

Overview of the 2015 St. Patrick's Day storm using CTIPe model and GNSS data

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The complexity of the Sun – Earth system increases during intense solar activity that causes magnetically disturbed conditions. One of the strongest geomagnetic storms occurred following a coronal mass ejection (CME) impact; it was the **St. Patrick's Day storm on the 17 March 2015**. As a result of these extreme conditions, ionospheric instabilities are produced, generating disturbances in the ionospheric density (**ionospheric storms**) that produce disruptions in communications and positioning.

To explore how the ionosphere – thermosphere system responded to this event, we use the **Coupled Thermosphere Ionosphere Plasmasphere electrodynamics** global, three dimensional, non-linear physics based model (CTIPe), that reproduces the changes in the thermospheric winds, composition and electron densities during the storm. To have a more complete understanding of the processes during the storm, observational data derived from GNSS and ground-based measurements are used.

Ionosphere Monitoring: CTIPe and GNSS TEC

The global 3D, time dependent non linear **CTIPe model** [1] can be used to study the dynamic and electrodynamic response of the ionosphere during this geomagnetic storm.

CTIPe is a self consistent model that solves the equations of momentum, energy and composition for neutral and ionized atmosphere. It uses as inputs, solar UV, EUV external drives, TIROS/NOAA auroral precipitation, Weimer electric field and tidal forcing form the lower atmosphere.

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 N_e along a ray path ds by TEC Units: $TEC = \int N_e ds$.

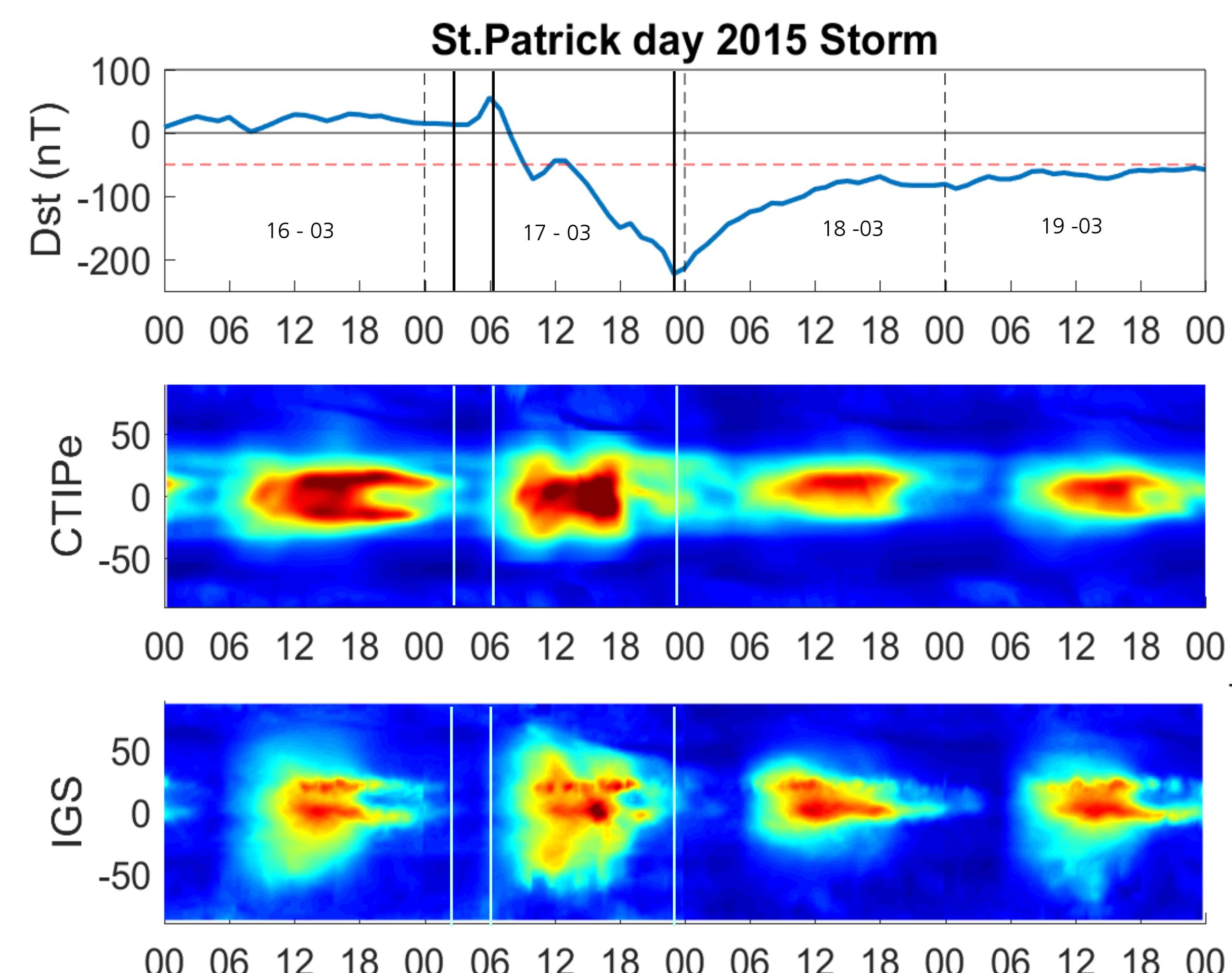


Fig.1. Dst Index (first panel), **CTIPe TEC** and **IGS TEC** (absolute values TECU) over the European – African sector (second and third panel).

Dst index displays the different storm phases: the **onset** (17/03 4UT), was followed by the **main phase** (17/03 6-00UT) with an steep decrease to a minimum below -200nT and **recovery phase** (until 19/03).

CTIPe TEC differences, between quiet (16/03) and disturbed day (17/03) show an enhancement of plasma density, with a two lobes structure at mid-low latitudes, corresponding with a partial recovery phase during the main phase of the storm, this behavior is consistent with [2].

IGS TEC exhibits the same two lobe enhancement during the main phase of the storm, except that it extends to higher latitudes on the southern hemisphere. This differences can be due to the fact that this CTIPe version does not include prompt penetration electric fields that could contribute to enhance TEC at higher latitudes.

F2 Layer (foF2, hmF2): CTIPe and Ionosonde data

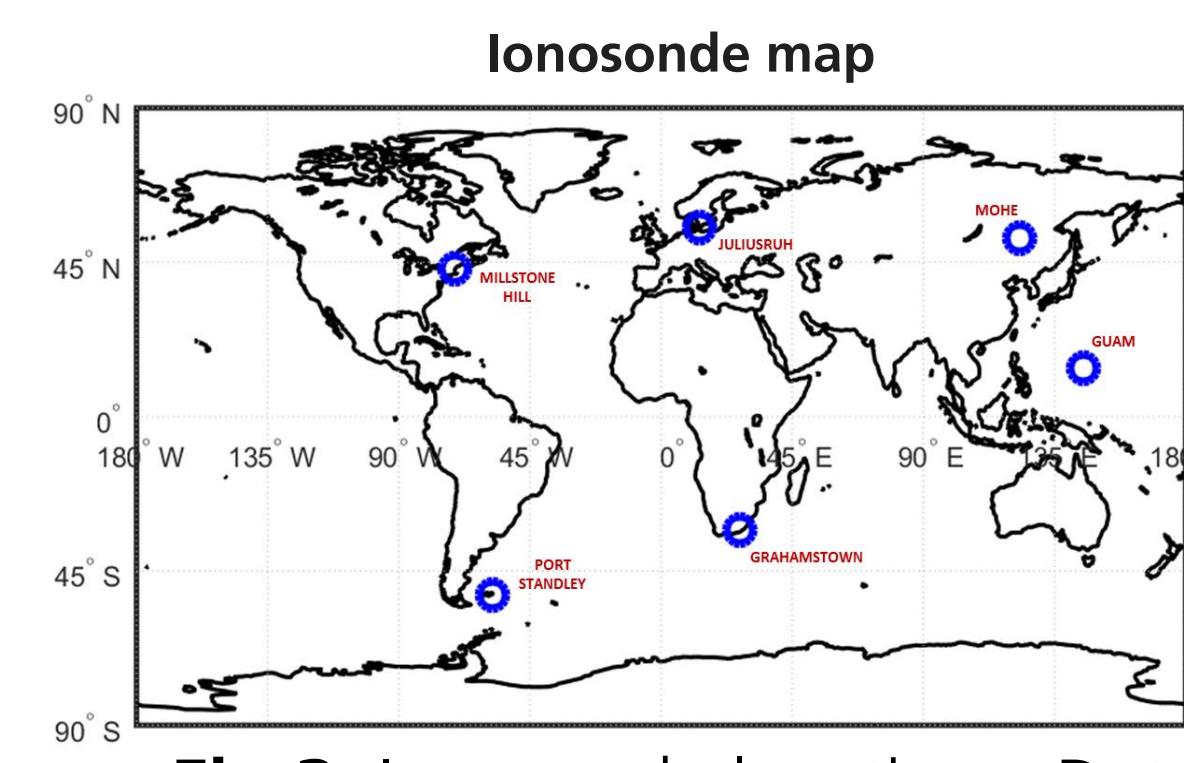


Fig.3. Ionosonde locations. Data available from DIDBase GIRO

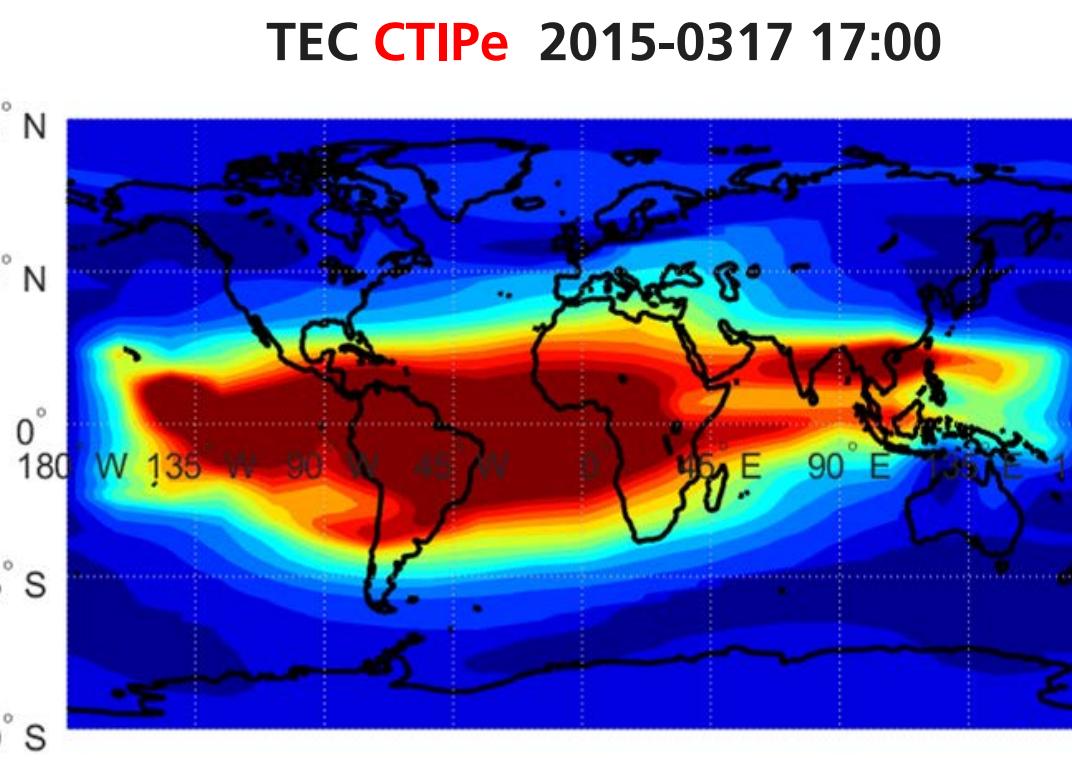


Fig.2. TEC CTIPe (left) and IGS (right) for the disturbed day 17/03 at 17:00

Ionosonde data (foF2 critical frequency, hmF2 maximum height of the F2 layer) shows same range of values in the northern and southern hemispheres.

CTIPe simulations show consistent results with ionosonde observations, such as plasma depletion over Mohe or Juliusruh. The model captures better the negative phase of the storm. The maximum high (hmF2) is very well represented by CTIPe in almost all cases.

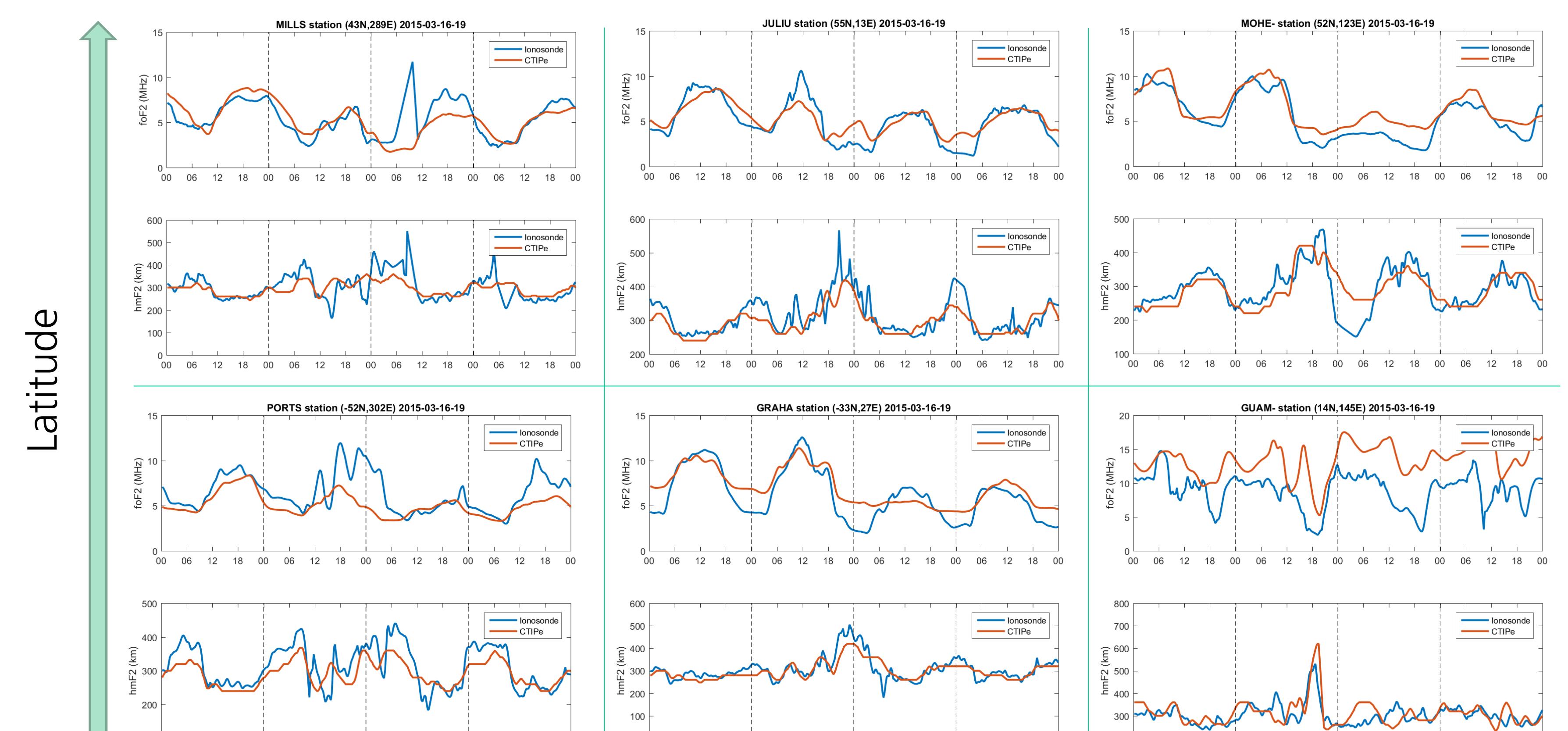


Fig.4. F2 layer maximum electron density frequency (**foF2**- upper panels) and high (**hmF2**- lower panels) during the period from 16 to 19 of March 2015. **Ionosonde observations** (from the ionosonde map) are shown in blue and **CTIPe** simulation results are presented in red.

Thermospheric drivers : CTIPe

Ionospheric disturbances can be caused by the superposition of many effects, like:

- Neutral winds
- Thermal expansion
- Composition changes

As a consequence of increased high latitude forcing, **CTIPe** exhibits a coherent storm response for thermospheric winds [3], and it is consistent with high latitude heating followed by driven migration of low Oxygen to Nitrogen air moving to lower latitudes, that correlates with high thermospheric temperature.

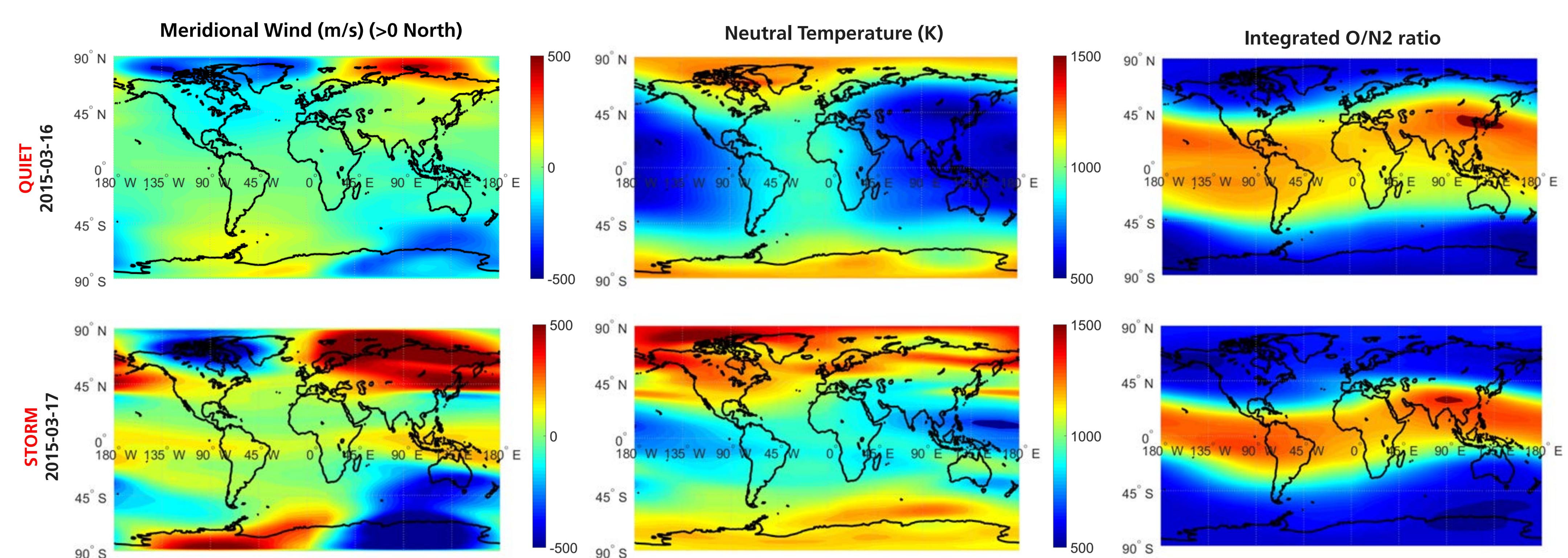


Fig.5. **CTIPe model** Meridional neutral wind (left), Neutral temperature (middle) and Integrated atomic Oxygen to molecular Nitrogen ratio (right); for quiet day 16/03 (up) and disturbed day 17/03 (down) at 17:00 UT. CTIPe shows consistent storm response to high latitude forcing.

Conclusions

- CTIPe can reproduce the ionospheric disturbances produced by the 2015 St. Patrick day geomagnetic storm as well as its thermospheric drivers.
- Analysis of data sets, such as ionosonde and GNSS TEC maps have been used to identify the ionospheric response to the geomagnetic storm.
- TEC, foF2 critical frequency and maximum high of F2 layer for ionosonde data show good agreement with CTIPe results.
- Further studies will be required to establish the influence of other mechanism contributing to the ionosphere response, such as disturbance dynamo electric fields.

[1] T.J. Fuller-Rowell and D. Rees, Journal of Atmospheric Sciences, 37(11), 2545-2567 (1980)

[2] C. Borries et al. Journal of Geophysical Research: Space Physics 121 (2016)

[3] M. Fedrizzi et al. Advances in Space Research, 36.3, (2005), 534-545

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