Automatic detection of TEC anomalous fluctuations and correlation with seismic events

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INTRODUCTION

Seismic events have been a subject of intense studies for last many years. Due to their mass destruction effects any new information associated with these phenomena is potentially of interest. The correlation between the seismic activity recorded on ground based stations and the anomalous fluctuations in ionospheric Total Electron Content (TEC) is the frame of a study in progress at our institute. It is well known that dynamics of ionosphere is linked to the season, the geomagnetic activity, and the local time. Consequently the identification of truly anomalous TEC fluctuation is quiet challenging. The purpose of this paper is to present the study in progress.

The strategy adopted to overcome the problem of TEC anomaly identification and to achieve the correlative study is composed of four distinct phases. The aim of the first phase was to collect and prepare the seismic and TEC databases. The seismic database contains the position, time and magnitude of all registered earthquakes with magnitude greater or equal to 5 during the time period [1992-2003]. It has been done using the data stored at the National Earthquake Information Centre. The TEC database is composed of the TEC measurements derived from the radar altimetry experiment on board the TOPEX/Poseidon spacecraft during the same period time [1992-2003].

The second phase was dedicated to the generation of reference maps to describe the statistical properties of TEC fluctuations all around the world. The obtained maps have been computed using the TEC database. They have a bin size of 4°x4° resolution in latitude and longitude and are given as a function of the four seasons with a local time resolution of 1 hour, and four different levels of magnetic activity.

The task to be achieved during the third phase is the automatic identification of the "anomalous" TEC fluctuations in the database. This is done by comparing the main statistical properties of the TEC measurements contained in the TEC database with the corresponding values provided by the reference map. A $\pm 2\sigma$ criterion is then used to identify the anomalies.

The last phase will be the correlation study of the time occurrence and position of identified TEC anomalies with the time occurrence and position of the most intense seismic events registered during the period [1992-2003].

This paper is divided into three sections. In the first section we describe the work done during the preparation of the databases. The second section is dedicated to the justification of the choices made for generation of reference maps. In the last section an automatic detection technique is presented with some detail.

DATABASE PREPARATION

In first step we prepared two databases. The first database contains the records of position, time, and magnitude of the seismic events registered worldwide during the time period [1992-2003]. We have selected the seismic events having a magnitude greater than 5, recorded by the National Earthquake Information Centre (USGC, a site of U.S. Geological survey). The web address for the above Information centre is **http://neic.usgs.gov/**. The mission of the National Earthquake Information Center (NEIC) is to rapidly determine location and size of all destructive earthquakes

For the second database, data has been taken from AVISO CDROM. The AVISO/altimetry centre, in Toulouse is the French Active Archive Data Centre for multi-satellite altimeter missions. Its first task is to serve the U.S./French TOPEX/POSEIDON mission. AVISO/Altimetry processes, validates and archives above level-2 altimeter data (full GDRs) from the TOPEX/POSEIDON mission, and distributes them to its broad user community. In our archive we had 300 CDs available and the total memory occupied by them was 128 Gb containing all the parameters. Thus it was essential to take out the relevant parameters pertaining to our study. So as a consequence 11parameters comprising of time, position (longitude and latitude), TEC measurements derived from Radar Altimetry experiment and their associated quality flags have been extracted.
These quality flags facilitate to eliminate TEC values having excessive limits and excessive changes directly .. Thus TEC archive, obtained finally contains 343 TEC files. Each TEC files contain data taken in 10 day-cycle of satellite and occupies 19 MB approx of space .All the TEC files have been stored on 6 CD which amounts to 6GB (19MBx343files). So the memory constraint has been reduced from 128 GB to 6 GB by a factor of 20.

GLOBAL TEC MAPS GENERATION

The second step of our study was dedicated to the generalization of reference TEC maps. As a preliminary step in preparing the TEC map we choosed a bin size of 4° × 4° resolution in latitude and longitude. TOPEX gives precise measurements of the TEC but they are valid only above the sea. So for our work we have taken only the TEC values above the sea surface and eliminated values above the continents. Then corresponding to each bin for TOPEX measurements statistical parameters(Maximum value, Minimum value, Average value and standard deviation) of TEC fluctuations have been calculated.

The time resolution of our data is 1s. In order to remove the instrumental noise effects, we applied the 14s running average scheme as described by [AVISO-CDROM user manual and Geonhwa Jee, Robert W et al.,] to our datasets.

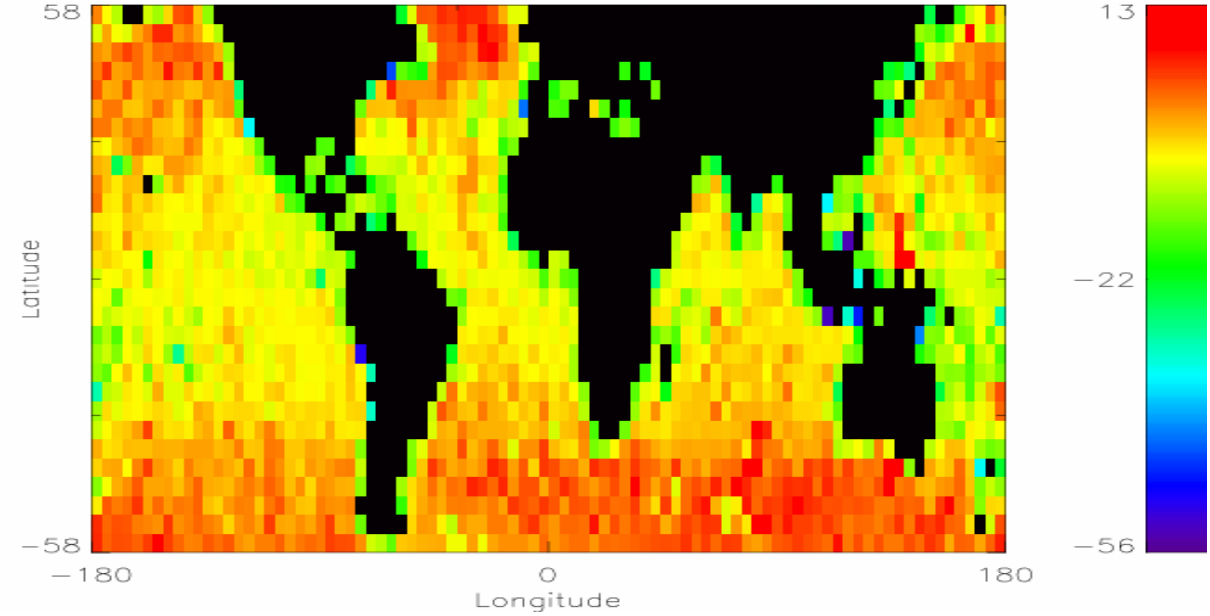
For the sake of our study involving nullifying the geomagnetic effect on TEC variation associated with seismic activity, we prepared third database of geomagnetic index (Am-mondial index or planetary index). Am index has been taken for the same period of time as in our TEC database. Am index is taken in our study because it is always better to use Am index rather than kp index when a precise indication of geomagnetic activity is needed especially in case of statistical studies. The resolution of Am index is 3 hrs. So there are 8 values corresponding to each day.

There are important seasonal variations of the ionosphere, and therefore we binned the TOPEX TEC data according to season also. So considering that TEC varies as a function of season (Su,Y.Z. et al.,), geomagnetic activity (Danilov,A.D et al.,) and local time, the final produced TEC maps we obtained are depending on these quantities. Thus each reference TEC map is associated with a given season (winter, autumn, summer, spring), a given level of geomagnetic activity (low, medium, relatively high, high), and a given local time. For the sake of simplicity the local time has been split in 24 subclasses with 1 hour resolution. So there are 25 classes, comprising of 24 classes with 1 hour resolution and 1 class comprising of all 24 hours. Similarly there are 5 class for season, comprising of 4 class for 4 season(Summer, Winter, Autumn, Spring) and 1 class for all season. We have divided geomagnetic activity into 5 grades- 4 grades for 4 activities (low, medium, relatively high and high) and 1 grade comprising all.

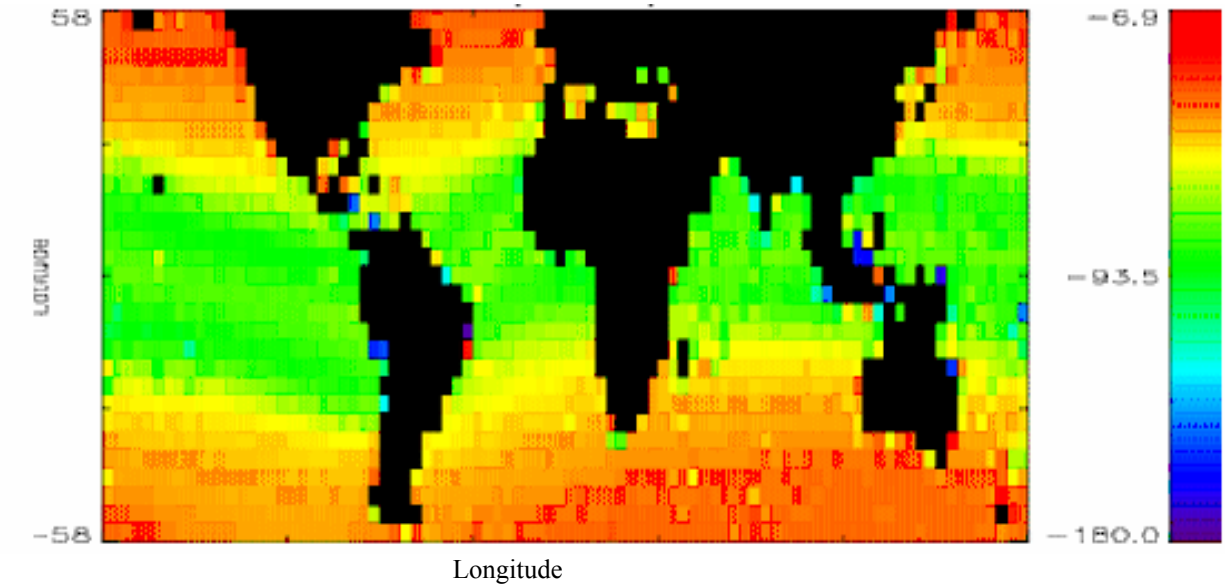
Thus there are 8 types of maps possible. There are three parameters-Local time, Season and Geomagnetic Activity. For fixed season and fixed geomagnetic activity we are having 24 maps corresponding to each hourly variation. Similarly for fixed Geomagnetic activity we are having (24 for hourly variation x 4 for seasonal variations=96) maps. Similarly with fixed local time but varying season and varying geomagnetic index we are having (4 for seasonal variation x 4 for geomagnetic activity=16) maps. For fixed local time, fixed season and fixed geomagnetic activity we are having 1 map.

Types	LT(Local Time)	Season	Am(Geomagnetic Activity)	Maps
I	Independent	Independent	Independent	1
II	Varying	Independent	Independent	24
III	Independent	Varying	Independent	4
IV	Independent	Independent	Varying	4
V	Varying	Varying	Independent	96
VI	Varying	Independent	Varying	96
VII	Independent	Varying	Varying	16
VIII	Varying	Varying	Varying	384
	TOTAL			625

So we have total Global 625 TEC maps corresponding to three parameters-Local time, seasons and geomagnetic activity. We have 11 years of TEC values in our archive. So overall we have total 12 x 625=7500 reference TEC maps



(fig 1)**MAXIMUM VALUE FOR TOPEX MEASUREMENT**



(fig 2) **AVERAGE VALUE FOR TOPEX MEASUREMENT**

figure 1 and figure 2 shows the maximum and average ionospheric correction values calculated for TOPEX measurement

AUTOMATIC DETECTION TECHNIQUE

The goal of this section is to produce an automatic detection algorithm for the anomalous TEC fluctuations in our data sets

➢ THE PICKING PROCEDURE

In this procedure we applied $\pm 2\sigma$ criterion. Mref denotes the averaged values and Sref denotes the Standard deviation values. The interval defines is [Mref-2Sref, Mref+2Sref].If our instantaneous value lies outside the defined interval, it is considered as anomaly.
A(i,j,k,l,m) is the instantaneous TEC value corresponding to particular longitude,latitude,local time, geomagnetic activity and season.

B(i,j,k,l,m)=1 if A(i,j,k,l,m) < Mref(i,j,k,l,m) – 2*Sref(i,j,k,l,m) or A(i,j,k,l,m) > Mref(i,j,k,l,m) + 2*Sref(i,j,k,l,m)
Otherwise B(i,j,k,l,m)=0

Pixel 1 represents an TEC anomaly and pixel 0 represents an average event.

This cart is compared with the seismic cart for the same period of time and for same position. The seismic cart called C has also been binarised ---1 if seismic event, 0 if no seismic event

If they are coherent (B AND C=A) gives the pixel representation of the place where anomaly has been detected.

Btec			Btec
	Btec		Btec
		Btec	
Btec			Btec

Csei			Csei
	Csei		Csei
		Csei	
Csei			Csei

A			A
	A		A
		A	
A			A

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