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# The determination of ionospheric TEC disturbance based on the cross-validation method

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**Abstract:** The ionosphere has an impact on the radio system, therefore, the determination of the ionospheric state is significant. The total electron content (TEC), as an important ionospheric parameter, can characterize the state of the ionosphere. This paper introduces a new ionospheric disturbed index N13 by correcting the existing index N27, and also proposes the theory foundation for determination the ionospheric state using cross validation method. The N13 is defined as the normalized relative variation of the ionospheric TEC, in which the TEC background value is the sliding median of 27 days. Analyzing the N13 calculated from the TEC data at Taipei station from January 2002 to July 2014, the results show that the two indexes N13 and N27 generally have the same statistical characters against with season and local time, however, they are always different at one time. Based on the probability density function of N13，an optimization model is also constructed to determine the ionospheric disturb proportion by cross validation method. It is found that the proportion is about 25%, when the ionospheric disturbed index range is $N_{13}<-1$ or $N_{13}>1$.

**Keywords:** Ionospheric disturbed index, Ionospheric disturbed proportion, Ionospheric disturbed determination, cross validation.

## 1. Introduction

The ionosphere is the upper atmosphere of the Earth in the altitude range of 60km~1000km above the ground. The presence of a large number of free electrons and ions in the ionosphere can change the speed of radio waves going through it, causing in refraction, reflection and scattering. The electron density varies strongly with many factors. Therefore, some efforts have been made to confirm the state of ionosphere to reduce its impact on the radio system.

In recent years, based on the observational important electron density parameters Total Electron Content (TEC) and frequency of F2-layer(foF2), the ionospheric disturbed index and the criteria for determining disturbed events have been proposed. Bremer [1] proposed an ionospheric activity index $AI$ based on European foF2 measurements , comparing current data with undisturbed historical data, and later revised it with Mielich [2] to an ionospheric activity index that can describe ionospheric storms in mid-latitudes, which is one of the most commonly used index by later authors. Another index proposed by Gulyaeva [3] to describe ionospheric storms is the ionospheric weather index ($W$ index), which is defined by setting the corrected ionospheric parameters to the logarithm with respecting to their reference values of the static day, given when $W=\pm1$ indicates quiet condition, when $W=\pm2$ indicates a moderate disturbance, when $W=\pm3$ indicates a storm, and when $W=\pm4$ indicates a large storm. Jakowski [4] introduces an interference ionospheric index based on GNSS (Global Navigation Satellite System) measurements to reduce the impact of space weather on GNSS navigation positioning. Nishioka [5] propose the method of standardized index $AI$, which is denoted as $\hat{P}_{TEC}$, and the index can be independent of local time, season and geographical location.

For the determination criteria of ionospheric disturbed events, Kouris [6] proposed that the relative deviation of ionospheric TEC from the monthly median value in which it occurred for 3 consecutive hours exceeds 0.1 as the basis of ionospheric disturbed events. Lekshmi [7] defined a storm event as one in which $\Delta N_{\max}$ exceeds 25% or is less than -25% and lasts longer than 3h, where the background value is the average value of the 7 calm days before the storm. Matamba [8] determined ±20% and ±40% as the ionospheric static time-varying rate based on the deviation of the observed values of foF2 and TEC data from the monthly median values obtained in the month in which they occurred, respectively. Chinese scholars Huang [9-10] analyzed

foF2 data from five Chinese stations and concluded that an ionospheric disturbed event is defined when the variation of foF2 exceeds 15% and is continuous for more than 6 hours. Chen [11] studied an event with $df \geq 0.15$ and a duration of 6h or more as a perturbation event based on the change of the observed value of foF2 data relative to the mid-month value noted as $df$. Gao [12] analyzed the types and the patterns of distribution of ionospheric disturbances at four mid- and low-latitude stations in the East Asian sector and proposed that an ionospheric storm event is considered to have occurred when the change in foF2 exceeds 15% and lasts for more than 4 hours, where the background value is the 27-day sliding median of the observed value. Liu [13] defined a storm event as one in which the absolute $R_{TEC}$ exceeds 15% and lasts at least 3h. Deng [14] analyzed TEC data from six Chinese observatories and gave the definition of positive (negative) phase storm disturbed events in ionospheric TEC as a continuous period of 6h and more $DI > 0.35 (DI \leq -0.3)$ and the period $DI$ not satisfying the value must not exceed 2 h. Here the $DI$ index is the $AI$ index, where the background value is the sliding median of 13 days before and after the corresponding moment of the observed day. Li [15] defined $\Delta foF2$ based on the relative deviation of the observed value of foF2 data from the mid-month value, and defined $\Delta foF2$ greater than or equal to 15% and continuous for more than 6 hours as an ionospheric storm event. Based on the disturbed determination criteria proposed by Gao [12] and Deng [14], Wu [16] considered the daily variation of TEC at storm subtracted from the average daily variation of the static days, and the difference exceeded 25% of the average value of the static days and the duration exceeded 3h as an ionospheric storm event, in which the geomagnetic activity index was used as the criterion for the selection of the static days, and the number of static days was not less than 7 days. Liu [17] defined a storm event as one in which $\Delta TEC$ exceeds 25% of the background level and lasts for more than 3 hours, where the average of the seven calm days before the storm is used to represent the background value.

In summary, there is no unified standard for the determination of ionospheric disturbed conditions and disturbed events. In order to better study the physical mechanism of ionospheric disturbances (storms), especially from the application point of view, providing the necessary and accurate ionospheric state information to the relevant equipment/users, performing ionospheric disturbed condition determination is the primary problem to be solved.

## 2. Data and Methods

### 2.1 Ionospheric TEC data and disturbed index

The data are ionospheric GPS-TEC data observed at the Chinese Taipei station with a data resolution of 15 min in this paper from January 2002 to July 2014. The cumulative duration is more than 12 years, about one solar activity cycle.

The ionospheric disturbed index is the index after normalizing the relative change of ionospheric TEC. It is as follows: the relative change of ionospheric TEC is defined first (equation 1), and then normalized (equation 2).

$$P_{TEC} = \frac{O_{TEC} - R_{TEC}}{R_{TEC}}, \tag{1}$$

$$N_{TEC} = \frac{P_{TEC} - \mu}{\sigma}, \tag{2}$$

Where $O_{TEC}$ is the ionospheric observed TEC, $R_{TEC}$ is the ionospheric TEC background value, the sliding median of 27 days is usually chosen, $N_{TEC}$ is the ionospheric disturbed index $\mu$ is the mean of $P_{TEC}$, $\sigma$ is the standard deviation of $P_{TEC}$.

From the above definitions, it is clear that differences in the background values of the ionosphere lead to differences in the final ionospheric disturbed index. In this paper, in order to better characterize the ionospheric disturbances physically, the method of using the median TEC sliding value of the past 27 days as the background value for Nishioka[5] is adjusted to the median sliding value of 13 days (27 days in total) before and after the observed time as the ionospheric background value, and then the ionospheric disturbed index is obtained. For comparison purposes, this paper uses $N_{TEC}$ to denote Nishioka's $\hat{P}_{TEC}$.