RWC USA 2014 Annual Report

1. Recent Accomplishments

1.1 Evaluation of Geospace Models

A multi-year effort has been completed in collaboration with NASA to evaluate models of geomagnetic field variability currently available at the Community Coordinated Modeling Center and to determine which model or models could be used to provide operational products. The focus of this evaluation was on products that can support the electric power industry. In addition, magnetohydrodynamic (MHD) models, of which three were evaluated, have additional capabilities that could be used to provide numerous other products to support a broad range of space weather customers. These include products of value to those who operate in regions affected by conditions in the magnetosphere, ionosphere, auroral zone, and polar cap. From the results of the evaluation, and information learned throughout the evaluation process, SWPC has determined that, at this time, only one of the models evaluated is able to deliver the results necessary for SWPC's needs. That model is the University of Michigan's Space Weather Modeling Framework (SWMF).

1.2 L1 Requirements (DSCOVR Follow-on) Workshop

A workshop was held on 7 April, 2014 in association with Space Weather Workshop in Boulder, Colorado to discuss observing requirements from the L1 orbit location. The U.S. will be launching the Deep Space Climate Observatory (DSCOVR) spacecraft in 2015 to L1 orbit, and NOAA is planning to replace DSCOVR in 2020. The workshop addressed issues with both in-situ measurements, focusing on possible modifications to existing NOAA requirements, and remote sensing observations, focusing on new observations to improve forecasting. A workshop report will be released in the near future.

1.3 Discussion on Ionospheric Scales

A discussion was held on 7 April, 2014 in association with the Space Weather Workshop in Boulder, Colorado to discuss the possibility of developing an ionospheric scale or index. The discussion was attended by representatives from North America, South America, Europe, and Australia. It was generally agreed that more than one scale is needed to target all the different user groups impacted by ionospheric disturbances, and that the initial focus should be on addressing the navigation, positioning and satellite communication users.

It was agreed that both regional and global scales are needed, with a global scale serving as a "heads-up" that will direct customers to the next level. It was recommended that interested collaborators work together on a regional basis, utilizing GNSS phase or code data to explore techniques to quantify ionospheric disturbances. The goal is to catalogue times of departure of TEC from "normal", or when steep spatial gradients or rapid temporal changes occur. The occurrences are to be binned by their degree of departure from a 10-day running mean. With different groups working initially somewhat independently, various approaches will be tested

and can then be compared. The attendees will organize efforts in their regions. Representatives need to be identified from Asia and Africa to initiate effort in these regions.

1.4 Solar Energetic Particle Intercalibration Workshop

A workshop to address solar energetic particle data intercalibration issues was held in association with Space Weather Workshop on April 11, 2014. The primary workshop organizer was Juan Rodriguez (NOAA National Geophysical Data Center and University of Colorado). At this workshop, ongoing intercalibration efforts were discussed, and a path forward for establishing a set of intercalibration guidelines was recommended. This activity is aligned with the objective of the Coordination Group for Meteorological Satellites to foster on-orbit sensor calibration and harmonization of operational space weather sensors and data formats with a view to ensure interoperability and data consistency.

1.5 New Product for Auroral Forecasts

SWPC recently introduced a new product to predict the location and intensity of the aurora. The model was developed by Pat Newell at the Johns Hopkins University Applied Physics Laboratory, with refinements to enable real-time execution made by scientists at NOAA's National Geophysical Data Center. The model uses real-time measurements of the solar wind conditions made by the ACE spacecraft to give 30-40 minute forecasts of the aurora and the globally integrated total energy deposition.

1.6 Spacecraft Environmental Anomalies Expert System

A new product to support the satellite industry is now available. The Spacecraft Environmental Anomalies Expert System – Real Time (SEAESRT) is a set of data-driven algorithms that indicate the likelihood of an environment-related anomaly on a geosynchronous satellite [O'Brien, 2009]. The target customers are operators of geosynchronous satellites who can benefit from guidance on the hazard levels during active space weather conditions to make decisions on the operation of their satellites, as well as to assess the possible causes of anomalies that have occurred.

SEAESRT gives hazard levels at geosynchronous orbit for four common types of satellite problems: surface charging, internal charging, single event upsets, and total dose effects. For each of these four hazard types, the software gives a hazard quotient that represents the probability that the current environmental conditions will result in a satellite anomaly, relative to the long-term average likelihood of an anomaly. A hazard quotient of unity indicates the likelihood of an anomaly is equal to the long-term average. In addition to the hazard quotient, the 95% confidence interval surrounding the hazard quotient is also given. All of the hazard quotients are derived from the statistical occurrence of on-orbit anomalies or their proxies. It is assumed that the probability of future anomalies has the same statistical relationship to the environmental conditions as the historical anomalies.

2. High Priority Product Goals

2.1 Regional Geomagnetic Disturbance Products

Based on the selected geospace model (Section 1.1), SWPC is developing new products to support the electric power industry and other activities impacted by geomagnetically induced currents (GICs). These new products will be regional, giving the predicted level of geomagnetic activity at various latitude and longitude sectors. The forecasts will be derived from real-time measurements of the solar wind conditions upstream from Earth at the L1 Lagrange point. The solar wind measurements are currently being obtained from NASA's Advanced Composition Explorer (ACE) spacecraft, and will be replaced by NOAA's Deep Space Climate Observatory (DSCOVR) spacecraft in 2015.

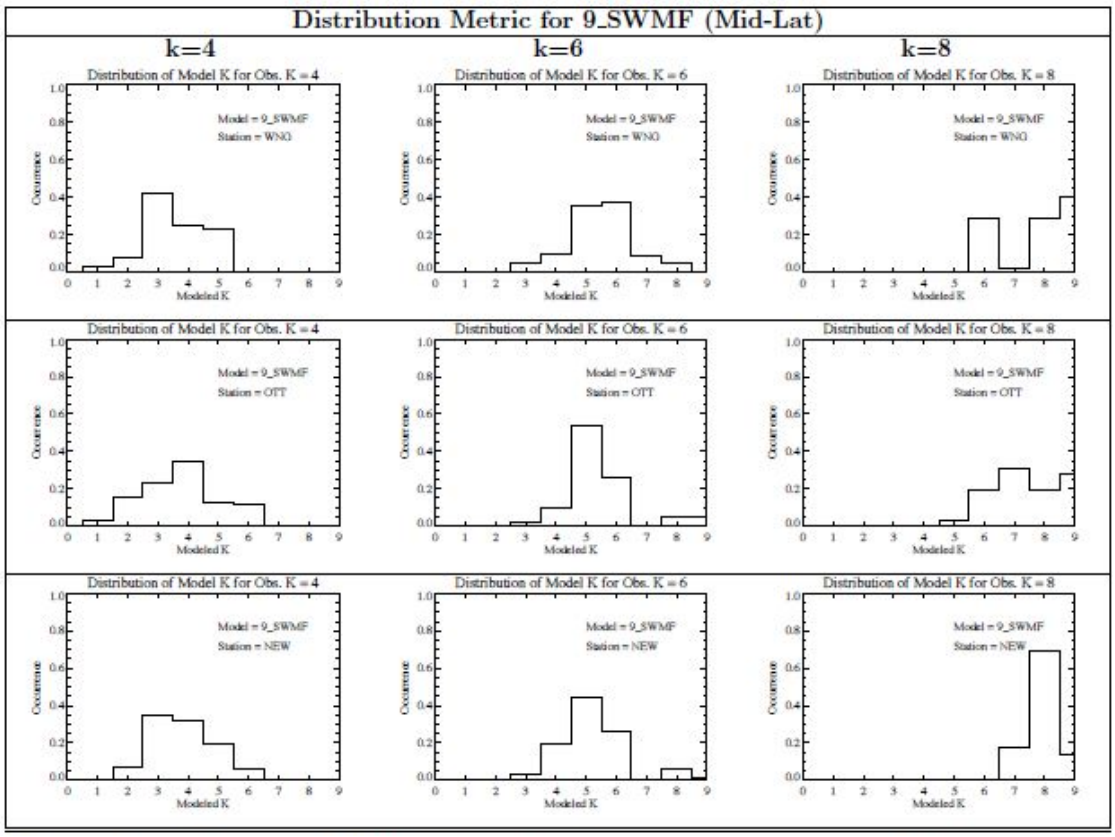

Figure 1: Distribution of model predictions at times corresponding to measured K values of 4 (left column), 6 (middle column) and 8 (right column). Each row represents comparisons obtained at different mid-latitude stations [Glocer et al., 2013].

The expected new products derived from the geospace model will give regional predictions of two different but related measures of geomagnetic activity. Among the measures under development are: 1) Regional d**B**/dt based on the rapid, 1-minute time rate of change of the surface geomagnetic field, 2) Regional K indices, and 3) Regional induced electric field, taking into account ground conductivity. Product development and validation are currently underway. As an example, results from a recent validation study [Glocer et al., 2013] shown in Figure 1 illustrate the uncertainty associated with regional K predictions from the University of Michigan

Space Weather Modeling Framework, which was one of the geospace models recently evaluated (see Section 1.1).
In addition to the model-based products describe above, new regional, real-time estimates of the induced electric field are being developed in collaboration with the United States Geological Survey. These products will utilize the real-time ground magnetometer data and models of ground conductivity to calculate the electric fields that drive the currents in electric power grids and other conductors such as pipelines.

2.2 Ionospheric Disturbance Products

SWPC is working to develop new ionospheric products to complement its existing North America TEC product. Initial prototyping has begun for a product based on the Rate of Change of TEC Index (ROTI) that will provide a proxy for the occurrence of ionospheric scintillation and the degradation of positioning accuracy. In addition, plans are under consideration to develop products based on steep spatial gradients of TEC and large deviations of TEC from climatology levels.

In order to enable long lead time products and higher forecast accuracy, scientists at SWPC and the University of Colorado Cooperative Institute have been working to couple the National Weather Service numerical weather model with an ionosphere model. The NWS Global Forecast System model has been extended to 600 km and integrated into the lower atmosphere data assimilation system. Schemes are being developed to extend the data assimilation into the middle and upper atmosphere. The ionosphere model has been developed and is being validated. The numerical weather model provides multi-day forecasts of the tides, and other atmospheric waves that impact the ionosphere, and the ionosphere model will incorporates the space environment conditions (solar EUV irradiance and geomagnetic storms). The coupled system will provide multi-day forecasts for GPS/GNSS, radio and satellite communications, and satellite drag and orbit prediction.

3. High Priority Data Needs

3.1 Solar Wind Measurements at L1

SWPC requires real-time measurements of the solar wind upstream from Earth, including the plasma density, velocity, and temperature and the vector magnetic field. These measurements enable forecasts up to one hour in advance of geomagnetic storms and to drive models of the magnetosphere/ionosphere response. These measurements are currently being made by the ACE spacecraft, and beginning in 2015 will be made by the DSCOVR satellites. Observations from ACE, and subsequently from DSCOVR, are used to generate warnings to customers in 98 countries which can then take action to ensure the electric power grids stay on and that GNSS dependent industries, including airlines, surveyors, oil exploration and others make the appropriate decisions to protect their investments.

NOAA is also planning to replace DSCOVR in 2020 with a follow-in L1 satellite to obtain measurements of the solar wind plasmas, magnetic field, low-energy ions, and a coronagraph.

Other instruments are being considered, including high-energy electrons and a heliospheric imager.

3.2 Coronagraph Measurements at L1 and L5

Images of the solar corona are required for determining the initial properties (speed, location, and size) of coronal mass ejections (CMEs) that erupt from the sun. CMEs are the drivers of severe space weather at Earth and the source of the largest geomagnetic disturbances, ionospheric disturbances, and solar energetic particle enhancements. With the information of the initial CME properties, numerical prediction models are initiated to calculate the trajectories of the CMEs through interplanetary space and to predict the arrival time at Earth. Estimates of CME properties are most accurate when coronal images are obtained from multiple vantage points, ideally one on the Earth-Sun line and one substantially off the Earth-Sun line, such as from the L5 Lagrange point. Coronagraph measurements are planned for the L1 DSCOVR follow-on mission in 2020, but there currently are no specific plans for a coronagraph at L5.

3.3 Radio Occultation Measurements of the Ionosphere

Space-based, radio-occultation measurements of GNSS signals are capable of obtaining dense and globally uniform (including over oceans) measurements of the vertical electron density distribution of the ionosphere/plasmasphere system. Data assimilation techniques are being developed to create accurate, high-resolution nowcasts and forecasts of ionospheric disturbances that introduce errors in GNSS applications. NOAA is participating with Taiwan in the upcoming COSMIC-2 mission that will provide GNSS radio occultation measurements.

4. User Impact Summary

4.1 Electric Power Industry

The electric power industry and U.S. government regulators are in the process of developing benchmark standards to define geomagnetic disturbance levels that must be mitigated. In 2013, the Federal Energy Regulatory Commission ordered the development of reliability standards for geomagnetic disturbances. Efforts are underway through the North American Electric Reliability Corporation (NERC) define benchmark geomagnetic activity levels. NERC is an international regulatory authority whose mission is to ensure the reliability of the North American power system.

4.2 Launch Delay and Airline Polar Flight Reroute

A solar proton event in January, 2014 impacted the aerospace and aviation industries. Due to the high fluxes of solar energetic particles observed by the GOES-13 spacecraft, a U.S. rocket launch was delayed. The launch vehicle was an Orbital Sciences rocket cargo to be delivered to the International Space Station. The rocket was successfully launched on a later day. In addition, the solar proton event caused major commercial airlines to route polar flights to lower latitudes to avoid HF communication outages.

4.3 Loss of Wide Area Augmentation System Service

A strong ionospheric storm on February 27, 2014 caused impacts to the Wide Area Augmentation System (WAAS) used for aviation. During this storm, the Localizer Performance with Vertical Guidance (LPV) system was unavailable in Eastern Alaska and Northeastern continental U.S.. At times, all of Alaska and North Central U.S. lost LPV service. With the LPV service, the WAAS GPS system is able to assist the aircraft down to 200-250 feet with greater accuracy and consistency, improving flight comfort and overall safety.

4.4 Customer Growth Though the Product Subscription Service

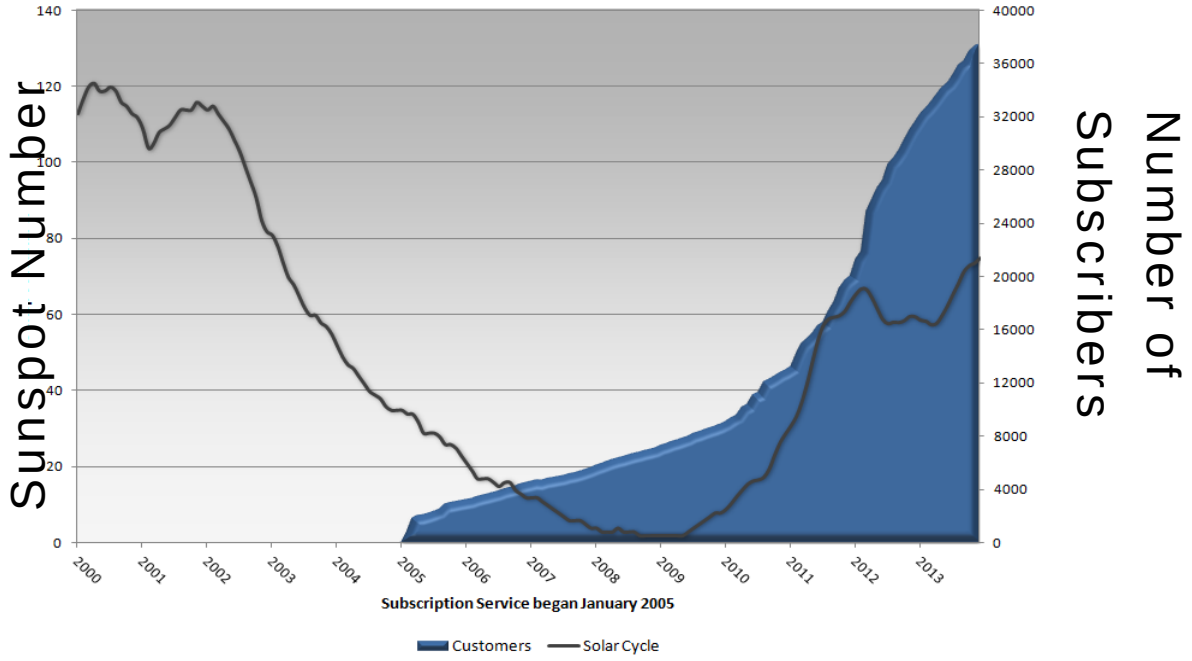

Figure 2: Total number of subscribers (blue) to the SWPC Product Subscription Service and sunspot number (black line).

5. Forecast Verification

SWPC continues to maintain its forecast verification/validation activities. Updated results through 2013 are available at http://www.swpc.noaa.gov/forecast_verification/. An example of solar proton event forecast reliability is shown in Figure 3. In addition, SWPC continues to focus on improvements in verification/validation forecast for CME arrival times based on the Enlil model.

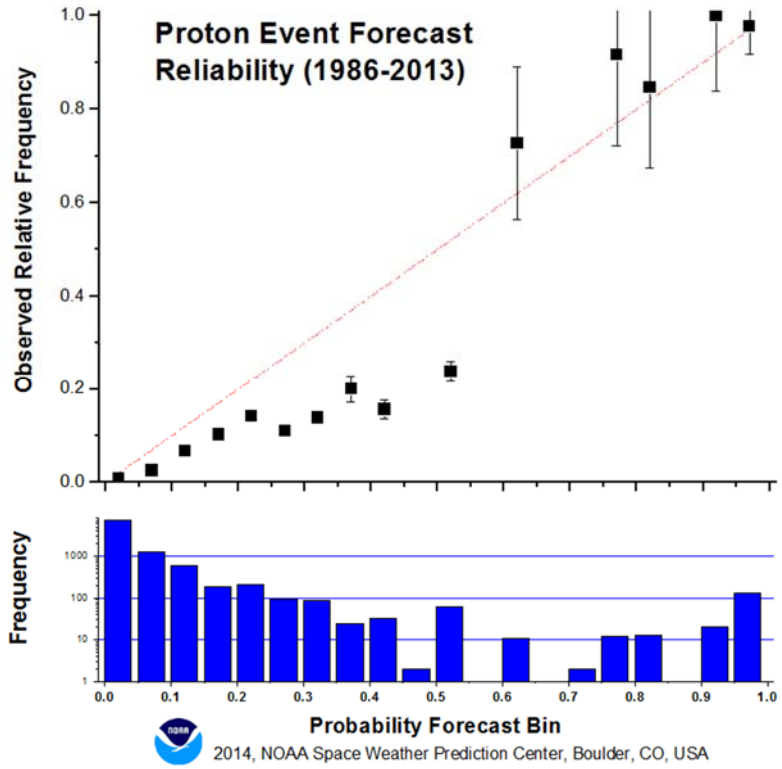

Figure 3: One-day lead time S1 Proton Event forecast "reliability" during the period 1986 to 2013. The top panel plots the observed relative frequency of 10 MeV Proton Events against their corresponding forecasts, grouped in 5% bins. Points falling below the diagonal indicate a tendency of the forecasts to overpredict the occurrence of Proton Events while points above the diagonal indicate underprediction. The number of forecasts in each bin is plotted in the bottom panel histogram. Note that the histogram Y-axis scale is logarithmic.

References

Glocer, A., L. Rastaetter, A. Pulkkinen, M. Kuznetsova, Geospace Model Evaluation to Support Model Transition to Operations. Phase II Report: Regional K-Index (Version 2013/08/31 updated 2013/09/06), Community Coordinated Modeling Center, CCMC, NASA Goddard Space Flight Center, Submitted to SWPC: 2013/08/31.

O'Brien, T.P. (2009), SEAES-GEO: A spacecraft anomalies expert system for geosynchronous orbit, *Space Weather, 7*, S09003, doi:10.1029/2009SW000473.