The Space Weather Reanalysis

E. A. Kihn,[1] A. J. Ridley,[1] and M. N. Zhizhin[2]

Received 17 September 2007; revised 5 February 2008; accepted 6 February 2008; published 22 February 2008.

[1] The Space Weather Analysis (SWA) is an 11 year space weather representation using the output of physically consistent data-driven space weather models. The resulting product is an enhanced look at the space environment on consistent grids, time resolution, coordinate systems and containing key fields allowing a user with modeling capability to quickly and easily incorporate the impact of the near-Earth space climate in environmentally sensitive models. The results will be made available via the eGY standards along with tools for intelligent data mining, classification and event detection developed jointly with WDC-B, Russia which will be applied to the historical space-weather database. *INDEX TERMS:* 2794 Magnetospheric Physics: Instruments and techniques; 2753 Magnetospheric Physics: Numerical modeling; 7959 Space Weather: Models; 7999 Space Weather: General or miscellaneous; *KEYWORDS:* space weather representation, monitoring systems, data mining, near-earth space environment.

Citation: Kihn, E. A., A. J. Ridley, and M. N. Zhizhin (2008), The Space Weather Reanalysis, *Russ. J. Earth. Sci., 10,* ES2001, doi:10.2205/2007ES000295.

Project Objective

[2] The objective of this project was to generate a complete 11 year space weather representation using physically consistent data-driven space weather models. The project created a consistent, integrated historical record of the near Earth space environment by coupling observational data from space environmental monitoring systems archived at NGDC with data-driven, physically based numerical models. The resulting product is an enhanced look at the space environment on consistent grids, time resolution, coordinate systems and containing key fields allowing an environmental scientist to quickly and easily incorporate the impact of the near-Earth space climate in environmentally sensitive models. Currently there are no long term climate archives available for the space-weather environment. Just as with terrestrial weather it is crucial to understand both daily weather forecasts as well as long term climate changes, so this project will demonstrate the ability to generate a meaningful and physically derived space weather climatology.

[3] The results of this project strongly support the Environmental Scenario Generator (ESG) project [*Kihn et al.,* 2004]. The ESG project provides tools for intelligent data mining, classification and event detection which could be applied to a historical space-weather database. The two projects together would provide a complete suite of tools for the user interested in modeling the effect of the near-earth space environment.

[1]National Geophysical Data Center, Boulder, Co., USA
[2]Geophysical Center RAS, Moscow, Russia

ISSN: 1681–1208 (online)

Background

[4] The term “space-weather” refers to conditions on the sun, in the solar wind, magnetosphere, ionosphere, thermosphere, and mesosphere, that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health [*Kamide and Chian,* 2007]. The magnetosphere is depicted in Figure 1. This is the region of space surrounding the Earth in which communication, weather, and observation satellites are stationed. Adverse conditions in this space environment can cause disruption of communications, navigation, electric power distribution grids, and satellite operations, leading to a broad effects on key operational missions.

[5] Near Earth space environmental events have a significant impact on technology and human activity both in space and on the ground. The space environment, though void of a significant number of particles, is highly charged electrically with ions and electrons flowing along the Earth’s magnetic field lines and being directed by the ambient electric fields. Space Weather events, i.e. those naturally occurring events in the electrically coupled solar, interplanetary, magnetosphere and ionosphere system that impact technology and human activity, disrupt communications, create errors in navigation systems, halt electric power distribution, and cause anomalies in satellite operations.

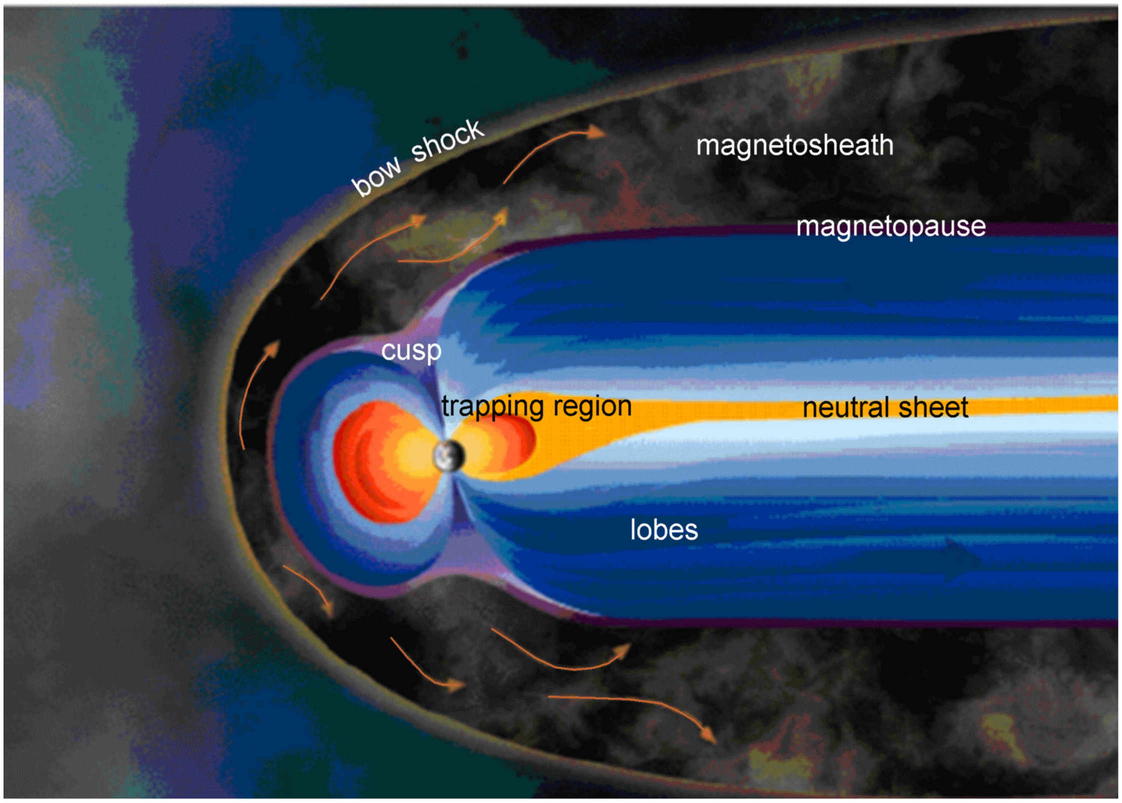

Figure 1. The Earth's magnetosphere.

[6] This project will attempt to do for space weather what the NCEP "Reanalysis " [*Kalney,* 1996] did for terrestrial weather when NCAR and NCEP produced a 50-year record of global analyzes of atmospheric fields in support of the needs of the research and climate monitoring communities. That effort involved the recovery of land, ship, rawindsonde, balloon, aircraft, satellite and other data, quality controlling and assimilating those data with a data analysis technique. The reanalysis is an invaluable resource for any modeler concerned with terrestrial weather effects on both the long and short-term basis. The "Reanalysis" database is used extensively by the Environmental Scenario Generator for advanced data mining, and as an initialization point for physics based model runs.

Execution Plan

[7] For the purposes of this effort the near-Earth space environment is defined to be that region of space where the Earth's magnetic field controls the flow of non-relativistic ions and electrons including the ionosphere, thermosphere, plasmasphere, and magnetosphere. However, since many near Earth plasma processes result from direct interaction between these processes and those occurring in the solar wind and on the sun, the coupled models must extend from the upper atmosphere to the sun. Figure 2 shows the dependencies and relations of the various layers.

[8] The National Geophysical Data Center maintains the official archive of space environmental monitoring data from civilian and military sources in a system called the Space Physics Interactive Data Resource (SPIDR) [*O'Loughlin,* 1997]. NGDC employs SPIDR and works with the principal authors of key space weather models to produce a historically accurate record of the near Earth space environment. NGDC scientists, along with guest workers and colleagues, have pioneered direct assimilation of data into space weather models. Various models exist which describe the near-Earth space environment. Typically these models describe either the high altitude neutral atmosphere, concentrating on the chemistry of the different regions, or the electrodynamics of the regions. One such data-driven physical model is the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) technique [*Richmond,* 1992]. AMIE is able to ingest many different data sets such as ground based magnetometer perturbations, incoherent scatter radar measurements of ion and electron drifts, densities, and temperatures, satellite measurements of precipitating particles and ion flows, and ultra-violet images of the aurora. Using these data, AMIE derives a specification of the high-latitude ionospheric electrodynamic state. This includes maps of the electric potential, the field aligned and horizontal currents, and ionospheric conductance's, and the amount of energy being deposited into the ionosphere from precipitating particles and ion/neutral coupling (i.e. Joule heating).

[9] Our work expands the AMIE model to act as an ingest system for historical geophysical databases and for use in

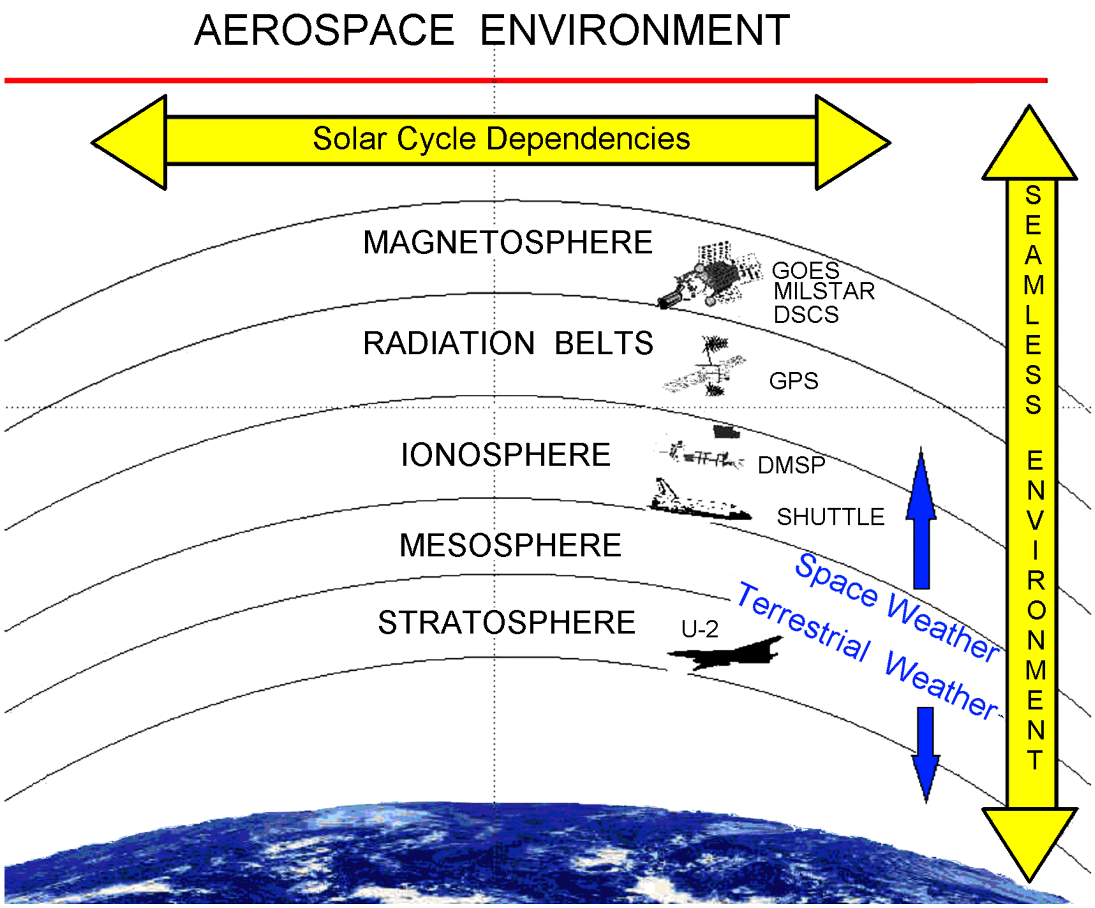

Figure 2. Simple illustration of regions of the near Earth space and impacts on aerospace operations.

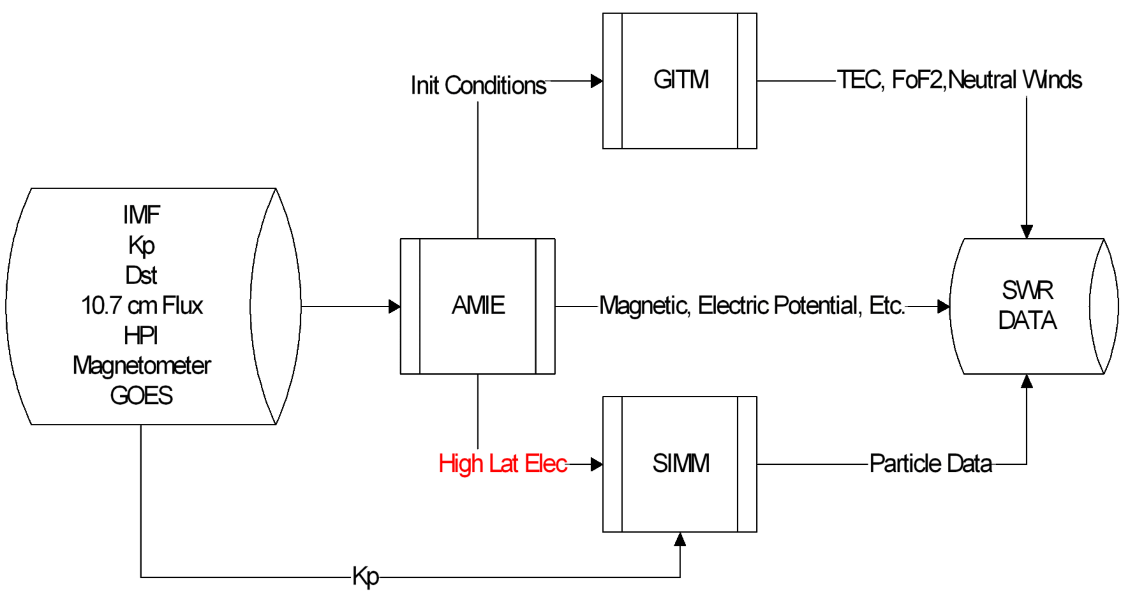

Figure 3. The SWR data flow.

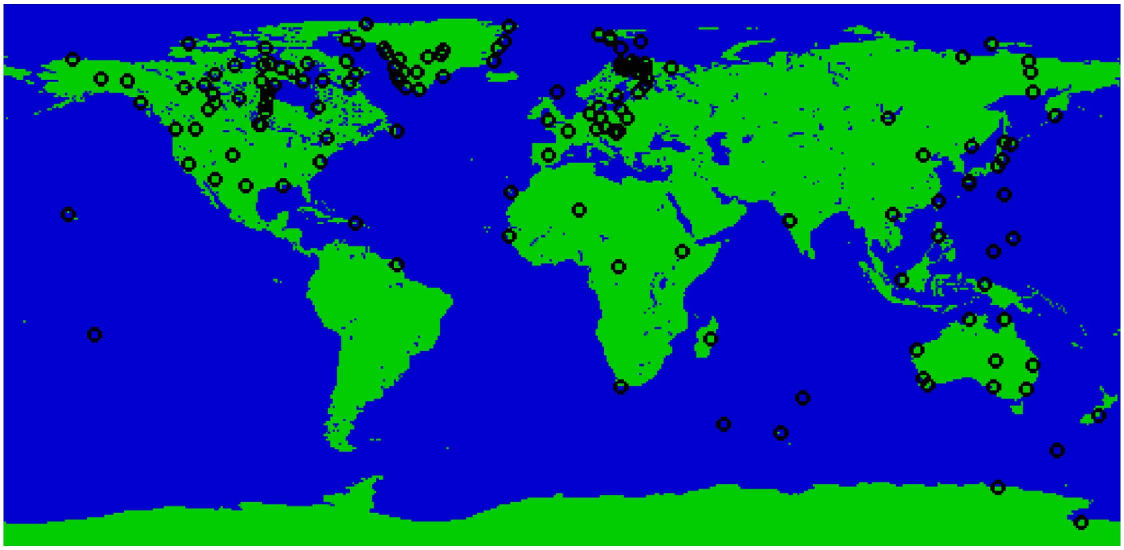

Figure 4. Stations added to SPIDR at NGDC (1997–1998).

retrospective analysis. We have driven the models described below with the output from the expanded AMIE assimilation system as seen in Figure 3.

[10] One such model is the newly created global ionosphere thermosphere model (GITM) [*Ridley et al.,* 2006] used to model the neutral and ion composition, temperature, and dynamics from 95–750 km altitude. GITM solves for:

- 6 Neutral Species
- 5 Ion Species
- Neutral winds
- Neutral Temperatures
- Ion and Electron Convection
- Ion and Electron Temperatures
- Solves in Altitude coordinates

[11] This model is a product of the University of Michigan. Another model the Simple Inner Magnetospheric Model (SIMM) is basically the Magnetospheric Specification Model (MSM) with AMIE output driving the high-latitude electric field. This model is from University of Texas Austin. The final output of the suite is a complete and physically integrated look at the space-environment over a long time period. This product has never been created before.

SWR Methodology

[12] In order to drive the three main models used in the SWR effort it was necessary to create/enhance three separate databases. In that effort NGDC added to the SPIDR data management system the Hemispheric Power Index (NOAA/DMSP) and the 1.0 minute Interplanetary Magnetic Field data. In addition the Geomagnetic Holdings at NGDC were expanded by including stations not normally part of the World Data Center system. This expanded the number of stations for the 1998 period by over 50% (see Figure 4).

[13] To understand the significance of the newly added stations compare the results in Figure 5 which displays the AMIE model run with minimal data (middle) and run with full data (left) as well as the net difference. Clearly in trying to create a realistic representation of the environment the more robust the data set, the better.

[14] Next it was necessary to develop a uniform Application Programming Interface (API) for the SPIDR system so that individual models could request the supporting observations they needed directly, without resorting to file based interactions. The API has been fully integrated and tested with both SIMM and AMIE is is able to provide data via the network to support the automated runs of these models.

[15] When trying to run models over an extended period, several factors come in to play which may not be a consideration in normal operation. Things such as instrument baseline shift, undetected spikes, or calibration drift can lead to a skewed result for the model. As such part of the SWR effort was to develop and extend automated algorithms to handle the long term data archives necessary to run the 1999-2004 time period. This effort has yielded vastly improved algorithms for detecting spikes and other quality issues but continues to be an area of focus for the SWR team. Currently the data is being reviewed by the automated quality control at each step.

Data Products

[16] The data archives created as part of the SWR are available for use through the SWR system. Users can select a time, a region and a subset of the model runs and then receive via ftp a subset of the SWR archive for their own

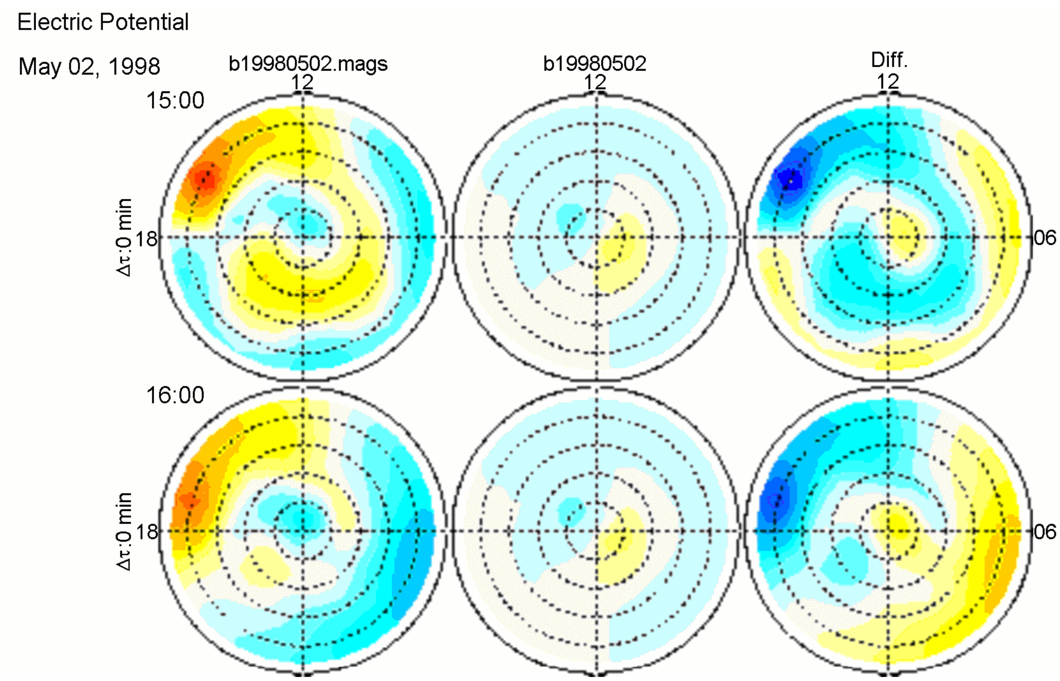

Figure 5. AMIE Electric Potential results for 2 May 1998.

use. Integration with the existing SPIDR archives provides a substantial resource for the space modeling and simulation community. Current data products available include:

- New HPI database (DMSP, NOAA)
- New 100 + magnetometer database.
  - 210 MM, Canopus, Tromso, Greenland, Image, etc..
- Complete IMF Record
- AMIE Runs @ 1.0 minute (1989-2003)
- GITM Runs (1991-2002)
- SIMM runs (1996-2003)

Conclusion

[17] The SWR is a multi-year look at the Earth's space environment. It is a first look at generating the long term climatology and "unblanking" the page in this innovative area. The SWR is a:

- a resource for those wanting an integrated space environment for inclusion in their own work.
- a standard resource for the modeling community.
- an extensible evolving project
- a place to perform evaluations and comparisons vs. data
- looking for interested participants.

[18] It is our intention to evolve the SWR through several more phases of model inclusion (including the radiation belts for example) and further data ingest. In the end it is hoped that the SWR will become a community reference for the state of the near-Earth space environment.

References

Kalnay, E. (1996), The NCEP/NCAR 40-Year Reanalysis Project, *Bull. Amer. Meteor. Soc., 77,* 437, doi:10.1175/1520-0477(1996)077<0437:TNYRP>2.0.CO;2.

Kamide, Y., and A. Chian (2007), *Handbook of the Solar Terrestrial Environment,* 539 pp., Springer, Berlin.

Kihn, E. A., M. Zhizhin, R. Siquig, and R. Redmon (2004), The Environmental Scenario Generator (ESG): a distributed environmental data archive analysis tool, *Data Science Journal, 3,* 10, doi:10.2481/dsj.3.10.

O'Loughlin, K. F. (1997), SPIDR on the Web: Space Physics Interactive Data Resource on-line analysis tool, *Radio Sci., 32*(5), 2021, doi:10.1029/97RS00662.

Richmond, A. (1992), Assimilative mapping of ionospheric electrodynamics, *Adv. Space Res., 12,* 59, doi:10.1016/0273-1177(92)90040-5.

Ridley, A. J., Y. Deng, and G. Tóth (2006), The global ionosphere-thermosphere model, *Journal of Atmospheric and Solar-Terrestrial Physics, 68*(8), 839, doi:10.1016/j.jastp.2006.01.008.

E. A. Kihn, A. J. Ridley, National Geophysical Data Center, Boulder, USA (Eric.A.Kihn@noaa.gov)

M. N. Zhizhin, Geophysical Center RAS, Moscow, Russia (jjn@wdcb.ru)