Neural network model of Electron density in the Topside ionosphere (NET)

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1. Abstract

The Earth's ionosphere affects the propagation of signals from the Global Navigation Satellite Systems (GNSS). Due to the non-uniform coverage of available observations and complicated dynamics of the region, developing accurate models of the ionosphere has been a long-standing challenge. Here, we present a Neural network-based model of Electron density in the Topside ionosphere (NET), which is constructed using 19 years of GNSS radio occultation data. The NET model is tested against in situ measurements from several missions and shows excellent agreement with the observations, outperforming the state-of-the-art International Reference Ionosphere (IRI) model by up to an order of magnitude, especially at 100-200 km above the F2-layer peak. The NET model depicts the effects of numerous physical processes governing the topside dynamics and can have wide applications in ionospheric research.

2. Model workflow

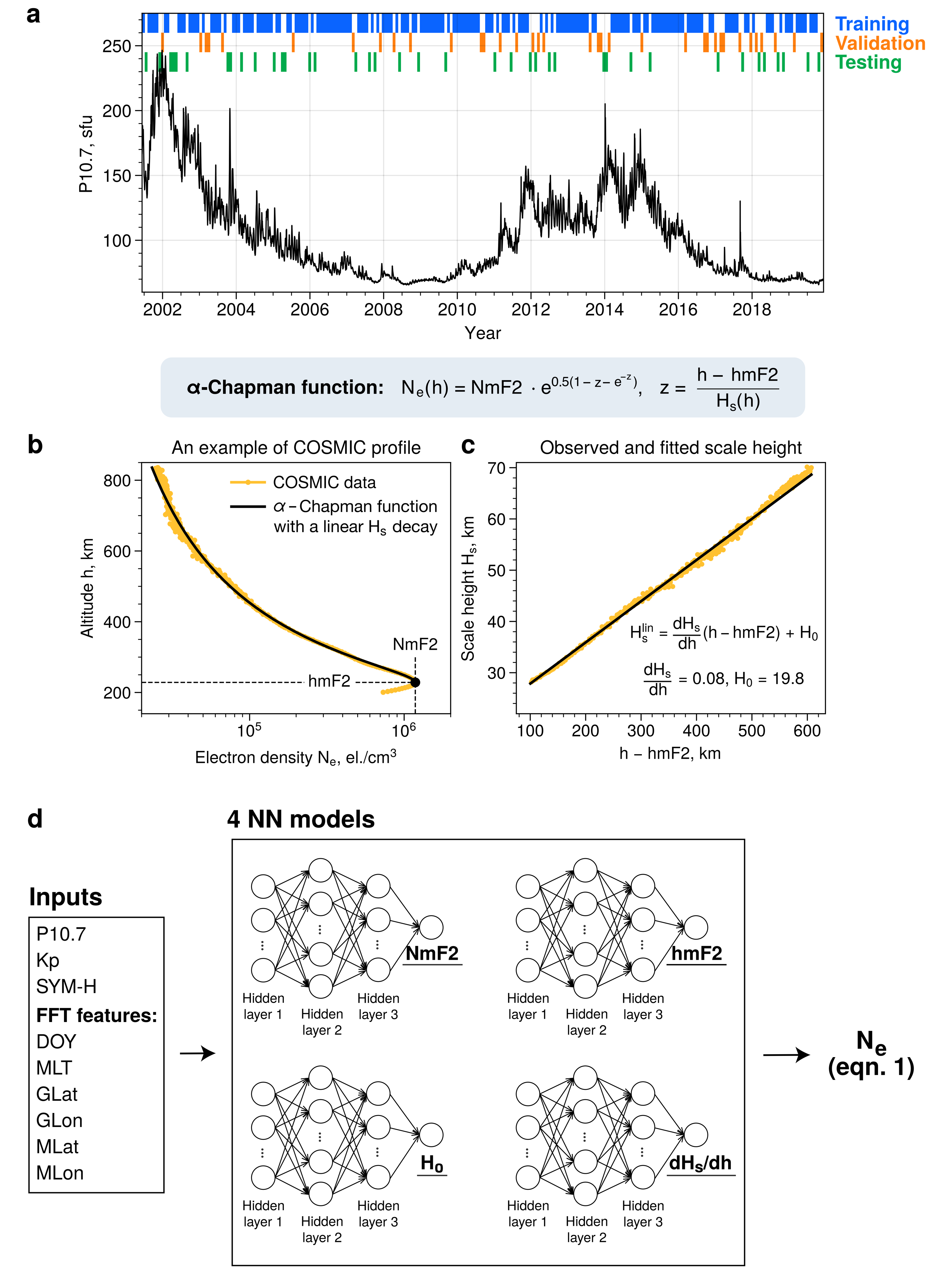

Figure 1. (a) Distribution of the P10.7 index and the data splitting; (b) An example of the COSMIC profile (orange) and the fitted data using the alpha-Chapman function with a linear decay of scale height with altitude (black); (c) Observed scale height and the linear fit; (d) Schematics of the model workflow.

3. Model comparison with COSMIC data

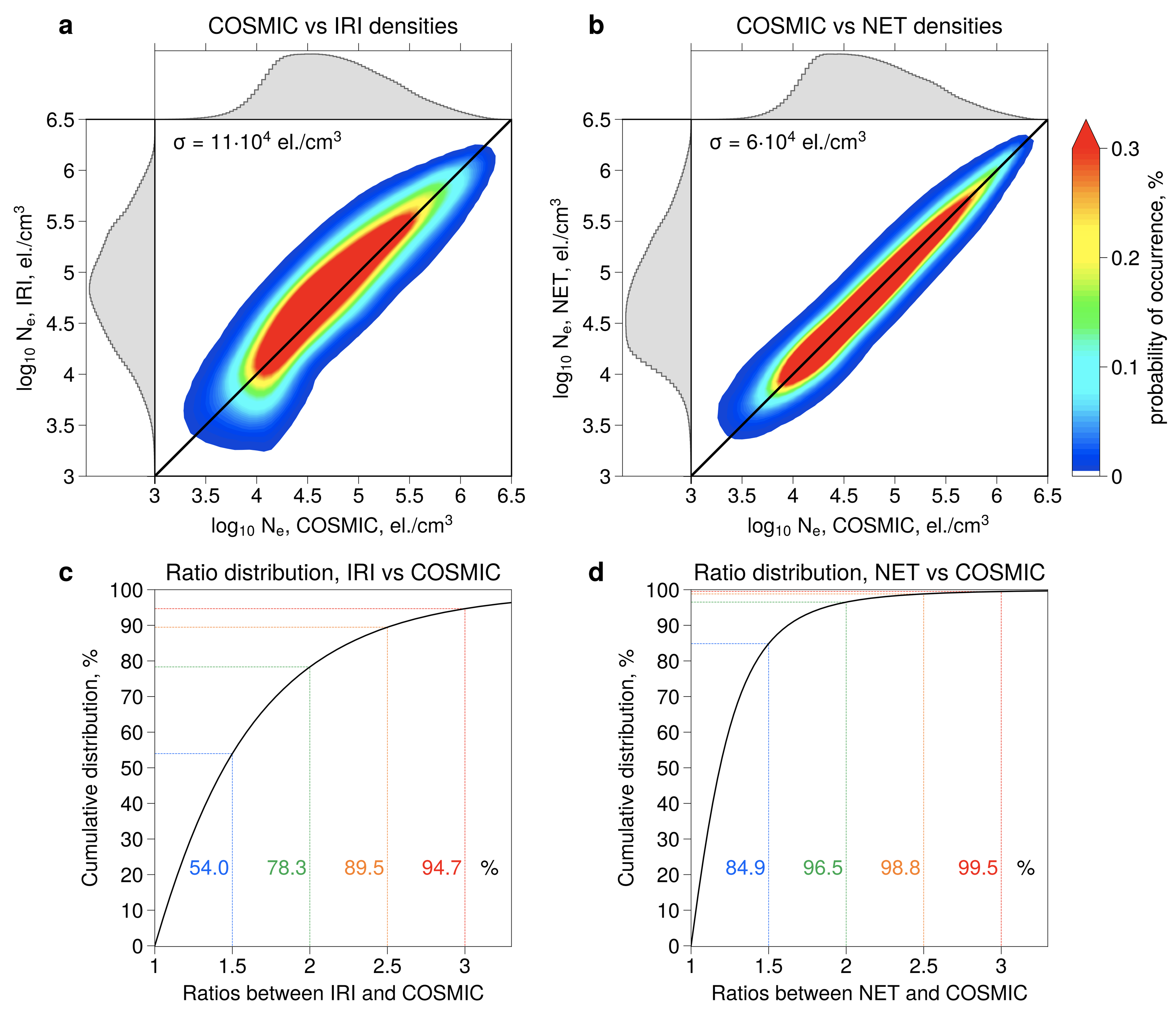

Figure 2. 2D histograms of electron density observed by COSMIC on the test set versus those predicted by the IRI model (a), and the developed NET model (b). (c) Cumulative distribution of ratios between the IRI model and the COSMIC data on the test set; (d) Cumulative distribution of ratios between the developed NET model and the COSMIC data on the test set.

4. Maps of predicted and observed parameters

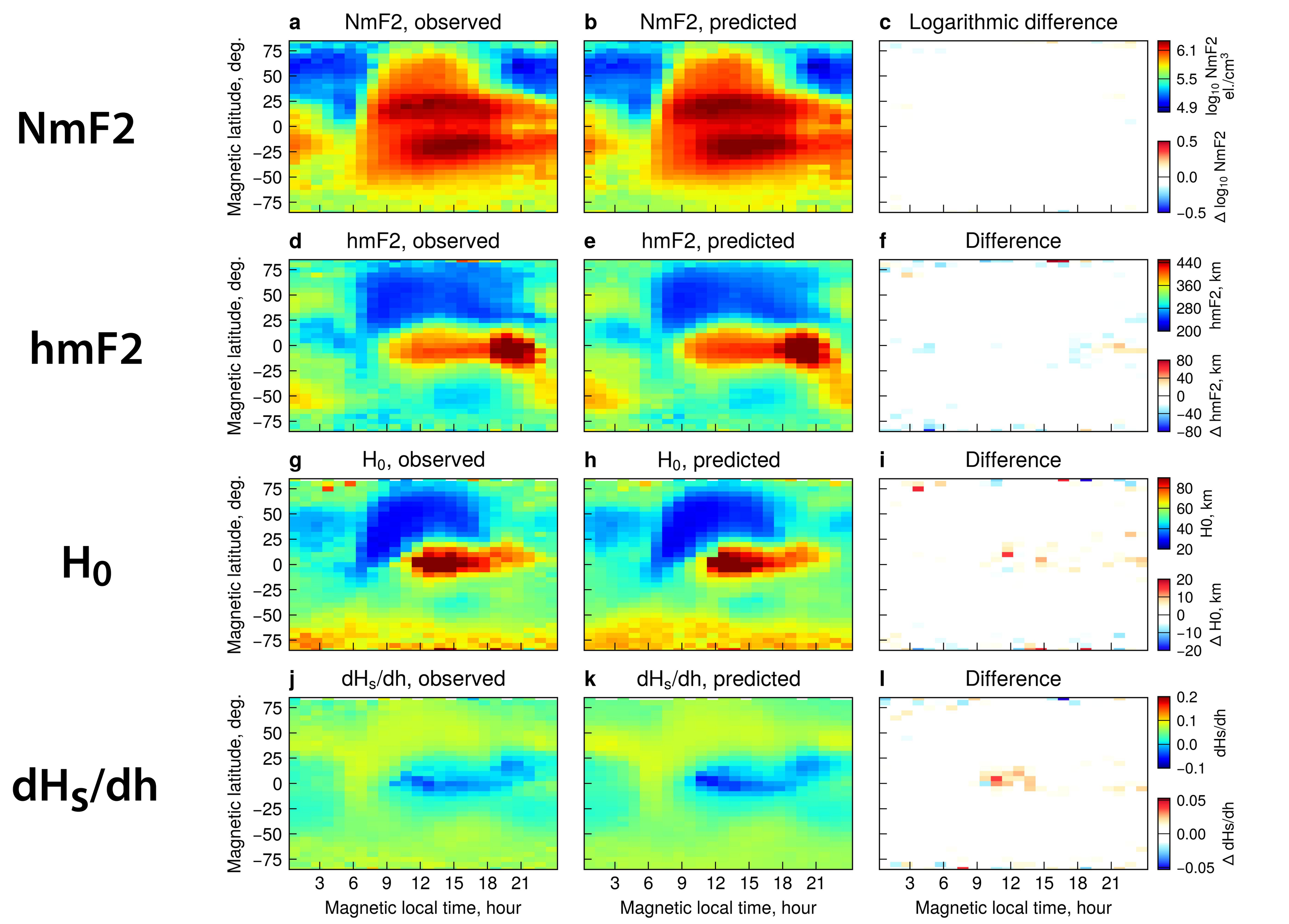

Figure 3. Maps of the four parameters observed by COSMIC and predicted using the NET model, binned by magnetic latitude and local time. The data cover the time interval from 11/2013 until 02/2014 (D-season conditions), and are sampled from the validation and test sets.

5. Vertical model residuals

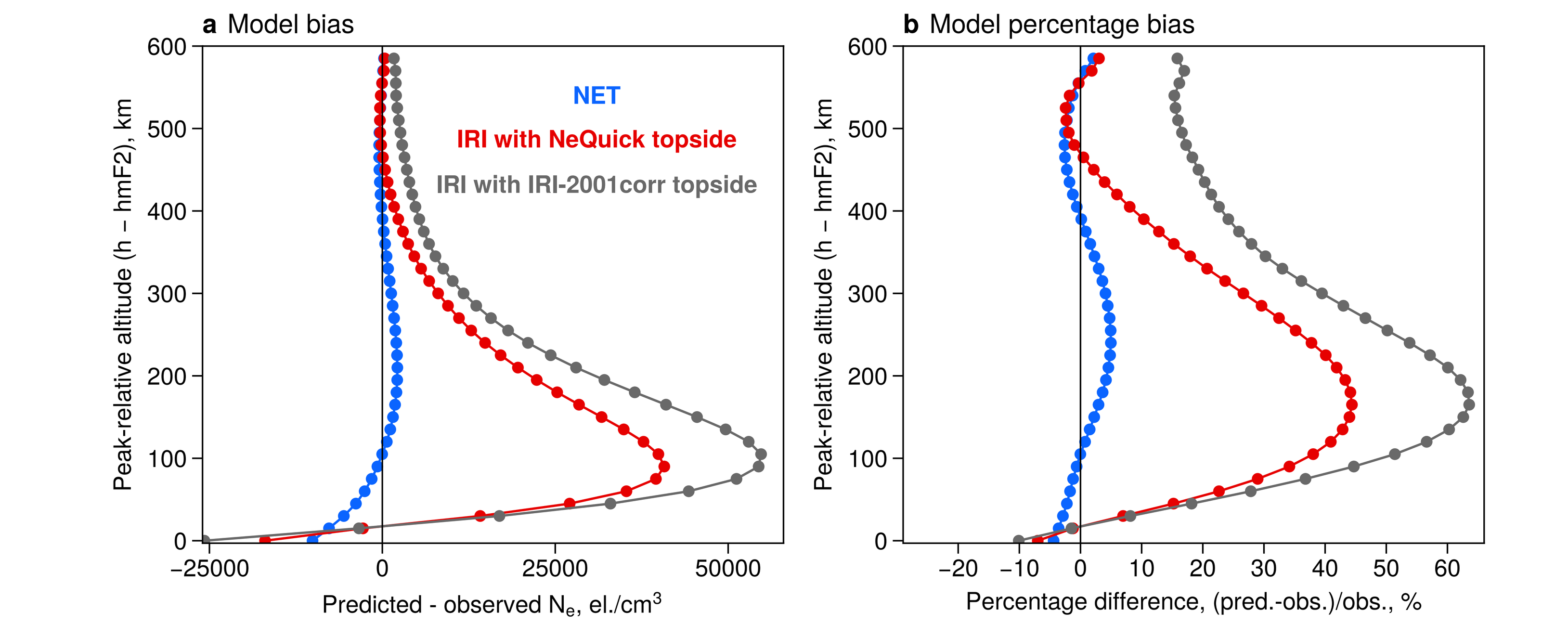

Figure 4. Median bias (a) and median percentage bias (b) versus altitude relative to the F2-peak, calculated on the test set of the COSMIC data. Biases of the developed NET model are plotted in blue. Vertical residuals of the IRI-2016 model are shown in red for the NeQuick topside option, and in grey for the IRI-2001corr topside shape.

6. Model testing on GRACE/KBR data

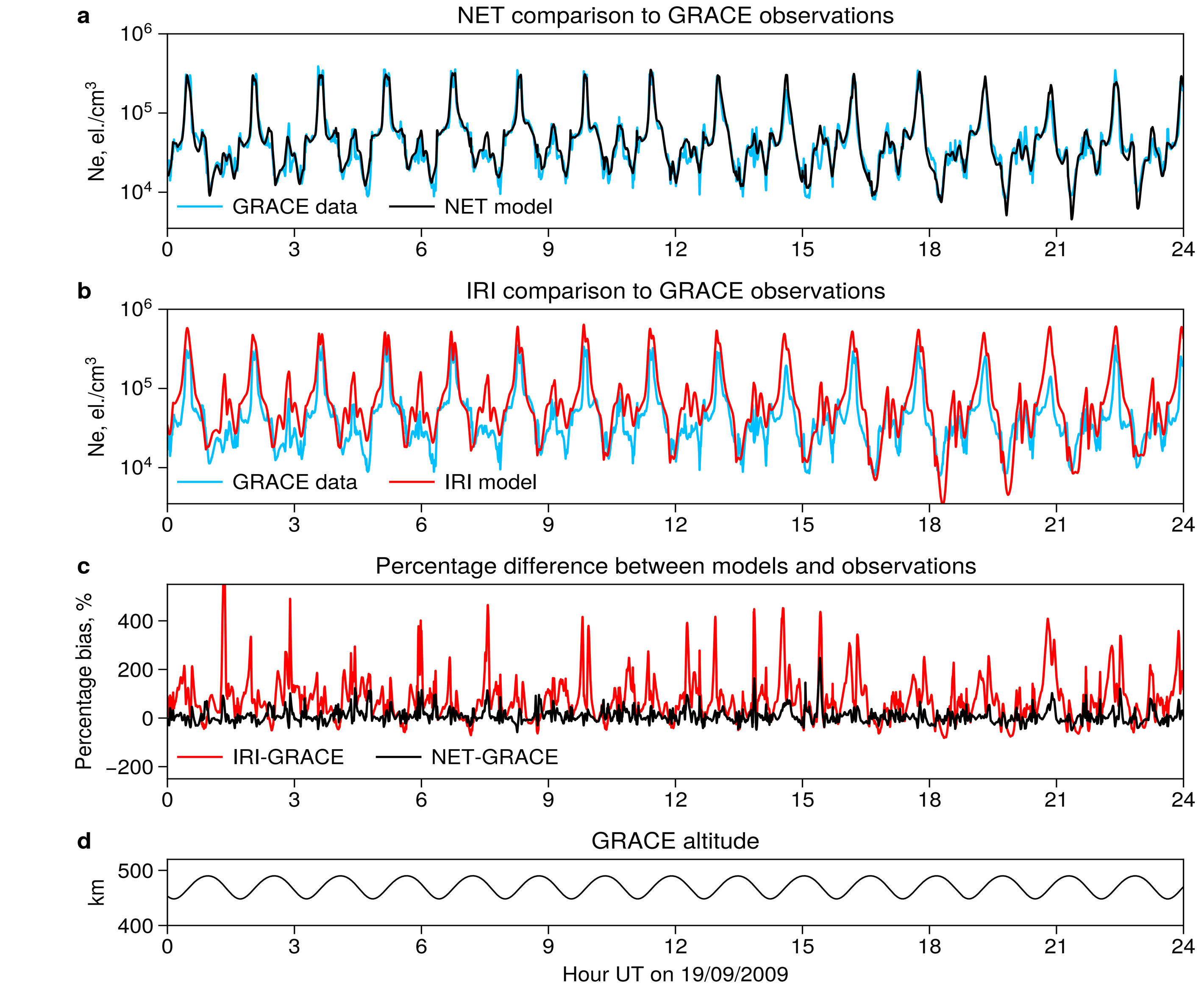

Figure 5. GRACE/KBR electron densities compared to the NET and IRI predictions on one of the days from the test set

7. Conclusions

- A new model of the topside ionosphere has been developed. The NET model uses feedforward neural networks to reproduce NmF2, hmF2, slope and intercept of the linear scale height decay with altitude
- The model gives highly precise electron density predictions, with near-zero bias for all seasonal and solar activity conditions
- The NET model has been extensively validated on independent in-situ data sets from CHAMP, GRACE and C/NOFS missions, showing excellent performance
- The model can be applied to reconstruct specific space weather events, calibrate data sets with unknown baseline offsets, as a background model for ionospheric tomography, and can become a new topside option for the International Reference Ionosphere
- The NET topside profiles can be extended into the plasmasphere to GNSS altitudes and beyond

REFERENCE: Smirnov, A., Shprits, Y., Prol, F., Lühr, H., Berrendorf, M., Zhelavskaya, I., & Xiong, C. (2023). A novel neural network model of Earth's topside ionosphere. *Scientific Reports*, 13(1), 1303. DOI: https://doi.org/10.1038/s41598-023-28034-z