Analysis of the 20th November 2003 extreme geomagnetic storm using CTIPe model and GNSS data

I. Fernández-Gómez[1], C. Borries[1] and M. V. Codrescu[2]

[1] Institute of Communications and Navigation, German Aerospace Center

[2] Space Weather Prediction Center, NOAA

During the 20th November 2003 extreme geomagnetic storm, significant perturbations were observed in the ionosphere – thermosphere system. Here, we replicate how this system responded to the onset of this particular storm, using the **Coupled Thermosphere Ionosphere Plasmaphere electrodynamics** (CTIPe) physics based model [1], that simulates the changes in the neutral winds, temperature, composition and electron densities [2].

Although modelling the ionosphere under this conditions is a challenging task due to energy flow uncertainties, the model reproduces the necessary features to interpret the physical mechanisms behind the Total Electron Content (TEC) increase and the dramatic changes in composition during this event. Corresponding effects are observed in the products derived from **Global Navigation Satellite system** (GNSS) [3] and ground – based measurements.

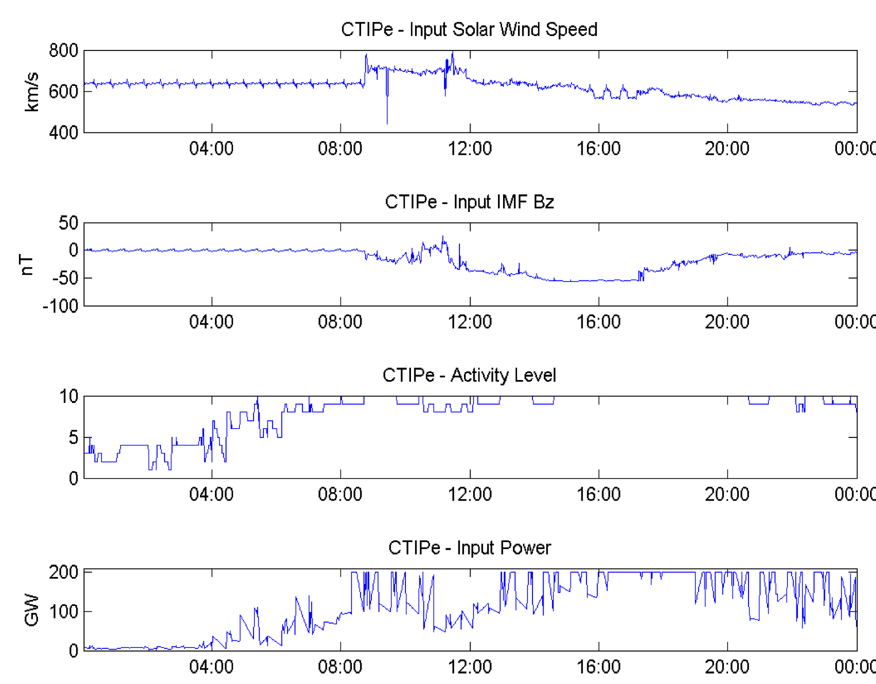
Ionosphere Monitoring: CTIPe and GNSS

The **ionosphere** is embedded in the outer layer of Earth's atmosphere, ionized by solar and cosmic radiation. It lies from 60 to 1000 km above the Earth and is characterized by its plasma density.

The ionospheric instabilities produced by solar activity tend to generate disturbances in ionospheric density (**ionospheric storms**) with important terrestrial consequences such as disrupting communications and positioning.

With **GNSS** measurements, maps of ionosphere's total electron content (TEC) in near real time are a powerful tool for detecting ionospheric storms and monitoring their behavior.

TEC can be derived integrating the electron density along a ray path by TEC Units.

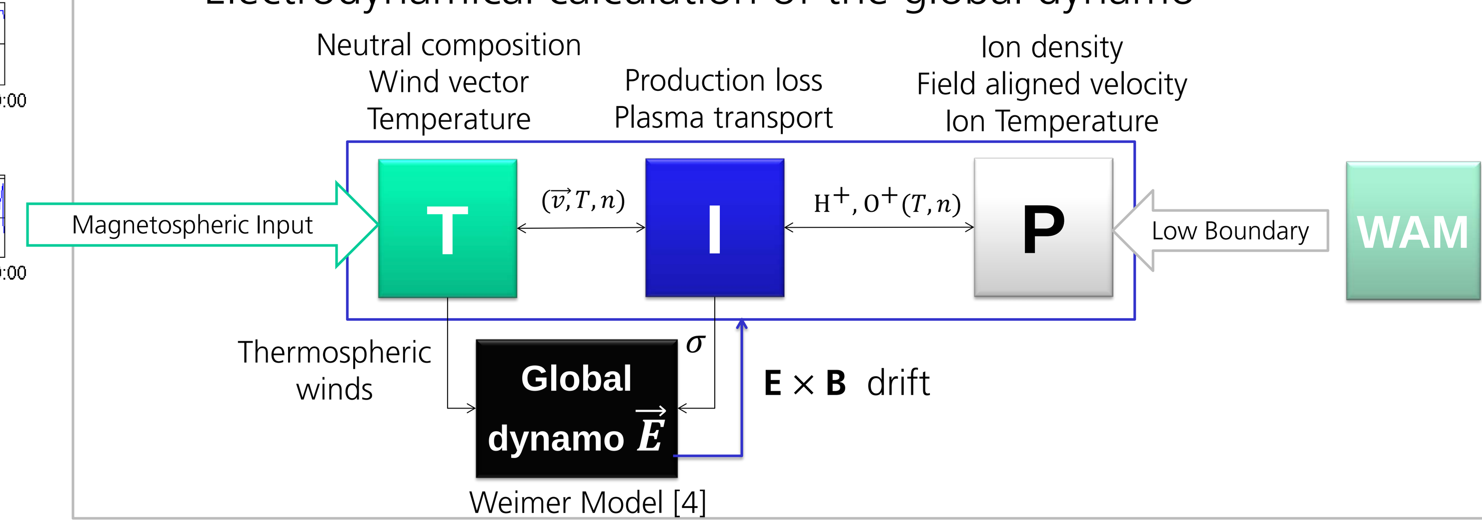


ACE level 2 - CTIPe Magnetospheric Input

For a more complete understanding of storm phenomena we need also information of the processes that operate in the ionosphere – thermosphere, using physics based models.

CTIPe is a non linear physics based model with self consistent electrodynamics scheme, with four distinct components:

- A global thermosphere model (T)
- A high latitude ionosphere model (I)
- A mid and low latitude ionosphere-plasmasphere model (P)
- Electrodynamical calculation of the global dynamo



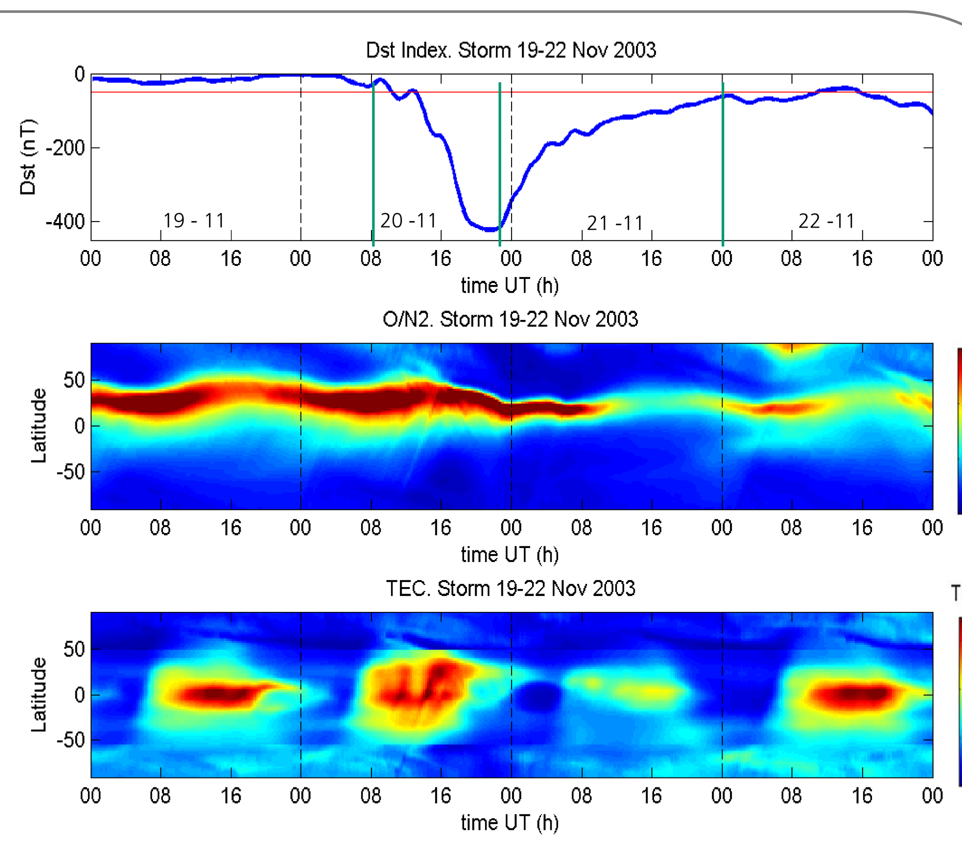
CTIPe results and GNSS comparison

Changes in the Ionosphere – Thermosphere System

Dst index: Rapid **onset** (8UT), followed by a short increase, **main phase** (8-23UT) with an steep decrease to a minimum below -400nT and **recovery phase** (until 00UT - 21 Nov).

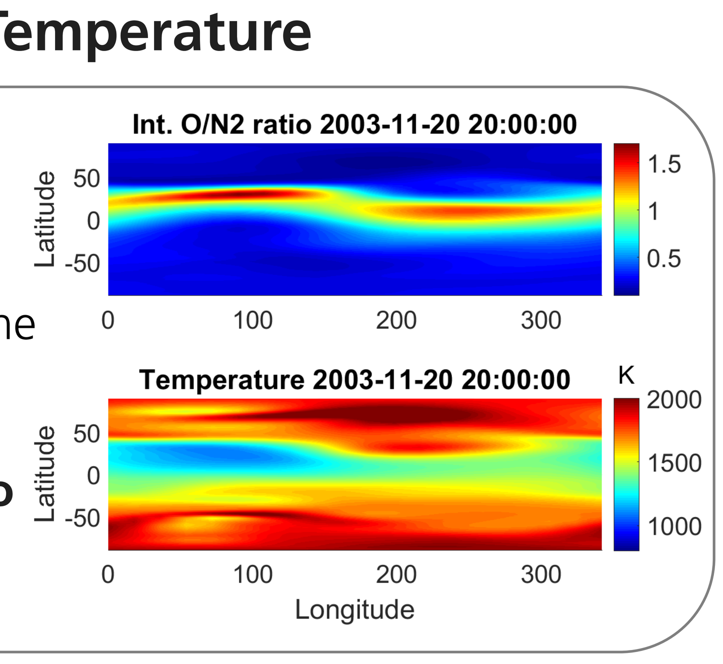
[O/N_2] ratio as indicator of composition changes in the Thermosphere. It shows how the perturbed air moves globally as a result of dynamical forcing.

Total electron content (TEC) in the ionosphere mainly influenced by solar radiation, solar wind energy input and other thermospheric conditions.



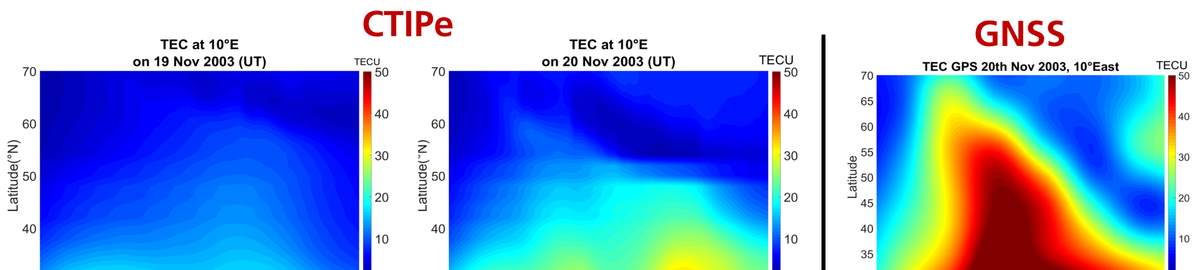
Composition change and Temperature

- (19/11): Hemispheric asymmetry caused by seasonal wind pattern, that increases the ratio in the winter hemisphere.
- (20/11): Migrating high/low **[O/N_2] ratio** towards the equator.
- Consistent with high latitude heating followed by driven migration of **low oxygen to nitrogen air to lower latitudes, that correlate with high thermospheric Temperature.**



Total electron content (TEC)

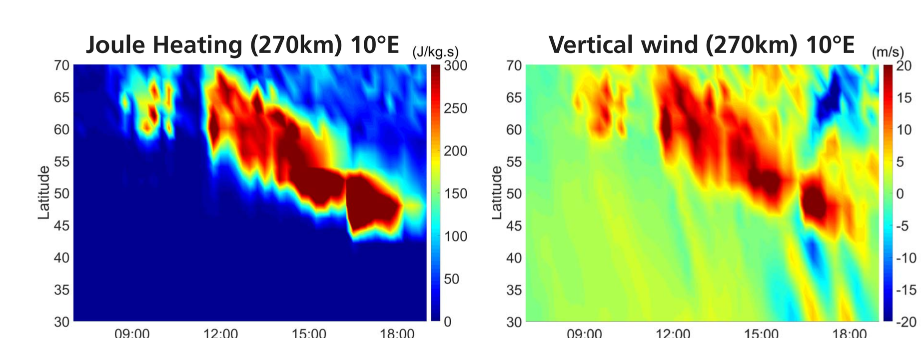
- **Enhancement of plasma density** at low and middle latitudes (over Europe) can be observed during the main phase of the superstorm.
- **TEC** depletion in response to reduced [O/N_2] ratio during the recovery phase
- Comparing CTIPe – GNS measurements show TEC enhancement is underestimated by the model.



The model result may be improved by using better estimates of the thermosphere ionosphere forcing during the storm

Joule Heating and Neutral Winds

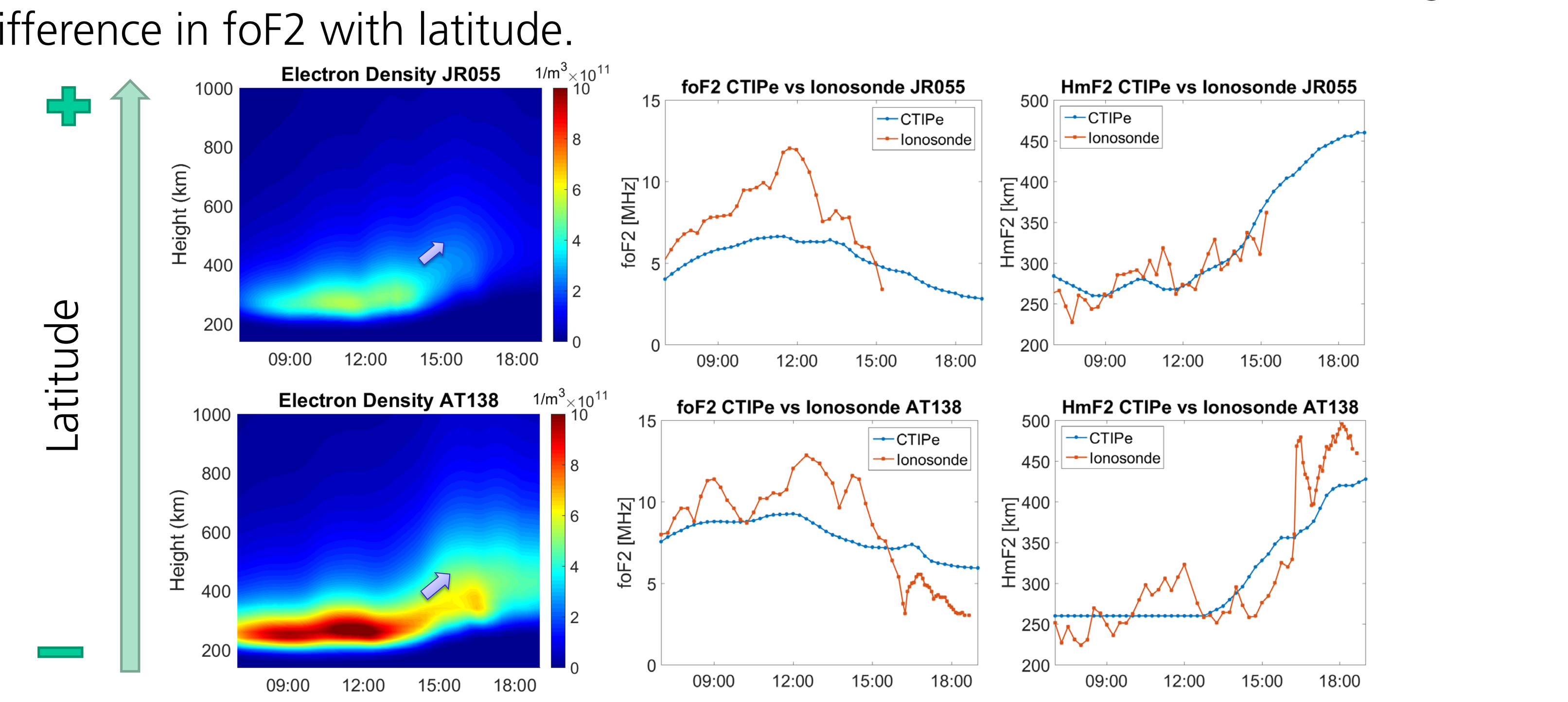
- CTIPe reproduces the strong perturbations in **Joule heating** over Europe.
- As response to this energy deposition there is a rapid increase in the temperature that causes upwelling of the neutral atmosphere, the **vertical wind**.
- Joule heating causes thermospheric expansion, changing the composition during the recovery phase.
- **We assume that Joule heating is the main driver of the ionospheric perturbations observed over Europe during this superstorm.**



Joule heating and neutral vertical wind over Europe at 270 km

Electron density, foF2, HmF2 and Ionosonde data

- CTIPe shows the **electron density uplifting,** and ionosonde data recorded significant increases in critical frequency **foF2** and the sudden uplift of the F2 layer.
- Model and measurements exhibit the same evolution in **hmF2** but increasing difference in foF2 with latitude.



- **This deviation could be due to the underestimation of the total energy input into the system and lack of detailed information of the spatial distribution of that input energy**.

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Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Contact: I. Fernandez-Gomez
DLR, Institut für Kommunikation und Navigation
Kalkhorstweg 53, 17235 Neustrelitz
Email: Isabel.FernandezGomez@dlr.de