Feed forward neural network based ionospheric model for the East African region

A. Tebabal[1], S.M. Radicella[2], B. Damtie[1], Y. Migoya-Orue'[2], M. Nigussie[1], B. Nava[2]

Beacon Satellite Symposium 2019, University of Mazury

19–23 August 2019, Olsztyn, Poland

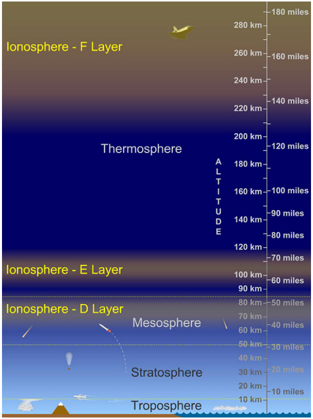
[1]Bahir Dar University, Bahir Dar, Ethiopia, [2]Abdus Salam International Center for Theoretical Physics, Trieste, Italy.

Outline

The Earth's Ionosphere

▶ The ionosphere is the ionized part of the Earth's upper atmosphere.

- The composition of the atmosphere changes with height, the ion production rate also changes.
- This leads to the formation of three main ionized peaks: D, E, and F regions.
- Earth's ionosphere is a highly variable in space and time.



source:https://scied.ucar.edu/ionosphere.

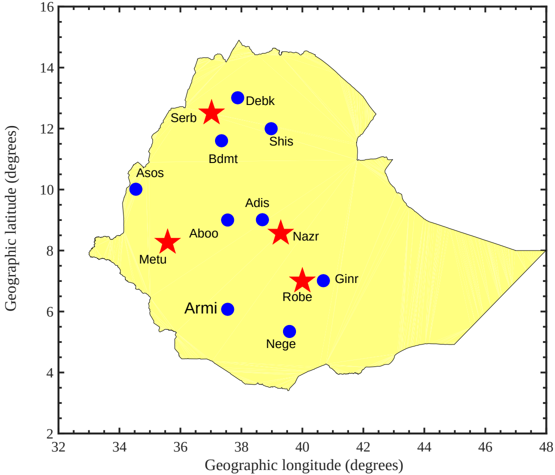
- Variability in the solar irradiance leads to variability in the Earth's atmosphere.

  1. UV variations $\xrightarrow{\text{modify}}$ ozone and the middle atmosphere structure.
  2. Heating of the upper atmosphere (EUV; 30-120 nm) $\longrightarrow$ satellite drag
  3. Formation of the ionosphere (XUV-EUV,1-120 nm) $\longrightarrow$ satellite communications

▶EUV is the primary driver of ionospheric variability but geomagnetic activity and lower atmosphere meteorology also contribute.

- Understanding the variations of the ionosphere is crucial to mitigate ionospheric effects and the drivers behind these variations.
- Ionospheric measurements are limited by their incomplete spatial and temporal coverage. Therefore, ionospheric models are employed.
- Developing a data driven model, to investigate the ionospheric variability, is the goal of this study.

Data Source



√ Hourly Total Electron Content (TEC) data from GPS stations marked with blue circles used for training and red stars for testing.

Model Approaches

Neural Networks

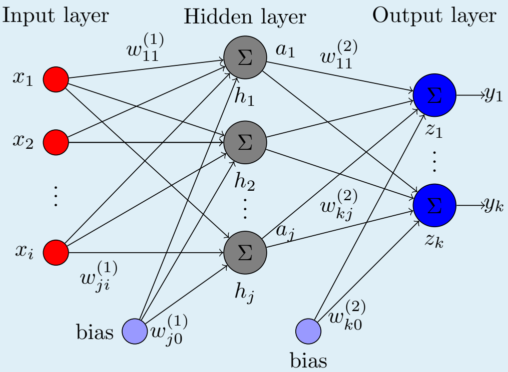
- are models that attempt to mimic some of the basic information processing methods found in the brain [Samarasinghem, 2007].

Benefits of Neural Networks

- its computing power,
- its ability to learn and generalization,
  - generalization means producing reasonable outputs for inputs not encountered during the training(learning).
- have useful properties such as nonlinearity, adaptivity and fault tolerance.

Model Approaches

- We employed a feed-forward neural network (i.e. fully connected layers)

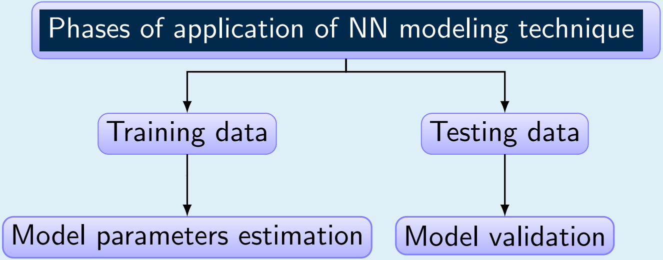


A schematic diagram of feed-forward neural network composed of three layers.

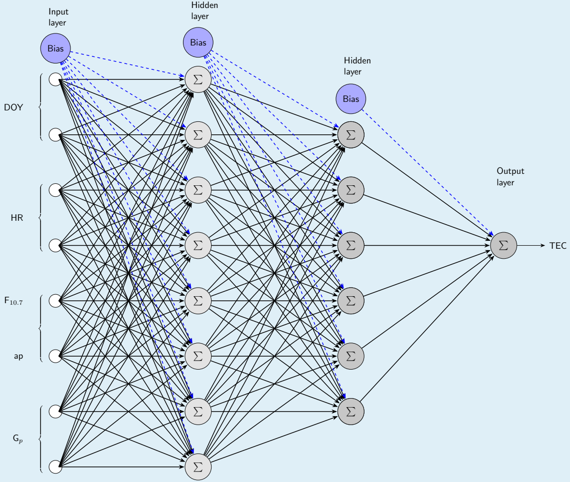
Model Approaches

The basic algorithm for NN

$$y_k = \varphi\left(\sum_j w_{kj}^{(2)} \varphi\left(\sum_i w_{ji}^{(1)} x_i + w_{jo}^{(1)}\right)_j + w_{ko}^{(2)}\right)_k \quad (1)$$



Model Input Parameters



Model validation and comparison

One hour ahead prediction

- TEC data from 2012 to 2014 used to develop the NN model parameters (weights and biases).
- Observations in the year 2015 used for validation/testing of the model.
  - model prediction RMS error ranges from 5.44 – 6.45 TECU.
  - correlation coefficients between model prediction and GPS–TEC ranges from 0.925 to 0.96.
- GPS-TEC observations from 2012 to 2015 used for further validation
  - model was able to explain more than 93% of the variability of GPS–TEC.
  - RMS error ranges from 3.9 – 6 TECU.

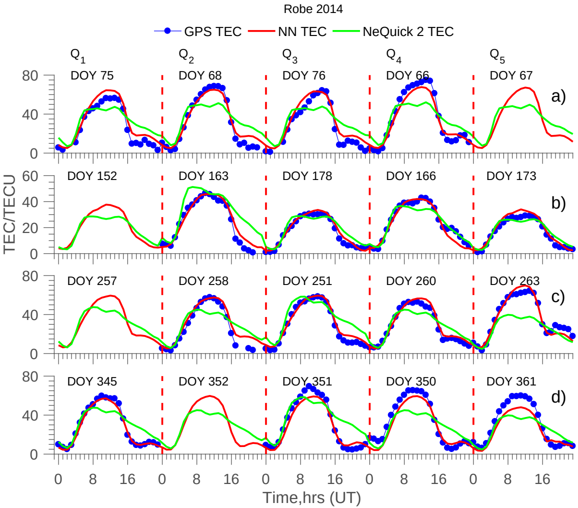
One day ahead prediction

- The response of ionosphere for solar and geomagnetic activity ranges 1–2 days (e.g., Kutiev et al. 2012).
- Model inputs are $F_{10.7}$ and ap index values of the previous day

Table: One-day ahead forecasting over for different GPS stations in the year 2015.

	GPS station	R	RMS (TECU)	STD (TECU)
1	Adis	0.945	6.166	6.109
2	Aboo	0.942	5.989	5.980
3	Armi	0.955	5.270	5.265
4	Asos	0.955	5.653	5.476
5	Ginr	0.947	5.670	5.669
6	Nege	0.949	5.557	5.555
7	Debk	0.938	6.504	6.406
8	Bdmt	0.948	5.879	5.854
9	Shis	0.962	5.485	5.345

Diurnal Variation analysis



Quiet days

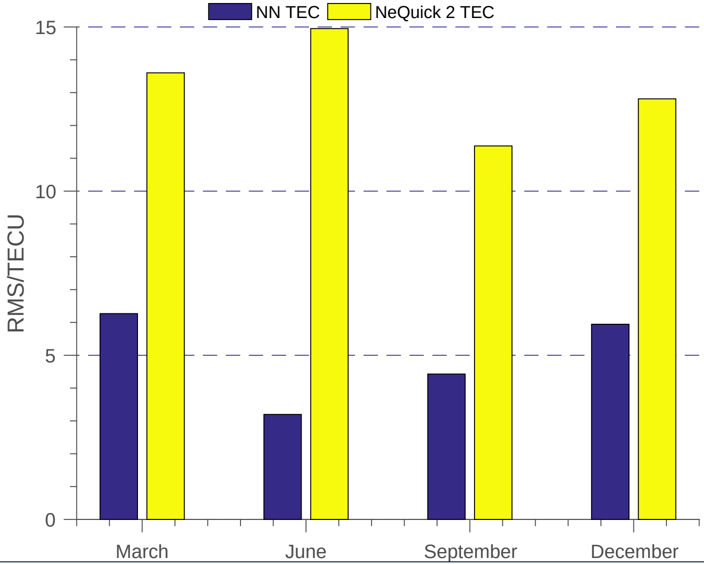
a) March

b) June

c) September

d) December

Quiet days RMS error



▶Performance of the NN model to disturbed conditions

- Four intense geomagnetic storms (with peak Dst $<$ -110nT) during 2012-2015 selected.
- These storm events occurred on:

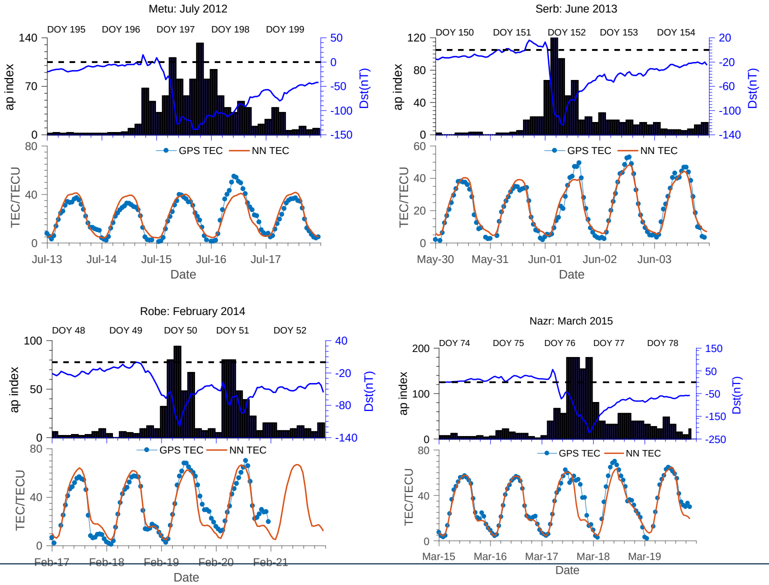
✓15 July 2012 with Dst index value of -139 nT,

✓19 February 2014 with Dst index value of -124nT,

✓01 June 2013 with Dst index value of -119nT, and

✓17 march 2015 with Dst index value of -223nT.

Disturbed conditions



Disturbed conditions

RMS Error between GPS-TEC and predicted values

Station	Year	Month	DOY	NN RMS error
Metu	2012	July	195	4.3198
			196	5.4912
			197	3.8134
			198	8.1569
			199	4.4319
Serb	2013	June	150	3.1788
			151	3.3501
			152	5.1312
			153	2.4064
			154	3.5089
Robe	2014	February	48	7.2002
			49	3.6411
			50	9.1111
			51	7.4774
			52	–
Narz	2015	March	74	2.8862
			75	1.7876
			76	12.0953
			77	6.0886
			78	5.4806

Summary

- We present an NN model for the East African region ionosphere.
- The model inputs are geographic locations, DOY, HR, $F_{10.7}$, and ap index and produce time dependent TEC.
- Our NN models result indicate
  - the overall RMS error between GPS TEC and the models prediction lies in the range of 3 to 6.05 TECU.
  - one-hour and one-day ahead prediction are in good agreement with the observed GPS-TEC values.
- Low latitude ionosphere is highly variable at different time scales.
  - Knowledge of the ionospheric response to other disturbance sources and corresponding observations required to increase the performance of the model.

Acknowledgments

I gratefully acknowledge

- Organizers of 20th International Beacon Satellite Symposium

ICG

International Committee on
Global Navigation Satellite Systems

Thank you for your attention!!