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Utilizing Probability Distribution Functions and Ensembles to Forecast Ionospheric and Thermosphere Space WeatherWeather

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The upper atmosphere of the Earth is strongly driven by the solar wind and interplanetary magnetic field (IMF), which are only measured about one hour before they encounter the Earth's magnetosphere. This means that it is almost impossible to predict the state of the upper atmosphere without predicting the solar wind and IMF. The research grant focused on predicting the solar wind velocity for up to five days ahead of time. A new model of the solar wind velocity was created using probability distribution functions. This new model performs as well or better than other modern models of the solar wind velocity. In addition, significant research was conducted on validating our upper atmosphere model and specifying the respond to drivers.

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Goals of Project

From our proposal, the four focus areas are:
• The state of upper atmospheric drivers during one solar rotation will be different than the state of these variables during the next. In order to produce usable forecasts, an analysis of the inherent uncertainties involved in utilizing the previous solar rotation drivers needs to be conducted. Probability distribution functions (PDFs) need to be created to better specify the possible instantaneous and temporal history of the drivers and their uncertainties.
• Because there are large uncertainties in the predicted drivers of the system, ensemble forecasts utilizing the PDFs can help in specifying the possible states that may occur. The optimal technique for constructing ensembles of drivers from the PDFs to be input into the models using data from the previous solar rotation will need to be determined. The number of ensemble members required to adequately specify the forecast will need to be assessed.
• The variability that is lacking within empirical models of the high latitude potential and aurora as well as solar irradiance models will have to be considered. Accounting for this variability will make the model more dynamic and realistic.
• The ability of an ensemble-driven ionosphere-thermosphere model to "predict" space weather needs to be proven. This will be done using historical measurements from 100s of ionospheric and thermospheric measurement locations.

Accomplishments

We have written 14 papers with support from this research grant, and have completed the research for at least two more. The 14 papers are described with their abstracts below.

One of the main studies that we have conducted was the creation of a new solar wind velocity precition model based on probability distribution functions (PDFs). The first paper that was published on this model is listed below and the abstract is given. The second paper is in preparation and will be submitted within the month. The abstract for that paper is given here:

Abrupt transitions from slow to fast solar wind represent a great concern for the space weather forecasting community. They cause important geomagnetic storms that can eventually affect systems in orbit and on the ground. Therefore, the Probability Distribution Function (PDF) model has been improved to predict high enhancements in the solar wind speed. New probability distribution functions allow for the predictions of the amplitudes and the duration of peaks while providing an interval of uncertainty on the prediction. It was found that 60% (91%) of the positive (negative) predictions are correct. 20% to 33% of the peaks in the speed are found by the model. This represents a considerable improvement of the first version of the PDF model. A direct comparison to the WSA model shows that the PDF model leads to less false positive predictions, and miss less events especially when the peak reaches very high speeds.

Basically, the PDF model works in the following way:

1. Given the current solar wind speed and whether the speed is increasing or decreasing, the model takes the most probable speeds over the following five days.
2. Using data from the last day, the optimum delay between one solar rotation ago and now can be estimated. This only works for a short amount of time, though, since the optimal delay changes rapidly.
3. The solar wind speed from one solar rotation ago can be used to predict the current solar wind speed and the solar wind speed for about 24 hours into the future. Beyond that, the time delay is most likely incorrect, and therefore the predictions based on the one solar rotation ago values are probably incorrect.
4. The predictions based on one solar rotation ago and the current speed and slope of the speed are combined linearly to allow for the best possible solution. The coefficients for the two predictions are determined by reducing the error as compared to data.
5. The method above is described as the PDF model, and is better than persistence after a few hours, and is statisticall better than the Wang-Sheely-Arge (WSA) model of the solar wind velocity.
6. The baseline PDF model does not do a very good job at predicting solar wind peaks, which is problematic. Therefore, we created an extension of the PDF model that specifically looks for peaks. If the slope of the solar wind velocity exceeds 4.77 km/s/hour, then the peak-seeking algorithm is implemented.
7. There are two key features the peak: (1) the time of the peak and (2) the strength of the peak. Probability distribution functions are used to find each. The time of the peak is estimated by looking at the median time from the lowest solar wind speed until the peak. This time is used in the model. Then, the strength of the peak is estimated from distribution functions of the difference between the peak speed and the minimum in speed.
8. The current speed (which is the point at which the slope exceeded the 4.77 km/s/hour) and the peak speed are joined together with a polynomial that is somewhat complex to explain in a simple way.
9. If there is a peak in the magnetic field or the solar wind density around the same time as the increased slope of the solar wind velocity, the model does better at predicting the peak in velocity, since the increase in the density and magnetic field typically indicates the presence of a shock.
10. The ability of the model to predict peaks in speeds was tested and compared to models such as the WSA. It is shown that the PDF model with the peak finding algorithm does better than the WSA model the majority of the time.

There was significantly more accomplished on this grant, so we list the papers published and their abstracts below. This should provide an overview of the research that was conducted.

Publications and Presentations

Here is a list of publications that have resulted in part to this grant (students are <u>underlined</u>, while post docs are in *italics*):

1. *Liu, X.*, Ridley, A. (2015), A simulation study of the thermosphere mass density response to substorms using GITM, *J. Geophys. Res. Space Physics, 120*: 7987-8001, doi: 10.1002/2014JA020962.

   Abstract: The temporal and spatial variations of the thermospheric mass density during a series of idealized substorms were investigated using the Global Ionosphere Thermosphere Model (GITM). The maximum mass density perturbation of an idealized substorm with a peak variation of hemispheric power (HP) of 50 GW and interplanetary magnetic field (IMF) Bz of -2 nT was 14% about 50 min after the substorm onset in the nightside sector of the auroral zone. The mass density response to different types of energy input has a strong local time dependence, with the mass density perturbation due to only an IMF Bz variation peaking in the dusk sector and the density perturbation due to only HP variation peaks in the nightside sector. Simulations with IMF Bz changes only and HP changes only showed that the system behaves slightly nonlinearly when both IMF and HP variations are included (a maximum of 6% of the nonlinearity) and that the nonlinearity grows with energy input. The neutral gas heating rate due to Joule heating was of same magnitude as the heating rate due to precipitation, but the majority of the temperature enhancement due to the heating due to precipitation occurs at lower altitude as compared to the auroral heating. About 110 min after onset, a negative mass density perturbation (-5%) occurred in the night sector, which was consistent with the mass density measurement of the CHAMP satellite.

2. Wang, H., Ridley, A., Zhu, J. (2015), Theoretical study of zonal differences of electron density at midlatitudes with GITM simulation, *J. Geophys. Res. Space Physics, 120*, 2951-2966, doi: 10.1002/2014JA020790.

   Abstract: This study investigated various physical processes responsible for the longitudinal modulation of electron density (Ne) at midlatitudes by employing the global ionosphere-thermosphere model (GITM). The good agreements between GITM outputs and CHAMP observations indicate that the model is a suitable tool to perform the theoretical study. Nine runs were carried out to determine the effects from geomagnetic field geometry, zonal wind, meridional wind, high-latitude activity, migrating tides from the lower atmosphere, and solar illumination in quantitative ways. Distinct features were discussed as follows. It was crucial that the geomagnetic and geographical axes were offset for the development of the longitudinal difference of Ne. The zonal wind contributes to about 80% of the fraction of the observed longitudinal dependence of Ne. The meridional wind effect is out of phase with the zonal wind over North America and Southern Ocean regions, which trims the fraction of the longitudinal difference to 65%. Over the South Pacific Ocean, the nighttime Ne maintains at a higher level because of in-phase effects from both zonal and meridional winds. The solar illumination was important in the formation of the background longitudinal pattern of the electron density. The migrating tide from the lower atmosphere could enhance the longitudinal difference of Ne by 15% over North America. Enhanced activities at high latitudes could alter the longitudinal pattern of Ne by transporting thermospheric composition disturbances to midlatitudes.

3. Sheng, C., Deng, Y., Wu, Q., Ridley, A. and Häggström, I. (2015), Thermospheric winds around the cusp region. *J. Geophys. Res. Space Physics, 120*: 12481255. doi: 10.1002/2014JA020028.

   Abstract: An equatorward wind has been observed first by the balloon-borne Fabry-Perot interferometer called High-Altitude Interferometer Wind Observation on the equatorward side of the cusp near the local noon, which is opposite to the typical direction of neutral wind driven by the day-night pressure gradient. However, this dayside equatorward wind was not reproduced by the standard Thermosphere Ionosphere Electrodynamics General Circulation Model under the resolution of 5° longitude by 5° latitude (5° x 5°). In this study, the Global Ionosphere Thermosphere Model has been run in different cases and under different resolutions to investigate the neutral dynamics around the cusp region. First, we compare the simulations with and without additional cusp energy inputs to identify the influence of cusp heating. Both runs have a resolution of 5° x 1° (longitude latitude) in order to better resolve the cusp region. After adding in the cusp energy, the meridional wind in simulation turns to be equatorward on the dayside, which is consistent with the observation. It indicates that strong heating in the cusp region causes changes in the pressure gradient around the cusp and subsequent variations in the neutral winds. The simulations with the same cusp heating specifications are repeated, but with different horizontal resolutions to examine the influence of resolution on the simulation results. The comparisons show that the resolution of 5° x 1° can resolve the cusp region much more stably and consistently than the 5° x 5° resolution.

4. Mannucci, A. J., O. P. Verkhoglyadova, B. T. Tsurutani, X. Meng, X. Pi, C. Wang, G. Rosen, E. Lynch, S. Sharma, A. Ridley, W. Manchester, B. Van Der Holst, E. Echer, and R. Hajra (2015), Medium-Range Thermosphere-Ionosphere Storm Forecasts. *Space Weather, 13*, 125129. doi: 10.1002/2014SW001125.

5. Zou, S., M. B. Moldwin, A. J. Ridley, M. J. Nicolls, A. J. Coster, E. G. Thomas, and J. M. Ruohoniemi (2014), On the generation/decay of the storm-enhanced density plumes: Role of the convection flow and field-aligned ion flow, *J. Geophys. Res. Space Physics, 119*, 85438559, doi:10.1002/2014JA020408.

   Abstract: Storm-enhanced density (SED) plumes are prominent ionospheric electron density increases at the dayside middle and high latitudes. The generation and decay mechanisms of the plumes are still not clear. We present observations of SED plumes during six storms between 2010 and 2013 and comprehensively analyze the associated ionospheric parameters within the plumes, including vertical ion flow, field-aligned ion flow and flux, plasma temperature, and field-aligned currents, obtained from multiple instruments, including GPS total electron content (TEC), Poker Flat Incoherent Scatter Radar (PFISR), Super Dual Auroral Radar Network, and Active Magnetosphere and Planetary Electrodynamics Response Experiment. The TEC increase within the SED plumes at the PFISR site can be 1.4-5.5 times their quiet time value. The plumes are usually associated with northwestward ExB flows ranging from a couple of hundred m s-1 to > 1 km s-1. Upward vertical flows due to the projection of these ExB drifts are mainly responsible for lifting the plasma in sunlit regions to higher altitude and thus leading to plume density enhancement. The upward vertical flows near the poleward part of the plumes are more persistent, while those near the equatorward part are more patchy. In addition, the plumes can be collocated with either upward or downward field-aligned currents (FACs) but are usually observed equatorward of the peak of the Region 1 upward FAC, suggesting that the northwestward flows collocated with plumes can be either subauroral or auroral flows. Furthermore, during the decay phase of the plume, large downward ion flows, as large as approximately 200 m s-1, and downward fluxes, as large as 10^{14} m-2 s-1, are often observed within the plumes. In our study of six storms, enhanced ambipolar diffusion due to an elevated pressure gradient is able to explain two of the four large downward flow/flux cases, but this mechanism is not sufficient for the other two cases where the flows are of larger magnitude. For the latter two cases, enhanced poleward thermospheric wind is suggested to be another mechanism for pushing the plasma downward along the field line. These downward flows should be an important mechanism for the decay of the SED plumes.

6. Bussy-Virat, C. D., and A. J. Ridley, Predictions of the solar wind speed by the probability distribution function model, Space Weather, 12, 337353, doi:10.1002/2014SW001051, 2014.

   Abstract: The near-Earth space environment is strongly driven by the solar wind and interplanetary magnetic field. This study presents a model for predicting the solar wind speed up to 5 days in advance. Probability distribution functions (PDFs) were created that relate the current solar wind speed and slope to the future solar wind speed, as well as the solar wind speed to the solar wind speed one solar rotation in the future. It was found that a major limitation of this type of technique is that the solar wind periodicity is close to 27 days but can be from about 22 to 32 days. Further, the optimum lag between two solar rotations can change from day to day, making a prediction of the future solar wind speed based solely on the solar wind speed approximately 27 days ago quite difficult. It was found that using a linear combination of the solar wind speed one solar rotation ago and a prediction of the solar wind speed based on the current speed and slope is optimal. The linear weights change as a function of the prediction horizon, with shorter prediction times putting more weight on the prediction based on the current solar wind speed and the longer prediction times based on an even spread between the two. For all prediction horizons from 8 h up to 120 h, the PDF Model is shown to be better than using the current solar wind speed (i.e., persistence), and better than the Wang-Sheeley-Arge Model for prediction horizons of 24 h.

7. Deng, Y., and A. J. Ridley, Simulation of non-hydrostatic gravity wave propagation in the upper atmosphere, *Annales Geophysicae, 32*, 443447, doi:10.5194/angeo-32-443-2014, 2014.

   Abstract: The high-frequency and small horizontal scale gravity waves may be reflected and ducted in non-hydrostatic simulations, but usually propagate vertically in hydrostatic models. To examine gravity wave propagation, a preliminary study has been conducted with a global ionosphere-thermosphere model (GITM), which is a non-hydrostatic general circulation model for the upper atmosphere. GITM has been run regionally with a horizontal resolution of 0.2° long 0.2° lat to resolve the gravity wave with wavelength of 250 km. A cosine wave oscillation with amplitude of 30 m s-1 has been applied to the zonal wind at the low boundary, and both high-frequency and low-frequency waves have been tested. In the high-frequency case, the gravity wave stays below 200 km, which indicates that the wave is reflected or ducted in propagation. The results are consistent with the theoretical analysis from the dispersion relationship when the wavelength is larger than the cutoff wavelength for the non-hydrostatic situation. However, the low-frequency wave propagates to the high altitudes during the whole simulation period, and the amplitude increases with height. This study shows that the non-hydrostatic model successfully reproduces the high-frequency gravity wave dissipation.

8. Ridley, A. J., A. M. Dodger, and M. W. Liemohn, Exploring the efficacy of different electric field models in driving a model of the plasmasphere, *J. Geophys. Res., 119*, 46214638, doi: 10.1002/2014JA019836, 2014.

   Abstract: The dynamics of the plasmasphere are strongly controlled by the inner magnetospheric electric field. In order to capture realistically the erosion of the nightside plasmapause and the formation of the drainage plume in a model of the plasmasphere, the electric field must be accurate. This study investigates how well five different electric field models drive the Dynamic Global Core Plasma Model during eight storm periods. The five electric field models are the Volland-Stern analytic formula with Maynard-Chen Kpdependence, two versions of the Weimer statistical models (96 and 05), and two versions of the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) technique using magnetometer and DMSP satellite data. Manually extracted plasmapause locations from images taken by the EUV instrument on the Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) satellite, as described by Goldstein et al. (2005), were compared to the simulation results throughout the main phase of the eight events. Three methods of calculating the plasmapause were employed to determine the best fit to EUV data, using the maximum gradient, a constant density contour (fit method), and the location in which the modeled density fell significantly below the specified saturation density for the given radial position (saturation method). It was found that the simulations driven by the Weimer (1996) model produced the best fit overall and that the fit and saturation methods worked best for matching the model results to the observations.

9. Zou, S., A. J. Ridley, M. B. Moldwin, M. J. Nicolls, A. J. Coster, E. G. Thomas, and J. M. Ruohoniemi,

Multi-instrument observations of SED during 2425 October 2011 storm: Implications for SED formation processes, *J. Geophys. Res., 118*, 77987809, doi:10.1002/2013JA018860, 2013.

Abstract:present multiple instrument observations of a storm-enhanced density (SED) during the 24-25 October 2011 intense geomagnetic storm. Formation and the subsequent evolution of the SED and the midlatitude trough are revealed by global GPS vertical total electron content maps. In addition, we present high time resolution Poker Flat Incoherent Scatter Radar (PFISR) observations of ionospheric profiles within the SED. We divided the SED observed by PFISR into two parts. Both parts are characterized by elevated ionospheric peak height (hmF2) and total electron content, compared to quiet time values. However, the two parts of the SED have different characteristics in the electron temperature (Te), the F region peak density (NmF2), and convection flows. The first part of the SED is associated with enhanced Te in the lower F region and reduced Te in the upper F region and is collocated with northward convection flows. The NmF2 was lower than quiet time values. The second part of the SED is associated with significantly increased NmF2, elevated Te at all altitudes and is located near the equatorward boundary of large northwestward flows. Based on these observations, we suggest that the mechanisms responsible for the formation of the two parts of the SED may be different. The first part is due to equatorward expansion of the convection pattern and the projection of northward convection flows in the vertical direction, which lifts the ionospheric plasma to higher altitudes and thus reduces the loss rate of plasma recombination. The second part is more complicated. Besides equatorward expansion of the convection pattern and large upward flows, evidences of other mechanisms, including horizontal advection due to fast flows, energetic particle precipitation, and enhanced thermospheric wind in the topside ionosphere, are also present. Estimates show that contribution from precipitating energetic protons is at most approximately 10% of the total F region density. The thermospheric wind also plays a minor role in this case.

10. Pulkkinen, A., L. Rastätter, M. Kuznetsova, H. Singer, C. Balch, D. Weimer, G. Toth, A. Ridley, T. Gombosi, M. Wiltberger, J. Raeder, R. Weigel, Community-wide validation of geospace model ground magnetic field perturbation predictions to support model transition to operations, *Space Weather, 11*, 369-385, doi: 10.1002/swe.20056, 2013.

    Abstract: In this paper we continue the community-wide rigorous modern space weather model validation efforts carried out within GEM, CEDAR and SHINE programs. In this particular effort, in coordination among the Community Coordinated Modeling Center (CCMC), NOAA Space Weather Prediction Center (SWPC), modelers, and science community, we focus on studying the models' capability to reproduce observed ground magnetic field fluctuations, which are closely related to geomagnetically induced current phenomenon. One of the primary motivations of the work is to support NOAA SWPC in their selection of the next numerical model that will be transitioned into operations. Six geomagnetic events and 12 geomagnetic observatories were selected for validation. While modeled and observed magnetic field time series are available for all 12 stations, the primary metrics analysis is based on six stations that were selected to represent the high-latitude and mid-latitude locations. Events-based analysis and the corresponding contingency tables were built for each event and each station. The elements in the contingency table were then used to calculate Probability of Detection (POD), Probability of False Detection (POFD) and Heidke Skill Score (HSS) for rigorous quantification of the models' performance. In this paper the summary results of the metrics analyses are reported in terms of POD, POFD and HSS. More detailed analyses can be carried out using the event by event contingency tables provided as an online appendix. An online interface built at CCMC and described in the supporting information is also available for more detailed time series analyses.

11. Honkonen, I., L. Rastätter, A. Grocott, A. Pulkkinen, M. Palmroth, J. Raeder, A.J. Ridley, M. Wilt-

berger, On the performance of global magnetohydrodynamic models in the Earth's magnetosphere, *Space Weather, 11*, 313-326, doi: 10.1002/swe.20055, 2013.

Abstract: We study the performance of four magnetohydrodynamic models (BATS-R-US, GUMICS, LFM, OpenGGCM) in the Earth's magnetosphere. Using the Community Coordinated Modeling Center's Run-on-Request system, we compare model predictions with magnetic field measurements of the Cluster, Geotail and Wind spacecraft during a multiple substorm event. We also compare model cross polar cap potential results to those obtained from the Super Dual Auroral Radar Network (SuperDARN) and the model magnetopause standoff distances to an empirical magnetopause model. The correlation coefficient (CC) and prediction efficiency (PE) metrics are used to objectively evaluate model performance quantitatively. For all four models, the best performance outside geosynchronous orbit is found on the dayside. Generally, the performance of models decreases steadily downstream from the Earth. On the dayside most CCs are above 0.5 with CCs for Bx and Bz close to 0.9 for three out of four models. In the magnetotail at a distance of about -130 Earth radii from Earth, the prediction efficiency of all models is below that of using an average value for the prediction with the exception of Bz. Bx is most often best predicted and correlated both on the dayside and the nightside close to the Earth whereas in the far tail the CC and PE for Bz are substantially higher than other components in all models. We also find that increasing the resolution or coupling an additional physics module does not automatically increase the model performance in the magnetosphere.

12. Wei, Y., W. Wan, B. Zhao, M. Hong, A. Ridley, Z. Ren, M. Fraenz, E. Dubinin, and M. He, Solar wind density controlling penetration electric field at the equatorial ionosphere during a saturation of cross polar cap potential, *J. Geophys. Res., 117*, A09308, doi:10.1029/2012JA017597, 2012.

    Abstract: The most important source of electrodynamic disturbances in the equatorial ionosphere during the main phase of a storm is the prompt penetration electric field (PPEF) originating from the high-latitude region. It has been known that such an electric field is correlated with the magnetospheric convection or interplanetary electric field. Here we show a unique case, in which the electric field disturbance in the equatorial ionosphere cannot be interpreted by this concept. During the superstorm on Nov. 20-21, 2003, the cross polar cap potential (CPCP) saturated at least for 8.2 h. The CPCP reconstructed by Assimilative Mapping of Ionospheric Electrodynamics (AMIE) procedure suggested that the PPEF at the equatorial ionosphere still correlated with the saturated CPCP, but the CPCP was controlled by the solar wind density instead of the interplanetary electric field. However, the predicted CPCPs by Hill-Siscoe-Ober (HSO) model and Boyle-Ridley (BR) model were not fully consistent with the AMIE result and PPEF. The PPEF also decoupled from the convection electric field in the magnetotail. Due to the decoupling, the electric field in the ring current was not able to comply with the variations of PPEF, and this resulted in a long-duration electric field penetration without shielding.

13. J.S. Shim, Kuznetsova, M.; Rasttter, L.; Bilitza, D.; Butala, M.; Codrescu, M.; Emery, B. A.; Foster, B.; Fuller-Rowell, T. J.; Huba, J.; Mannucci, A. J.; Pi, X.; Ridley, A.; Scherliess, L.; Schunk, R. W.; Sojka, J. J.; Stephens, P.; Thompson, D. C.; Weimer, D.; Zhu, L.; Sutton, E., CEDAR Electrodynamics Thermosphere Ionosphere (ETI) Challenge for systematic assessment of ionosphere/thermosphere models: Electron density, neutral density, NmF2, and hmF2 using space based observations, *Space Weather, 10*, doi: 10.1029/2012SW000851, 2012.

    Abstract: In an effort to quantitatively assess the current capabilities of Ionosphere/Thermosphere (IT) models, an IT model validation study using metrics was performed. This study is a main part of the CEDAR Electrodynamics Thermosphere Ionosphere (ETI) Challenge, which was initiated at the CEDAR workshop in 2009 to better comprehend strengths and weaknesses of models in predicting the IT system, and to trace improvements in ionospheric/thermospheric specification and forecast. For the challenge, two strong geomagnetic storms, four moderate storms, and three quiet time intervals were selected. For the selected events, we obtained four scores (i.e., RMS error, prediction efficiency, ratio of the maximum change in amplitudes, and ratio of the maximum amplitudes) to compare the performance of models in reproducing the selected physical parameters such as vertical drifts, electron and neutral densities, NmF2, and hmF2. In this paper, we present the results from comparing modeled values against space-based measurements including NmF2 and hmF2 from the CHAMP and COSMIC satellites, and electron and neutral densities at the CHAMP satellite locations. It is found that the accuracy of models varies with the metrics used, latitude and geomagnetic activity level.

14. *Yiğit, E.*, A. J. Ridley, and M. B. Moldwin, Importance of capturing heliospheric variability for studies of thermospheric vertical winds, *J. Geophys. Res., 117*, A07306, doi:10.1029/2012JA017596, 2012.

    Abstract: Using the Global Ionosphere Thermosphere Model with observed real-time heliospheric input data, the magnitude and variability of thermospheric neutral vertical winds are investigated. In order to determine the role of variability in the Interplanetary Magnetic Field (IMF) and solar wind density on the neutral wind variability, the heliospheric input data are smoothed. The effects of smoothing the IMF and solar wind and density on the vertical winds are simulated for the cases of no smoothing, 5-minute, and 12-minute smoothing. Various vertical wind acceleration terms, such as the nonhydrostatic acceleration, are quantified. Polar stereographic projections of the variabilities of vertical wind and ion flows are compared to highlight existing correlations. Overall, the smoother, that is, the less variable the IMF and solar wind parameters are, the weaker are the magnitude and the variability of the thermospheric vertical winds. Weaker IMF variability leads to smaller variability in ion flows, which in turn negatively impacts the variability and the magnitude of Joule heating. Small-scale temporal variation of the vertical wind acceleration, and thus the variability of the vertical wind, is dominated by the nonhydrostatic term that is controlled primarily by the temporal variation of the Joule heating, which in turn is related to ion flow variations that are shaped by the IMF in the high-latitude thermosphere. Wavelet analysis of the vertical wind data shows that gravity waves of 5 and 10-minute periods are more prominent when the model is run with high-resolution real-time IMF and solar wind data. Better capturing of the temporal variation of the IMF and solar wind parameters is crucial for modeling the variability and magnitude of thermospheric vertical winds.

Here is a list of presentations that have been made at major scientific meetings:

1. Ridley, A., The Role of High Latitude Drivers in Accurately Modeling the Thermospheric and Ionospheric Response to Geomagnetic Storms (Invited), American Geophysical Union, Fall Meeting, San Francisco, Calif., 14-18 Dec., 2015.

2. Ridley, A. J.; Zhu, J., Exploring the Sources of Acoustic and Gravity Waves in the Thermosphere (Invited), American Geophysical Union, Fall Meeting, San Francisco, Calif., 9-13 Dec., 2013.

3. Ridley, A. J.; Pawlowski, D. J.,Understanding the Uncertainties in the Lower Thermosphere and Their Effects on the Structure of the Atmosphere (Invited), American Geophysical Union, Fall Meeting, San Francisco, Calif., 9-13 Dec., 2013.

4. Zou, S., Ridley, A., Nicolls, M., Coster, A., Thomas, E., Ruohoniemi, J., Hampton, D., Deformation of Polar Cap Patches During Substorms, American Geophysical Union, Fall Meeting, San Francisco, Calif., 14-18 Dec., 2015.

5. Bussy-Virat, C., Ridley, A., Ensemble Simulations of the Thermosphere to Quantify the Relationship between Uncertainties in the Space Environment Drivers and the Orbital Position of LEO Satellites, American Geophysical Union, Fall Meeting, San Francisco, Calif., 14-18 Dec., 2015.

6. Zhu, J., Ridley, A., Luhr, H., Investigating the response of the electron temperature to field-aligned currents using SWARM observations, American Geophysical Union, Fall Meeting, San Francisco, Calif., 14-18 Dec., 2015.

7. Greer, K., Immel, T., Ridley, A., Longitudinal Hemispheric Differences During Geomagnetic Storm Times Examined with GITM, American Geophysical Union, Fall Meeting, San Francisco, Calif., 14-18 Dec., 2015.

8. Shim, J.-S., and others, Quantitative Evaluation of Ionosphere Models for Reproducing Regional TEC During Geomagnetic Storms, American Geophysical Union, Fall Meeting, San Francisco, Calif., 14-18 Dec., 2015.

9. Perlongo, N., Ridley, A., Ring Current Influence on Ionospheric Morpology using HEIDI/GITM, American Geophysical Union, Fall Meeting, San Francisco, Calif., 14-18 Dec., 2015.

10. Xianjing, L.; Ridley, A., Simulation Study of the Thermosphere Mass Density Response to Substorms Using GITM Model, American Geophysical Union, Fall Meeting, San Francisco, Calif., 14-19 Dec., 2014.

11. Shim, J.; et al., Assessment of Modeling Capability for Reproducing Storm Impacts on TEC, American Geophysical Union, Fall Meeting, San Francisco, Calif., 14-19 Dec., 2014.

12. Greer, K.; Immel, T.; Ridley, A., Modeling Longitudinal Hemispheric Differences during Geomagnetic Storm Times, American Geophysical Union, Fall Meeting, San Francisco, Calif., 14-19 Dec., 2014.

13. Boll, N.; Ridley, A.; Doombos, E., Validation of Thermospheric Density Models for Drag Specification, American Geophysical Union, Fall Meeting, San Francisco, Calif., 14-19 Dec., 2014.

14. DeJong, A.; Ridley, A.; Bell, J., Ionospheric Conductance During Substorms and Steady Magnetospheric Convection Events (SMCs), American Geophysical Union, Fall Meeting, San Francisco, Calif., 14-19 Dec., 2014.

15. Zhu, J.; Ridley, A., Improved electron and ion temperatures and application to the Nov-24-12 substorm, American Geophysical Union, Fall Meeting, San Francisco, Calif., 14-19 Dec., 2014.

16. Mannucci, A.; et al., Forecasting Ionospheric Space Weather Due To High Speed Streams, American Geophysical Union, Fall Meeting, San Francisco, Calif., 14-19 Dec., 2014.

17. Bussy-Virat, C.; Ridley, A., Predictions of Geospace Drivers By the Probability Distribution Function Model, American Geophysical Union, Fall Meeting, San Francisco, Calif., 14-19 Dec., 2014.

18. Gao, Y.; Ridley, A. J., An empirical model to forecast solar wind velocity through statistical modeling, American Geophysical Union, Fall Meeting, San Francisco, Calif., 9-13 Dec., 2013.

19. Zou, S.; Moldwin, M.; Nicolls, M. J.; Ridley, A. J.; Coster, A. J.; Yizengaw, E.; Lyons, L. R.; Donovan, E., Magnetosphere-Ionosphere Coupling Processes in the Ionospheric Trough Region During Substorms, American Geophysical Union, Fall Meeting, San Francisco, Calif., 9-13 Dec., 2013.

20. Yigit, E.; Immel, T. J.; Ridley, A. J.; Liemohn, M. W., Modeling the ionospheric UT effect during the August 2013 geomagnetic storm with a nonhydrostatic general circulation model, American Geophysical Union, Fall Meeting, San Francisco, Calif., 9-13 Dec., 2013.

21. Perlongo, N. J.; Ridley, A. J., Thermospheric Response to Solar Wind Electric Field Fluctuations, American Geophysical Union, Fall Meeting, San Francisco, Calif., 9-13 Dec., 2013.

22. Pawlowski, D. J.; Ridley, A. J.; Flegal, J., Investigating ionosphere-thermosphere space weather using ensemble based modeling, American Geophysical Union, Fall Meeting, San Francisco, Calif., 9-13 Dec., 2013.

23. Zhu, J.; Fisher, D.; Ridley, A. J.; Makela, J. J.; Meriwether, J. W.; Conde, M.; Hampton, D. L.; Bristow, W. A., Validating Thermospheric Neutral Winds Produced by a Global Model, American Geophysical Union, Fall Meeting, San Francisco, Calif., 9-13 Dec., 2013.

24. Burrell, A. G.; Ridley, A. J., Assessment of Ionospheric and Thermospheric Drivers on Interhemispheric Transport, American Geophysical Union, Fall Meeting, San Francisco, Calif., 9-13 Dec., 2013.

25. Deng, Y.; Fuller-Rowell, T. J.; Ridley, A. J., Influence of the perpendicular ion-drag force on the vertical wind and neutral density in the equatorial region, American Geophysical Union, Fall Meeting, San Francisco, Calif., 9-13 Dec., 2013.

26. Mitchell, E. J.; Newell, P. T.; Ridley, A. J., Modeling Cleft-Region Particle Precipitation Using the Interplanetary Magnetic Field and Generalized Auroral Electrojet Indices, American Geophysical Union, Fall Meeting, San Francisco, Calif., 9-13 Dec., 2013.

27. Liuzzo, L. R.; Ridley, A. J.; Conde, M.; Hampton, D. L.; Bristow, W. A.; Nicolls, M. J.; Mitchell, E. J., High-latitude ionospheric drivers and their effects on wind patterns in the thermosphere, American Geophysical Union, Fall Meeting, San Francisco, Calif., 9-13 Dec., 2013.

28. Shim, J.; Kuznetsova, M. M.; Rastaetter, L.; Swindell, M.; Codrescu, M.; Emery, B. A.; Foerster, M.; Foster, B.; Fuller-Rowell, T. J.; Mannucci, A. J.; and 8 coauthors, Sensitivity of Ionosphere/Thermosphere to different high-latitude drivers, American Geophysical Union, Fall Meeting, San Francisco, Calif., 9-13 Dec., 2013.

29. Burrell, A. G.; Ridley, A. J.; Hairston, M. R.; Stoneback, R., Storm Time Response of Interhemispheric Transport in the Topside Ionosphere, American Geophysical Union, Fall Meeting, San Francisco, Calif., 9-13 Dec., 2013.

30. A.J. Ridley, M. Conde, S. Zhou, Thermospheric and Ionospheric Reaction to Small-Scale Drivers, 2012 Fall Meeting, AGU, San Francisco, Calif., 3-7 Dec., 2012.

In addition to these talks, we have given many talks at meetings such as GEM, CEDAR, and other workshop-type of meetings with no official program.

1.

1. Report Type

Final Report

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Grant/Contract Number
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Aaron Ridley

Program Manager
The AFOSR Program Manager currently assigned to the award

Julie Moses

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Abstract

The upper atmosphere of the Earth is strongly driven by the solar wind and interplanetary magnetic field (IMF), which are only measured about one hour before they encounter the Earth's magnetosphere. This means that it is almost impossible to predict the state of the upper atmosphere without predicting the solar wind and IMF. The research grant focused on predicting the solar wind velocity for up to five days ahead of time. A new model of the solar wind velocity was created using probability distribution functions. This new model performs as well or better than other modern models of the solar wind velocity. In addition, significant research was conducted on validating our upper atmosphere model and specifying the respond to drivers.

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