IONOSPHERIC RADIO OCCULTATION AS A TOOL FOR MODEL VALIDATION

Joana Pires Morgado Fernandes Pereira [1], Claudia Borries [1], Frank Heymann [1], Isabel Fernandez Gomez [1], Michael Schmidt [2].

1) Institute for Solar-Terrestrial Physics, German Aerospace Center (DLR), Neustrelitz, Germany
2) Deutsches Geodätisches Forschungsinstitut der Technischen Universität München (DGFI-TUM), Arcisstr. 21, 80333 München, Germany

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INTRODUCTION

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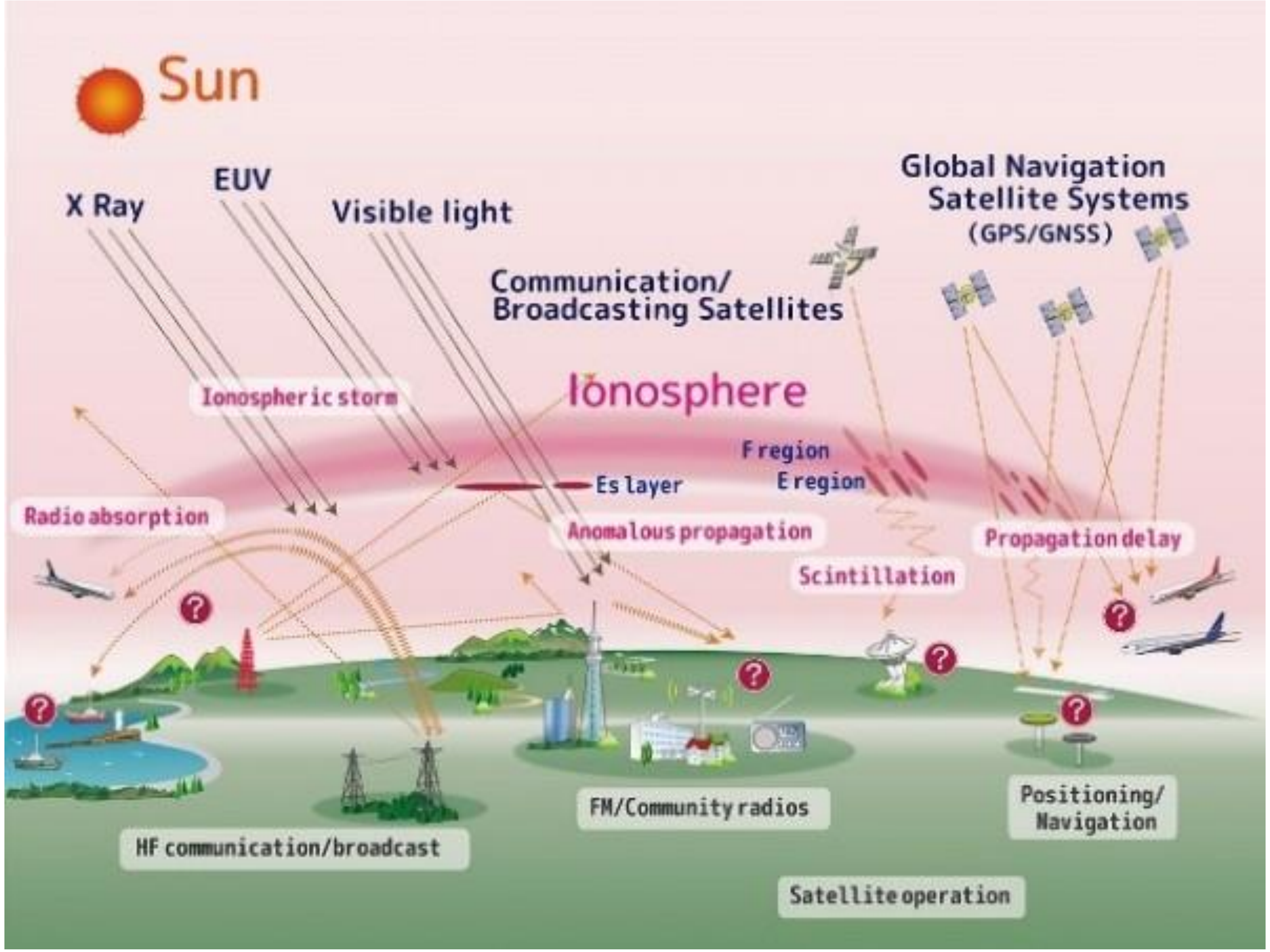
The significant role that the Thermosphere-Ionosphere system plays in our technological society

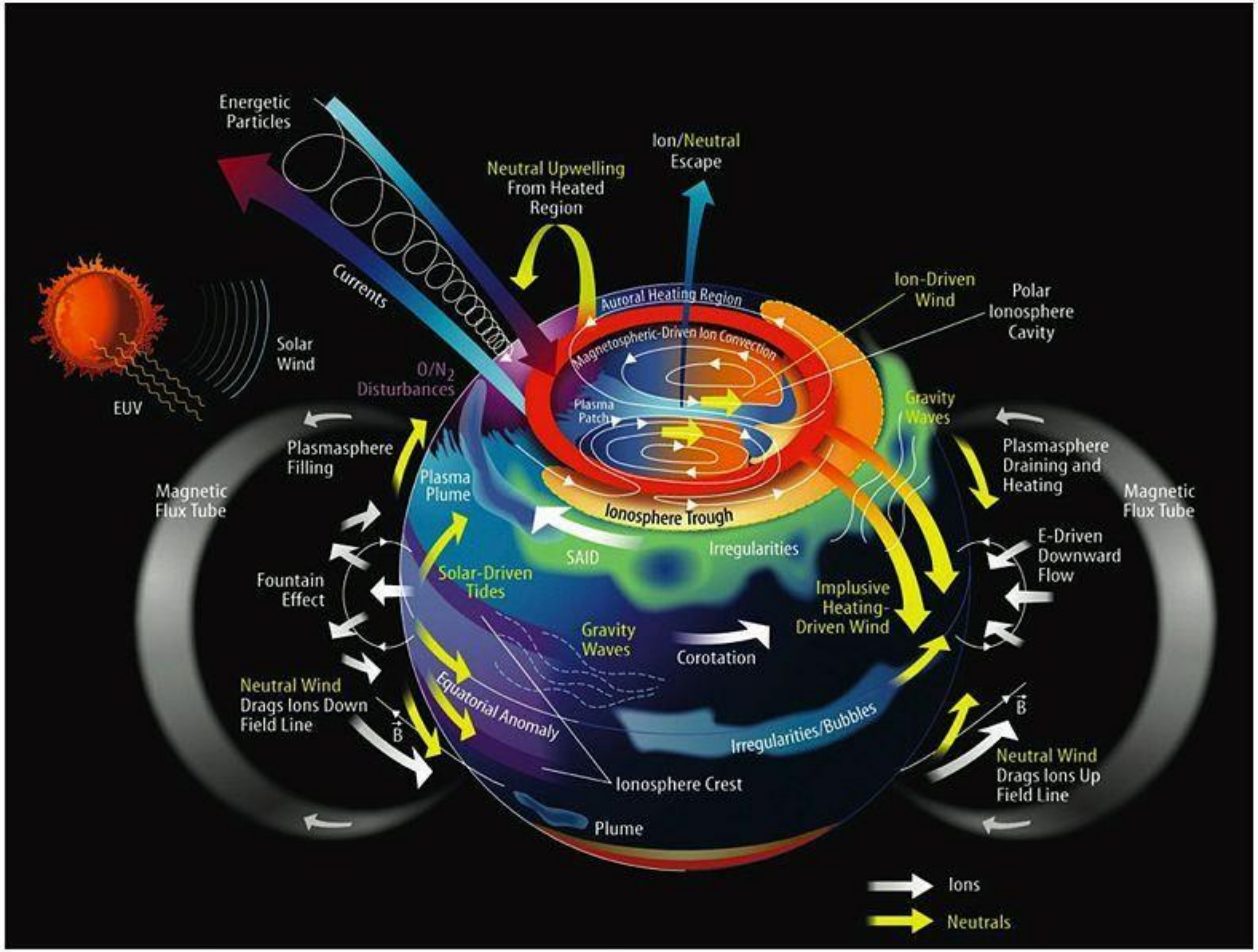


This system is influenced by the sun and geomagnetic activity.

Space weather events 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.

The complexity of the Thermosphere-Ionosphere system



Accurately representing the thermosphere-ionosphere system is challenging due to its complex interactions with the lower atmosphere and the magnetosphere.

Space weather 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 space weather effects.

Name	Type	Description	Main outputs
IRI (International Reference Ionosphere) model	Semi-Empirical	• Global Ionosphere • Data sources: ionosondes, incoherent scatter radars, topside sounders, in situ instruments. • Ionosphere variability (Plasma Density, ion Drift Velocity). • Navigation and communications.	Ne, Te, Ti, ions, TEC
TIEGCM (NCAR Thermosphere-Ionosphere-Electrodynamics General Circulation Model)	Physical	• Global Ionosphere and Thermosphere • First-principles, 3D, non-linear. • Ionosphere variability (Plasma Density, ion Drift Velocity, TIDs). • Atmosphere variability (Atmosphere Expansion, Neutral Composition, Neutral Wind, TADs). • Navigation, communications and satellite/debris drag.	Ne, Te, Ti, ions, TEC
CTIPe (Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics Model)	Physical	• Global Ionosphere and Thermosphere • 4 coupled model components • Navigation, communications and satellite/debris drag.	Te, Ti, NmF2, HmF2, No density
WACCM-X (NCAR Whole Atmosphere Community Climate Model)	Physical	• Global Ionosphere and Thermosphere • Self-consistent general circulation model. • Navigation, communications and satellite/debris drag.	Tn, Ti, Te, Ne, Ni, TEC
NeQuick	Empirical	• Based on the Effective ionisation level • Ionospheric delay corrections for single-frequency users (Galileo)	Ne, TEC
GITM (Global Ionosphere-Thermosphere model)	Physical	• Global Ionosphere and Thermosphere • Navigation, communications and satellite/debris drag. • Ionosphere and Atmosphere variability	Tn, Ti, Te, Ne, TEC
GAIM (Global Assimilation of Ionospheric Measurements) model	Physical (+ data assimilation)	• Global Ionosphere • Gauss-Markov Kalman Filter (GMKF) model • Ionosphere variability (Plasma Density). • Navigation and communications.	Ne, TEC
NTCM-GL - Neustrelitz global TEC Model (DLR)	Empirical	• European GPS ground station network of the International GNSS Service • For TEC mapping	TEC

Model Validation

The development and improvement of Ionosphere-Thermosphere modeling techniques depends on model validation.

Validation

Measurement of the deviation between model and observation

- Discover bias in the models (positive or negative)
- Identifies errors which can be caused by external factors (solar cycle, daily or seasonal variability)

So far, there is no standard set of validation tools or reference datasets that can be used in the TI domain.

- To establish a good set of validation tools and techniques to be used in model validation and in the validation of a future ensemble model.

Ionospheric Radio Occultation (IRO) COSMIC-2

6 COSMIC-2 remote-sensing satellites over the tropics detect and measure a signal (x,v,φ) bended by the atmospheric refractivity.

Doppler shift

↓

Bending angle

↓

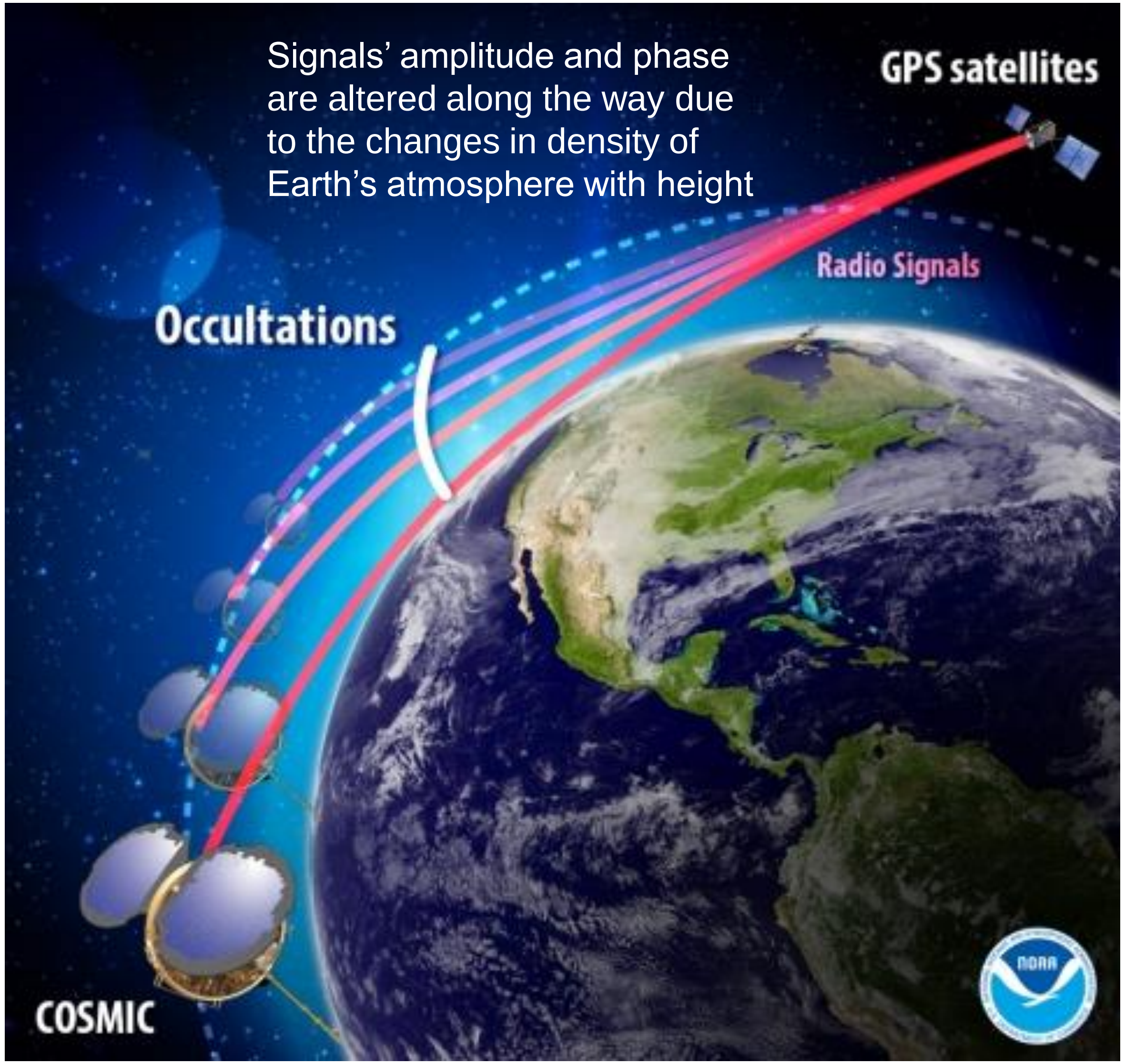
Refractivity index

↓

Density

↓

Ne, T, P…



Global Positioning System satellites send signals to receivers on Earth.

COSMIC-2 produces 5,000 vertical profiles per day using IRO.

Data used - Electron Density Profiles obtained by inversion of calibrated TEC data. These are consistent with the ground-based data with no significant biases.

Methodology

Models

International Reference Ionosphere (IRI)

– Empirical model: based on experimental data; use the physical equations combined with data

– ref : https://github.com/space-physics/iri2016

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Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM)

– Physics based: uses the physical and mathematical equations and numerical modeling

– ref : https://www.wdc-climate.de/ui/entry?acronym=OTHITACS_tiegcm_2020

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- The models were run with the same time and spatial resolution of COSMIC observations.

Methodology

Analysed events

- 20-22 of March, 20-22 of June, 22 to 24 of September and 21 to 23 of December.
- 27 of September 2020

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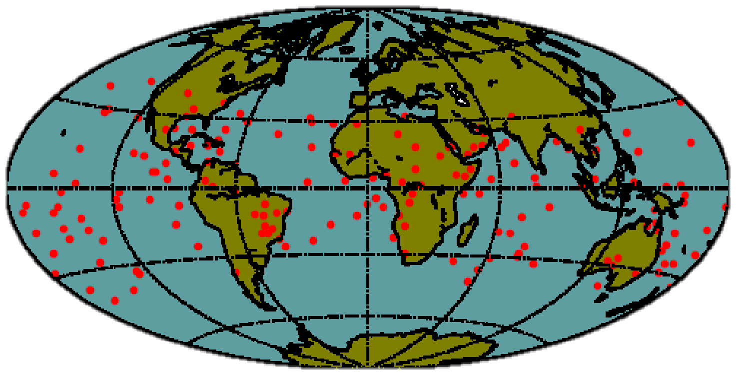
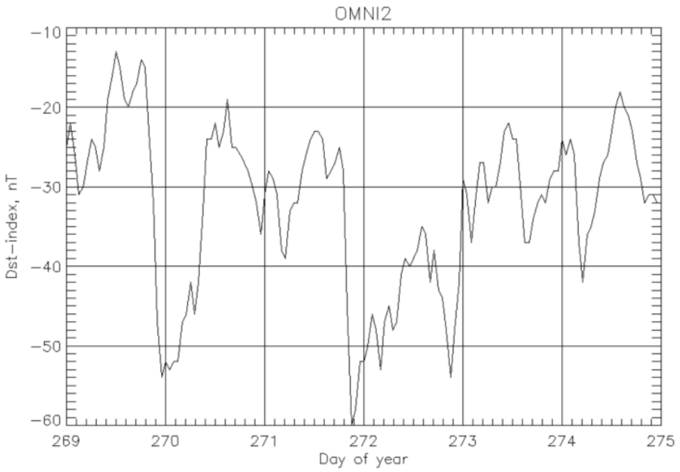
COSMIC2 coverage for the chosen intervals



Dst index during the disturbed period (25-30 September 2020)



- Ne Profiles are 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). Data was bounded between 150-600km.

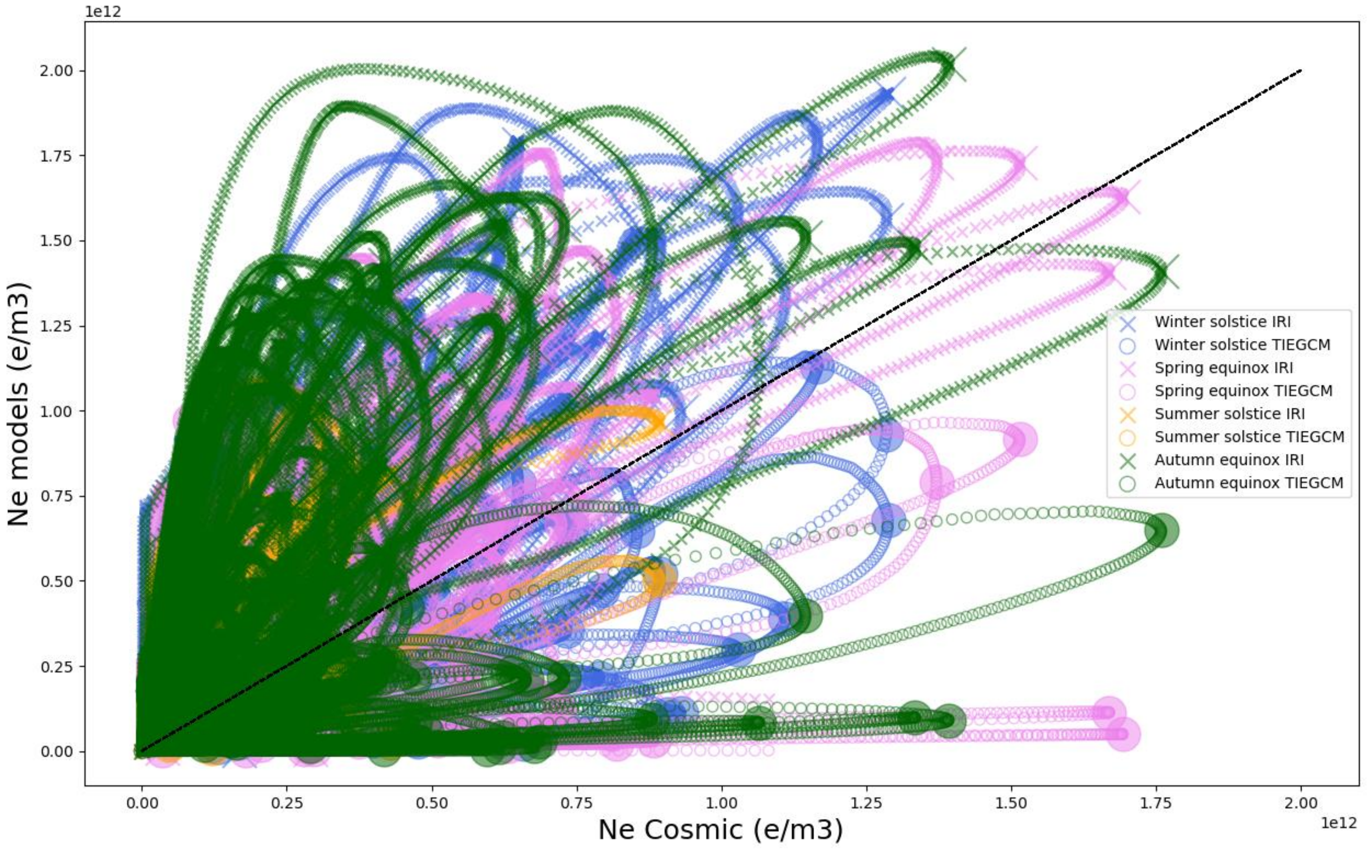
Methodology
Validation metrics

Evaluate the profile given by a model based on how accuratly it predicts the F2 layer peak predicion: maximum density (NmF2) and altitude where the NmF2 occurs (HmF2).

- Plotted profiles and Model vs Observation plots.
- Mean error (ME) where Error is defined as E = (model-data)/data
- NmF2 and HmF2 from the data and the model
- NmF2 error defined as ΔNmF2 = NmF2(model)-NmF2(data)
- HmF2 error defined as ΔHmF2 = HmF2(model)-HmF2(data)

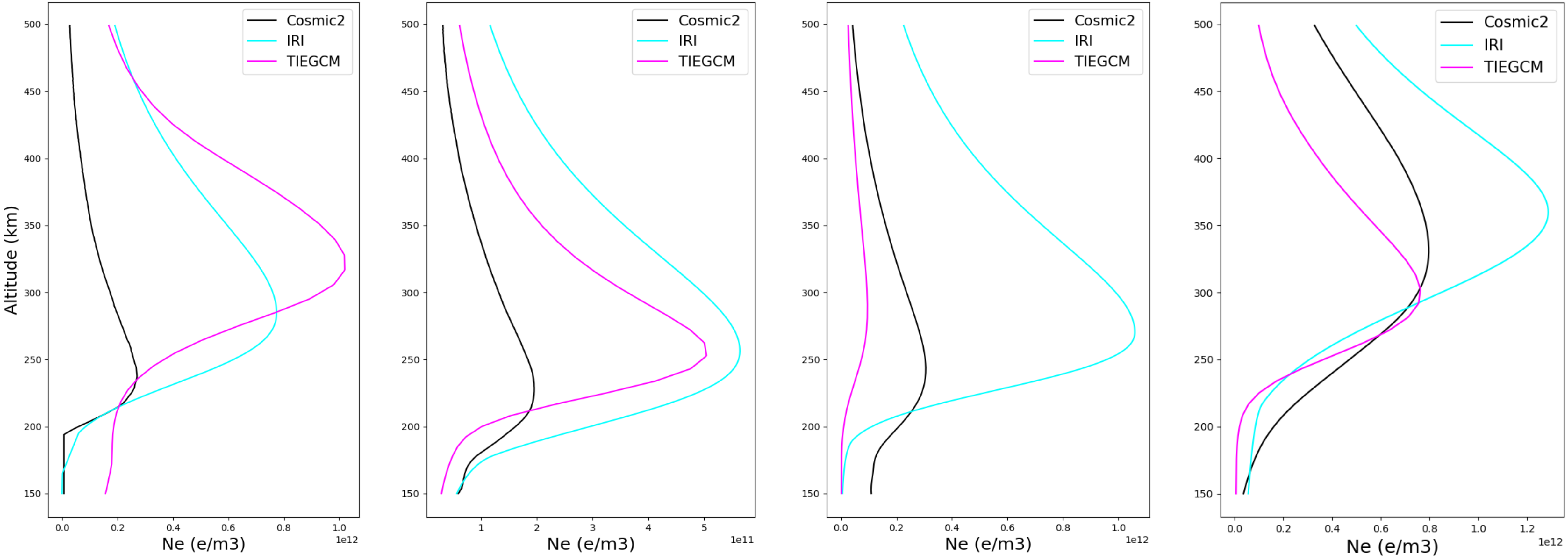
Preliminary results

Fig. 3. Scatter plot between modeled vs observations during all quiet periods. Larger dots and crosses represent the maximum model Ne for observed NmF2



Preliminary results

Fig. 4. Observed and modeled (IRI and TIEGCM) Ne profiles on the storm day (27 September 2020) from left to right: before the storm (11h), sudden storm commencement (13h), main storm phase (20h), recovery phase (23h)



Preliminary results - Metrics table

COSMIC2 uncertainty is being estimated to be NmF2 ~0.99-1.76 × $\mathbf{10^{11}}$ e/m3 and HmF2 ~13–25 km.

- Shi, S.; Li, W.; Zhang, K.; Wu, S.; Shi, J.; Song, F.; Sun, P. Validation of COSMIC-2-Derived Ionospheric Peak Parameters Using Measurements of Ionosondes. *Remote Sens.* **2021**, *13*, 4238.
- Iurii Cherniak, Irina Zakharenkova, John Braun, Qian Wu, Nicholas Pedatella, William Schreiner, Jan-Peter Weiss, and Douglas Hunt, Accuracy assessment of the quiet-time ionospheric F2 peak parameters as derived from COSMIC-2 multi-GNSS radio occultation measurements, J. Space Weather Space Clim. **2021**, 11,18.

Metric	ME		NmF2 ($x10^{11}$) and (ΔNmF2)			HmF2 (km) and (ΔHmF2)		
Date	IRI	TIEGCM	Cosmic2	IRI	TIEGCM	Cosmic2	IRI	TIEGCM
March	2.35	2.30	5.04	8.31 (3.27)	3.52 (-1.51)	256	286 (29.55)	285 (28.76)
June	5.35	3.46	2.21	5.39 (3.18)	2.23 (-0.01)	267	288 (21.13)	264 (-2.75)
September	5.27	2.87	4.37	10.87 (6.50)	2.47 (-1.89)	266	290 (23.30)	278 (11.70)
December	3.98	2.10	5.19	10.22 (5.03)	4.15 (-1.04)	289	297 (8.23)	299 (10.63)
27.09 (11h)	3.49	7.08	2.71	7.74 (5.03)	10.20 (7.49)	238	285 (47)	317 (79)
27.09 (13h)	2.28	0.99	1.95	5.64 (3.69)	5.04 (3.09)	228	257 (29)	253 (25)
27.09 (20h)	2.50	-0.64	3.06	10.59 (7.53)	0.96 (-2.10)	244	271 (27)	290 (46)
27.09 (23h)	0.21	-0.46	7.97	12.86 (4.89)	7.63 (-0.34)	330	360 (30)	302 (-28)

Concluding, the model’s ability to reproduce an Ne profile is related to how well the model represents the peak of the F2 layer.

- The study presented here shows that simple statistics and metrics can be the basis for an initial model validation framework. It covers the accuracy, bias and predictability of NmF2 and HmF2, making it simple to compare different models.
- As future work it is proposed that more models are evaluated in this way and that cross validation with other data sources and models is done.
- Furthermore, more periods of geomagnetic activity should be considered such as solar cycles, solar rotations and other geomagnetic storms with different origin, duration and intensity.
- Ionospheric Radio Occultation (IRO) is a promising technique in reconstructing the ionospheric electron density profiles in a broad range of heights and global coverage.

CONCLUSION AND FUTURE WORK

THANK YOU!
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Preliminary results
Ploted NmF2 error

Fig. 5. Absolute error of NmF2 for the two models (left: TIEGCM, right: IRI)