Artificial Neural Network Model based Estimation of Equatorial Vertical ExB Drift over South American and Indian sectors

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ABSTRACT

Forecast of the equatorial and low latitude ionosphere continues to remain a challenge since it is governed by the complex interplay of various factors like solar flux, ExB drifts, meridional neutral winds, solar flux and space weather apart from forcing from lower atmosphere. In order to achieve useful forecast, it is imperative to assimilate accurate inputs into the models. In this study, a robust dataset of equatorial vertical ExB drifts is generated by developing a multi-layer feed-forward artificial neural network, trained using a large number of samples of input parameters over South American sector. The RMS error of newly developed model as low as 2.4 m/s represents rigorous training which yields realistic values of ExB drifts. The validation of the derived ExB drifts is performed for several quiet and disturbed cases over Jicamarca using observations from JULIA and Jicamarca ISR data. This network is also employed to derive ExB drifts over Indian sector where only ΔH measurements from magnetometer are available. Although considering the longitudinal differences, a training of ANN from ExB drift observations from Indian sector would have yielded better accuracy; nonetheless, results of this drift model are compared with available observations from Radar and Satellite measurements. The model is found to perform satisfactorily even over Indian sector.

Key words: Artificial Neural Network, vertical ExB Drift, ionospheric models, GPS-TEC

1. Development of ANN model

Considering that vertical ExB drift is bound to have seasonal variations and solar flux dependence along with other variabilities, Artificial Neural Network (ANN) is considered to be a sophisticated and reliable tool to estimate the vertical ExB drifts from the difference between the H-components of magnetometers located at an equatorial and off- equatorial location, which is denoted by ΔH. ANN is widely accepted to be a robust and rigorous method wherein meticulous supervised training can provide reliable output. In this study, an ANN is developed using multi-layer perceptron with 1 hidden layer. The various inputs used are year, day of year, Ap and Kp indices, F10.7 cm solar flux, 81 day running average of F10.7 cm solar flux, ΔH and the local time. We have used the maximum available datasets from JULIA from 01 August 2001 to 30 September 2003 for training. Days when data was available in common for both the stations were extracted and further, days when JULIA data was available for these days is finally selected and sampled at 5 minute resolution. Outliers were carefully removed from all datasets and only physically possible inputs were shown to the network. The feed forward algorithm channels the information forward and the back propagation algorithm allows the ANN to minimize error through each epoch. In total, 14101 data samples were laboriously prepared and shown to the feed forward neural network for training.

2. Training and achievement of Minimum RMS Error

Using a sigmoid activation function, resilient gradient descent and back propagation algorithm, the training is performed several times by tuning the learning rates. The training is continued till root mean square saturates with a minimum value. Further training will not produce any difference in the output. After around 100 training epochs, the error value starts to diminish and beyond 800 epochs, it almost saturates. The training is repeated multiple times until the minimum most error is obtained. Also the network is trained by replacing Ap and Kp indices with Dst index to make it more relevant to the low latitude region. However, not only did this experiment yield no new result, other combinations replacing all input parameters barring ΔH made no difference to the trained output. Thus, an ANN is developed that can produce vertical ExB drift values within an error range of 2.4 m/s.

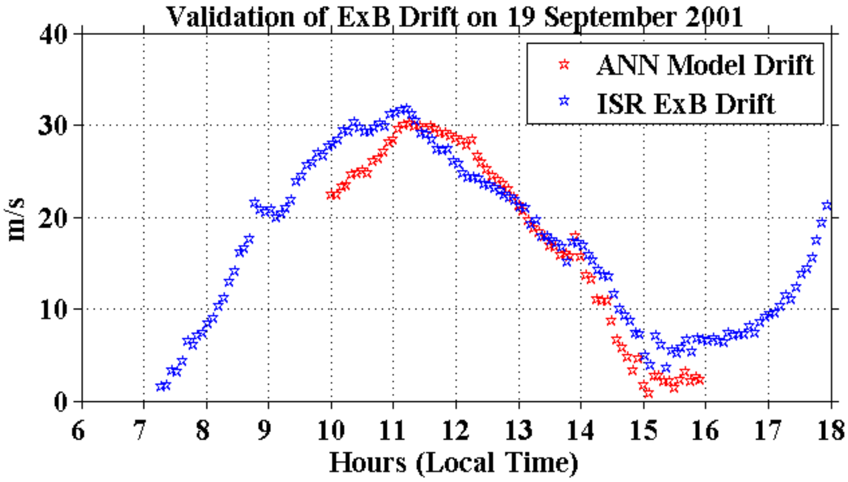
3. Results

3.1 Quiet Time Validation

The ANN derived ExB drifts is subject to validation using the data available from Jicamarca ISR and JULIA. Since the ANN is trained using daytime data, it is possible to compare only daytime observations with ANN derived drifts. First, an example of quiet day validation is shown for 19 September 2001. ExB drift from Jicamarca ISR shows a steady increase from ~2 m/s at 7 LT to a maximum of ~32 m/s at ~11 LT over a period of 4 hours. Then a gradual fall is seen with a small kink around 14 LT and after 15 LT, a rise is also observed. This pattern and amplitude is very well captured by the ANN derived drift and is seen in the Figure 1(a).

3.2 Storm Day Validation

An example of comparison of observed storm time ExB drift with ANN based ExB drift is shown for 17 April 2002 in Figure 1(b). It can be seen that the ExB drifts undergo episodic variations which is very well captured by the ANN derived drifts. The sharp fluctuations are found to be oscillating from ~50m/s to -20m/s giving rise to a difference as large as 30 m/s in less than an hour. Next, in figure 1(c), a case of a moderate storm event is shown. On 9 March 2012, Dst recorded a minimum value of -145 nT at 9 UT. With the storm onset on 8 March, ExB drift started to show rapid fluctuations as can be seen in both derived and observed drifts. On the storm day, a peak value of ~25 m/s is seen at about 11:45 LT that quickly falls and again rises at about 13 LT to a value of ~15 m/s. Further, a gradual fall is observed and on 10 March, there are no fluctuations observed as the vertical drift gradually rises, reaches a peak of ~28 m/s and then steadily falls after 12 LT.



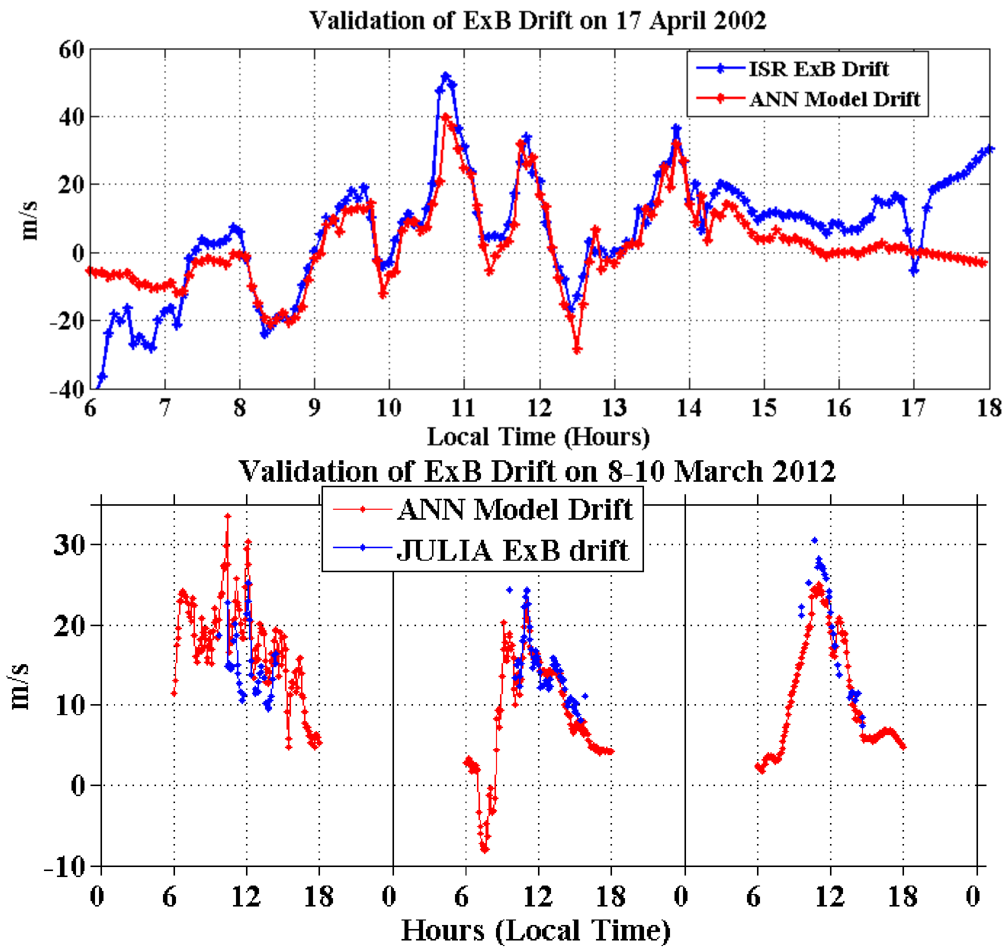


Figure1 (a).Validation of ANN derived ExB drift model with Jicamarca ISR ExB drift on a quiet day of 19 September 2001. (b) Validation of ANN derived ExB drift model with Jicamarca ISR ExB drift for storm day on 17 April 2002 and (c) Validation of ANN derived ExB drift model with JULIA ExB drift for 8-10 March 2012.

3.3 ExB Drift over Indian Sector

Several cases were tested to validate the ExB drifts developed and trained for the South American sector covering all seasons spanning both solar cycles 23 and 24 during quiet and disturbed days. It is thus established that the ANN is a powerful tool to generate a reliable set of ExB drift data with minimum error. These validations lead to generate similar dataset for the Indian longitude sector by transferring the learning from the same network. Thus, ExB drift over Indian sector is derived from ANN using magnetometer data from Tirunelveli (dip equatorial station) and Alibagh (off equatorial station). The results are shown in Figure 2 (a) and (b) fort years 2009 and 2013. In 2009, low solar activity was recorded while 2013 was a high solar activity year. The estimated drifts show higher values during equinoxes with September equinox showing ~25-30 m/s and 30-35 m/s during 2009 and 2013 respectively. During March equinox, the maximum values are ~22 m/s in 2009 and 27 m/s in 2013.

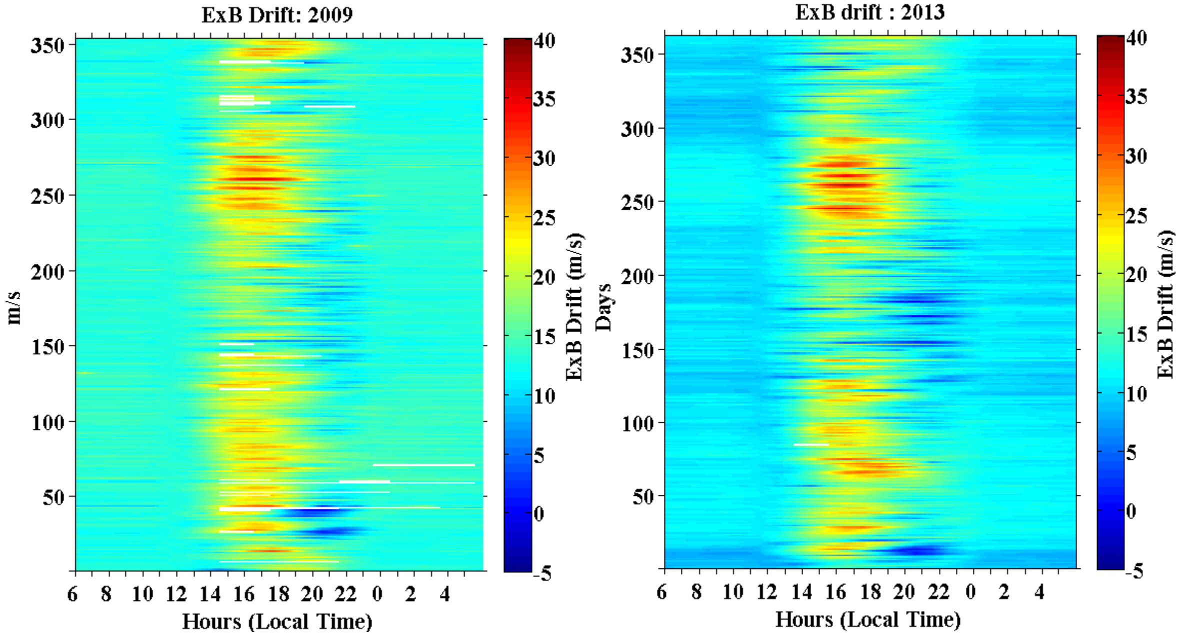


Figure 2(a) ANN derived ExB drifts for 2009 and (b) ANN derived ExB drift for 2013 over Indian sector

3.4 Observation of GPS-VTEC from Indian sector:

Figure 3 shows the hourly mean variation of observed GPS VTEC over Gadanki, which is located ~5^0 N of geomagnetic equator in the Indian sector. The variations for years 2009 and 2013 are shown along the local time. This figure highlights a very interesting feature which is that the VTEC in high solar activity year 2013 is almost 3 times higher than in 2009, which was a solar low year. Along with seasonal variations, it can be noted that a maximum of 90 TECU was registered in November 2013 whereas the maximum was 35 TECU in October 2009.

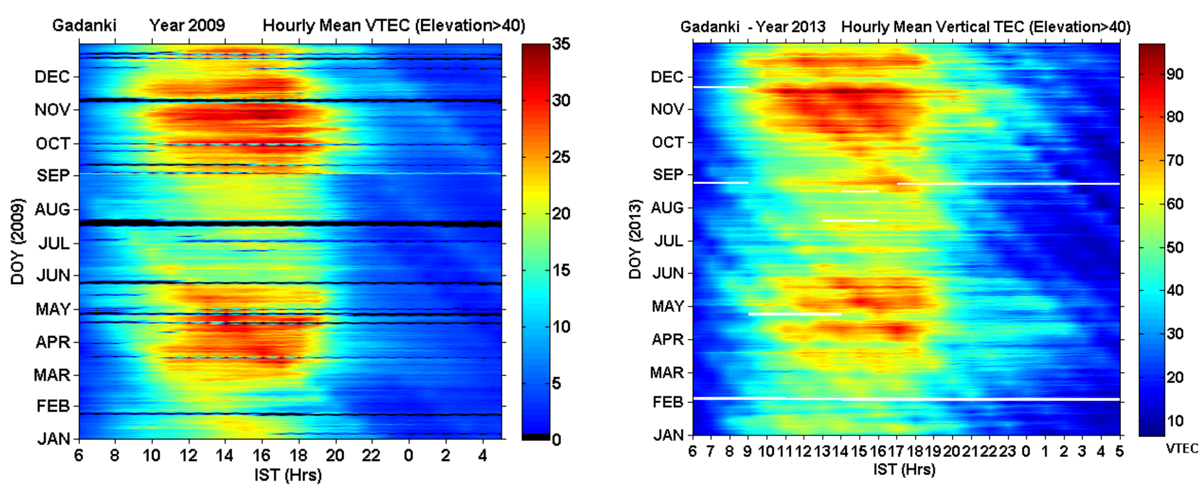


Figure 3 Observed GPS-VTEC over Gadanki in Indian sector (Geomag. Lat ~5^O N, Geog.Long. 79.12^o E) for years (a) 2009 and (b) 2013.

4. Summary

Thus, in this study, a robust artificial neural network is developed and trained using a large dataset to achieve minimum error compared with observations in South American sector. It is found that the ANN derived drifts stand a fair chance to be used to provide potential information regarding ExB drifts over the Indian sector where almost no observations of ExB drift are available. The output ExB drift of the ANN based drift model is suitable to be a potential candidate in physics based models. This provides with a scope of enhancement in realistic representation of equatorial and low latitude ionosphere by models like SAMI2 and SAMI3. Comparisons of model run with ANN based drift to the observed VTEC would be presented in detail.

References:

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