Study of Ionospheric Response to Geomagnetic Disturbances Using TEC Regional Maps and the NeQuick 2 Model

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21-24 June 2015 Geomagnetic Storm

- ❑ Major storm (class G4, max Kp =8, min Dst = -198 nT)
- ❑ Southward IMF-Bz
- ❑ Sudden increase in B, Vsw, P, and AE
- ❑ SSC commenced at 18:45 UT

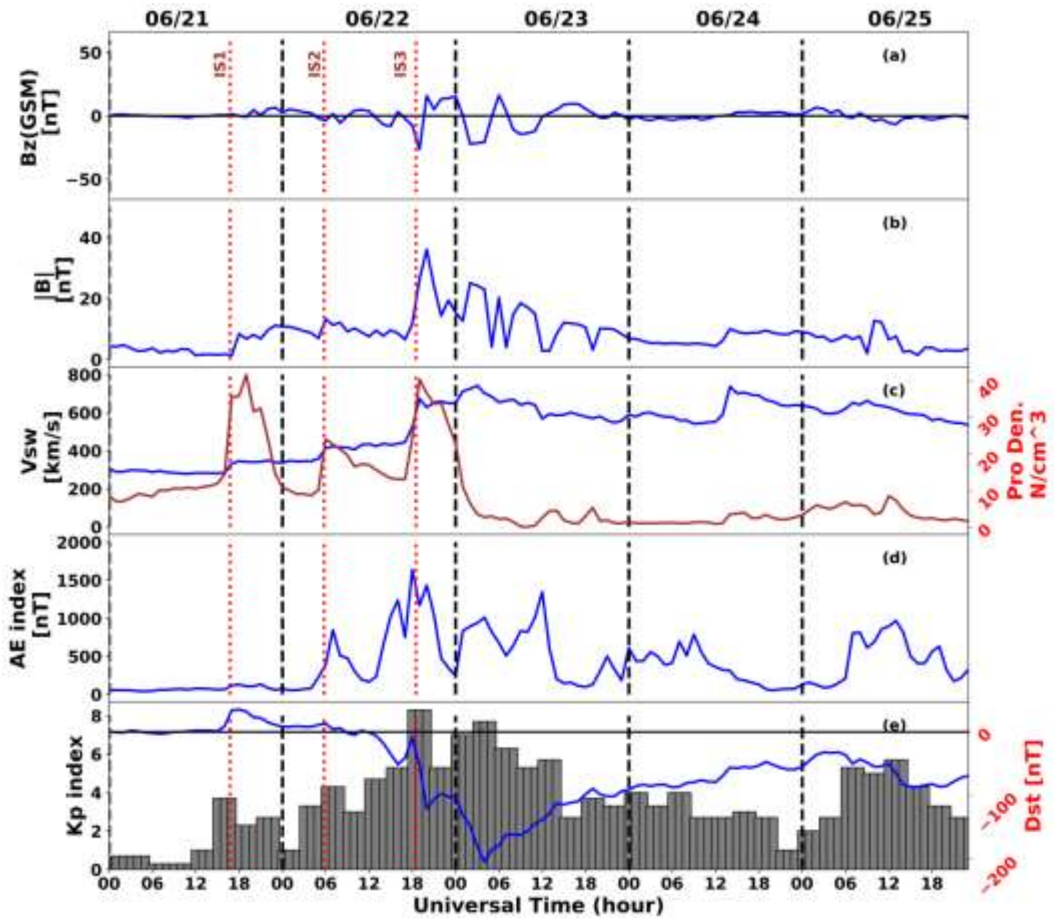
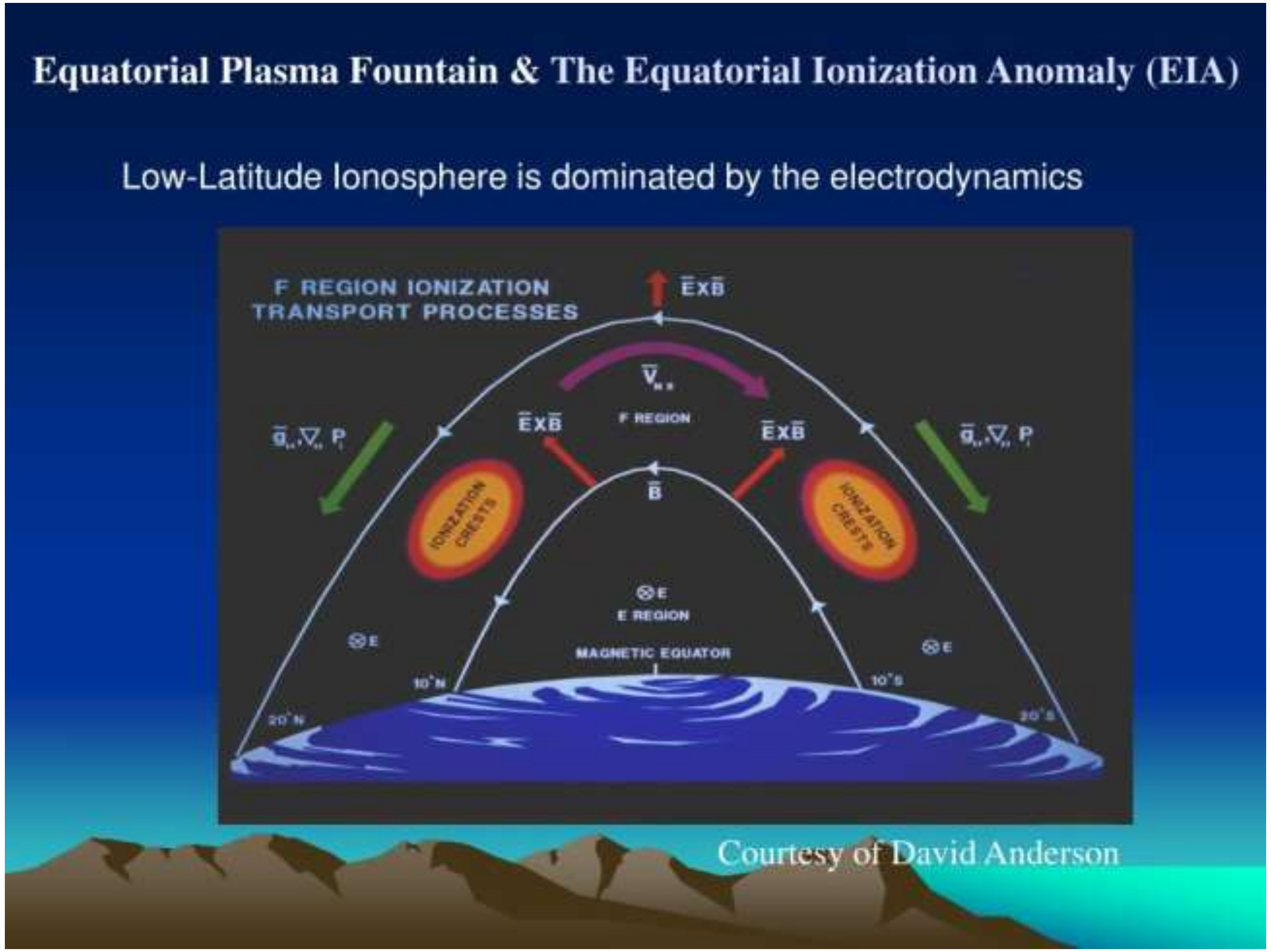


Figure 1: Interplanetary and geomagnetic indexes from June 21 to 24, 2015. (a) The interplanetary magnetic field Bz component (nT), (b) Solar wind speed Vsw (km/s) and Proton Density (N/cm-3), (c) AE index (nT), (d) Dst index (nT), and (e) Kp index

Motivation: The Low-Latitude Ionosphere



Dataset of GNSS and Digisonde

- ***foF2*** from **2 Digisondes** located over Brazil
- 4 GNSS test stations
- $$\Delta TEC\ (Az) = \sqrt{\frac{\left(\sum_{i=1}^{N}\left(TEC_{GNSS} - TEC_{NeQuick}(Az)\right)^2\right)}{N}}$$

(Osanyin et al., 2023)

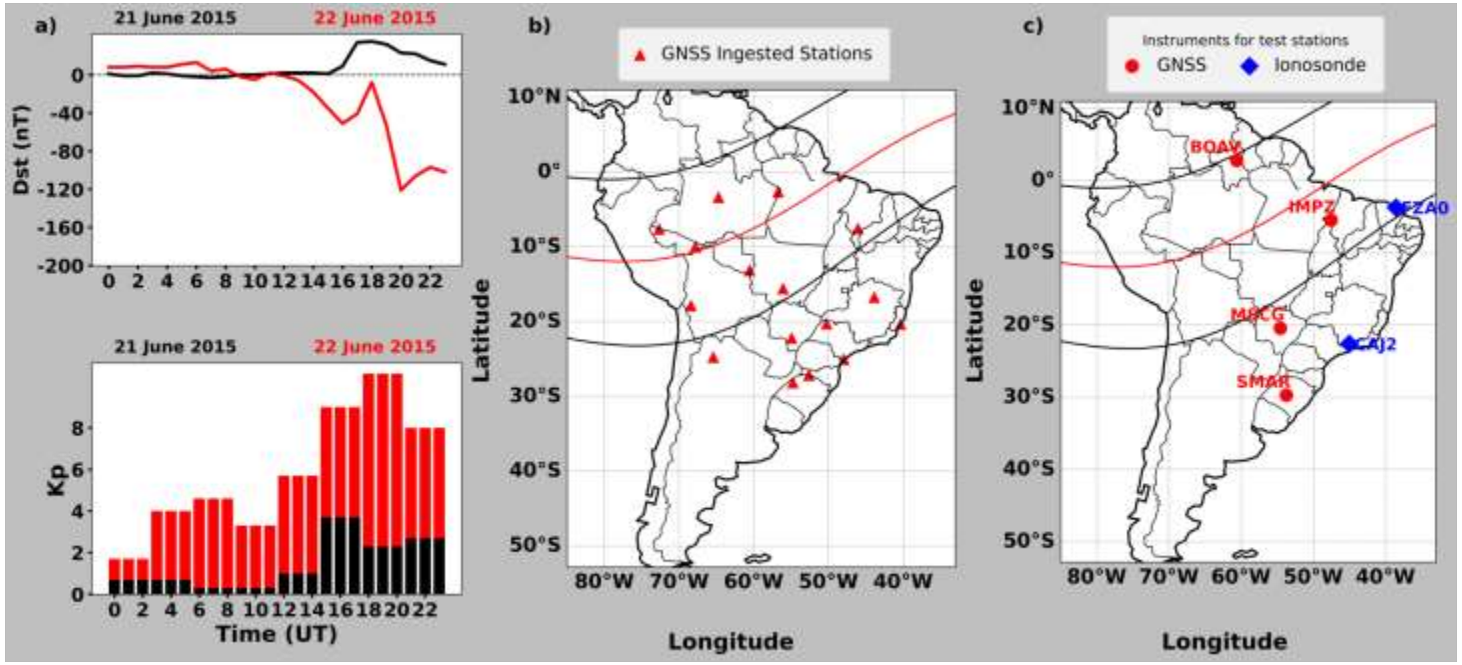


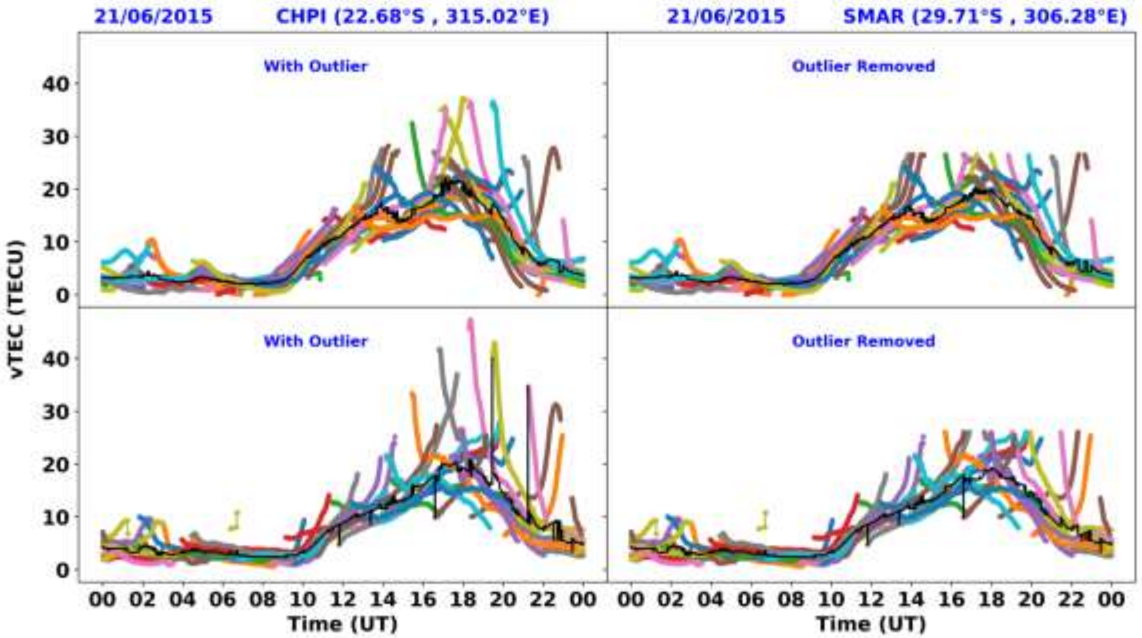
Figure 2: Variation of (a) Dst and Kp indices, (b) location of GNSS ingested stations, (c) test stations used for validation where red markers represents GNSS and blue markers are for the digisonde stations. The red and blue lines in (b) and (c) depicts the geomagnetic equator and dip latitude for the year 2015 respectively.

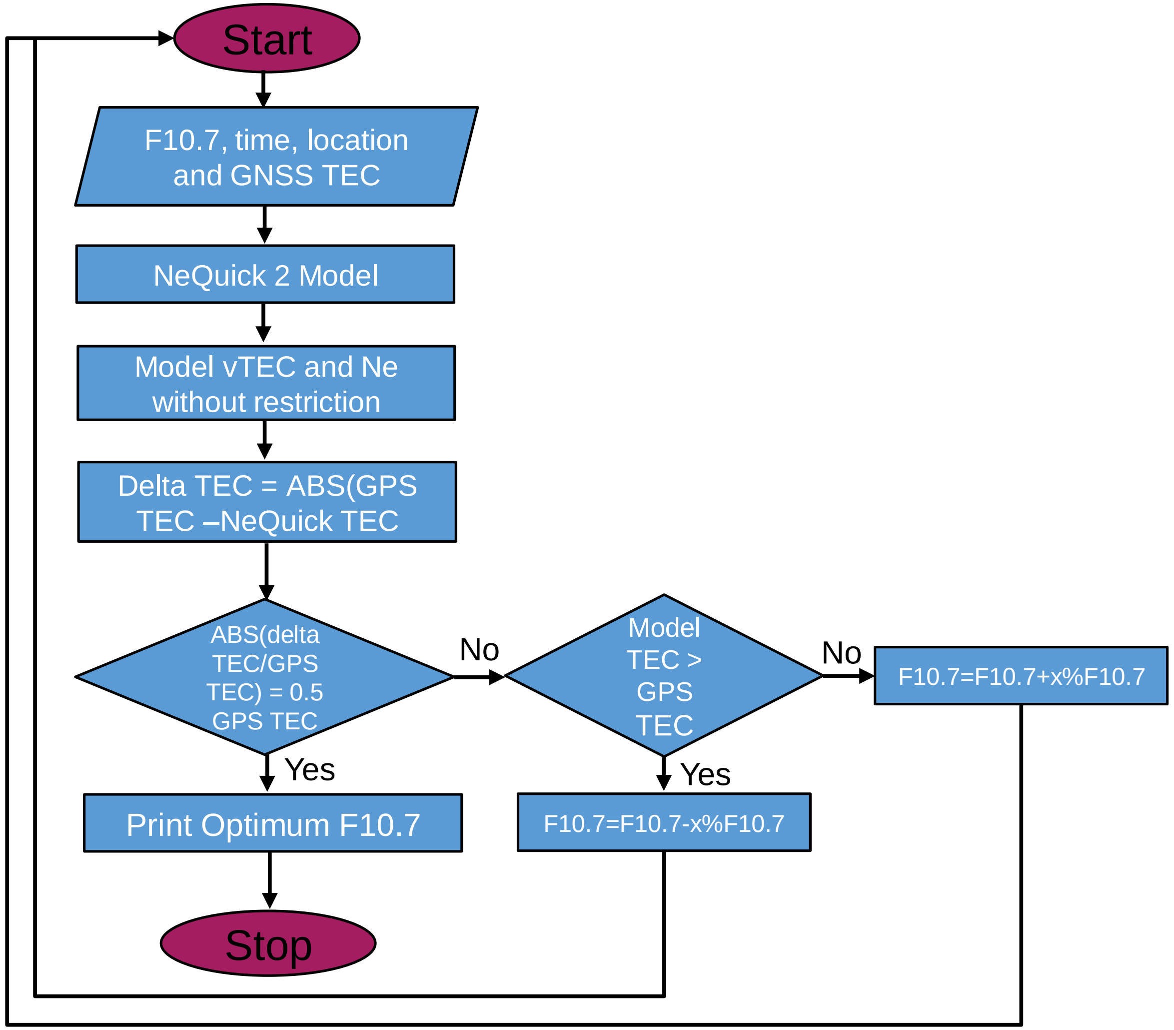
TEC Processing and TEC data ingestion

- The Gopi Seemala software(version 2.9.9)
- The Median Absolute Deviation (MAD) technique:

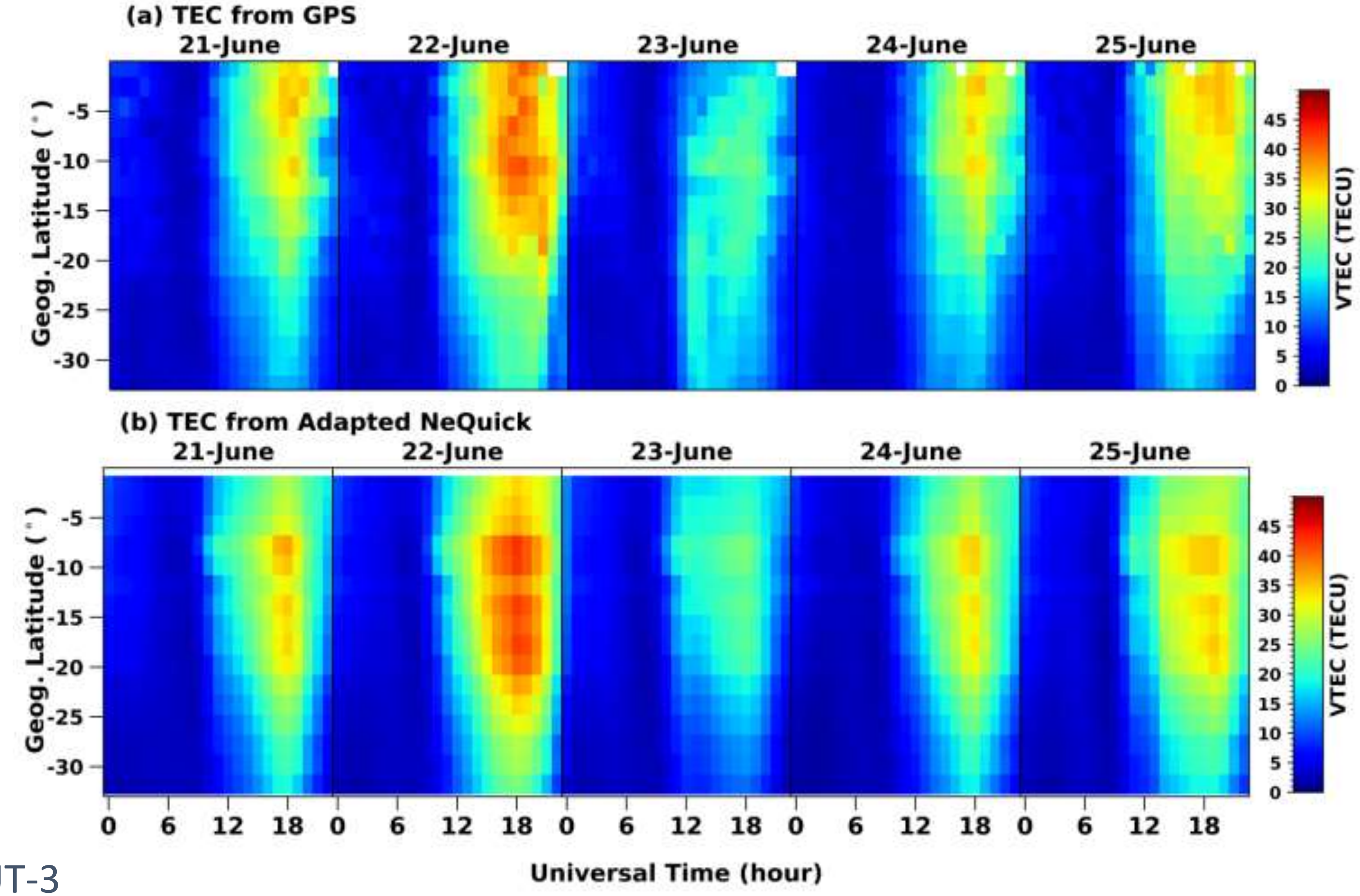
  $\sigma = 1.4826 * med \{|x_i - med\{x_j\}|\}$ (Huber & Rochentti, 2009)

- An elevation above 30 degrees.





Spatio-Temporal Variation of TEC



LT = UT-3

Figure 3: Variations of ionospheric VTEC (a) from GPS and (b) from Adapted NeQuick 2 model values in the low latitude region from June 21 to 24, 2015.

- Strong TEC enhancement on SSC
- NeQuick reproduces Ionospheric variability during the storm period.

TECMAPs from GNSS and NeQuick on 21/06/2015

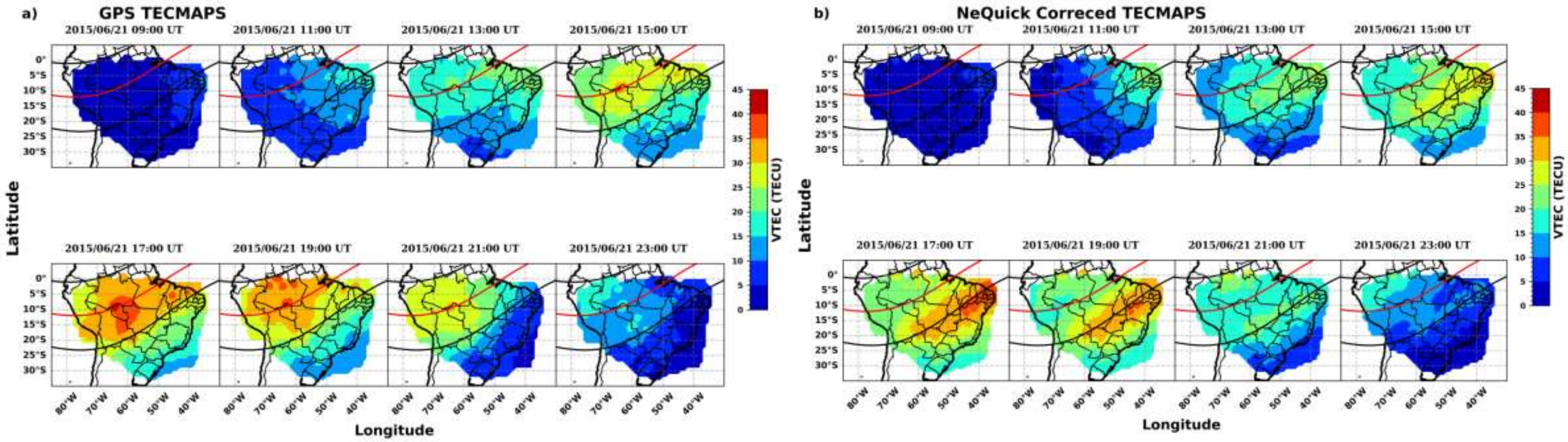


Figure 4: Sequence of TEC MAPS produced over Brazil during geomagnetically quite period at 2-hours interval from 9:00 UT to 23:00 UT from (a) GPS observation, (b) Adapted NeQuick. In each panel, the x-axis and y-axis represent geographic longitude and latitude, respectively, and the color scale indicates the TEC in TECU.

TECMAPs from GNSS and NeQuick on 22/06/2015

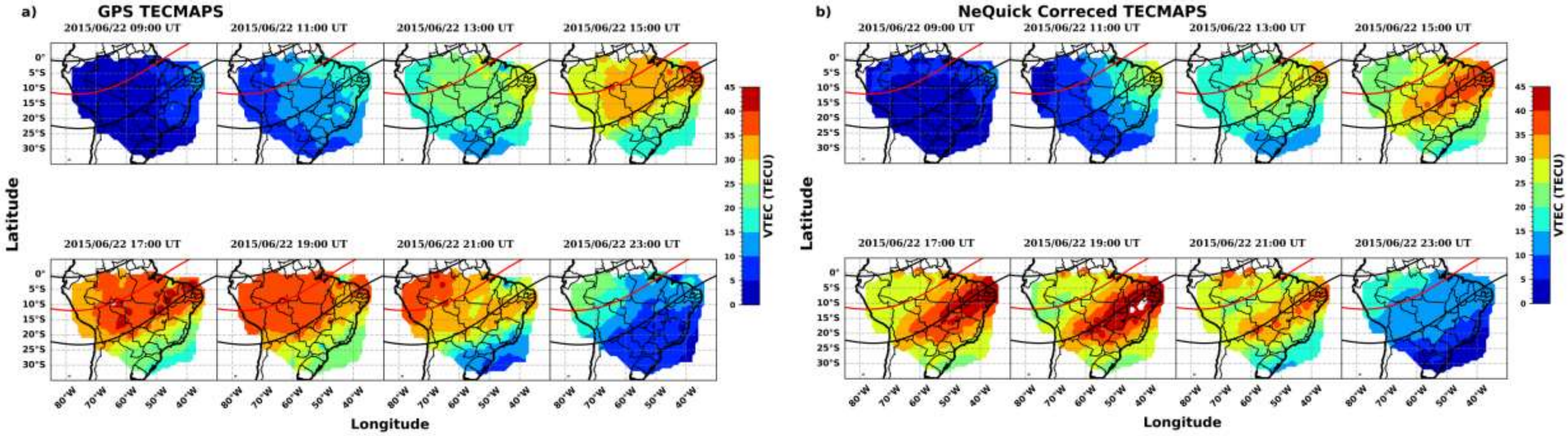


Figure 5: Sequence of TEC MAPS produced over Brazil during geomagnetically disturbed period at 2-hours interval from 9:00 UT to 23:00 UT from (a) GPS observation, (b) Adapted NeQuick. In each panel, the x-axis and y-axis represent geographic longitude and latitude, respectively, and the color scale indicates the TEC in TECU.

Measured vs NeQuick-modeled TEC

At all latitudes, the **NeQuick climatological empirical model** does not represent all the features exhibited by *TEC* when compared to measured values **during both quiet & disturbed conditions**.

- ❑ TEC enhancement on SSC (see BAOV, MSCG & SMAR)
- ❑ TEC reduction beyond SSC
- ❑ RMSE strongly depends on dip latitude

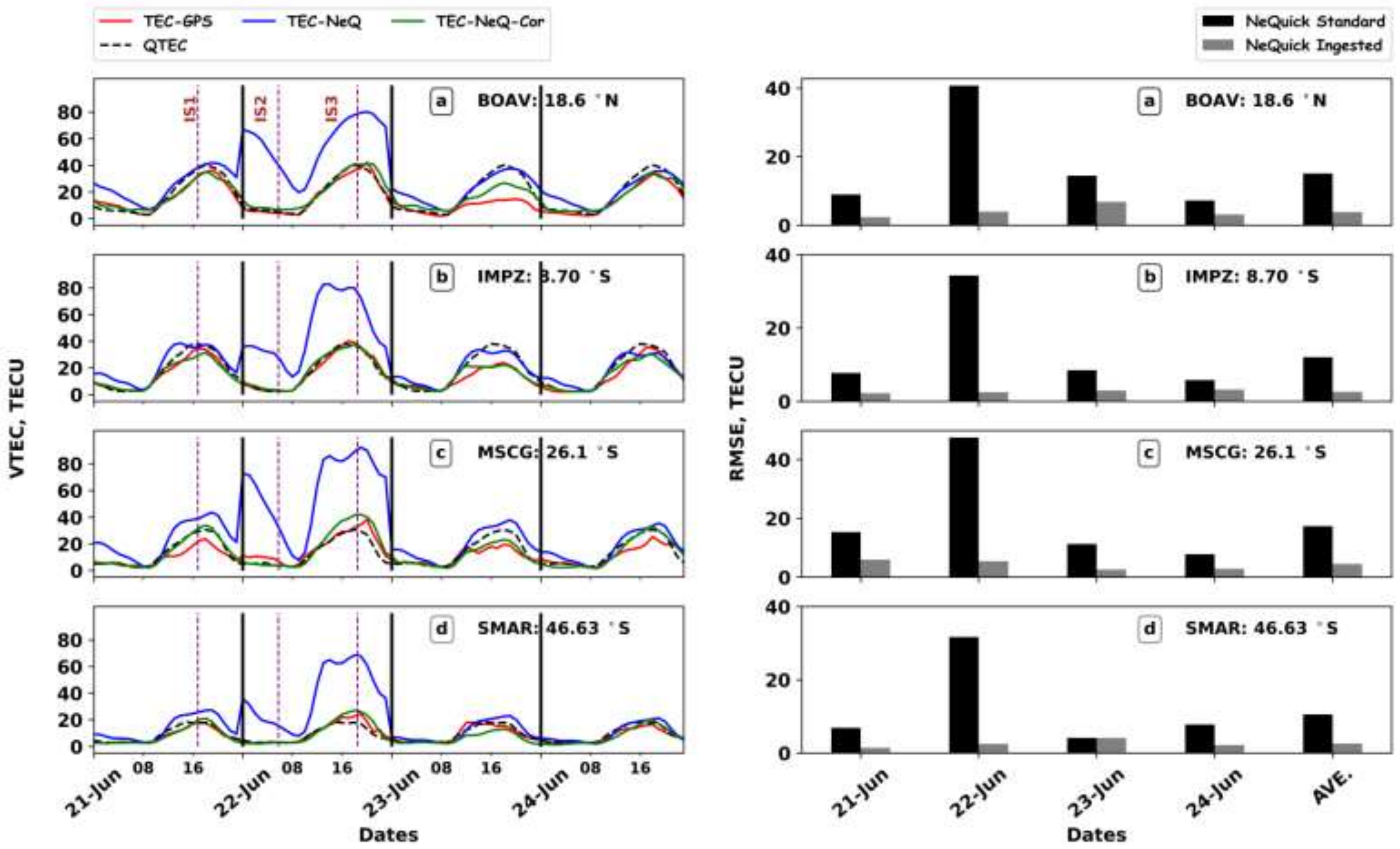


Figure 6: Variations of the ionospheric TEC over four GPS stations from June 21 to 24, 2015.

Measured vs NeQuick-modeled foF2

- Ionospheric variability is captured by data-driven NeQuick;
- TEC enhancement in the Southern crest region;
- RMSE varies with dip latitude.

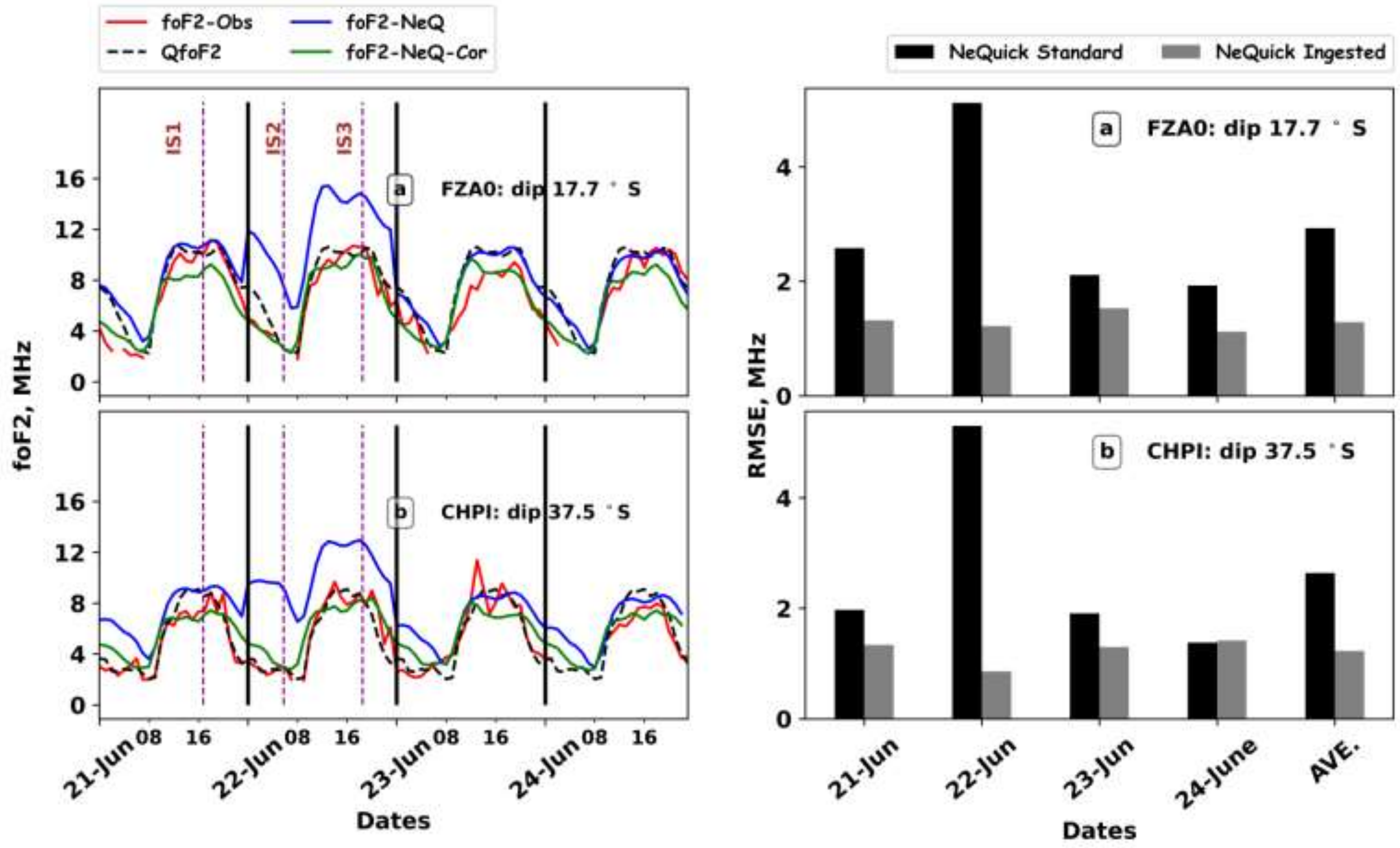


Figure 7: Variations of the ionospheric foF2 over two Digisonde stations from June 21 to 24, 2015.

Percentage Deviation from background

$$\mathbf{L}\ (\%) = \frac{vTEC_{experimental/model} - vTEC_{median}}{vTEC_{median}} \times 100$$

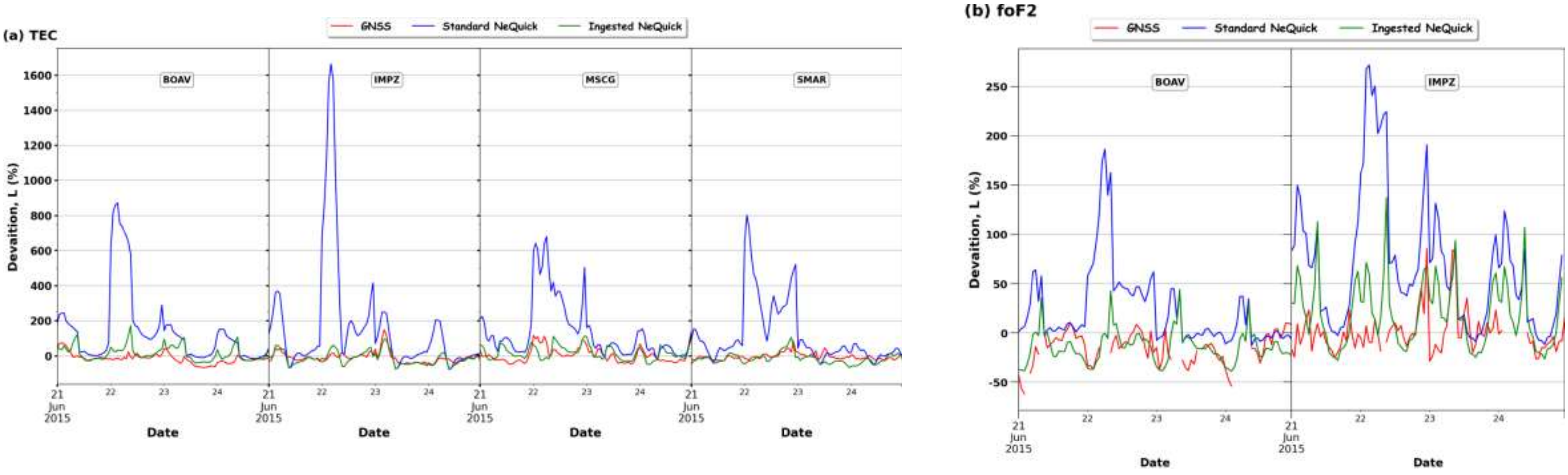


Figure 8: Variation off the relative difference between (a) GNSS/model and (b) Digisonde/model to the average backgound

Conclusion

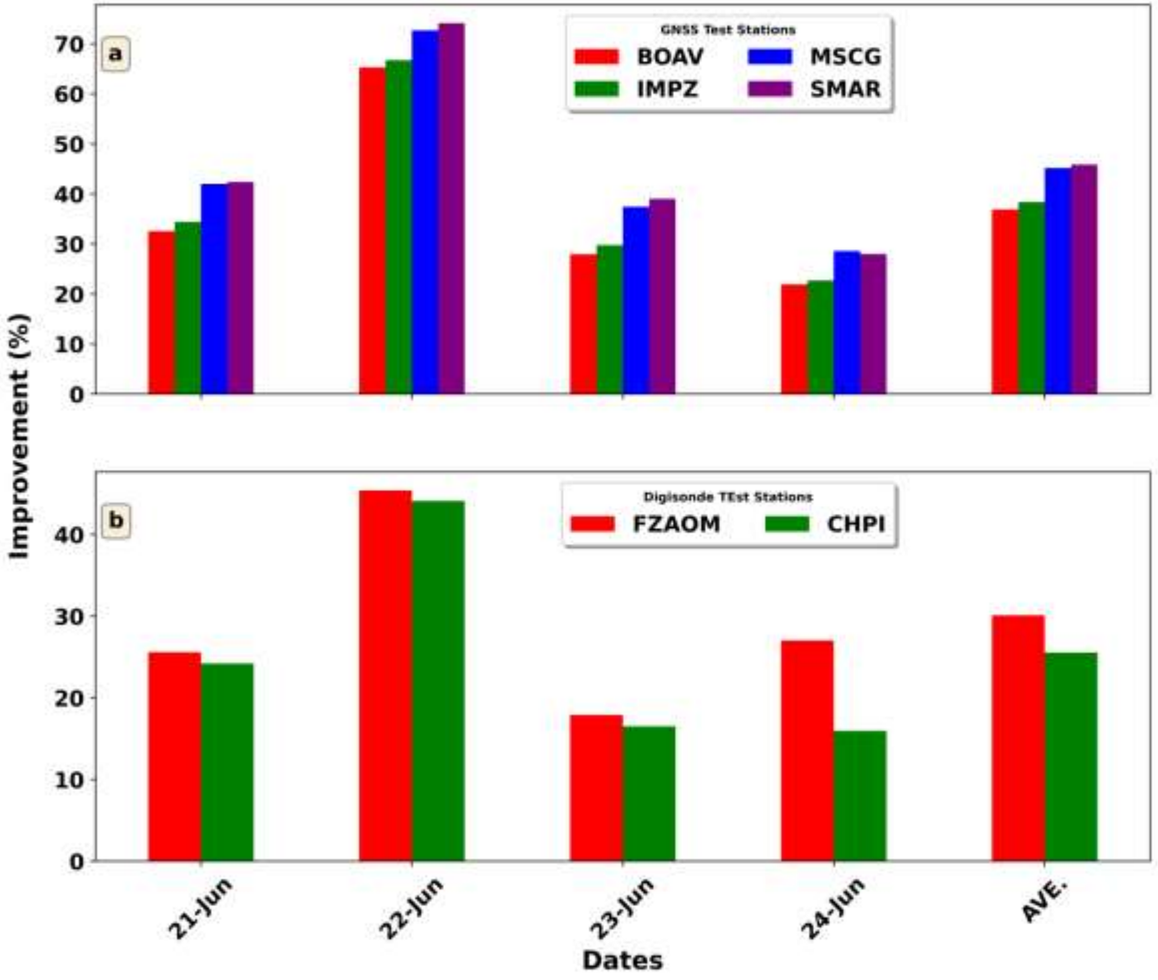


Figure 9: Statistical representation of percentage improvement values for (a) GNSS and (b) Digisonde in the equatorial low-latitude

$$\boldsymbol{Improvement, P}\ (\%) = \frac{RMS_{SN} - RMS_{AN}}{RMS_{SN}} \times 100$$

- Approximately 45 % and 25 % improvements on average in the low-latitude during the storm period for TEC and foF2 were recorded.
- Data-driven NeQuick captures ionospheric variabilty during the daytime.
- Further improvement is needed for the nightside ionosphere.

Acknowledgement & data availability statement

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- The T/ICT4D Laboratory of the ICTP, Trieste, Italy.
- Embrace/INPE for supporting the GNSS data analysis methodology (https://www2.inpe.br/climaespacial/portal/tec-map-home/) and providing the Digisonde data.
- The World Data Center for Geomagnetism, Kyoto, for the Dst index data (https://wdc.kugi.kyoto-u.ac.jp/wdc/Sec3.html), and NOAA for the Kp index and solar radio flux data (//ftp.swpc.noaa.gov/pub/indices/).
- The GNSS ground-based receiver data were collected from different GNSS networks in South America: RBMC from IBGE (https:/)

References

Huber, P. J., & Ronchetti, E. M. (2009). Robust statistics, 2nd edn. hoboken. *NJ: Wiley, doi, 10*, 9780470434697.

Osanyin, T.O., Candido, C.M.N., Becker-Guedes, F., Migoya-Orue, Y., Bosco Habarulema, J., Obafaye, A.A., Chingarandi, F.S., Santos, S.P.M., Performance of a locally adapted NeQuick-2 model during high solar activity over the Brazilian equatorial and low-latitude region, Advances in Space Research (2023), doi: https://doi.org/10.1016/j.asr.2023.07.018.

Thank you!

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Thermospheric Composition

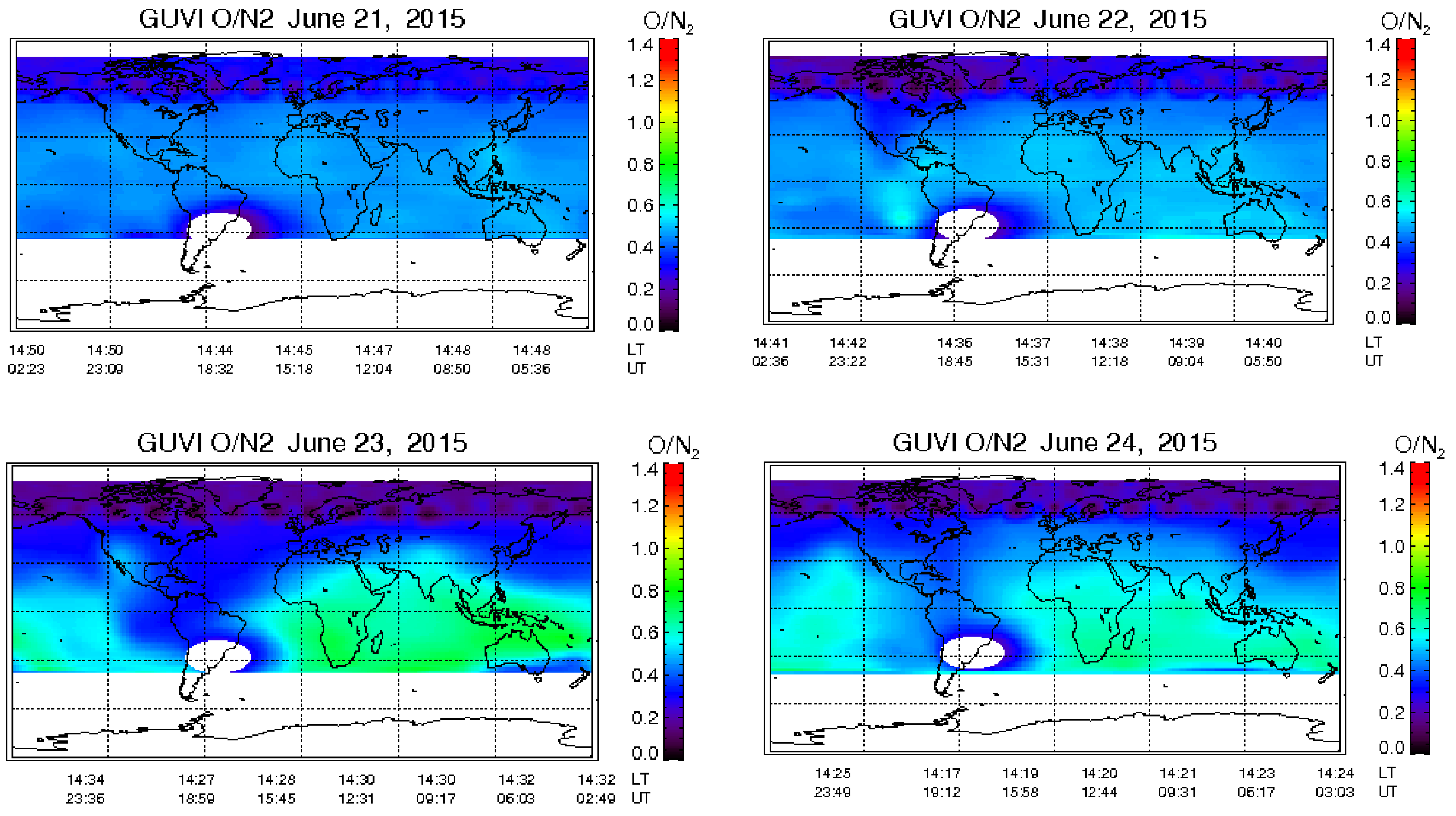

Figure 10: Variation of [O]/[N2] during the storm period of 21-24 June, 2015

- Enhancement in [O]/[N2] on June 22 in the Southern SA region.
- [O]/[N2] depletion on June 23 in the Southern SA region.