Third School on Cosmic Rays and Astrophysics

August 25 to September 5, 2008, Arequipa - Perú

Solar Flares detected by the Punta Lobos (PLO) station of the network SAVNET

Jorge E. Samanes C [1,3]. , Walter Guevara D.[1] , Jean-Pierre Raulin [2].

(1) Comision Nacional de investigacion y desarrollo Aeroespacial (CONIDA), Lima – Peru

(2) Universidade Presbiteriana Mackenzie, Centro de Radioastronomia e Astrofísica Mackenzie – CRAAM/EE, Sao Paulo-Brasil

(3) Universidad Nacional del Callao (UNAC), Lima-Peru

Abstract

Solar flares emit intense X-ray fuxes that can cause a pertubation in the ionospheric D-region, altering their electrical characteristics. GOES satellites measure X-ray fluxes on the full-disk of the Sun, these are characterized as X, M, C and B class.The propagation characteristics of VLF waves, during their propagation through the Earth-ionosphere (D-region) waveguide, are used for study of the ionospheric D-region. The antennas of the SAVNET measure phase and amplitude in VLF signals. During solar flares variations in the phase and amplitud of VLF signales were detected. The phase and amplitude variations due to Solar Flares of B, C and M class, during April-December 2007, have been detected in the SAVNET station at Punta Lobos (12^0 30' S, 76^0 47' W)-CONIDA, Lima-Peru. Using data from this station and GOES satellites developeded a preliminary database, for cataloging solar flares detected moreover of preliminary calculation of phase variations and delay time during solar flare.

Introduction

Solar flares are tremendous explosions on the surface of the Sun, which release energy in many forms - electromagnetic (γ rays, X-rays, UV, radio, microwave), energetic particles (protons and electrons), and mass flows. GOES satellites measure X-ray fluxes from the Sun in two energy bands (0.5 – 4.0 Å and 1.0 – 8.0 Å). Flares are characterized by their peak flux in X-rays as X, M, C and B class, the biggest and more intense being X-Class flares. The solar X-ray fluxes take a few minutes to reach the Earth, and play a major role in the ionization of the terrestial atmosphere. It is well known that solar X-rays ($\lambda < 2$ Å) and Lyman-α radiation ($\lambda = 1216$ Å) are mainly responsible for the formation of the normal D-region of the ionosphere. Because of their high stability during the propagation over long distances (thousands of km), very low frecuency (VLF ~ 3 – 30 kHz) waves are used to study the electrical characteristics of the D-region of the ionosphere. When a solar flare (X-rays) occurs, there is a major increase in the flux of X-rays from the Sun (during quiet solar conditions, the X-ray emission from the Sun is not a signicant source of ionization in the D region). This can cause additional photoionizaion of all neutral constituents of the D-region. The result of additional ionization is a variation in the characteristics of Earth-Ionosphere waveguide. These changes affect the phase and amplitude of VLF waves during their propagation through this waveguide.

SAVNET (South America Vlf NETwork) is an international project that is composed by an arrangement of VLF receiving, which are located in different parts of South America (Brazil, Peru, Argentina). One of the scientific objectives of SAVNET is to use the low ionosphere behaviour as a solar activity monitor.

Instrumentation and data acquisition

A SAVNET station is composed by three antennas, a vertical type and two loop type, a pre-amplifiers to enhace the VLF signal received, a GPS, a sound card (used as an A/D converter) and the SoftPAL (Software Phase and Amplitude Logger) program. In the Loop antennas a potencial diference is generated due to the variation of the magnetic flux through the area of the loop. In the vertical antenna an electric current is induced by the vertical (E_z) component of the wave electric field. The four signals (3 antennae and GPS) are digitized by a sound card DELTA44 and treated with SoftPAL, which calculates the amplitude (dB) and phase (degree) of the signals. We have monitored the phase and amplitude of VLF signals from a network of transmitters mainly located in the north hemisphere.

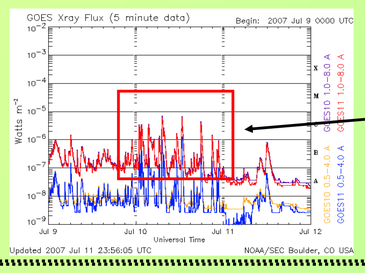
SAVNET – VLF Phase and Amplitude measurements at Punta Lobos

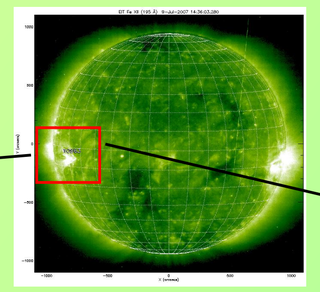
The VLF phase and amplitude measurements recorded and reported here were obtained at Punta Lobos (12º 30' S, 76º 47'O), during the period of April-December 2007, which included a solar minimun. The frequencies recorded were:

Station(ID)	*Frequency (kHz)*	*Latitude/Longitude*	*Location*	*Distance(PLO-Estation) (Km)*
NAA	*24*	*44,65N -67,3W*	*USA*	*6389Km*
NWC	*19,8*	*21,8S 114,2E*	*Australia*	*16049Km*
NAU	*40,75*	*18,40N -67,18W*	*USA*	*3499Km*
NDK	*25,2*	*46,35N -98,33W*	*USA*	*6819Km*
NPM	*21,4*	*20,4N -158,2W*	*USA*	*9608Km*
NLK	*24,8*	*48,20N -121,92W*	*USA*	*7455Km*

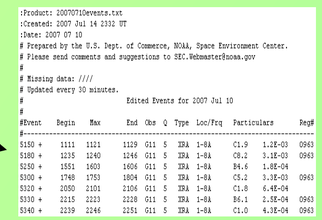
Solar Flare Data

Solar X-ray fluxes are now routinely monitored by the GOES satellites, and the data are readily available from the US National Geophysical Data Center website (www.ngdc.noaa.gov)





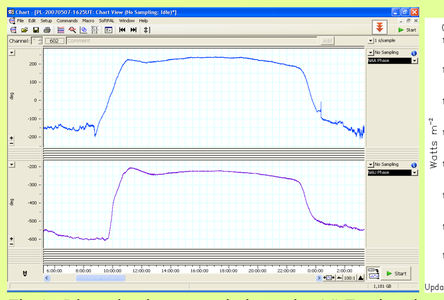
Solar Flares detected on july 10th 2007



VLF perturabations during solar flares

In Fig.1 we show the diurnal phase variations of VLF signals during quiet solar conditions (no solar flares on May 5th, 2007) monitored at SAVNET-PLO. Signals detected were NAA-24 kHz and NAU-40.75 kHz.

In Fig. 2 we show representative VLF phase perturbations recorded at Punta Lobos resulting from four distinct flares in the period 12:00 – 20:00 UT (7:00 – 15:00 LT at the receiver) on July 10th, 2007. GOES flare data are classified as C8.2, C5.2, B4.6 and C1.8 which correspond to X-ray fluxes in the 0.1 – 0.8 nm band.



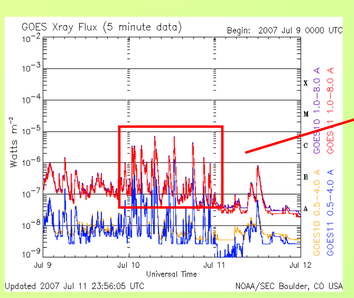


Fig.1 Diurnal phase variations in VLF signals emitted by NAA and NAU during a day without flares, 05 May 2007. Universal Time is used.

Fig.2 Diurnal phase variations in VLF signals emitted by NAA and NAU, on a very disturbed day. 10 July 2007.

Simultaneous monitoring of VLF phase and X-ray flux (SAVNET - GOES)

Fig.3 Variation of the solar X-ray flux, as monitored by GOES on July 10th 2007 (upper plot), and diurnal phase variations for NAU (lower plot). C and B class solar flares are shown.

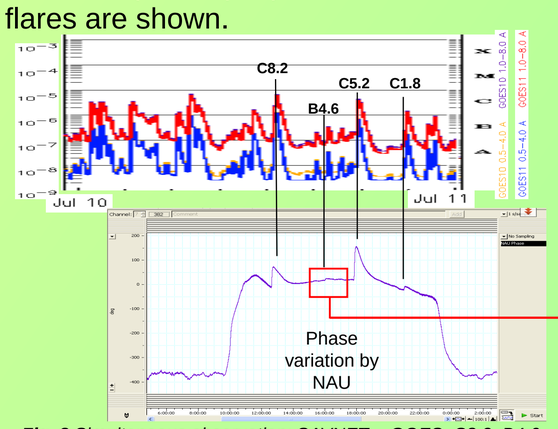


Fig. 3 *Simultaneous observation: SAVNET – GOES. C8.2, B4.6, C5.2 and C1.8 class solar events are shown.*

Fig. 4 Phase variations for a quiet day and for a disturbed day for a B4.6 class solar flare, on July 10th 2007,15:51UT (upper plot). Variation of the solar X-ray flux measured by GOES 11. A B4.6 class solar flare is distincly displayed (lower plot).

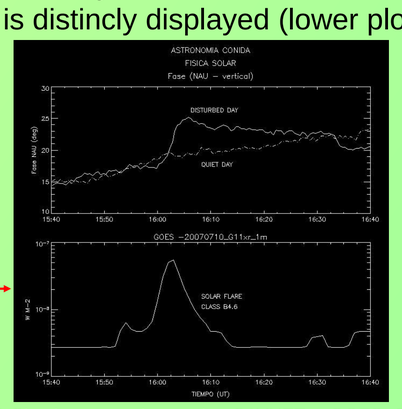


Fig. 4 *Simultaneous observation SAVNET – GOES. B4.6 class solar events is shown.*

Observational results on the detectability of solar flares

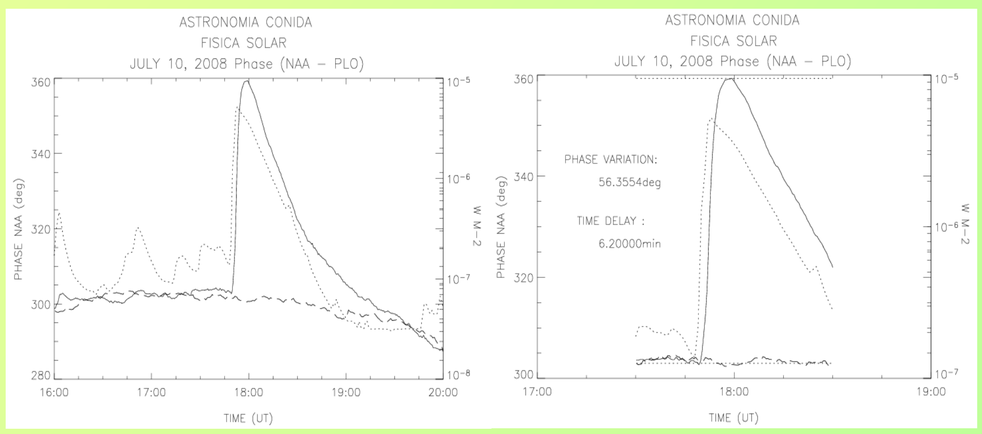
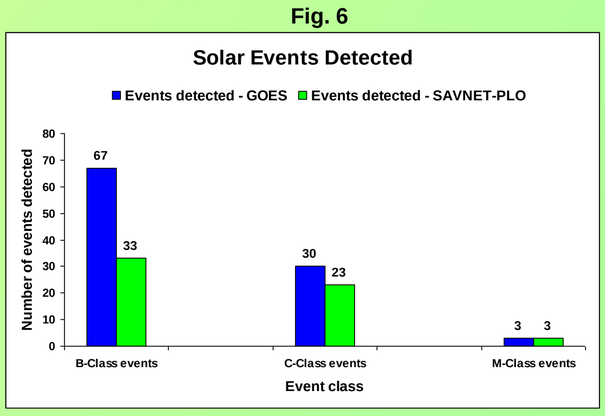


Fig. 5

In Fig. 5 we show representative VLF phase perturbations recorded at Punta Lobos resulting from a C5.2 class solar flare, in the period 17:48 – 18:04 UT (12:48 – 13:04 LT at the receiver) on July 10th, 2007. *Left and right plot:* Flare-induced phase enhacement (solid line), regular phase variation on the respective UT interval, but on the closest unperturbed day July 6th, 2007 (long dashed line) and variation of the solar X-ray flux (dotted line), in the right plot we show maximum phase variation due a solar flare and "time delay".

Fig. 6



During the period of April 2007- August 2008, phase perturbations have been regularly detected. In Fig. 6 we show the solar events detected by SAVNET-PLO (green bars) and detected by the GOES satellites (blue bars).For the elaboration of the plot in the Fig.6 we considered solar flares more intense than B3.7-class and events occurring when D-Region is present, from 10:00 to 24:00 UT (05:00 to 19:00 LT).

Remarks

- Calculation of phase variations and time delay will allow us to determine effective recombination coefficients during solar flares.
- In Fig. 6 we show that 100% of M-class events, 78% of C-class events, and 48% of B-class events more intense than B3.5-class have been detected by SAVNET-PLO.
- Because of low observing conditions on some days, a few B and C class events were not detected.
- The observational results obtained and shown here have been analyzed preliminarily. The data to find out short phase variations during solar events less intense than B3.7-class remain to be analyzed.
- Data for every day of observation with events detected by the SAVNET-PLO station is arranged in a catalogue of solar flares, and will be available placed at the website of CONIDA.

References

- Mitra A. P. ***Ionospheric efects of solar flares***. Astrophysics and Space Library, Dordrechet: Reidel,1974.
- Davies, K. ***Ionospheric Radio Propagation***. Dover Publications*, 1966.*
- Raulin, J. P. ;Pacini. A. ; Kaufmann, P.; Correia, E.; Martinez, M. A. G. ***On the detectability of solar x-ray flares using very low frecuency sudden phase anomalies***. Journal Atmospheric and Solar-Terrestrial Physics, v. 68, n.9, p. 1029-1035, May 2006

Acknowledgements

The authors would like to thank CONIDA for its support and the SAVNET project for providing the data used in this work. We thank Hernan Rivero for his assistance