Hindcasting the Ionosphere via the assimilation of thermospheric mass density into physics – based models during storm conditions.

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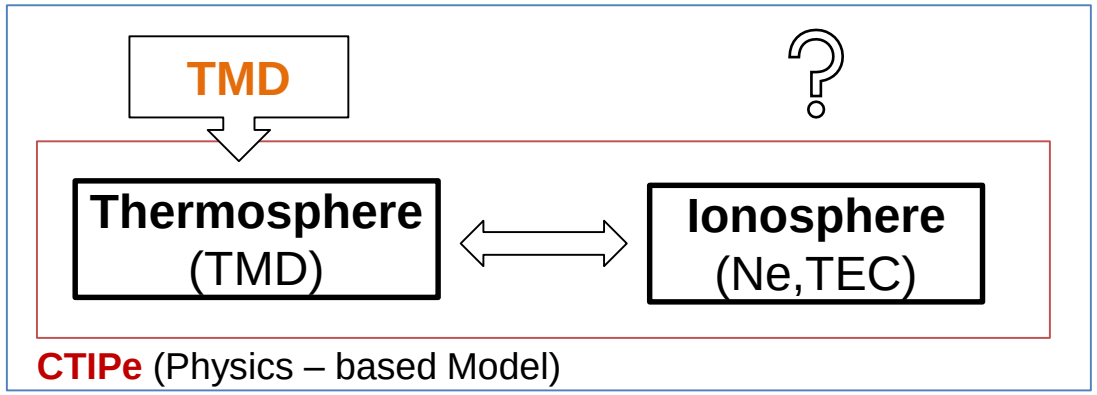
Objective: Impact of TMD data assimilation (DA) in the ionosphere…

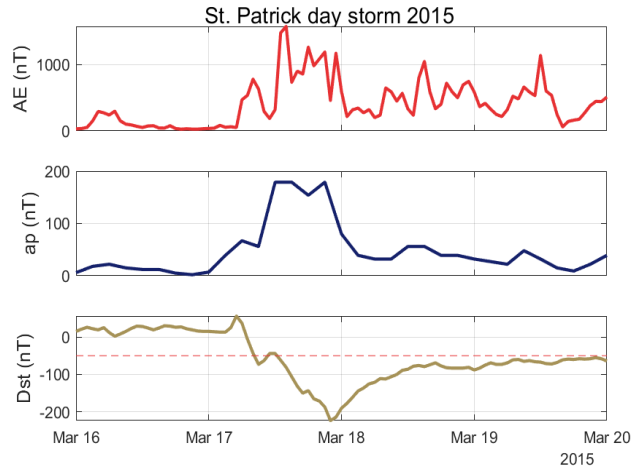


TIDA (Thermosphere Ionosphere Data Assimilation scheme)

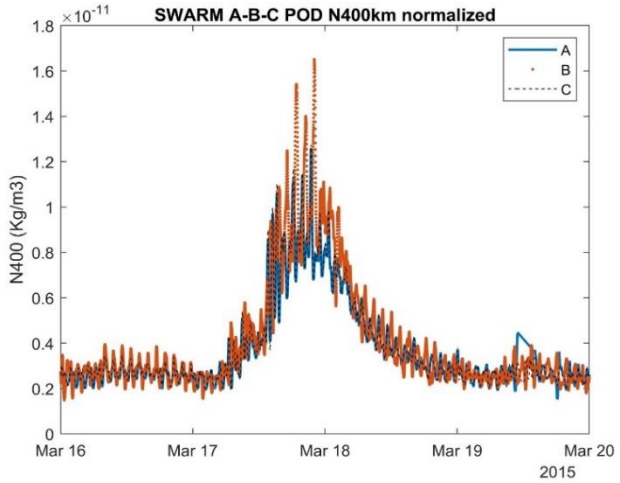
- **Thermosphere – Ionosphere** (TI) system response to **storm conditions**.
- **Assimilate Thermospheric Mass Density** (TMD) into **physics – based model** CTIPe.
- Assimilating thermospheric parameters will improve the thermosphere, but **what happens in the ionosphere?**

Objective: Impact of TMD data assimilation in the ionosphere during storm conditions

Geomagnetic Storm Conditions



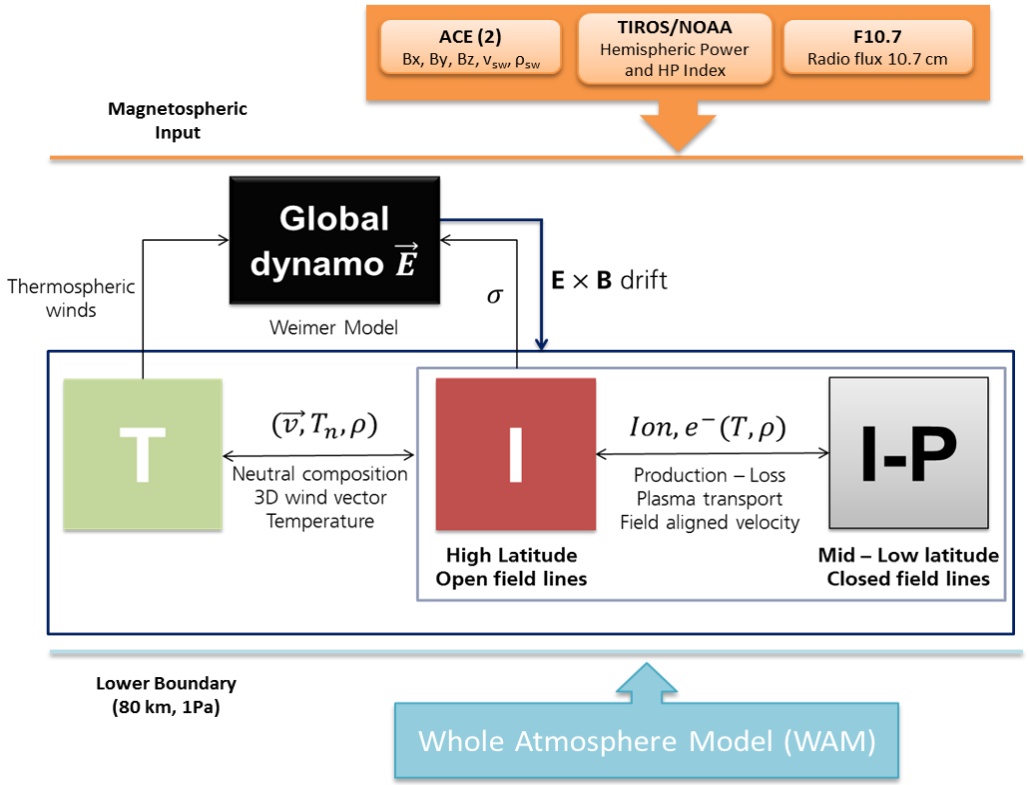
Assimilated data: SWARM TMD (400 km)



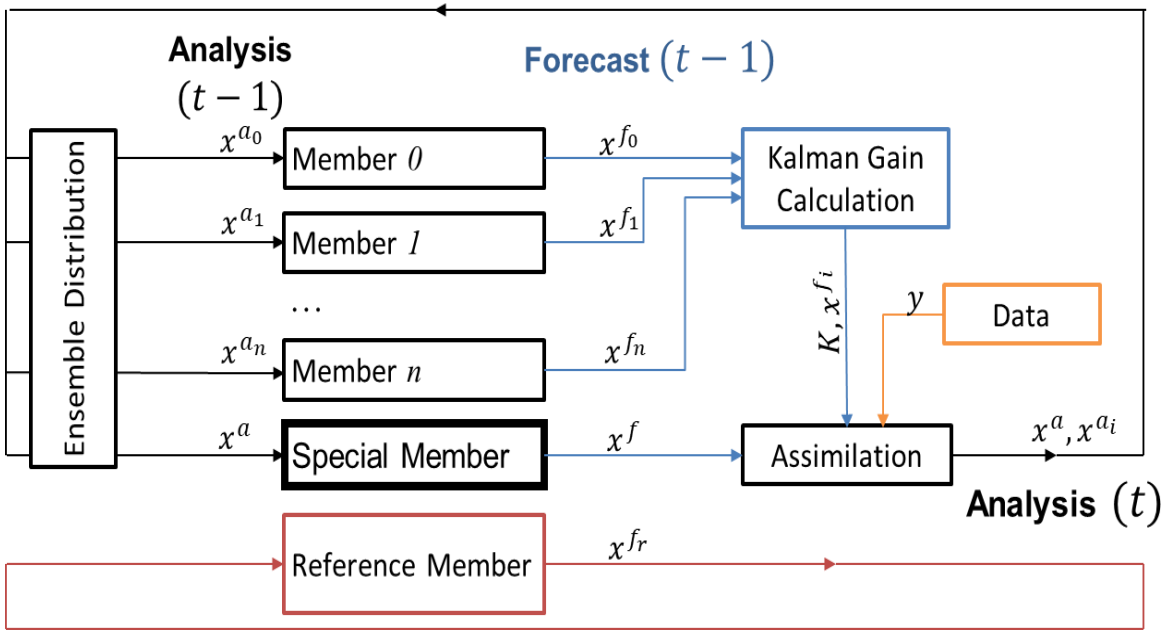
- **Thermosphere – Ionosphere** (TI) system response to **storm conditions**.
  - St. Patrick day storm 2015
- **Assimilate Thermospheric Mass Density** (TMD) into **physics – based model** CTIPe.
  - TMD derived from SWARM satellites normalized to 400 km
- Assimilating thermospheric parameters will improve the thermosphere, but **what happens in the ionosphere?**

Model: CTIPe model + TIDA data assimilation scheme

CTIPe



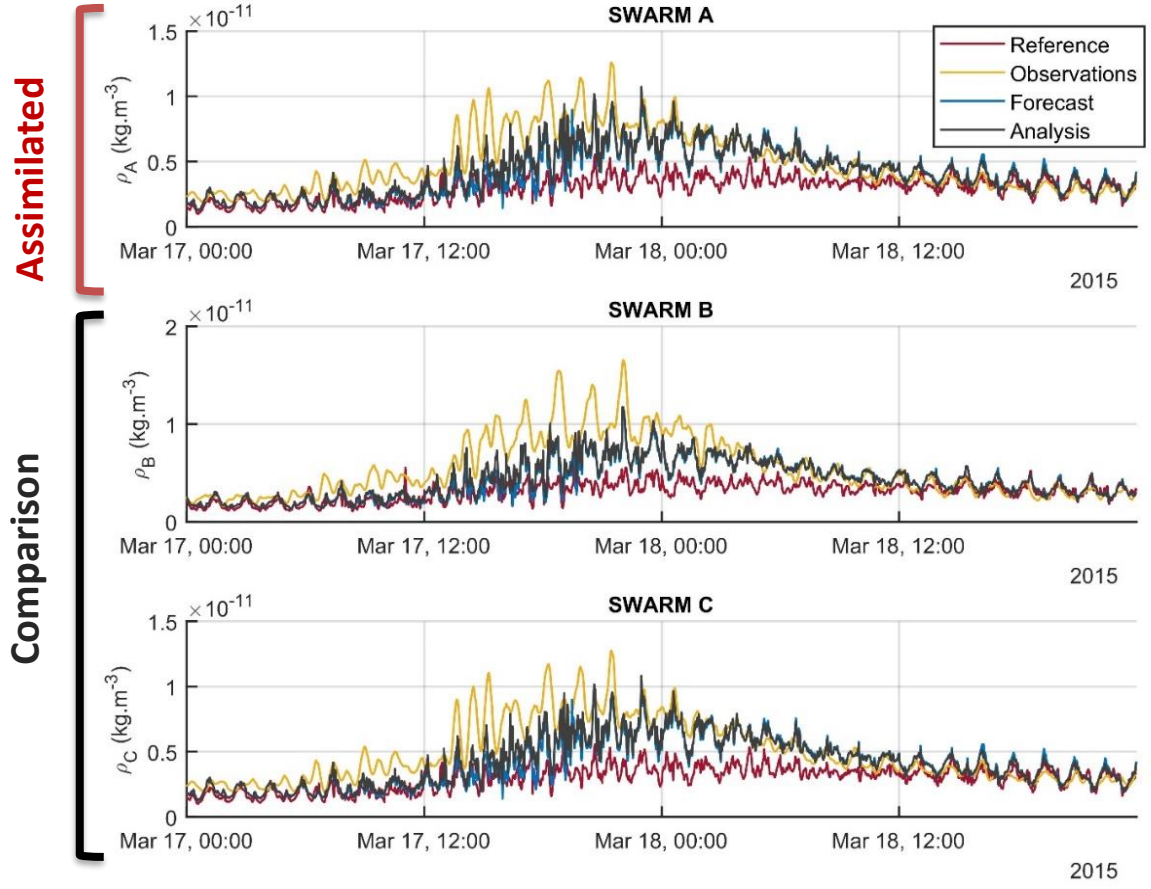
TIDA



State Vector $x = \begin{bmatrix} model\ forcing \\ model\ state \end{bmatrix}$ → $x^a = x^f + K(y - h(x^f))$, $y^f = h(x^f)$ **KF update equation**

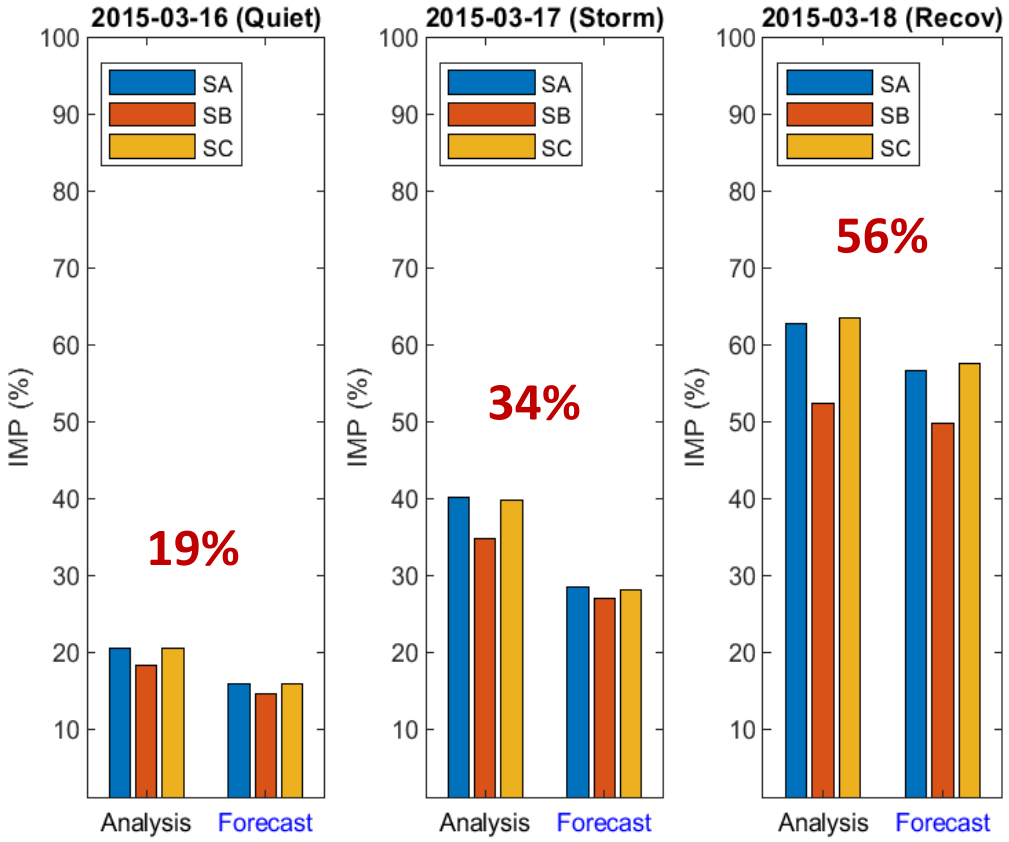
$$x = \{F_{10.7}, |v_{sw}|, \rho_{sw}, B_N, B_\theta, T_n, \gamma_O, \gamma_{O_2}, \gamma_{N_2}, M, U, V\}$$

Impact of TMD data assimilation in the **Thermosphere**



- In the experiment SwarmA-400km is assimilated, and compared to B and C satellites.
- TMD **observations** are compared to **reference**, **forecast** and **analysis** estimations, where:
  - **Reference** is the background model run with no assimilation
  - **Forecast** is the first guess or prior state estimate
  - **Analysis** is the estimation with all the observations
- Differences between **reference** and **analysis**/**forecast** are evident during the day of the storm and recovery phase.

Impact of TMD data assimilation in the **Thermosphere**



- We define **improvement** as:

$$\mathbf{IMP}(\%) = \frac{\mathrm{RMSE(ref)} - \mathrm{RMSE(analysis)}}{\mathrm{RMSE(ref)}} x\ 100$$

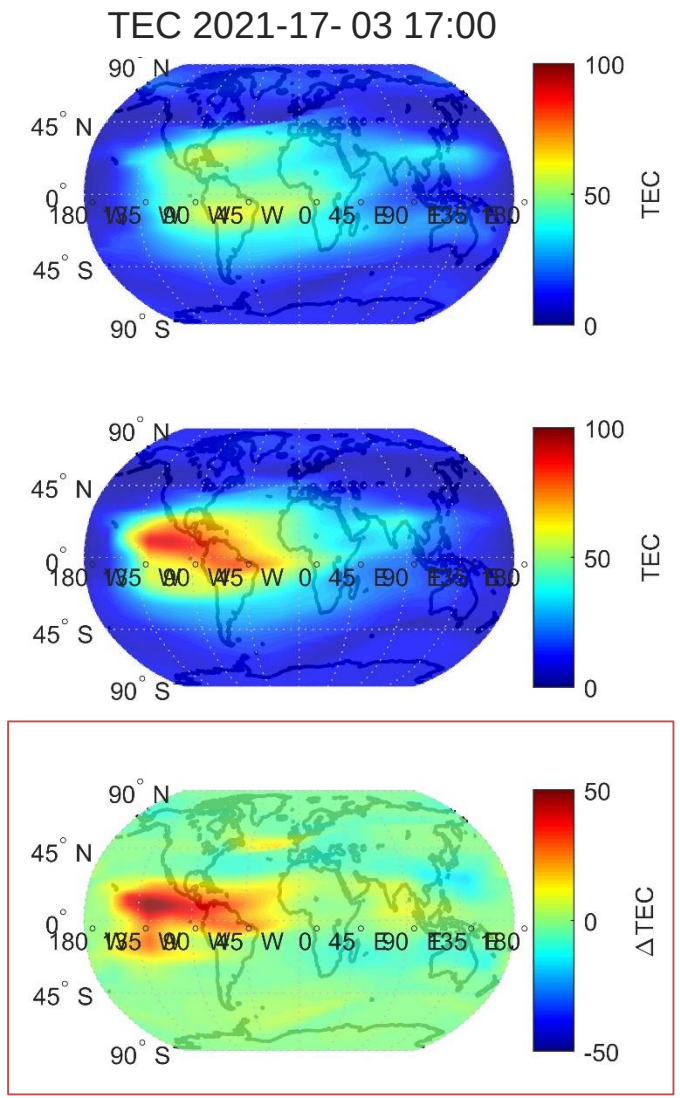
- Very similar results for SWARM A/C satellites
- Improvement increases from the quiet day to recovery day
- Averaged **TMD improvement of $\sim 40\%$** for analysis estimate and $\sim 32\%$ for the forecast.

Impact of TMD data assimilation in the **Ionosphere**

Reference

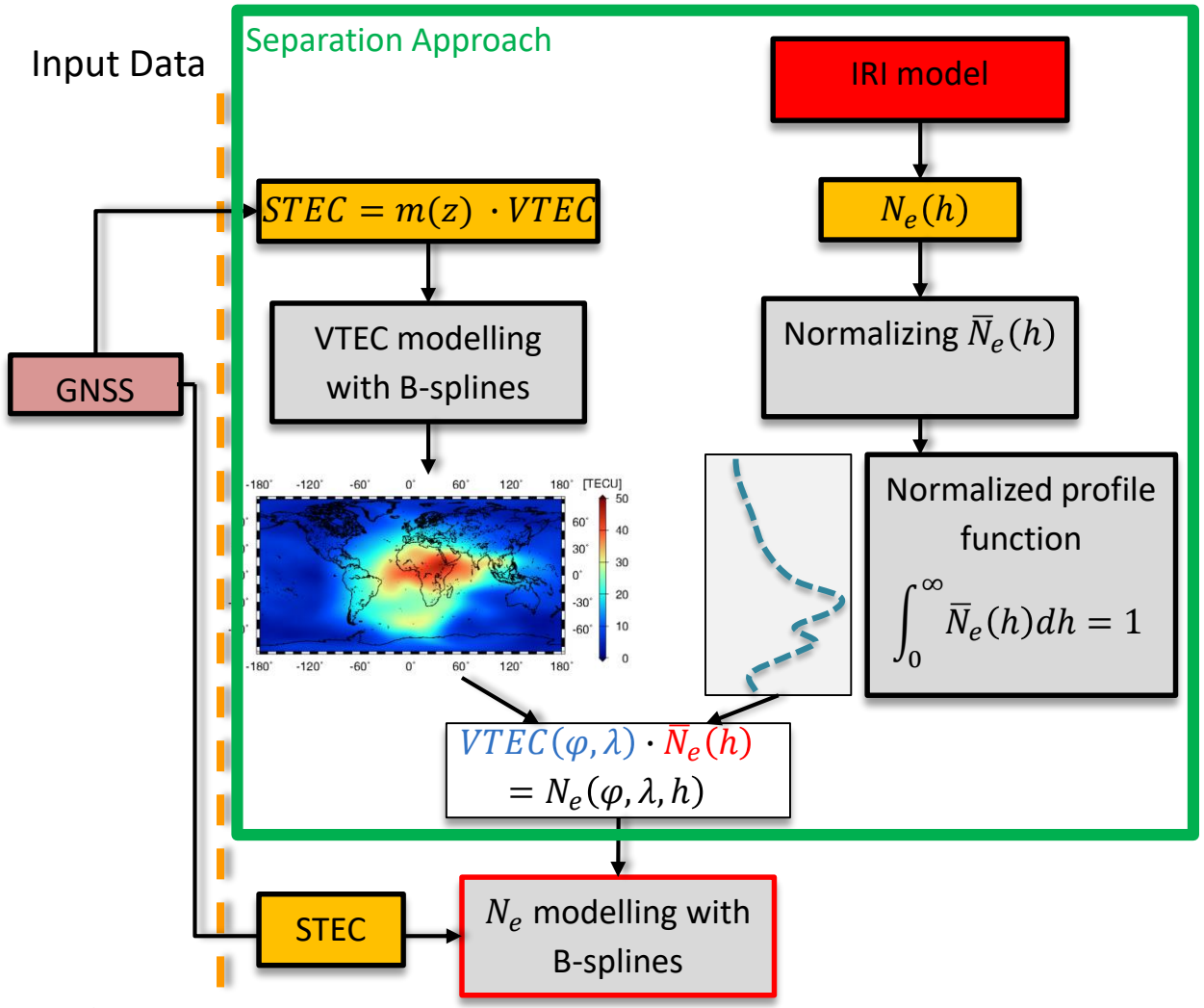
Analysis

Difference



- One of the parameters that define the ionosphere is the total electron content (TEC).
- TEC global maps during the main phase of the storm.
- Differences between reference run and analysis estimation TEC show the **impact of TMD DA in the ionosphere.**
- The biggest differences are found in the **equatorial region.**
- But are those **changes in the ionosphere an improvement**?

Impact of TMD data assimilation in the **Ionosphere**

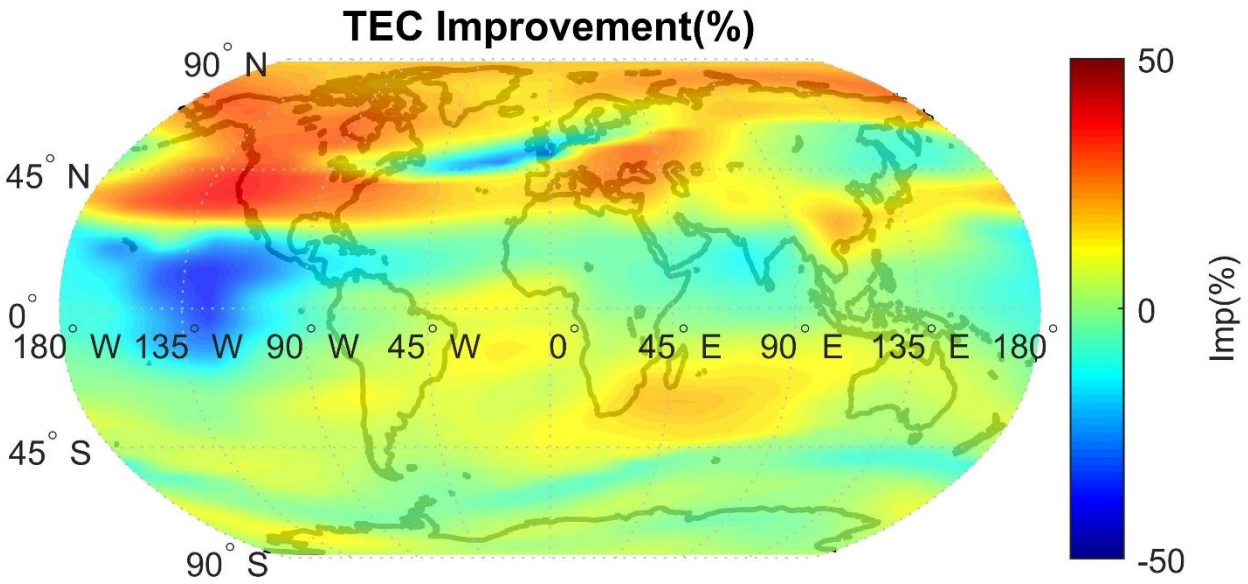


B-Spline Electron Density Model (DGFI-TUM):

- The **separation approach** provides the division of the three-dimensional function $N_e(\varphi,\lambda,h)$ into a horizontal $VTEC(\varphi,\lambda)$ and a vertical $\bar{N}_e(h)$ fraction at each position $P(\varphi,\lambda)$ on the Earth's surface.
- The $N_e(\varphi,\lambda,h)$ generated by means of the separation approach and additional observations from GNSS (GPS and GLONASS) have been used to estimate the Chapman parameters of the $\boldsymbol{F_2}$**-layer**.

- Provides high accuracy VTEC validated against independent data (GNSS, altimetry)
- **Used to evaluate the impact of the TMD data assimilation in the ionosphere**

Impact of TMD data assimilation in the **Ionosphere**



- We define **improvement** as:

$$\mathbf{IMP}(\%) = \frac{\mathrm{RMSE(ref)} - \mathrm{RMSE(analysis)}}{\mathrm{RMSE(ref)}} x\ 100$$

- TEC improvement global map
- North Hemisphere analysis estimate **TEC improvement of $\sim 40\%$**
- Areas of negative improvement

Summary

- Differences in thermospheric mass density and total electron content between the **reference** run and **analysis** estimates are an indicator of how the **Thermosphere - Ionosphere system is affected by the assimilation of thermospheric observations,** specially during storm conditions.

- Thermospheric mass density assimilation has a direct **impact on the thermosphere** with an **average improvement of a 40%** with respect to observations.

- The **effect on the Ionosphere** is mainly localize to the Northern Hemisphere, **improving the TEC estimation up to 40%.**

Thanks for your attention