RESPONSE OF THE DISTURBANCE IONOSPHERE INDEX TO GEOMAGNETIC STORMS

VII SBGEA

VII Simpósio Brasileiro de Geofísica Espacial e Aeronomia

Picanço, G. A. S. [1]; Denardini, C. M. [1]; Nogueira, P. A. B. [2]; Barbosa Neto, P. F. [1]; Romero-Hernandez, E. [3]; Resende, L. C. A. [1]; Carmo, C. S. [1], Chen, S. S. [1] Bertollotto, T. O [1]; Bilibio, A. V. [1]; Moro J. [4,5];

[1] National Institute for Space Research (INPE) – Aeronomy Div. - Av. dos Astronautas, 1758, Jd. da Granja, ZIP: 12227-010, São José dos Campos - SP, Brazil. [2] Federal Institute of São Paulo (IFSP) - R. Antônio Fogaça de Almeida, 200, Jardim Elza Maria, ZIP: 12322-030, Jacareí - SP, Brazil. [3] Autonomous University of Nuevo León (UANL) - R. Pedro de Alba, Ciudad Universitaria, ZIP: 66455, San Nicolás de los Garza - NL, Mexico. [4] Southern Regional Space Research Center (CRS/INPE), Mailbox 5021, Av. Roraima, 1000, Campus Universitário, ZIP: 97105-970, Santa Maria - RS, Brazil. [5] State Key Laboratory of Space Weather, National Space Science Center, Chinese Academy of Science (NSSC/CAS) - Beijing, China.

giorgio.picanco@inpe.br

Abstract

The Disturbance Ionosphere Index (DIX) is an index originally designed to express the response of the ionosphere to magnetic disturbances. In this work we present a preliminary analysis of results obtained from the DIX calculation during geomagnetic disturbed periods. The DIX values are calculated from the deviation of TEC data from a non-perturbed reference baseline, such as a 3-hour moving average of the TEC obtained during a quiet period. We assume that such deviation is related to the degree of perturbation in the ionospheric content, providing a quick and approximate estimation of the ionospheric local state. Consequently, different mathematical approaches to estimate the ionospheric state can emphasize certain physical phenomena mainly observed during day or nighttime. Therefore, we calculated the DIX for some magnetic storm periods using different methods to estimate the TEC-baseline deviation and adjust the peak-valley normalization on the DIX scale. The results are presented and discussed in terms of a statistical analysis, focusing on the physical relation between DIX values and ionospheric disturbances observed in TEC data.

Introducing the $\mathrm{DIX_{BR}}$ index

Ionospheric disturbances caused by magnetic storms have a strong influence on the performance of radio-based space systems (e.g., GPS, Galileo, and GLONASS). These effects may include errors caused by rapid phase and amplitude fluctuations in satellite signals, as well as interruptions in the satellite-receiver connection (Klobuchar, 2006). Jakowski et al. (2006) proposed a Disturbance Ionosphere indeX (DIX) based on TEC data to quantify the perturbation degree of the ionosphere, and, at first, express the ionospheric response to magnetic storms. This work intends to contribute to the improvement of DIX, analyzing its accuracy from the use of different approaches to represent the quiet ionosphere and including new terms in the DIX equation to better represent ionospheric disturbances.

The methodology proposed in this study is a modified version of the one presented in Jakowski et al. (2006). The original DIX is defined from the deviation of TEC from a non-perturbed reference baseline such as monthly averages (in the original study). Thus, the DIX is defined by the following formula:

$$DIX = \left|\left(TEC_k - TEC_k^{LB}\right)/TEC_k^{LB}\right|,$$

where $\mathrm{TEC_k}$ is the measured TEC value for a given GNSS station and $\mathrm{TEC_k^{LB}}$ is the corresponding baseline value.

Our contribution includes the use of 3 new terms in the DIX equation: Δ_{TEC}, k and j. Thus, we can define a new equation, the $\mathrm{DIX_{BR}}$, from the following equation:

$$DIX_{BR} = \left[\frac{k\left|\frac{TEC_k - TEC_k^{LB}}{TEC_k^{LB}}\right| + \Delta_{TEC}}{j}\right]$$

- The Δ_{TEC} term represents the difference between measured TEC values and baseline values , providing a better visualization of the ionospheric disturbances with respect to their amplitude. This term is given by the following relation:

$$\Delta_{TEC} = \left|TEC_k - TEC_k^{LB}\right|$$

- The k term is an amplitude adjustment parameter, and is used to level the DIX term (deviation term) with the Δ_{TEC} term. This term is calculated by the ratio between nighttime values observed in both terms Δ_{TEC} and DIX.
- The j term is a scale normalization parameter, and is defined from a peak amplitude analysis of $\mathrm{DIX_{BR}}$ values during intense magnetic storms, in order to assign to the index a maximum perturbed value on a scale of 0 to 5 .

Defining a quiet-ionosphere baseline for $\mathrm{DIX_{BR}}$ calculation

Besides a monthly average, as seen on the original DIX study, two other methods were used to calculate the quiet-ionosphere baseline for $\mathrm{DIX_{BR}}$:

- The first method consisted of a centered moving average of 1, 3 and 6 hours of the geomagnetically quietest day of the period (according to the GFZ classification).
- The second method consisted of using TEC data from the International Reference Ionosphere (IRI) model, as a attempt to represent quiet-ionosphere values.

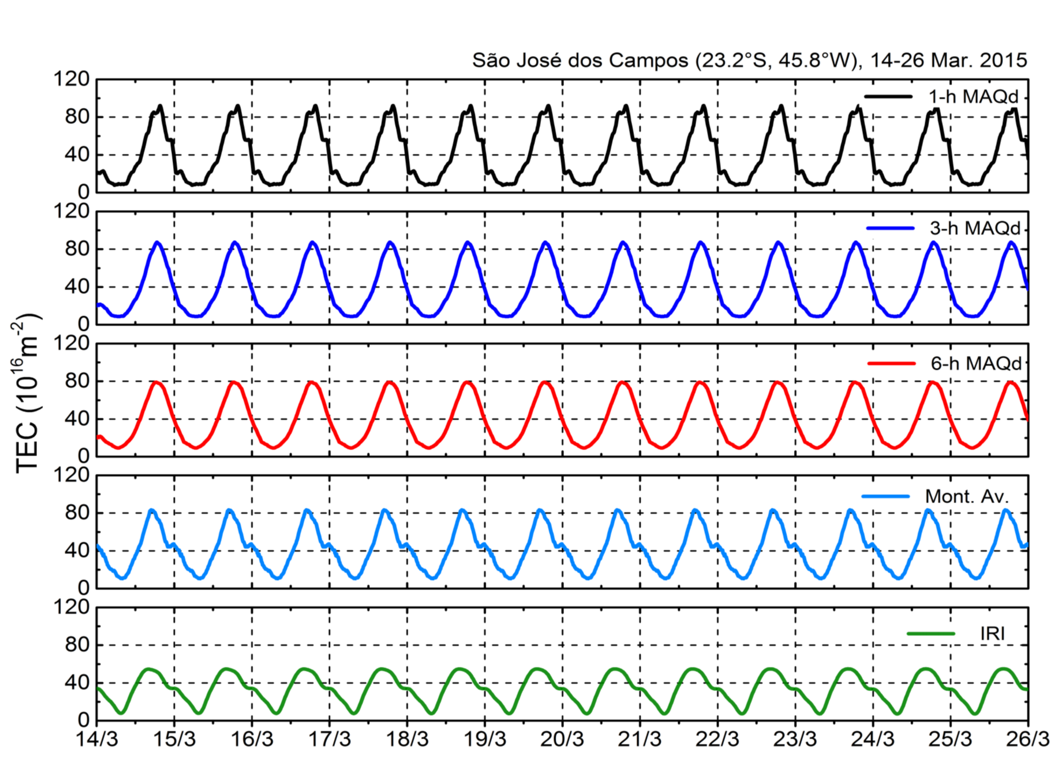

Fig. 1 – Baselines calculated from the proposed methods: 1, 3, and 6-hour moving average, the original method, a monthly average, and IRI-model data.

The most mathematically appropriate method to represent the $\mathrm{DIX_{BR}}$ baseline was chosen according to the Pearson coefficient (r), and considering the coefficients of the linear fits (Figure 2). The chosen baseline was the one calculated from a moving average with a temporal resolution of 3 hours.

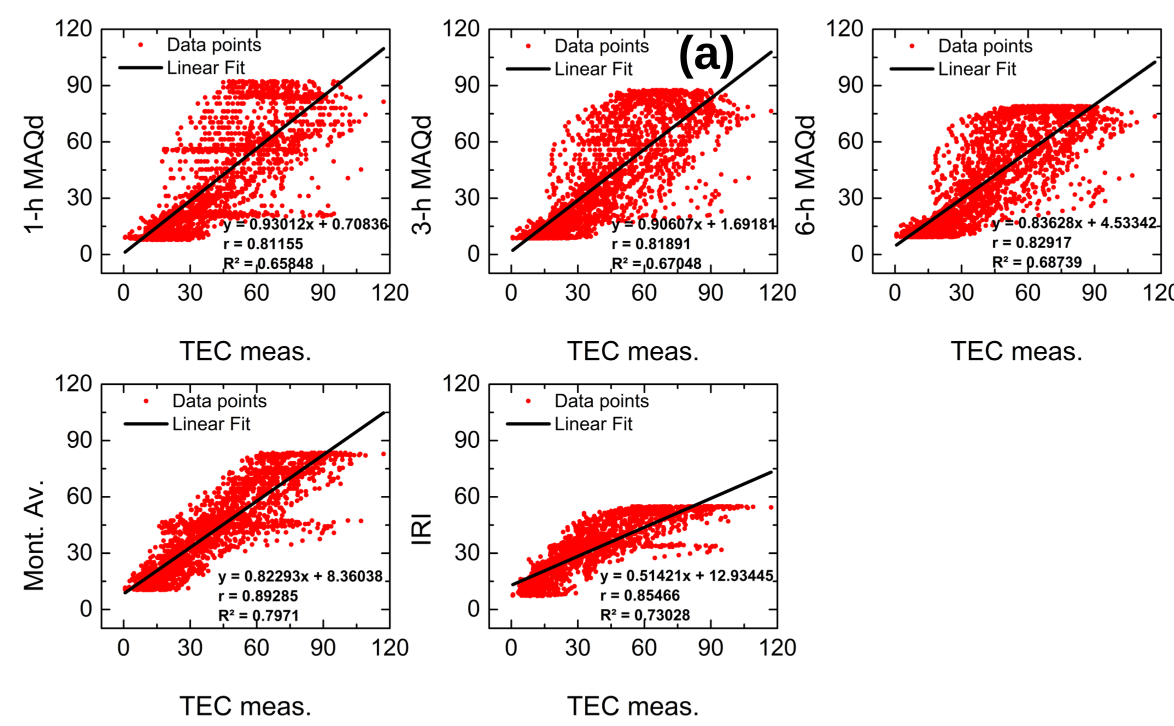

Fig. 2 – Scatter plots of the methods used to determine the quiet-ionosphere baseline and the measured TEC data. Based on the observations, the chosen baseline was the one calculated from the moving average using a temporal resolution of 3 hours (a).

Application to the St. Patrick's Day Geomagnetic Storm (March 2015)

A preliminary analysis of $\mathrm{DIX_{BR}}$ can be made from its application in calculating the perturbation degree of the ionosphere during the St. Patrick's Day Magnetic Storm, which occurred in the period from March 17 to 19, 2015 (Figure 3). This phenomenon can be classified as a superstorm, according to the abrupt variation observed in the Dst index, which reached values below -200 nT during the main storm phase (Gonzalez et al., 1999; Maurya et al., 2018).

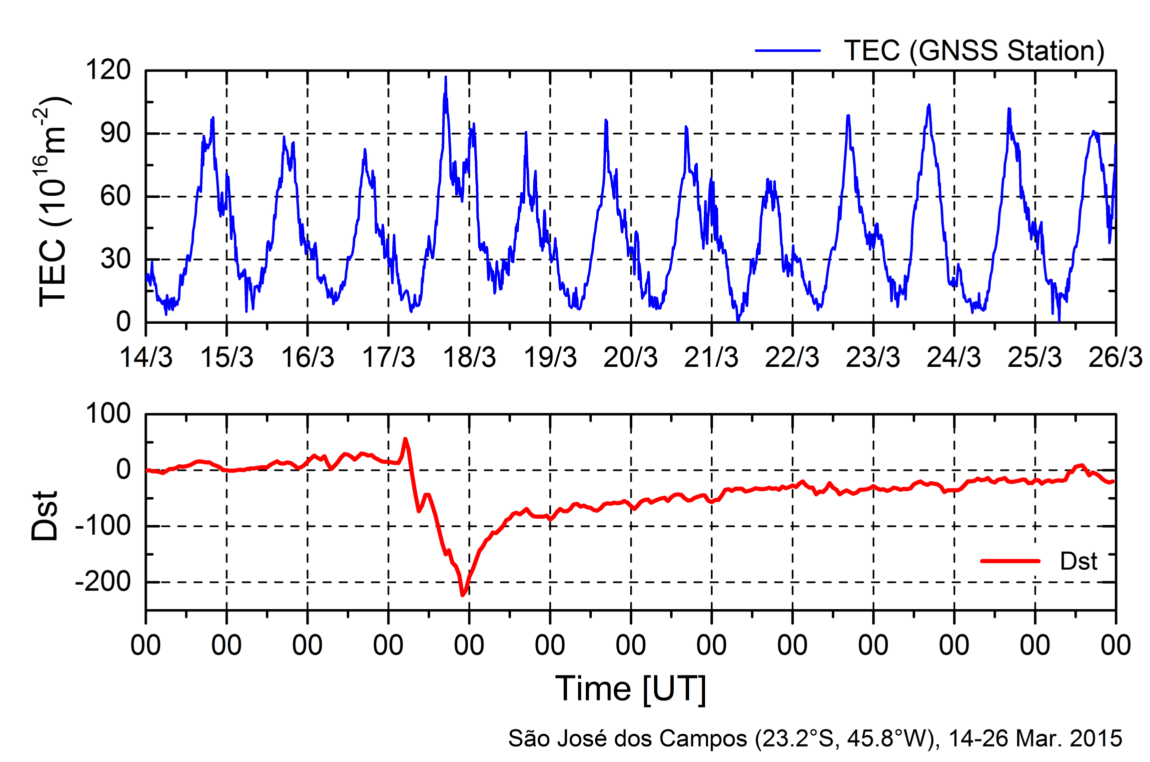

Fig. 3 – TEC data measured by a GNSS station at São José dos Campos and Dst values for the period from March 14 to 26, 2015.

The $\mathrm{DIX_{BR}}$ values was calculated for the period of March 14-26 using TEC data from a GNSS station located in São José dos Campos, Brazil (23.2ºS, 45.8ºW). Compared to original DIX values, we can see the disturbances in the $\mathrm{DIX_{BR}}$ with greater clarity and precision (Figure 4).

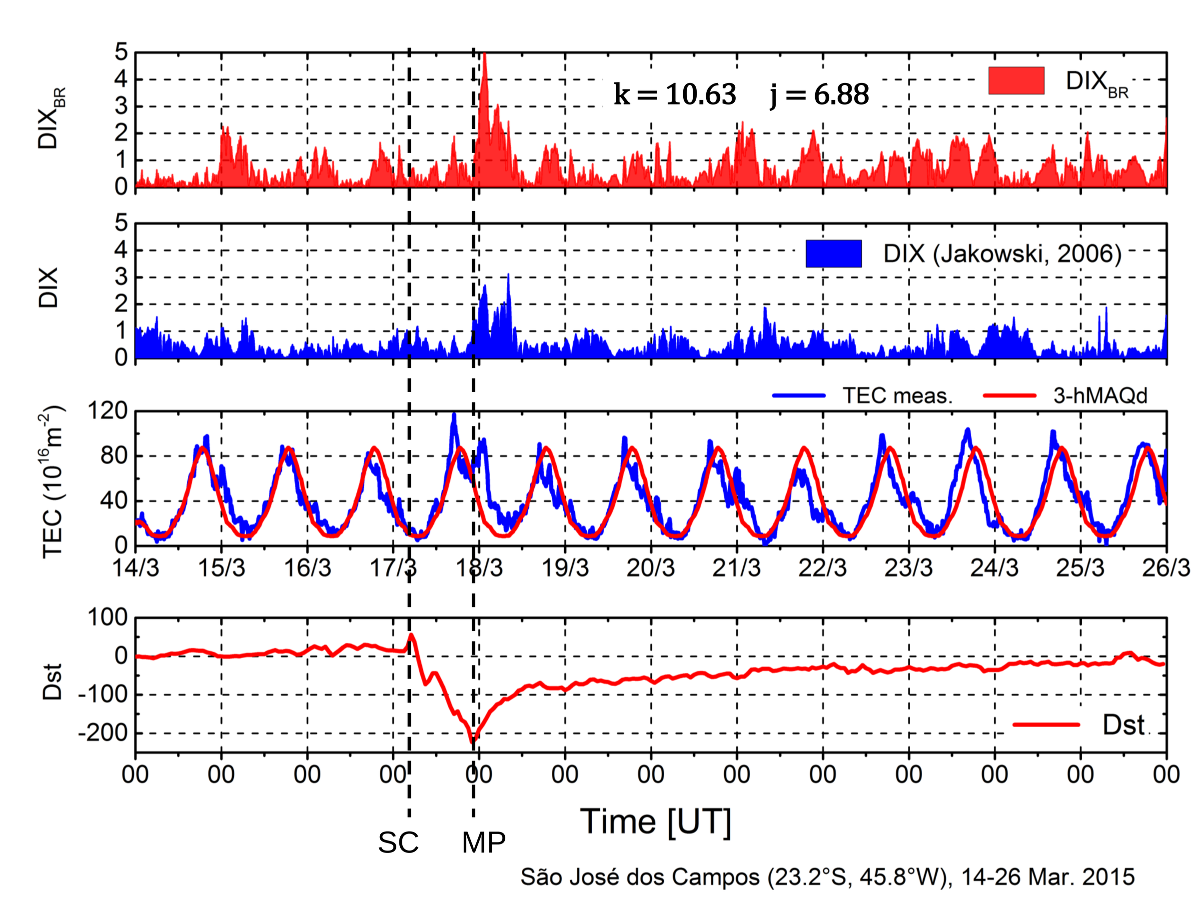

Fig. 4 – $\mathrm{DIX_{BR}}$ represents the calculated index using the proposed methodology. DIX represents the index calculated using the original methodology. The (SC) and (MP) markers represent the Sudden Commencement and Main Phase minimum Dst value during the magnetic storm, respectively.

Summary

- We have observed that the most successful method to represent the quiet day profile is using a moving average of 3 hours.
- The proposed methodology has proved to be sensitive to ionospheric disturbances associated with magnetic storms, which is in agreement with the methodology proposed by Jakowski et al. (2006).

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VII SBGEA, 05 - 09 de novembro de 2018, Santa Maria – RS, Brasil

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.