will provide citizens, commercial enterprises, and government agencies the alerts and warnings they need to safeguard systems and lives. SEC will remain the definitive voice for space weather information, by being customer oriented in providing service, and by remaining quality focused and future oriented.

Objectives and Actions

What follows is a comprehensive list of strategic objectives and the actions that will achieve those objectives. They are organized by Perspectives and are listed in priority order under each Perspective. This Strategic Plan is tightly defined while being complete in its description of the work done at SEC.



Science and Service

(External Perspective)

SEC, with both research and operational arms, will use its unique position to advance our understanding of the space environment and to use the best research models and data to improve operations, thereby improving service to customers.

- *Be a center of excellence for space weather services.*
- *Improve our understanding of the space environment and its effects.*
- *Transition research into operations.*
- *Provide guidance, vision, and information regarding space weather issues.*
- *Increase space weather awareness.*
- *Support a space weather services industry.*
- *Seek guidance and advice.*

Organizational Culture

(Internal Perspective)

SEC will conduct its business with an awareness of the "best practices" of business and government, ensuring that the best work is accomplished with the proper attention and support.

- *Utilize strategic and tactical planning to set priorities.*
- *Be adaptable and poised to take advantage of changing circumstances.*
- *Support SEC goals by having all components work together.*
- *Strive to improve all aspects of SEC.*
- *Maintain and evolve infrastructure and technology.*

Our Human Side

(Human Perspective)

SEC values each individual in the Center and will work to encourage and promote communication, career development, empowerment and local decision-making.

- *Attract and retain a diverse, well-trained, and competent staff.*
- *Maintain a balanced staff workload.*
- *Maintain a workplace that supports high productivity.*
- *Empower staff to work with initiative.*

Resources

(Financial Perspective)

The SEC commitment to excellence cannot be separated from the realities of financial constraint. SEC will manage its financial responsibilities with commensurate attention.

- *Achieve financial health.*
- *Use resources effectively and efficiently.*

Projects

Planning for 2002, we have identified 15 projects, many of which cut across the Divisions of the Center, to focus our efforts. All effort at SEC will be charged to one or another of these 15. In the future, the list of tasks will change as needs and plans evolve.

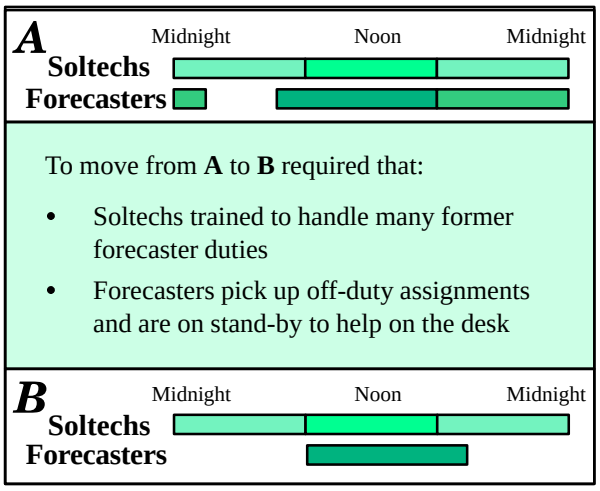
1. Real-time Solar Wind Systems
2. Ground Facilities
3. Outside User System (OUS)
4. IT Support
5. Engineering Support
6. IT Architecture and Infrastructure
7. External Affairs
8. Space Weather Operations
9. Space Weather Enhancements
10. Research & Development
11. GOES SEM
12. GOES SXI
13. POES/NPOESS
14. Space Weather Data System (SWDS)
15. Management and Administration

Space Weather Operations Reassessment

Over the past 2 years a number of significant events have had strong impacts on Space Weather Operations (SWO). First, some key personnel retired and due to a stringent budget, these senior individuals could not be replaced. Their departures were losses not only from the personal perspective, but professionally they possessed a wealth of irreplaceable experience. Second, space weather activity occurring during this maximum epoch of Solar Cycle 23 has not been as severe as anticipated. With Solar Maximum levels of activity less than anticipated, it was possible to revise the shift schedule of the 24/7 operation.

With short staff and lower activity levels, changes in the concept of operations were proposed, and as an aid to change, a full review of SWO activities was planned. This "reassessment" was designed to bring experts in the field of operational space weather services to SEC, and from them gain a fresh insight into the practices that have so long been embedded in SWO culture. In March 2001, a panel of seven external reviewers worked with SEC staff to evaluate what SWO does, and to recommend how that endeavor could be improved. The panel said SWO needs to know its customers as well as possible, and to design products and services to meet their needs. A few other significant recommendations were to emphasize working with external partners, improve the verification program, and more effectively transition operationally desired models.

Although the reviewers gave feedback focused on suggested changes, they repeatedly praised how well SWO is currently providing services in light of the stringent personnel and fiscal constraints. These very knowledgeable reviewers see SWO as the leader in worldwide space weather services, a high compliment. The reviewers came from TRW, Northwest Research Associates, the Air Force Research Lab (AFRL), the University of Michigan, the Air Force Weather Agency, NASA, and IPS Sydney.



Their questions revolved around the issues listed below, and focused, always, on balancing efficiencies, limited resources, and high quality and quantity services.

- Vision (SWO perceptions of itself and its users)
- Operational Functions (efficiencies and emphases)
- Users (providing appropriate services)
- Products and Delivery (the right products delivered the right way)

Results

Recommendations from the group were clear, direct, relevant and helpful. As a result, some changes were set in motion.

- On August 1, SWO transitioned to a single, 10-hour forecaster shift each day. To prepare, SWO devised an extensive training program for the Soltechs, who are now bearing a heavier operational load, and new standardized documentation was written to help the transition. The new duties resulted in the definition of a new job title (Operations Specialists) and a more attractive and fulfilling career path for the former Soltechs. Reducing forecaster time on-shift makes more time available for the forecasters to work in the areas of verification, model transition, and customer service as recommended by the panel. The transition to one forecaster shift each day, better documentation, and enhanced Soltech skills, were all suggestions of the panel.
- SWO ceased production of the Solar Coronal Disturbance Report in early June 2001, after notifying customers and helping them shift to better data sources for that information. That took a bit of work — it's surprising how much effort it takes to stop doing something — but it saved resources, and the product had outlived its utility. This was another action suggested by the review panel.

Acquire and Use New Data

Satellite and ground-based data are used to monitor the space environment that affects customer operations, to provide input to models, to validate model outputs, and to improve our understanding of the solar-terrestrial system. SEC relies heavily on space environment measurements from our own NOAA geostationary (GOES) and low-altitude polar-orbiting (POES) satellites. Other examples of the thousands of data sets SEC receive are solar data from the NASA and ESA SOHO satellite; solar data from ground-based solar observatories; solar wind and energetic particle data from the NASA ACE satellite; geomagnetic variation data from the USGS ground-based magnetometers; and ionospheric data from the Air Force network of ionosondes.

SEC invests significant effort evaluating the need for new data, and participating in other agency, institution, or international programs that hold promise for providing data crucial for improving space weather services. One recent example involves participation in the NASA Living with A Star Program where SEC is helping to define the elements of the program. SEC eventually expects to take advantage of the data that will be returned.

A few highlights of data activities are described below.

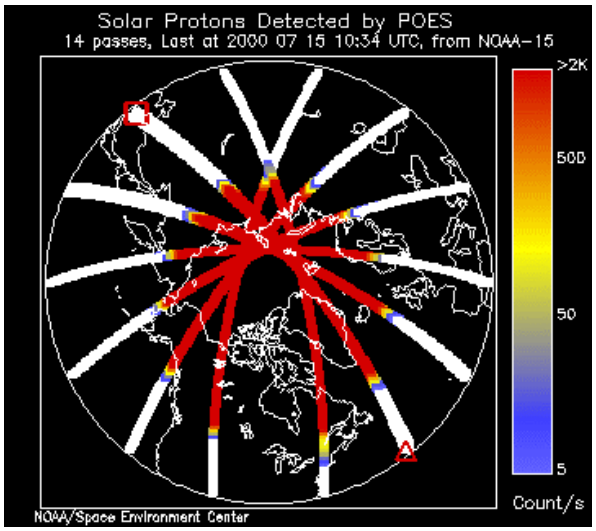
Geostationary Operational Environmental Satellite (GOES)

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 to supply critical data to the space weather community. The SEMs include measurements of solar energetic particles, solar whole-disk integrated X-rays, energetic particles in the Earth's magnetosphere, and geomagnetic field variations. Recent GOES launches were GOES-11 on May 3, 2000, and GOES-12 on July 23, 2001. While supporting the development and testing for SEMs on the next generation of GOES satellites, SEC has also begun preparations for ingesting data from satellites that include new instruments to measure solar EUV and a broader range of energetic particles. The first of these satellites, GOES-N, is scheduled for launch no earlier than 2004. SEC has also contributed to planning and writing an operational requirements document for yet another generation of GOES satellites, the GOES-R series that will be launched no earlier than 2010.

Polar Operational Environmental Satellites (POES)

NOAA-16, which carries a SEM, was launched and placed in operation in September 2000. Together with NOAA-12, NOAA-14, and NOAA-15, it provides a constellation of four POES spacecraft for monitoring the low-Earth-orbit space environment. This constellation will be augmented by NOAA-17 scheduled for launch in mid-2002. While several of the detectors in the older NOAA-12 and NOAA-14 SEMs have suffered degradation over the years, all instruments continue to provide useful observations at a high cadence and in a timely fashion.

Auroral particle observations are utilized as soon as data are available at SEC to estimate the level of auroral activity. Those estimates, together with a visualization of the geographic location and extent of aurora for that level activity, are updated every 10 minutes and made available on the SEC Web page. In 2001, a new Web page, designed to provide information of the impact of solar proton events upon the atmosphere, was implemented (see below). This page displays the most recent 8 hours of energetic proton data from all satellites and shows the geographic extent of energetic solar proton influx to the polar region. This provides information

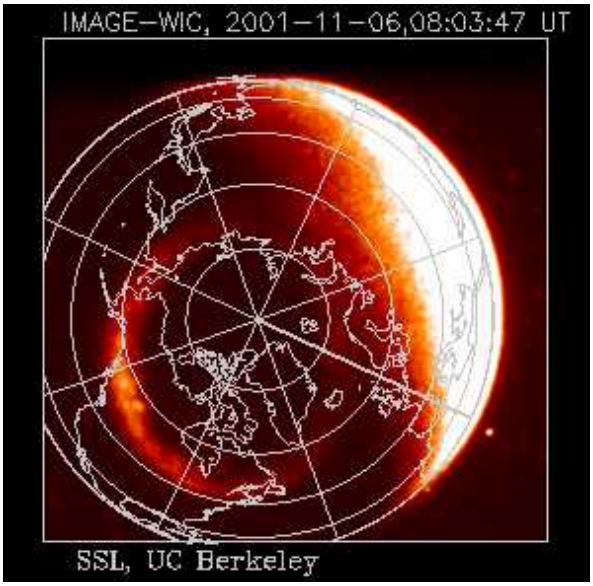


Solar Proton Event (SPE) data in the northern hemisphere observed by POES satellites during the July 2000 storm. This sample display clearly shows the bounds of the solar proton influx for individual satellite transits. With modest extrapolation, the boundaries can be defined on a global basis.

about the areas of the globe that will suffer degraded HF radio propagation.

With the launch of NOAA-16, NOAA is once again collecting solar UV data with the SBUV2 ozone instrument. SEC has upgraded the ingest system to provide near-real-time analysis of the SBUV2 data and prompt output of the Mg II index. This proxy for solar chromospheric activity has proven to be a much better proxy for solar EUV flux than the radio brightness of the Sun (F10.7) and is now being provided operationally to our CRADA partner and to the US Air Force.

Imager for Magnetopause-to-Aurora Global Exploration (IMAGE)



This Figure shows the north pole of Earth from the IMAGE Satellite. The sunlit part of Earth is on the right and the aurora can be seen in the left half of the image

An important activity for SEC is to identify new data and research capabilities and to test them for their potential application to space weather needs. The IMAGE satellite is a NASA Explorer mission designed to view Earth's space environment as it is driven by solar activity. This satellite was launched in March 2000. SEC receives images of high-latitude auroral activity in real time through partnerships with NOAA/NESDIS in Fairbanks, Alaska; the University of California, Berkeley; the Communications Research Laboratory (CRL) in Japan; and NASA Goddard Space Flight Center. These images indicate, roughly, the location and intensity of high-latitude space weather disturbances that affect, for example, electric power networks, satellite navigation and communication, and geophysical exploration.

Real-Time Solar Wind Data from ACE

The NASA Advanced Composition Explorer (ACE) satellite was launched in 1997 into a special orbit 1.5 million km (about 1 million miles) from Earth. The satellite was modified to broadcast a continuous flow of real-time space weather data. Within 5 minutes of broadcast from ACE, the date are collected by an antenna in a worldwide network of ground systems, sent to SEC, processed, used in Space Weather Operations, and made available to forecasters, operational models, and the general public. During the last 2 years the worldwide tracking network partnership expanded to include a second NOAA tracking station, located at Wallops Island, Virginia. Long-time partners include CRL in Japan, Rutherford-Appleton Laboratory (RAL) in England, the Indian Space and Research Organization in India, SEC in Colorado, the Deep Space Network run by NASA, and the USAF network.

These data allow SEC to issue highly reliable alerts and warnings up to an hour in advance of impending major space weather storms. If a major event occurs, it can cause dramatic changes in the geomagnetic field of Earth, leading to problems in delicate technological systems on satellites, in electric power grids, and in navigational systems. These data are relied on and used throughout the United States by other federal agencies, scientists, commercial firms, and the general public. This critical data stream is expected to continue until about 2010.

GOES Solar X-Ray Imager (SXI)

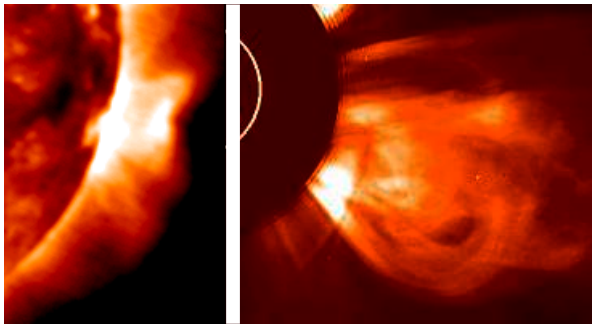
The first SEC Solar X-Ray Imager (SXI) was launched aboard GOES-12 on July 23, 2001. This was the culmination of 20 years of effort to develop and fly this instrument, and several years of effort to build the ground system to handle the data.

Night Launch of GOES-N

During the 4-month post-launch test period, more than 160,000 images were generated by the SXI instrument. Over 100,000 were of the Sun. Images were supplied in real time to SEC and USAF space weather forecasters. In addition, the images were available on the Web in real time.

The SXI performed as expected and demonstrated that it met the needs set forth by the NOAA and the USAF:

- Locate coronal holes for forecasts of recurring geomagnetic activity.
- Locate flares for forecasts of solar energetic particle events.
- Assess active region complexity for flare forecasts.
- Monitor active regions beyond the east limb for F10.7 forecasts.
- Monitor for changes in the corona that may indicate coronal mass ejections.



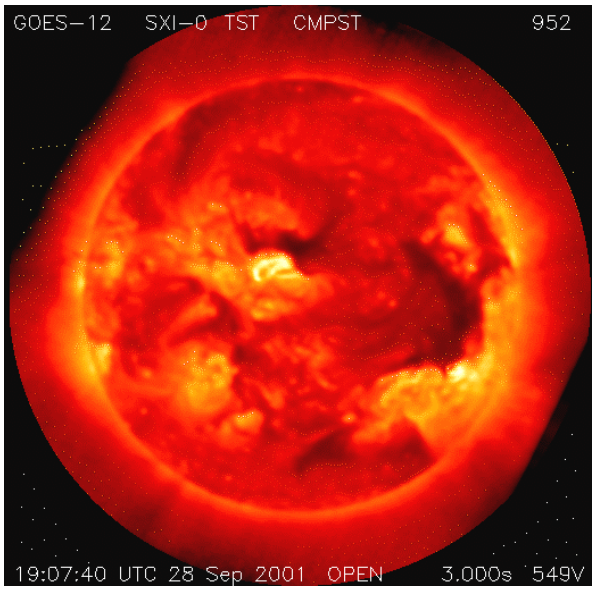
SXI open filter image (left) shows post-flare arcade at the base of a coronal mass ejection seen by a coronagraph aboard the joint NASA-ESA research spacecraft SOHO (right, courtesy of Naval Research Laboratory). The white arc shows the size and location of the Sun.

Following testing, SXI was turned off and the spacecraft placed in storage mode, where it will remain until either GOES-8 or GOES-10 fails.

The ground data system for the GOES-12 SXI was completed, tested, and then extensively used during post-launch testing. The system provides real-time images, movies, and derived products to operational users at SEC and across the country. Remote operational users include the Air Force Weather Agency (AFWA), NASA, and the NOAA Spacecraft Operations Control Center. The system also provides an operational store of the most recent 60 days of data and the tools to analyze that data. In close collaboration with the NOAA National Geophysical Data Center (NGDC) the images are archived as they are processed and are available live on the NGDC Web site.

The next two SXI instruments being built for the GOES N/Q series spacecraft made substantial progress. Flight Model 1 was built, calibrated, and delivered to the spacecraft contractor. Flight Model 2 is nearing completion and should enter the test phase soon.

Progress accelerated on planning for future solar imaging on GOES spacecraft. An operational requirements document was developed for X-ray imaging on the GOES-R series of spacecraft, which will launch no earlier than 2010. In addition, a workshop was held to incorporate input from the broader scientific community on the most promising solar observations for improving space weather forecasting.



SXI open filter image showing coronal holes, seen as the dark regions (right of disk center), and active regions, seen as bright regions (for instance, near disk center).

Utilizing Numerical Modeling

Unlike terrestrial weather conditions that are monitored routinely at thousands of locations around the world, conditions in space are monitored, by comparison, with only a handful of space-based and ground-based facilities. 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.

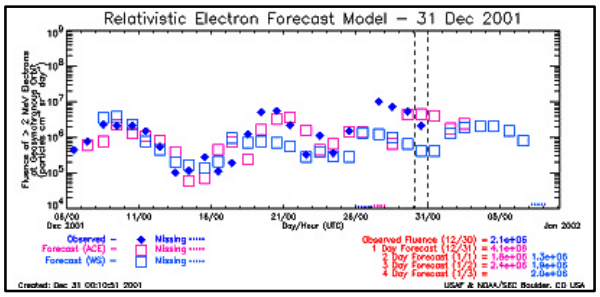
SEC conducts multiple research efforts to enhance the value and availability of numerical models. In one role, SEC staff perform basic research, developing and improving models of the space environment. SEC is also involved in various collaborative activities designed to develop numerical models and further their validation and availability for operational use. SEC is a consortium member of the Community Coordinated Modeling Center (CCMC) along with other government agencies, including NASA, USAF, the Office of Naval Research, and NSF. 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.

In another role, SEC staff transition research models into space weather operations. Toward this goal, SEC has established an objective evaluation process to prioritize new models and data. Applying this process to the available models brought the Relativistic Electron Forecast Model to the top. It was successfully transitioned into operational use. Space Weather Week (see page 13) continues to be a useful forum for identifying new models and data with high potential value. The Beowulf cluster (see page 12) is now being used as a test platform for large-scale models. Highlights of recent model development and transition achievements are described below.

Relativistic Electron Forecast Model (REFM)

This model uses measurements of the solar photosphere, the solar wind, and the particle environment at geosynchronous orbit to predict, as much as one week into the future, the intensity of radiation belt electrons. The REFM predicts the greater than 2 MeV 24-hour electron fluence at geosynchronous orbit using a linear prediction filter in which correlation coefficients are created from historical data. These coefficients, applied to real-time data, predict the daily 24-hour fluence with lead times of 1–8 days. Output from the REFM primarily benefits operators responsible for satellite systems in geosynchronous orbit. The model output also provides valuable guidance to space weather forecasters concerning expected near-term changes in the energetic electron particle environment.

Historical verification of the model accuracy and continuous measures of performance is available; this is the goal for all operational products.



The figure above is the standard REFM plot, displaying roughly 30 days of observed and forecast data. Two vertical dashed lines indicate the most recently observed 24-hour period and the date shown on the plot applies to the beginning of the period.

Global Assimilation of Ionospheric Measurements (GAIM)

The DoD, through a five-year Multi-disciplinary University Research Initiative (MURI), is funding the development of the GAIM model. Through the joint NOAA/University of Colorado Cooperative Institute for Research in the Environmental Sciences (CIRES), scientists at SEC are key players in the University consortium developing GAIM.

The goal is to characterize the state of the ionosphere, globally, regionally, and locally, providing both ionospheric specification and forecasts. The approach parallels space weather specification and forecasts developments in the weather forecasting community to apply data assimilation methods. The basis for GAIM is a physics-based ionosphere-plasmasphere model that will assimilate a diverse set of near real-time ground-based and satellite observations of the ionosphere and neutral atmosphere.

At the halfway point of GAIM model development (2 $^1/_2$ years), several significant SEC accomplishments can be identified:

- The development of an ensemble Kalman filter that realistically assimilates satellite observations of neutral atmospheric densities of atomic oxygen (O) and molecular nitrogen (N2). This provides a global specification of the neutral atmosphere from 90 to 500 km altitude that is a required input to the physics-based GAIM model;
- The development of two independent techniques (a Kalman adaptive filter using ionospheric sounder observations, and ground-based magnetometer observations) for providing the the vertical $\mathbf{E} \times \mathbf{B}$ drift velocity as a function of local time that is required in the the low-latitude ionospheric portion of GAIM;
- A global thermospheric wind model based on theoretically calculated wind velocities obtained from the Coupled Thermosphere Ionosphere Plasmasphere (CTIP) model forms the basis for the GAIM Operational Wind Model. CTIP was developed at SEC in a joint NOAA–University of Colorado CIRES effort.

Planning for Future Ionospheric Services

With the development of data assimilation techniques under the GAIM program, the opportunities are ripe to revolutionize ionospheric services at SEC. The foundation of future communication and navigation products will come from an accurate specification and forecast of ionospheric weather using these new methods. GAIM is developing the techniques pioneered by the meteorological weather forecasting community, to combine data and physical models in an optimal way, and applying them to the space environment. SEC is laying the foundation for their implementation, but the plans will put a substantial demand on SEC infrastructure. Efforts are underway to understand and estimate the effort necessary to utilize these new techniques operationally, including computer resources and access to new ground-based and satellite data sources, many of which will depend on the Global Positioning System (GPS). In the short-term, SEC plans to use the ionosonde data network, and investigate access to the NOAA-CORS network of dual-frequency GPS stations and USAF DMSP satellite data. In the longer term, improved global coverage will come from satellite-based GPS ionospheric occultation measurements from constellations such as COSMIC, and their operational follow-ons.

Empirical Storm-time Ionospheric Correction Model (STORM)

A new real-time model of ionospheric storm-time changes provides an estimate of the expected change in the ionosphere during periods of increased geomagnetic activity. The model estimates the departure from normal of the F-region critical frequency (*FoF2*) every hour of the day. Values are given in six separate geomagnetic latitude bands, 20° wide, from 20° geomagnetic latitude to the North and South magnetic poles. The storm-time correction of the F-region critical frequency primarily benefits radio communicators using the high-frequency band (3-30 MHz). During a geomagnetic storm the F-region ionospheric electron density can be either depleted or enhanced. When the ionosphere is enhanced, higher communication frequencies can be used, enabling a reduction in absorption and an increase in received signal strength. If the ionosphere is depleted, the maximum usable communication frequencies must be reduced to ensure reflection of the radio signal by the ionosphere to the receiver. STORM model output is now accessible at *http://sec.noaa.gov/storm.*

Coupled Magnetosphere-Ionosphere-Thermosphere Models (CTIP)

Another major area of development has been the coupling of the global thermosphere-ionosphere code, CTIM, with the UCLA magnetospheric magneto-hydro-dynamic (MHD) code*. This self-consistent magnetosphere-ionosphere coupling code has been implemented on the new SEC Beowulf computer system and has been used to determine the effect of thermospheric winds on the magnetospheric driven electric field. The results for quiet, steady state conditions, showed that the modification of the polar cap potential by the thermospheric wind dynamo is small, and that field-aligned currents from the neutral wind dynamo are only 10% of the magnetospheric-driven current. The winds did have an effect of slightly displacing the dawn electric potential cell due to neutral wind inertia. The results also indicated that local time and latitude and seasonal modulation of the solar-produced conductivity may have a more significant effect on the electric potential pattern.

Ionospheric Electric Field Variability

To accurately predict the response of the thermosphere and ionosphere to geomagnetic activity, the magnitude and spatial configuration of the magnetospheric forcing needs to be known. Physical models up to now have

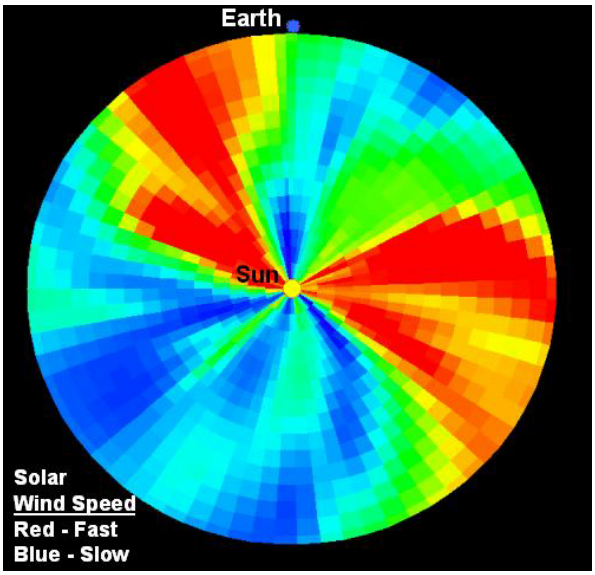
* Raeder, J., Y. Wang, and T. J. Fuller–Rowell, Geomagnetic storm simulation with a coupled magnetosphere–ionosphere–thermosphere model, *AGU Geophysical Monograph* **125**, 377–384, 2001.

relied on the specification of the average magnetospheric convection pattern, which significantly underestimates the magnitude of the Joule-heating energy source, so they are unable to reproduce the temperature and composition structure. Correcting the underestimation of the high-latitude energy input is critical. It is known that the high-latitude electric fields are variable on a variety of spatial and temporal scales. Since the amount of Joule heating is proportional to the average of the square of the E field, the variability leads to significantly more high-latitude energy input. Including estimates of the electric field variability leads to much better agreement in the modeled and observed temperature and composition structure of the thermosphere.

Wang-Sheeley Solar Wind Model (WS)

The Wang-Sheeley model* is a partially physics-based representation of the quasi-steady global solar wind flow, and can often reliably predict the background solar wind speed and the interplanetary magnetic field polarity at Earth 4 days in advance. It uses solar photospheric magnetic field data from the Office of Naval Research supported observatories as input to a magnetostatic model of the coronal expansion.

Originally, the model relied exclusively on data from the Wilcox Solar Observatory. To improve the continuity of coverage, however, data from both Mount Wilson and the National Solar Observatories were also incorporated into the primary input stream. Daily updated solar wind predictions are now routinely made using data from all three solar observatories. Work is underway to improve the WS model further by incorporating additional and more realistic physics-based models into the prediction routine. This includes improving the modeling of the Sun's upper corona as well as the interplanetary propagation component of the solar wind flow. The WS algorithm is also being modularized to make future improvements and modifications easier.



The Wang-Sheeley Model predicts the background solar wind speed and the interplanetary magnetic field polarity at Earth, two important parameters required for predicting geomagnetic activity (e.g., Ap).

* Arge, C. N., and V. J. Pizzo, Improvement in the Prediction of Solar Wind Conditions Using Near-Real Time Solar Magnetic Field Updates, *J. Geophys. Res.*, **105**, 10465, 2000.

Geomagnetic Storm Prediction—Chen Model

The Chen prediction technique** is designed to identify and predict accurately the occurrence, duration, and strength of large geomagnetic storms using real-time solar wind data. It estimates the interplanetary magnetic field and the geoeffectiveness of the solar wind upstream of a monitor like the Advanced Composition Explorer (ACE) satellite. It can provide warning times that range from a few hours to (in principle) more than 10 hours. The model identifies physical features of solar wind structures that cause large storms, such as long durations of southward interplanetary magnetic field. Recently a comprehensive verification study was conducted on the model using 3 years of ACE data (1998–2000). The study showed that the model would have successfully predicted 33 out of 41 (about 80%) storms for which there were concurrent ACE and *Dst* data, with only 11 false alarms, 9 warnings, and 8 misses. For the 33 successfully predicted storms, it provided an average warning time of 2.1 hours with a maximum of about 10 hours and a minimum of 0 hours. This means the model can more than double, on average, the approximately 1-hour advanced warning time presently available using L1 data alone. A real-time prediction web page has been developed and is on-line at SEC.

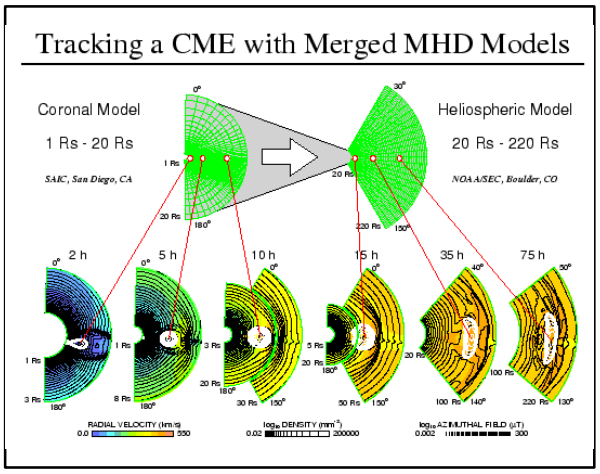
Other Solar-Heliospheric Modeling

A simplified modular model is being developed to explore issues relating to operational aspects of Sun-Earth space weather models. Because quantitative solar inputs are currently quite limited, the modular components of the prototype Sun-Earth model consist of simple physics-based and semi-empirical models, and numerical MHD models that can be run efficiently on workstations. An advantage of the modular architecture is that it allows for extensive experimentation and permits

** Arge, C. N., S. Wahl, J. Chen, S. Slinker, and V. J. Pizzo, Implementation and Verification of the Chen Prediction Technique for Forecasting Large Nonrecurrent Storms, submitted to *Adv. in Space Res*, Proceedings of the COSPAR Colloquium in Beijing China, 2002.

easy replacement of individual models when improved ones (and any required data streams) become available. The model will also highlight issues with near-real-time data ingest and assimilation, error handling, quality control, linkages, verification (using appropriate metrics), display, archiving, and other operational requirements.

In an effort to develop a Sun-to-Earth model, 2-D and 3-D coronal and heliospheric codes, developed at SAIC San Diego and SEC, have been merged into a combined solar-heliospheric model (a Merged MHD model). These models employ different physical approximations and numerical grids, to simulate physical phenomena over their respective spatial and temporal domains. Transient disturbances generated by a solar magnetic eruption and propagating through interplanetary space are simulated as self-consistent and coupled dynamic phenomena.



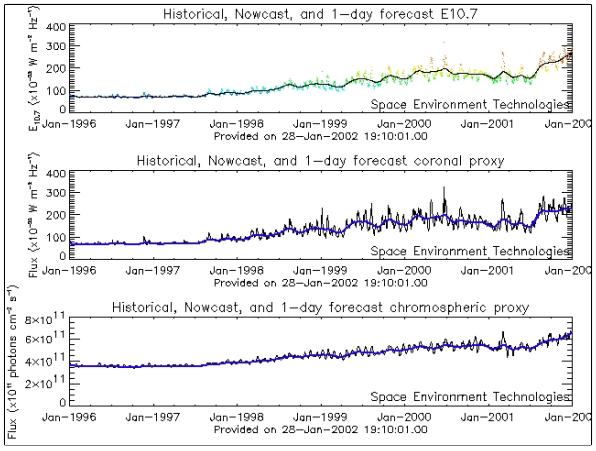
Merged solar coronal and heliospheric models that follow a transient disturbance from the sun, through interplanetary space, to Earth.

Another Sun-to-Earth numerical modeling project, called the Hybrid Heliospheric Modeling System (HHMS) is underway; it will improve SEC's forecasting of geomagnetic activity. Existing physics-based global 3D models for the solar corona and solar wind are combined with new empirical models to predict the geomagnetic *Ap* index from a sequence of solar magnetograms. Verification, testing, and parameter tuning studies are underway. The HHMS also provides a new means to investigate some scientific issues regarding the source and acceleration of the solar wind.

Cooperative Research and Development Agreement (CRADA)

A CRADA was established with the Federal Data Corporation in May 2000 to create a product, or products, based on a Solar Irradiance Specification Tool. The product(s) will be especially designed to provide better estimates and nowcasts of solar irradiance values at the top of Earth's atmosphere. The CRADA has since transferred to Space Environment Technologies, Space WX Division, but involves the same key personnel as before. Space Environment Technologies creates specialized space weather products and markets them to government agencies and private industries. The products are tailored to the specific needs of the company or agency that purchases them.

The most notable product provided through this CRADA is an empirical model of the solar EUV spectrum called SOLAR2000. This product is available in several forms. The simplest version is available free and is intended as a research tool for scientists studying the upper atmosphere and ionosphere. The more complex version includes forecast capabilities and is being provided to the Air Force for improved tracking of satellites. The role of SEC is to verify the SOLAR2000 products and distribute them as operational products. SEC also provides the *Mg II index*, derived from POES satellite observations, which is one of the key inputs to the SOLAR2000 model. As this CRADA matures, SEC will continue to provide the near-real-time *MgII* input measurements and the SOLAR2000 nowcasts as official SEC products. New products, some based on SEC research efforts, will be evaluated and tested for SEC operations, and Space Environment Technologies will create value added products for commercial use.



E10.7, an index of the EUV brightness of the Sun, is shown for daily and 81-day "running average" values. The solar cycle, epochs of active region evolution, and solar rotation are all apparent in the UV/EUV irradiance the E10.7 index represents.

Information Technology

The emphasis for SEC's information technology (IT) staff prior to January 1, 2000, was preparing for Y2K, which SEC accomplished flawlessly. The current system-wide emphasis is computer system and network security. SEC has established an IT Security Team, to work with a Computer User Committee to develop and implement policies to address security.

Solar X-ray Imager (SXI) Preparation

Nearly one half of SEC development resources have been devoted to the acquisition, ingest, processing, storage and display of SXI data from GOES-12. A new data ingest processing architecture was developed to allow for reliable near-real-time delivery of SXI data to NGDC. A new MSSQL relational database system was designed and implemented to store SXI data.

Data Delivery Systems

There were significant improvements in reliability and maintainability of the SEC communications systems:

- The CORBA-based Information Dissemination System (IDS), is now the primary system for data delivery to NGDC and to space weather vendors.
- The new Data Display System (DDS), utilizing the IDS technology provides the majority of data displayed in our forecast center, the NASA Space Radiation Analysis Group and several Air Force sites.
- In an effort to improve integration of our systems with those of NCEP, we are now disseminating NOAA Weather Wire products through the Boulder office of the National Weather Service.
- New dedicated wide-area network connections allow us to pass data directly to AFWA and to the NOAA Spacecraft Operations Control Center.

Web Redesign

Access to the SEC outside user system through the World Wide Web has increased in the last 2 years from an average of just over 100,000 to about 400,000 file transfers each day ("hits"). Peak demand, associated with space weather storms, reached more than 1,000,000 file transfers each day on 20 occasions, with a maximum of over 2,100,00 files in a single day.

To better serve our customers, the SEC Web site was redesigned to improve navigation, content and presentation. Among the new pages and features available are:

SEC Home Page at http://sec.noaa.gov

- a new Home page with new artwork and more focused choices;
- a Space Weather Now page of current space weather data and conditions, designed for the public;
- improved organization of SEC On-line Data;
- a News Media page featuring media support information.

Beowulf

SEC implemented a 10-dual-processor-node Beowulf system to provide parallel processing for faster execution of complicated numerical models. This system is being used as a testbed for development and testing of research models for operational use. Eventually, each operational model may run on its own Beowulf system.

Plans

SEC has begun efforts to replace and modernize two critical data handling systems: (1) a new data ingest and processing system, and (2) a new database, the Space Weather Database System (SWDS). The SWDS will build upon and extend the successful relational database used for SXI; it will replace an obsolete flat-file system.

New software for SWO to issue alerts will be implemented in early 2002. This system will provide better tools for the forecast center to monitor events, and will incorporate re-designed alert formats to improve customer support (see page 13).

Significant resources will be devoted to planning and implementing the GOES N-Q acquisition, processing and storage systems.

Outreach and Customer Relations

Space Weather Week

Space Weather Week, in a unique and valuable way, blends researchers, vendors, users, and providers of space weather services into one event. This excellent venue allows cross communications, and gives SEC the opportunity to further NOAA research and customer service goals. The goals include of translating research developments into operational use, learning what users need and how to provide better service, reviewing current research in the field, and helping to foster a space weather service industry. Space Weather Week is the premier meeting of the year, worldwide, for space weather practitioners. Along with SEC, it is co-sponsored by the Air Force Research Lab, National Science Foundation, and NASA Office of Space Science.

Space Weather Week 2000 integrated activities with concurrent sessions during the week. Space Weather Week 2001 had only plenary sessions, and focused on the recent solar and geomagnetic activity as they looked from the research side and from the user side. Speakers from a variety of industries spelled out specific space weather impacts on their operations from ionospheric disturbances, auroral currents, geomagnetic storms and their solar drivers, radiation belts, and solar energetic particles.

Vendors of Space Weather Services

Vendors fill an important need of users by producing such things as region-specific ionospheric current predictions, modeling the ground conductivity, and the modeling of space weather effects on specific electric power grid configurations.

SEC supports vendors in their efforts to provide services through contact with users at Space Weather Week, by listing their services on a Web page with links to service providers, and by entering partnerships with vendors.

Two formal partnerships between SEC and vendors are *Small Business Innovative Research* (SBIR) grants and *Cooperative Research and Development Agreements* (CRADAs). An SBIR Phase II grant, awarded to Northwest Research Associates, Inc., finished in 2000. With the grant, Northwest developed a distributed computing system to provide specific products to individual users and distribute data and products to a network of users.

SEC currently has a CRADA with Space Environment Technologies to develop a solar irradiance model, SOLAR2000, which will provide better estimates of solar extreme ultraviolet (EUV) flux. The primary focus has been to help customers estimate and predict satellite drag. Work on this CRADA is described on page 11.

SEC Space Weather Alerts Service

The SEC Space Weather Alerts Service is being improved and enhanced in a planned, step-wise implementation. These changes will be implemented in February 2002:

- Message formats revised to enhance readability and support automatic decoding by recipients.
- More alerts issued when rising values cross thresholds instead of after the event, and summaries will be issued after events end.
- New products introduced which relate events to the higher thresholds described in the NOAA Scales, such as higher energy proton events.
- New SEC web pages available showing current alerts, related data, and an archive of alerts.

K-12 Education and the Public

The initiation of the NOAA Space Weather Scales in 1999 brought forth the need to educate the public on the meaning and use of the scales. As part of that effort, a Space Weather Poster was designed and printed, in English and Spanish, for use in classrooms. The posters feature a simplified listing of the scales and an attached study sheet which enables further inquiry by students. About 6,000 posters have been distributed to teachers in the last 2 years.

Another prominent aid to teaching about space weather has been the delightful comic book, written and illustrated by Zander Cannon, an award-winning illustrated novelist. This was published in English (and will be printed in Spanish) and will be distributed to teachers through the National Science Teachers Association and at various other teacher events.

In addition to these very visible teaching tools, SEC participated in other important educational programs, including hosting a workshop for teachers to learn how to build a magnetometer in the classroom.

With funding in 2001 from the NOAA Minority Serving Institutions Program, SEC began a collaboration with the Denver Museum of Nature and Science to educate museum-goers about space science. In keeping with the goals of NOAA and the Museum, much of this effort will be targeted to minority students.

Vision of SEC in 5 Years

SEC intends to follow a planned and prioritized path that is structured by the Perspectives and Themes in the SEC strategic Plan. SEC also plans to take advantage of time-specific opportunities. Specifically, at any one time, SEC will also undertake a limited number of featured projects that are ripe, offer payoffs disproportionately larger than the NOAA investments in them, are necessary, or build a launch pad for SEC's future. The amount of effort, and thus the level of accomplishment in these projects, depends upon the success in acquiring adequate resources and upon the level of participation of NOAA-funded partners. Described below are three areas of opportunity and their current emphasis at SEC.

Provide More Guidance to Forecasters and Model Output to Users

The quality of meteorological forecasts has risen dramatically since larger computers, more complex models, and a better understanding of the science of weather and climate combined to fuel the improvement. Similarly sophisticated, predictive numerical models will prove to be of benefit to the entire community affected by space weather. These are some of the most important new models to the space weather user and researcher communities. SEC will implement these models, and others, as resources permit.

Magnetosphere Modeling will provide important benefits to SEC operations, giving numerical guidance for conditions that affect on-orbit spacecraft and electric power grids, and in providing inputs to other models.

Ionosphere Modeling will provide a variety of products, not now available, to radio communicators, radionavigators and military users. It will assimilate multiple data streams to characterize and predict the storm-time and quiet ionosphere.

Solar-Wind Modeling will predict the speed density and magnetic polarity of the solar wind at Earth, providing the most complete specification and forecast of the drivers of geomagnetic activity.

Data Assimilation Techniques will allow us to assimilate diverse data from observations into descriptive and predictive models. This will provide a coherent picture of current and future space weather conditions on scales and resolutions ranging from global to regional. The first major data assimilation will come in ionospheric modeling.

Verification of new products, of model outputs especially, is critically important to vendors in the space weather services industry; they will be basing value-added products on these model outputs.

Provide More Guidance to Forecasters and Model Output to Users

Milestone	*Completion*
Transition of 2 models per year, starting in FY 04	6 additional models in operation by FY 06

Examples of New Model Development and Transition: New Ionospheric Services

While SEC has distributed data and some products related to the ionosphere for years, a new line of product development promises to improve services. The understanding of the ionosphere as a critical region that couples activity on the Sun with the Earth has been developing rapidly in the research community. Ionospheric variations directly and adversely affect some of the most critical new technologies; new customers, new technologies, and a better understanding of the science have elevated our commitment to advance SEC efforts in this area.

The program to develop a predictive ionospheric model will involve these concurrent steps:

- prepare and test software to assimilate multiple varieties of data (this work is largely supported by DoD);
- evaluate the benefit of each of these new and current space-based and ground-based observations;
- design and provide data ingest and database system enhancements for the selected data sources;
- implement the forecast capability through the SEC Rapid Prototyping Center.

Even after operations commence, new observational sources will be integrated as they become available. SEC sees the area of new ionospheric services enabled by this project as an excellent opportunity for vendors to tailor specific customer services.

Develop New Ionospheric Services	
Milestone	***Completion***
Additional ionosopheric data to support GAIM model	FY 03
Data stream benefits evaluated	FY 03
Database and data acquisition hardware and software	FY 03
Limited operational provision of products	FY 05

Acquire and Use New Data

In the last few years, SEC has worked with several of its partners, especially NASA and the Department of Defense, to promote new space missions that will provide the most critical missing solar observations. Excellent cooperative work has ensured instrument construction and operation that will obtain real-time data to fill gaps in the current NOAA observing program. The long planning and execution cycles for space-borne sensors dictates that this effort must be expended many years before desired data begin to flow.

Solar wind data—SEC will pursue, in partnership, new satellites and instruments for measuring the solar wind about to strike Earth. An example is the GEOSTORMS mission in orbit at either the Lagrange L1 point or, by using solar sails, a point nearly twice as far from Earth as L1.

Solar X-ray Imager (SXI)—SEC will employ a series of SXI instruments, funded by NOAA and USAF, on GOES-M, N, and P. SEC will work with NESDIS and its external partners to have redundant SXI instruments on GOES (and other) spacecraft.

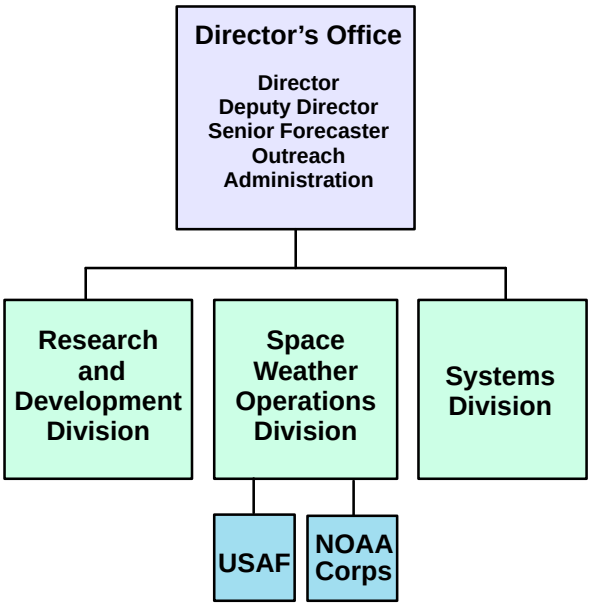
NOAA Satellites—Improved space environment monitors (SEM's) will be developed for the GOES-NO/PQ series. GOES NO/PQ will include solar extreme ultraviolet (EUV) measurements for the first time from GOES, a second-generation solar X-ray imager (SXI), an expanded range for the whole-sun X Ray Sensor (XRS), and greatly enhanced measurements of energetic particles from the Energetic Particle Sensor (EPS). Because the NASA and ESA SOHO research mission has shown how valuable solar imagery is for space weather services, SEC will seek additional solar imagery from the GOES-R+ series. The POES spacecraft will have the Solar Backscatter Ultraviolet Sounding Spectral Radiometer (SBUV) instruments.

SEC will assist with the National Polar Orbiting Operational Environmental Satellite System (NPOESS), which will launch after the period covered by this plan, with improved space weather and total EUV monitoring.

Research Satellites—SEC will continue to take advantage of new sensors flown for research purposes by NASA, ESA, NASDA, DoD, ISAS, and others when they provide observations useful to space weather operations and basic research. The current major initiative by NASA, Living with a Star, is one of the missions that will provide SEC with new information about the space environment.

Acquire and Use New Data	
Milestone	***Completion***
Study technology for Solar Imagery from GOES-R+	FY 02
Initiative to plan GEOSTORMS, in partnership with USAF	FY 04
Obtain solar imagery from GOES-R	FY10

Facts about SEC



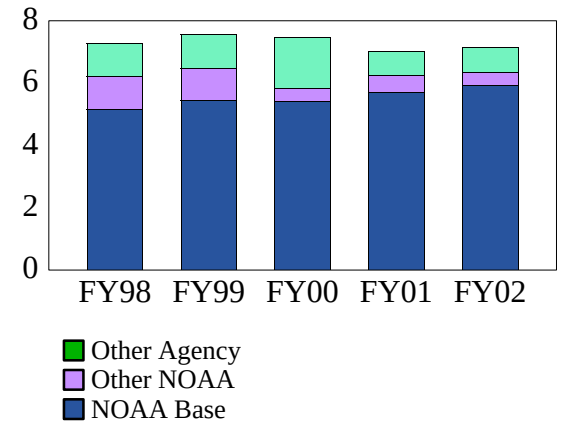
Center Organization—SEC continues to operate within a streamlined structure that minimizes organizational levels but allows redeployment of resources quickly as situations change. Staff is encouraged to work across organizational boundaries to support the many Center-wide tasks outlined on p. 3.

Funding—The major source of funding at SEC is direct appropriation from Congress; supplementing this base funding is a nominal amount from special NOAA programs and from other government agency sponsors. In the past few years NOAA and the Office of Oceanic and Atmospheric Research have focused on rectifying the erosion of Laboratory funds caused by increasing labor costs. This effort has paid off; in both 2001 and 2002, SEC has received adjustments to base that, while not erasing the problem completely, has helped slow the required decreases in staff that has been necessary.

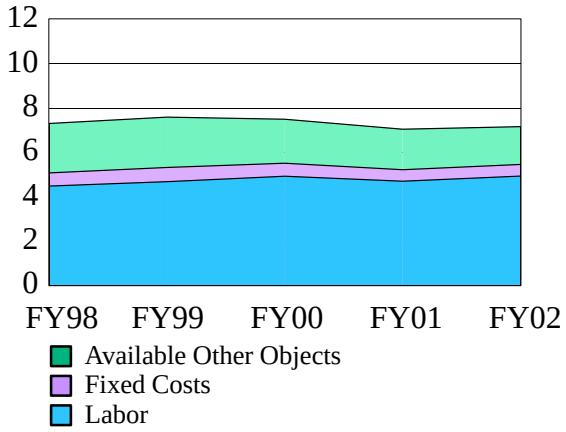
This year SEC has made a concerted effort to align its financial planning and execution with its strategic planning. All costs will be tracked directly to the project that they support. This effort will make it possible to track and analyze financial data as it flows through the system. This will also allow financial measures to be applied to the ongoing performance analysis of SEC projects.

Partners—SEC could not succeed without its partners. The SEC forecast center is a joint operation between NOAA and the USAF Weather Agency, which assigns three persons to SEC. Two NOAA Corps officers also work at SEC and one helps run the USAF solar observatory at Learmonth, Australia. Partnership with our joint institute, CIRES at the University of Colorado is extremely beneficial. Finally, all interested federal agencies are loosely bound together in the National Space Weather Program, a vehicle which has successfully encouraged partnerships among the agencies.

SEC Income Profile



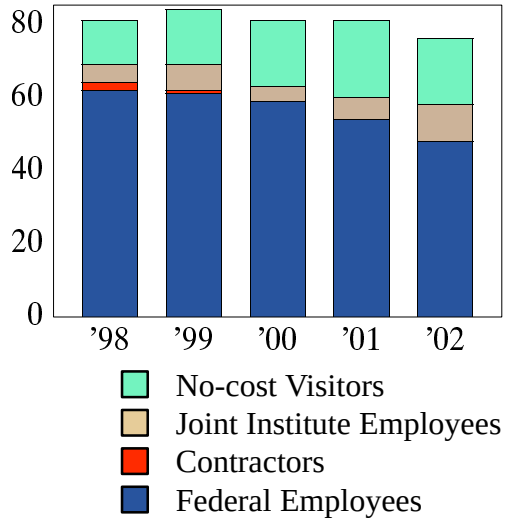
SEC Expense Profile



Personnel

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

SEC Labor Profile



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 of participants in the space weather and space physics fields, SEC has devoted resources to the development of educational materials for elementary, junior, and high schools. Stemming from the NOAA "Survey Feedback Action" effort regarding employee morale, and from work done with the "balanced scorecard" (see p. 2), SEC formed a Quality of Work Life Team to review SEC's quality of work life and to make recommendations to further enhance that work life. A number of recommendations from that team have been successfully implemented and are beginning to show positive effects within the Lab.

Committee memberships, review boards, planning groups—SEC staff members played critical roles in the space environment community, authoring numerous scientific papers, participating in proposal and journal article reviews, and leading professional organizations, interest groups, and members of numerous organizing committees of meetings. A few examples of SEC staffers' critical roles follow:

- Co-chair of the National Space Weather Program governing Committee on Space Weather.
- Secretary, ISES; member, ISES Directing Board.
- Fellow, CIRES.
- Member, SHINE Steering Committee.
- Member, NASA Living with a Star Science Architecture Team.
- Member, Editorial Advisory Board, *GPS Solutions* Journal
- Members, NASA Geospace Mission Definition Team.
- Member, National Solar Observatory SOLIS advisory group.
- Member, High Altitude Observatory Director's Advisory Committee
- Chair, American Astronomical Society, Solar Physics Division Hale Prize Committee
- Member, Coordinated Community Modeling Center Advisory Committee
- Chair, COSPAR (Committee on Space Research) Panel on Space Weather.
- Secretary, American Geophysical Union Space Physics and Aeronomy-Solar Magnetospheric Section.
- Member, NSF Geospace Environment Modeling (GEM) Steering Committee.
- Member, SCOSTEP S-RAMP Committee on Space Weather.
- Member, National Solar Observatory Users Committee.
- Member, Science Advisory Committee for the International Arctic Research Center in Fairbanks, Alaska.
- Members of four of the National Academy Panels for Solar and Space Physics: A Community Assessment and Strategy for the Future.
- Working group leader, 2002 SHINE meeting.
- Organizer of the Symposium S1: Space Weather Prediction Techniques of the First S-RAMP Conference, in Sapporo, Japan, Oct. 2000.
- Members, several NASA Peer Review Panel for Solar research proposals to the Living with a Star program, November 2000.
- Member, Government Advisory Team for the NPOESS Space Environment Sensor Suite.
- Fellow, Center for Integrated Plasma Studies, Boulder, Colo.

Space Environment Center Staff and Associates

Staff who worked at SEC sometime during 200–2001

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Cruickshank, Cheryl
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Finelli, Dave
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Koga, Kiyokazu
Matsuo, Tomoko
Mayer, Leslie
Minter, Cliff
Neupert, Werner
Odstrcil, Dusan
O'Laughlin, Karen
Pap, Judit
Sauer, Herb
Speiser, Ted
Tomita, Tom
Wahl, Susan
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Zwickl, Ron, Asst. Director

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Bouwer, Dave
Grubb, Dick
Joselyn, JoAnn

SEC Works Published in FY 2000 and 2001

Aarons, B. Lin, M. Mendillo, K. Liou, and **M. Codrescu**, Global positioning system phase fluctuations and ultraviolet images from the Polar satellite. *J. Geophys. Res*., **105**, 5201–5213, (2000).

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