## SA21B-0468 0830h POSTER

### The Response of Thermospheric Nitric Oxide to the Geomagnetic Storm of April 2002

Scott M. Bailey[1] (907-474-7741; scott.bailey@gi.alaska.edu)

Geoff Crowley[2] (210-522-3475; crowley@picard.space.swri.edu)

Stanley C. Solomon[4] (303-497-2179; stans@ucar.edu)

Daniel N. Baker[3] (303-492-4509; dan.baker@lasp.colorado.edu)

[1]Geophysical Institute, University of Alaska 903 Koyukuk Dr., Fairbanks, AK 99775-7320, United States

[2]Southwest Research Institute Southwest Research Institute , 6220 Culebra Rd., San Antonio, TX 78238-5166, United States

[3]High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO 80307, United States

[4]Laboratory for Atmospheric and Space Physics, University of Colorado 1234 Innovation Drive, Boulder, CO 80303, United States

The presence of nitric oxide in the lower thermosphere is important for several reasons. NO plays a strong role in the thermospheric energy balance as it emits efficiently in the infrared, it is the terminal ion in the lower ionosphere and, if transported to lower altitudes, will catalytically destroy ozone. NO is primarily produced through the reaction of excited atomic nitrogen with molecular oxygen. One of the primary loss mechanisms of NO is photodissociation by solar ultraviolet irradiance. In order to produce the excited atomic nitrogen atom, the strong N2 molecular bond must be broken. It has been shown that at high latitudes, auroral electrons and the energetic secondary electrons provide the source of energy that leads to the large amounts of NO that are observed. The Student Nitric Oxide Explorer (SNOE) satellite has been observing NO in the thermosphere daily since February of 1998. Global observations of the abundance of NO were made throughout the period of the large geomagnetic storm that occurred April 16-20 of 2002. Large increases in NO abundance were observed during the storm. Auroral production of the NO is demonstrated by the distribution with magnetic latitude. Equatorward enhancement of NO was observed and suggests transport by meridional winds. Because the NO molecule has a lifetime of about one day, a high latitude observation of NO provides an indication of the integrated auroral energy deposition over the previous day. In this talk we will present the NO observations during the time period of the storm. We will also compare the observations to results from the ASPEN version of the TIME-GCM model now in use at SWRI.

## SA21B-0469 0830h POSTER

### Comparison of the TIMEGCM model to Jicamarca and Arecibo measurements during the April 2002 World Day observations

Jonathan J Makela[1] (jjm20@cornell.edu); Michael C Kelley[1] (mikek@ece.cornell.edu); Geoff Crowley[2] (crowley@picard.space.swri.edu); Michael J Nicolls[1] (mjn25@cornell.edu); Jorge L Chau[3] (chau@geo.igp.gob.pe); Sixto Gonzalez[4] (sixto@naic.edu)

[1]Cornell University, School of Electrical and Computer Engineering, 351 Rhodes Hall, Ithaca, NY 14853, United States

[2]Southwest Research Institute, 6220 Culebra Rd., Building 178, San Antonio, TX 78238-5166, United States

[3]Radio Observatorio de Jicamarca, Instituto Geofisico del Peru, Apartado 13-0207, Lima, PER 00000, Peru

[4]Arecibo Observatory, National Astronomy and Ionosphere Center, HC3 Box 53995, Arecibo, PR 00612, Puerto Rico

The April 2002 ISR World Day observations spanned both a very calm time period and a time of intense storm activity lasting several days. This dataset provides an ideal setting to evaluate the response of the Thermosphere Ionosphere Mesosphere Electrodynamic General Circulation Model (TIMEGCM) for unusually stressed space weather conditions. We make comparisons between TIMEGCM and both an equatorial station (the Jicamarca Radio Observatory) and a midlatitude station (the Arecibo Observatory), both of which were collecting data during this time period. Parameters used in this comparison include the electron density, ion and electron temperatures, ion velocities, and the neutral wind. There are many regions of good agreement between the model and the data, and we identify areas where the model could be improved.

## SA21B-0470 0830h POSTER

### Thermospheric Density Response to Solar Disturbances During April 15-24,2002: CHAMP/STAR Accelerometer Measurements

Jeffrey M. Forbes[1] (303-492-4359; forbes@zeke.colorado.edu)

Sean Bruinsma[2] (+33-561253098; sean.bruinsma@cnes.fr)

Steven Nerem[1] (303-492-6721; steven.nerem@colorado.edu)

Xiaoli Zhang[1] (303-492-2746; zhangx@rtt.colorado.edu)

[1]Department of Aerospace Engineering Sciences, UCB 429 University of Colorado, Boulder, CO 80309-0429, United States

[2]Department of Terrestrial and Planetary Geodesy, Centre National dEtudes Spatiales 18, Avenue E. Belin, Toulouse 31401, France

During April 15-24, 2002, disturbances originating on the Sun were manifested in the upper atmosphere of Earth through the deposition of particle, field, and photon energy. In the present work, the response of total mass density near 410 km is investigated through STAR accelerometer measurements on the CHAMP satellite. Data are available near 1500 LT and 0300 LT from 87°S to 87°N latitude. The latitude vs. time response of the upper atmosphere is thus revealed on both the day and night sides of the Earth. Perturbations over quiet levels of order 50-100% occur. A variety of density enhancement and depletion structures are also apparent at high latitudes.

## SA21B-0471 0830h POSTER

### A study of shear in the neutral wind during geomagnetic storms

Michael J Nicolls[1] (mjn25@cornell.edu)

Michael C Kelley[1] (mikek@ece.cornell.edu)

Jonathan J Makela[1] (jjm20@cornell.edu)

[1]Cornell University, School of Electrical and Computer Engineering, 304 Rhodes Hall, Ithaca, NY 14853, United States

A good assumption in most cases, and one that is used often as a boundary condition, is that there is very little shear in the neutral wind in the thermosphere. However, we have noticed that in cases of strong density perturbations, such as a sudden rise in the height of the F peak, there are often strong shears in the neutral wind as ion drag drives the wind, overpowering viscocity. On April 17, 2002, during an intense geomagnetic storm, there was strong electron density depletion over the Arecibo Observatory accompanied by a significant shear in the neutral wind. Neutral winds over Arecibo are calculated using the standard Burnside method, and we compare the results to FPI measured winds to ensure that we reproduce the correct trend. We compare the predicted neutral wind from TIMEGCM to the calculated wind over Arecibo, and note that TIMEGCM does not predict this shear. We present a local model based on first principles to attempt to recreate this shear. We also compare the forcing terms from TIMEGCM, our local model, and the actual data.

## SA21B-0472 0830h POSTER

### Analysis of the April 2002 Geomagnetic Storm Effect on Global $CO_2$ Infrared Limb Emission as Observed by TIMED/SABER.

Jeremy R Winick[1] (781-377-3619; jeremy.winick@hanscom.af.mil); Peter P Wintersteiner[2] (781-890-3330 X231; winters@arcon.com); Richard H Picard[1] (richard.picard@hanscom.af.mil); Larry Paxton[3] (larry.paxton@jhuapl.edu); Manuel López-Puertas[4] (puertas@iaa.es); Martin G Mlynczak[5] (m.g.mlynczak@larc.nasa.gov); James M Russell[6] (james.russell@hamptonu.edu); Andrew Christensen[7] (Christensen@eumetsat.de); Yongliang Zhang[3] (yongliang.zhang@jhuapl.edu); Larry Gordley[8] (larry@gats-inc.com)

[1]Air Force Research Laboratory, AFRL/VSSS 29 Randolph Rd, Hanscom AFB, MA 01731, United States

[2]ARCON Corporation, 260 Bear Hill Rd, Waltham, MA 02451, United States

[3]Johns Hopkins U Applied Physics Laboratory, 11100 Johns Hopkins Rd, Laurel, MD 20723, United States

[4]Instituto de Astorfisica de Andalucia, Apdo. 3004, Granada 18000, Spain

[5]Nasa Langley Research Center, 21 Langley Boulevard, Hampton, VA 23681, United States

[6]Center for Atmospheric Sciences, Hampton University, Hampton, VA 23668, United States

[7]EUMETSAT, Am Kavalleriesand 31, Darmstadt D-64295, Germany

[8]GATS, 11864 Canon Blvd., Suite 101, Newport News, VA 23606, United States

The SABER instrument on TIMED is continuously measuring limb radiance profiles of $CO_2$ $\nu_3$(4.3-$\mu$m) and $\nu_2$(15-$\mu$m) with unprecedented sensitivity. SABER provides limb radiances up to 130km for the 15- $\mu$m channel and 140-150km (approaching 200km during strong aurora) for the 4.3-$\mu$m channel. During the April 2002 geomagnetic storm the 4.3-$\mu$m band nighttime emission which also includes aurorally excited $NO^+$(v) emission above about 100km responded dramatically. In the auroral region limb radiance was enhanced by more than a factor of 20 above the quiescent nighttime levels, at times being as bright as the daytime emission. The enhancement expanded equatorward as the storm effects intensified. However, the $CO_2$ 15-$\mu$m band was not significantly enhanced. We will examine the global behavior of the limb radiance, including other bands such as the $O_2$ $^1\Delta_g$1.28$-\mu$m band and the 2.0-$\mu$m band, and TIMED GUVI EUV atomic oxygen and molecular nitrogen emissions, in an effort to distinguish direct auroral excitation from storm related temperature and composition changes.

# SA22A MCC: 124 Tuesday 1330h

## Extracting Power from Multiple Rivers of Data II *(joint with SH, SM)*

***Presiding:*** **J W Hughes,** Boston University**; R A Behnke,** National Science Foundation

## SA22A-01 1330h INVITED

### Data Assimilation In Models: The Time Has Come

Ernest Hildner (303-497-3311; ernest.hildner@noaa.gov)

NOAA Space Environment Center, 325 Broadway, Boulder, CO 80303, United States

Models of the space environment are maturing; at the same time, increasing amounts and kinds of observational data are becoming available. If meteorological modeling experience is any guide, the development of physics-based space environment models that assimilate multiple data streams, during the model calculation, will improve our understanding of the physical processes at work. This type of data assimilation is quite different from using observations to set initial or boundary conditions on models. The need for data assimilation was recognized by the National Research Councils recent Decadal Survey of solar and space physics.

This talk sets the stage for this session by presenting the case for building data assimilation into models of the space environment. I will show the remarkable abundance of data quantity and types that will become available in the next few years. Some of the data will be available in real time; other data will become available later to provide a more comprehensive description of an event. The benefit of using contemporaneous in situ and remote sensing (perhaps from multiple perspectives) observations in models will be illustrated by cartoon examples.

## SA22A-02 1350h INVITED

### Atmospheric data assimilation for scientific and operational purposes.

Lars P Riishojgaard (3016146245; riishojgaard@dao.gsfc.nasa.gov)

Data Assimilation Office, Goddard Space Flight Center, Greenbelt, MD 20771, United States

Data assimilation can be thought of as a mathematical technique for updating the fields of a forecast model in a controlled manner with information obtained directly by observations. The technique was originally developed for numerical weather prediction purposes, and much of the progress obtained in this field over the past few decades has been made possible by advances in data assimilation algorithms. These algorithms are now being applied also in other areas of the atmospheric sciences (e.g. atmospheric chemistry and climate research), as well as in other geo-sciences (most prominently in oceanography). In this presentation, we will give an introduction to the conceptual framework upon

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which data assimilation systems are built. We will provide a brief overview of some of the main characteristics of the current generation of assimilation systems, and we will attempt to highlight some of the most important applications in the atmospheric sciences.

## SA22A-03 1410h

### Physics-Based Kalman Filters for Neutral Density Specification and Forecasts

Tim Fuller-Rowell[1] (303-497-5764; tim.fuller-rowell@noaa.gov)

Clifton Minter[1] (303-497-3051; cliff.minter@noaa.gov)

Mihail Codrescu[1] (303-497-6763; mihail.codrescu@noaa.gov)

Frank Marcos[2] (617-377-3037; frank.marcos@hanscom.af.mil)

[1]CIRES University of Colorado and NOAA Space Environment Center, 325 Broadway, Boulder, CO 80305, United States

[2]Air Force Research Laboratory, Hanscom AFB, Hanscom, MA 01731, United States

With sufficient global data coverage, accurate neutral density specification can be accomplished using a Gauss-Markov Kalman filter where the state is assumed to gradually relax to climatology. However, in data sparse regions and in forecasting, the state propagator becomes more critical in the data assimilation process. The value of physical models as Kalman state propagators is that they can capture the time-dependent response to geomagnetic events, including the propagation of neutral density waves and the development of deep density holes. If sufficient observations are available to specify the current conditions and initialize the physical model, a short-term forecast is feasible. The problem in the use of physics-based models is that they require accurate specification of the spatial and temporal variation of the geomagnetic sources at high latitudes that are used to drive the model. The approach is to include the model drives in the Kalman state and optimize the model forcing as well as the initial conditions. Such models will be able to use the observed neutral density response to automatically adjust and optimize the model forcing functions. The best estimate of the current state can then be used as the initial conditions for a short-term forecast.

## SA22A-04 1425h

### Considering Model Error when Applying Data Assimilation to New Systems

Clifton F Minter[1] (303-497-3051; Cliff.Minter@NOAA.gov)

Timothy J Fuller-Rowell[1] (303-497-5764; Tim.Fuller-Rowell@NOAA.gov)

Mihail V Codrescu[1] (303-497-6763; Mihail.Codrescu)

[1]NOAA/Space Environment Center, Skaggs Research Center 325 Broadway, Boulder, CO 80305, United States

Most data assimilation techniques, including Kalman filtering, consider errors in the model and use this information, along with estimated measurement errors, to provide a best state estimate. As a down side, however, these techniques assume that the model error is random and has a zero mean, which is often not the case. Typically, errors in the model are not random but change slowly with the dynamics of the system. Additionally, the actual amount of error in the model may be unknown especially in the early design stages of the data assimilation system. This lack of knowledge about the model error decreases the accuracy of the state estimate when the data assimilation technique is applied.

To demonstrate the effects this problem, two electric field models are used to provide the neutral composition in the thermosphere. A Weimer electric field is used to create a simulated truth data set and a Foster electric field is used in a Kalman filter to reproduce, as best as possible, the original truth data set. The vice versa application of these models can also be used since their differences are the main point to consider. The two electric fields provide two slightly different composition patterns to mimic a slowly changing, non-random error as may occur in a realistic situation. As expected, the traditional application of the Kalman filter shows a bias in the state estimate when trying to reproduce the truth set.

In this research, it is proposed that the Kalman filter can be supplemented by an auxiliary method to account for the unknown error. The auxiliary method is applied based on the assumption that the errors in the measurements are better known in comparison to the model errors. The measurement errors alone are used in an auxiliary method to estimate the bias, and this calculated bias is then used to correct the model in the main Kalman filter solution. Methods for calculating the model error by the auxiliary method are varying. These methods, including neural nets, two-point boundary value problems, and minimum model error estimators, are compared. The results are evaluated by comparing the estimated state to the original simulated truth file.

## SA22A-05 1440h INVITED

### Data Assimilation into Global MHD Magnetosphere-Ionosphere Models: A New Challenge for Space Physics

Tamas I. Gombosi[1] (734-764-7222; tamas@umich.edu); Dennis S. Bernstein[1] (dsbaero@umich.edu); Robert C. Clauer[1] (rclauer@umich.edu); Kenneth G. Powell[1] (powell@umich.edu); Aaron J. Ridley[1] (ridley@umich.edu); Quentin F. Stout[1] (qstout@umich.edu)

[1]Center for Space Environment Modeling, The University of Michigan, Ann Arbor, MI 48109

Recently, there has been significant progress in data assimilation technology into global ionosphere models. However, global magnetosphere models represent a new challenge since the in-situ magnetospheric data stream is spatially and temporally very sparse. This fact represents new mathematical challenges for data assimilation techniques. This talk briefly outlines the physics and mathematics of previous data-rich inversion techniques, and discusses the mathematical challenges and potential avenues for progress in the data-limited regime of data assimilation techniques.

## SA22A-06 1525h

### The Role of Data Assimilation in Modeling the Sun-Earth Connected System

Ayris Falasca[1] (Ayris.Falasca@gsfc.nasa.gov)

Michael Hesse[1] (301-286-8224; hesse@gsfc.nasa.gov)

Masha Kuznetosva[1] (masha@elbrus.gsfc.nasa.gov)

Lutz Rastaetter[1] (lr@waipio.gsfc.nasa.gov)

Kristi Keller[1] (kkeller@pop600.gsfc.nasa.gov)

[1]CCMC, NASA GSFC, Code 696, Greenbelt, MD 20771, United States

Developing the capability to model the Sun-Earth connected system, from the Solar corona to Earth's upper atmosphere, remains a grand challenge problem of space science. Research of model chains, which cover the entire domain, promises new scientific insight, as well as new abilities to predict the effect of solar disturbances on humans and human assets in space and on the ground. The nature of the coupling between adjacent elements of such chains can be quite different, ranging from a relatively simple driven response to considerably more complicated two-way interactions. In the latter case, as well as within most of the module elements, nonlinearities in the evolution often play a dominant role. By its very nature, an evolution described by nonlinear physics deviates from reality over time, even if the physical description is perfect. Therefore, a standalone model chain will ultimately be insufficient. Instead, predictive models typically must be corrected to remain close to the real evolution. At this point, assimilation of real-time measurements becomes critically important. With the exception of atmospheric and ionospheric modeling, we presently lack both approaches and concepts to deal with sparse data sources and nonlocal physical models. In this presentation, we will discuss the need for data assimilation, analyze present activities in the research community, and try to point out future directions for assimilation approaches.

URL: http://ccmc.gsfc.nasa.gov

## SA22A-07 1540h INVITED

### Data Assimilation Into Physics-Based Models Via Kalman Filters

Robert W Schunk[1] (435-797-2978; schunk@cc.usu.edu)

Ludger Scherliess[1] (435-797-7189; ludger@gaim.cass.usu.edu)

Jan J Sojka[1] (435-797-2964; fasojka@sojka.cass.usu.edu)

[1]Utah State University, Center for Atmospheric and Space Sciences 4405 Old Main Hill, Logan, UT 84322-4405, United States

The magnetosphere-ionosphere-thermosphere (M-I-T) system is a highly dynamic, coupled, and nonlinear system that can vary significantly from hour to hour at any location. The coupling is particularly strong during geomagnetic storms and substorms, but there are appreciable time delays associated with the transfer of mass, momentum, and energy between the domains. Therefore, both global physics-based models and vast observational data sets are needed to elucidate the dynamics, energetics, and coupling in the M-I-T system. Fortunately, during the coming decade, tens of millions of measurements of the global M-I-T system could become available from a variety of in situ and remote sensing instruments. Some of the measurements will provide direct information about the state variables (densities, drift velocities, and temperatures), while others will provide indirect information, such as optical emissions and magnetic perturbations. The data sources available could include: thousands of ground-based GPS Total Electron Content (TEC) receivers; a world-wide network of ionosondes; hundreds of magnetometers both on the ground and in space; occultations from the COSMIC Satellites, numerous ground-based tomography chains; auroral images from the POLAR Satellite; images of the magnetosphere and plasmasphere from the IMAGE Satellite; SuperDARN radar measurements in the polar regions; the Living With a Star (LWS) Solar Dynamics Observatory and the LWS Radiation Belt and Ionosphere-Thermosphere Storm Probes; and the world-wide network of incoherent scatter radars. To optimize the scientific return and to provide specifications and forecasts for societal applications, the global models and data must be combined in an optimum way. A powerful way of assimilating multiple data types into a time-dependent, physics-based, numerical model is via a Kalman filter. The basic principle of this approach is to combine measurements from multiple instrument types with the information obtained from a physics-based model, taking into account the uncertainties in both the model and measurements. The advantages of this technique and the data sources that might be available will be discussed.

## SA22A-08 1600h

### Resolving MIT Electrodynamic Processes by Analyzing GEC Data Streams

Jan J. Sojka[1] (435-797-2964; fasojka@sojka.cass.usu.edu)

Michael David[1] (435-797-3573; michael@sim.cass.usu.edu)

Lie Zhu[1] (435-797-2967; zhu@cc.usu.edu)

Robert W. Schunk[1] (435-797-2978; schunk@cc.usu.edu)

Timothy J. Fuller-Rowell[2] (303-497-5764; tim.fuller-rowell@noaa.gov)

[1]Center for Atmospheric and Space Sciences, Utah State University, 4405 Old Main Hill, Logan, UT 84322-4405, United States

[2]NOAA/SEC, 325 Broadway, Boulder, CO 80303-3328, United States

The NASA Solar Terrestrial Probe (STP) Mission Geospace Electrodynamic Connections (GEC) will consist of three identical satellites measuring thermosphere and ionosphere state variables along with magnetospheric coupling parameters. These measurements will be made from a simple orbit whose perigee will drop to below 130 km while the intersatellite temporal spacing will range from seconds to 33 minutes. GEC will explore for the first time the electrodynamic coupling processes that exist in the ionosphere-thermosphere driven by the magnetosphere. Because of the triple satellite configuration, GEC will acquire the measurements necessary to resolve the space-time ambiguities concerning the energy transfer scales between the magnetosphere-ionosphere-thermosphere (MIT) system. But how will scientists analyze the GEC data streams to obtain this new understanding?

This presentation will address initial considerations on how the analysis of GEC observations will be pursued. That GEC will generate over 60 parallel but independent science parameter data streams is but the "tip of the iceberg"; almost all are coupled via physical processes that have a wide range of spatial and temporal scales. The presentation will focus on how case studies will strive to use these GEC data (and probably additional observations) to constrain physical models of the coupling processes. Various GEC-Model-MIT scenarios will be synthesized and analyzed to demonstrate the problem facing scientists. The spatial and temporal dynamics of the MIT system is synthesized by using the Utah State University (USU) Magnetosphere-Ionosphere (M-I) model simulation of a substorm along with the NOAA/SEC thermosphere-ionosphere (CTIM) simulation of a large storm as drivers for a high resolution ionospheric simulation using the USU Time Dependent Ionospheric Model (TDIM). Resulting from these model runs is a numerical data base with spatial scales ranging from 20 km to global and temporal scales from 20 seconds to hours. This synthetic environment is then sampled along probable GEC orbit paths. The temporal spacing of the satellites is a variable to be used

in testing proposed analysis techniques. These techniques range from the usual visual orbit inspection, through epoch analysis, correlation-covariance analysis, to wavelet analysis.

## SA22A-09 1615h

### A Physics-Based Kalman Filter for the Ionosphere in GAIM

Ludger Scherliess[1] (435-797-7189; schunk@cc.usu.edu)

Robert W Schunk[1] (435-797-2978; schunk@cc.usu.edu)

Jan J Sojka[1] (435-797-2964; fasojka@sojka.cass.usu.edu)

Donald C Thompson[1] (435-797-2357; thompson@cc.usu.edu)

[1]Utah State University, Center for Atmospheric and Space Sciences 4405 Old Main Hill, Logan, UT 84322-4405, United States

A physics-based data assimilation model of the ionosphere is under development as the central part of a DoD MURI funded program called GAIM (Global Assimilation of Ionospheric Measurements). With the significant increase in the number of ionospheric observations that will become available over the next decade, this model will provide a powerful tool towards an improved specification and forecasting of the global ionosphere, with an unprecedented accuracy and reliability. The goal of this effort will be the development of an operational ionospheric assimilation model that will provide specifications and forecasts on spatial grids that can be global, regional, or local (50 km x 50 km). The specification/forecast will be in the form of 3-dimensional electron density distributions from 90 km to geosynchronous altitudes (35,000 km). In GAIM, the data assimilation is performed by a Kalman filter using a new physics-based ionosphere/plasmasphere model (IPM). This model includes 6 ion species ($O_2^+$, $N_2^+$, $NO^+$, $O^+$, $H^+$, and $He^+$) and currently covers the low and mid-latitudes from 90 km to about 20,000 km altitude. As a practical implementation the Kalman filter in GAIM is based on approximations of the state error covariance matrix, employing a reduction of the model dimension and a linearization of the physical model for the propagation of the error covariance matrix. These approximations lead to a dramatic reduction in the computational requirements. In this paper, we will give an update on the status of the Kalman filter development and present results from a global assimilation run. In this test three different data types were considered, including bottomside electron density profiles obtained from several digisondes, slant TEC from a network of ground-based GPS receivers, and in situ electron density measurements from DMSP satellites.

## SA22A-10 1630h

### Solar Wind to Radiation Belt Energetic Electron Response Functions Using Multi-Channel Prediction Filters

E Joshua Rigler[1] (303-492-4831; jrigler@colorado.edu)

Daniel N Baker[1] (Daniel.Baker@lasp.colorado.edu)

[1]Laboratory for Atmospheric and Space Physics, 1234 Innovation Drive, Boulder, CO 80303, United States

A number of recent studies have used linear and nonlinear data filtering techniques to generate response functions that characterize, spatially and temporally, the coupling between solar wind velocity and energetic electron flux variations in the Earth's magnetosphere. This data intensive modeling technique is not new, but has historically been of limited use because it requires long, continuous, and relatively high-quality data sets with which to train the filters. The SAMPEX satellite provides just such a data set with its 2-6MeV electron channel (ELO). The ELO data is available as either daily or orbit-averaged flux measurements, in 0.1 L-shell bins, from L = 0.1 to L > 8.0, providing both high time and spatial resolution flux measurements. In addition, autoregressive (AR) filters have been shown to behave as an efficient multi-bandstop filter, capable of effectively removing diurnal variations in electron flux data without losing short time scale dynamics. This means that impulse response functions can be determined at time scales down to 90 minutes (the orbit period of SAMPEX, and effective sampling period of the data used). Finally, adaptive optimization algorithms have been used to provide real-time updates to the model parameters with each new solar wind and SAMPEX measurement, demonstrating the nonlinearity and non-time stationarity of the Earth's radiation belt response to solar wind inputs. Previous studies will be reviewed in the context of this being a purely data-based assimilation technique, and expanded to include additional solar wind inputs via multi-channel, autoregressive prediction filters. The resulting models offer a visually intuitive description of the dominant dynamical drivers of electron loss and enhancement in space (L-shell) and time, in addition to providing a robust and reasonably accurate short-term space weather forecasting tool.

## SA22A-11 1645h

### Data Fusion of Multi-Spacecraft Data Using the Example of Plasma Gradients

Martin P. Wüest[1] ((210)522-5832; mwuest@swri.edu)

Jörg-Micha Jahn[1] ((210)522-2491; jjahn@swri.edu)

Sandee Jeffers[1] ((210)522-2010; sjeffers@swri.edu)

[1]Southwest Research Institute, Space Science Department 6220 Culebra Road, San Antonio, TX 78238-5166, United States

In coming years we will see an explosion in our need to routinely perform a complex multi-viewpoint data analysis of space physics data sets. Orchestrated multi-spacecraft measurements open access to new physical quantities not accessible with single spacecraft, and they remove spatio-temporal ambiguities. Our ability to appropriately analyze data from three-dimensional spacecraft formations and the proper ingestion of those data into models is currently underdeveloped. Providing comprehensive data fusion tools for these new data sets is necessary in order to utilize these data effectively. We are presenting our system, currently under development, which is designed to give full access to the three-dimensionality of the space environment by calculating gradients, divergences and curls from measurement of vector and scalar quantities performed simultaneously by identical instruments on multiple satellites. On the local level this allows to obtain spatial or temporal scales at high resolution and on a global level this reduces the amount of data considerably and facilitates the interface with global numerical models.

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Pan, C., The rotation of ron-rigid Earth, *Eos Trans. AGU, 83*(47), Fall Meet. Suppl., Abstract U41A-05, 2002.

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