Topside ionospheric electron temperatures from GPSRO using an Artificial Neural Network model

Andong Hu[1], Brett Carter[1], Suqin Wu[1], Julie Currie [1], Kefei Zhang[1,2]

[1] SPACE Centre, School of Mathematical and Geospatial Sciences, RMIT University, Melbourne, Australia
[2] School of Environmental Science and Spatial Informatics, China University of Mining and Technology, CUMT, XuZhou, China

Corresponding Email: andong.hu@rmit.edu.au

RMIT UNIVERSITY

Abstract

This study is an investigation into whether the GPS Radio Occultation (GPSRO) technique can be used to obtain the electron (Te) and ion (Ti) temperature in the topside ionosphere. Currently, Incoherent Scatter Radars (ISRs) are one of the most reliable and long-term sources of topside ionospheric electron density and plasma temperature information. However, a shortfall of using the ISR databases is the relatively low number of ISR stations around the world. In contrast, GPSRO provides topside ionospheric electron density data from all over the world, but Te information is not directly detected. Previous researchers have investigated the relationship between the electron density and the plasma temperature, but these studies have not explicitly considered some parameters that are known to influence the plasma temperature; such as, solar and geomagnetic activity level.

This study uses an Artificial Neural Network (ANN) technique to create a new topside electron temperature model that has been trained using 7 years of ISR data from two stations; Arecibo (low-latitude) and Millstone Hill (mid-latitude). This model was trained using electron density profile information (e.g., vertical scale height, HmF2 and NmF2) and solar and geomagnetic activity (F10.7 and Kp, respectively), and the model provides Te profiles. This modelled relationship between the electron density profile and the electron temperature profiles thus allows the extraction of electron temperature information from the GPSRO electron density profiles. This model's GPSRO electron temperature profiles are validated against out-of-sample ISR data, and a comparison of the GPSRO results versus the Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM) outputs is conducted. It is found that the electron temperature profiles from the ANN had a relative accuracy of 95% in the low-latitude region (i.e., against Arecibo data), compared to 90% in the mid-latitude region (i.e., against Millstone Hill data). Finally, a statistical analysis of the diurnal electron temperature profiles obtained from GPSRO are shown to agree well with the TIEGCM outputs in low-latitude regions.
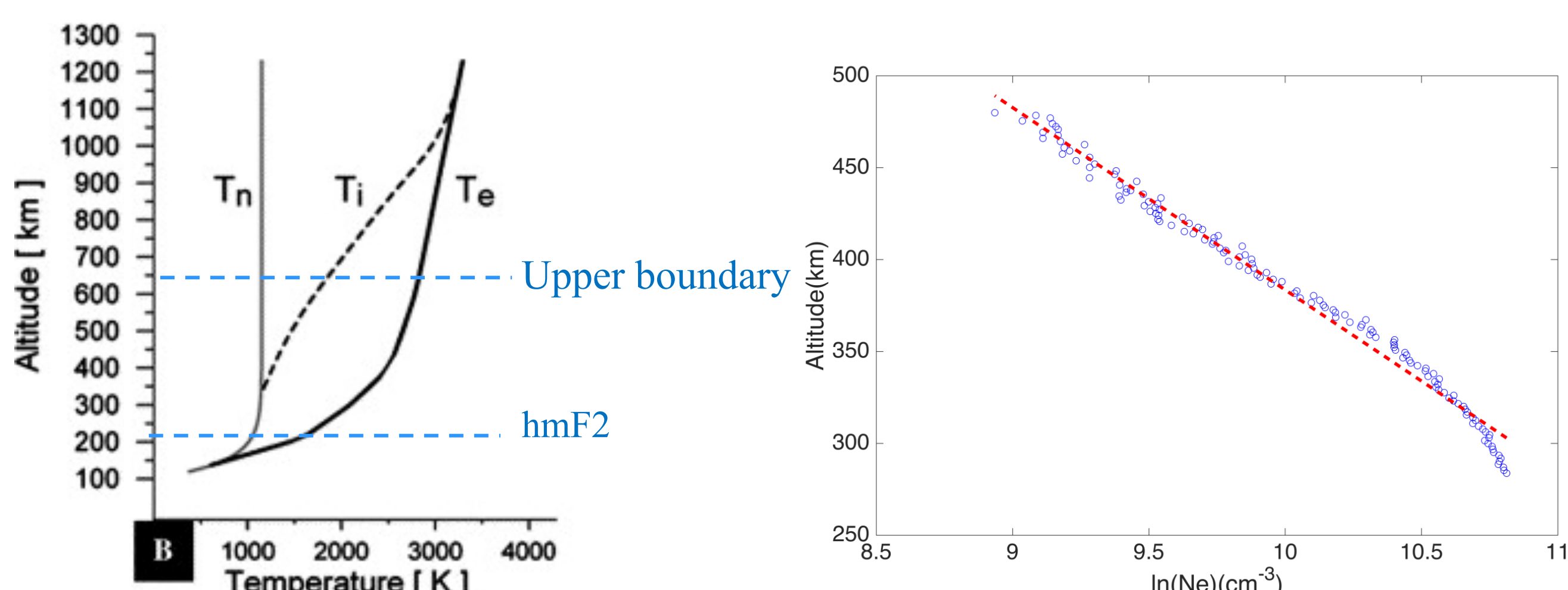
Fig. 1 The variation of electron/ion/neutral temperature (Te/Ti/Tn) wrt altitude, and the study area of altitude

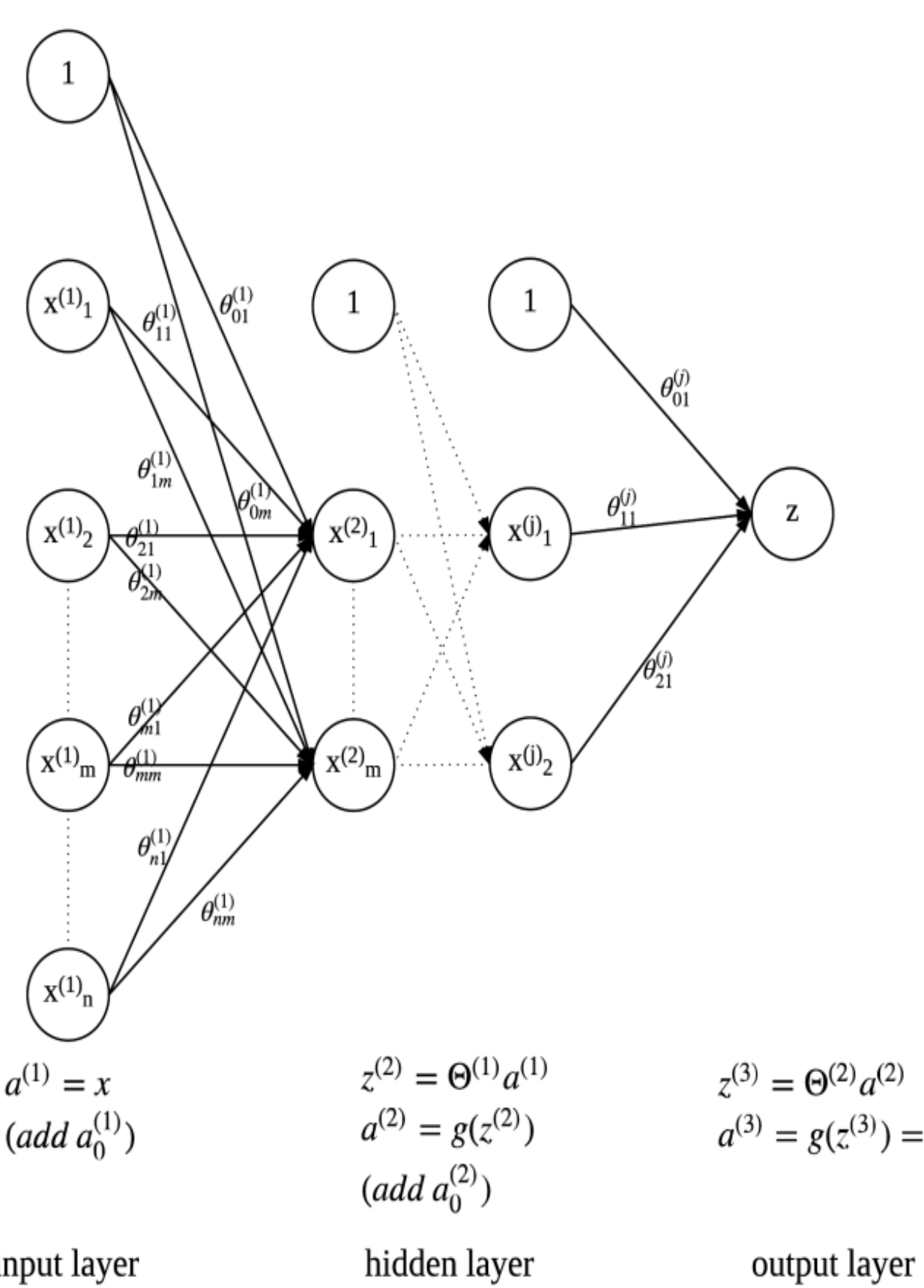Fig. 2 Definition of vertical scale height (VSH) for a ln (Ne) topside profile

ANN methodology

$$d^{(1)} = x$$
$$(add\ d_0^{(1)})$$

$$z^{(2)} = \Theta^{(1)} d^{(1)}$$
$$a^{(2)} = g(z^{(2)})$$
$$(add\ a_0^{(2)})$$

$$z^{(3)} = \Theta^{(2)} d^{(2)}$$
$$a^{(3)} = g(z^{(3)}) = h_\theta(x)$$

input layer   hidden layer   output layer

Fig. 3 Structure of the ANN

training dataset 60%
cross-validation dataset 20%
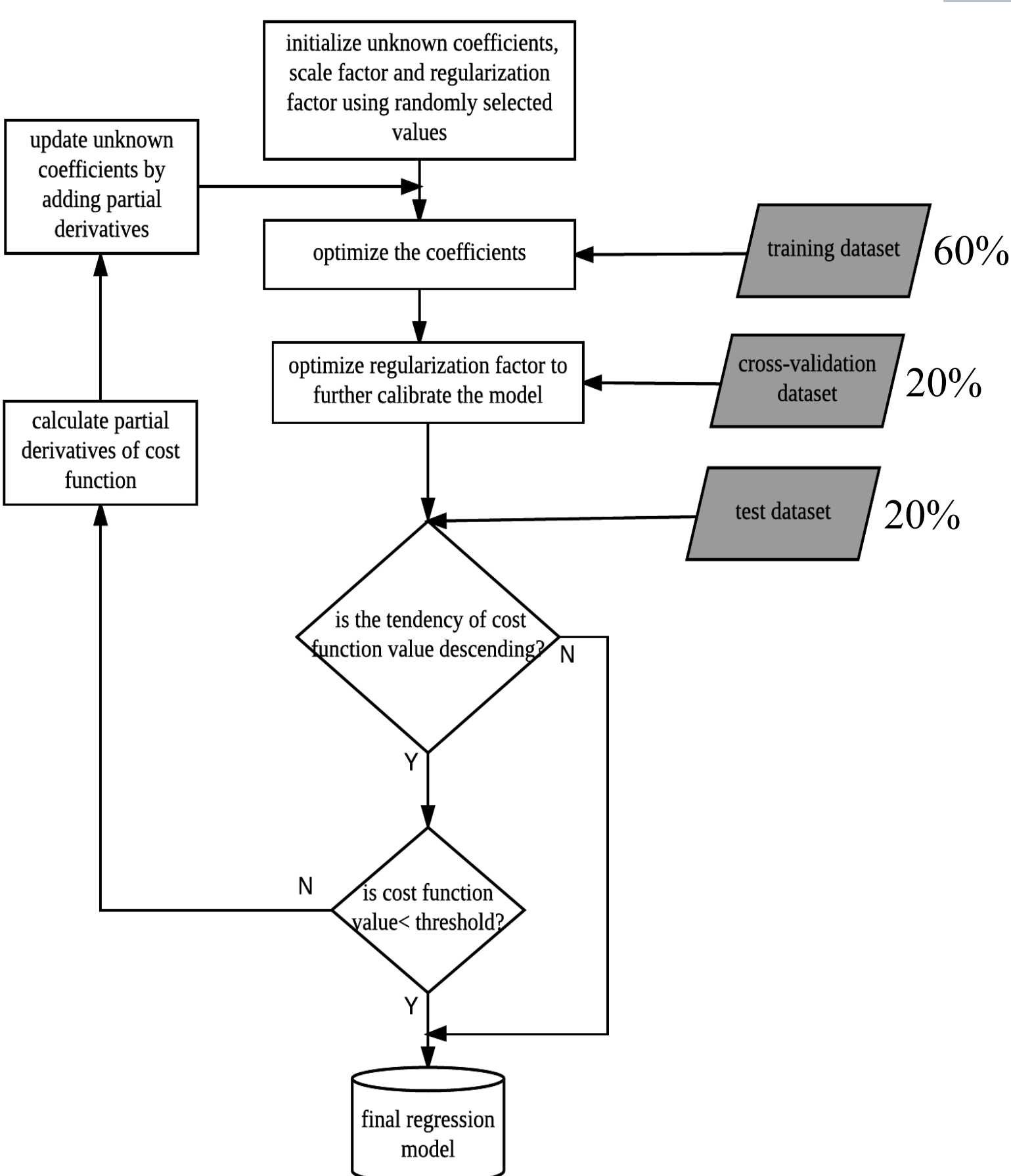test dataset 20%

Fig. 4 Flowchart of the ANN methodology
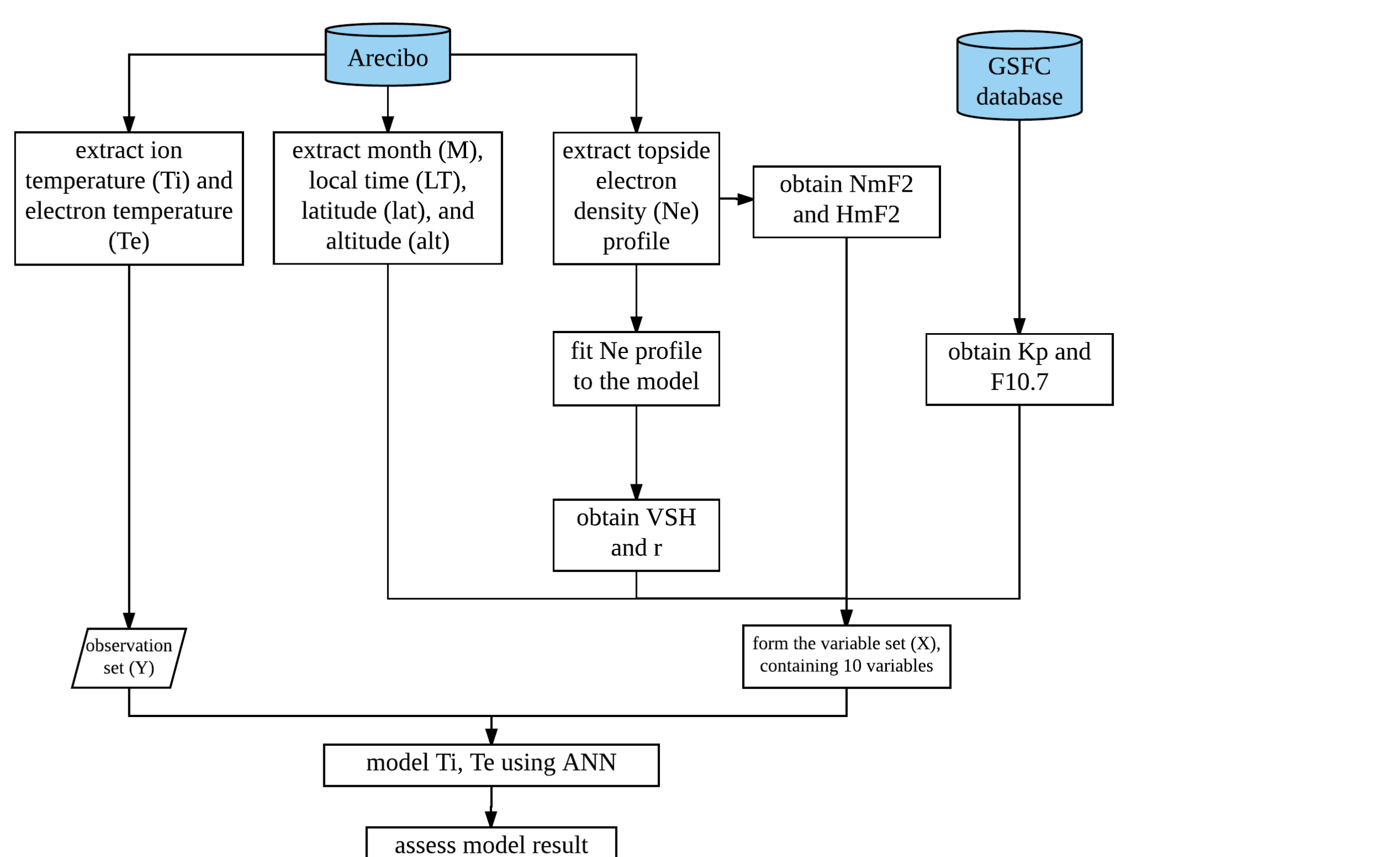
Modelling methodology

Fig. 5 Flowchart of the proposed Te model (In this study, Arecibo, one of the ISR stations in low latitude, is adopted as measurement was selected as sample data;)

Te profile comparison

The comparison between the ANN model result and IRI result (Brace, 1978) (w.r.t. out-of-sample measurements) is shown in Fig. 6, which implicates that the purposed model significantly outperforms the the model inside IRI in all epoch of a whole day.
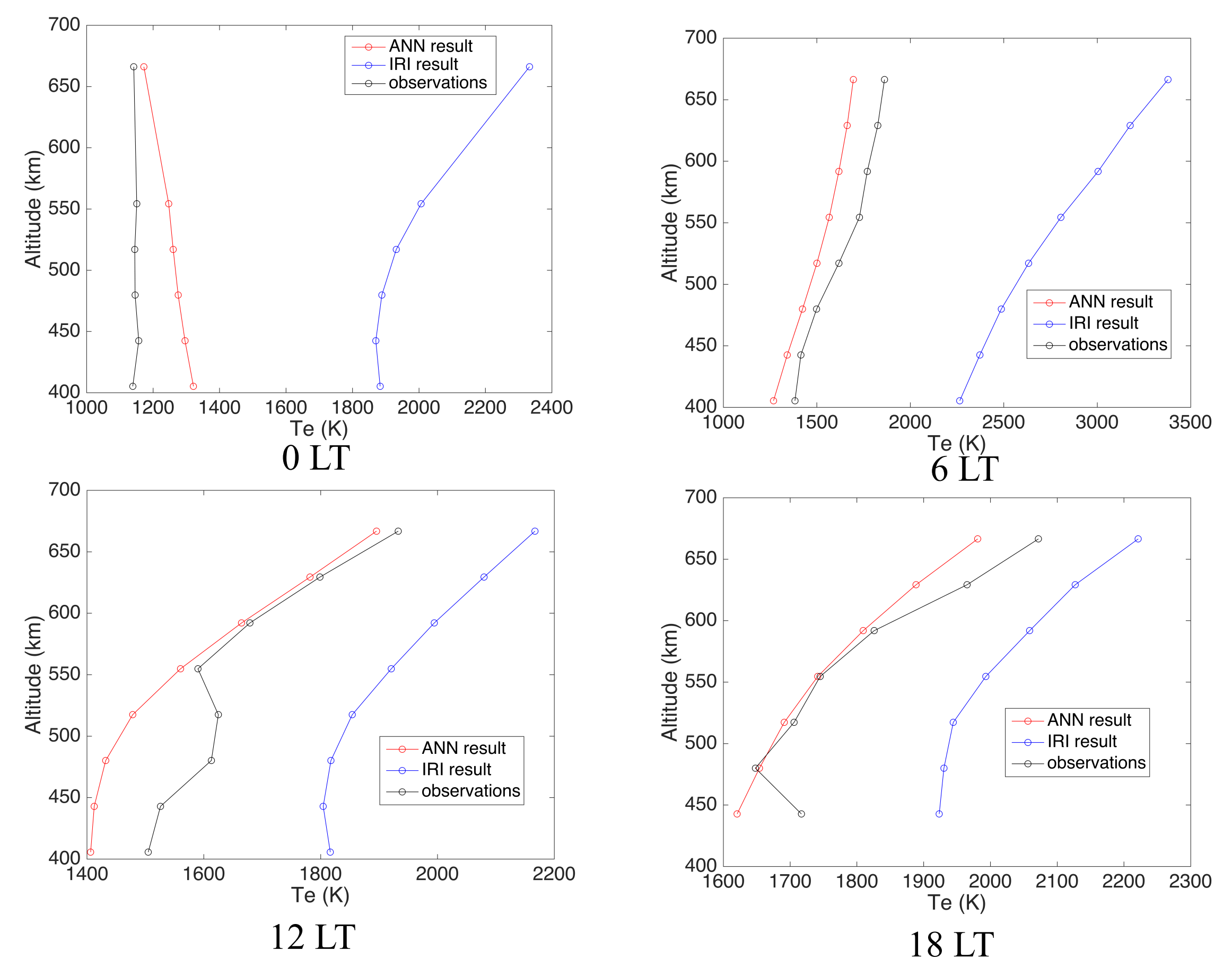

Fig. 6 The assessment of ANN model in each epoch (0, 6, 12, 18 local time)

Te comparison with physics-based modelling result

The NCAR Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM), a self-consistent physical thermosphere-ionosphere model, is used as a reference to test the outputs of the modelled Te from IRO data.

The figure below reveals that with enough IRO data, the IRO-based model shows similar tendencies (in the box-highlight part) to the TIEGCM results (e.g. morning and evening peaks).
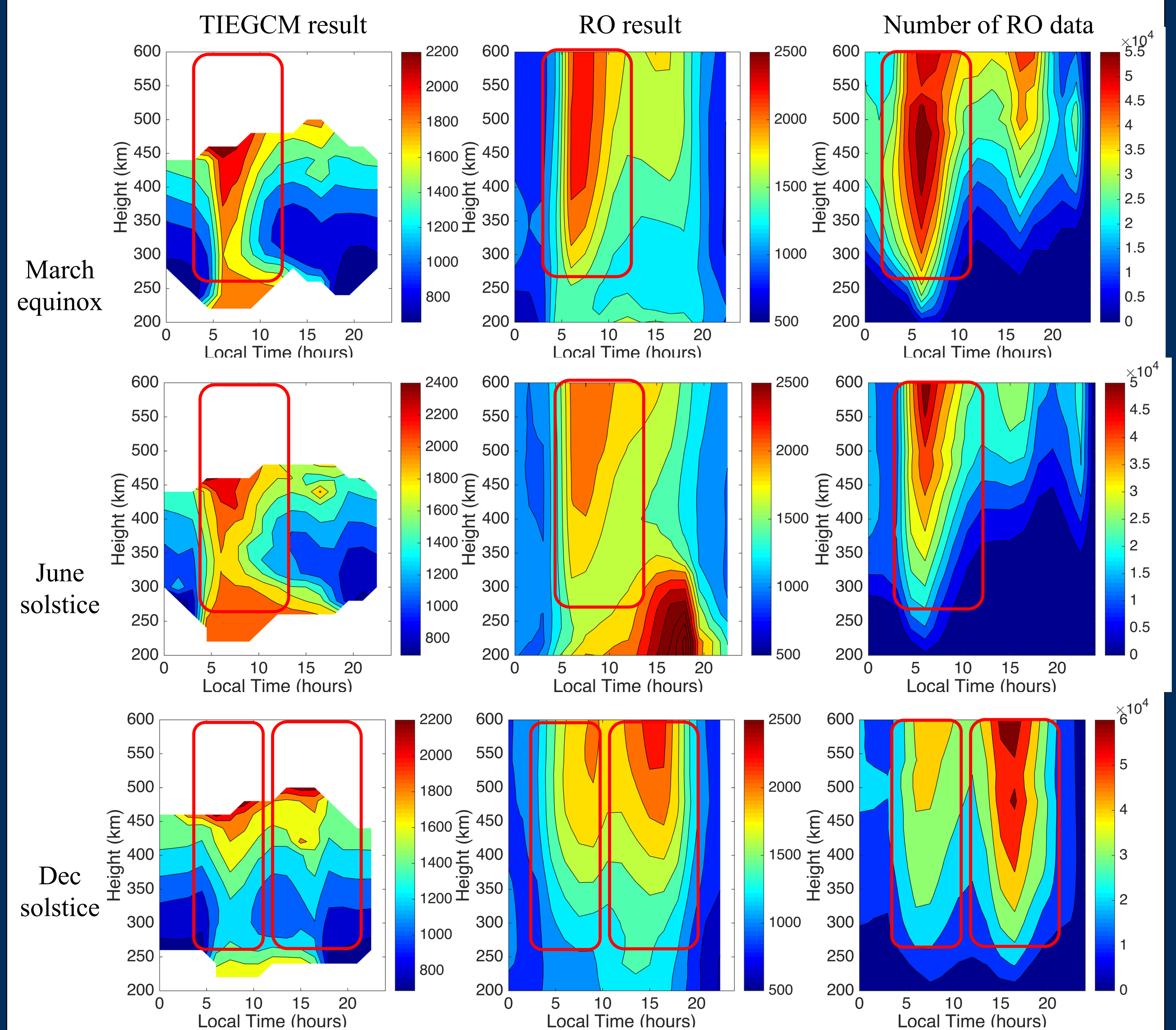

Fig. 7 Comparison between the model-derived Te from IRO data and the Te generated from the TIEGCM, together with the number of IRO data as a function of local time and height, at March equinox, June solstice and Dec solstice

Conclusion & Future Work

This study generated Te from IRO measurements based on ANN training using ISR data. The out-of-sample measurements and the TIEGCM results are used to assess its performance. In conclusion,

1) ANN can be applied to quantitatively and accurately describe the relationship between Te and ionospheric electron density profile parameters.
2) The model-derived Te shows similar diurnal and seasonal variations compared with the TIEGCM model outputs.

Currently more IRO satellite missions are ready to launch (e.g. COSMIC-2, GNOS-2, etc.), thus the number of RO data will increase and so will the number of Te measurements. Our future work will focus on extracting Ti from IRO electron density profiles for future space weather studies.

Acknowledgments