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REGIONAL REFERENCE TOTAL ELECTRON CONTENT MODEL USING 2-D MAPPING AND NEURAL NETWORK

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Abstract. A regional reference model of TEC was constructed using data from the GPS Earth Observation Network (GEONET), which consists of more than 1000 GPS satellite receivers distributed over Japan. The data covered one solar cycle since April 1997. First, TECs were determined for 32 grid points over Japan at 15-minute intervals. Secondly, the time-latitude variation on each day was approximated by the surface harmonic functional fitting. The coefficients of the fitting were then modeled by using a neural network technique with input parameters of the season (day of the year) and solar activity proxies (F10.7, SOHO_SEM$_{26-34}$, and Mg II cwr).

1 INTRODUCTION

Direct measurements of the ionospheric total electron content (TEC) using radio waves transmitted from the Global Positioning System (GPS) satellites have been collected for the period longer than one solar cycle. Thus, GPS-based TEC data are now available to construct an empirical model of TEC. Meanwhile, artificial neural network (ANN) techniques have been applied to a variety of topics in the study of upper atmosphere. Multilayer feed-forward networks are used to specify the ionosphere by approximating a relationship between geophysical conditions (seasons, solar activities, local times, longitude/latitude etc.) and observed ionospheric parameters ($f_OF_2, h'F_2, hmF_2$ etc.), short-term forecasting of ionospheric conditions, and long-term trend analyses. Because of the input-output mapping features of ANNs, they could be used to generate reference ionospheric models. For this purpose, a so-called training data set must cover a whole range of possible input parameter variations, say, a data period longer than one solar cycle.

2 DATASET AND ANN MODELING

In Japan, a dense GPS receiver network called GPS Earth Observation Network (GEONET) has been developed by the Geographical Survey Institute, Japan, and data from more than 1000 locations have been collected since April 1997, covering the entire solar cycle. About

300 GEONET receivers were chosen for evaluating TEC to ensure uniform coverage over Japan. In this study, slant TECs were converted to vertical TECs (vTEC) at the piercing point where the ray path crossed a shell at a height of 400 km (a thin shell model). By assuming that the vTECs in a small area $2 \times 2°$ in longitude and latitude surrounding a grid point were the same in a short period of time, we calculated the daily instrumental biases and vTEC in each small area at 15-min intervals1. The vertical TEC obtained in this way is referred to as the grid TEC (gTEC).

TEC variation in time and latitude on a given day was expressed as a two-dimensional map; the longitudinal dependence can be assumed to be equivalent to the local mean time (LMT) dependence in a limited longitude area such as Japan's longitudes. The two- dimensional TEC map is the target of the ANN and this technique greatly reduces the computer storage. To generate TEC maps from the gTEC, the surface harmonic expansion method based on the associated Legendre's function was used, as shown in Equation (1), by considering the LMT (hour) at each grid point as the azimuth parameter, i.e., $\phi = 2\pi(LMT/24)$.

$$TEC = \sum_{m=0}^{M} \sum_{n=m}^{N} (A_{nm} \cos m\phi + B_{nm} \sin m\phi) P_n^m(cos\theta) \tag{1}$$

Here, θ is the colatitude and $N = M = 7$. The functional fitting was performed to determine coefficients A_{nm} and B_{nm} in Equation (1). As dummy data were set in the southern hemisphere for mathematical convenience, the entire spherical distribution map is symmetrical with respect to the equator (resultant map data outside the latitude range from 29 to 45° N were disregarded). In other words, A_{nm} and B_{nm} with the odd number of $n + m$ are equal to zero. Thus, our ANN had a total of 36 target parameters that were required to reconstruct diurnal- latitudinal TEC maps2. The coefficient set was calculated for each day through the entire 11- year solar cycle from 1 April 1997 to 31 March 2008.

3

SOLAR PROXIES

The major driver of the ionospheric variation is the change in the solar EUV radiations. As EUV radiations are absorbed in the upper atmosphere and direct measurements of irradiance by satellites are not always available, several proxies have long been used in the theoretical and empirical modeling of the ionosphere-thermosphere system. The sunspot number (R) and the 10.7-cm radio flux ($F_10.7$), which are measured on the ground, have been widely used. Previous empirical atmospheric models such as a series of MSIS (Mass Spectrometer and Incoherent Scatter radar) use F 10.7 and the 81-day centered average of $F_10.7$ as proxies of solar UV heating. The International Reference Ionosphere (IRI) model uses the 12-month average of R as a proxy of solar activity.

Recently, solar irradiance datasets based on satellite measurements were extensively examined in connection with aeronomical applications. The integrated 26-34 nm solar

EUV emission has been measured by the solar extreme ultraviolet monitor (SEM) onboard the Solar and Heliospheric Observatory (SOHO) at the Lagrange Point since its launch in late 1995. These wavelengths overlap with the wavelengths of EUV that ionize the Earth's upper atmosphere unlike the other proxies. Other measurements are the ratio of the irradiance in the core of the Mg 280-nm line to the irradiance at neighboring wavelength, referred to as the Mg II core-to-wing ratio (cwr). Mg II cwr is first proposed as a measure of chromospheric solar active region activity3.

We have examined above four proxies and decided to use Mg II cwr, SOHO_SEM$_{26-34}$, and $F_1 0.7$ to represent chromosphere, transition region, and corona activities. These proxies exhibit different short-term and long-term variation amplitudes; short-term variations are induced by the localized activity region and the solar rotation, and long-term variations are the gradual evolution of localized plages and their decay into longitudinally dispersed active networks. The contrast between plages and networks differs from one proxy to others. To compensate these characteristics, in addition to daily parameters, values averaged over 27- and 7- day periods were used. After several experiments, the 27- and 7-day periods were taken backward4. This is an advantage in the real time use of the model because only previously measured proxy values are sufficient to predict TEC variations.

4 RESULTS

In Figure 1a, the observed and ANN predicted TECs at 03 UT (12 LT) at the latitude of 35°N are compared for 30 solar rotations or approximately 2 years and 3 months around the solar maximum. The top panel is the observed and ANN predicted TECs and their difference (ΔTEC). The middle panel is the three solar proxies, and the lower panel is the daily geomagnetic activity index, Ap (not used for the ANN training). The seasonal trend of summer minimum and the 27-day modulations of TEC are generally reproduced. However, relatively large errors related or unrelated with magnetic disturbances are noticed occasionally. For example, associated with the largest magnetic disturbance on 31 March 2001 and several moderate to weak disturbances before and after it, ionospheric storms are recognized in the ΔTEC curve; the ANN prediction errors are ascribed to the magnetic activity, while the large positive and negative ΔTEC in January and February 2002 cant be related with magnetic activities. Figure 1b shows the next 30 solar rotations for a moderate solar activity period. The 27- day modulations of TEC are reproduced quite well. The magnetic disturbance from 29 to 31 October 2003 again caused a negative TEC disturbance. As the solar activity decreased, there appeared quasi periodic variations of ΔTEC with a period of approximately 6 days, e.g. March and April 2005. As is exampled above, even for large magnetic disturbances the TEC errors were comparable with those not related with magnetic activities. Further, there are quasi-periodic variations in errors. The TEC errors unrelated with magnetic activities should be ascribed to other origin such as forcing below the ionosphere including coupling with planetary wave activities. From the other point of view, the TEC reference model based on the solar proxies benefits to separate solar effects from the ionospheric variations or to provide a background to disturbances including ionospheric storms and atmospheric coupling.

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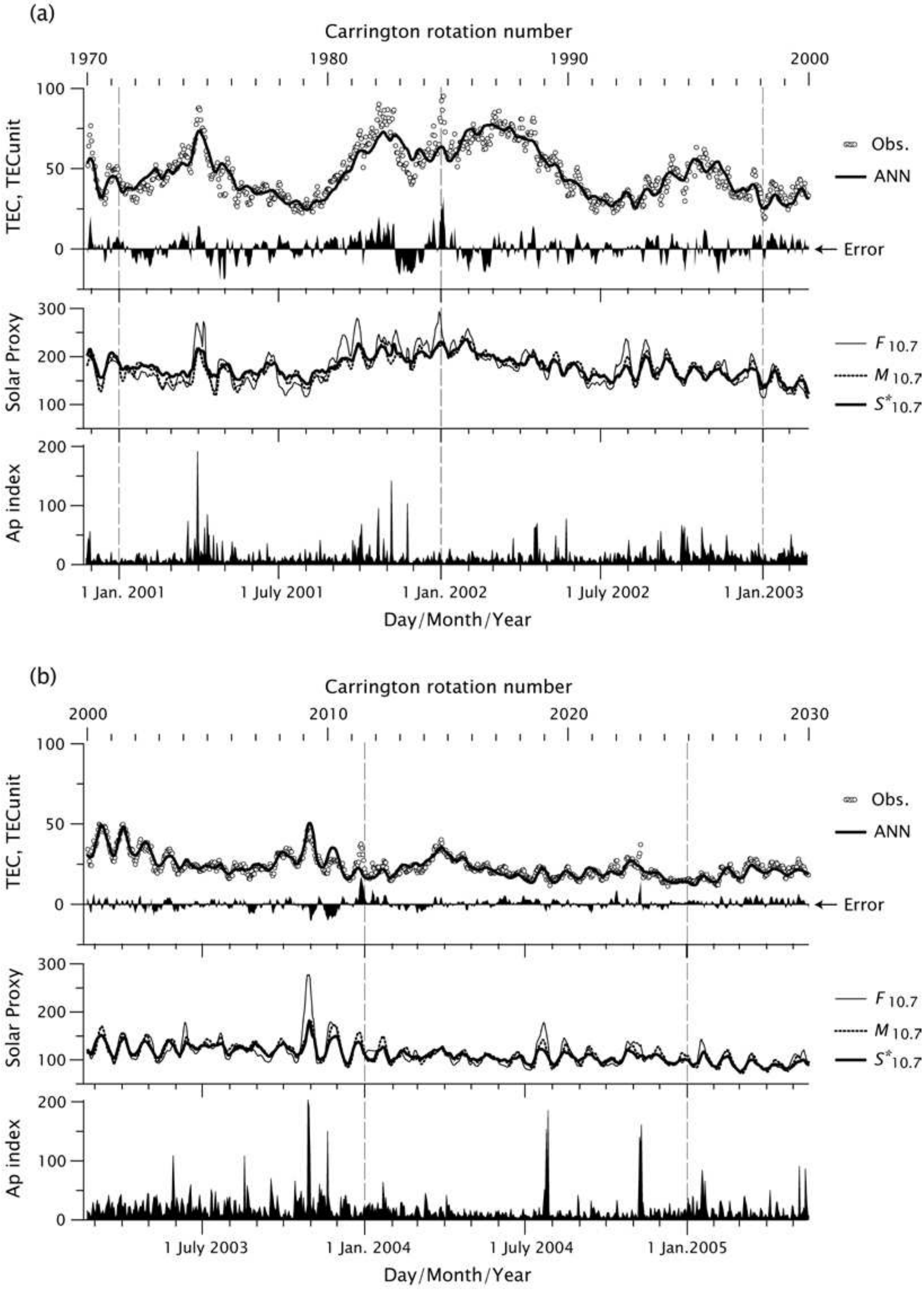

Figure 1: (a) Observed and ANN modeled daily TEC for 30 solar rotations (approximately 2years and 3 months) and their difference (top panel), solar proxies, and planetary Ap index (bottom panel) for the solar maximum. (b) Same as (a) but for the moderate to low solar activity period.