Solutions Network Formulation Report

Candidate Solution Title: Forecast of Space Weather Influences on Aviation Communications and Navigation Systems

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Abstract:

The Global Assimilation of Ionospheric Measurements (GAIM) model available at the NASA co-sponsored Community Coordinated Modeling Center (CCMC) will be used to provide a solution for predicting disruptions in aviation radio communication and navigation systems during solar-geomagnetic storms. This is in alignment with the Aviation National Applications. Global maps of ionospheric Total Electron Content (TEC), which is easily derived from the GAIM model, is a proxy for assessing the level of ionospheric disturbances caused by space weather influences that adversely affect radio communication and navigation systems. The proposed solution is to derive TEC from the GAIM model output and provide a global graphical display for the NOAA Space Environment Center (SEC), the FAA, and the commercial airline industry to readily assess the potential for communication and navigation degradation and outages. The solution will benefit all air travelers by increasing air transportation safety. Also, the solution could potentially save the airline industry millions of dollars by preventing unnecessary cancellation and rerouting of aircraft because of inaccurate or incomplete information on ionospheric conditions.

Problem Description:

Government, commercial, and societal reliance on space-based technologies is rapidly increasing, which accelerates the need for space weather observations, models, and data products. Specific to this candidate solution, the next-generation air transportation system could rely heavily on GPS navigation, which is susceptible to ionospheric disturbances caused by the propagation of solar plasma, ejected during solar storms, through interplanetary space and its subsequent interaction with the Earth's atmosphere and near-space environment HF radio communications can also be seriously disrupted during these solar-terrestrial storms. Although ionospheric disturbances can occur at any geographic location, a region particularly sensitive to space weather influences is the high-latitude

region. The commercial airline industry is planning to significantly increase the number of polar routes from the U.S to Asia, because of the tremendous savings in fuel expenses and time by minimizing head-winds. Moreover, international flight trajectories out of Chicago, Detroit, and even New York City, enter geographical high-latitude regions susceptible to space weather influences. There is a growing need for an ionospheric forecast model with an output that is easily accessible and understandable to the aviation community. The Global Assimilation of Ionospheric Measurements (GAIM) is an ionospheric forecast model from which aviation data products, such as TEC, could be easily derived. The TEC forecast would determine the likelihood, the time and geographical location of those ionospheric disturbances that carry the potential to degrade and disrupt aviation HF communication and navigation systems.

Airspace managers and commercial airline operators require a simple tool to quickly assess space weather conditions that may compromise the safety of a flight. Furthermore, some space weather influences, such as the ionospheric disturbances which are the focus of this solution, can develop on short time scans and, consequently, can develop in route, requiring that pilots have access to space weather conditions in the cockpit. Currently, decisions are made by government controllers and airline dispatchers to route aircraft through polar airspace based on single-valued ionospheric indices available from the NOAA Space Environment Center (http://www.sec.noaa.gov/). These indices provide no track-specific information. The proposed graphical display of TEC would satisfy the needs of the FAA, airline ground operations, and pilots in the air to quickly and easily assess the impact of sudden detrimental space weather influences on aircraft communication and navigation systems. The aviation end-user could assess the level of ionospheric disturbance at a glance, via the visual TEC map, and plan accordingly.

NASA Research Results:

The GAIM model was developed at UTAH State University under the auspices of the DoD Multidisciplinary University Research Initiative (MURI), and is now publicly available to the space weather community through the NASA co-sponsored Community Coordinated Modeling Center (CCMC) (Schunk et al., 2005). As demonstrated by the meteorology and oceanography communities, the most reliable weather forecast models are physics-based, data-driven models that utilize data assimilation techniques. The physics-based component of GAIM calculates three-dimensional, time-dependent density distributions for the electron and major ions of the ionosphere from approximately 90 km to 1600 km, with coupling between the ionosphere and plasmasphere (Schunk et al., 2004). The densities are computed by numerical solution of the electron and ion continuity, momentum, and energy equations. Data assimilation in GAIM is performed by a Kalman filter, with approximations that have led to significant reduction in the computational requirements (Schierliess et al., 2004). The GAIM model assimilates a wide range of data types from ground-based locations and space-based platforms (Schunk et al., 2005, 2006). The data sources include in-situ electron densities from satellite (e.g., the Air Force DMSP satellite system), bottomside electron density profiles from the DISS network of ionosondes, line-of-sight TEC measurements between as many as several thousand ground stations and GPS

satellites, TECs between low-altitude satellites with radio beacons and several ground-based receiver chains, radio occultation TECs between various low-altitude satellites and between low- and high-altitude satellites, and satellite line-of-sight UV airglow emission data. The GAIM model has been validated against independent measurements not included in the assimilative date sources, e.g., dynasonde measurements located at Bear Lake Observatory near Logan, Utah, and TEC observed by the TOPEX satellite (Schunk et al., 2006). The GAIM model is also the operational ionospheric forecast model used by the Air Force Weather Agency.

Candidate Solution:

The proposed solution is to develop an interface between the GAIM model, with run-time capabilities from the CCMC, and a global graphical display of vertical TEC, which is made available to the NOAA SEC web page of space weather predictions, the NOAA aviation data products web page, the FAA, commercial airline operations and aircraft cockpits. The interface will include the capability to run one-day forecasts, with hourly updates for aircraft in route. The output from the GAIM model runs will be used to derive the global maps of vertical TEC. The primary output of the GAIM model is the time-dependent, three-dimensional electron density distribution. TEC is simply obtained by vertically integrating the electron density profiles. The derived TEC is a scalar quantity geographically distributed over the globe, and projected on a world-map for visual inspection. Flight departure and arrival coordinates are entered and the corresponding flight path trajectory is displayed on the TEC map, enabling the aviation end-users to quickly assess the condition of the ionosphere for the projected flight path. The FAA, NOAA SEC, and commercial airline records of reported communication and navigation disruptions and outages will be used to determine the color scale of the TEC map. A color-scale will be established to characterize the degree of communication and navigation degradation. The GAIM-TEC aviation space weather product will be tested by simulating forecasts over previous solar-geomagnetic storm periods. The TEC output will be compared to records of HF communication and GPS navigation disturbances, i.e., cases not included in developing the TEC color-scale. The next logical step would be a Rapid Prototyping Capability (RPC) experiment to examine the potential of this solution.

The proposed GAIM-derived TEC product will benefit all commercial airline travelers by providing critical space weather forecasts that enhance air transportation safety accurately characterizing the degree of continuity and reliability of the aviation radio communication and navigation systems during flights. The proposed solution could potentially save the airlines millions of dollars during solar-terrestrial storm periods. United airlines reported that, through direct and indirect costs, it lost approximately one million dollars by the necessity of cancelling flights due to communication outages over the polar region during the October-November 2003 solar storm period. Thus, the cost to the airlines in mitigating adverse space weather influences is on the order of millions of dollars. As a result, proposed GAIM-derived TEC product provides the societal benefit of safer air travel by accurately predicting regions of ionospheric disturbances, while it provides the commercial

airline industry an economic benefit by accurately predicting regions where the ionosphere is not adversely disturbed during solar-terrestrial storm periods.

References:

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