SHORT TIMESCALE VARIATIONS IN IONOSPHERE CAUSED BY IRREGULAR SOLAR ELECTROMAGNETIC RADIATION

Liming He [1], *Lixin Wu* [2,1], *Sergey Pulinets* [3], *Shanjun Liu* [1]

1. College of Resources and Civil Engineering, Northeastern University, Shenyang, P.R. China, 110004;
2. Academy of Disaster Reduction and Emergency Management, Beijing Normal University, Beijing, P.R. China, 100875;
3. Fiodorov Institute of Applied Geophysics, Moscow, Russia, 129128.
heliming@mail.neu.edu.cn awulixin@263.net

ABSTRACT

Solar activity dependency of the ionosphere in local region during a short timescale is of great importance for the analysis of ionospheric anomalies probably caused by local events such as earthquakes and volcanic eruptions. Recently, a nonlinear background removal method based on multiresolution wavelet transform (MWT) for seismo-ionospheric anomaly analysis has been developed by He et al. To further evaluate the method performance, three years of different solar activity levels have been chosen to examine the relationship between the TEC variations and solar activities during 23rd solar cycle. The results showed that the MWT-based method is able to handle well the solar radiation background in the ionospheric TEC data, especially under a complex solar activity situation.

Index Terms—Total electron content (TEC), Solar activity, Ionospheric anomaly phenomena, Local events

1. INTRODUCTION

The ionosphere is one of the most important parts of the solar-terrestrial space environment, which locates between the low neutral atmosphere and the high magnetosphere. It is an open and dynamic system with complex spatio-temporal variations, fluctuating regularly and irregularly over timescales from minutes to decades. As we known, the formation of the ionosphere is primarily due to the ionization of the upper atmosphere by solar X-ray and extreme ultraviolet (EUV) radiations. Observations indicate that ionospheric parameters, such as the total electron content (TEC), are strongly controlled by solar activity in a rather complicated way [1, 2]. A number of works have been devoted to the study of the ionospheric variations due to solar activity changes in global scale during a long time [3, 4]. Such studies are of great importance for the ionosphere modeling because a periodicity in the intensity of solar activity is clearly seen in long data records. However, little attention has been devoted to study the solar activity dependency of the ionosphere in regional scale during a short time. In many cases, ionospheric anomaly changes are short timescale variations, such as the TEC anomalies probably caused by earthquakes and volcanic eruptions etc. In periods of unquiet solar activity, solar radiation variations over the short timescale (e.g., month) are intensive, rapid and nonlinear. For analyzing to these ionospheric data, the solar radiation background in a signal is just like noise, which often increases difficulties in further processing, as the background always blurs the analytical signals. Generally, it is difficult or even impossible to analyze signals with a strong background. Therefore, removing and evaluating the ionospheric variations resulted from irregular solar electromagnetic radiation before ionospheric data analysis for local events turns to be of utmost importance.

Recently, a nonlinear background removal method for seismo-ionospheric anomaly analysis under a complex solar activity situation has been developed by He et al. [5]. To further evaluate the method performance under different solar activity levels, three years have been chosen to examine the relationship between the TEC variations and solar activities during 23rd solar cycle (Fig. 1). Solar 10.7 cm radio flux (F10.7) is commonly used as proxy for solar activity. In this paper, the daily data of F10.7 provided by the National Oceanic and Atmospheric Administration (NOAA) Data Center (ftp://ftp.ngdc.noaa.gov) were utilized. Fig. 1 shows that the variations of F10.7 from 1 January, 1996 to 31 December, 2008. The periods colored by cyan are three years of different solar activity levels to be studied according to the amplitudes of F10.7.

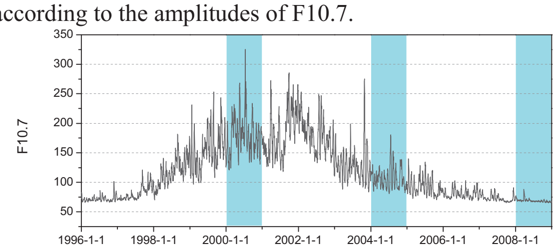

Fig.1 Solar activity index F10.7 time series from 1 January, 1996 to 31 December, 2008. The periods colored by cyan are three years of different solar activity levels to be studied according to the amplitudes of F10.7 during 23rd solar cycle.

In order to study the ionospheric seasonal differences and spatial distributions of the solar activity effects during a short timescale, four 30-day periods covered different seasonal conditions included January, March/April, June/July and September/October in 2000, 2004 and 2008 are selected, respectively. The day of year and average solar activity ($\overline{F10.7}$) values are given in Table 1.

Table 1 Average solar activity conditions for the four 30-day study periods in 2000, 2004 and 2008.

	Day of Year	$\overline{F10.7}$ in 2000	$\overline{F10.7}$ in 2004	$\overline{F10.7}$ in 2008
Jan	001-030	153.7	111.1	72.0
Mar/Apr	080-109	195.1	108.3	73.6
Jun/Jul	172-201	204.1	110.5	67.8
Sep/Oct	266-295	178.9	91.6	68.4

2. METHODOLOGY AND DATA

The methodology used herein is an extraction technique for ionospheric solar activity effects during a short time based on multiresolution wavelet transform (MWT). For a more detailed description of the method, readers are referred to He et al. [5]. Due to the complex solar activity variations in different years, we improve the selection method of the wavelet decomposition number to obtain the best background removal effect. In this paper, correlation is applied as a quantitative indicator, which measures the similarity between the solar activity index F10.7 and the extracted background approximations. For each pixel, all the correlations for the levels of decomposition of 1—10 are computed. The best decomposition number could be determined by selecting the maximum correlation. The ionospheric data used in this study were generated on a daily basis at Center for Orbit Determination in Europe (CODE) using TEC data from approximately 250 continuously operating GPS receivers of the International GNSS Service (IGS) and other institutions. CODE TEC maps were generated every 2 hours to produce 2 hourly snapshots of the global ionosphere. Each global ionosphere map (GIM) has a spatial resolution of 2.5° × 5° in geographic latitude and longitude. Three years CODE GIMs of 2000, 2004 and 2008 are utilized in this study.

3. RESULTS

Fig. 2 shows the global correlation coefficients between the extracted solar background and the solar flux index F10.7 for the four 30-day study periods in different seasons in 2000 with a high solar activity. It can be found that the extracted solar background has remarkable correlations with the F10.7 index during the examined time period in different seasons around the globe. However, the correlations are complicated and behave positive and negative characteristics in different seasons and local regions. In the spring of 2000, there are significant positive correlations in almost all regions over the globe, but significant negative correlations in most regions are observed in the winter of 2000. In the summer and fall, a large part of region is of positive correlation, while the region of negative correlation is sizeable.

Fig. 3 gives the results in 2004 with a medium solar activity. It also can be seen that the extracted solar background and F10.7 have a pronounced correlation. There are significant positive correlations in most regions over the globe for the four 30-day study periods in 2004, and a litter stronger correlation is noted for the summer and fall in comparison with the spring and winter of 2004.

Fig. 4 displays the results in 2008 with a low solar activity. We can note that the extracted solar background and F10.7 have a good correlation only in the spring and summer. Weak negative and positive correlations in most regions over the globe are observed in the fall and winter of 2008, respectively.

4. DISCUSSION AND CONCLUSION

To illustrate the weak correlation in the fall and winter of 2008, all the F10.7 time series for the four 30-day study periods in 2000, 2004 and 2008 are examined. As shown in Fig. 5, all the time series show nonlinear and complex variations expect the time series in the fall and winter of 2008. It can be seen that the solar activities in the fall and winter of 2008 are almost unchanged. Therefore, the ionospheric parameter variation caused by solar irregular electromagnetic radiation is very small, and there is no necessary to remove the solar activity background in ionospheric data under quiet solar activity condition.

It can be seen in Fig. 5 that the F10.7 in the fall of 2000 increased more than 2-fold (from 161.5 to 325.1) (in units of $10^{-22}W/m^2/Hz$) during the 30-day study period. The result in Fig. 2 shows that the extracted solar background has remarkable correlations with the solar F10.7 index in all regions around the globe. In addition, through the analysis of the solar activity effects for four 30-day periods covered different seasonal conditions in three years of different solar activity levels, the results show that the MWT-based method presented in He et al. [5] can handle well the solar irregular radiation background in the ionospheric TEC data in all seasons under complex solar activity situations.

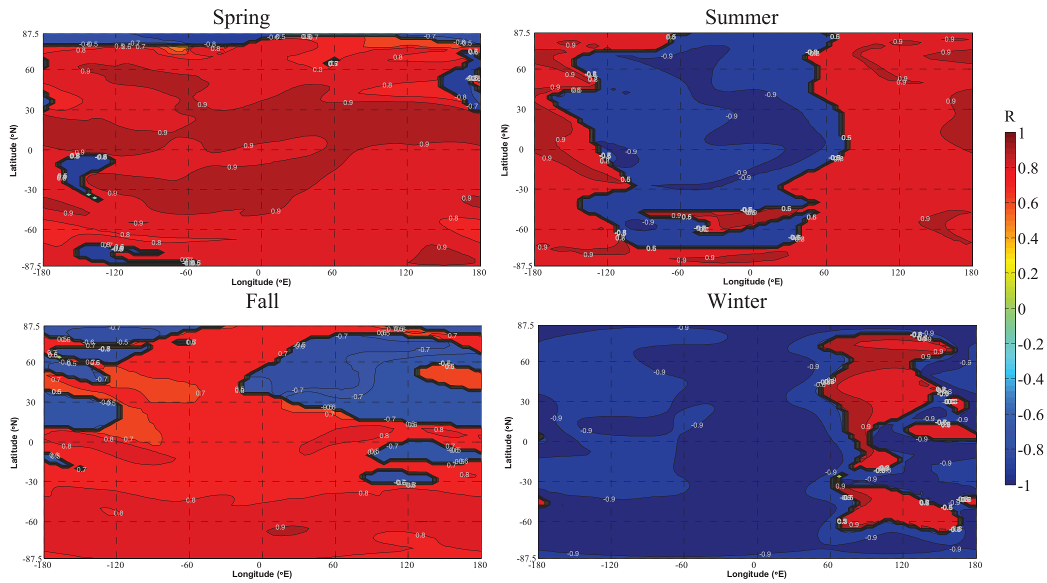

Fig. 2 The global correlation coefficients between the extracted solar background and the solar flux index F10.7 for the four 30-day study periods in different seasons in 2000.

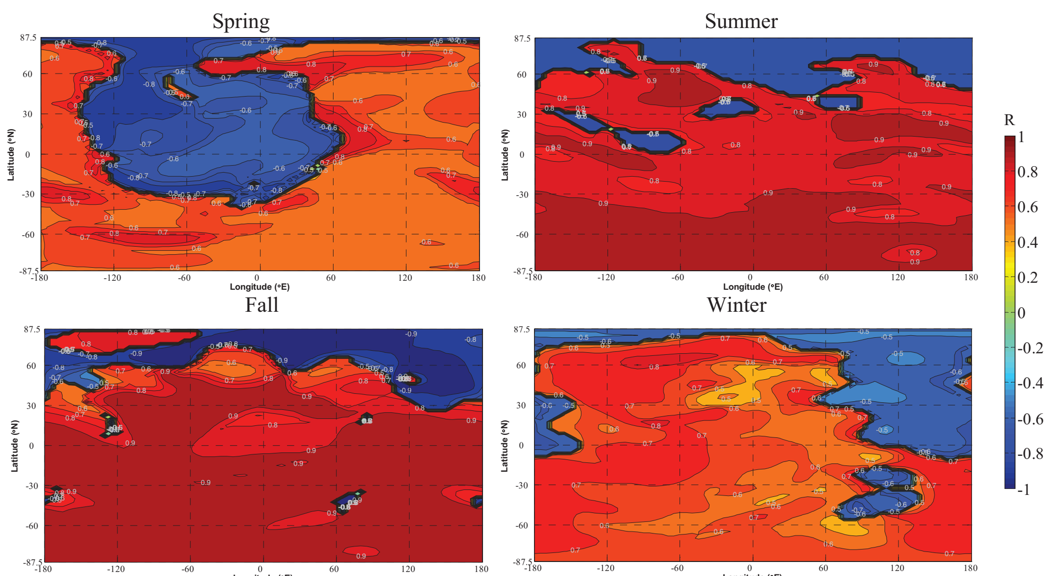

Fig. 3 The global correlation coefficients between the extracted solar background and the solar flux index F10.7 for the four 30-day study periods in different seasons in 2004.

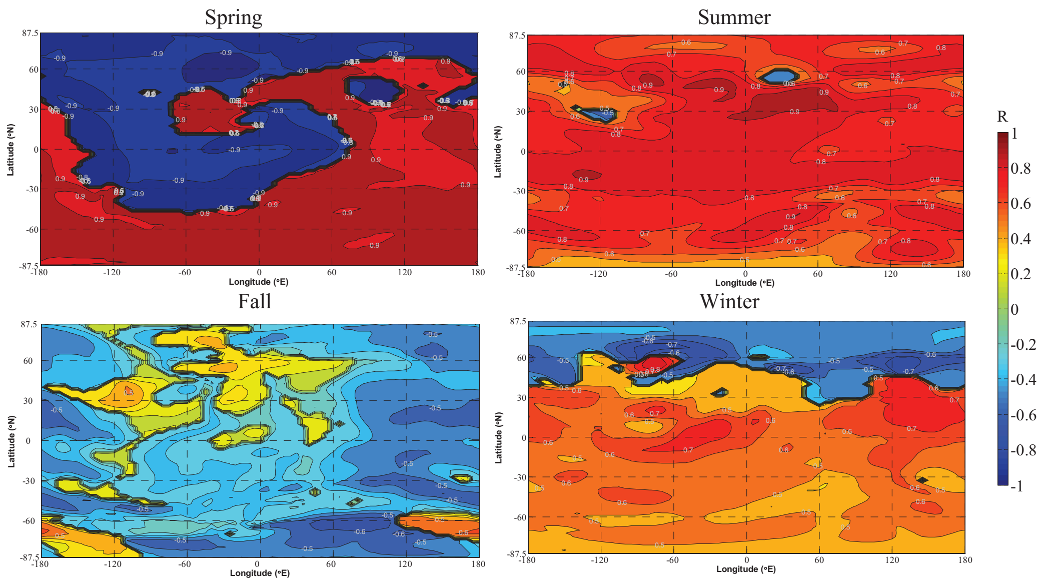

Fig. 4 The global correlation coefficients between the extracted solar background and the solar flux index F10.7 for the four 30-day study periods in different seasons in 2008.

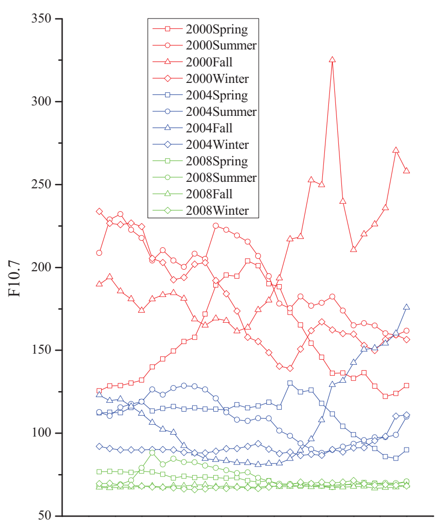

Fig. 5 The F10.7 time series for the four 30-day study periods in 2000, 2004 and 2008.

It is noteworthy that the ionospheric parameter variations over the short timescale are very complicated, thus the level of decomposition should be selected automatically according to the ionospheric TEC data for each pixel during the observed period. Moreover, the positive and negative correlation should be noted in further processing of TEC data to reveal the local anomaly variations probably associated with local events, such as earthquakes and volcanic eruptions.

5. ACKNOWLEDGEMENTS

This research was supported by the National Important Basic Research Project (973 Program, Grant No. 2011CB707102), the National Natural Science Foundation of China (Grant No. 41104104) and the Key Plan for Introducing Overseas High-level Culture-education Experts. The authors acknowledge the International GNSS Service (IGS) and the Center for Orbit Determination in Europe (CODE) for providing the GPS TEC data. The F10.7 indices were downloaded from the NGDC database.

6. REFERENCES

[1] M. Kelley, *The Earth's ionosphere: plasma physics and electrodynamics*, 2 ed. San Diego: Academic Press, 2009.

[2] H. Rishbeth and O. Garriott, *Introduction to ionospheric physics*. New York: Elsevier, 1969.

[3] L. Liu, et al., "Climatology of the mean total electron content derived from GPS global ionospheric maps," *J. Geophys. Res.*, vol. 114, 2009.

[4] L. Liu and Y. Chen, "Statistical analysis on the solar activity variations of the TEC derived at JPL from global GPS observations," *J. Geophys. Res.*, vol. 114, 2009.

[5] L. He, et al., "A nonlinear background removal method for seismo-ionospheric anomaly analysis under a complex solar activity scenario: a case study of the M9.0 Tohoku earthquake," *Adv. Space Res.*, vol. 50, pp. 211-220, 2012.