SOLAR FLARE DETECTION SYSTEM APPLIED TO THE X65 FLARE ON 6th DECEMBER, 2006

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ABSTRACT

A system to detect solar flares in advance has been developed. It is based on monitoring the ionospheric **T**otal **E**lectron **C**ontent (**TEC**) variations by using **G**lobal **P**ositioning **S**ystem (**GPS**) data. The detector can be applied to look for solar flares backwards or in real time as well without high computational load requirements.

This work is mainly focused on the results obtained for the X65 flare that occurred on 6th December, 2006. This solar flare is still of great interest because many **GPS** receivers were disrupted after its associated radiation reached the Earth. This was related to a severe drop down of the **SNR** of the GPS signals that affected a wide area of the Earth.

Introduction

Solar flares are sudden violent eruptive events that take place on the Sun's atmosphere and are associated with the ejection of large amounts of charged particles and with an increase of emitted radiation (mainly in x-rays and ultraviolet). This radiation reaches the Earth in about 8 minutes and produces an overionization of the ionosphere that can be detected before the arrival of particles. Since solar flare emissions (particles as well as radiation) can cause important problems, such as interferences in communications, satellite damages or serious risks for astronauts, the detection system can be helpful to prevent them.

The above mentioned overionization is translated in a sudden enhancement of the ionospheric **TEC**. Therefore, solar flares can be detected by monitoring this parameter with the **G**lobal **N**avigation **S**atellite **S**ystems (**GNSS**), as for example **GPS**. Such constellation, of about 30 Medium Earth Orbit transmitters, allows to perform an accurate ionospheric sounding, thanks to the global network of hundreds of permanent dual-frequency receivers worldwide distributed (**I**nternational **G**NSS **S**ervice).

Detection technique

First of all, it is necessary to gather the dual-frequency **GPS** data of a set of stations distributed all over the world. Then, the Vertical **TEC** or **VTEC** (i.e. in the radial direction regarding to the Earth geocenter) at the **I**onospheric **P**ierce **P**oint (**IPP**) can be derived from the **GPS** carrier phase ionospheric combination $\mathbf{L_I}$:

$$L_I = L_1 - L_2 = \mathrm{STEC} + B_I = M \cdot \mathrm{VTEC} + B_I$$

Afterwards, a double temporal difference is performed to **VTEC** (each 180 seconds), as a way to almost cancel the low frequency TEC variations and common bias:

$$\mathbf{d^2VTEC}(t) = \mathbf{VTEC}(t) - 2 \cdot \mathbf{VTEC}(t - 180s) + \mathbf{VTEC}(t - 360s)$$

Finally, the developed detection approach, called **PO**sitive **IN**crease **DET**ector or abbreviated as POINDET, is applied. This detector is based on calculating, for three different bands of Solar zenith angle (**sza** bands), the Impact coefficient or I_{coef} (defined as the percentage of satellites with a $\mathbf{d^2VTEC}$ positive increase above 0.1 TECUs, in this work). A solar flare is considered if I_{coef} is below or above a certain threshold, and if the following main conditions are accomplished:

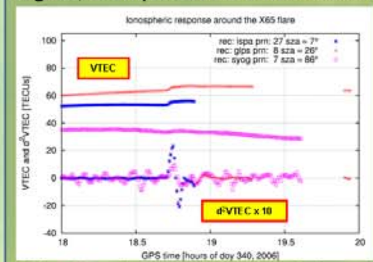
1. Solar radiation can only affect the Earth's sunlit Ionosphere.
2. Other phenomena (**TIDs**, **Scintillations**) typically affect in a more local context .

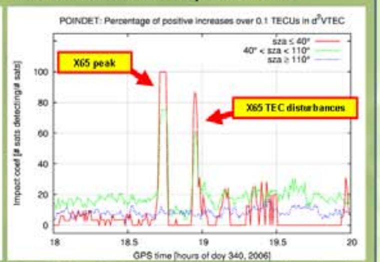
Computations and Results

The results have been obtained using **GPS** data, with measurement sampling of 30 seconds, of a set of 79 **IGS** stations distributed regularly over the entire Earth surface. This is important in order to be able to detect flares with a high temporal and spatial resolution.

6th December, 2006

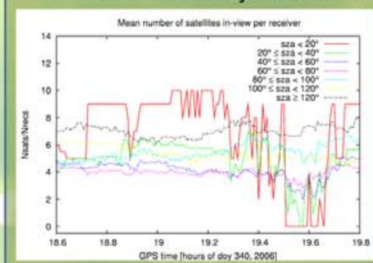
The X65 solar flare that occurred on 6th December, 2006, has been analyzed by using POINDET detection approach. In the below left hand figure, examples of the ionization sudden increase are represented.

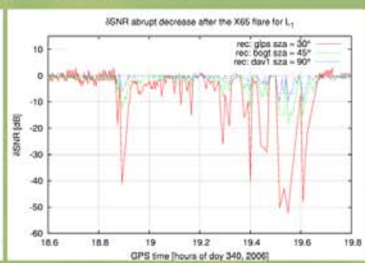




The flare is correctly detected and the detected peak of intensity is at 1845 UT approximately (see above right hand figure). That is compatible with the flare records in the **G**eostationary **O**perational **E**nvironmental **S**atellite (**GOES**) database. In addition, satellite disruptions at different epochs can be observed for the three satellites.

In order to characterize these disruptions, the mean number of satellites in-view per each **IGS** receiver has been plotted for different **sza** bands. It is clear that the mean decreases abruptly after the solar flare at about 1854 UT and also at about 1930 UT, except for night-side satellites. Moreover, the disruptions cause a worse mean when getting closer to the solar zenith (i.e. **sza**=0º), as can be seen in the below left hand figure. Notice that there is only one **IGS** receiver with **sza**<20º.

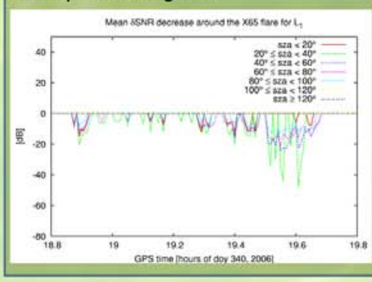


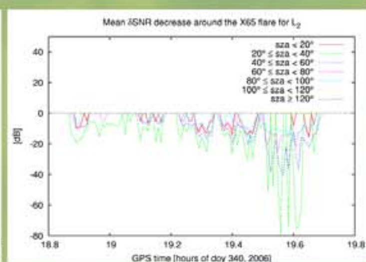


Furthermore, and as shown in the above right hand figure, the disruptions are related to an important drop down of the **SNR**. Notice that a sidereal day difference has been applied to cancel the common periodic effects, as well as an elevation mask of 50º.

$$\delta\mathbf{SNR}(t) = \mathbf{SNR}(t) - \mathbf{SNR}(t - 86160s)$$

Below, the mean δ**SNR** decrease is also represented for both L_1 and L_2 to show as well that the closer to the solar terminator the **IPP** is, the less abrupt **SNR** is given.





Conclusions

The POINDET detector is able to detect in real-time solar flares facing the Earth, such as the one occurred on 6th December, 2006.

For that particular case, there is a strong dependence of the disruptions and the **SNR** behavior with the solar zenith angle of the corresponding **IPP**s. That means that those effects seem to be strongly related to the previous arrival of the X65 solar flare's related radiation. Therefore, the presented solar flare detection system can be helpful to prevent them.

More details in

García-Rigo, A., Hernández-Pajares, M., Juan J.M., et al. **Solar flare detection system based on global positioning system data: First results.** Adv. Space Res., IRI05-35, doi:10.1016/j.asr.2006.09.031, 2006.

Hernández-Pajares, M., Juan J.M., Sanz, J. . **High resolution TEC monitoring method using permanent ground GPS receivers.** Geophys. Res. Lett., 24(13): 1643-1646, 1997