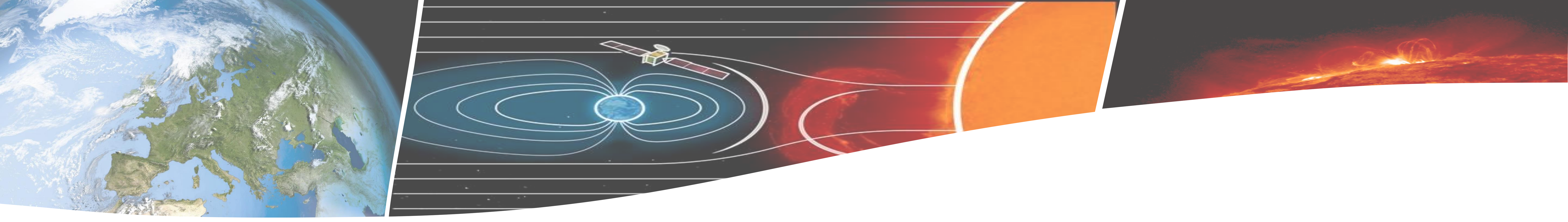

Ionospheric model validation using COSMIC 2 - Preliminary results

Joana Morgado Pereira (joana.piresmorgadofernandespereira@dlr.de), Claudia Borries (claudia.borries@dlr.de), Frank Heymann (Frank.Heymann@dlr.de), Isabel Fernandez Gomez (Isabel.FernandezGomez@dlr.de) (1), Michael Schmidt (mg.schmidt@tum.de) (2).

1 - Institute of Solar-Terrestrial Physics, German Aerospace Center, Neustrelitz, Germany.

2 - Deutsches Geodätisches Forschungsinstitut (DGFI-TUM), TUM School of Engineering and Design, Technical University of Munich, Munich, Germany.

Introduction

Space weather events (SWE) that result in geomagnetic storms influence electromagnetic wave propagation in the Earth's ionosphere and atmosphere, affecting communications, navigation, and positioning. Forecasting the state of the upper atmosphere and conditions following SWE is one of the key aspects to protect the current high technological society. However, accurately representing the thermosphere-ionosphere (TI) system is challenging due to its complex interactions with the lower atmosphere and the magnetosphere that are challenging to correctly represent. SWE events have often been poorly observed which can lead to uncertain conclusions about these phenomena. TI modeling is essential for understanding the complex coupling interactions between thermosphere and ionosphere to predict and mitigate SWE effects and their impacts. Model validation is crucial to assess the capabilities of these models and to develop new modelling techniques. It assesses the performance of the models and identifies errors which can be caused by factors such as the solar cycle, daily or seasonal variability and other biases. So far, there is no standard set of validation tools or reference datasets that can be used in the TI domain. In this work Ionospheric radio occultation data (electron density) from the COSMIC2 mission serves as the basis for validating two models, (1) the International Reference Ionosphere (IRI) and (2) the Thermosphere-Ionosphere Electrodynamics General Circulation Model (TIEGCM). A set of verification and statistical methods is applied to evaluate these models under geomagnetically quiet conditions. The outcome of this study is an initial model validation framework that employs different statistics and metrics, allowing the comparison of model performances.

Data/Methods

- **Observations: Ionospheric Radio Occultation (IRO) Electron density (Ne)**

COSMIC-2 produces 5,000 vertical profiles per day (see Fig. 1.)
ref : https://www.cosmic.ucar.edu/what-we-do/cosmic-2/data
The data used for this work are the Ne Profiles obtained by inversion of calibrated TEC data, assuming spherical symmetry of the atmosphere. This causes significant errors below the F layer (such as large negative values of Ne). For this reason, profiles containing negative values and outliers were removed.*

- **Used empirical and physical models**
  - International Reference Ionosphere (IRI) - Empirical, ref : https://github.com/space-physics/iri2016
  - Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM) - Physics based, ref : https://www.wdc-climate.de/ui/entry?acronym=OTHITACS_tiegcm_2020
- **Datasets:**
  - four sets during 72 quiet hours that correspond to the equinoxes and solstices of 2020: 20-22 of March, 20-22 of June, 22 to 24 of September and 21 to 23 of December.
- **Validation metrics:**
  - Correlation (scatter) plot and correlation coefficient
  - Root mean square error (RMSE)
  - NmF2 and hmF2 from the data and the model
  - NmF2 model to data differences (deviations), ΔNmF2 = NmF2(model)-NmF2(data)
  - hmF2 model to data differences (deviations), ΔhmF2 = hmF2(model)-hmF2(data)

*Out of the 35,648 profiles in the dataset, only 9,357 were used.

Results

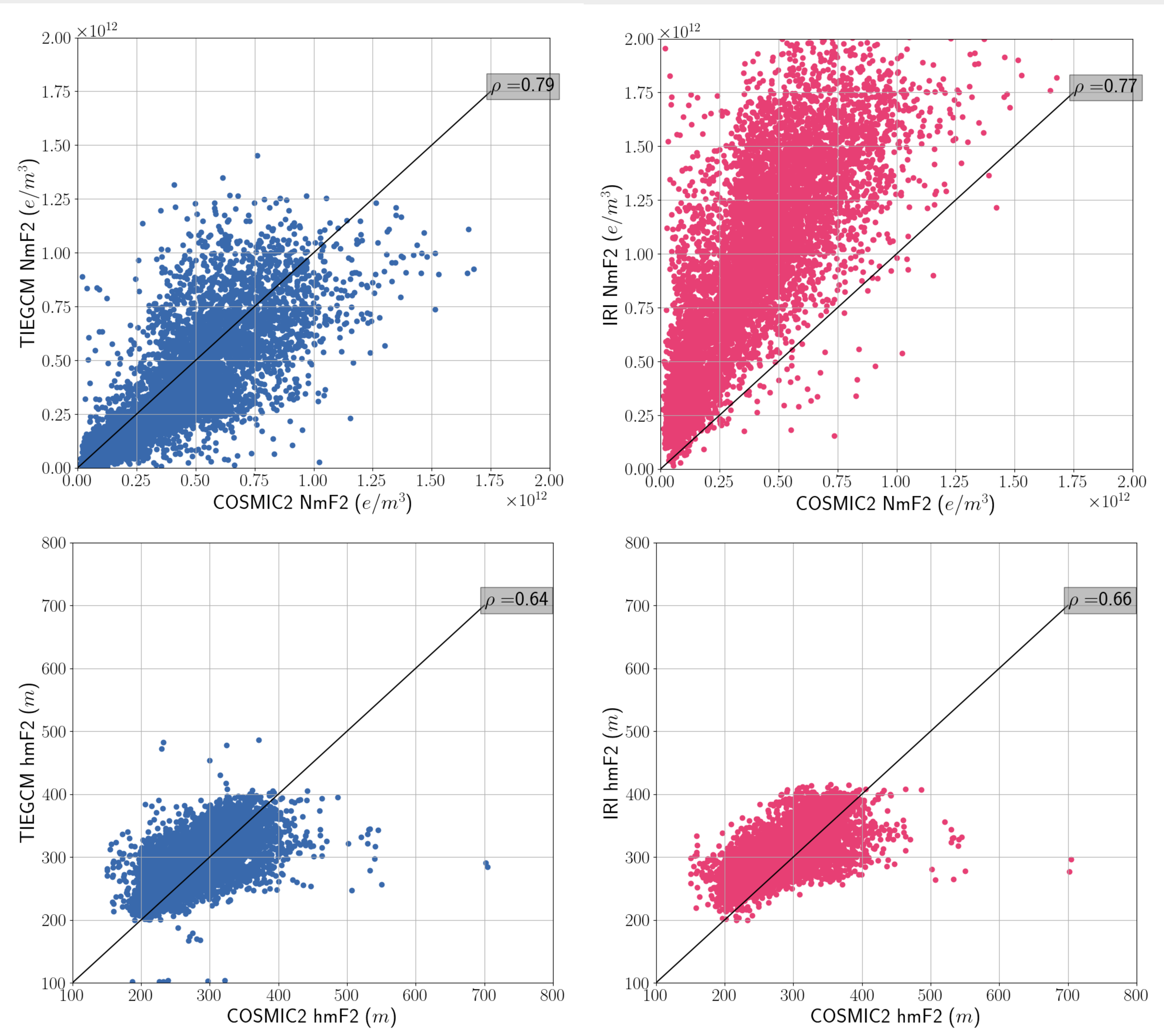

Fig 1. Scatter plots of modeled vs observed NmF2 (top) and hmF2 (bottom) values for TIEGCM (left, blue) and IRI (right, pink), and the respective correlation coefficient (Pearson**) and the x=y line.
**Pearson coefficient quantifies how two variables are linearly correlated with each other and the strength , but it does not account for bias.

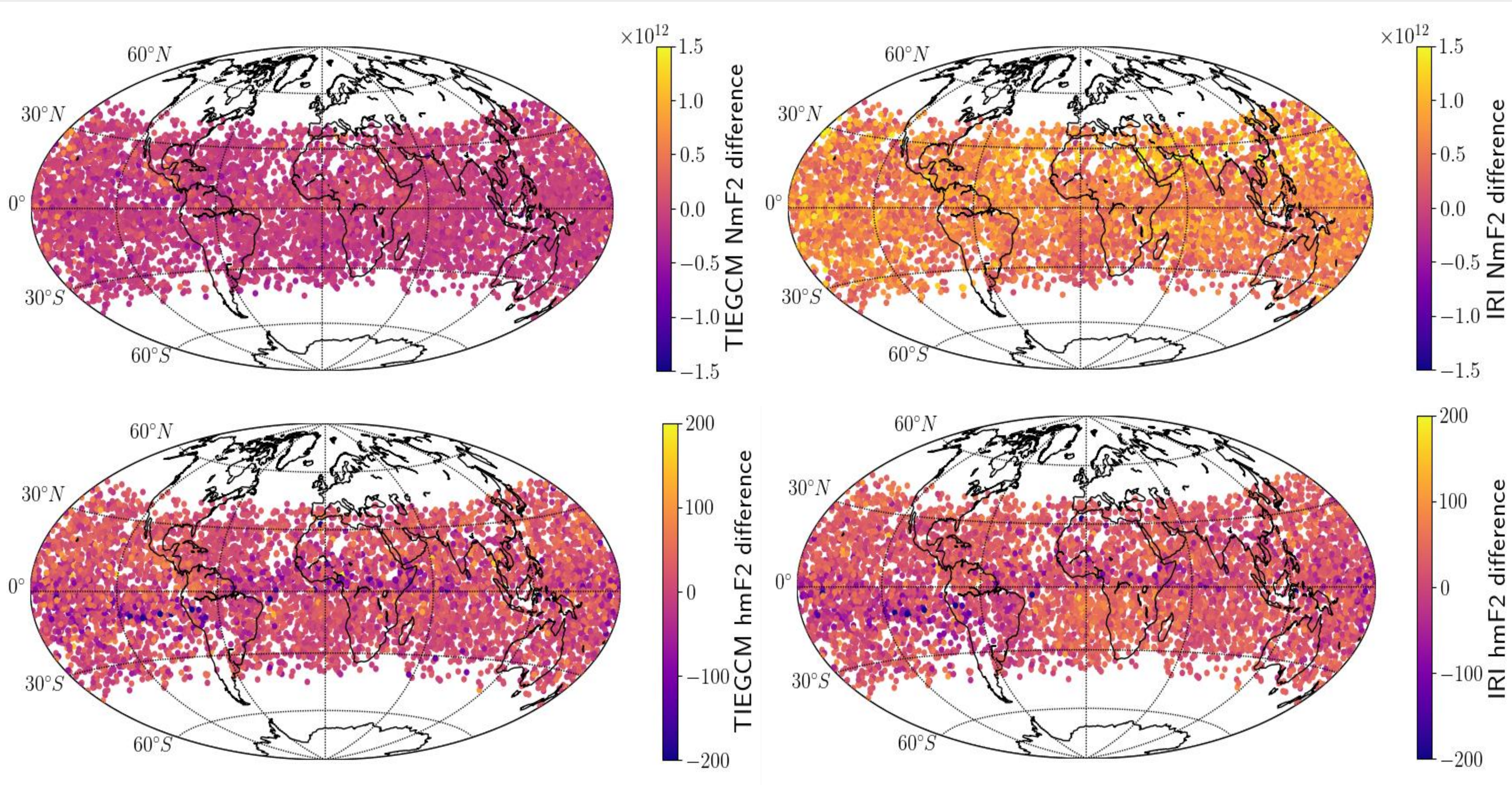

Fig 2. Map plots of the difference between modeled and observed NmF2 (upper) and hmF2 (lower) for TIEGCM (left) and IRI (right).

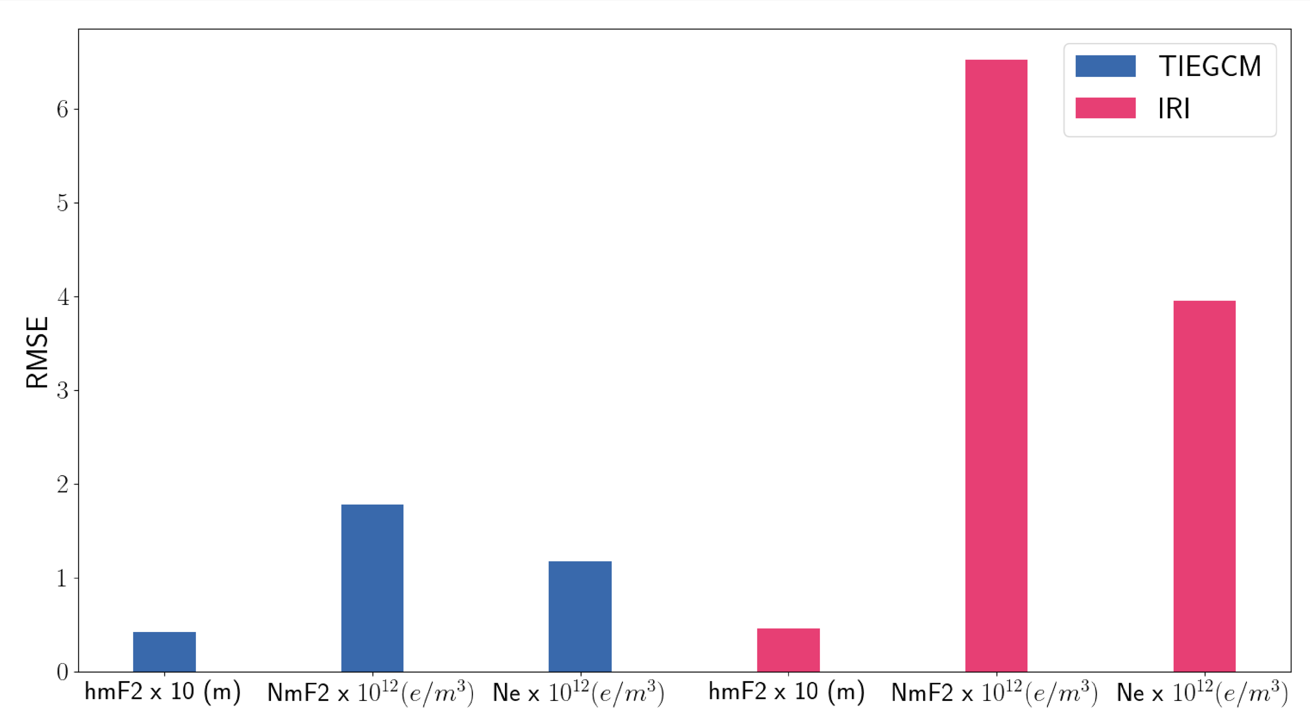

Fig 3. RMSE for (left to right) hmF2, NmF2 and Ne in TIEGCM (pink) and IRI (blue).

Discussion

The scatter plots show that TIEGCM has a larger correlation coefficient and provides a better estimate of NmF2 than IRI; in fact, IRI mostly overestimates the observed NmF2 values, being above the x=y line (see Fig. 1. top).
Both models perform similarly when predicting hmF2 (see Fig. 1. bottom). The maps in Fig. 2. confirm the overestimation of NmF2 from IRI (top, right). There is an underestimation of the hmF2 over the magnetic equator line in both models. Regarding the overall performance of the model, from the plotted RMSE it is possible to see that the model's error in reproducing an Ne profile could be correlated to how well the model represents the peak of the F2 layer (hmF2 and NmF2).

Conclusions & Future work

The validation performed was able to compare two models globally, for quiet conditions. We conclude that the performance of TIEGCM is better than that of IRI for the metrics used and the dataset chosen.

As future work it is proposed that the dataset is increased, covering at least one solar minimum and one solar maximum year (2020 and 2024 respectively).

Furthermore, the periods of geomagnetic activity should be validated separately using a quiet background from the 20 quiet days around the geomagnetic storm.
In the context of ionospheric modeling, ensemble modeling is the combination of different forecasts. Physics-based models rely on different input parameters, assumptions, physical equations and driving conditions. In an ensemble of physics-based models, their output can be combined in a weighted average. The validation framework being developed in this work, can be used to choose and define the weighting of each physics-based model by comparing it to observations and a background empirical model (such as IRI).Then, the validation framework will be used to evaluate the model ensemble.

References: Chou, M.-Y et. al. (2023) "Validation of Ionospheric Modeled TEC in the Equatorial Ionosphere During the 2013 March and 2021 November Geomagnetic Storms" | A. T. Chartier et. al. (2023) "Validating Ionospheric Models Against Technologically Relevant Metrics" | Francisco J. Tapiador and Vincenzo Levizzani, (2021) "2.3 Climate Model validation" | H. Wang, (2008) "Validation of the Space Weather Modeling Framework using observations from CHAMP and DMSP" | K.A. McWilliams R.G. Harrison K.A. Nicoll, (2013) "Space weather driven changes in lower atmosphere phenomena" | JA Guerra, SA Murray, and E Doornbos, (2020) "The use of ensembles in space weather forecasting"| A. Pignalberi, D. Bilitza, P. Coısson et al., Validation of the IRI-2020 topside ionosphere options through in-situ electron density observations by low-Earth-orbit satellites, Advances in Space Research | Shaikh, M. M., Nava, B., & Haralambous, H. (2018). On the use of topside RO-derived electron density for model validation. Journal of Geophysical Research: Space Physics, 123, 3943–3954.

DLR Deutsches Zentrum für Luft- und Raumfahrt