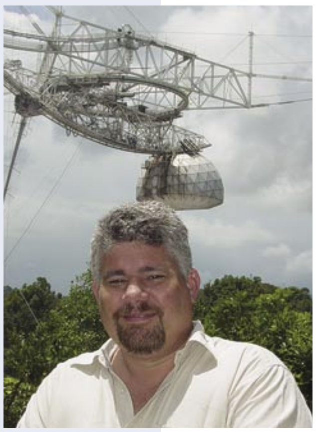
THE CEDAR POST
Coupling, Energetics and Dynamics of Atmospheric Regions

From the CSSC Chair

It is with great pleasure that we welcome our GEM colleagues to the forthcoming Santa Fe joint meeting. The joint GEM-CEDAR meeting will provide an opportunity for our scientists and students to get to know each other better and benefit from cross disciple interactions. Needless to say the Santa Fe environment will be particularly conducive for these activities and its surroundings are spectacular.



Significant milestones have been achieved in the AMISR project. On December 15, 2004 the AMISR panel installed at Jicamarca was turned on, and on January 30, 2005 the 8-panel AMISR configuration at the HAARP Facility was turned on. Way to go the SRI Team!

The central theme for the Santa Fe meeting will be Magnetosphere-Ionosphere-Atmosphere Processes. This time round our CEDAR participants will be able to get the real "scoop" from our magnetospheric colleagues on the other end of M-I processes. The new capabilities associated with the AMISR's highlights the need for mutual education on how best to optimize the new science pursuits. Further down stream are the tantalizing possibilities associated with DASI to actually "see" the detailed weather evolution in our A-I-M systems in ways that none of our theoretical or modeling developments even hint at.

Data assimilation has become more than a buzz word in our community. But do we all have the same understanding of the term data assimilation? A number of articles on this topic have been solicited from several of our data assimilation activists to provide various prospectives on "data assimilation".

Sixto A. González
Arecibo Observatory

INSIDE

Assembling antennas onto a panel/cart at Jicamarca.

A Preview of Advanced Modular Incoherent Scatter Radar

The Advanced Modular Incoherent Scatter Radar (AMISR) development reached a number of important milestones during the winter of 2004/2005. Chief among those milestones were the field testing of eight-panel mini-AMISR systems at the Jicamarca Radio Observatory (JRO) in Peru and at the HAARP Observatory in Alaska. These field deployments provided opportunities to demonstrate the relocatable aspects of the AMISR design in very different environments. As an exciting additional benefit, they are also yielding interesting scientific measurements of diverse ionospheric phenomena at the two sites.

Jicamarca

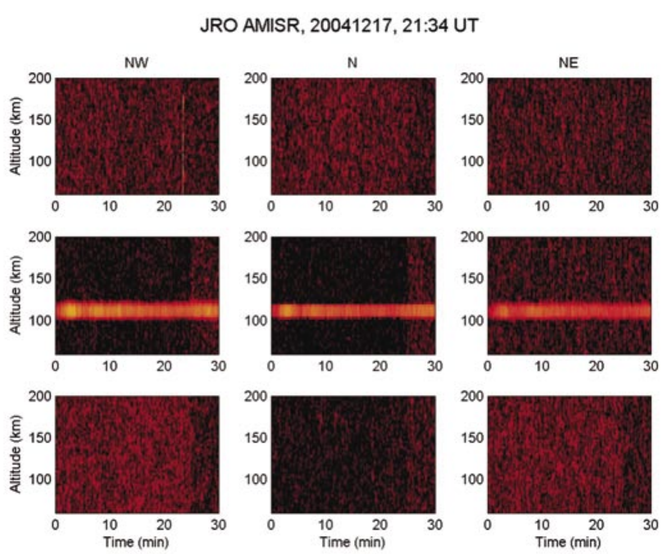
JRO was chosen as the first test site for a number of reasons. The infrastructure and interest by the JRO staff were clearly key aspects, as was the potential scientific return from such a limited AMISR system. Initial calculations suggested that we might see sufficiently large radar cross sections (RCSs) from both Equatorial Electrojet (EEJ) and Equatorial Spread F (ESF) irregularities in the 430 to 450 MHz operating frequency range to allow detection by an 8-panel array (128 KW peak power, ~44 m^2 effective aperture). If so, then the rapid steering capabilities of AMISR, in combination with simple interferometric analysis of a split array, could lead to detailed probing of the structures.

In anticipation of our arrival, JRO prepared a concrete pad for the array, a small out building to house the control and data acquisition electronics, and carts for the panels themselves. These carts allow for flexibility in configuring the panel geometry for various scientific goals. Though based on carts used for the assembly of panels, they were different enough that an unpopulated aluminum panel (plus associated hardware) was shipped down in mid October for a test fit. The bulk of the remainder of the shipment left California on 3 November and arrived in Peru on 18 November 2004. This shipment, however, did not include a final set of custom cables needed for operating the system. These cables, after heroic efforts by the JRO staff, were finally released from Customs and arrived on site on 11 December.

AMISR array and calibration antennas at Jicamarca.

Installation crew at JRO.

With the bulk of the hardware finally on site, the team proceeded to complete the panel assembly (installation of panels on carts, installation of the custom cables, and attachment of antennas) and the array calibration. JRO also provided a tower near the array for the calibration antennas. The initial array configuration was along magnetic north-south orientation aimed at maximizing the EEJ signal strengths by matching the antenna pattern to the expected RCS distribution in the ionosphere. On 15 December, before the antenna calibration was completed, the AMISR system saw its first EEJ returns. The calibration was completed on 17 December and the first 'calibrated' measurements collected that same day. The SRI team left the next morning (as planned) and made it home for Christmas with several data sets 'in the can'.

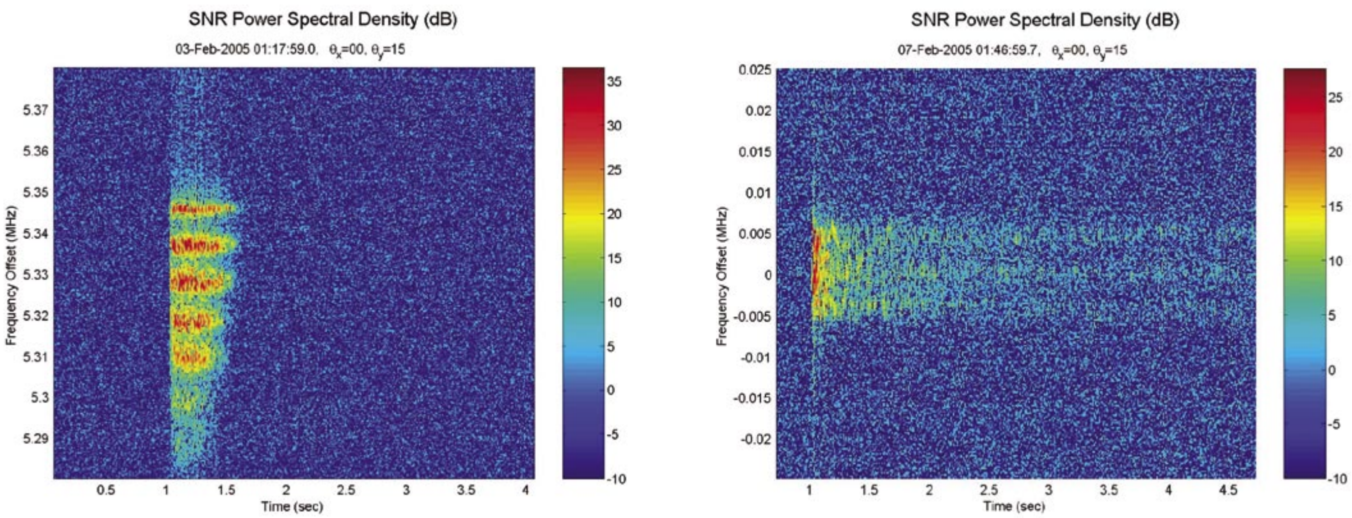


Thirty minutes of EEJ power measurements in 9 simultaneous directions (vertical, in the center, and 20 degrees from vertical in the NW, N, NE, E, SE, S, SW and W directions).

Since those first measurements, the JRO staff and Rudy Cuevas have continued developing appropriate data collection strategies and comparing measurements from AMISR with those from the Jicamarca radars. The success of this deployment depended heavily on their help and expertise.

HAARP

It would have been difficult to find a site more unlike Jicamarca than Gakona, Alaska, the location of the HAARP Observatory. The installation there occurred in the dead of winter, January 2005, though site preparation had been completed earlier, before the weather had turned cold. In addition to providing a location for field testing AMISR hardware in the arctic, HAARP also offers the opportunity to measure interesting phenomena excited by the HF heater (ionospheric modification experiments). HAARP is not an NSF funded facility, but there is considerable scientific overlap between much of the work done at that facility and that intended for the AMISR systems. RCS enhancements due to HF heating also represent one of very few opportunities to measure ionospheric phenomena at high latitudes with a modest array because geometry largely prevents access to measurements made perpendicular to B.



(left) *Four seconds of up-shifted plasma line overshoot measurements. Heating at 5.35 MHz, O-mode, turned on at time 1 sec on the x-axis.* **(right)** *Four seconds of enhanced ion line overshoot measurements. Heating at 4.25 MHz, O-mode. Note that the enhanced ion line return does not fall to background levels during this period. (Data collected by Brenton Watkins)*

The schedule for the deployment was driven largely by an HF heating campaign that started on 28 January. Panel installation started approximately a week and a half before that time. A number of issues prevented a completely smooth installation, but those issues were eventually solved (due in no small part to a very can-do attitude from the on-site HAARP staff). The first heater enhanced plasma line data were collected on 30 January.

NSF's AMISR-8 at HAARP was configured in a roughly square pattern, yielding a nearly symmetric beam pattern. The array was oriented in the magnetic cardinal directions with the 'boresight' direction oriented vertically. During experiments, the array was generally phased to look into the heated region of the ionosphere.

Approximately square array at HAARP.

Data were collected which show the well-known overshoot effect in the backscatter enhancements of both the plasma lines (up and down shifted) and the ion line. The overshoot is a transitory increase in the return power occurring immediately after the onset of heating but gradually decaying over the course of several hundred milliseconds as the plasma responds to the heating. During different heating exercises, the decay mode line sometimes dropped in intensity to the background noise level and sometimes did not. Several (5 or 6) cascade modes were also typically visible. Further work will be required to look at the conditions surrounding both types of behavior.

Summary

In summary, the two AMISR-8 deployments were successful from an engineering standpoint. Many lessons were learned and those results have made their way into the final design and planning for the Poker Flat, Alaska, installation of a full 128-panel AMISR. Additionally, interesting scientific data continue to be collected from both sites.

— **Craig Heinselman** and **John Kelley,**
SRI International, Menlo Park, California

New AMISR Support Opportunities

The NSF Division of Atmospheric Sciences has released an announcement for two distinct funding opportunities that relate to AIMSR. ***The full proposal deadline is June 3, 2005.***

SYNOPSIS

The Advanced Modular Incoherent Scatter Radar (AMISR) is a solid-state, phased array incoherent scatter radar that will measure basic properties of the upper atmosphere and ionosphere with unprecedented versatility and power. The phased-array design allows pulse-to-pulse beam steering, thus enabling three-dimensional "imaging" of ionospheric properties, such as electron density, electron and ion temperatures, and ion drift velocities. The modular design facilitates reconfiguration of the radar antenna, as well as relocation in response to changing scientific priorities. Current plans are for deployment of AMISR systems at Poker Flat, Alaska, and Resolute Bay, Canada. The radar system at Poker Flat consists of a single face approximately 35 meters square, while the system at Resolute Bay will consist of two such faces arranged to extend coverage across the polar cap.

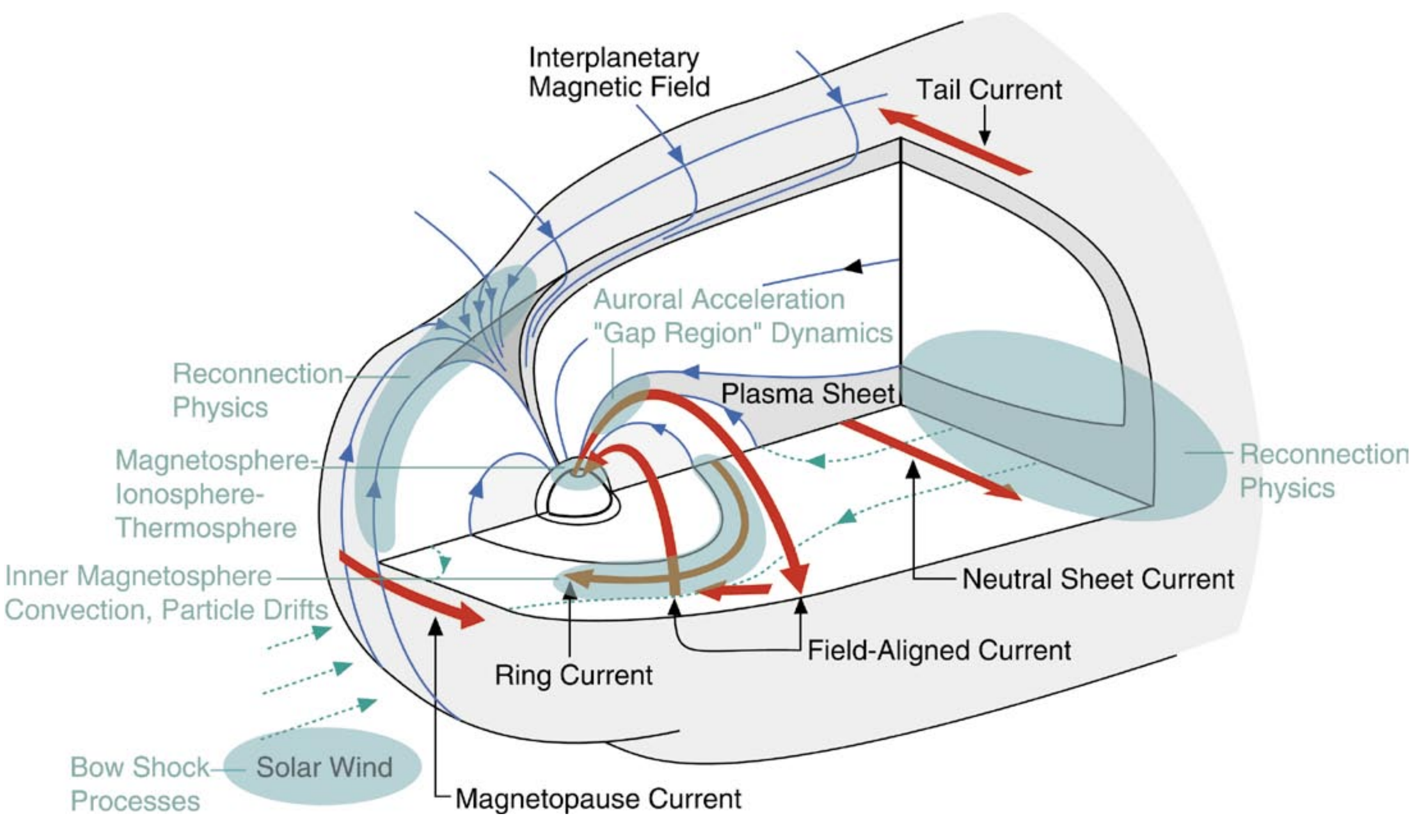
AMISR scientific goals will be enhanced by the addition of two important activities. One is the training of graduate students to help establish a user base of highly-qualified scientists who are knowledgeable in incoherent scatter theory and understand the practical challenges of designing and executing radar experiments. Second, is the development and deployment of optical instrumentation capable of observing properties of the upper atmosphere not measurable by AMISR. This solicitation is to provide funding for graduate students and optical instrumentation in support of the AMISR systems at Poker Flat and Resolute Bay. The graduate student activity entails support for scientists at academic institutions to pay graduate student costs for three years, plus no more than one month of the graduate student advisor's salary support for each of three years. Optical instrumentation support is for acquisition, design, development, and deployment of instruments at one of the two AMISR sites, or at a nearby site as appropriate.

This announcement can also be found at: http://www.nsf.gov/funding/ ➜ *On the funding page search for AMISR, will bring up the title "Graduate Student and Optical Instrumentation Support Related to the Advanced Modular Incoherent Scatter Radar (AMISR)".*

Geospace General Circulation Models and the NSF-GEM Program

The National Science Foundation's Geospace Environment Modeling program (GEM) has a long-standing goal in the development of a Geospace General Circulation Model (GGCM). The GGCM is envisaged as being the geospace analog to other general circulation models prevalent in the atmospheric and ocean sciences communities. Originally the GGCM was planned to be supported by the NSF through GEM. As fiscal realities have come in to play, the GGCM effort within GEM has evolved to instead identify the key components of a GGCM. In addition, various centers have been established that may develop a GGCM-like computational resource, obviating the need for a separate NSF GGCM. Specific examples are the NSF-sponsored Center for Integrated Space Weather Modeling (CISM), with Boston University as the lead institution, and the University of Michigan Comprehensive Solar-Terrestrial Environment Model (COSTEM) for Space Weather Predictions, sponsored by the DoD Multidisciplinary University Research Initiative program (MURI). In addition, the multi-agency sponsored Community Coordinated Modeling Center (CCMC), hosted by the NASA Goddard Space Flight Center, may also be a means for implementing a GGCM. While the CCMC is not explicitly involved in numerical code development, many of the individuals who submit codes to the CCMC are also actively involved in GEM, CISM, or the University of Michigan MURI.

As the mechanism for implementing a GGCM has evolved so has the GEM community's understanding of the underlying architecture of a GGCM. The Figure shows a representation of the Earth's magnetosphere in order to demonstrate our current understanding of what is involved in a GGCM. The figure shows the various regions



Schematic of the terrestrial magnetosphere showing the major regions and primary current systems. The regions marked in turquoise are regions that require modifications to global MHD codes.

of the magnetosphere, labeled in black, as well as the primary current systems, shown as red arrows. The turquoise regions are regions that may require modifications to the global magnetohydrodynamic (MHD) codes that are now envisaged as forming the basis of a GGCM.

Global MHD codes have evolved sufficiently that they can represent gross features of the terrestrial magnetosphere with reasonable fidelity. However, MHD codes by their nature ignore many physical phenomena that fall into what we might refer to as the kinetic regime, where details of the particle phase space distributions are important. In addition, MHD assumes a single fluid, and for most implementations, isotropic pressure. These assumptions break down in many of the regions highlighted in the Figure. As an example, reconnection occurs in an MHD code because of resistivity. This resistivity can be either numerical or explicitly included in the set of MHD equations. Recent work has shown that reconnection depends on the decoupling of electron and ion dynamics. Means for capturing this within the MHD codes need to be developed. Options include the use of a parametric resistivity model that captures the essential physics, or the use of higher resolution Hall-MHD or kinetic codes as a sub-grid module within the MHD code.

Other areas that may require either sub-grid modules or parameterized representation of the underlying physics include: the solar wind; the high latitude magnetosphere-ionosphere-thermosphere (MIT) system; the auroral acceleration region; and the inner magnetosphere. Some of these regions, such as the MIT, are already being included in global MHD models. In earlier MHD models the ionosphere was represented as an infinitely thin layer, which might have assumed a uniform Pedersen conductivity. The models have evolved to include conductivity gradients, as well as Hall conductivity. Some models now include coupled ionosphere-thermosphere models, allowing for neutral wind effects as well as vertical gradients. On the other hand other thermosphere-ionosphere dependent processes, such as ionospheric mass outflows, have not yet been fully implemented in MHD codes.

Efforts are also underway within the community to better capture processes within the inner magnetosphere. MHD codes tend to underestimate the ring current and the associated Region-2 Birkeland currents. By coupling a convection model such as the Rice Convection Model (RCM) to an MHD model, particle drifts and the associated particle pressures can be incorporated into the MHD models.

At high latitudes auroral effects have been incorporated through modeling ionospheric conductivity enhancements associated with particle precipitation, but most models treat the lower one or two Earth radii of an auroral flux tube as a gap across which MHD parameters can be mapped without change (other than those associated with changes in flux-tube area). Investigations are now underway to determine if dynamics within this gap region (i.e., induction) need to be included.

The last region shown in the Figure is the solar wind. It is often assumed that MHD captures the bow shock with sufficient fidelity that no other modifications are needed. The foreshock, however, can act to precondition the solar wind prior to encountering the bow shock. Again these effects may need to be included in a full GGCM.

The development of a GGCM also helps to define the various GEM campaigns. Currently GEM has three campaigns: the Inner Magnetosphere/Storms (IM/S) campaign, the Magnetosphere-Ionosphere Coupling (MIC) campaign, and the Global Interactions (GI) campaign. This last campaign is the newest campaign, and its scope is still being defined. In the context of the Figure, the GI campaign includes the regions labeled as “bow shock” and “reconnection physics.” The MIC campaign includes the “magnetosphere-ionosphere-thermosphere” region as well as the “auroral acceleration” region. The “inner magnetosphere” region is obviously included within the IM/S campaign.

In conclusion, I hope that this brief article has provided some background as to what the GEM community means when discussing the GGCM. The goal of developing a GGCM provides a direction for the GEM program, and helps to define the various physics topics addressed at the GEM workshops.

— **Robert J. Strangeway,** *GEM Steering Committee Chair*

What is Data Assimilation?

The past half-dozen years have seen a blossoming of data assimilation developments in our Aeronomy community. Although these have been heavily focused upon ionospheric data assimilation, these techniques have a much broader application. Historically our community has the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) procedure as its earliest effort in this area. For background on data assimilation one usually hears that the meteorologists have been "doing" data assimilation for over 50 years. However, on closer inspection of their efforts in data assimilation one finds it has different meanings to different meteorologists. Hence, we have taken the viewpoint of inviting our own aeronomers to address the question of "what is data assimilation?" in an Aeronomy context. Due only to space limitations, this first selection of articles may seem weighted towards the ionosphere. To redress this, the subsequent CEDAR Posts will invite articles from a thermosphere, a magnetosphere, etc. perspective. Indeed an open dialogue will be provided on the topic. *—CEDAR Post editorial team*

Ionospheric Data Assimilation: A New Paradigm

I am one of more than 70 program officers in the Department of Ocean, Atmosphere and Space at the Office of Naval Research and the only space scientist. Data assimilation is one of the more persistent themes heard in reviews from these other two disciplines. Oceanographers have been using data assimilation for the past 20 years but struggle to maintain the continuity and reliability of deep ocean data sources. In comparison, the meteorologists have been using dozens of different techniques for data assimilation successfully for more than 40 years and routinely ingest several million observations per day from surface, airborne and satellite platforms – with plans for up to 100 million data points in the near future, mostly from satellite platforms.

For meteorologists the problem addressed by assimilation is weather specification and forecast for a very complex system that has a tendency to go chaotic. The great success in weather forecast skill the past few years has resulted from the combination of fast computers, basic physics algorithms and massive amounts of data. Assimilation for the meteorologists is not data fusion or data interpolation—the large data sets are used to constrain the numerical noise in the physical models at each time step in order to propagate forward to provide forecasts.

For operational ionospheric models, the few thousand data points available from in situ satellites, ionosondes and GPS receivers has not been sufficient to sustain an assimilation model. However, with the addition of ultraviolet measurements from DMSP weather satellites, GPS occultation satellites, and more widespread ground-based GPS receivers, the total available data approaches a few hundred thousand to a million observations. Maxwell's Equations apply for the ionosphere and therefore this environment should be more deterministic than the troposphere and the hope is that an assimilation model for the ionosphere could be developed and sustained with less data. In 1999, the DoD agreed and released a Multidisciplinary University Research Initiative (MURI) topic for the development of such a model. Utah State University and the University of Southern California won the award and 5 years later an assimilating model for the ionosphere is now undergoing transition into operation at the Air Force Weather Agency.

— **Dr. Robert P. McCoy,** *Office of Naval Research*

Data Assimilation and High Latitude Electrodynamics

Background

Data assimilation (DA) is the process through which real-world observations create a coherent and objective picture of a physical system by combining information from physical models and data. Such algorithms fall into two categories: analysis and evolutionary. Analysis algorithms satisfy physical laws and fit data as best possible, consistent with the data errors; however, these algorithms have no explicit time dependence. They focus on a complete specification of the system at a given time, producing a snapshot. Evolutionary algorithms produce forecasts using observations and all known physics (or at least a good approximation) by evolving a system in time from an initial state to a future state. In addition to physical laws and observations, evolutionary models also incorporate other best guess information, such as climatology, to provide initial or boundary conditions and to constrain the model output. When observations and valid statistical data are optimally combined in an assimilation process, the resulting field (the analysis) is statistically the most likely state of the system given the information at hand. As long as the statistics give a proper description of the errors, even poor data can lead to an improved analysis. In the evolutionary procedures, real-world observations provide a safeguard against model error growth and contribute to the initial conditions for the next model run. Thus, they become part of the model's forecast cycle.

The DA cycle for an evolutionary system is a logic loop that governs the assimilation of data into a forecast model [Daley, 1991]. An evolutionary model becomes a vehicle for extracting information from observations to create a spatial and temporal structural rendering (stills or motion pictures) of the dynamic system consistent with the model's physics and resolution. Figure 1 shows a flow chart of an assimilation procedure used by the ocean-atmosphere community [after Robinson and Lermusiaux, 2000]. The goal is estimation of state variables, such as velocity, temperature, density, and pressure in the vicinity of the ocean-atmosphere interface. Parameters such as diffusivity, conductivity, representation of body forces, etc., describe fundamental properties of the system and may also be estimated. Recognizing that observations may be incomplete, inaccurate, or both, the first step after data acquisition is a quality control (QC) algorithm for the incoming data. The QC algorithm flags and /or rejects flawed observations (for example, the rejection of low count particle observations) and is different for different instruments. Some DA algorithms allow an observation's influence to change as the analysis goes through its iterations. Subsequent to the quality control cycle, the good observations are processed into an analysis model to create a global map of the observations. This map is then assimilated into an evolutionary model. The evolutionary model evolves the system in time and provides the background model for the next analysis model run. It is worth noting that some collected data may be withheld from the assimilation runs. Such data can be used separately for ongoing verification that can identify model deficiencies and lead to model improvements.

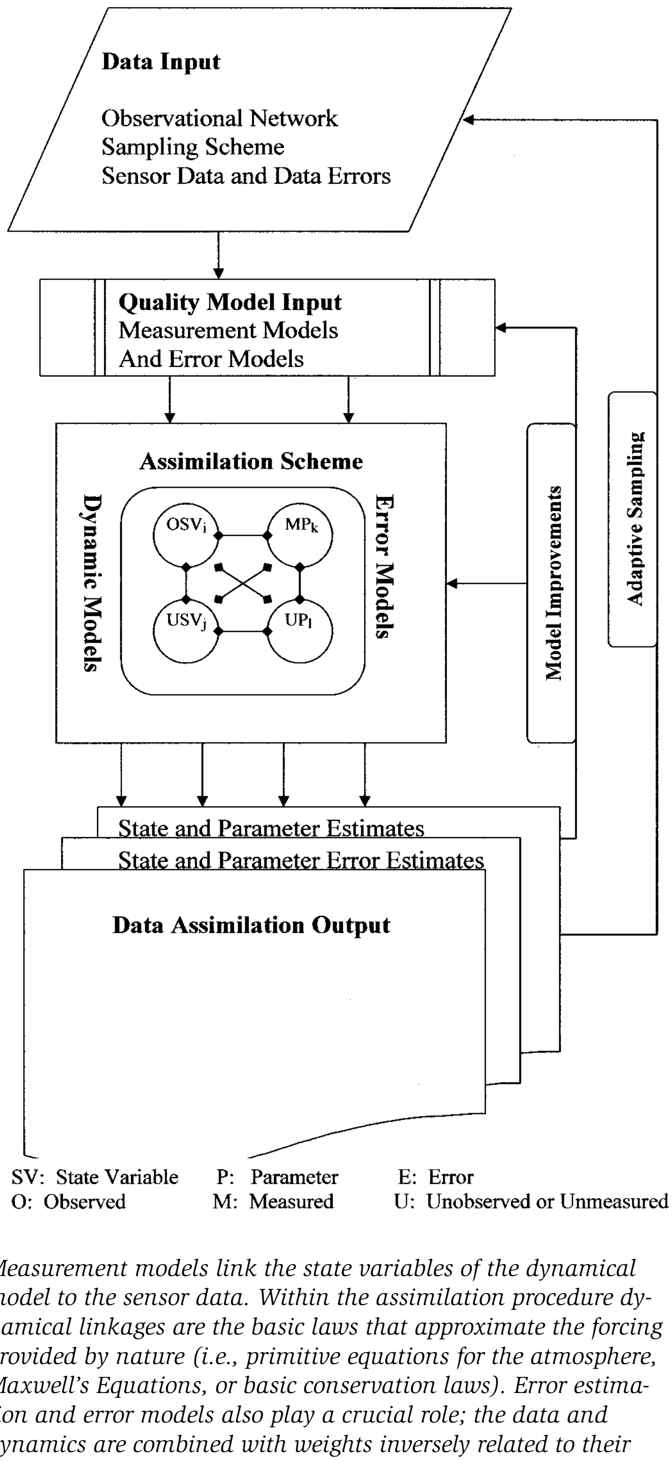
Space Physics and Space Weather

What is the value of DA to the space physics and aeronomy communities? DA is needed for more accurate nowcasting and forecasting of plasma and neutral gas distributions in ionosphere, thermosphere, and magnetosphere where large scale changes can be much faster than those in terrestrial weather systems. In both domains there is a need to incorporate diverse data sets, which DA can do efficiently. Further, the last few years have seen the maturation of theory and numerical specification models, so the physical forcing of the Earth's space environment is better understood, and this physics can be incorporated into DA schemes.

Space physics data assimilation is important for two reasons. First is the need to stretch information from limited data sources. Many aspects of the ionosphere, thermosphere, and magnetosphere remain poorly sampled compared to the domains of the meteorological and oceanographic communities. The use of climatological data and a priori patterns provide a framework in which limited data can be well used. The second reason for DA is the

FIGURE 1

Data Assimilation Flow Chart



Measurement models link the state variables of the dynamical model to the sensor data. Within the assimilation procedure dynamical linkages are the basic laws that approximate the forcing provided by nature (i.e., primitive equations for the atmosphere, Maxwell's Equations, or basic conservation laws). Error estimation and error models also play a crucial role; the data and dynamics are combined with weights inversely related to their relative errors. The final estimates should agree with the observations within data error bounds and should satisfy the dynamical model within model error bounds [after Robinson and Lermusiaux, 2000].

substantial volume of some types of remotely sensed observations that need spatial and temporal context. More importantly, it is often the case that raw or processed observations convey useful information beyond themselves as they are put in physical context. An example is that assimilation of electron column content measured along various lines-of-sight can help constrain the modeling of 3-dimensional electron volume density in the ionosphere and can be potentially applied to estimate certain forcing of dynamical models. Data assimilation provides a comprehensive model representation of large data sets that is most consistent with the ensemble of data. Examples in the latter category include: 1) Global Positioning Satellite (GPS) measurements of total electron content on a global scale and 2) Super Dual Auroral Radar Network (SuperDARN) measurements of coherent scatter echoes from drifting plasma. Literally hundreds of measurements may be available from either of these systems at any given instant in time.

Space Weather Analysis Data Assimilation

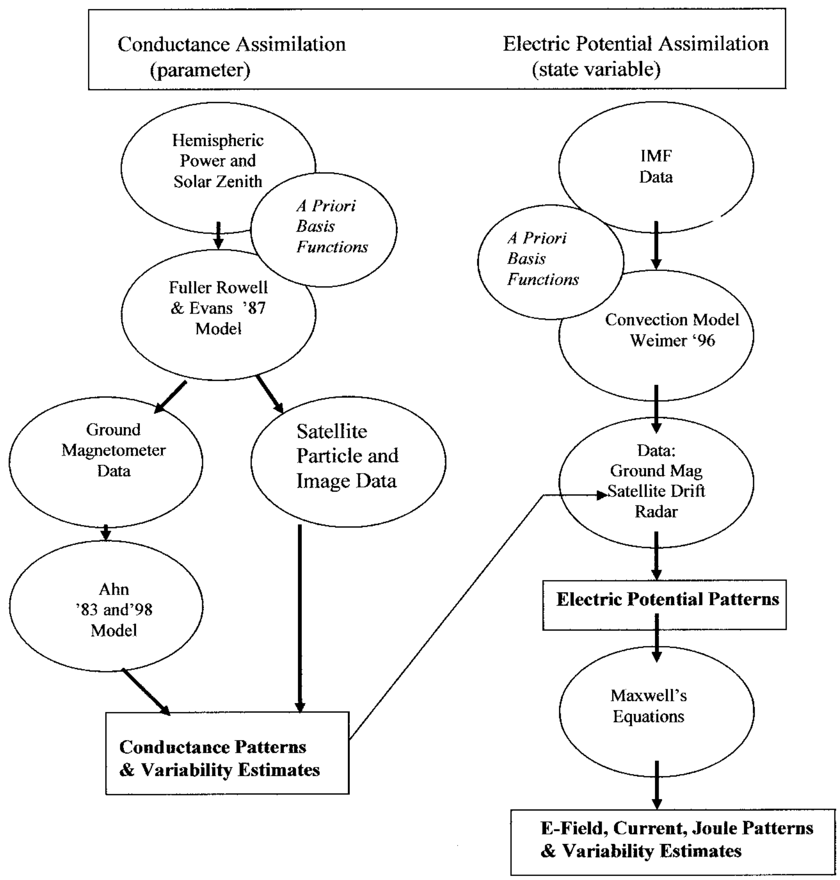
The terrestrial weather community has produced weather analyses charts using elements of DA for over 50 years. In the ionospheric and space weather community, data assimilation is a much younger endeavor. CEDAR-sponsored efforts in data assimilation began in the late 1980s. As in the atmospheric science community, some fledgling efforts had limited physics, others had limited climatology. Current space weather assimilation efforts are becoming more robust and providing results that drive new science. In this section and in follow-on sections in subsequent CEDAR-posts, we highlight the progress arising from data assimilation.

The earliest space weather effort was the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) procedure. AMIE is a data assimilation procedure that ingests multiple types of data to specify the state of several high latitude electrodynamic parameters on regional and global scales. Richmond and Kamide [1988] developed the AMIE procedure to create snapshots of the electrodynamic state of the high-latitude (>50° magnetic) ionosphere. The procedure retained several of the features of the previously developed Kamide, Richmond and

Matsushita (KRM) magnetogram inversion technique [Kamide et al., 1981]. The algorithm produced maps of the electric field, currents, and conductance at 110 km. The fit procedure (see Figure 2) is a weighted, least-squares fit to multiple data sets that are optimally constrained by physics (Maxwell's equations and Ohm's Law) and climatology. Originally the maps were fitted to ground magnetometer data and incoherent scatter radar measurements. In subsequent revisions, new data sets, such as DMSP ion drift observations, magnetometer measurements, and precipitating particles were included in the assimilation. More recently polar cap ionosonde data, coherent scatter radar observations, and estimates of conductance based on satellite imagery have also been assimilated. The procedure incorporates a number of features including: 1) checking for data outliers to help identify extreme or bad data; 2) the ability of the algorithm to function even when data are sparse, and; 3) estimation of uncertainties in the mapped output. The procedure has supported numerous investigations into the ionospheric electrodynamics processes at high-latitudes and the processes coupling the high latitude ionosphere to the neutral atmosphere, the magnetosphere, and the solar wind.

FIGURE 2

Assimilative Mapping of Ionospheric Electrodynamics Two-Step DA process



The AMIE procedure is a dual analysis DA algorithm. See text for description

In the first AMIE assimilation step global estimates of the Pedersen and Hall conductances at 110 km are derived. The derivation proceeds by choosing an appropriate climatological background conductance model (which includes solar zenith angle and hemispheric power information). Subsequently satellite particle and ground magnetometer data that have been processed through empirical models to give local measurements are assimilated. The a priori information helps to determine the physical nature of the fit. For example, the auroral zone is known to be stretched in longitude and to be rather narrow on the dayside and thicker on the nightside. These characteristics can be characterized mathematically in the covariance matrix of the procedure, dependent on the chosen basis functions. After the assimilation process is run, conductance analysis maps are produced. These maps provide useful information about the state of the ionosphere in their own right, but are also used as a key input in the second DA algorithm which estimates the electric potential pattern for the high latitude ionosphere.

In the second step of the AMIE procedure, interplanetary magnetic field data are used to select an appropriate climatological electric potential pattern. Ion drift data and radar drift data are then assimilated along with ground or satellite magnetometer data that have been related to the electric field via appropriate physics and conductance models. Once the electric potential pattern is determined, Maxwell's equations and other laws of physics guide the assimilation procedure in creating ionospheric current and Joule heating maps, as well as other maps of interest. Estimates of variability and uncertainty are also created in each DA step.

— **Delores J. Knipp,** *USAF Academy, Colorado*

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What is Data Assimilaton?

Data assimilation is the process of forcing a predictive model to agree with predictable observations within a computational loop. The use of the term "data assimilation" to describe a predictive model running with real-time model drivers (such as solar wind data) is a misnomer that should be avoided. Data assimilation is a cycle composed of four different components [*Daley*, 1991]: 1) quality control, 2) objective analysis, 3) model initialization, and 4) theoretical forecast.

The first component is the quality control of data. Quality control involves the verification of the data and the errors associated with the data. Ideally, this process should be conducted by a consortium of data providers who have developed rigorous and uniform standards for data quality and error bars. Often, this task is left to the data users who may perform basic buddy (each individual observation is in rough agreement with surrounding measurements) and sanity (no unphysical values) checks. Objective analysis, the second component of the data assimilation cycle, is the process of compiling the available, quality-checked data into a coherent map of the observations. Most space scientists are familiar with predictive or evolutionary models, which solve for the future states of a system given the initial state and the boundary conditions. An objective analysis algorithm addresses a different question. It seeks to completely specify a system at a given time from partial information of the system. Typi-

Where did the DASI Concept Come From?

The Solar and Space Physics Survey Committee (National Research Council of the National Academies) developed a Decadal Research Strategy in Solar and Space Physics entitled, "The Sun to the Earth and Beyond" which was published by the Academy in 2003. One specific initiative described in their decadal report is a small program referred to as "Small Instrument Distributed Ground-Based Network." This is described as an "NSF program to provide global-scale ionospheric and upper atmospheric measurements for input to global physics-based models." The Decadal Survey further outlines the objectives of the program as "A Small Instrument Distributed Ground-Based Network will combine state-of-the-art instrumentation with real-time communications technology to provide both broad coverage and fine-scale spatial and temporal resolution of upper atmospheric processes crucial to understanding the coupled AIM system." In June 2004 a workshop was held at Woods Hole to explore the scientific rationale for this concept. John Foster was the chair and the acronym DASI (Distributed Array of Small Instruments) appeared.

cally, objective analysis are preformed on the same grid as the forecast model and create maps of the system at larger scales than any one observation can see. The third component of the data assimilation cycle is the model initialization. In this process, the maps from the objective analysis are inserted into the forecast model. This process is the core of data assimilation cycle, and *Daley* [1991] devotes much of his book to explaining initialization techniques. Model initialization is complicated because integrating the maps into the system often excites natural modes of the systems. Hence, each initialization process is different and must be investigated separately. Finally, the forecast comes from a driven first-principles model similar to those models with which the CEDAR community is already familiar. The forecast model is usually only slightly modified from the existing, well-established full-physics model. Through the initialization process, the physics model continues to run forward in time with updated conditions for the previous (initialization) time step.

Together these components form a data assimilation system, however, all of the components except the model initialization can be developed and used separately. Quality control procedures which validate large data sets are useful to the community as a whole. This is especially true of the CEDAR community which uses physical data from some of the complex and sophisticated radio and optical instruments available. Similarly, the large-scale space weather maps that are produced by the objective analysis algorithms provide the CEDAR community with observational views of the system on synoptic and global scales. These maps illuminate the larger-scale behavior of the system in ways that individual measurements cannot. Finally, the development of first-principles, full-physics models is an established goal of the CEDAR community. These models capture the global understanding of the physics and chemistry of the system and represent the present state of knowledge in the CEDAR community.

As the physical models mature, the computational resources increase, and observational networks expand, data assimilation will become a more important and usable tool for both the operational space weather community and the CEDAR science community. Data assimilation systems and their component parts will provide the science community with reliable trusted data sources, coherent maps of the larger scale phenomena, insight into the natural modes of the ionosphere-thermosphere-mesosphere system, and a clear understanding of the limitation of our physical understanding. The CEDAR community has already taken steps towards developing fully operational data assimilation systems, most noticeably in the development of theoretical models (such as the TIME-GCM [*Roble and Ridley,* 1994] and the IFM [*Schunk et al.,* 1997]). While some work has been done on objective analysis algorithms (such as AMIE [*Richmond and Kamide,* 1988] and IDA3D [*Bust et al.,* 2004]), more objective analysis algorithms need to be developed. Most importantly, the CEDAR community needs to work together to establish and standardize the quality control of data. The CEDAR database provides an excellent site for this quality control process. It also provides a framework for the community to discuss how the data quality should be checked. It is important for whole CEDAR community to be involved in the process because the quality control must be standardized if it is to be useful.

— **T. W. Garner, G. S. Bust**, and **T. L. Gaussiran II,**
Center for Ionospheric Research, Univ. of Texas at Austin

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A 'New' Tool for Ionospheric Sciences and Applications

Data assimilation techniques have long been used in many different areas of science and engineering and are generally based on estimation and control theory. Over the past decades, these techniques have become a dominant tool for specifications and forecasts in meteorology and oceanography and more recently data assimilation techniques have also been used in space physics applications. In particular, over the past several years data assimilation models were developed for the Earth's ionosphere and the first ionospheric data assimilation model is scheduled to become operational at the Air Force Weather Agency (AFWA) in the summer of 2005.

The ionosphere, like the lower atmosphere and the oceans, is a complex and dynamic medium that exhibits weather features at all latitudes and longitudes. Although the climatological behaviour of the ionosphere is well understood and physics-based theoretical and/or numerical models of the ionosphere are able to reproduce many of the ionospheric features, they typically fall short in reproducing ionospheric weather. The major reason for this is the lack of reliable specifications of the ionospheric driving forces and to a lesser extend to the lack of reliable initial conditions.

Yet at any instance in time only a limited number of observations is available to determine the state of the ionosphere. These observations can come from many different data sources and are typically inhomogeneously distributed in space. Furthermore, observations from different instruments generally have different error characteristics and different availability and cadence. Therefore, it comes at no surprise that additional information that complements the observations is needed to create a detailed and coherent picture of the ionosphere. In data assimilation models this additional information is obtained from the numerical model. In particular, the knowledge about the evolution of the medium and its probable structure embodied in the numerical model. With this, observations distributed in time can be used to construct a consistent picture that agrees with the data and the physical laws embedded in the model. The information of previous observations is preserved in the assimilation process and consequently data assimilation is not just a question of fitting new data. Since the model needs to preserve and evolve all the information acquired from the past observations, it is important that the model not only has a sufficiently high resolution but also that it incorporates all of the important physical processes.

Most advanced data assimilation methods are based on a statistical foundation. The estimation of the state of the system is constructed from weighted combinations of the observational data and the model forecast. The weights in this scheme are determined from the errors in the observational data and the errors in the numerical forecast. However, the use of errors in this melding scheme also creates its biggest challenge. To obtain reliable estimates and predictions of the Earth's upper atmosphere millions of numbers are needed to represent its state. The estimation of all their likely errors, their interrelationships and their evolution is extremely difficult.

Typically, data assimilation proceeds sequentially through time. At any instance, the numerical model organizes the information obtained from previous observations and then propagates this information forward in time and makes a short-term forecast. New observations, as they become available, are compared with the model forecast and used to correct the model state, to obtain an optimal estimate (in a statistical sense) of the state that is as consistent with the observational data and the previous information as possible. This correction can include modifications of the state's initial conditions, of uncertain internal model parameters or of the external driving forces. In this scheme, the model organizes the information embedded in the observational data and interpolates and extrapolates the information into data-void regions in time and space. The data, on the other hand, keep the model trajectory "on the road".

The new ionospheric data assimilation models will continuously track the global electron density variations through time, and the results will be available to ionospheric applications as well as for scientific studies. These models should lead to a major advance in our understanding of ionospheric physics similar to the advances that occurred in meteorology and oceanography after physics-based data assimilation models were introduced in those fields.

— **Ludger Scherliess,** *Center for Atmospheric and Space Sciences, Utah State University*

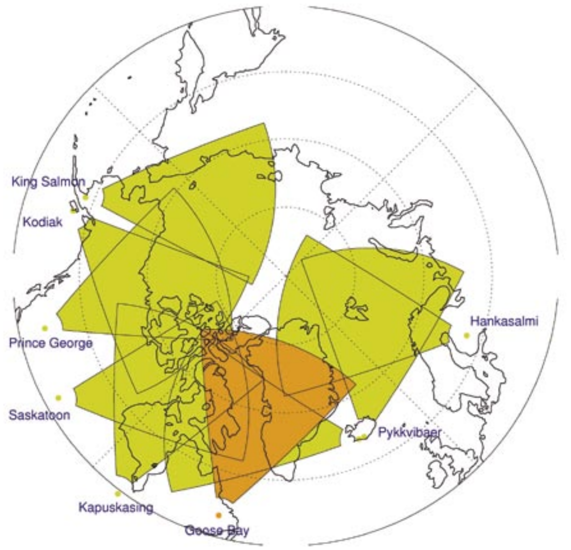

Figure 1: Fields of view of several northern hemisphere SuperDARN radars.

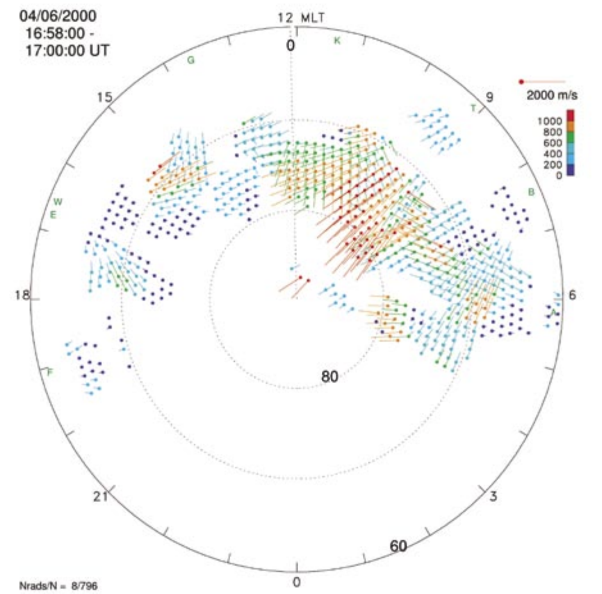

Figure 2: Distribution, directions, and magnitudes of line-of-sight velocities observed by SuperDARN radars on 04/06/2000 in a 2 minute interval.

Assimilation of SuperDARN Plasma Convection Measurements into Global Convection Maps

In the 1980s, the first HF radars of the SuperDARN type were installed at Goose Bay, Labrador, by JHU/APL and Halley Station, Antarctica, by the British Antarctic Survey. The field of view of the Goose Bay radar is highlighted in *Figure 1.* These single-station radars measured the velocity of plasma convection in the high latitude ionosphere and established the value of the coherent-scatter technique. A larger view of plasma processes was obtained by exploiting the conjugate aspect of the observations with Greenwald et al. [1990], showing for the first time with direct observations the hemispheric asymmetry in the By dependence of the dayside flows. With the inauguration of SuperDARN in the early 1990s as an international collaboration to build and jointly operate a network of HF radars new sites came into operation in central Canada and Iceland. The radars were configured in pairs with overlapping fields of view so that the two-dimensional velocity could be unambiguously resolved through bistatic observations. An early triumph was the first complete mapping of a reverse dayside convection cell under northward IMF conditions [Greenwald et al, 1995]. However, the bistatic capability was limited to the areas of overlap and therefore local in character. Much more velocity information was available in the sets of line-of-sight velocity data as shown in *Figure 2.*

As radars continued to be added to the network, various methods were tried to extend the methods developed for the original single-station radars to global scales. These were cumbersome and inevitably gave rise to inconsistencies. Finally, the problem was recast in terms of solving for the global distribution of electrostatic potential, that was most consistent with all the available data. This ‘large-bore’ approach ensures that the solution for the convection pattern is physically reasonable in that the requirement of incompressibility of the ionospheric plasma is immediately satisfied. It also accommodates conflicting tendencies between the datasets in a mathematically rigorous way. It should be remembered, however, that the solution will be optimal only in a global sense; the best estimate of the local velocity will still be obtained by consideration of the datasets of the relevant radar or radars and bistatic determination of the velocity vector, if possible.

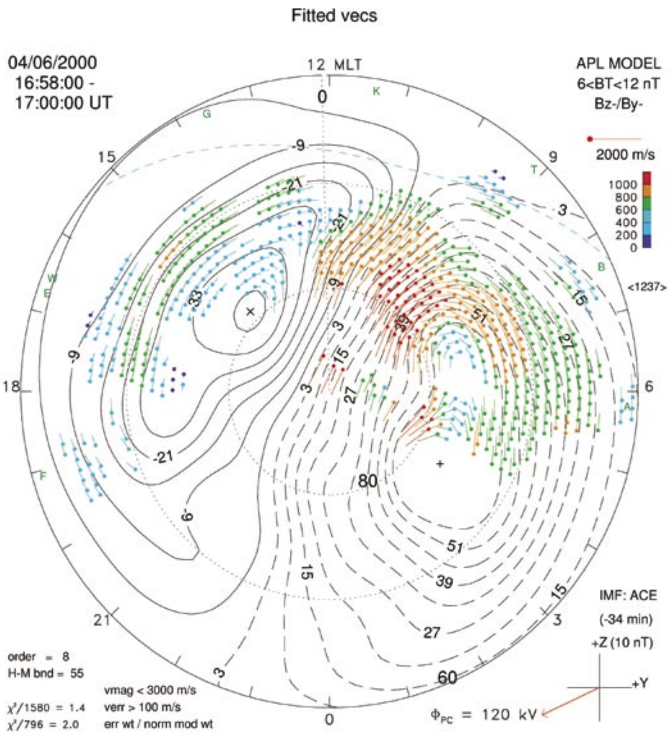

Figure 3: Comparison between SuperDARN line-of-sight observations (colored lines) and the assimilated convection pattern (dashed contour lines) for the same 2 minute interval shown in Figure 2.

The datasets of the individual SuperDARN radars are assimilated, then, into a representation of the global potential pattern, as shown in Figure 3. The mapping algorithm with enhancements was described by Ruohoniemi and Baker [1998] and Shepherd and Ruohoniemi [2000]. A radar velocity measurement provides an estimate of the gradient of the electrostatic potential in the direction orthogonal to the radar line-of-sight. The potential is expressed as a series expansion in terms of spherical harmonic functions. The ensemble of velocity measurements is fitted to the expansion in a least-squares sense that takes account of the uncertainty in the velocity measurements. The physical content of the solution is contained in the coefficients of the expansion. The degree and order of the expansion determines the spatial resolution. One complication in implementing this procedure is the lack of constraints on the solution over areas of no radar measurements. This was addressed by including a module for sparsely sampling a statistical convection model for vectors that are representative of the prevailing IMF conditions. The model vectors are weighted in accordance with the order of the fitting to just stabilize the solution. As radars have continued to be added to the network the provision of data has become more extensive and the reliance on the statistical model has been reduced.

Some other parameters that are needed to constrain the fitting, such as the size of the convection zone, are gauged directly from the radar data. *Figure 3* shows the approximate boundary of the convection zone as a dashed blue line and also depicts resolved velocity vectors from the fitting at those positions where radar measurements were made. The quality of the fitting can be gauged by the extent to which the input velocity data are reproduced. The SuperDARN convection maps are generated at the 1–2 min cadence of the radar scans. With internet links to the northern radars, data are assimilated at JHU/APL in near real-time and a 'nowcast' of the convection pattern is posted to the web.

— **J. Michael Ruohoniemi,** *The John Hopkins University Applied Physics Laboratory.* [http://superdarn.jhuapl.edu/rt/map/index.html]

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Letter from Program Director

To the Cedar Community:

It has been a pleasure to administer, along with Bob Robinson, the CEDAR program at NSF these last two years. It has also been a pleasure to recognize the status of the CEDAR community within the GEO Directorate at NSF, and to become familiar with the details of the scientific advances this community has made. Due in part to thoughtful leadership, and due in part to an engaged community, CEDAR remains the most referenced example of a successful, coordinated, grass-roots organization in GEO, and perhaps within NSF as a whole.

That reputation alone does not expand CEDAR funding, and there are many concerns about new limitations to federal support for basic research, including Aeronomy. In fact, the greatest funding challenge we face is driven by the excellence of our accomplishments—it will be challenging to find the resources to support a wide variety of new and exciting CEDAR directions. Let me give just a few examples.

AMISR is poised to extend our ISR radar chain to the polar cap, improving our perception of the global ionospheric morphology. The experimental possibilities of the phased array design are certain to break new ground in our understanding of the polar ionosphere and of basic plasma physics. LIDAR development has transformed our familiarity with an atmospheric region characterized just twenty years ago as the "ignorosphere" to a region we sample with a few degree temperature resolution and 1 m/s wind resolution. We have demonstrated remarkable chemical and dynamic detail in multiple E and D-region metal layers. Optical imagers have revolutionized remote sensing of the mesosphere and thermosphere, and array detection has made all-sky wind maps, delivered every few minutes, a reality. High-speed cameras nested with the radars are providing observational signatures of magnetosphere-ionosphere coupling. For the first time, sub-Rayleigh emissions can be accurately sampled using large aperture telescopes and high quantum efficiency detectors. We have learned to sample micrometeors with precisions that provide wind and wave information over large atmospheric areas once thought intractable, while we simultaneously create a new assay of solar system debris relating directly to our solar system origin and evolution. We have discovered a new signature of the global electric circuit in optical emissions above thunderstorms, and we find that this circuit may actually modulate the charge distribution of cloud condensation nuclei in the troposphere—and therefore cloud cover and global albedo. We have developed radar, GPS, and magnetometer chains that are untangling the mysteries of ionospheric irregularity generation, and the associated communications disturbances are truly becoming predictable. We have quantified the possible atmospheric responses to increasing greenhouse gas deposition, and have thus established superior climate-change indicators. We are on the verge of quantifying, (with accuracies approaching our knowledge of UV energy input into the upper atmosphere) the momentum flux from gravity waves into the thermosphere on a global scale, while we isolate significant lower atmosphere sources of gravity waves.

The plans to carry these capabilities to a global scale are especially exciting. We contemplate already the next, best, location for AMISR (or even additional faces). There are plans for expanding coherent radar arrays, GPS arrays, magnetometer arrays, and for creating imager and Fabry-Perot arrays. Our community has responded to these capabilities with the necessary coordination: The Radar, Lidar, and passive optical sub-communities have all convened in the last two years, and each has chosen to institutionalize a collective, integrated approach to our expanding observational abilities. There is a new initiative to develop a global array of observing instruments called the Distributed Array of Small Instruments (DASI).

As a community, we have been wise to nurture, rather than consume, our offspring. There are four new CEDAR postdoc awards this year, and CEDAR has sponsored, in the last two competitions, five new faculty members who have received their Ph.D. since 1996—in addition to the Faculty Development in Space Sciences initiative that the NSF Upper Atmospheric Research Section sponsored this year (producing eight new faculty positions).

The multi-agency effort to understand and predict space weather has led to many new research endeavors, including the Center for Integrated Space Weather Modeling and the Community Coordinated Modeling Center. One of the important aspects of these activities is that space scientists are beginning to realize the importance of understanding space weather as a system connecting Earth with the sun. This connectiveness has been a hallmark of the CEDAR program since its inception. I am looking forward to the joint CEDAR/GEM Workshop in Santa Fe this summer, as it demonstrates our commitment to better understand the coupled ionosphere-magnetosphere system.

Without question CEDAR Phase III is a resounding scientific and educational success. But, how can we maintain and expand so many new capabilities? In fact, it is that unpredictability of federal policy, coupled with the excellence of CEDAR science, that gives me confidence in a bright future. As scrutiny of agency budgets intensifies, it is our new and highly relevant research that promises budget increases, even as other disciplines may falter. Our task is to maintain the fire hose of exciting research ideas that are the fruit of the CEDAR organization, and to clearly demonstrate the relevance of that research to the policy fashions of today—including space exploration, climate change, space weather, security, and defense. It is a familiar challenge.

It really is an exciting time for CEDAR, and I thank you for letting me pitch in on the administrative side of things. In that capacity, I have learned just how vigorous and relevant CEDAR is, and is likely to be in the future.

— **Bob Kerr**
Program Director
NSF GEO/ATM Aeronomy

2005 Joint CEDAR-GEM Workshop Plans

Sunday, June 26 to Friday, July 1, 2005
Eldorado and La Fonda Hotels,
Santa Fe, New Mexico

The Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) 2005 Workshop will be held jointly with the Geospace Environment Modeling (GEM) Workshop in Santa Fe, New Mexico. Most of the CEDAR meetings will be at the Eldorado Hotel, while the GEM headquarters will be at the La Fonda Hotel. Please note that CEDAR is scheduled to remain in Santa Fe for 2006 (19-23 June) and for 2007 (24-29 June).

The regular registration fee is $350, the same as last year. Student registration fees are less, and they can receive travel from US institutions and lodging, and sometimes per diem funds. Students need a certification (an email) from their advisors that they are working in an area of CEDAR related work before they are elegible for funding. All CEDAR (not GEM) students need to fill in the biographical form that will be part of the registration process. Further funding and other information for CEDAR students is given in: http://cedarweb.hao.ucar.edu/workshop/students.html

Special rates are available for rooms at the Eldorado Hotel and Fort Marcy Suites for CEDAR, and at the La Fonda and St Francis Hotels for GEM. Whether flying into Albuquerque or to Santa Fe, it is not necessary to rent a car since there are about 120 restaurants within walking distance of the hotels. We recommend NOT renting a car since the parking can get expensive. In addition, we will be offering selected tours using the bus that will bring participants from Colorado to the workshop. Like last year, we will have a bus tour to Bandelier National

Park, Chimayo Hispanic Village, Museum Hill in Santa Fe, and some more things through Santa Fe Destinations. We will also have a couple of free trips to Tin-Nee-Ann Trading Company, which is one of the best and most complete souvenir stops in Santa Fe.

There are several joint social events, including the icebreaker/reception Sunday evening for everyone at the Eldorado, followed by student bowling, a Bar-B-Q for the students at Fort Marcy Suites on Monday night, and a banquet for everyone at La Fonda on Wednesday evening. Of course, the reason for our joint meeting is joint scientific activities. We have scheduled four joint plenary sessions, seven joint workshops including the student workshop, and one joint poster session.

- ➜ **Sunday:** The joint Sunday student workshop topic is 'Solar Wind-Magnetosphere-Ionosphere Coupling', where student representatives Carlos Martinis (martinis@bu.edu) and Jichun Zhang (jichunz@engin.umich.edu) are in charge.
- ➜ **Monday:** Monday morning are historical perspectives of CEDAR by Tim Killeen and of GEM by Chris Russell at the Eldorado Hotel. The MLT poster session will be in the late afternoon in the Pavilion of the Eldorado.
- ➜ **Tuesday:** Joint sessions on Tuesday morning at La Fonda cover Magnetosphere-Ionosphere Coupling (MIC) and Inner Magnetosphere/Storm (IM/S) topics of electrodynamic Sub-Auroral Plasma Streams (SAPS) and mass transfers in the stormtime plasmasphere. The joint workshops are at La Fonda in the morning and at the Eldorado after lunch, including a joint workshop on the IHY, IPY and eGY programs. The joint poster session follows in the Pavilion at the Eldorado from 4-9 PM.
- ➜ **Wednesday:** The Wednesday joint session at La Fonda will cover the Polar Ionosphere, AMISR, DASI, and modelling including asssimilations, with joint workshops in the Eldorado in the afternoon.
- ➜ **Thursday and Friday:** We then go our separate ways on Thursday and Friday, although any CEDAR participant can attend any GEM function and vice versa. GEM's second poster session will be Thursday evening at La Fonda.

For More Information

Workshop Homepage:
http://cedarweb.hao.ucar.edu

Agenda:
http://cedarweb.hao.ucar.edu/workshop/agenda.html

Agenda Day-by-Day & Summary:
http://spacibm.rice.edu/~gem/gem2005

Poster Info:
http://cedarweb.hao.ucar.edu/workshop/posters.html

Students Info:
http://cedarweb.hao.ucar.edu/workshop/students.html

Contact persons:
http://cedarweb.hao.ucar.edu/workshop/contacts.html

Deadlines:
http://cedarweb.hao.ucar.edu/workshop/deadlines.html

We are very excited at the prospect of finally having a joint CEDAR-GEM workshop in the same city at the same time. We hope this opportunity to get to know each other will foster long-lasting personal and professional relationships between members of our two groups. Hope to see you all there!

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Each issue of the CEDAR Post is posted on the web, which Barbara Emery announces at the time of completion. If you are willing to give up your paper version of future issues and access the electronic version instead, please e-mail Jill Tarbell at jtm14@cornell.edu. Thank you for your kind consideration!

The CEDAR Post is published three times a year and is mailed to more than 1200 scientists worldwide.
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