Thermosphere – Ionosphere dynamics of the 20th November 2003 superstorm modeled by CTIPe

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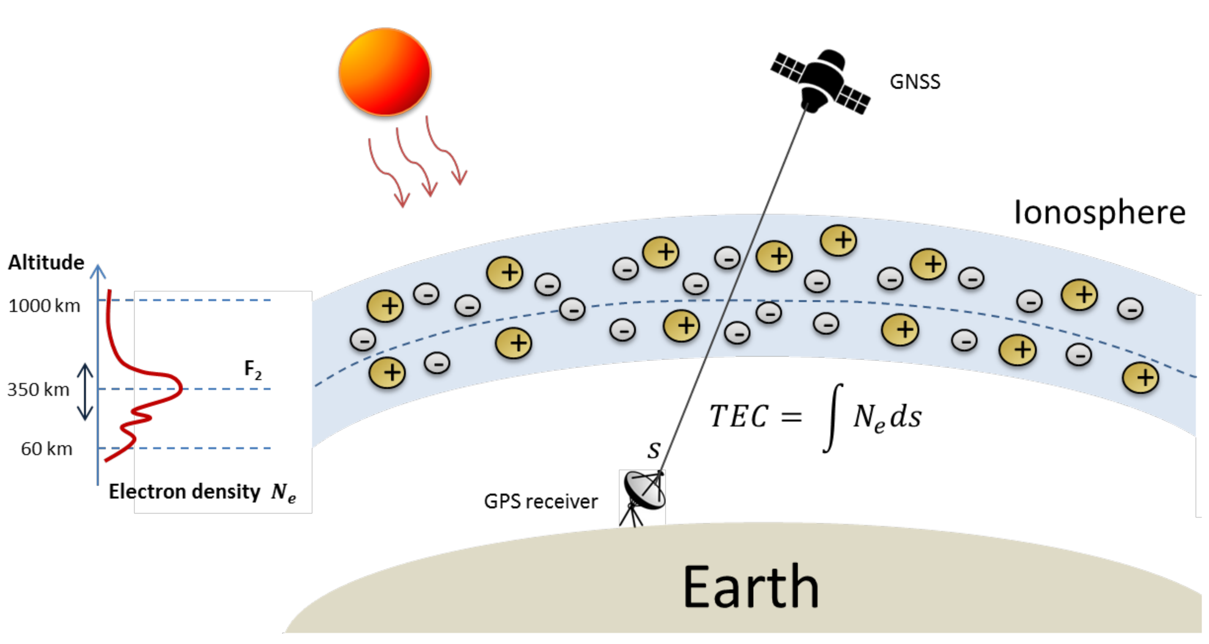
The complexity of the Sun – Earth system increases during intense solar activity causing magnetically disturbed conditions. One of the strongest geomagnetic storms occurred the **20th November 2003**. These extreme conditions generate ionospheric instabilities or disturbances in the ionospheric density (**ionospheric storms**) that produce disruptions in communications and positioning.

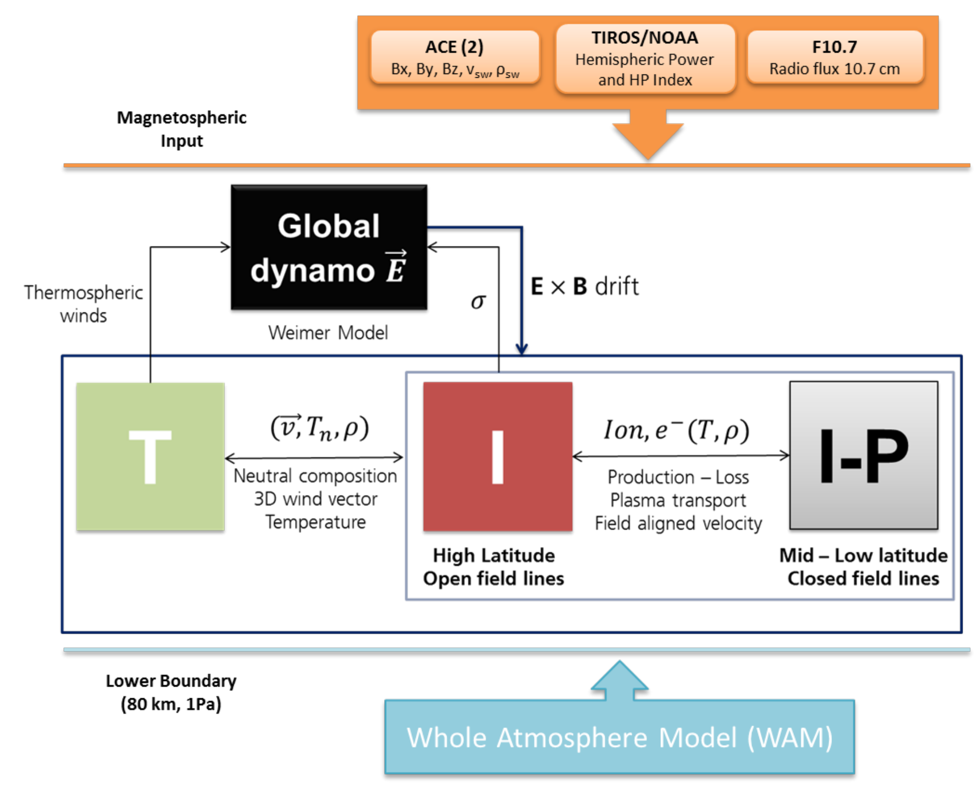
To investigate how the thermosphere – ionosphere system responded to this event, we use the **Coupled Thermosphere Ionosphere Plasmasphere electrodynamics** physics based model (CTIPe), that reproduces the changes in the **thermospheric winds**, **composition** and **electron densities** during the storm. To complete the study, observational data derived from CHAMP satellite, GNSS and ground-based measurements are used.

Ionosphere GNSS TEC



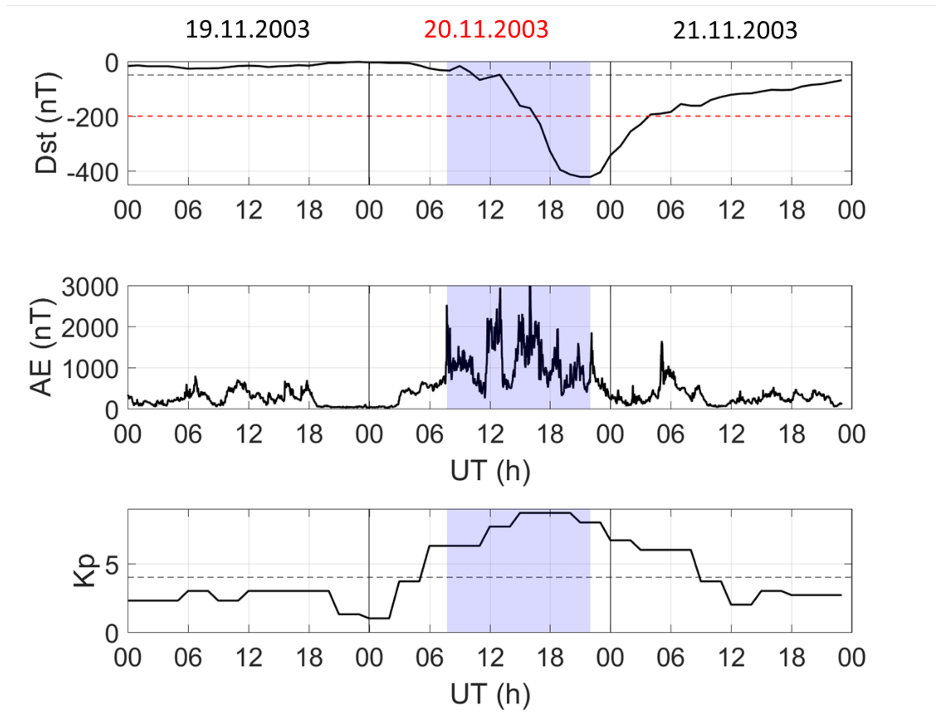
Maps of ionosphere's **Total Electron Content** (TEC) in near real time derived from **GNSS** measurements, are a powerful tool for detecting ionospheric storms and monitoring their behavior. **TEC** can be calculated integrating the electron density N_e along a ray path ds, and measured in TEC units (1 TECU = $10^{16}\, e^-/m^2$).

CTIPe Model



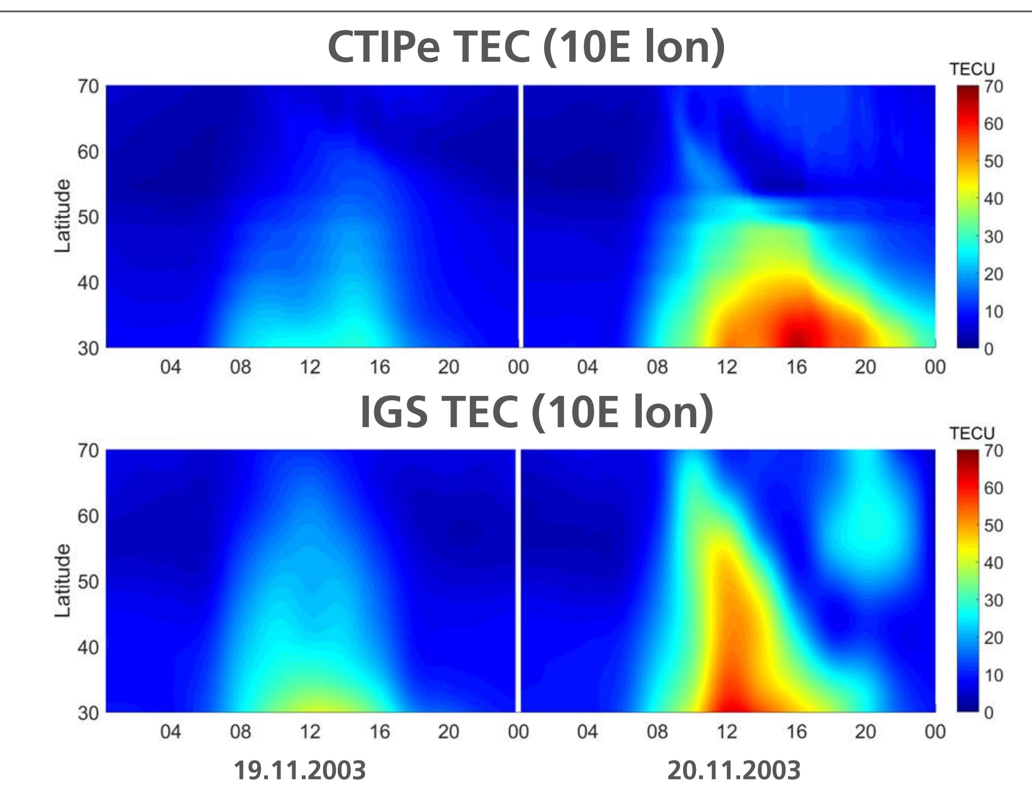
CTIPe [1] is a global non linear physics based model that solves the equations of momentum, energy and composition for neutral and ionized atmosphere. It uses as inputs: ACE measurements, TIROS/NOAA auroral precipitation, solar UV, EUV, electric field [Weimer, 2005] model and the WAM for the lower atmosphere.

20th November 2003 Storm



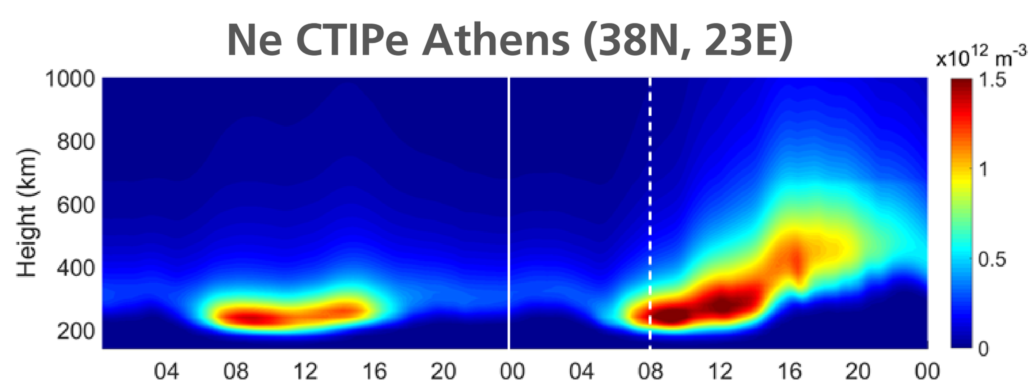
Dst [2] (geomagnetic storm magnitude) as indicator of the storm phases: **Onset** 8UT, **main phase** 8-23UT with a minimum -470nT and **recovery** phase until next day's 0UT. **Auroral Electrojet** shows heating enhancement after onset. **Kp** quantifies the disturbances in the horizontal component of the Earth's $\vec{B}_E$.

Ionosphere Dynamics

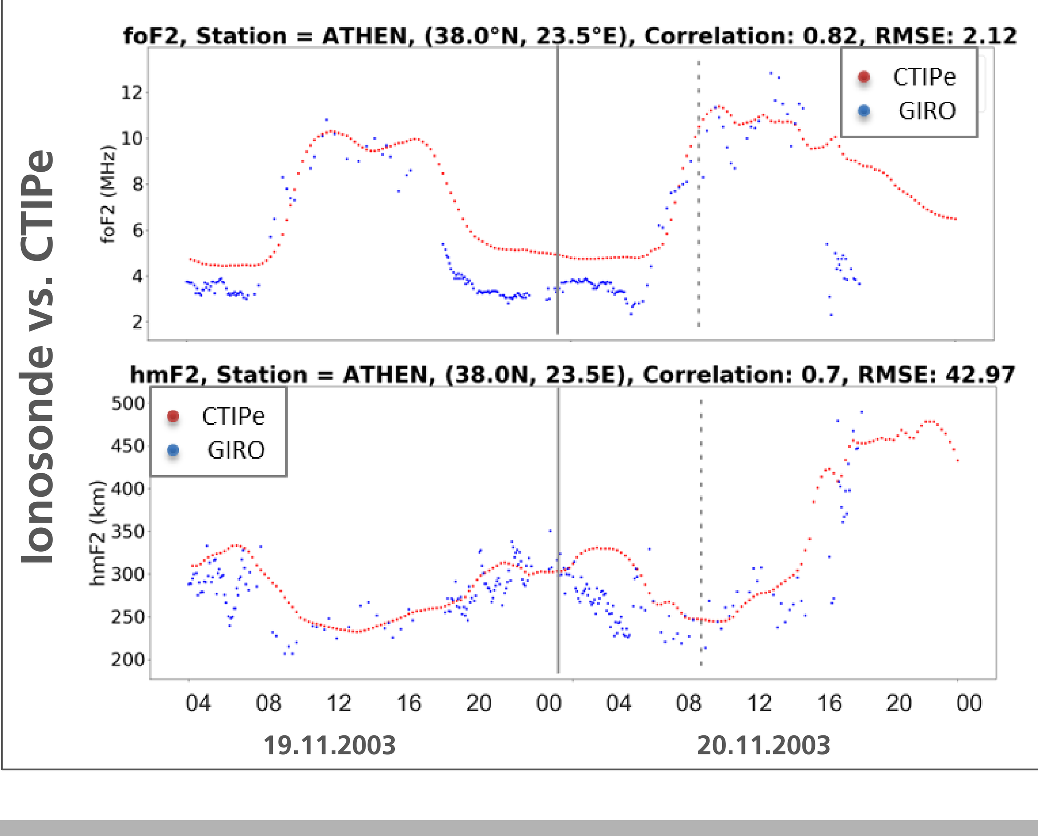


CTIPe and IGS [3] **TEC** change in latitude vs. time for a fixed longitude of 10° E (over Europe).

- Positive phase of the storm following the storm onset (8UT). Differences of 40 TECU compare to the quiet day.
- Depletion area travelling from high latitudes towards the equator during storm day.
- IGS TEC shows an enhancement at high latitudes during the evening.



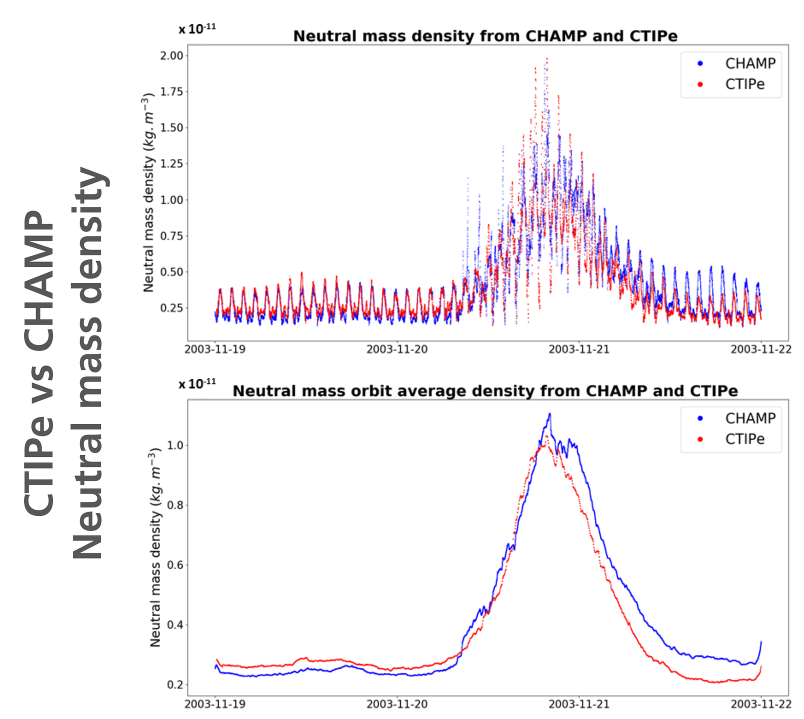
CTIPe **electron density** at Athens ionosonde location. It reveals strong enhancement during the main phase and uplift of the F2 layer starting in the afternoon hours from 250 to 500 km.



The critical F2 layer frequency **foF2** (∝ NmF2) and height **hmF2** are reproduced by the model (red) in comparison with ionosonde measurements (blue) [4].

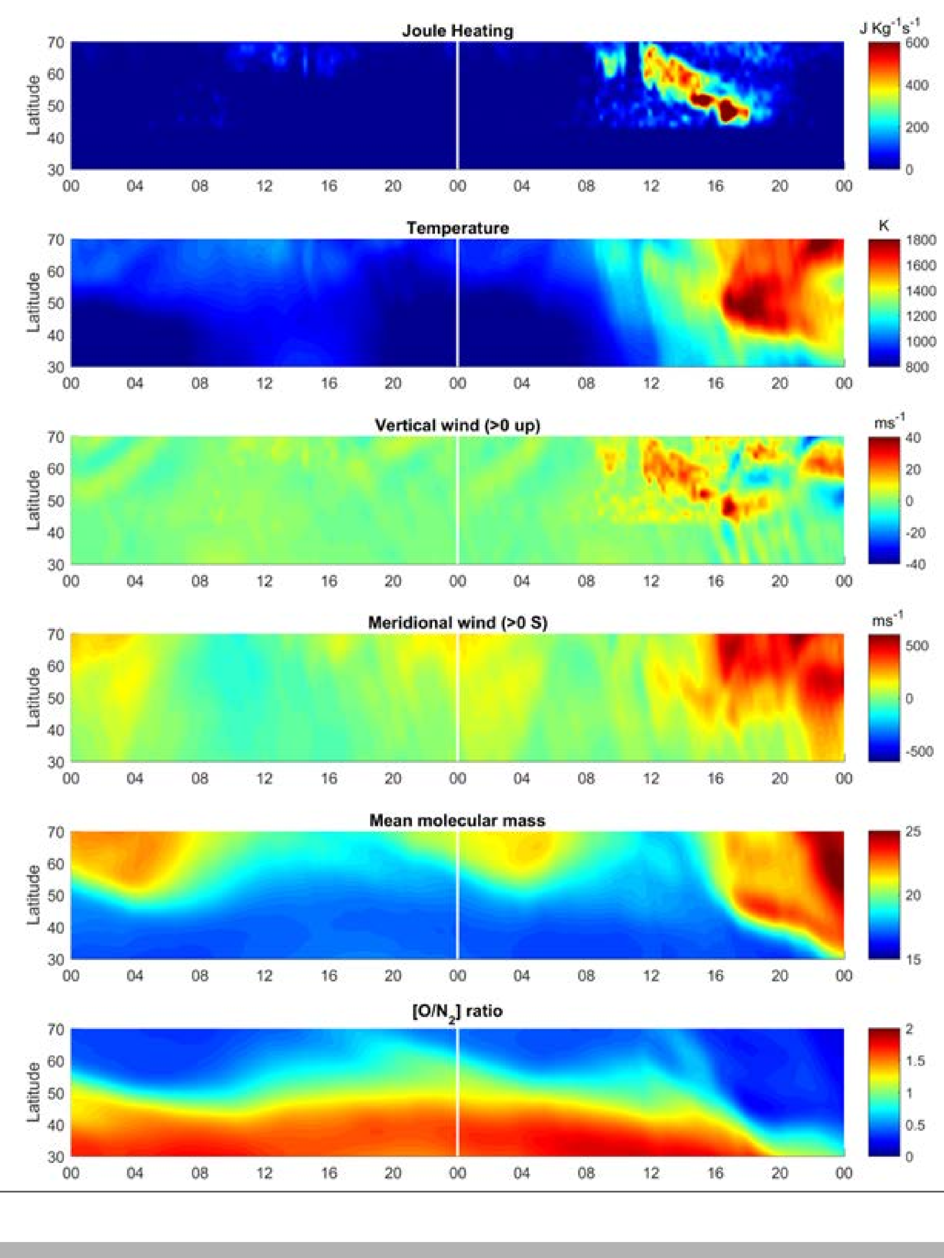
Both model and observations exhibit the same evolution and magnitude for foF2 and hmF2, although CTIPe deviates from the variability displayed in the ionosonde measurements.

Thermosphere Dynamics



A significant increase of the **neutral mass density** (ρ) can be identified in the comparison between values derived from CHAMP [5] (blue) and CTIPe results (red). It was generated by the storm disturbances reaching a maximum one order of magnitude bigger than quiet values.

The good agreement of both, indicates that the model characterized the storm thermospheric conditions very well.



CTIPe reproduces strong perturbations in **Joule heating** over Europe. A rapid increase of the **temperature** causes expansion of the atmosphere, upwelling of neutral atmosphere above the heating region, **vertical winds**, and the launch of atmospheric surges.

Behind the traveling perturbations, a large scale storm circulation is added to the global circulation, and these enhanced **meridional winds** can also cause global ionospheric storm effects.

The heating of the neutral atmosphere causes departure from diffusive equilibrium increasing the **mean molecular mass** and a decrease in the $\sum\left[\frac{O}{N_2}\right]$ **ratio** traveling equatorward.

Conclusions

- CTIPe can reproduce the ionospheric disturbances produced by the 20th November 2003 geomagnetic superstorm as well as its thermospheric drivers.
- Analysis of data sets, such as ionosonde, GNSS TEC maps and CHAMP satellite data have been used to identify the thermosphere - ionosphere response to the geomagnetic storm.
- TEC, foF2 critical frequency, maximum height of F2 layer for ionosonde data and neutral mass density show good agreement with CTIPe results.
- Joule heating has been identified as the main driver of the positive ionospheric storm over Europe.

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[1] T.J. Fuller–Rowell el al., STEP Handbook, 239,(1996)
[2] World Data Center for Geomagnetism, Kyoto (http://wdc.kugi.kyoto-u.ac.jp/index.html)
[3] IGS TEC maps (http://www.igs.org)
[4] Ionosonde GIRO database (http://ulcar.uml.edu/DIDBase)
[5] CHAMP satellite neutral mass density (http://thermosphere.tudelft.nl/acceldrag/index.php)

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