A Case Study for the IONEX CODE-Database Processing Tool Software: Ionospheric Anomalies before the M_w 8.2 Earthquake in Mexico on September 7, 2017

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***Abstract*—A software tool was developed in the Imaging Processing Research laboratory (INTI-Lab) that automatically downloads several IONEX files around a specific user input date and also performs statistical calculations to look for ionospheric anomalies through the generation of differential vertical total electron content (ΔVTEC) maps. The IONEX CODE-Database Processing Tool (ICPT) software allows to save a considerable amount of time spended in gathering the necessary IONosphere map EXchange (IONEX) files for the production of differential VTEC maps. Using the ICPT software we were able to detect ionospheric anomalies before the devastating earthquake that happened in Mexico on September 7, 2017. A positive and negative ionospheric anomalies were detected nine days and one day before the seismic event. Due to stable geomagnetic conditions we suggest that the anomalies are assocciated to the earthquake event. Furthermore, It is very likely that the collision between the North American and Coco's plate is producing the ionization necessary of the air to generate the disturbances observed.**

Keywords*—Earthquake; IONEX CODE-Database Processing Tool; ionospheric anomalies; geomagnetic storm; global ionospheric maps(GIM); IONosphere map EXchange (IONEX)

I. Introduction

Several natural disasters arise around the globe from time to time and even in this era of high-performing computers devices, we cannot still predict the location of an earthquake. However, global ionospheric maps (GIMs) may provide some relevant information [1], [2], [3] that may indicate some possible relation between ionospheric anomalies and the occurrence of an earthquake . Due to the fact that there are several earthquakes around the globe and most of them occurring near populated areas, we believe it is necesary to keep researching these topics so in the near future we may predict seismic events and save uncountable lives.

Ionospheric anomalies are not 100% caused by earthquakes, they can also by generated by, for example, geomagnetic storms and also even by humans [4]. In this study we focused in the earthquake that happened in Mexico on September 7, 2017 at 04:49 UTC with a moment magnitude of 8.2. Using the IONEX CODE-Database Processing Tool (ICPT) software developed by the two authors of this study, we generate differential vertical total electron content (VTEC) maps from GIMs.

In this paper, differential VTEC (ΔVTEC) maps around the date of the Mexico seismic event are presented. ICPT software is a useful tool to quick detect any anomalies in some days close to the event day.Futhermore, It quickly performs multiple tasks to finally plot ΔVTEC maps. Finally, the detected ionospheric disturbances are shown and briefly discuss their possible origin.

II. ICPT Software

The software tool automatically downloads IONEX files for an interval of days selected according to a certain date given by the user [5].

The IONEX files are provided in a web ftp server (ftp.aiub.unibe.ch/CODE/) which commonly has hundreds of files in different folders arranged per year (e.g., for the year 2017 the path folder would be: 2017/). In this study, It was builded a software to enhance the productivity time (i.e., saving it) rather than spending it in downloading manually several files. Additionally, the ICPT software carries out a statistical process [5] to generate ΔVTEC maps .

Even though this process could be done by any user manually, there are some issues before downloading a IONEX file. The desired date should be translated into the IONEX labelling file name which is the current day number of the year.

A detailed graphical description of what the ICTP software does step-by-step is presented in Fig. 1. In reference [5] describes in details each step of the software tool.The ICPT software is avaible at https://sourceforge.net/projects/ionex-processing-icpt/files/ to download for free.

A. Statistical method to produce differential VTEC maps

The statistical method to find and analize ionospheric anomalies requires to process a group of IONEX files with continuous dates. Assuming the VTEC values follow a normal distribution within a range of days, a sliding window is then applied to obtain the VTEC mean value (μ) and the interquartile range (IQR). ICTP performs the task downloading 17 days before and 11 days after the given date chosen by the user. In this range, ICTP calculates the VTEC means

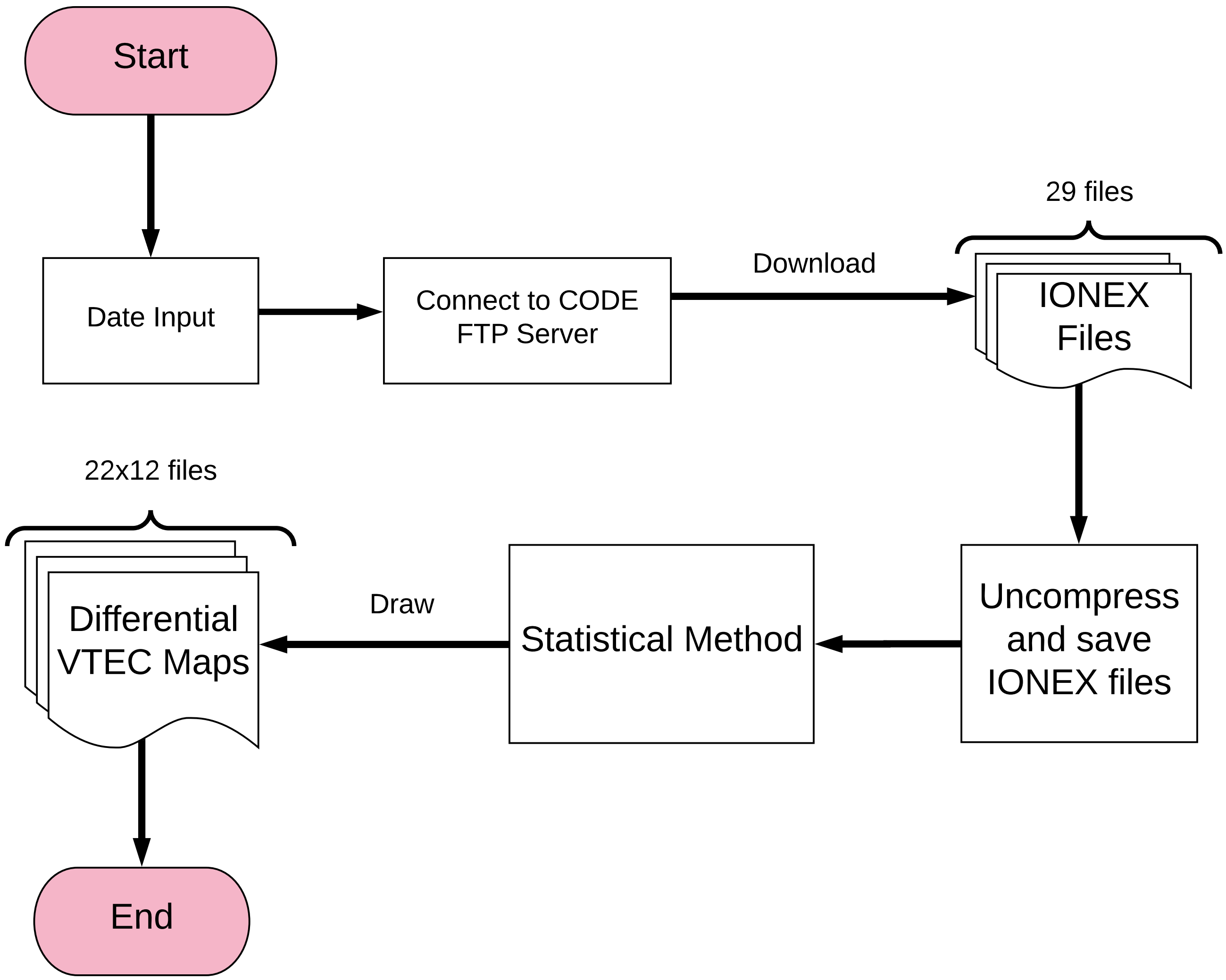

Fig. 1. Flowchart of the ICTP software.

and the associated IQRs. The statistical method to generate ΔVTEC maps consists in calculating the upper and lower bounds (UB and LB, respectively) of the normal background VTEC variation. Under the assumption that the VTEC follows a Gaussian distribution within a certain period of days for a particular hour of the day, the UB and LB can be defined as:

$$UB = \mu + 2\sigma \tag{1}$$

$$LB = \mu - 2\sigma \tag{2}$$

were μ is the mean and σ is the standard deviation. If the VTEC for a certain day at a particular hour of the day falls above the UB, we say that there is a positive anomaly. Otherwise if the VTEC falls below the LB, a negative anomaly is identified. In case that the VTEC is between the UB and LB there is no detection of a ionospheric disturbance. Given a tolerance of 2 used in equation 1 and 2 we say that there is a detection of a positive or negative ionospheric disturbance with a 95% confidence level.

III. Geomagnetic Conditions

Because ionospheric anomalies can also be produced by geomagnetic activitiy we have looked into two important geomagnetic indices (Dst and Kp). The Kp index measures the disturbance of the horizontal component of the geomagnetic field. Data for this index was obtained from the German Research Center for Geosciences (GFZ). The Dst index monitors the level of intensity of geomagnetic storms. It was retrieved Dst index data from the World Data Center for Geomagnetism in Kyoto. In Fig. 2, data for the Dst and Kp indices are shown between August 18, 2017 and September 13, 2017.

IV. Pre-Earthquake Ionospheric Anomalies

Figure 3 shows ΔVTEC maps for August 30, 2017 (9 days before the seismic event). It can be seen that at 16:00 UT on August 8, 2017 there are no ionospheric anomalies visible inside the preparation's zone to the earthquake. This preparation region is defined by radius obtained from the Dobrovolsky equation [6]:

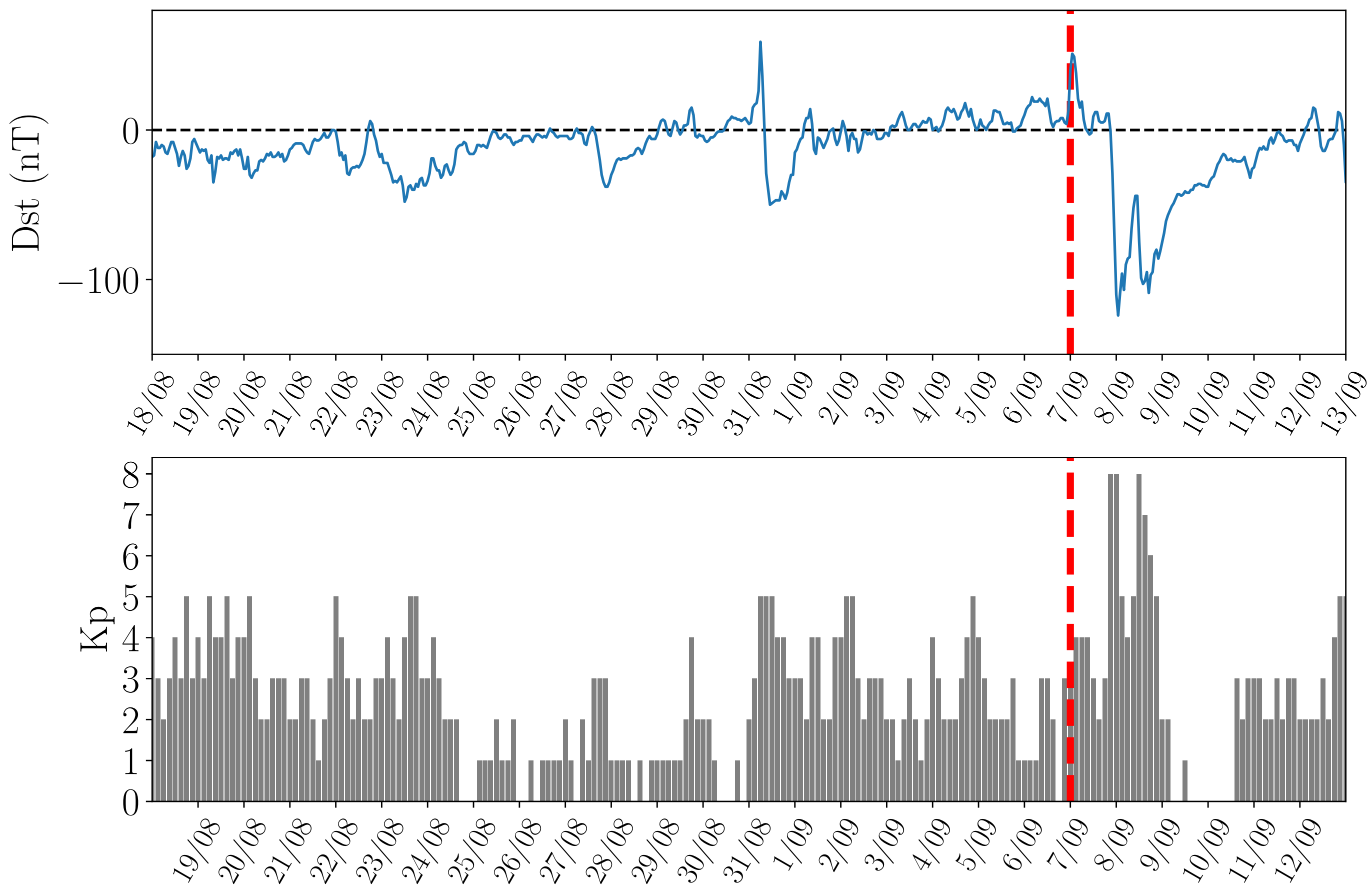

Fig. 2. Dst and Kp geomagnetic indices during August and September 2017.

$$R = 10^{0.43M}[\text{km}], \tag{3}$$

where M is the moment magnitude of an earthquake. For the M_w 8.2 earthquake, the preparation radius is ∼3357 km. At 18:00 UT and 20:00 UT on September 7, 2017, a negative ionospheric anomaly can be seen to appear and displace in the same direction as the Sun. Moreover, this anomaly falls well within the area defined by the radius R. At 22:00 UT this anomaly is nearly gone. Looking into the geomagnetic indices from Fig. 2 we notice that September 7, 2017 was a day of relatively quiet geomagnetic conditions; hence, we can suggest that the origin of the anomaly is product of the earthquake's preparation.

In Fig. 4, ΔVTEC maps for September 6, 2017 (one day before the earthquake) are presented. It can be observe that a positive ionospheric anomaly appears to the north of the epicenter at 14:00 UT moving westwards until it disappears at 18:00 UT. This positive anomaly also falls inside the earthquake's preparation region at different hours. In a similar approach as the observed negative anomaly on August 30, 2017, the geomagnetic conditions during this day were stable (Kp $<$ 3 and Dst $<$ 20nT). Thus, It can be also hinted that this anomaly is also associated to the earthquake. The previous findings suggest that ionosphere anomalies were produced by the earthquake's preparation. However, according to some studies [7], [8], ionization of the air due to radiation from the Earth's crust (due to the collission in this case of the North American and Cocos' plates) can produce ionospheric anomalies which are visible in VTEC and ΔVETC maps. Depending on the level of ionization positive or negatives anomalies can be observed. Consequently, we consider that this mechanism may be at work producing the anomalies observed 9 and 1 days before the September 7, 2017 earthquake. The ICTP software gives quick results about ionosphere disturbances, however, It cannot be concluded that those anomalies came from earthquakes's preparations. Nonetheless, the software can detect anomalies around the globe base on the IONEX files downloaded. The user must discard any possible source of anomalies such as geomagnetic storms to correspond the anomaly to an earthquake event.

V. Conclusions

This paper has used a software that allows to produce differential VTEC maps using public data (IONEX files) from CODE. The ICTP software also allows to considerably reduce the time spended in gathering the data for the respective analysis. We used our software to search for anomalies before the catastrophic seismic event that happen on September 7, 2017 in Mexico. We detected 9 days before the occurrence of a negative ionospheric anomaly. On the other hand, 1 day before the earthquake we identified a positive one to the north

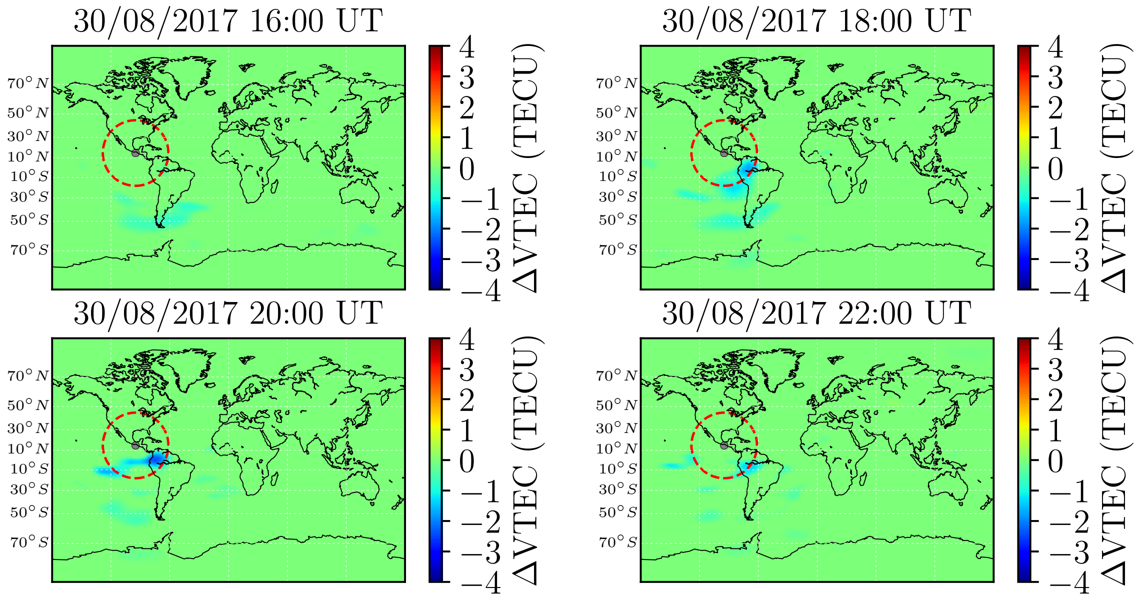

Fig. 3. Differential VTEC maps for August 30, 2017. The grey circle indicates the epicenter and the red dashed circle delineates the earthquake's preparation region.

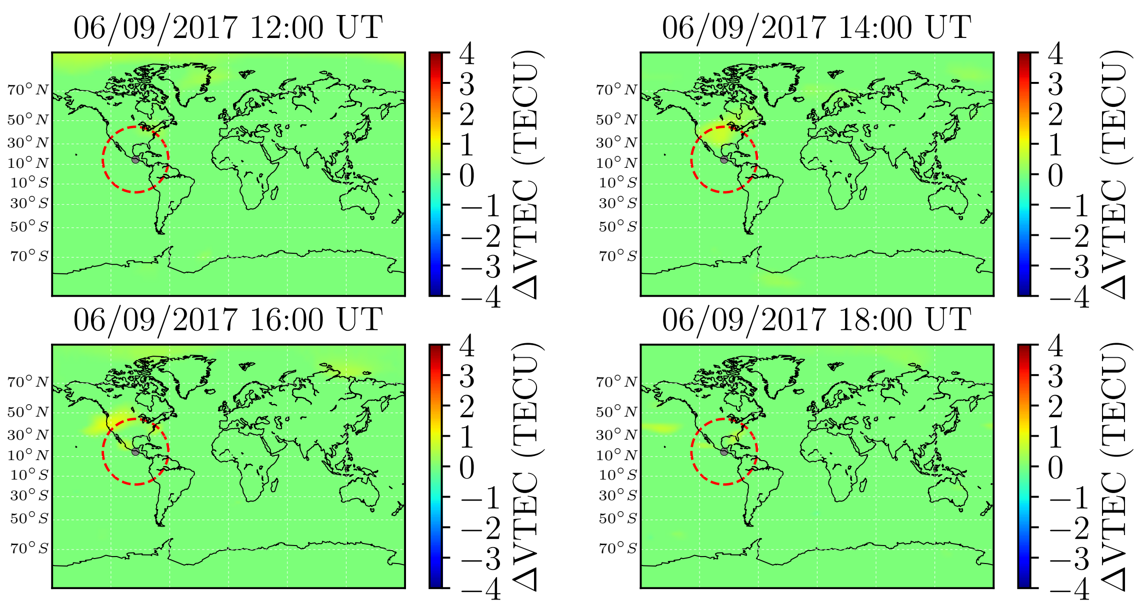

Fig. 4. Differential VTEC maps for September 6, 2017. The grey circle indicates the epicenter and the red dashed circle delineates the earthquake's preparation region.

of the epicenter. Due to the quiet geomagentic conditions during these two days, we attribute the disturbances observed to the earthquake's preparation. Moreover It is very likely that radiation from the Earth's crust is causing these ionospheric disturbances. Finally, we encourage students and researches to use this software for their own research since our main objective is to give a computational tool to test any other similar research and compare your results about ionosphere anomalies with other scientific works.

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