Comparison of IRI simulated top-side ionosphere with the *in-situ* satellite observations

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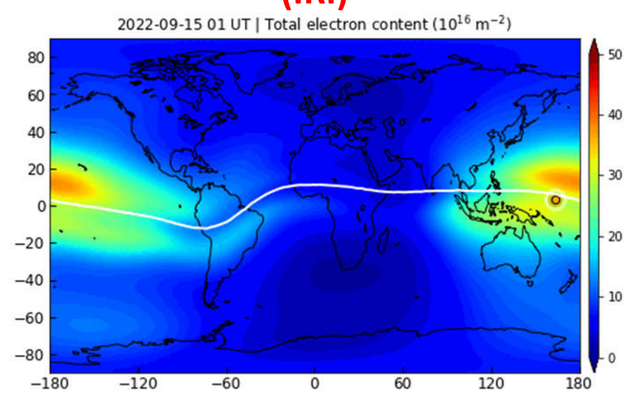
Satellite
(Formosat-1/ROCSAT-1)

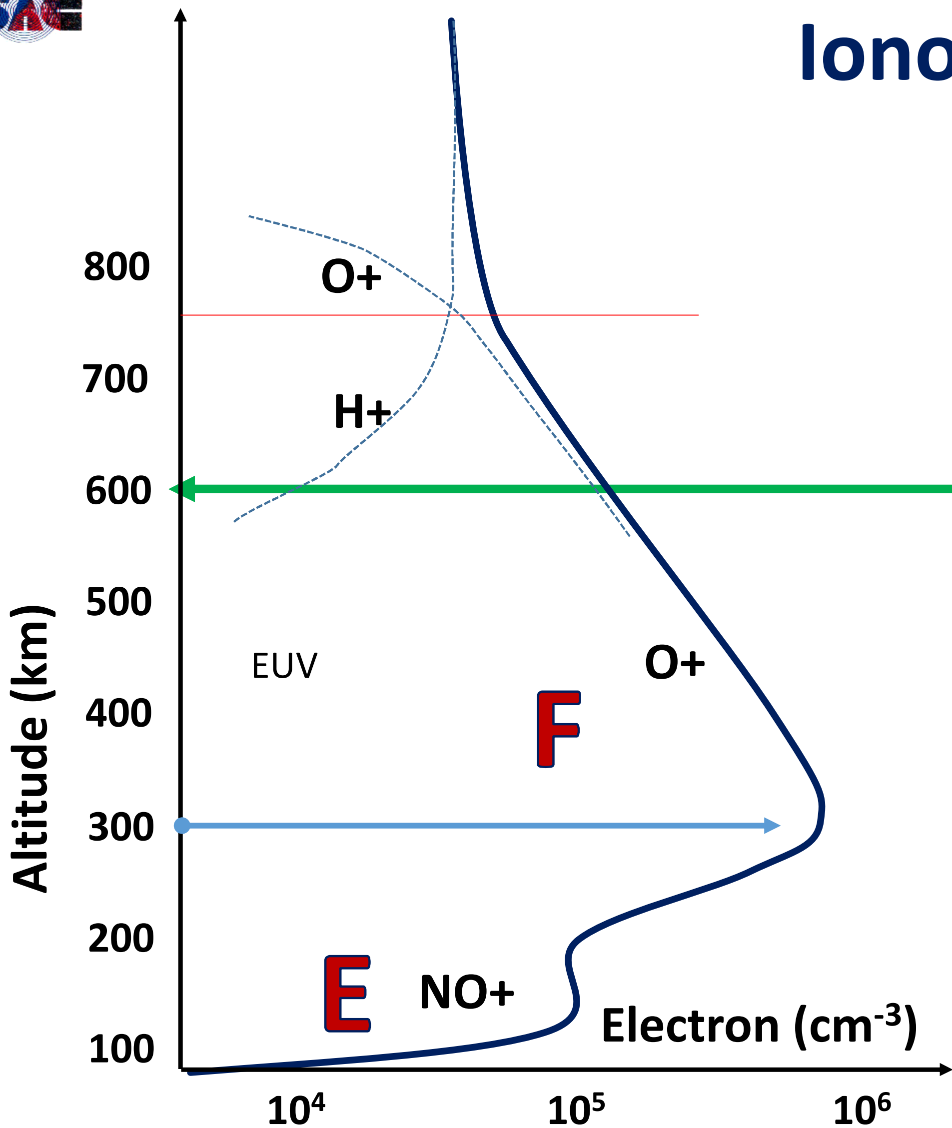
Empirical model
(IRI)



Preamble

- Topside ionosphere (above F peak) is a dynamic and transition region between F-peak and protonosphere, whose variability is driven by influences from below atmosphere and solar forcing from above including EUV fluxes.
- Top-side Ionosphere has remained relatively less explored as it is not easy to probe it from ground and there is a relative scarcity of in-situ measurements.
- Ionospheric models, analytical/theoretical as well as empirical, are advancing towards accurately representing the top-side ionosphere. Comprehensive understanding of this region is evolving.
- In the present study, we evaluate the internationally-recognized standard **International Reference Ionosphere (IRI)** model using the in-situ measurements by **Formosat-1 (ROCSAT-1) in top-side ionosphere**.

Ionosphere



Satellite based in situ measurements

- Formosat -1 or ROCSAT-1
- (1999-2004); Altitude: 600 km
- Inclination: 35°

- Ionospheric Plasma and Electrodynamics Instrument (IPEI)
- IPEI consist of four sensors: IT and RPA; Drift meter (2)
- Ion Trap: → Ion Density,
- Retarding Potential Analyzer (RPA) → Ion Temperature, and Ion composition (O+, H+, He+, and NO+)

Model Simulations- IRI: International Reference Ionosphere

Inputs:
Daily update:
(a) Solar (Sunspot) and Ionospheric indices (IG)
(b) Magnetic index (Ap) and F10.7 (flux)

Five years:
(a) International Geomagnetic Reference Field (IGRF)
(b) Definitive IGRF coefficients

IRI-2020

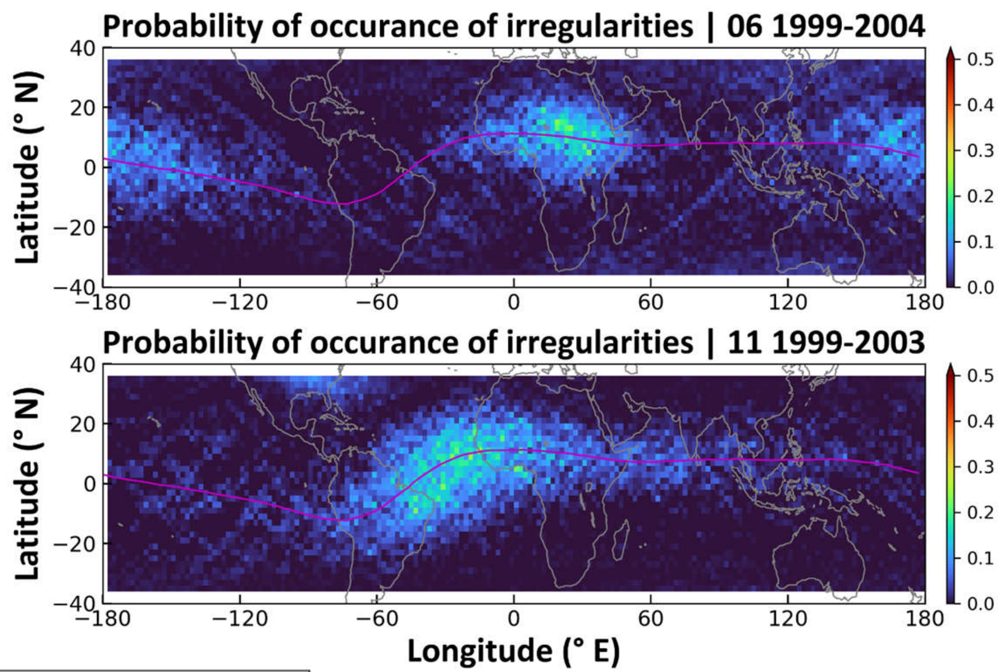
IRI model (FORTRAN)

August 2022

Output (50-1500 km):
1. Electron density,
2. Electron temperature,
3. Ion temperature and
4. Ion composition (O+, N+, He+, H+, NO+, O2+)
5. TEC

- IRI is recognized as the standard for the ionosphere by **ISO**: International Standardization Organization, **URSI**: International Union of Radio Science, **COSPAR**: Committee on Space Research, **ECCS**: European Cooperation for Space Standardization
- IRI is an empirical model of the ionosphere constructed from the global ionospheric observations, specifying monthly averages of electron density, ion composition, electron temperature, and ion temperature in the altitude range from 50 km to 1500 km
- ~2.3 x 10^5 observations and co-located simulations are used to generate monthly means at grids of ~ 4° x 4°
- The knowledge of ion composition is important for calibration of the Langmuir probes.
- Bilitza et al., 2001; Bilitza and Reinisch, 2008; Bilitza et al., 2011; Bilitza et al., 2014; Bilitza et al., 2017

Data exclusion corresponding to the irregularities prior to the comparison

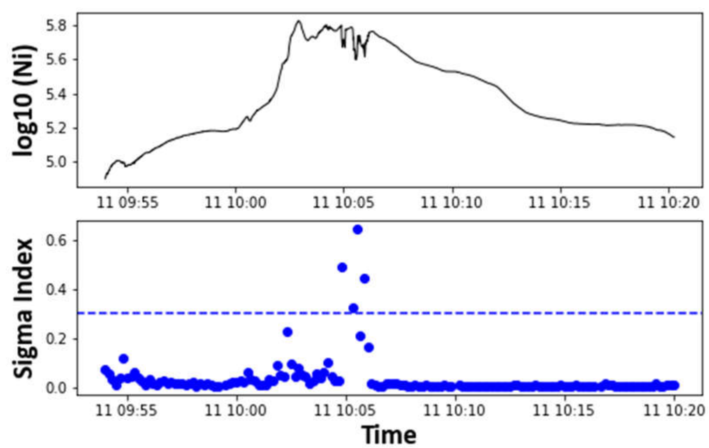


Irregularities Detection

using Sigma Index

Su et al., 2006

$$\sigma = \frac{\left[\frac{1}{10}\sum_{i=1}^{10}(\log n_i - \log n_{oi})^2\right]^{1/2}}{\frac{1}{10}\sum_{i=1}^{10}\log n_{oi}}$$

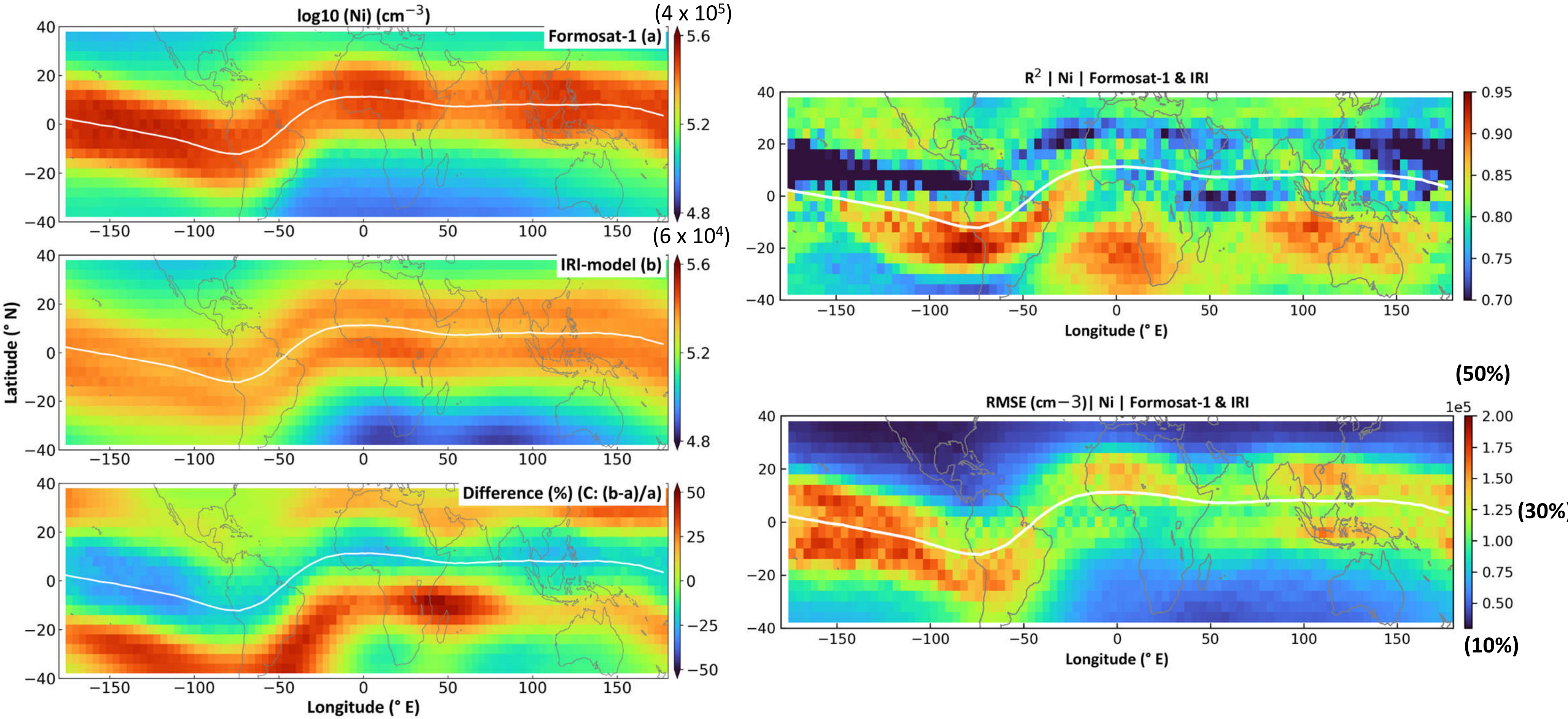


Data used: averaged over 1 sec

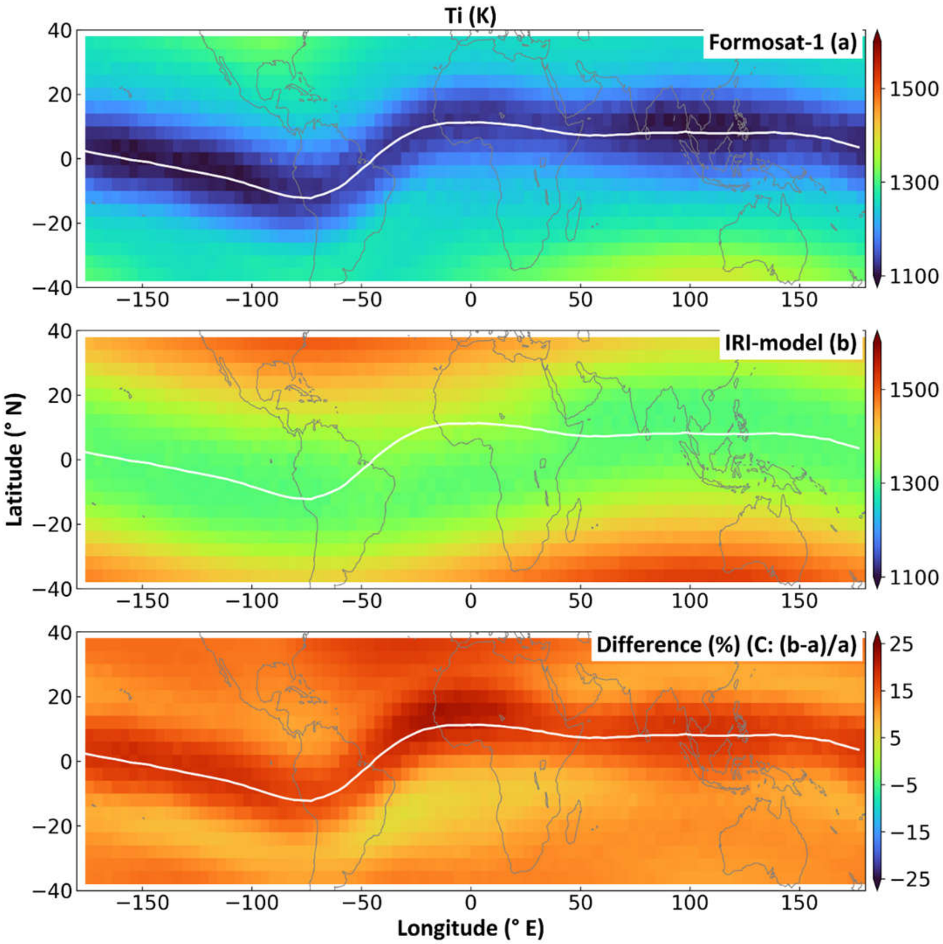
The small scale (~80 km) irregularities
10 second measurements

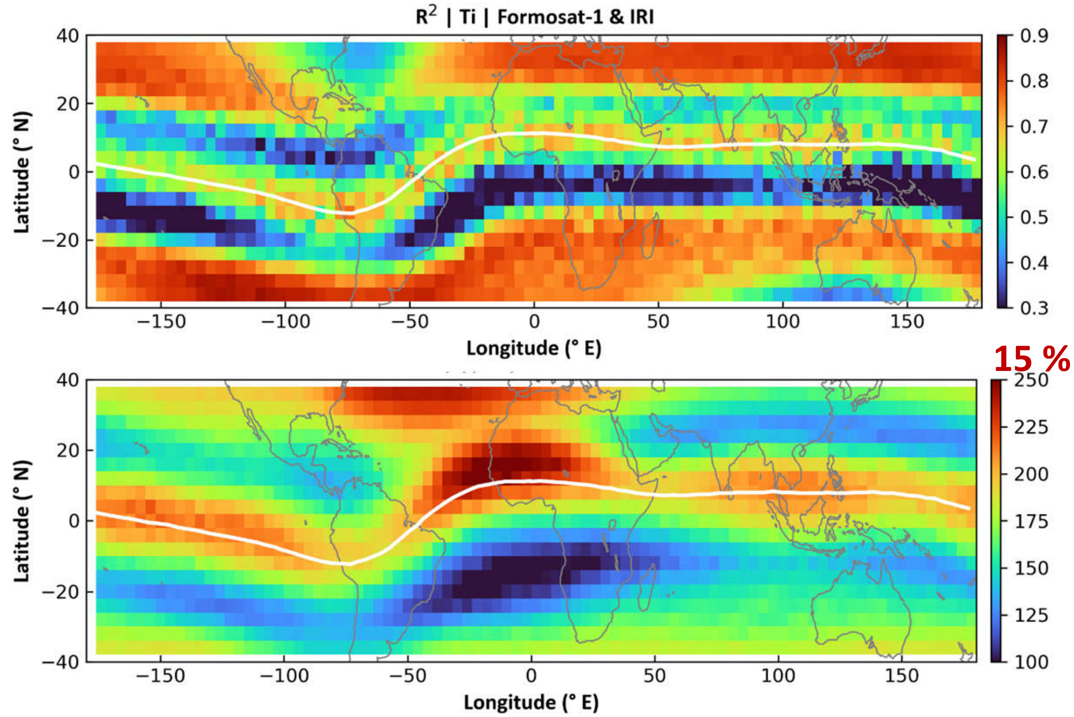
8640 calculations per day
Total: ~1.7 x 10^7 calculations (1999-2004)

Comparison of Ion Density



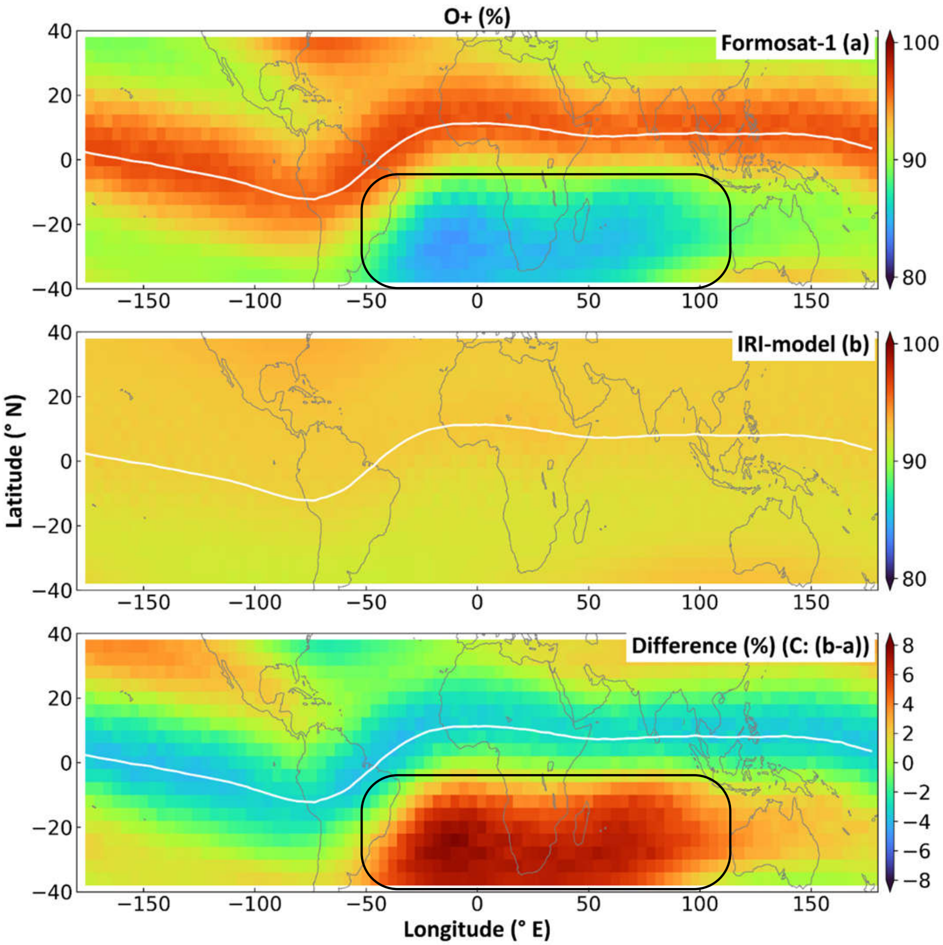
Comparison of Ion Temperature

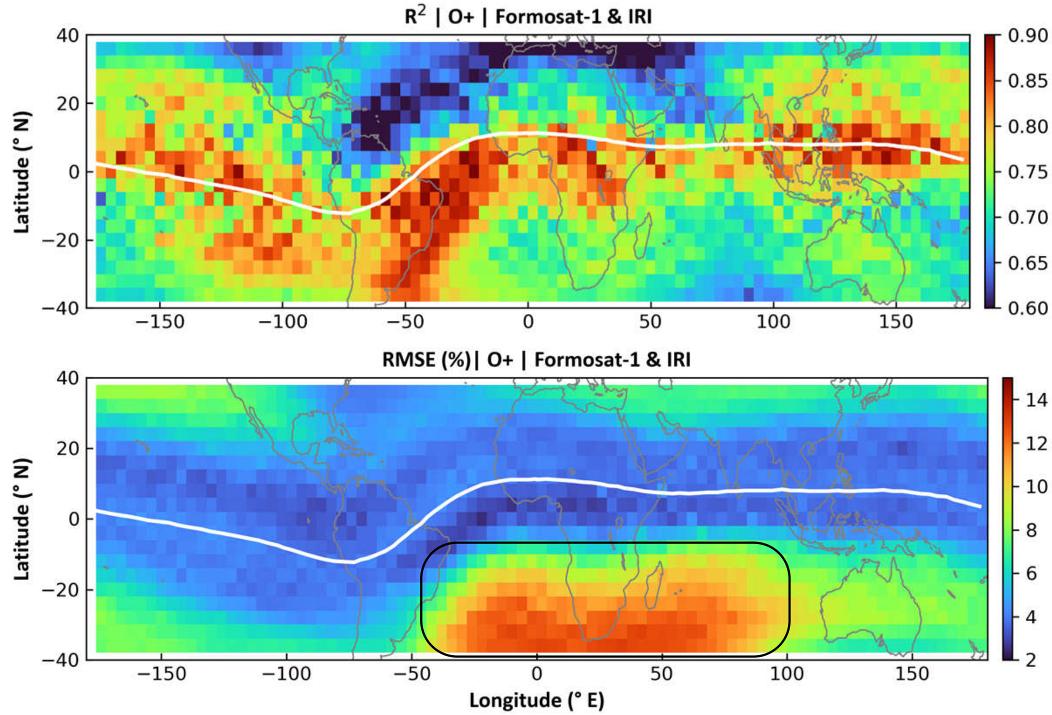




- ~10% of positive and 15% of error
- Temperature variability is weakly reproduced over equatorial ionisation anomaly

Comparison of Ion composition: O+

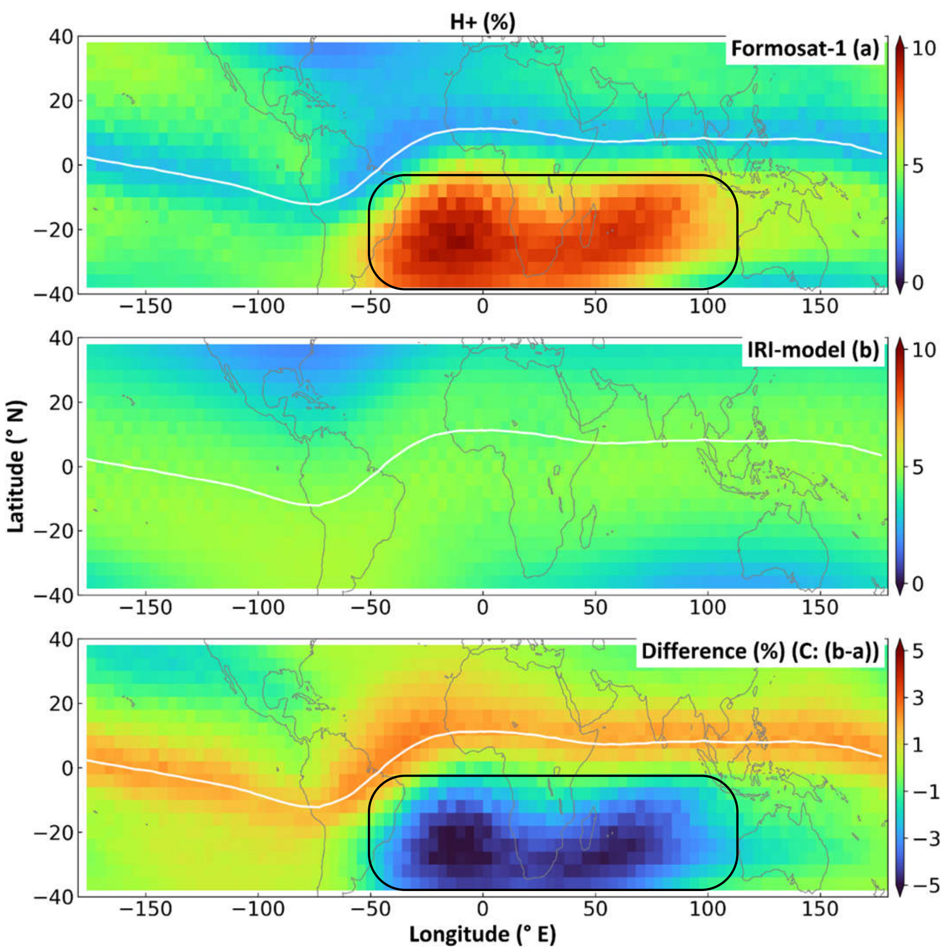


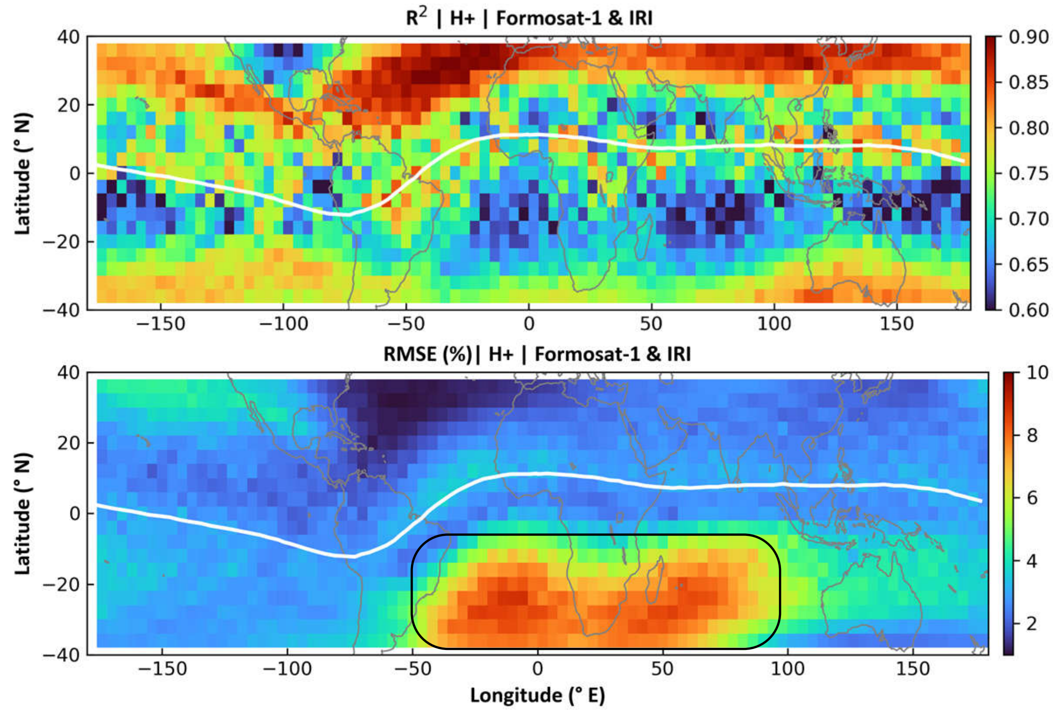


Over estimation of O+ over southern mid latitude [-50 to 100 E]

Ion composition for height>300km → Truhlik et al., 2015
Atmosphere Explorer (AE) C & E; Intercosmos-24 (IK-24) 1973-91

Comparison of Ion composition: H^+

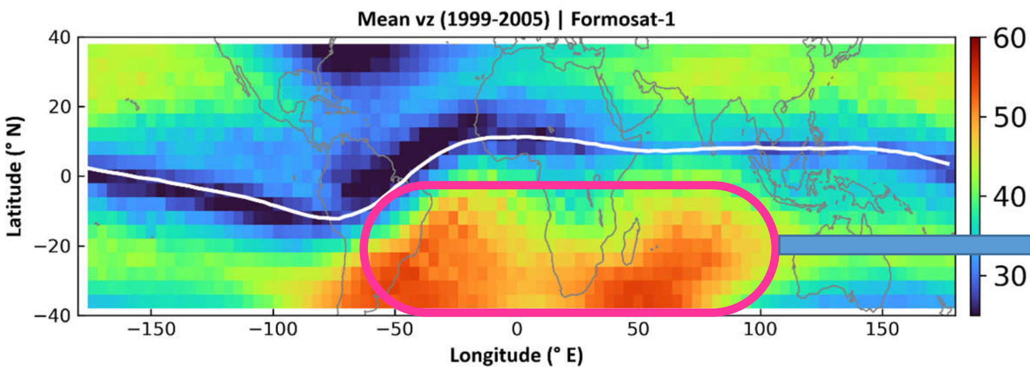


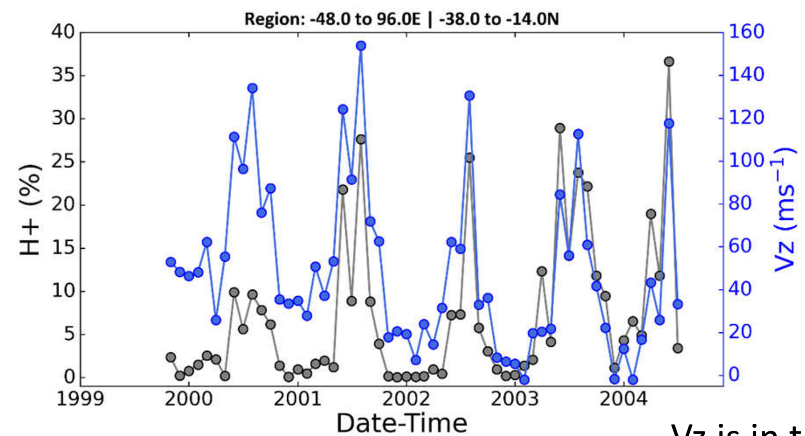


O+ and H+ are major ions around 600 km. While fractional O+ is overestimated southern mid latitude [-50 to 100 E], H+ is underestimated with higher error over this region.

Under estimation of H^+ by model: Downward flux of H^+

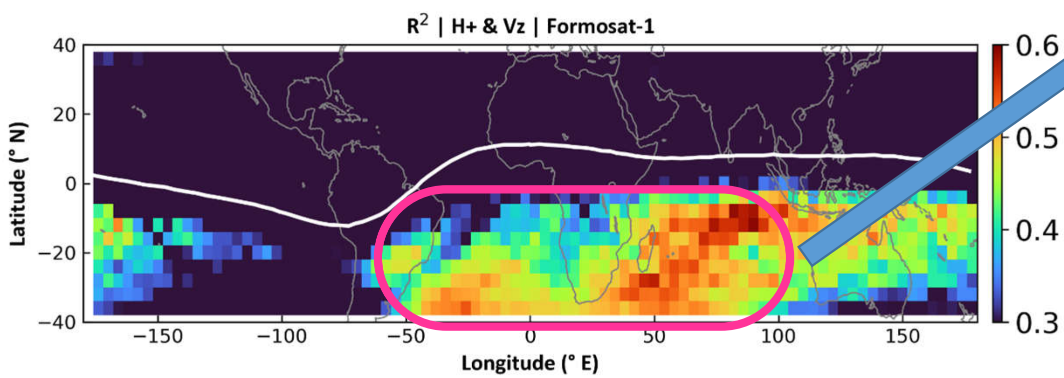
Mean Vz

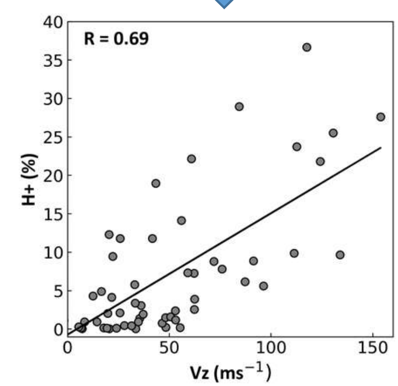




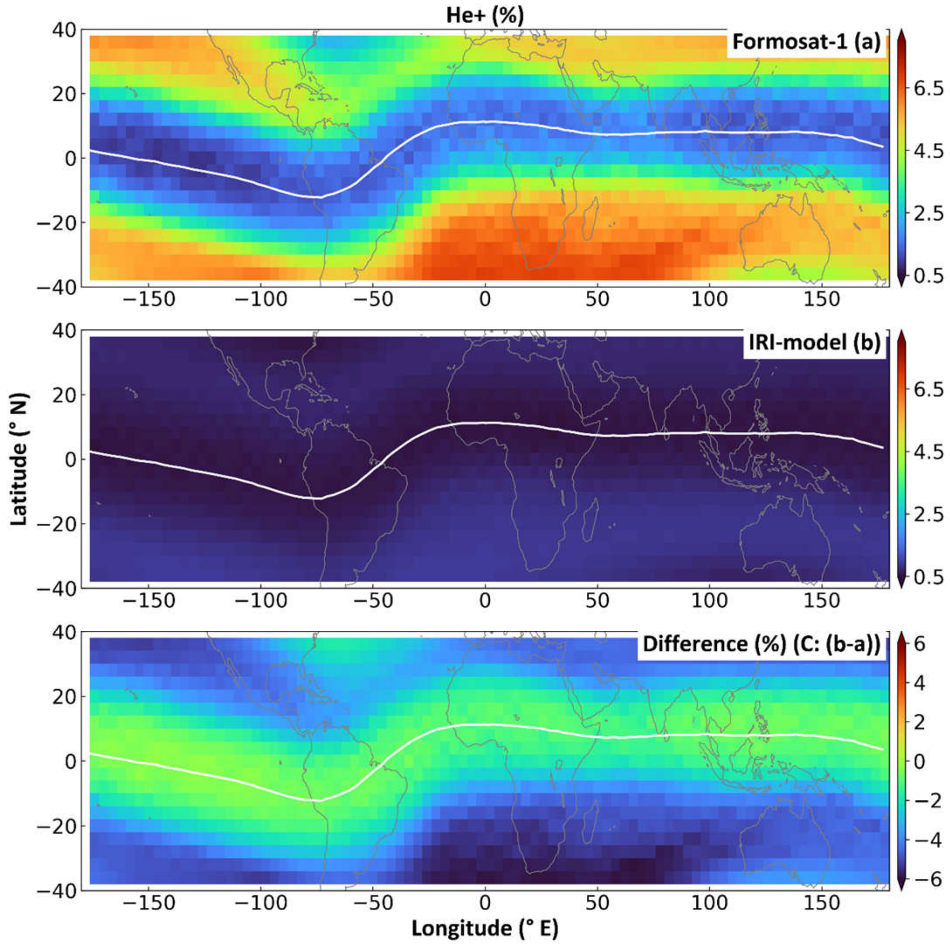
Vz is in the nadir direction

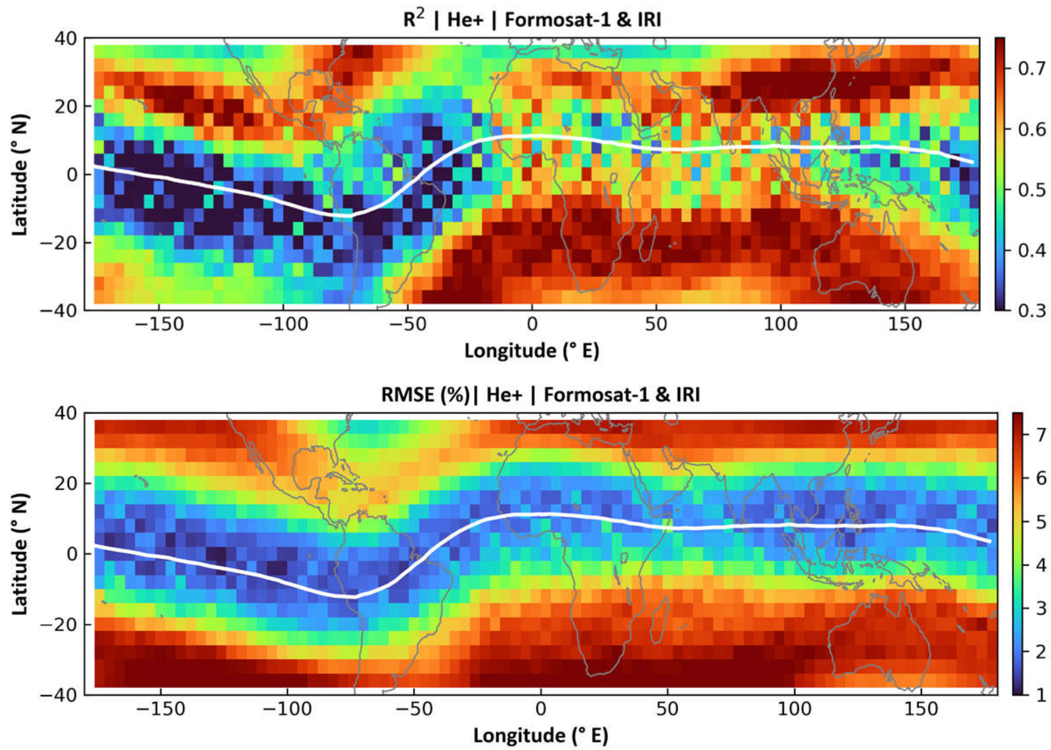
R^2 between H^+ & Vz





Comparison of Ion composition: He^+

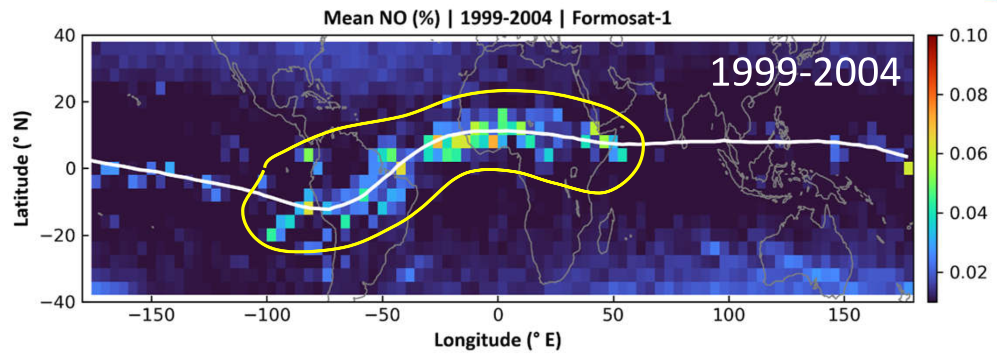


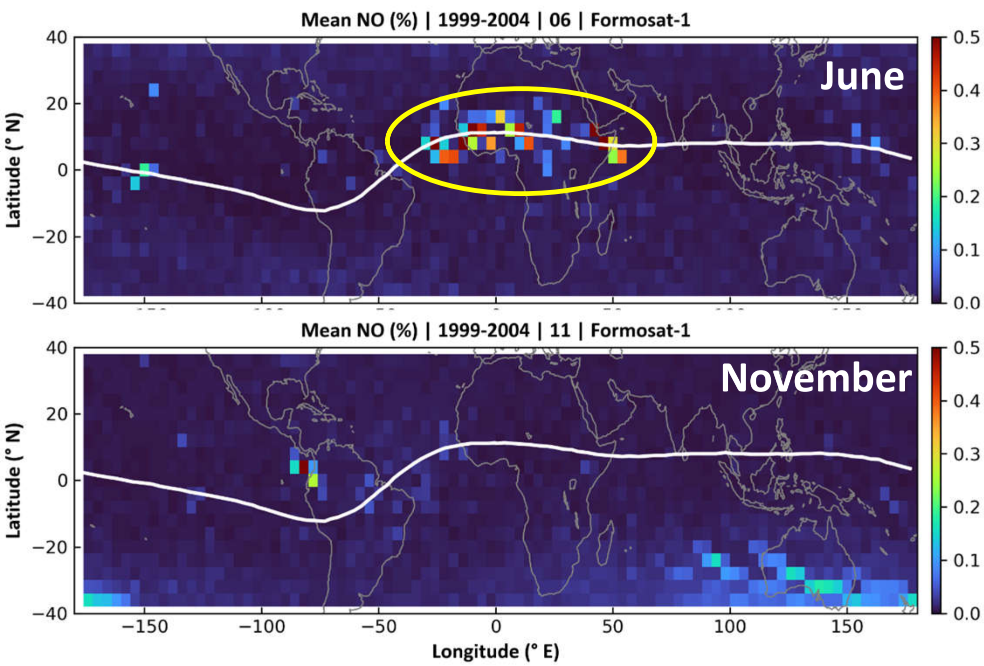


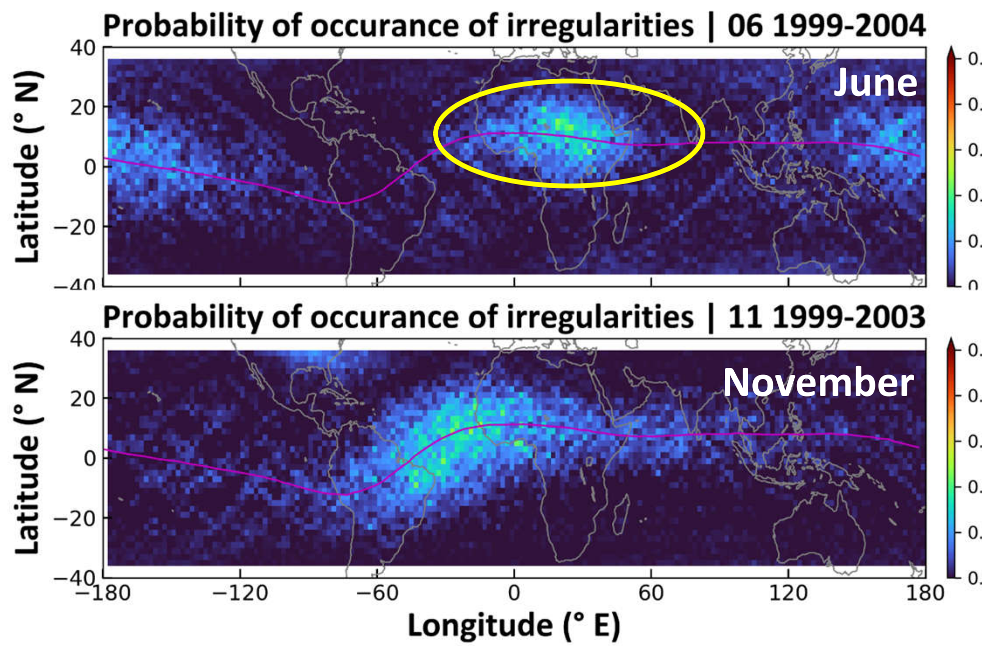
Lower bias and error over equatorial belt, however poor variability reproduced over western longitude

Enhancement in fractional NO^+ over ESF region

- Turbulence during spread-F pushes lower ionospheric plasma (having higher fractional NO) to higher altitude





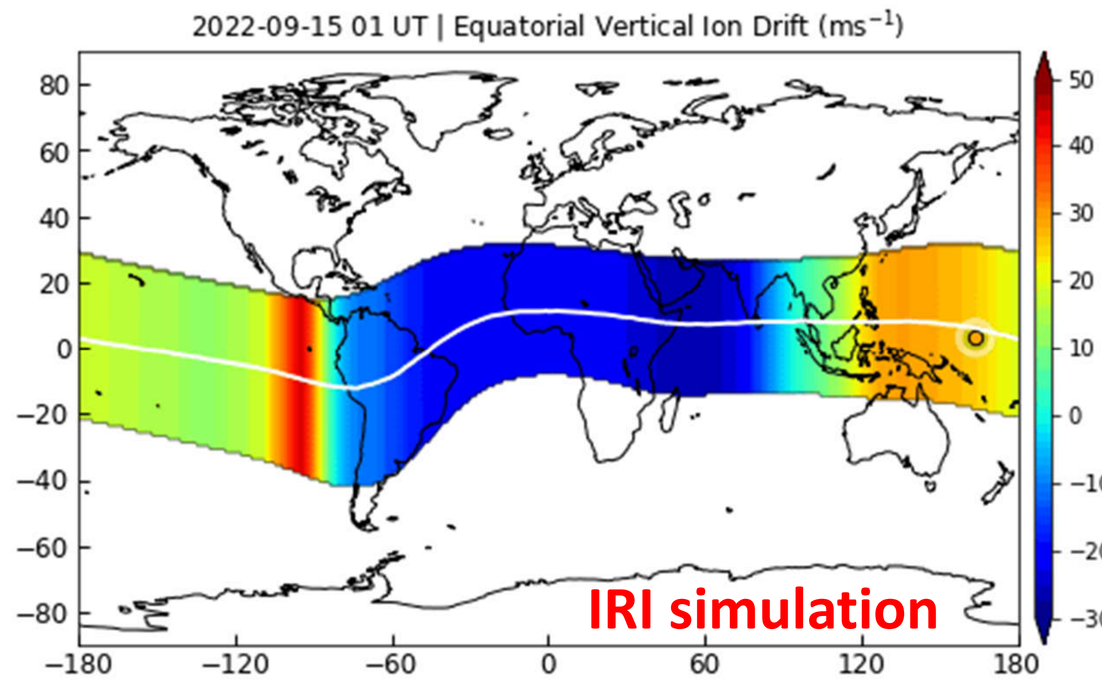


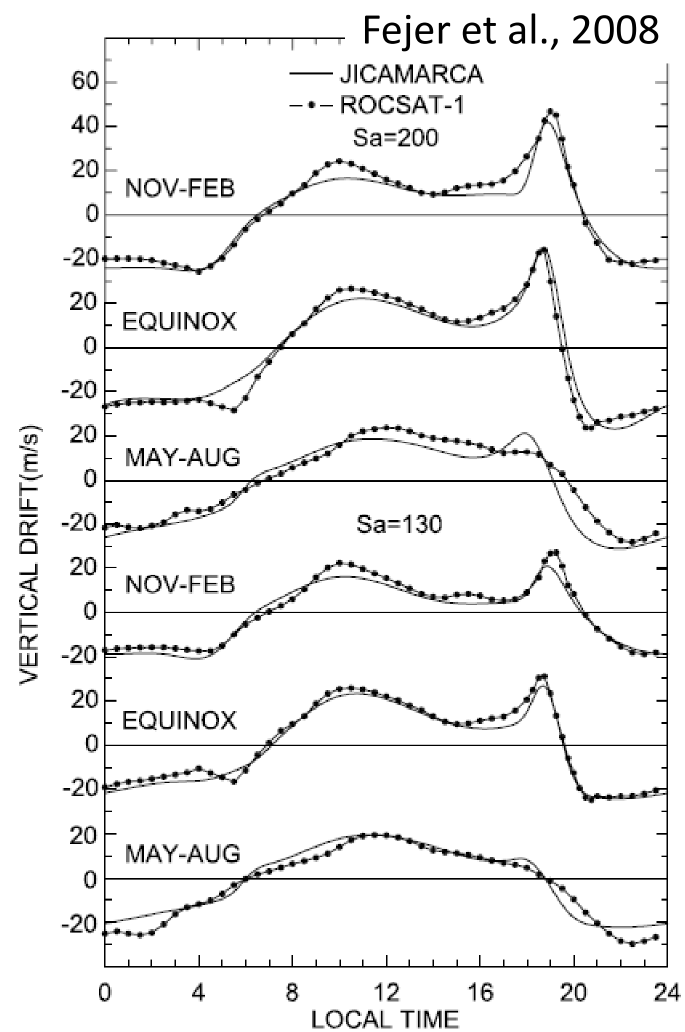
- IRI model: NO+=0 when height is >300 km as indeed it is close to zero for practical purposes

Equatorial Vertical Ion Drift

Addition to IRI-2020

Quite time F region
[empirical model based on Formosat-1 observations]





- Error of drift measurement ~10% (Ni>10^3 & O^+ >85%)

Summary

- Present study shows that the IRI model reproduces monthly variations of top-side ionospheric state (Ion Density, Temperature and composition) with a good agreement with in-situ observations from FORMOSAT-1 satellite. However, there are region dependent bias and error, which vary for different ionospheric parameters.
- Under estimation of H+ (& over estimation of O+) by the model over southern mid latitude (-50 to 100E) could be due to downward drift of plasma having higher fractional H+.
- Relatively higher NO+ over is seen over ESF region probably due to turbulence during spread-F pushing the low-altitude plasma to higher altitude. However, mechanism behind this NO+ enhancement need to be investigated further.

Parameter	Bias (Model – Observation)	R^2	RMSE
Ion Density	-50 to +50 %	0.70–0.95	0.01 – 5 x 10^5 (cm^{-3}) [maximum 50%]
Ion Temperature	5 to 25%	0.3 (equatorial anomaly region) – 0.9	100 – 250 K [maximum 15%]
Composition O+ H+ He+	 -2 to +8 % -5 to +3 % -6 to 0 %	 0.6 – 0.9 0.6 – 0.9 0.3 – 0.75	 2 – 14 % 2 – 10 % 1 – 8 %

Acknowledgements

- Formosat-1 observations were obtained from https://cdaweb.gsfc.nasa.gov/pub/data/formosat-rocsat/formosat-1/ipei/

- We acknowledge Su et al., National Central University of Taiwan and the NASA SPDF/Coordinated Data Analysis Web (CDAWeb)

- IRI model was obtained from irimodel.org and we acknowledge various researcher and working group who has contributed to the model.

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Thank you