New numerical tool SIDLab to monitor Sudden Ionospheric Disturbances (SID)

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Abstract: The SID/SuperSID receivers[1] are part of the United Nation's International Space Weather Initiative (ISWI) [2]. These receivers, tuned in the VLF range, allow the detection of Sudden Ionospheric Disturbances (SID), which affect the VLF radio waves propagation in the earth-ionosphere waveguide and caused by solar flares. We propose here, a useful and convivial numerical tool 'SIDLab1.0', dedicated to a fast: detection, identification and classification of these VLF disturbances. Wide public: kids, amateurs and even students and researchers, can quickly and easily integrate it in their analyses. For instance, for a social impact and outreach goal, a public demonstration will be held in Tunis Science City (Tunisia) on 21 Jun 2013, a day called "**Solar day**" to celebrate the summer solstice.

Keywords: SID, Solar flares, convivial numerical tool, SIDLab, IgorPro 6, outreach.

I. Introduction

Sudden Ionospheric Disturbances (SID) result from abnormal ionization of the D layer of the terrestrial ionosphere by extraterrestrial ionizing sources like stellar and solar flares, gamma-ray bursts. Monitoring of these disturbances can be traced back to the cause that gave them birth. In the remainder of this paper, we focus on SIDs events which are provoked by solar flares and we applied to them a statistical analysis based on durations of every SID event. To facilitate the analysis of the VLF records and help to the determination of those durations, we developed with the IgorPro 6 environment, new software with convivial and well interfaced tools that we propose to all SID users.

II. Detection of solar flares by GOES satellite

Solar X-ray activity is constantly monitored by research organizations such as NOAA (National Oceanic and Atmospheric Administration) and NASA (National Aeronautics and Space Administration). Measures of flux intensity are recorded by the GOES satellites; these measures are distributed instantly and available on the web [3] by the SWPC (Space Weather Prediction Center). The spectral ranges covered are in the X-ray field. For example, the satellite GEOS provides spectra for two ranges: 0.5 1.0 4.0A and 8.0A.

II.1 Intensity classification of a solar flare

In Figure 1, left scale gives the flux in Watts / m^2, while the right scale is used to characterize the flare class (red line). A multiplier is used to indicate the level of each class. For example, the peaks of Figure 1 show M1.9 = 1.9 10^{-5} W/m^2 and M1.8 = 1.8 10^{-5} W/m^2.

Class	Peak of the band from 0.1 to 0.8 nm (watts/m^2)
A	$I < 10^{-7}$
B	$10^{-7} \leq I < 10^{-6}$
C	$10^{-6} \leq I < 10^{-5}$
M	$10^{-5} \leq I < 10^{-4}$
X	$I \geq 10^{-4}$

***Table 1**: Classification of Solar Flares*

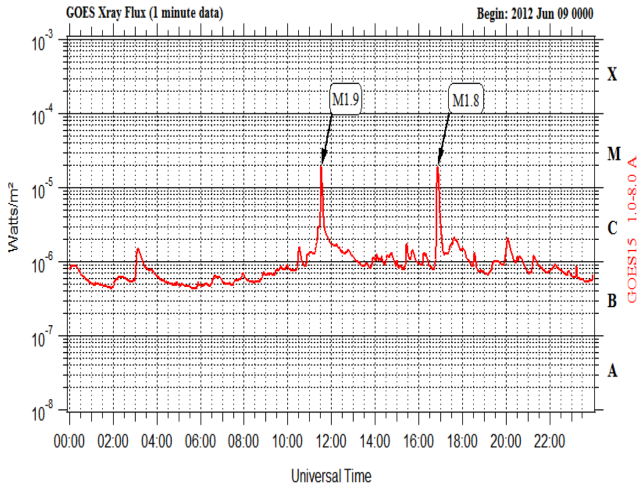

***Figure 1**: Diagram of X-ray intensity as a function of time recorded by GOES15 for June 9, 2012.*

III. Detection of solar flares by VLF reception

X-ray radiation produced during a solar flare; affect the ionosphere by sharply increasing its electron density. It follows a change in the plasma state that affects the propagation of radio waves VLF (3-30 kHz). Indeed, VLF waves are electromagnetic waves that propagate along the waveguide earth-ionosphere. This guide is not ideal as its upper and lower limits are not perfect conductors. However, for this frequency range, this approximation is satisfactory.

Different VLF transmitters, widespread all over the word, produce the VLF waves to carry these disturbances. For example, on April 22, 2013, about 10:29 UT a C5.2 solar flare generated by the group of sunspots 1726. The figure 2 shows this solar flare observed by two different techniques:

- **Direct observation:**

In figure 2, in the top part, the C5.2 solar flare observed by the SDO satellite (from the left to the right) using: AIA131, AIA 171 and AIA304. In the lower part, the red line shows X-ray flux emitted by the sun recorded by GOES15 satellite on April 22, 2013. In this diagram, the C5.2 flare interpreted from peak that reached its maximum ($5.2\ 10^{-6}\ W/m^2$) at about 10: 29 UT.

- **Non direct observation:**

The blue line in figure 2 shows a VLF signal emitted by the HWU station (France; 21.75 KHz) and received by the SuperSID monitor (Tunisia-CST) located at the Tunis Science City (Tunisia) on 22 April 2013. The flare is characterized by a sudden drop in signal at about 10: 29 UT followed by a slower recovery.

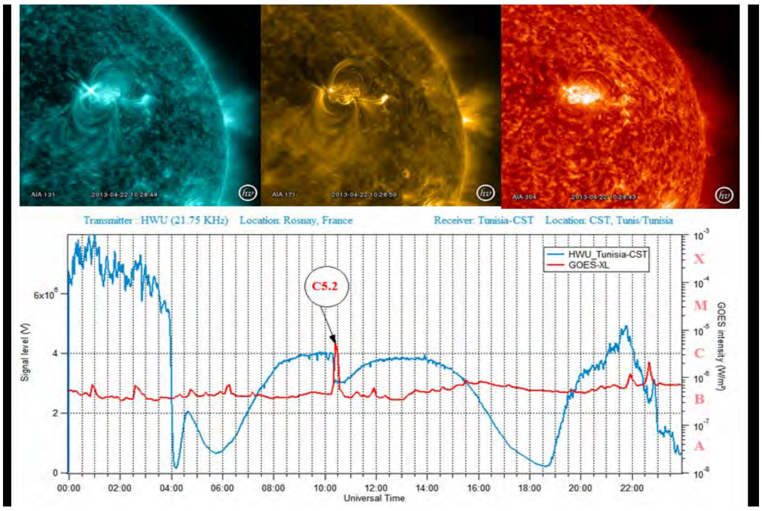

***Figure 2**: Measurements of the X-ray flux between 1.0 and 8.0 Å (red color) received by the satellite GOES15 on April 22, 2013, which shows the correlation of C5.2 flare with the SID event on the VLF signal (blue color)*

IV. Classification of VLF signals using SIDLab1.0 tool

To work on VLF data with less effort, less time and highly precision we implemented a convivial numerical tool named SIDLabV1.0 under the Wave Metrics software IGOR Pro

6[4]. This tool allows users studying and comparing new and old methods of SIDs events classifications. It's composed by two parts:

- The first part, named "**Sorting**" (figure 3), allows user to sort VLF data, interactively, to identify SIDs events and isolate them from raw signal. With this interface, user can generate automatically a table used for SDs classification.

- The second part, named "**EMD**" (figure 4), uses EMD method (Empirical Mode Decomposition) [5,6] for further analysis. We added a new command to denoise raw signals and rise up tiny SIDs events from those noisy signals.

  Users could view the GOES X-ray satellite spectrum superposed to VLF signal for comparison purposes.

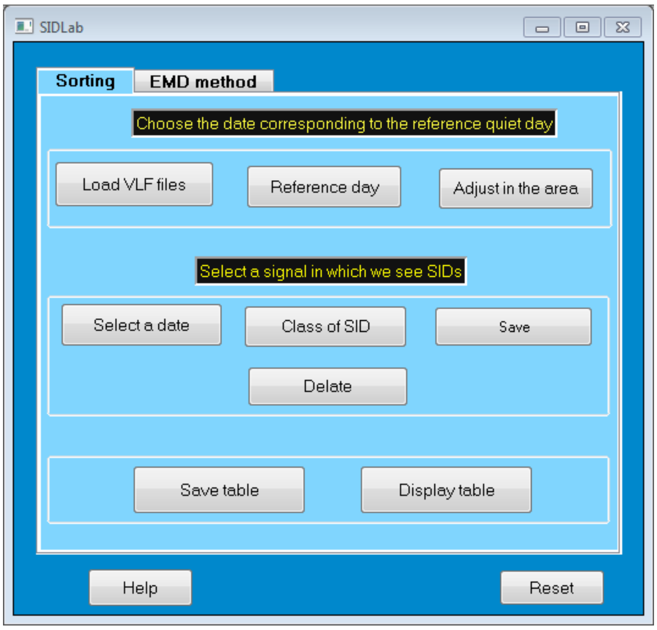

Figure 3: *Interface that allow the user to visualize the VLF signals, extract SIDs and generate a table of VLF classification in a semi-automatic mode.*

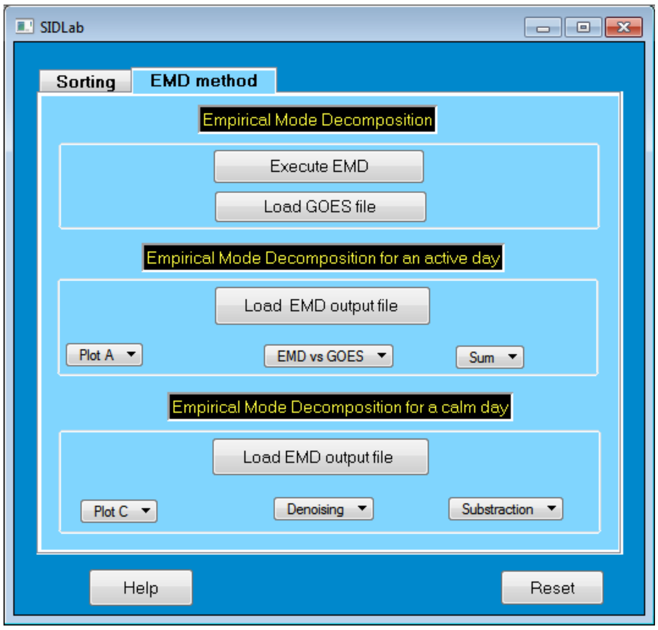

Figure4: *Interface that allow the user to visualize and analyze semi-automatically: the VLF signals, IMFs calculated using the EMD, making comparisons with the GOES satellite signals and denoising.*

V. Tunisian SID &SuperSID group

Till now, there are five SIDs and SuperSIDs monitors operational in Tunis, the capital city of Tunisia as shown in figure 5 and figure 6 and we are installing two others. Owners of these SIDs and SuperSIDs monitors aim to form the Tunisian group who is interested in all regards of this activity.

Figure 5: *Localization of Tunisi in the Mediterranean sea.*

Figure 6: *Zoomed rectangle showing the sites of SIDs and SuperSIDs in the capital city Tunis*

VI. The Solar day event in the Tunis Science City 2013

On June 21 of each year, the Tunis Science City organizes an event to celebrate the day of the summer solstice. This event called a “Solar day” on which it provides its visitors with informations, workshops, observations and conferences to better understand our Sun and all astronomical events related by this star. In this year, 2013, and for the first time a workshop about SID events presented by the use of SIDLab tools for the purpose of showing how to detect solar flare through VLF radio waves.

Figure 7: *SuperSID antenna on the roof of the Tunis Science City*

Figure 8: Poster and photo of the *Solar day 2013*

References

[1] The SID Monitor, Stanford's Solar Centerhttp://solar-center.stanford.edu/SID/sidmonitor/

[2] International Space Weather Initiative (ISWI) http://www.iswi-secretariat.org

[3]GOES X-ray Datahttp://www.swpc.noaa.gov/ftpmenu/lists/xray.html

[4]WaveMetrics software IGOR Pro 6http://www.wavemetrics.com/

[5]Huang, et al. "The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis." Proc. R. Soc. Lond. A (1998) 454, 903–995.

[6] Lionel Loudet. "Application of Empirical Mode Decomposition to the detection of Sudden Ionosphéric Disturbances by monitoring the signal of a distant Very Low Frequency transmitter" available at:http://sidstation.loudet.org/emd-en.xhtml

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