CHAPTER 5

TECHNOLOGY TRANSITION AND DATA MANAGEMENT

5.1 Developing Operational Models

Success of the National Space Weather Program (NSWP) requires that the knowledge and models of the space weather system generated by the research community be incorporated into operational models of use to forecasters and/or external customers. The goal of the research model is to demonstrate understanding of the physics appropriate to the bounded system being modeled. Input may or may not include realistic data, and output is typically in the form of scaled parameters that illustrate the behavior of the system under a variety of conditions, mostly idealized. In contrast, an operational model must be able to use existing real data to produce clear-cut results applicable to all types of conditions.

The strict requirements imposed on operational models have made the development process slow and difficult. A high priority in the implementation of the NSWP is the creation of a system to encourage development of appropriate research models and to incorporate research results into operational models quickly and efficiently. At the core of the process are the Community Coordinated Modeling Center (CCMC) and the Rapid Prototyping Centers (RPCs). Figure 5-1 graphically depicts this process. The CCMC provides support and structure to the development of needed research models and transitions them to the RPCs. At the RPCs, immediate feedback is provided to the development team as concepts are tested in a quasi-operational environment. RPCs allow competing methodologies or techniques to be examined quickly, cheaply, and creatively, often generating a product with more capability than originally envisioned.

5.1.1 Community Coordinated Modeling Center (CCMC)

At a Committee for Space Weather (CSW) meeting held at the Office of the Federal Coordinator for Meteorology in March 1998, the Air Force Space Command presented a proposal for a Community Coordinated Modeling Center. This center would provide a place where space science researchers could try out new models currently in the development stage. With further refinement of the concept and unanimous support from

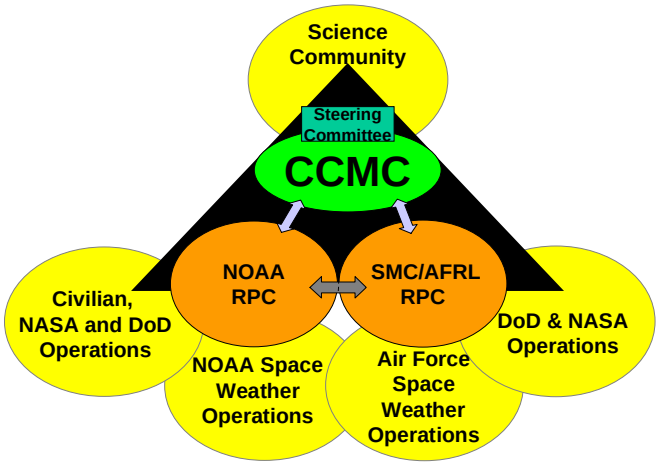

Figure 5-1. Linking the Science Community with Operational Centers

the CSW and space weather community to proceed, a consortium of federal agencies comprised of the Air Force Materiel Command, Air Force Office of Scientific Research, Air Force Directorate of Weather, Air Force Weather Agency, NASA, NOAA, and NSF began development of the CCMC. It will be operational in the year 2000.

The mission of the CCMC is to provide a computing facility to enable, support, and perform the research for next generation space science and space weather models, preparing them for transition to operations through the RPCs. This process is shown graphically in Figure 5-1. However, it should be noted that the CCMC is not necessarily the only conduit for models to move into the RPCs.

The CCMC's goals are to:

- Develop with the community and execute next generation space research models, aiming specifically at space weather needs
- Integrate existing models to cover the necessary range of physical scales
- Provide computational infrastructure for space weather modeling
- Prepare models for transition to rapid prototyping centers
- Make research models developed at CCMC as well as their output available to all in the community
- Support of community research
  - through execution of model runs on request
  - through preparation of visualization and analysis tools
  - through source code dissemination and model output availability
  - through general community-based development
- Perform basic research
  - using existing and newly merged models

- for the development of new models
- in support of space weather goals

In addition to meeting these goals, the CCMC will provide additional benefits such as enhancing scientific understanding, providing broad access to research models, providing effective use of mission data, enabling cross-disciplinary science, and aiding mission conception and design. It is designed to be integrated with the NASA's Sun-Earth Connections Roadmap and the "Living with a Star" program, the National Security Space Architect's Space Weather Architecture Transition Plan, and the NSWP.

The CCMC concept is to meld science and operational requirements and provide a venue for the development and testing of research models with the intent of eventual transition to operations through the Rapid Prototyping Centers. The CCMC operates under the NSWP with an interagency steering committee overseen by the Committee for Space Weather. The Steering Committee consists of individuals from the consortium agencies with assistance from two working groups, one for science and one for operations. The Science Working Group consists of representatives from GEM, CEDAR, SHINE, and ISTP. The Operations Working Group consists of representatives from the Air Force's Space and Missile Systems Center (SMC) and AFRL RPC, the NOAA RPC, and the Headquarters Air Force Directorate of Weather (HQ USAF/XOW).

The Center, located at the Goddard Space Flight Center, Greenbelt, Maryland, supports code adaptation, provides visualization capability and web access, disseminates mature

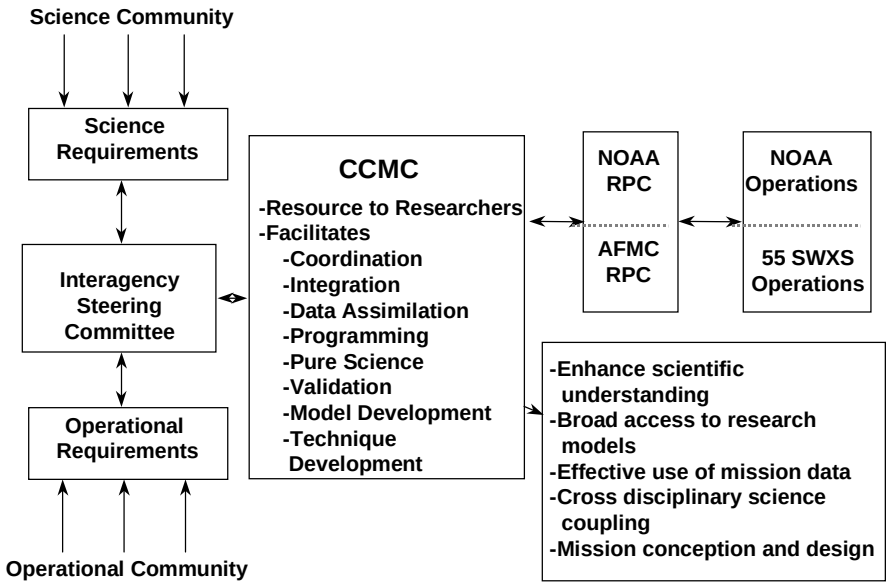

Figure 5-2. CCMC Operational Concept

codes, and performs research in support of CCMC goals. It also provides the front-end computing and access to supercomputer facilities hosted by the Air Force Weather Agency (AFWA), Offutt Air Force Base, Nebraska. Although the core computational capability is massively parallel, this does not preclude the development and validation of smaller models that may be run in a workstation environment. The National Space Science Data Center (NSSDC) provides archived space weather data for use in the CCMC and a real-time data feed into AFWA is planned for the future.

The NSF provides software infrastructure support and, in conjunction with AFOSR, supports research post-doctoral positions in the center. The Air Force and NOAA support the transition to operations process through their respective RPCs and NASA provides the facilities at Goddard Space Flight Center and the supporting technical and research staff.

The CCMC is a novel approach to the development of space weather models and is an example of effective interagency collaboration. The research community has shown considerable interest at GEM, CEDAR, and SHINE workshops and initial model selection has begun.

5.1.2 Rapid Prototyping Centers (RPCs)

The transition of research results into operational capability is incredibly difficult not just for space weather but for virtually every scientific endeavor. However, significant progress has been made in space weather since the initial NSWP Implementation Plan was published in 1997. NOAA has established a Rapid Prototyping Center (RPC) and initiated a Cooperative Research and Development Agreement (CRADA) with Sterling Software to transition the Rice University Magnetospheric Specification Model. The DOD RPC is developing, working with the Air Force Research Lab and Space Battle Lab to create new graphically based, operationally focused space weather products. These products address the DOD operational need for information on ionospheric scintillation impacts to Global Positioning Satellite and Ultra-High Frequency (UHF) satellite communications, High-Frequency (HF) radio communications, and auroral interference with ground radars. When these early successes become operational, the DOD RPC will continue to improve the line of space weather products issued by the 55 SWXS.

5.1.2.1 RPC Concept of Operations

RPCs will publish standards to which models must adhere before they are accepted into the rapid prototyping process. Models must be validated--they must properly represent the physical processes, function correctly within the natural range of input variables, and be coded correctly. Standard structured programming techniques will be required, as will appropriate documentation. Standard computer languages will be specified so that code will be transportable between the hardware platforms and operating system environments under use at the centers. RPCs may also specify output formats to facilitate interaction with in-place visualization tools.

As illustrated in Figure 5-3, the rapid prototyping process uses models matured in the CCMC as well as other research models in conjunction with a realistic data stream. The models are evaluated as necessary to check their ability to produce accurate results under the full range of possible input values. They must be *suitable* to the task at hand, produce *reliable* results, and be easily *usable* to the space weather forecaster. The operational models must deal with momentary or extended data dropouts, different data sampling rates, and rapid rates of change in sensor output that may or may not be noise. Sometimes models must knit together sets of data from very different and non-collocated sensors, extrapolating data, if necessary, or filling in with proxy data. Output errors must be controlled as the model moves forward in time or space, and all model outputs must be self-consistent. The successful operational model should also validate itself against actual measurements and reinitialize itself, or notify operators that errors have become unacceptable. Finally the model should accommodate forecasters with various skill levels, adapt to a variable production demand, and be relatively easy to modify if new data, products, or hardware or software upgrades become compelling.

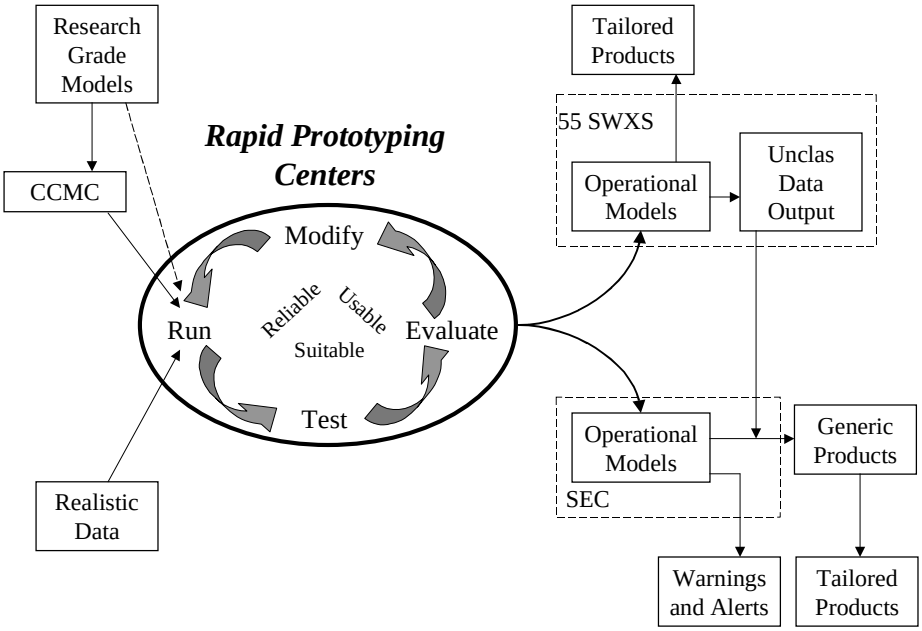

Figure 5-3. RPC Development Process for Operational Models

5.1.2.2 NOAA SEC Rapid Prototyping Center and Cooperative Research and Development Agreement

The Rapid Prototyping Center (RPC) is a facility developed at the Space Environment Center to expedite the validation of numerical models and data and to efficiently bring new near-real-time information into operational use. The RPC is developing a competitive and efficient evaluation and transition process to ensure the rapid utilization of the extensive research, modeling, and monitoring efforts directed at the space environment. Its operational output will provide the basis for improved forecasts and for

tailored space weather products. The output will be available to the broad user community, in support of SEC operations, the U.S. Air Force space weather operations, commercial space weather concerns, and the research community.

The development of the RPC has been enhanced through a Cooperative Research and Development Agreement (CRADA) with Sterling Software, Inc. SEC entered into this CRADA on June 9, 1997, starting the first public-private partnership to provide space weather services. The SEC/Sterling team has completed an extensive analysis of the requirements for SEC's Rapid Prototyping Center and operational system and has begun the code development and testing of space environment models.

This project has been progressing through a series of iterative stages. The initial stage concentrated on establishing the foundation of computer software that provides the broad functionality of the RPC. The software design follows the object-oriented paradigm and will provide a generic capability for data access, model execution, output verification, output dissemination, and archival.

The second stage involved implementing and providing routine output for a specific space environment model—the Magnetospheric Specification Model. Magnetospheric particle fluxes calculated from the Magnetospheric Specification Model are now available through SEC's Outside User System. The model output is available every three hours as a "routine test product" after being verified by SEC forecasters. The goal of this test product is to allow access to the model output and to obtain feedback, both internally and externally, that will drive further modifications before the model output becomes fully operational. In addition to providing the operational output in support of government services, the output is available to private vendors who will develop value-added products based on the operational output and then market these products to users of space weather services.

The current stage of NOAA RPC development involves expanding the initial software infrastructure to include broader functionality and bringing additional models and data into the transition process and eventually into operations. The RPC data ingest and archival functions will utilize the Information Dissemination System that is under development at SEC to standardize the interfaces that all models will use in development and in operations. Also, the verification and model analysis capabilities will be enhanced over what has been established in the initial stages. As the infrastructure matures, new models are being used to validate the RPC capabilities and to provide additional operational capabilities. Models of solar energetic protons, ionospheric currents, and radiation belt particles are among those currently being considered for near-term transition to operations.

5.1.3 Operationalizing New Models

Research models and analysis techniques that "graduate" from the CCMC and RPC processes will automatically have become incorporated into the appropriate operational

space weather centers. The 55 SWXS, which supports military users of space weather data, produces a set of tailored products from the model outputs for specific military needs and provides unclassified data to SEC. These data, along with other data generated at SEC are available for civilian customers. In addition, these data can be used to help industry and, perhaps, universities tailor civilian products in response to specific customer demands. An exciting possibility is the formation of small businesses aimed specifically at tailored-product development such as that envisioned in the new SEC/Federal Data Corporation CRADA signed on May 2, 2000. As larger, more integrated, and more sophisticated models reach operational use, the volume of data feeding these models will grow significantly. Timely development of operational sensors and bridging the gaps between research observational capabilities and operational sensors is imperative.

5.2 Developing Operational Observing Capability

Developing operational models is a high priority of the NSWP. However, for models to mature through increasingly more stringent verification and validation, they will require the necessary observational elements needed to accurately specify and forecast the space environment. These observations may come from dedicated operational observing systems or from research sensors and observing systems adapted to operations. The NSWP also places a high priority on the development of operational observing capability.

Operational sensing systems mature through a similar process, beginning as a research effort to prove the science and technology, then the development and fielding of an operational sensor. Unfortunately, a gap of several years often occurs between the end of a research mission and the subsequent deployment of an operational capability. Every effort must be made to bridge this gap as creatively and effectively as possible. The Advanced Composition Explorer (ACE) spacecraft and the solar wind information it provides is an outstanding example of interagency cooperation and collaboration to employ a research system in an operational mode.

The generally high cost of developing and deploying operational observing systems, especially space-based systems, and continuing budgetary pressures represent a significant obstacle in achieving the NSWP goals. The NSWP will continue to support expanding interagency efforts to bridge the gap between research and operational observing systems and to develop and deploy the operational systems required. As observing capabilities expand, the volume of data produced by these systems will undoubtedly increase, as will the size and complexity of model output based on these observations. An effective data management system must be developed to collect and disseminate space weather data and information.

5.3 Data Management

The NSWP guides improvements in the capability to process, assimilate, analyze, distribute, and archive increasingly complex data sets. Rapid advances in computer and communications technology have opened a realm of possibilities for the development of expert systems, image feature recognition, real-time data access, and database systems. Near-real-time data assimilation is also required for initializing and updating forecast models.

Space weather services depend on data collection and processing in the same way that tropospheric weather services do. Data need to be collected from a large number of sensors strategically placed on Earth's surface, in Earth orbit, and in interplanetary space. The forecast centers need computer and communication systems that can rapidly process and analyze large volumes of observational data; run complex models in real time; display and manipulate imagery; derive, generate, and disseminate useful products; and facilitate data sharing and backup responsibilities. Acquisition of new data sets and development of advanced models, with complex calculations, will require greatly enhanced computer systems at the core of space weather services. The forecast centers must replace and continually upgrade both hardware and software to deal with the growing computational and communications needs. The CCMC and RPCs provide a foundation for these capabilities, and the SEC is building its National Space Weather Information System to address these needs.

5.3.1 National Space Weather Information System

SEC began development and implementation of three new general purpose information systems in FY98 and FY99, including an information dissemination system (IDS), a data display system (DDS), and a data simulation system (DSS). The goal of this effort is reduced maintenance, increased system and network security, expanded operability, better management and control of user access, maximized fault tolerance, and a reduced number of unique interfaces required for each application. The IDS will be an open and extensible system that provides a common interface to SEC data stores (real-time and historical data, model output, data simulations, etc.) for local and remote systems and through a local area network, a dedicated wide area network, and the Internet. The DDS will be a separate but related development project to provide a single system which will consolidate and replace SEC present data display systems and web-based display systems. The DSS will operate through the IDS to provide simulated real-time data for SEC and NASA/Space Radiation Analysis Group (SRAG) applications including the DDS.

5.3.2 Data and Information Management Policies and Interaction with Vendors

The DOD and NOAA SEC space weather operations centers each have different customers with different requirements. Beyond providing alerts and warnings for the protection of life and property, the SEC is additionally bound by legal proscriptions defining the extent to which they may tailor products versus providing generic data to value added resellers in the private sector. In the DOD, finely tailored products are the rule rather than the exception but in some cases more generic data may be provided for use in distributed decision support systems across the department. This information is communicated through common user channels to the maximum extent possible. The SEC has developed a set of policies to guide its data and information management, particularly in light of commercial vendors. Additional information is available at the SEC's web site at http://www.sec.noaa.gov/.

5.3.3 Archiving and Analyzing Space Weather Data

Climatological studies and products must also be improved to satisfy the needs of planners and engineers to know the range of conditions their systems may encounter and the probabilities of those conditions. However, before improved climatological studies may be conducted, a more usable archive of space weather data is needed and a database of space weather impacts is also needed to better correlate space weather events with their effects.

Space weather data are not all archived and what is archived is distributed across a variety of locations and agencies and in both research and operational forms. The NSWP plans to develop a structured approach that will unify the various sources of data and establish a set of common standards for metadata (data about the data). Critical needs in this area are a system of quality control for the data and an effective method of archiving checked data so that they are readily accessible to the research community. In addition to quality controlled archives, it may be necessary to provide at least some "raw data sets" for use in testing models intended for operational use, providing the opportunity to test the model with sometimes noisy, sometimes incomplete input.

Some progress has been made in developing an impacts database, but national security and proprietary commercial concerns will continue to mitigate against collecting this information. The NSWP will continue to seek innovative ways to address these concerns and expand on this database.

5.4 Summary

Although the transition of research into operational capability continues to be a problem across the spectrum of scientific activity, significant progress has been made in bridging this chasm in space weather. The development of the Community Coordinated Modeling

Center (CCMC) paves the way to build research models already structured for easier transition and the Rapid Prototyping Centers (RPCs) provide the vehicle to test models in an operational setting, validate them, and seamlessly integrate them into daily operations.

The NSWP must continue to encourage interagency and international collaboration to obtain research observations for operational use wherever possible and to expedite the development and deployment of the necessary operational observing systems.

The NSWP will continue to promote and coordinate development of improved standards for data collection, formatting, communication, and management. This improvement will facilitate processing and use of the increasing volume of observations, model output, and products within and between operational centers and customers.