# PHYSICAL INTERPRETATION OF THE THERMOSPHERE-IONOSPHERE RESPONSE TO THE APRIL 2002 MAGNETIC STORM

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## Abstract

The April 2002 storm event was not one of the most severe magnetic storms that occurred during the Solar Cycle 23. Nevertheless, large CMEs and one of the largest solar flares of the current solar cycle impacted the Earth's space environment during this storm period. This storm occurred just after equinox, so the ionosphere-thermosphere system was undergoing an equinox transition. The global wind and composition structure therefore might still retain characteristics of the preceding equinox, but also reveal signatures of the coming solstice. In this study, a global, three-dimensional, time-dependent, non-linear coupled model of the thermosphere, ionosphere, plasmasphere, and electrodynamics (CTIPe) is used to examine and analyse the relative contribution of various physical mechanisms responsible for the ionosphere-thermosphere response to this storm event. Horizontal thermospheric winds, thermal expansion and electric fields are amongst the investigated mechanisms. Observational data from ground and space, such as GPS-TEC provided by the Space Environment Center (SEC) data assimilation model in its global configuration (MAGIC), are used to compare and support results provided by the physical model.

## Research Goal and Approach

The Sun-Earth relations during magnetically disturbed periods are very complex. A superposition of many effects can be responsible for ionization enhancements and depletions observed during a particular magnetic storm. The disturbances in the neutral and ionized upper atmosphere associated with magnetic storms have been investigated for many years, but it is still very hard to identify the relative contributions of the various mechanisms playing a role in this response. The identification and investigation of these effects is feasible when using an assimilation model to compute TEC values during a storm, and comparing the output with a physically-based model. Such an approach can be used to determine the appropriate choice of model drivers that are able to reproduce the observed storm-time response and quantify the relative importance of the various mechanisms contributing to the response.

The role of horizontal thermospheric winds, thermal expansion, magnetospheric and disturbance dynamo electric fields, the time of response, the longitude sector affected by these electric fields and their effects on the dayside and nightside sectors will be investigated, as well as the composition disturbance and the ionospheric gradients.

Besides model simulations and GPS TEC measurements, all data available from satellites (e.g. DMSP, TIMED), ionosondes and incoherent scatter radars will be used to help interpreting the results. By using both physical models and data assimilation models, contributions can be made to the understanding of the ionospheric response to magnetic storm, improving the space weather forecast. The impact of space weather on the ionosphere can influence the performance and reliability of space-borne and ground-based communication and navigation systems.

## Acknowledgements

- Scripps Orbit and Permanent Array Center (SOPAC) - GPS data.
- Continuous Brazilian Monitoring Network (RBMC) - GPS data.
- UMLCAR DIDBase - Ionosonde data.
- IPS Radio and Space Services - Ionosonde data.
- NOAA NGDC Solar Terrestrial Physics Division - Ionosonde and Kp data.
- The Johns Hopkins University Applied Physics Laboratory - GUVI data.
- World Data Center for Geomagnetism, Kyoto - SYM-H data.
- NASA/GSFC/SPDF/Modelweb - IRI 2001

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### Geomagnetic Indices

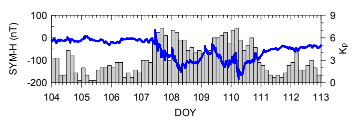


Figure 1. SYM-H and Kp indices for the period April 14-22, 2002.

### Ionosonde Observations

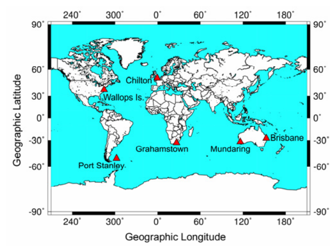


Figure 2. Ionosonde stations. Data are available at http://umlcar.uml.edu/, http://spidr.ngdc.noaa.gov/ and http://www.ips.gov.au/.

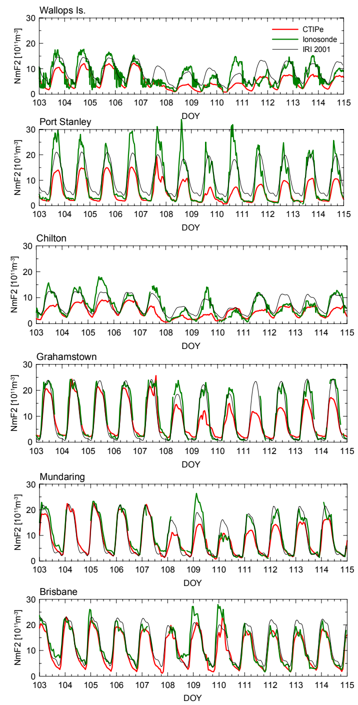


Figure 3. F2 layer maximum electron density (NmF2) for midlatitude ionosonde stations during the period April 13-24, 2002. Ionosonde observations are shown in green and CTIPe simulation results are presented in red. As an additional comparison, results from IRI 2001 (http://modelweb.gsfc.nasa.gov/models/iri.html) are shown in black.

### TEC Observations

The data assimilation model MAGIC (Spencer et al., 2004) is a Kalman-filter-based data assimilation algorithm for imaging the Earth's ionosphere in four dimensions using GPS data. It is the result of a Space Environment Center (SEC) - National Geodetic Survey collaboration, and is the foundation of the SEC's Real Time U.S.-TEC test product (http://sec.noaa.gov/ustec/) (Fuller-Rowell, 2005). The SEC US-TEC product uses MAGIC in a regional mode; the present study will use MAGIC in its global configuration.

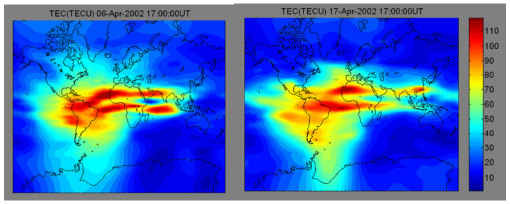


Figure 4. Global TEC observations for the quiet day April 6, 2002 (left) and the disturbed day April 17, 2002 (right) at 17:00 UT. Data from more than 500 GPS stations were used in the data processing.

### CTIPe Simulations

The global, three-dimensional, time-dependent, non-linear coupled model of the thermosphere, ionosphere, plasmasphere and electrodynamics (CTIPe) will be used to investigate the dynamic and electrodynamic response of the global ionosphere during magnetic storms (Fuller-Rowell et al., 2002). CTIPe is a self-consistent model and solves the momentum, energy, and composition equations for the neutral and ionized atmosphere. It requires a few external drives, such as solar UV and EUV, Weimer electric field, TIROS/NOAA auroral precipitation, tidal forcing from the lower atmosphere, and penetration electric fields (not used in this simulation). The high-latitude sources force the global storm-time wind fields, which act as the driver of the disturbance dynamo electric fields. The solar wind is used as the driver for high latitude electric fields.

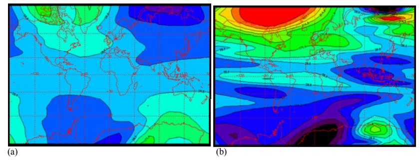

Figure 5. CTIPe thermospheric winds simulated for 17:00UT on (a) the quiet day April 15, 2002 and (b) the disturbed day April 17, 2002.

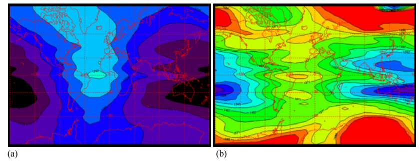

Figure 6. CTIPe neutral temperature simulated for 17:00UT on (a) the quiet day April 15, 2002 and (b) the disturbed day April 17, 2002.

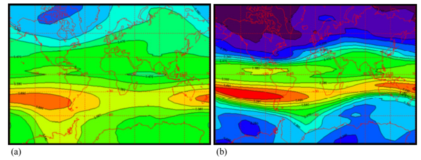

Figure 7. CTIPe $O/N_2$ ratio simulated for 15:00UT on (a) the quiet day April 15, 2002 and (b) the disturbed day April 17, 2002.

### Preliminary Results

- Even only 3 weeks after equinox, the global characteristics of both thermosphere an ionosphere are solstice-like.
- Ionosonde data shows higher NmF2 values in the southern hemisphere, which is a typical behaviour during summer in the north hemisphere and the winter in the south hemisphere, due to the seasonal thermospheric winds and global neutral composition structure.
- CTIPe simulations are in better agreement with ionosonde observations in the southern hemisphere. The model also captures the negative phase in both northern stations of Wallops Island and Chilton during some of the storm days.
- GPS TEC and ionosonde observations show consistent results, such as the plasma depletion over Wallops Islands (North America) and the enhancement over Port Stanley (South America).
- The CTIPe storm response of thermospheric winds, neutral temperature and O/N2 ratio are consistent with the increased high latitude forcing. The modeled storm-time changes in neutral composition are in good agreement with GUVI data.
- In certain longitude sectors there can be competition between the various physical mechanisms producing the positive and negative ionospheric phases.

### GUVI Observations

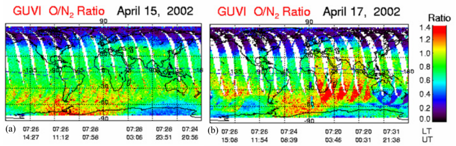


Figure 8. GUVI $O/N_2$ ratio (http://guvi.jhuapl.edu/) on (a) the quiet day April 15, 2002 and (b) the disturbed day April 17, 2002.

### Summary

Further and extensive analysis of data-sets, such as ionosonde, GPS, GUVI, and other available data is being done as part on an ongoing study to identify, separate and quantify the relative contribution of mechanisms in the ionospheric storm-time response magnetic storms. Results showing the contribution of thermal expansion and thermospheric winds in changing hmF2 during the March 31, 2001 storm event have been presented by the same authors previously, and the same analysis will be done for the April 2002 storm case. In the near future, simulations will include Rice Convection Model (RCM) results, which will be used to impose low latitude prompt penetration electric fields.

References

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