Traveling Ionospheric Disturbances (TIDs) Detection using Deep Learning Models

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ABSTRACT & MOTIVATION :

- Both energy and momentum can be transferred from lower atmospheric (Tropospheric) region to upper atmosphere via Atmospheric Gravity Waves (Azeem et. al, 2017). These AGWs can perturb local electron density via ion-neutral collisions and generate Traveling Ionospheric Disturbances (TIDs).
- TIDs are the source of severe scintillations of GNSS satellite and Navigation signals.
- In this study, we focus on concentric TIDs induced by different climatological events like tornadoes, hurricanes, and convective storms.
- We aim to develop deep learning model that can effectively detect these TIDs and extract their characteristics features like wavelength, time period and frequency.
- We also performed some statistical analysis to calculate the wavelength, frequency and time period of these TIDs generated vis convective storm and tornado events.

DATASET USED & METHODOLOGY:

- We use the detrended TEC (dTEC) values obtained from dense GNSS network over the Contiguous US.

Events used:

- **Training Dataset**: April 04, 2014 (Convective Storm)
  October 07, 2016 (Hurricane Matthew)
- **Validation Dataset:** September 19-21, 2022 (Hurricane Fiona)
  August 27-28, 2020 (Hurricane Laura)
- **Test Dataset:** April 28, 2014 (Tornado)
- ***For statistical analysis***, we fixed the latitude of the deep convection center to plot keogram plots.
- ***For the detection mode***l, we used YOLOv12 as the backbone for our model to detect TID regions in TID maps.

OBSERVATIONS & RESULTS:

- **Statistical Observations & Calculations:**

Convective Storm

Tornado

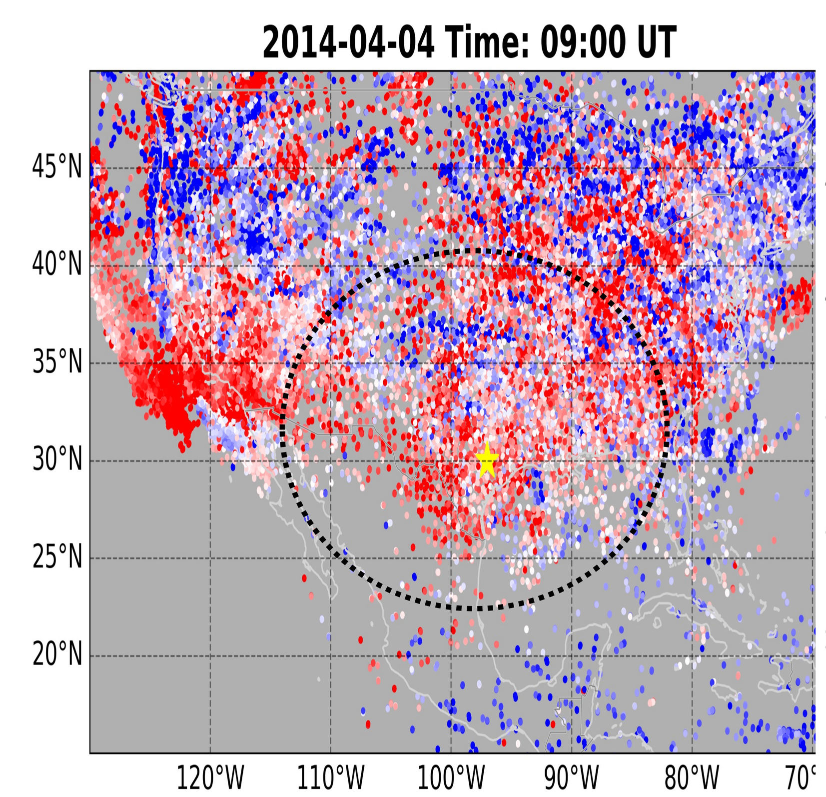


Fig. 1a.

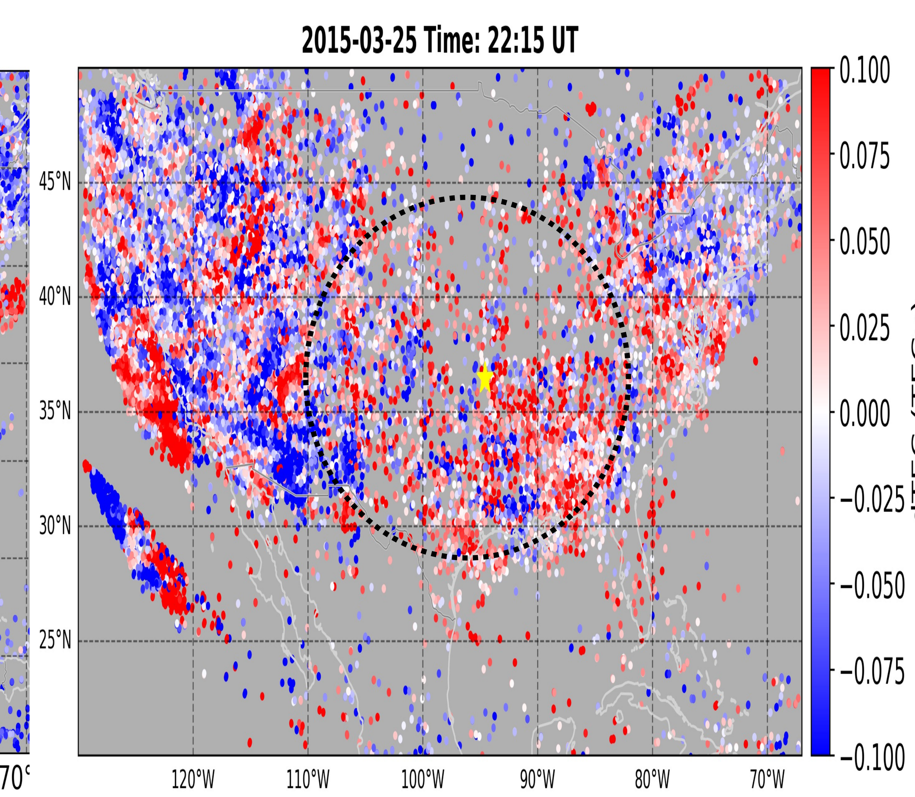
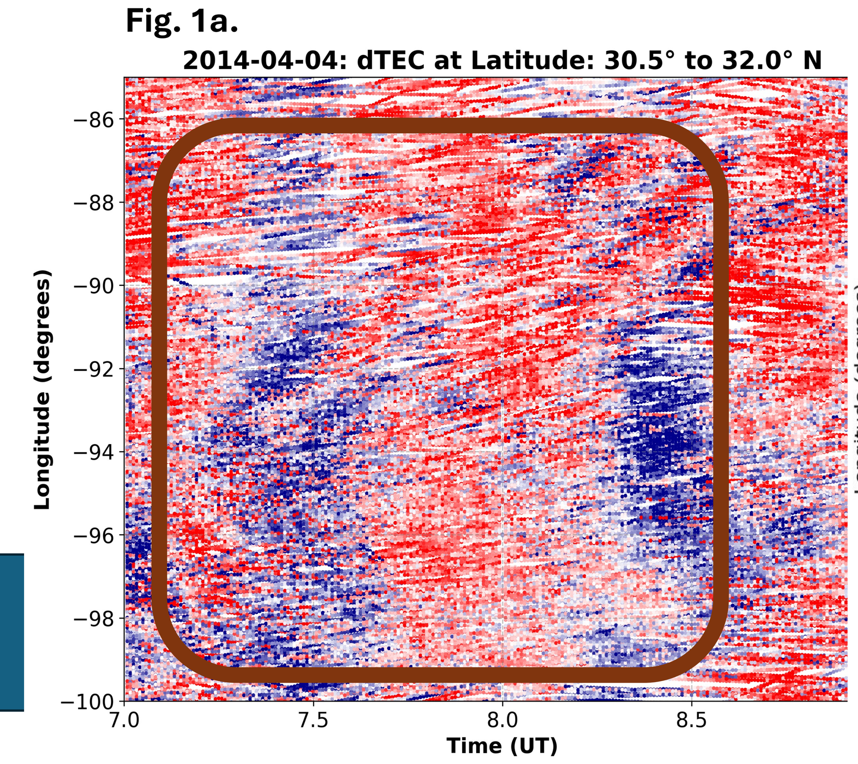


Fig. 2a.



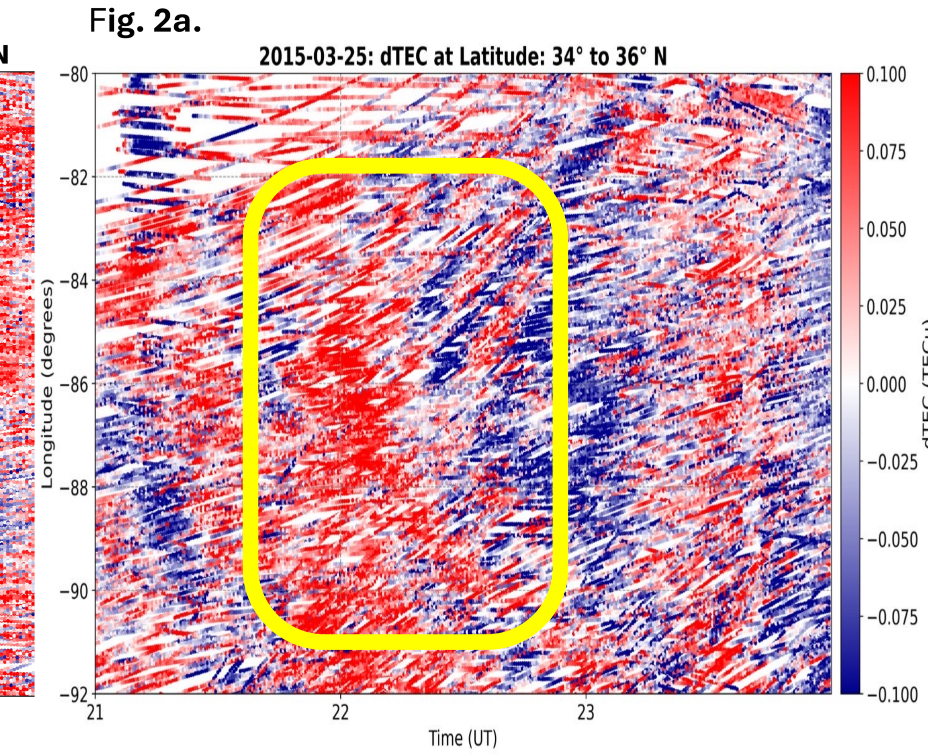


Fig. 1a : Scatter plot of dtec amplitudes over North American spatial extensions showing TIDs. The "star" shows the latitude of Convective storm center.

Fig. 1b: Keogram plot at fixed latitude ~30*N

Fig. 2a : Scatter plot of dtec amplitudes over North American spatial extensions showing TIDs. The "star" shows the latitude of Convective storm center.

Fig. 2b: Keogram plot at fixed latitude ~35*N

Eastward Direction
Wavelength: ~ 110 km
Time Period: 18 mins
Frequency: 0.001 sec^{-1} -> 1 mHz

Westward Direction
Wavelength: ~ 187 km
Time Period: 24 mins
Frequency: 0.0007 sec^{-1} -> 0.7 mHz

Eastward direction:
Wavelength: 220 km
Time Period: 12 mins
Frequency: 0.001 sec^{-1}--> 1 mHz

Westward direction:
Wavelength: 110 km
Time Period: 6 mins
Frequency: 0.003 sec^{-1} -> 3 mHz

- **Model training and Output:**

Training Image Generation:

- Training images are TID maps generated at time cadence of 1 minute.

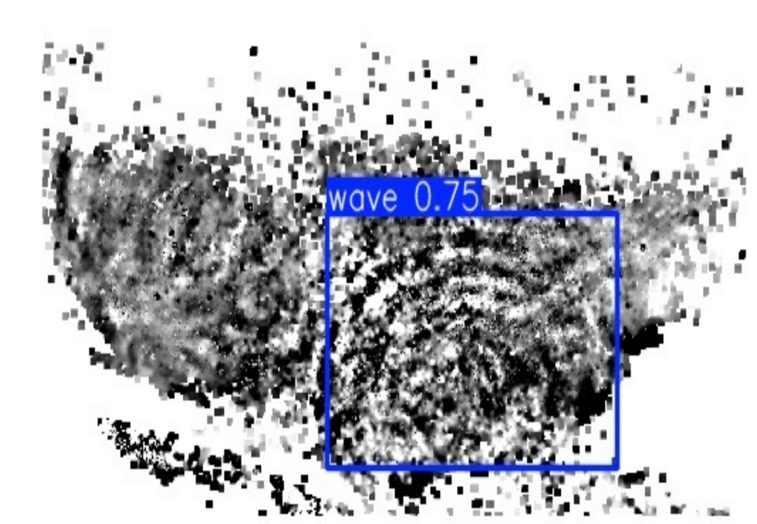
Sample training and Validation Images:

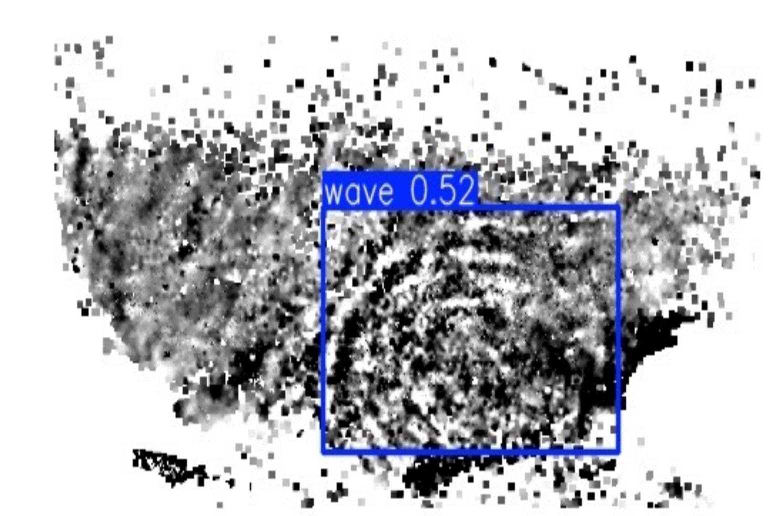
Fig. 3a.

Fig. 3b.

Fig. 3a & 3b: TID maps for April 04, 2014 and September 21, 2022 respectively showing concentric TIDs. The image has been formed with grid resolution of 0.125° x 0.126° in latitude and longitudinal directions respectively.

Model Detection results:





CONCLUSIONS & FUTURE WORK:

- Extend this model to extract the wavelengths, time period and frequencies of these TIDs.
- Perform Statistical analysis for a solar cycle to observe the seasonal and solar cycle dependences of these TIDs.

REFERENCES:

1. *Azeem, I., Barlage, M., 2017. Atmosphere-ionosphere coupling from convectively generated gravity waves. Adv. in Space Research (61), (2018), 1931 – 1941*
2. *Liu, P., Yokoyama, T., Fu, W., & Yamamoto, M. (2022). Statistical analysis of medium-scale traveling ionospheric disturbances over Japan based on deep learning instance segmentation. Space Weather, 20,*