Effects of Swarm neutral density assimilation in the ionospheric state estimate during St. Patrick's Day storm 2015

Isabel Fernandez-Gomez*, Timothy Kodikara, Claudia Borries, Michael Schmidt, Jacob Flurry and Anja Schlicht*

Institute for Solar – Terrestrial Physics
German Aerospace Center (DLR)

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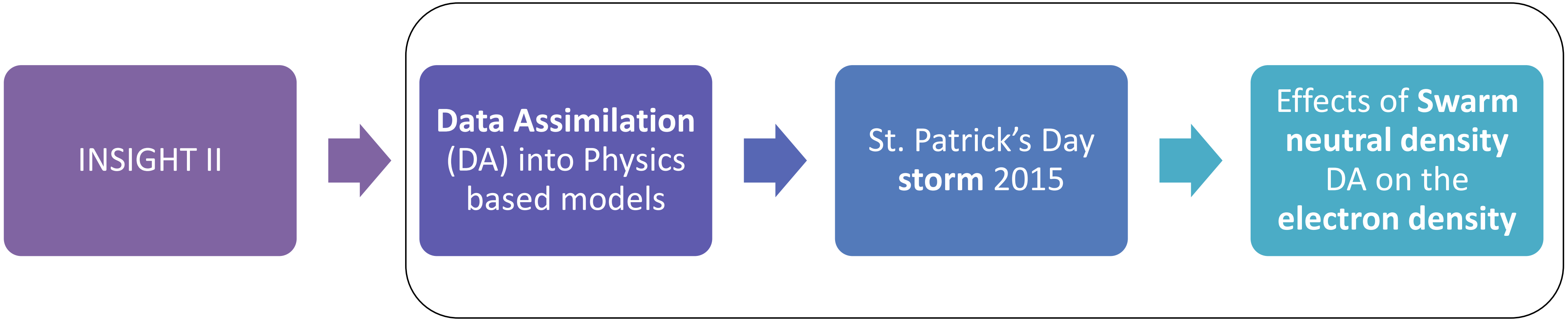
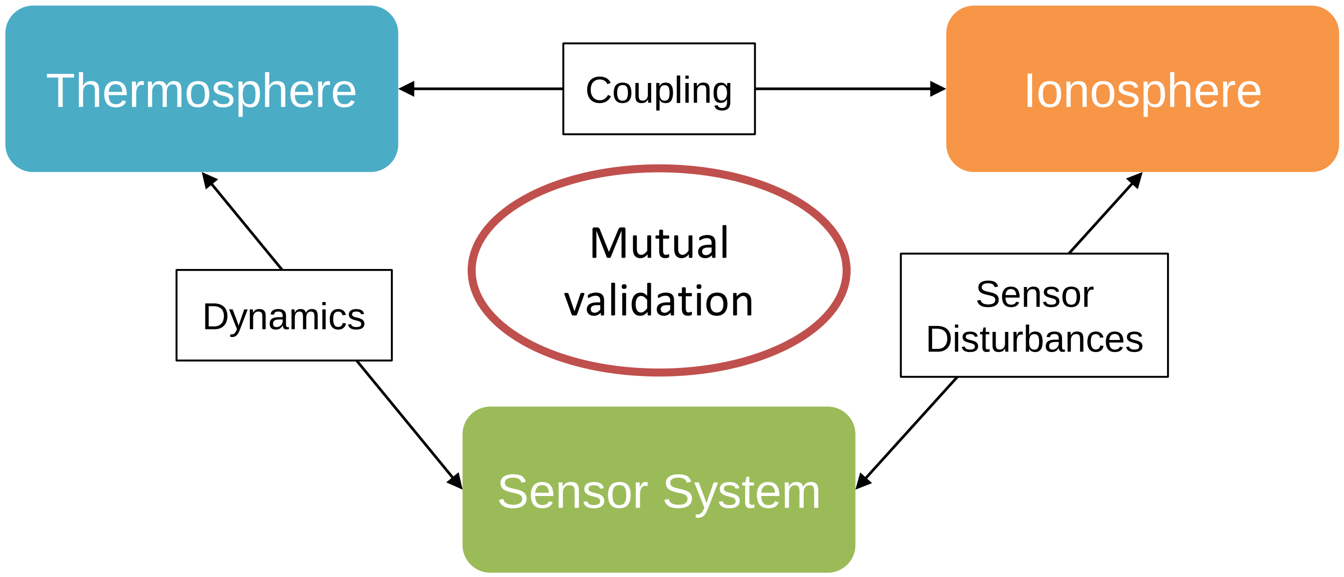
DLR TUM Leibniz Universität Hannover

Outline

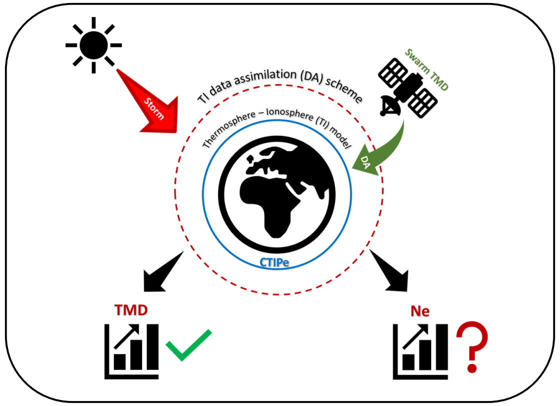

INSIGHT II
Data Assimilation (DA) into Physics based models
St. Patrick's Day storm 2015
Effects of Swarm neutral density DA on the electron density

INSIGHT II: Interactions of Low-orbiting Satellites with the Surrounding Ionosphere and Thermosphere



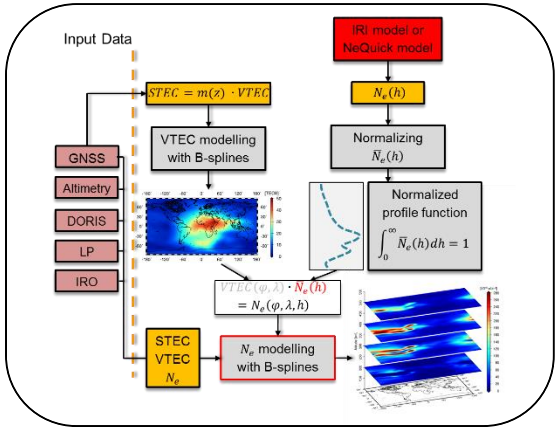
INSIGHT II

DA physics-based model and Storms



(DLR)

DA empirical model and Validation



Courtesy of M. Schmidt (DGFI-TUM)

Thermosphere ← Coupling → Ionosphere

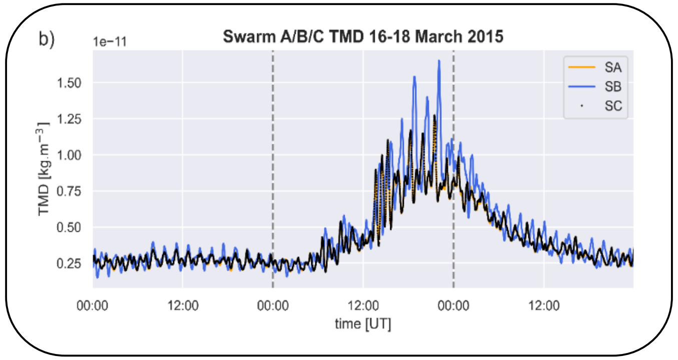
Mutual validation

Dynamics

Sensor Disturbances

Sensor System

Data evaluation and correction



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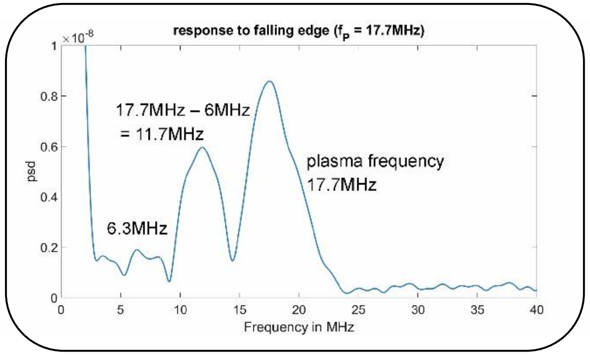
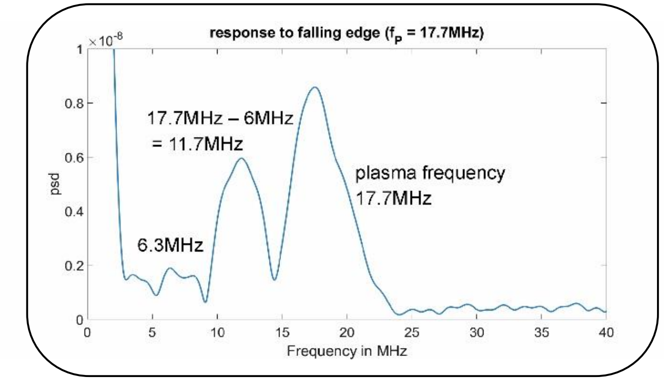
Sensor – Ionosphere Interaction



Courtesy of A. Schlicht (TUM)

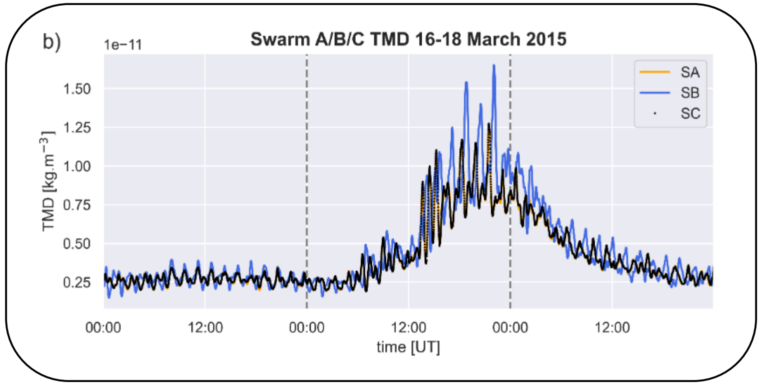
INSIGHT II

Sensor – Ionosphere Interaction



Courtesy of A. Schlicht (TUM)

Data evaluation and correction



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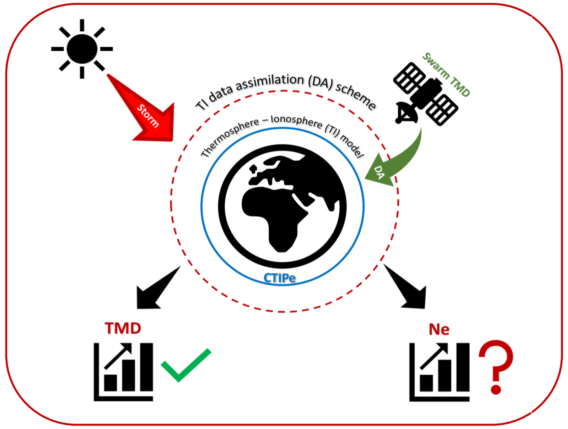
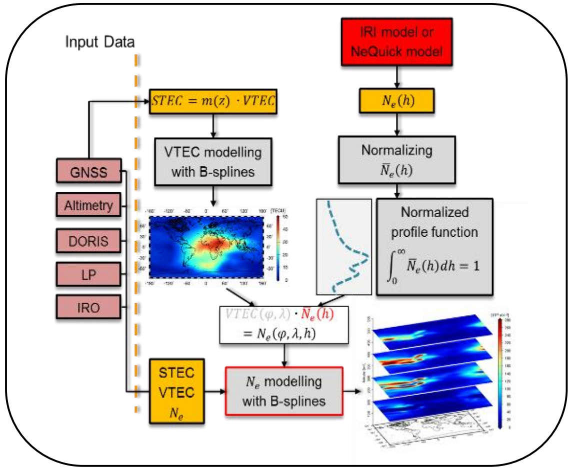
DA physics-based model and Storms



(DLR)

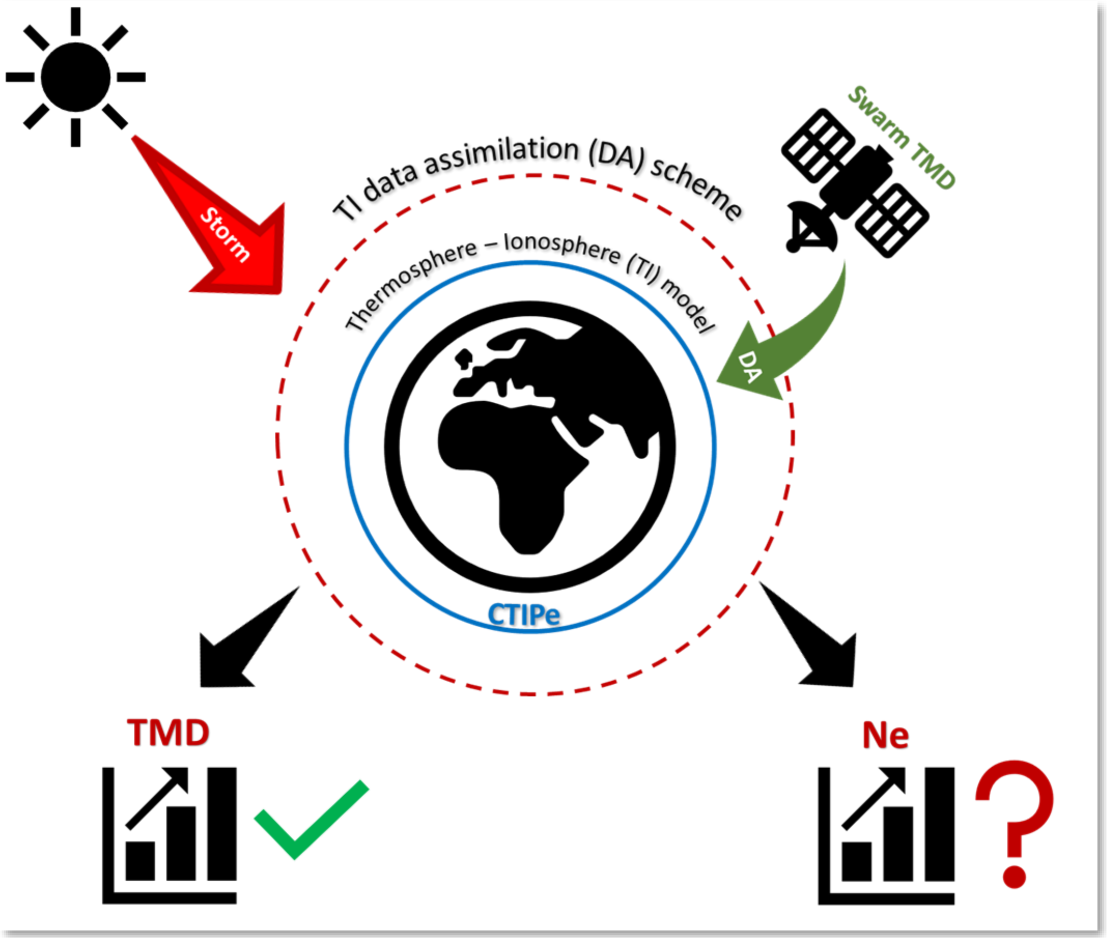
DA empirical model and Validation



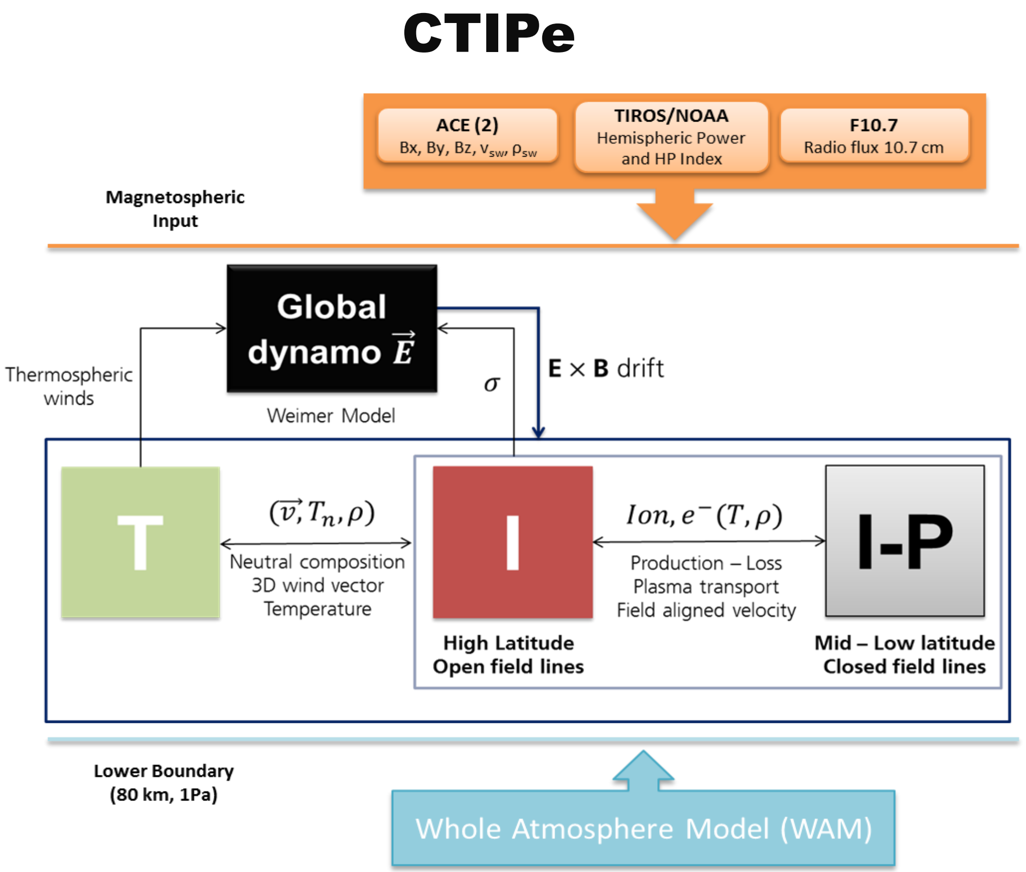
Courtesy of M. Schmidt (DGFI-TUM)

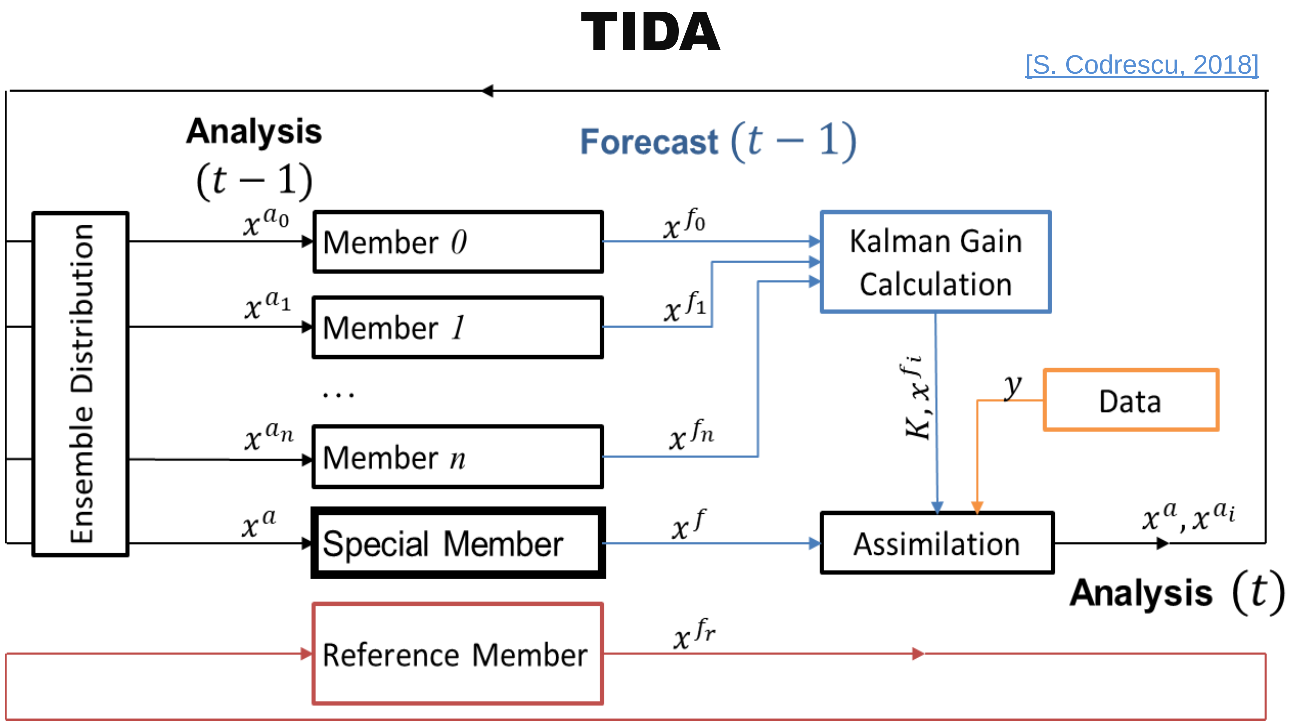
INSIGHT II: Swarm TMD data assimilation effect in electron density

- Can we improve **electron density** (Ne) by assimilating **thermospheric mass density** (TMD) during **geomagnetic storm conditions**?
  - St. Patrick's Day storm 2015
  - Assimilated Swarm TMD into CTIPe – TIDA
  - Evaluate the Thermosphere – Ionosphere effects



CTIPe – TIDA: Physics based model with neutral mass density DA





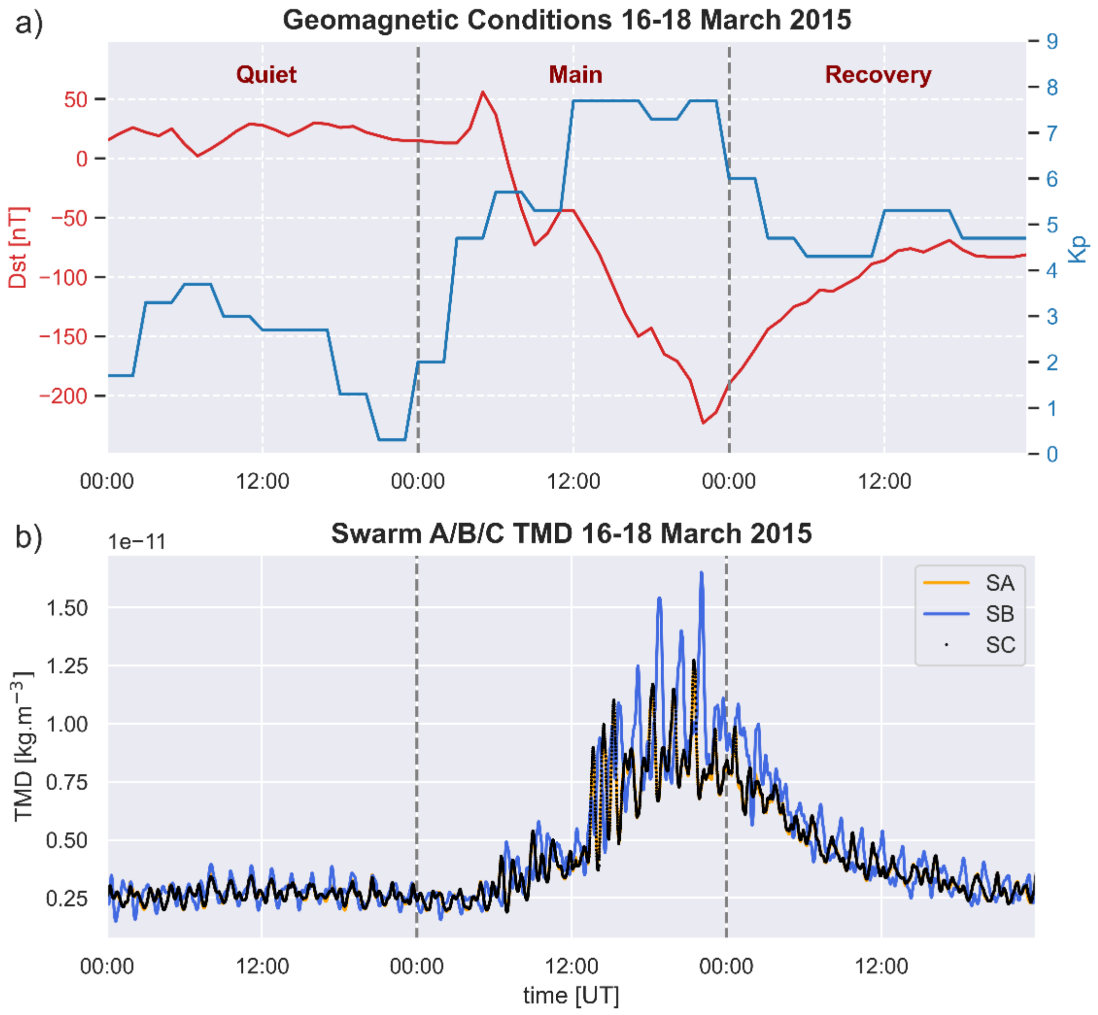
State Vector $x = \begin{bmatrix} model\ forcing \\ model\ state \end{bmatrix}$

$$x^a = x^f + K(y - h(x^f))$$
$$y^f = h(x^f)$$

KF update equation

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

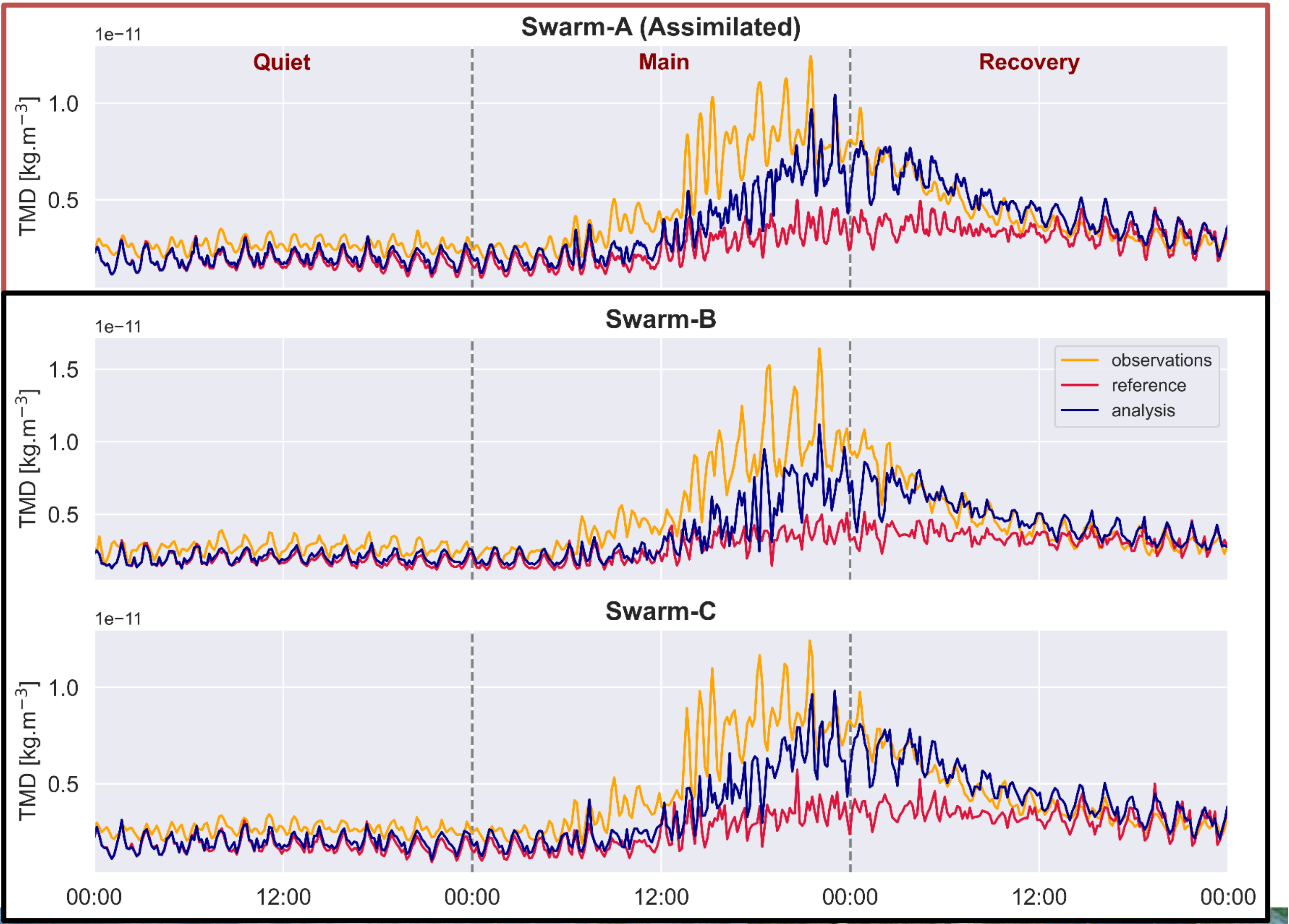
St. Patrick's Day storm 2015 and DA conditions



- **Period:** 16-19 March 2015 containing St. Patrick's Day storm
- Days are classified are quiet (16), main phase (17) and recovery (18)
- **TMD Data**: Swarm – A /B/C observations normalized to the common altitude of 400 km.
- **State vector**: Updates the forcing parameters and the necessary quantities to calculate neutral density.
- **Assimilation window**: 10 minutes
- TMD uncertainty is 10%

Swarm TMD assimilation into CTIPe – TIDA

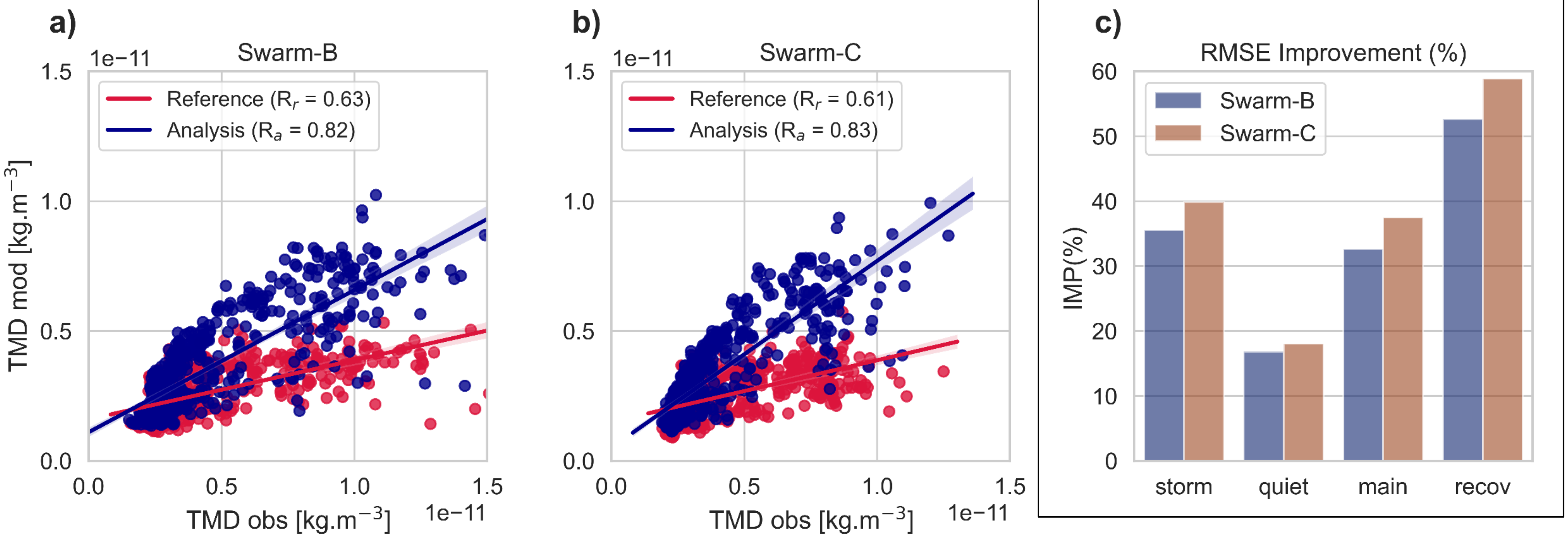
- **Assimilated data**: Swarm – A TMD observations normalized to the common altitude of 400 km.
- **Period:** 16-19 March 2015 containing St. Patrick's Day storm.
- Along the orbit neutral density
- **Observations**: Neutral density from Swarm A/B/C
- **Reference**: Background model results without assimilation
- **Analysis**: Assimilation estimate
- **Differences between Reference and Analysis** show the effect of data assimilation.



TMD DA impact on the Thermosphere

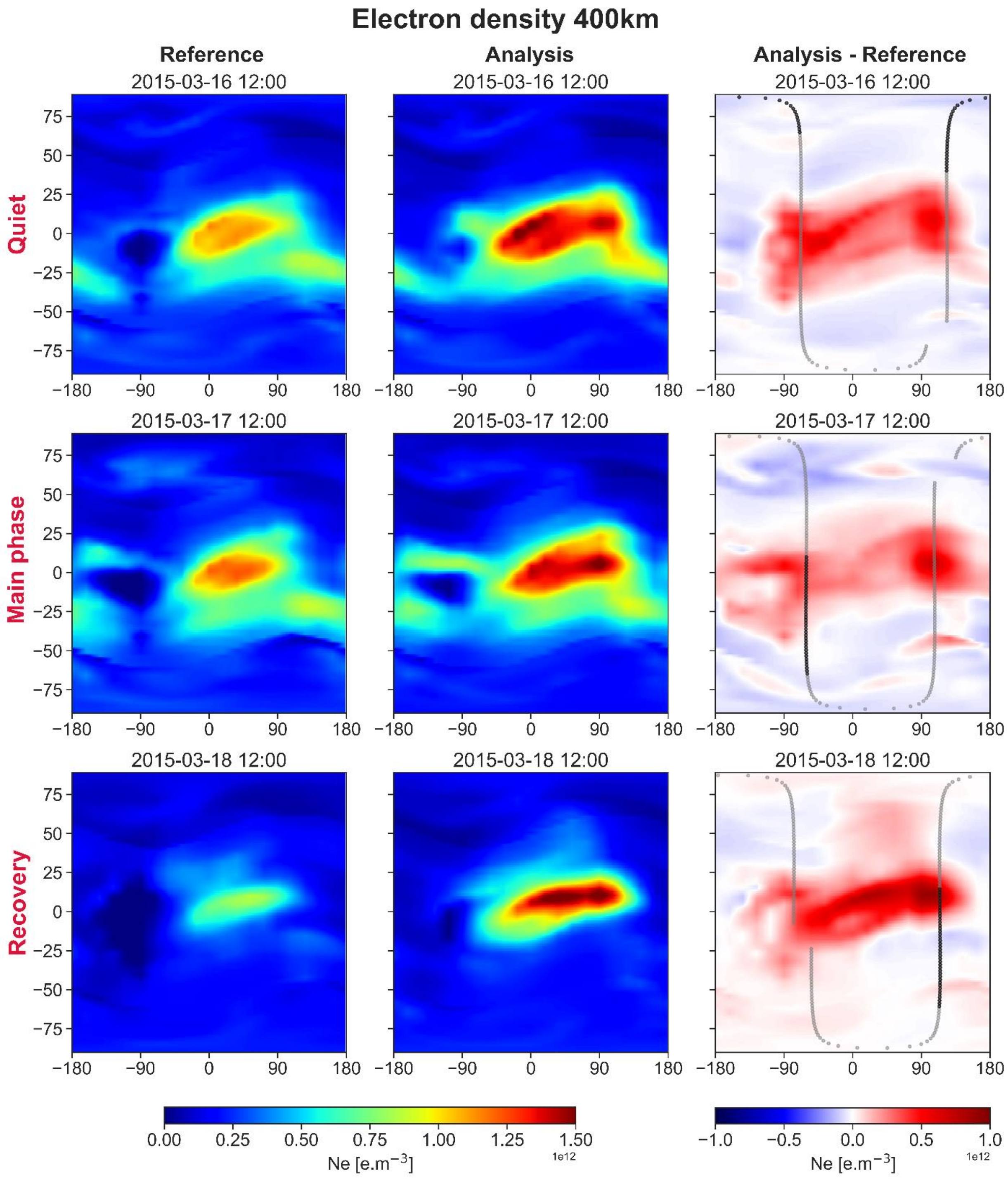
$$\mathrm{RMSE} = \sqrt{\frac{\sum(\mathrm{Obs} - \mathrm{Mod})^2}{\mathrm{N}}}$$

$$\mathrm{IMP}(\%) = \frac{(\mathrm{RMSE}_r - \mathrm{RMSE}_a)}{\mathrm{RMSE}_r} 100$$



TMD DA impact on the Ionosphere

- **Electron density** maps at 400 km altitude
- Reference, analysis and difference
- Quiet day, main and recovery phases at 12:00 UT
- Location of Swarm orbit is represented in the difference plot (grey line)
- Highlighted area of the last two assimilation intervals before 12:00 UT
- The **difference between analysis and reference** shows the **effect of TMD DA in electron density**
- The effect in altitude extends from 200 km to 800 km



TMD DA impact on the Ionosphere: B-Spline Electron density model

$$\text{RMSE} = \sqrt{\frac{\sum(\text{Obs} - \text{Mod})^2}{\text{N}}}$$

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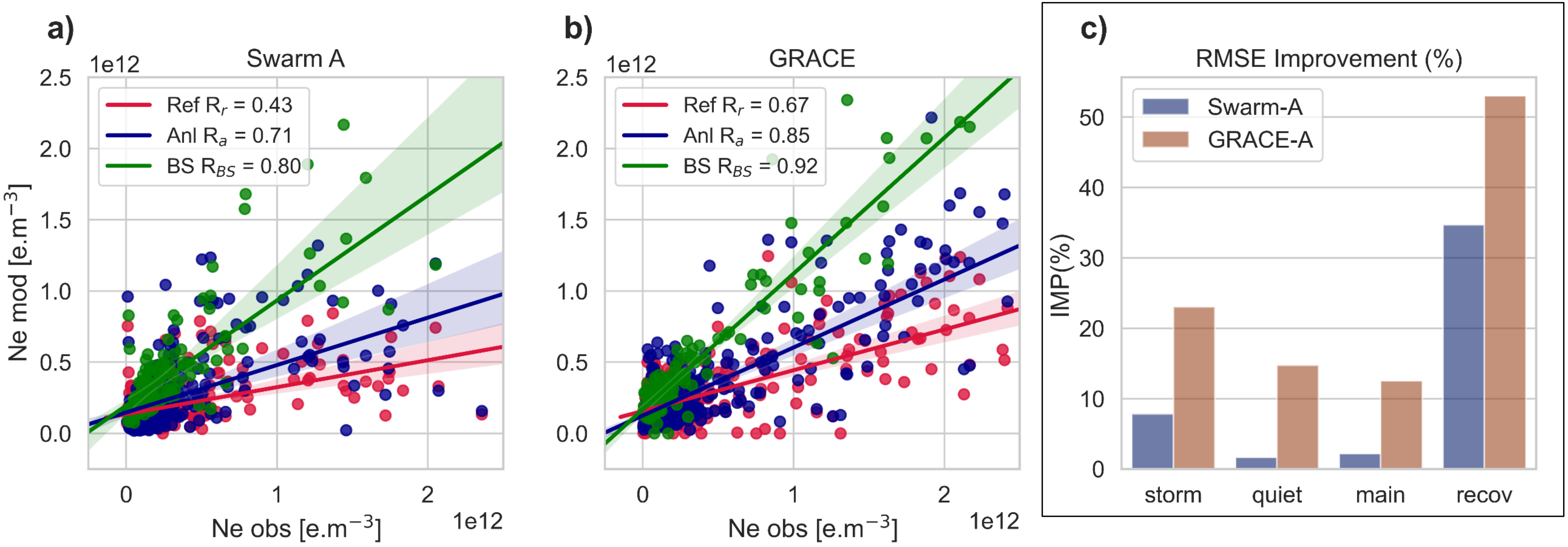
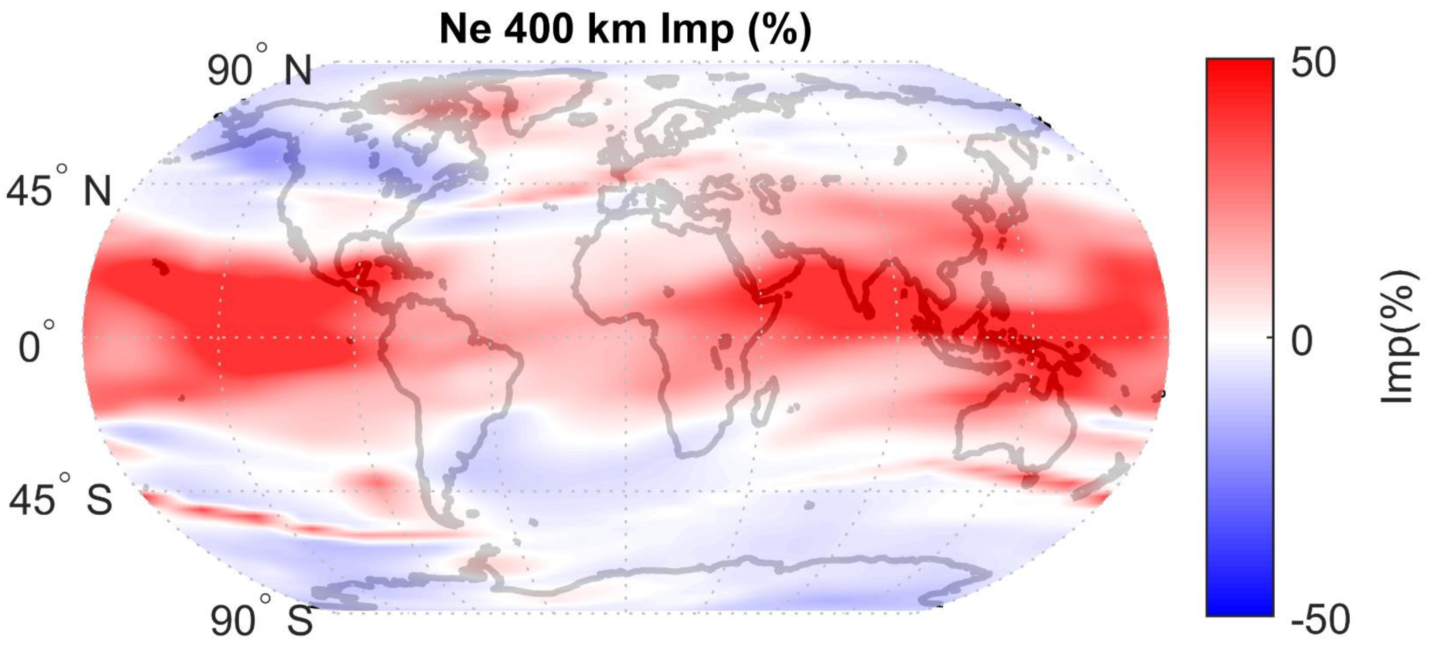


TMD DA effect on the Ionosphere: B-Spline Electron density model

- **Electron density global improvement at 400 km** between analysis and reference with respect to the B-Spline electron density model
- For the three days of the storm
- Lower RMSE → Better fit of the model to observations
- Improvement (%) of RMSE of the analysis and reference differences.
- **Positive values** are areas of improvement
- The **main area of improvement (red) is around the equatorial region** (-45, 45) deg latitude.
- In altitude the improvement extends from 200 km up to 600 km.

$$\mathrm{IMP}(\%) = \frac{(\mathrm{RMSE}_r - \mathrm{RMSE}_a)}{\mathrm{RMSE}_r} 100$$



Summary

- **Insight II** project goes from the study of the **sensors – ionosphere interactions**, going through **data evaluation and correction**, the **assimilation of that data** into physics-based models and **validation** of those results with other models and sources of data.

- **Assimilation of neutral density** measurements into a physics-based model **during storm conditions** in capable of **correcting the thermosphere and the ionosphere** (with limitations).
  - Neutral density improves along the orbit of the non assimilated Swarm – B/C satellites up to 40%
  - Electron density difference maps (analysis – reference) show the effects of TMD DA
  - Electron density improvement along the orbit of Swarm-A and GRACE are 8% and 22% respectively.
  - The **global electron density improvement** map shows the areas affected by TMD assimilation.
  - The **largest improvement in the electron density** estimates takes place during the **recovery phase** (negative storm driven by composition changes).

Dynamic Earth Special Issue (in revision)
"Improving estimates of the ionosphere during geomagnetic storm conditions through assimilation of thermospheric mass density"
I. Fernandez-Gomez, T. Kodikara, C. Borries, E. Forootan, A. Goss, M. Schmidt and M. Codrescu
https://doi.org/10.21203/rs.3.rs-1342228/v1

Thanks for you attention!