Correlation Between Solar Activity and Earth’s Ionospheric Electron Content During the 23rd Solar Cycle.

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Introduction

One of the future challenges of the Space Weather community will be to predict the Earth’s Ionosphere state in response to variations of the Solar activity (Fig. 1). The Earth’s Ionosphere is the atmospheric layer degrading the most radio communications, particularly the GNSS (Global Navigation Satellite Systems, e.g. GPS, GLONASS, GALILEO).

The beginning of the 23rd Solar cycle (May 1996 to December 2008) coincided with the start of the catalogue of global ionoscopy modeling based on GNSS data from dense ground networks. In addition, many parameters of the Solar activity are historically measured.

In this study, we compared the daily Sunspot Number (SN) and F10.7 flux with the daily mean Ionospheric Total Electron Content (TEC) obtained from GNSS data during the 23rd Solar cycle in order to better understand the ionization response to Solar activity variations. The main questions we address are:

What are the correlations between Solar and Ionospheric states?  
Which Solar parameter shows the best correlation with Ionospheric TEC?  
Do these correlations vary in time (seasons, Solar cycle phases)?  
Is there a geographic dependency of these correlations?

1. Ionospheric Data

Global Ionoscopy Maps (GIMs)

GIMs from the CODE Analysis Center [Schaer et al., 1999] are used as ionospheric data. The CODE GIMs product (Fig. 2) consists of global Vertical Total Electron Content (VTEC) estimated from GNSS data. The GIMs are modeled in a Solar geomagnetic reference frame using a spherical harmonics expansion up to degree and order 15 with piecewise linear functions for the temporal evolution of the VTEC. An ionospheric single thin layer (STL) hypothesis is used to express the VTEC at a given altitude (typically 400-450 km, in the F region of the ionosphere where the electron concentration is maximum).

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The Daily Sunspot Number

The daily Sunspot Number (SN) provides the longest available record of Solar activity since 1818 and is the main reference Solar index. SN represents the recurrence of intense magnetic loops visible on the Sun surface. Presently, the estimated International SN (Fig. 3) is distributed by the Solar Influences Data Center (SIDC) and is based on statistical processing of the data of a worldwide network of 86 stations from 29 countries [Clette et al., 2005].

F10.7 Solar Flux

The integrated emission from the Solar disk density at 2800 MHz (10.7 cm wavelength called F10.7) is recorded routinely (Covington, 1989 since 1942).

Two sets of fluxes are used here (Fig. 3):  
(1) the observed flux (F10.7o) which is the true measured values,  
(2) the adjusted flux (F10.7a) which describes more purely the Sun’s behavior (corrected for the changing distance between the Earth and Sun throughout the year). The 10.7 cm Solar flux is expressed in Solar Flux Unit (1 SFU = 10^-24 Wm^-2Hz^-1). In this study we used the daily F10.7 estimated from the radio telescope in Penticton, British Columbia and accessible via the NSDC-NOSA website.

VTEC Data

The daily mean VTEC in TECU (Fig. 3) is estimated from the GIMs (see section 1) and corresponds to the average of the daily VTEC.

We study the correlation between Solar (SN, F10.7o) and Ionospheric (VTEC) data from 1995-001 to 2009-275 (5388 days).

4. Latitudinal Correlations

In this section, the latitudinal distribution of the correlation between the VTEC and the observed F10.7o is investigated. The daily mean VTEC is computed each 10° of latitude between 180° S to 90° N by the mean VTEC from a band of 20° (in latitude) around the given latitude.

Results 3

- The correlation between mean daily latitudinal VTEC expressed in geometric coordinates and F10.7o does not significantly change except close to 30° of latitude.  
- The maximum correlation (R=0.95) is observed close to 110° N.  
- A dichotomy is identified with a lower correlation in the Southern Hemisphere (R=0.81-0.86) compared to the North (R=0.92-0.95).

Seasonal Dependency of the Correlation VTEC/F10.7o

To study the VTEC response to relative position and orientation of the Earth/Solar system, the latitudinal daily mean VTEC and F10.7o are divided in four seasonal periods: Spring, Summer, Autumn and Winter corresponding to seasons in the Northern Hemisphere (Fig. 6).

Results 3

- The maximum correlation (R=0.84) is close to 530° latitude during winter while the minimum (R=0.74) occurs during summer period close to the South pole.  
- The correlation is improved during Autumn (R=0.88-0.92) compared to Spring and Summer periods (R=0.87-0.84).

Solar Cycle Dependency of the Correlation VTEC/F10.7o

The latitudinal daily mean VTEC and the F10.7o are now divided in three Solar cycle phases (Fig. 7):


Results 4

- The correlations are consistent for the two transition and minimum phases.  
- The correlation is larger during Solar transition activity phases (R=0.71±0.09) and decreases during maximum (R=0.49±0.09) and minimum (R=0.32±0.19) phases with a complete de-correlation at N50° during solar minimum.

Conclusion

From the study of the correlations between ionospheric VTEC extracted from CODE GIMs and Solar indices we can draw two major conclusions:

- The correlation is maximum when:  
  - Considering F10.7o observed vs. VTEC.  
  - During winter period in the Southern Hemispheres.  
  - During Solar transition phase activity.  
  - When geomagnetic coordinates are considered for VTEC extraction.

- There is a clear dichotomy between the Southern and Northern Hemispheres concerning the response of the ionosphere to Solar activity.