Long Short-Term Memory Neural Network for predicting Global Ionospheric Total Electron Content 24 hours ahead

Marjolijn Adolfs[1,2], Mohammed Mainul Hoque[1] and Yuri Y. Shprits[2,3,4]

[1] German Aerospace Center (DLR), Institute of Solar-Terrestrial Physics, Neustrelitz, Germany (marjolijn.adolfs@dlr.de)
[2] University Potsdam, Institute of Physics and Astronomy, Astrophysics, Potsdam, Germany
[3] Space Physics and Space Weather, Geophysics, GFZ German Research Centre for Geosciences, Potsdam, Germany
[4] Department of Earth, Planetary and Space Sciences, University of California Los Angeles, Los Angeles, USA

1. Abstract

- A long short-term memory (LSTM) network architecture is utilized to make 24-hour ahead global ionospheric total electron content (TEC) predictions trained on the rapid UQRG*1 global ionosphere maps (GIMs) comprising a period of two solar cycles (1998-2020).
- We investigated the LSTM performance using proton density, solar wind forcing parameters, interplanetary magnetic field components, ionospheric disturbance index SYM-H, solar radio flux index F10.7 and geomagnetic activity index Hp30 as external model drivers.
- The model's performance was analyzed for a test dataset (excluded from the training data) containing quiet and geomagnetic storm days together with a low and high solar activity period.
- The model's near real-time (RT) performance was tested using the combined RT products of the international GNSS service (IGS), e.g. IRTG*2 GIMs and compared to another neural network (NN)-based method (feedforward NN (FNN)) and the Neustrelitz TEC model (NTCM).

2. Data and Model

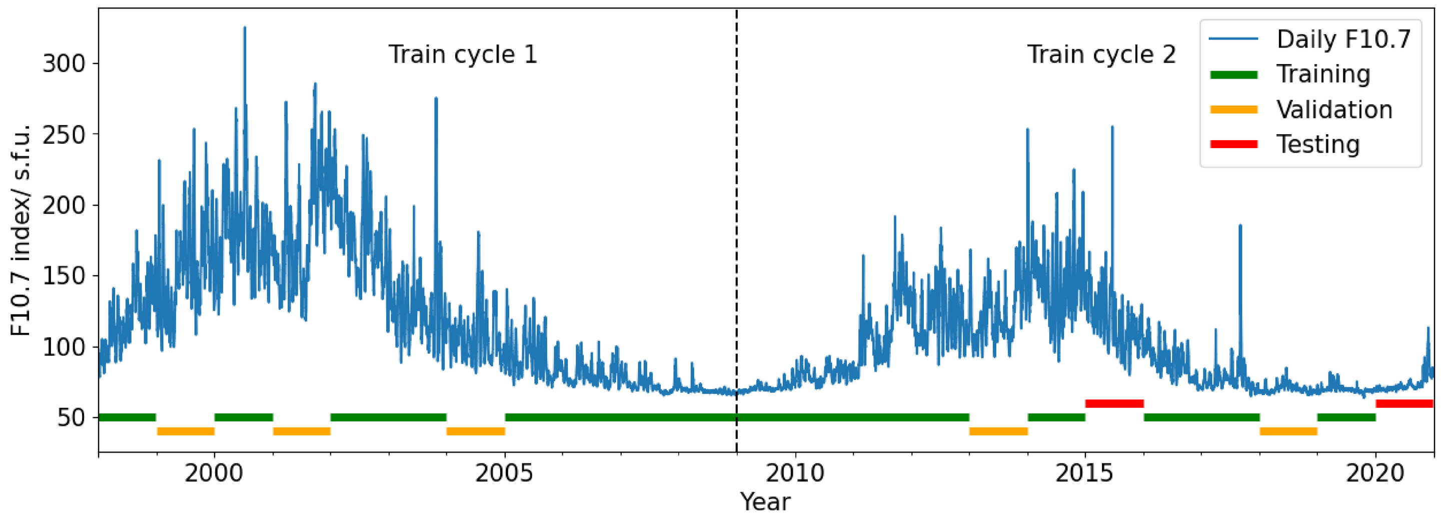

Figure 1: The F10.7 plotted together with the division of training, validation and testing datasets. The training cycles are also shown where the final model is trained first with data from training cycle 1 and retrained with data from training cycle 2.

FLARE model

Fast **L**stm-b**A**sed **R**eal-time model of total **E**lecton content

Model input parameters

- 3-day historical TEC
- geographic longitude
- geographic latitude
- universal time (UT)
- day of year (DOY)

→

Output

- Up to 24-hour TEC

3. Model Performance UQRG GIMs

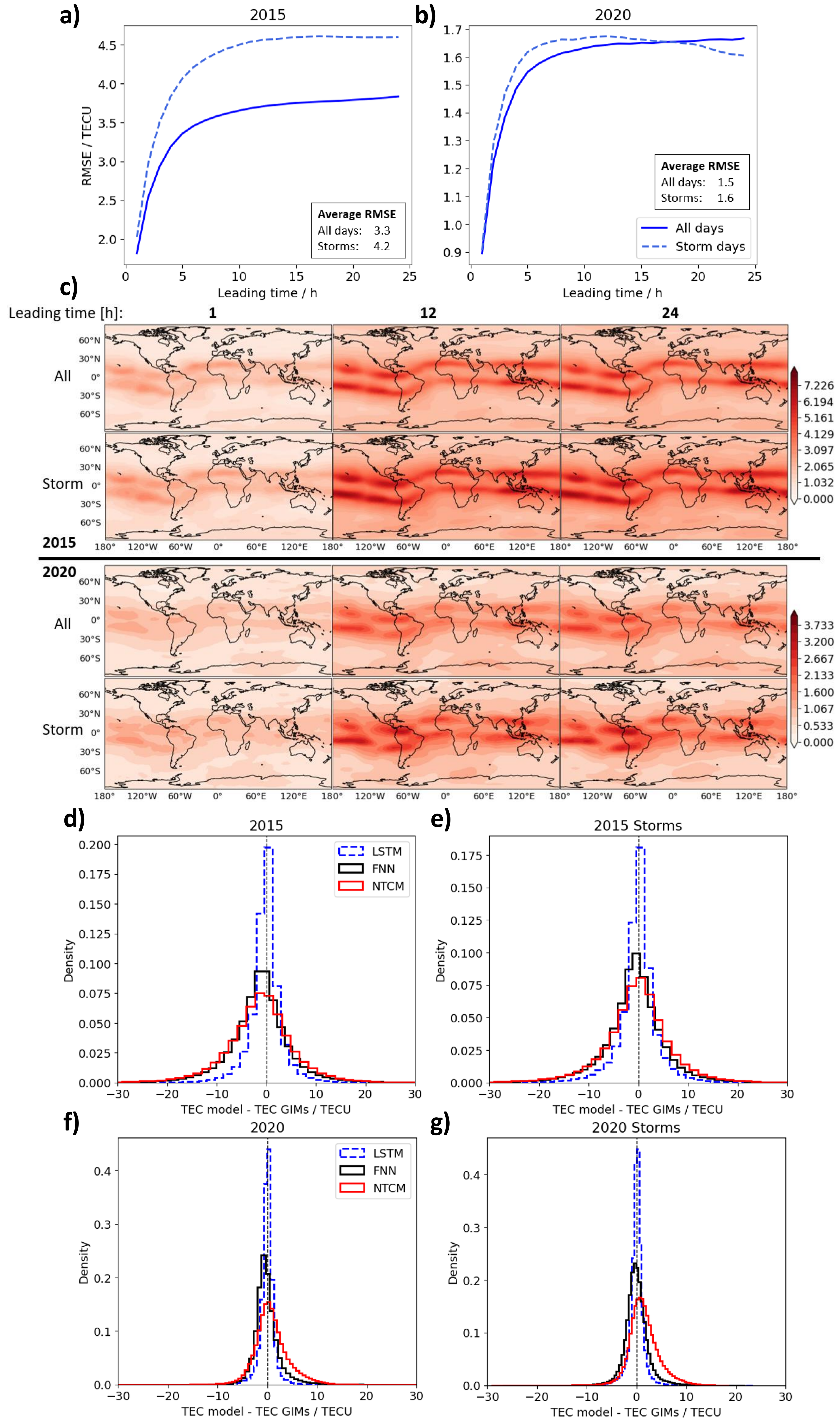

Figure 2: An overview of the model's performance using the UQRG GIMs as input for the historical TEC. Panel a) shows RMSE values plotted against the leading time for all days and storm days in 2015 (high solar activity). Panel b) shows the same but for the year 2020 (low solar activity). The global RMSE for the complete years (2015 and 2020) and during storm days are shown in panel c). Panel d) shows the histograms of the residual errors in 2015 for all days and panel e) during storm days for the LSTM, FNN and NTCM predictions. The same is plotted in panels f) and g) but for year 2020.

4. Near Real-Time Performance IRTG GIMs

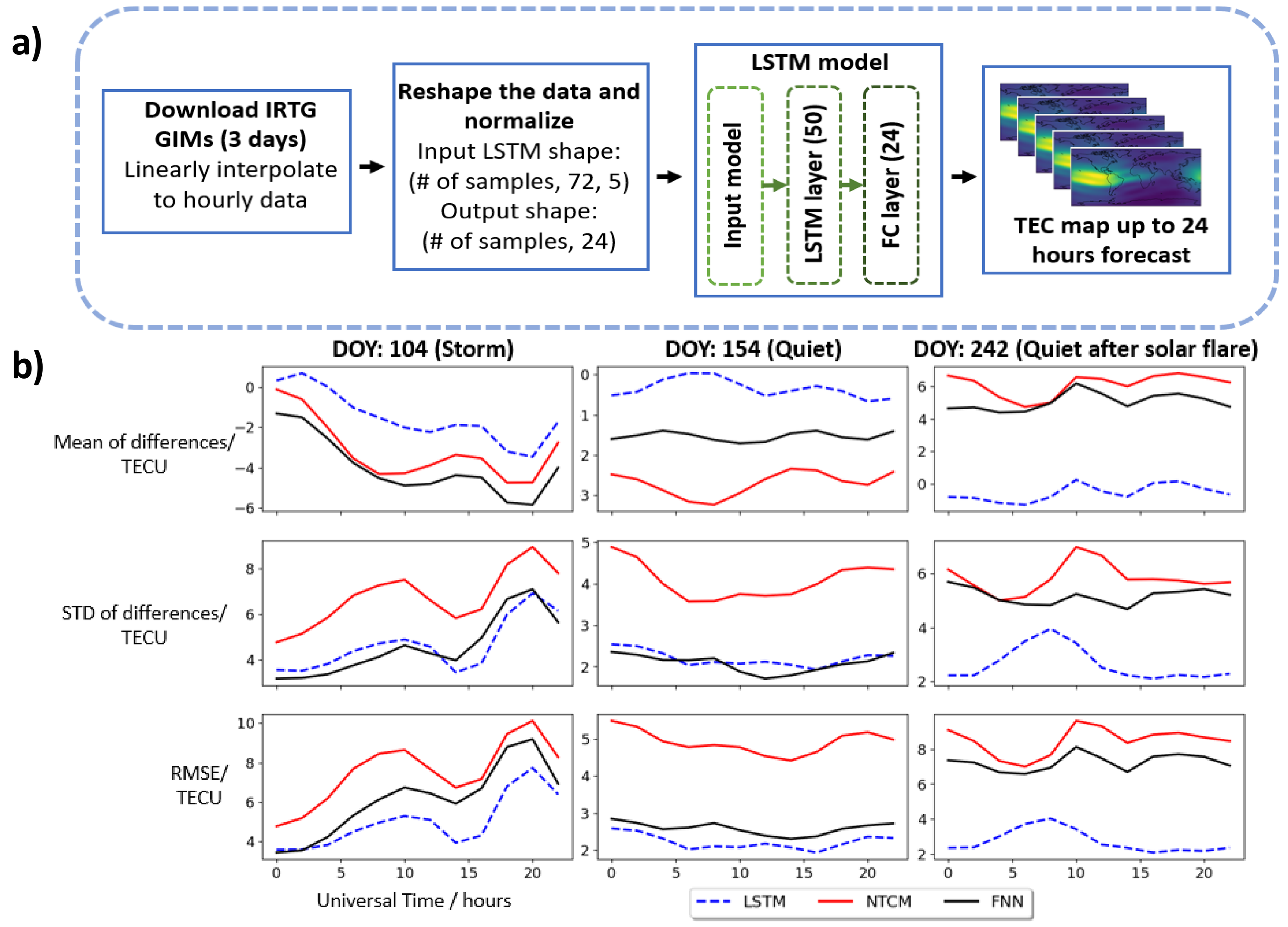

Figure 3: The near real-time performance of the LSTM-based model is shown in this overview where the IRTG GIMs are used as input for the 3-day historical TEC. In panel a) the workflow is shown together with the model's architecture where the number of neurons, in case of the LSTM and fully connected (FC) layer are shown between the brackets. In panel b) the performance is shown in terms of mean, standard deviation and RMSE of the differences for the LSTM-based, FNN-based and NTCM model for the 14th of April (104), 3rd of June (154) and 30th of August (242) in 2022.

5. Conclusion

- The developed FLARE model only uses the historical TEC data from the past 3 days, UT, longitude, latitude and DOY as model inputs. FLARE showed good performance during a high and low solar activity year (i.e., 2015 and 2020) as well as during quiet and geomagnetic storm conditions.
- Including additional drivers did not improve the accuracy of the model significantly.
- The model showed the worst performance during storm days in 2015. However, the performance during storm conditions in 2020 was almost the same compared to all data during the same year.
- Different GIMs were used for the 3-day historical input (UQRG and IRTG). Using the RT GIMs the model's application in near real-time applications has been shown.
- The FLARE model was significantly outperforming the FNN-based model and NTCM for both cases, e.g. using the IRTG or UQRG maps where a performance improvement up to several TEC units could be seen.

The images are reprinted from manuscript in review: Adolfs, M., Hoque, M.M. & Shprits, Y.Y. (2024) Forecasting 24-Hour Total Electron Content with Long Short-Term Memory Neural Network. [Manuscript submitted for publication]

*1 UPC Quarter-of-an-hour time resolution Rapid GIMs (UQRG)
*2 IGS combined RT-GIM (IRTG)