# Sequential Calibration and Data Assimilation for predicting atmospheric variability

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Introduction

Source: https://geomag.bgs.ac.uk/
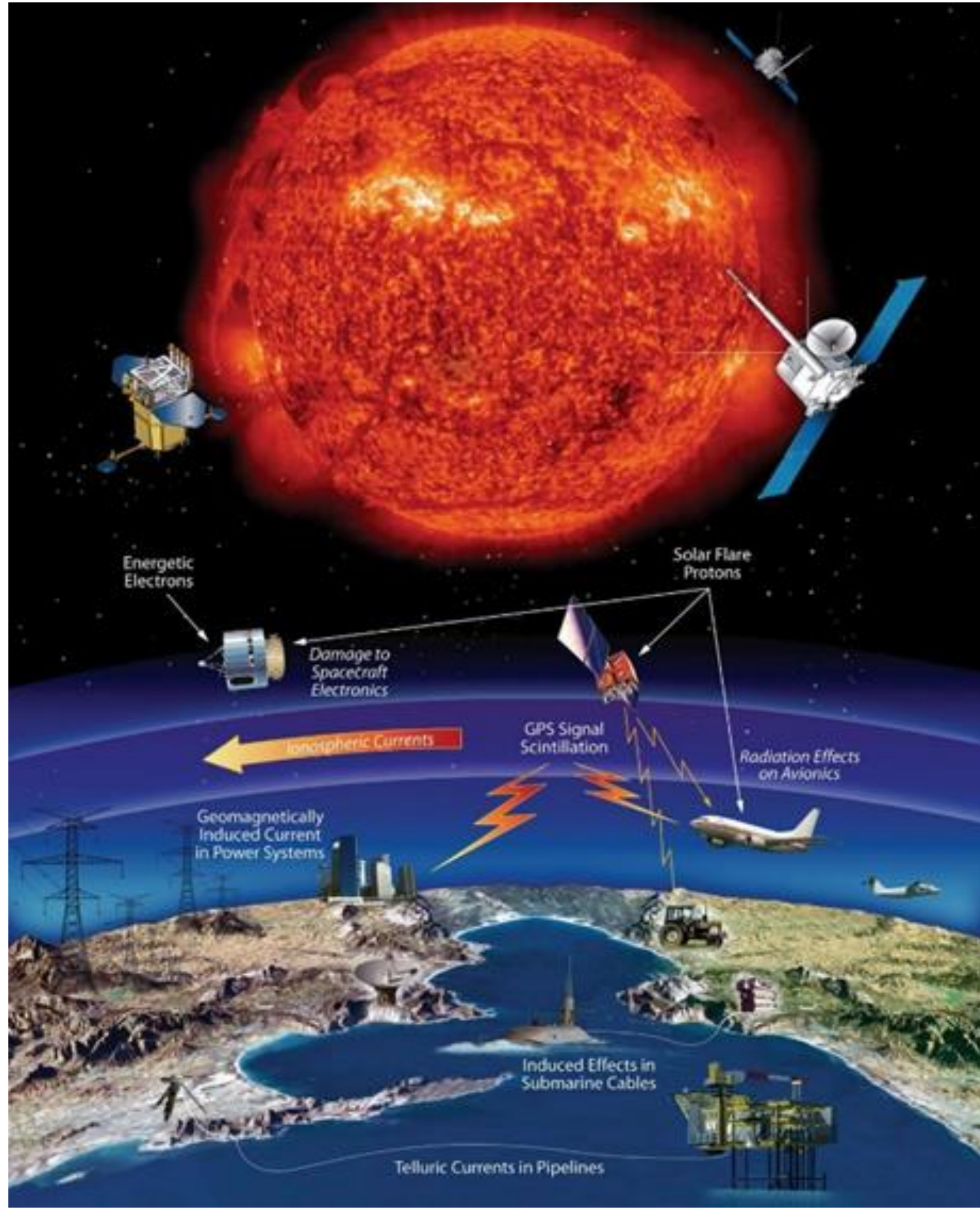
Mind the gap in atmosphere!
Promoting TEC/Ne and Thermosphere Neutral Density as Essential Geodetic Variables through the GGOS and IAG
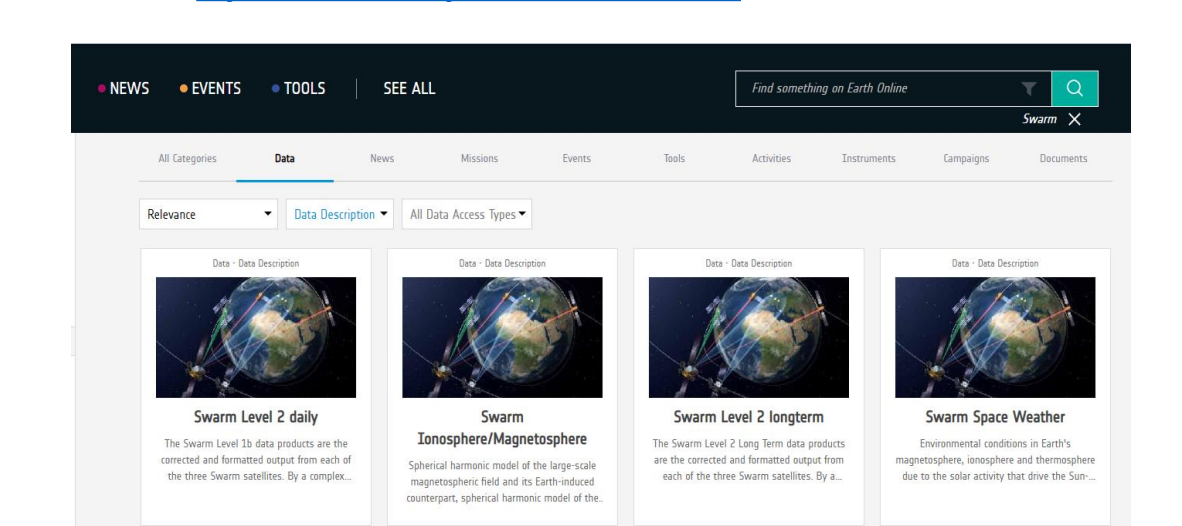Spatial / Temporal resolution?
Coverage? Latency?

Data & Model

Space-borne Thermosphere Neutral Density (TND)
Total Electron Content and Density
NRLMSISE-00
IRI
TIE-GCM

All freely available on our FTP server. You might need a FTP client to open the link (user anonymous, any password is accepted).
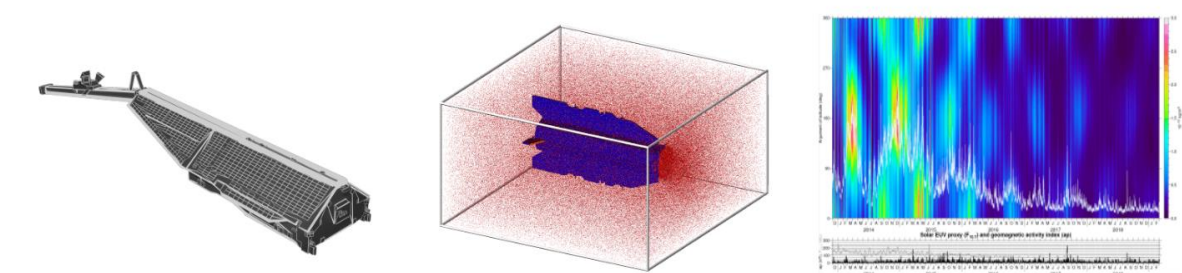
Geometry models
High-fidelity geometry models for the CHAMP, GRACE, GOCE and Swarm satellites are freely available under Creative Commons licence (CC BY-NC-SA).
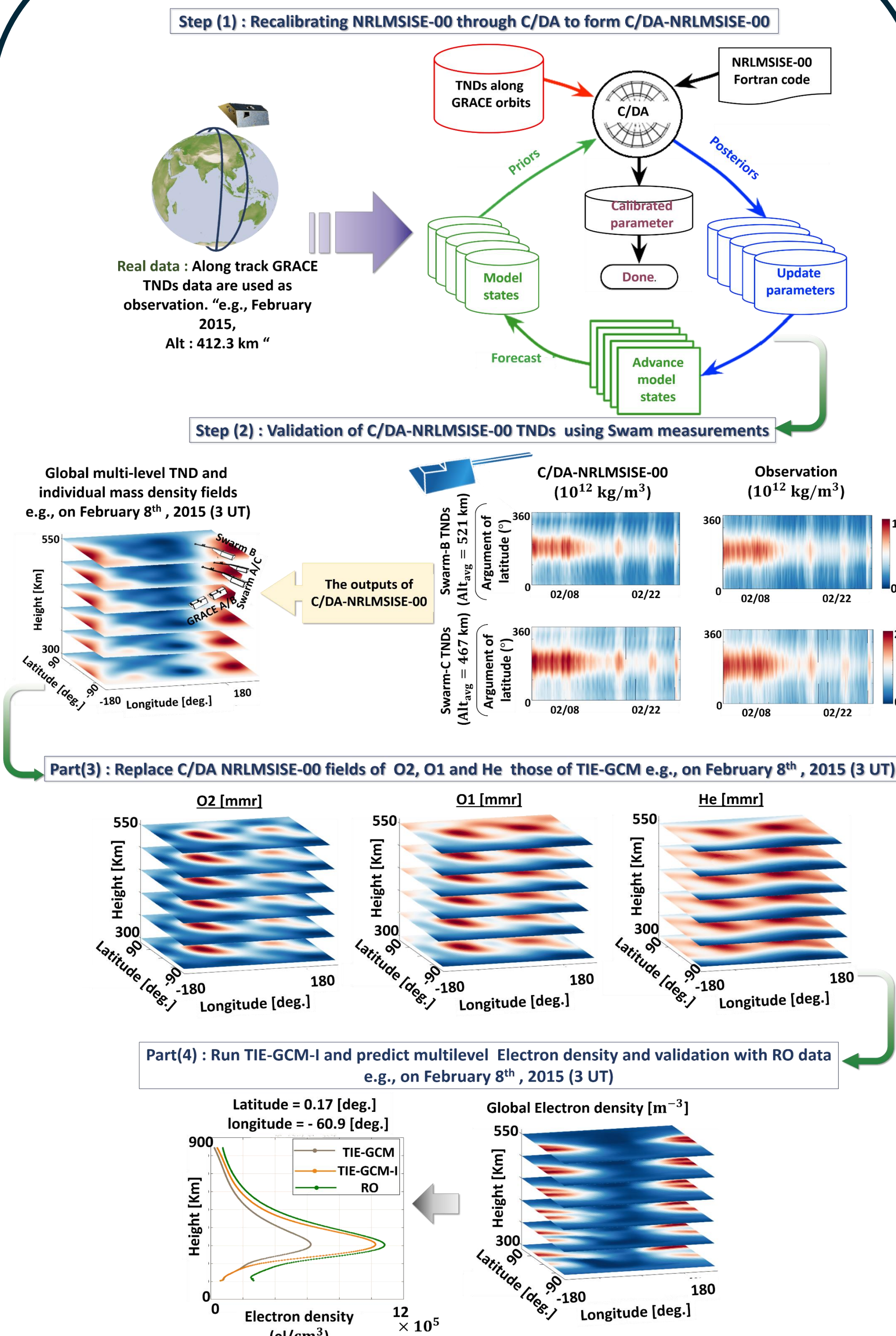
Aerodynamic models
Aerodynamic models generated by the SPARTA direct simulation Monte Carlo simulator.

Density and wind data
Density and wind data are freely available for the CHAMP, GRACE, GOCE and Swarm satellites.

ftp://thermosphere.tudelft.nl/

https://swarm-diss.eo.esa.int/

PANGAEA.
Data Publisher for Earth & Environmental Science

Vielberg, Kristin; Lück, Christina; Corbin, Armin; Forootan, Ehsan; Löcher, Anno; Kusche, Jürgen (2021): and Swarm. PANGAEA, https://doi.org/10.1594/PANGAEA.931347

$$N_e(\lambda, \varphi, h) = \sum_{k=1}^{K} \sum_{n=1}^{N} d_{n,k}\, g_n(\lambda, \varphi) Z_k(\lambda, \varphi, h)$$

N_e is the 3-D electron density,

g_n represents Slepian base functions

Z_k contains height-dependent functions

$d_{n,k}$ unknown coefficients to be estimated

(Simons et al., 2006)

Farzaneh and Forootan, 2018, Reconstructing regional ionospheric electron density: a combined spherical Slepian function and empirical orthogonal function approach. Surveys in Geophysics, doi:10.1007/s10712-017-9446-y
Farzaneh and Forootan, 2020, A least squares solution to regionalize VTEC estimates for positioning applications. Remote Sensing, doi:10.3390/rs12213545

Method

Step (1): Recalibrating NRLMSISE-00 through C/DA to form C/DA-NRLMSISE-00

Real data : Along track GRACE TNDs data are used as observation. "e.g., February 2015, Alt : 412.3 km "

Step (2): Validation of C/DA-NRLMSISE-00 TNDs using Swarm measurements

Global multi-level TND and individual mass density fields e.g., on February 8th , 2015 (3 UT)

The outputs of C/DA-NRLMSISE-00

Part(3): Replace C/DA NRLMSISE-00 fields of O2, O1 and He those of TIE-GCM e.g., on February 8th , 2015 (3 UT)

Part(4): Run TIE-GCM-I and predict multilevel Electron density and validation with RO data e.g., on February 8th , 2015 (3 UT)


Setup of C/DA
- Method: Ensemble Kalman Filter (EnKF).
- The ensemble size 30-90
- The assimilation window size is 0.5 - 3 hours.
- Experiment Dates: difference atmospheric activity
- Assimilated observations: CHAMP, GRACE, Swarm A-B-C TNDs, GNSS TEC, etc.
- Validations: Radio occultation, In-situ GNSS, positioning applications, etc.

CDA
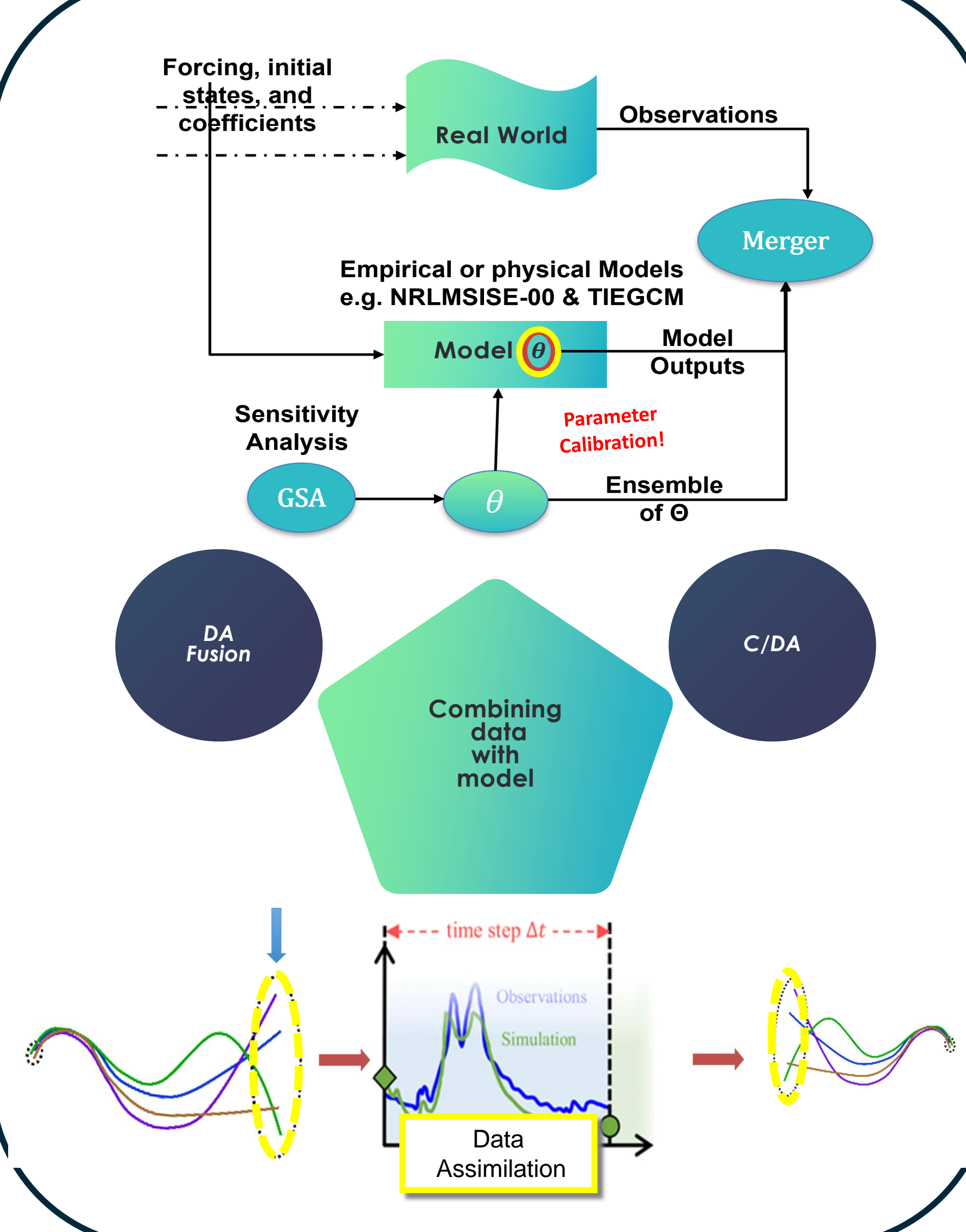
Results

Forecasting of C/DA-NRLMSISE-00 TNDs along the Daily Tracks Swarm: Higher spatial correlation of 98.25, 97.53, and 98.25% are found between the TNDs from C/DA-NRLMSISE-00 and observed values along Swarm-A, Swarm-B, and Swarm-C orbits.
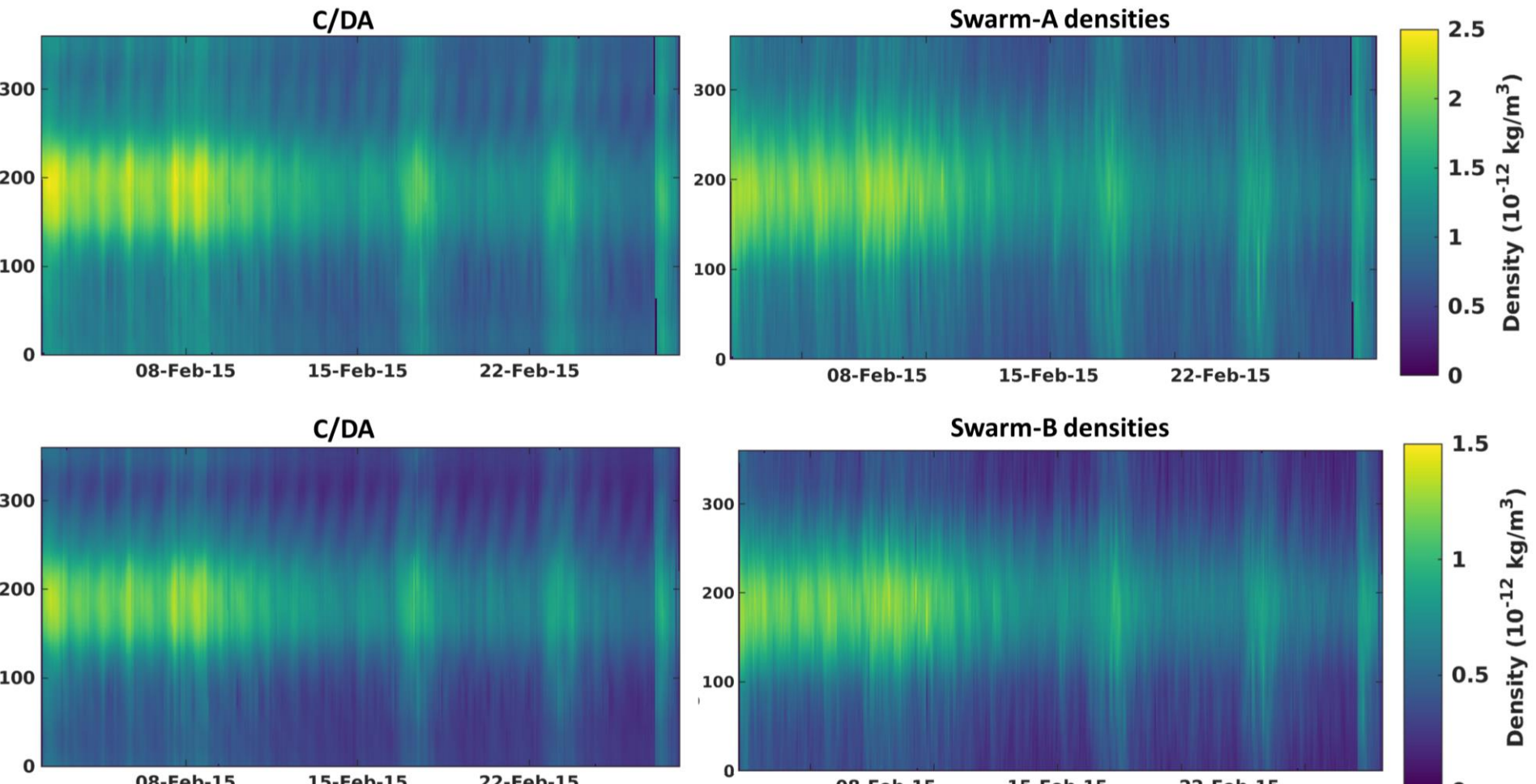

Multi-level Variations of the global TND: C/DA NRLMSISE-00 can be used to simulate neutral mass densities in other altitudes and locations.
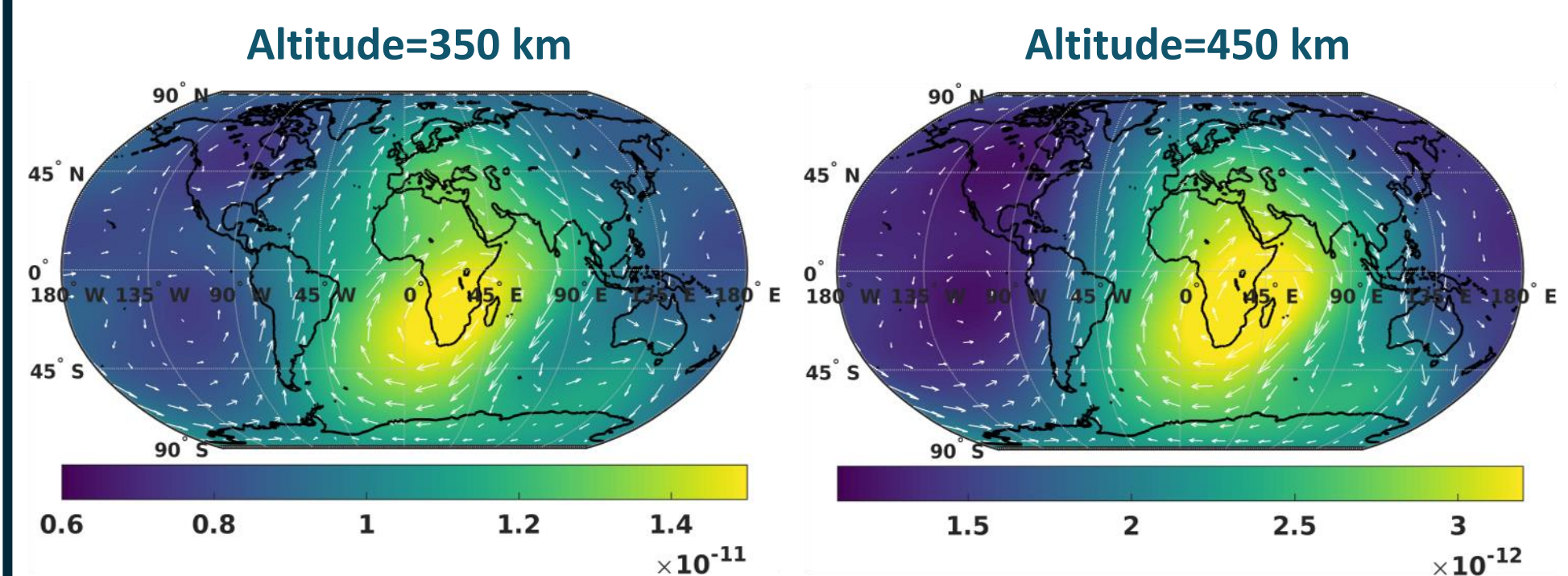
Spatial and Temporal Impacts of C/DA through the PCA: The Principal Component Analysis (PCA) method is applied on the hourly differences between the original and C/DA model during February 2015. PC1 is found to be correlated with the solar activity index with the correlation coefficient of 50.04%.
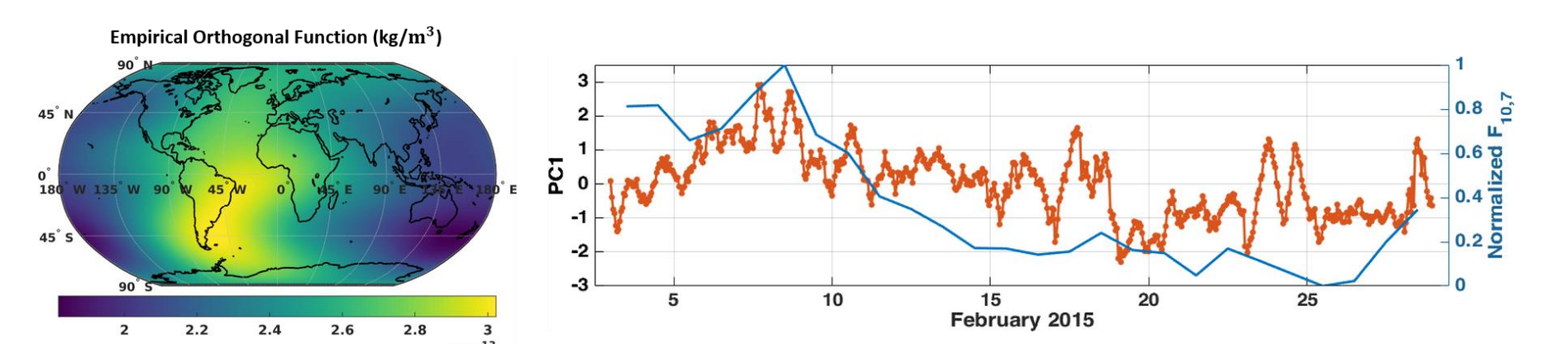
Forecasting Ionospheric Parameters: The TIE-GCM-I reduces the RMSE between the electron density forecasts and RO observations within the range of 0.2-90.6% (on average 30.92%).
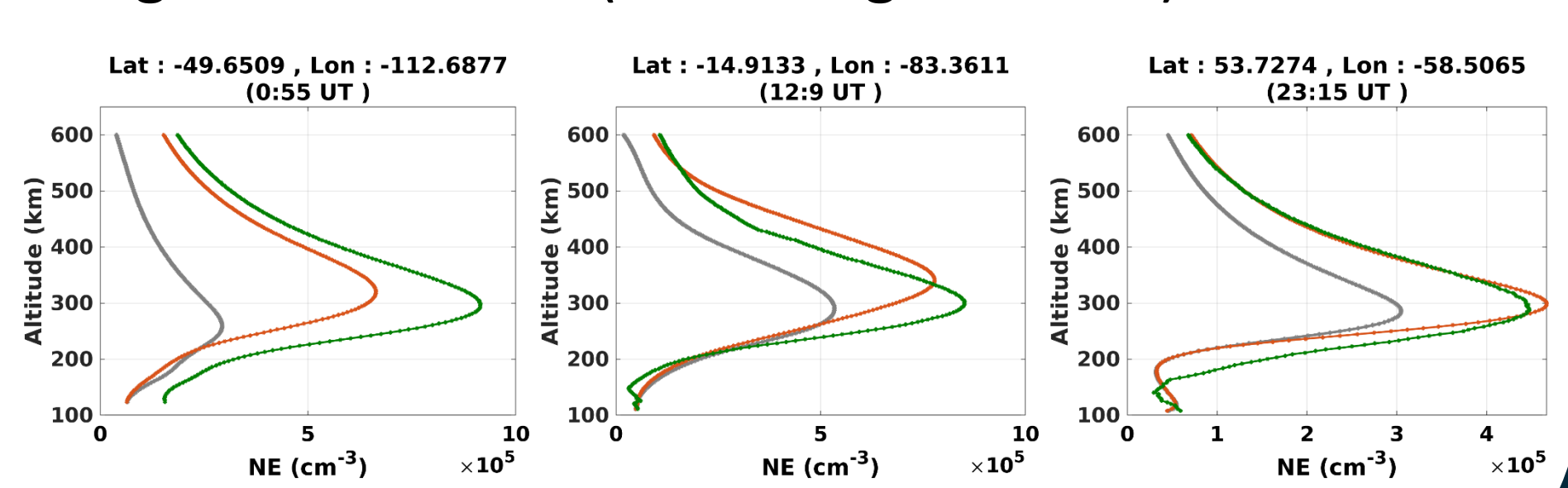
Reference

➢ Forootan, E., Farzaneh, S., Kosary, M., Schmidt, M., Schumacher, M. (2021). A simultaneous calibration and data assimilation (C/DA) to improve NRLMSISE00 using thermospheric neutral density (TND) from space-borne accelerometer measurements. Geophysical Journal International, 224(2), 1096-1115. doi: 10.1093/gji/ggaa507

➢ Forootan, E., Kosary, M., Farzaneh, S. et al. (2022). Forecasting global and multi-level thermospheric neutral density and ionospheric electron content by tuning models against satellite-based accelerometer measurements. Sci Rep 12, 2095. doi:10.1038/s41598-022-05952-y.

➢ Kosary, M., Forootan, E., Farzaneh, S. Schumacher, M. (2022). A sequential calibration approach based on the ensemble Kalman filter (C-EnKF) for forecasting total electron content (TEC). J Geod 96, 29. doi:10.1007/s00190-022-01623-y.

➢ Forootan, E., Farzaneh, S. Kosary, M. et al. (2023). Predicting global thermospheric neutral density during periods with high geomagnetic activity. Sci Rep 13, 20322 (2023). https://doi.org/10.1038/s41598-023-47440-x

➢ Forootan, E., Kosary, M., Farzaneh, S., Schumacher, M. (2023). Empirical data assimilation for merging Total Electron Content data with empirical and physical models. Surv Geophys 44, 2011–2041 (2023). https://doi.org/10.1007/s10712-023-09788-7

➢ Kosary, M., Farzaneh, S., Schumacher, M., Forootan, E. (2024). Assimilating space-based Thermospheric Neutral Density (TND) data into the TIE-GCM coupled model during periods with low and high solar activity. Space Weather,22, e2023SW003811. https://doi.org/10.1029/2023SW003811

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