



Review of the D region study using the awesome VLF receiver in Algeria

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The VLF technic is a powerful tools to study the coupling between the Magnetosphere, Thermosphere and the ionosphere

The Algiers AWESOME Receiver : Installed in August 2006







It is able to record data in Broadband and Narrowband channels

For the Narrowband data, the VLF transmitter signals show the changes of the D region due to day/night transition and other sources of disturbances.





Broadband data

In the Broadband data all frequencies between 3kHz and 50 kHz are recorded which include: lightning sferic, VLF transmitters (Tx), tweaks, magnetospheric hiss...

VLF signal perturbations dues to Solar Flares

From 2007 to 2013 more than 2000 solar flares associated with perturbations in amplitude and phase were studied





From the VLF measurements and as function of the flare 74 power: the signal parameters and the Wait parameters were dispersed and cannot be used for correlation

- The flares occurred at different zenithal angle
- A succession of flares with a short time delay
- More than one flare occurred at the same time

Overestimation of the perturbed electron density

The comparison between electron density produced by C and M solar flare classes



C class Solar flares of low $|\chi|$ can produce electron density enhancement of same order of M class with high $|\chi|$

GCP: NRK-ALG=3495 km, Period: 2007- 2013. C classes 0 40 M classes 30 20 N_e *10⁸ (m⁻³) M1.2 C9.3 10 9 C3.1 M1.2 8 M3.1 oC 6 5 -20 0 20 40 60 80 100 -60 χ (deg)

Fixing the χ values will gives a smoother variation of all signal parameters, the ionospheric Wait parameters (h' and β) and the D region electron density as function of the flare power. Where all parameters increased when the flare power increases



Solar cycle and the VLF signal

- The Sun emits light at different wavelengths where the most powerful of them ionize the neutral atmosphere and form the ionosphere
- The number of electron density depends on the intensity of the incoming light (mainly X and UV)
- According to Chapman theory, the ionization rate is function of the Solar position (Zenithal angle)
- Is there an effect on the ionosphere due to the changes that appear on the Sun?

We recorded the signal amplitude at 10 am each day from June 2007 to December 2015 following these criteria

- We eliminated the data when 10 am coincides with a solar flare (beginning, maximum or recovery times)
- We removed the periods when the Tx or Rx were off
- We removed the periods that coincide with a strong geomagnetic storm (Dst <-100 nT)

The signal amplitude has a shape of a half circle

The χ effect

- From 2007 to 2010 : The amplitude is nearly the same
- 2010 to 2015 : The signal amplitude increased
- The half circle shape of 2014 disappeared
- The maximum of the signal amplitude does not fellow the SSN evolution.

This means that even if the SSN is low, the active regions with important brightness can disturb the ionosphere much more than during maximum solar cycle.





A monster active region as big as the planet Jupiter observed on October 2014



The Early/Fast VLF perturbations and TLEs

Participation to the EuroSprite campaign since 2007

- All captured TLEs were in association with the Early/Fast signal perturbations
- New category of Early events known as Early/Slow (onset duration > 100ms) were listed
- Multi-paths observations showed that different kind of perturbation signs can be recorded which is due to the modal interference of the propagating signal





Event 2

Mysterious cases • NRK On September 02 2009, two larges sprites (named Gigantic Sprites) were captured near different VLF paths to Algiers and that their sizes : 70km (from 30km to 100km) vertically and 80km Horizontally 03:07:43 CG: 216 kA GQD DHO 02:33:17 CG: 153 kA To NAA • HWU Events locations - 90 - 80 . ICV Altitude (km) - 70 - 60 - 50 - 40 - 30 • NSC Direct GCP Algiers Scattered GCP Amplitude Data Starting On 02-Sep-2009 60 Total Events (510 Events) 21.5 NS DHO-Algeria 21 20.5 TLE Nbr X 2 (100 Events) 20 window and the product of all as the fingly proved and provided 50 19 4 as about near the All A. All 23 23 40 22,5 Nbr of Events 30 NS NAA-Algeria 16.5 16 Rapid recovery time $15.5 \\ 10$ NS NRK-Algeria dada Herewal and provide a strain a strain from the strain the strain at the -10 🖌 NS GOD-Algeria 10 10 upply work to prove the NS NSC-Algeria 090830 090930 091030 091130 2:32:45 2:33:00 2:33:15 2:33:30 2:33:45 2:34:00 2:34:15 2:34:30 2:34:45 2:35:00 Days Time (UT)



GJ and VLF perturbations

This analysis confirmed the association between the -15 kA CG and the GJ triggering which was not clearly evident in the GJ Video frames

In addition to the observation we simulated the electron density increase due to GJ+Sprite and Elve using Signal perturbation parameters and LWPC code

Criteria:

- The disturbed region has a limited dimensions
- The ionosphere recovers gradually to the ambient level outside the disturbance zone
- The bar error between simulated and measured parameters must be $<0.5~\rm dB$ in amplitude and 5° in Phase
- Considered the direct scattering paths only: NRK-Tunis and ICV-Algiers









The simulated signal parameters (Amplitude and Phase) showed that:

- At the disturbance zone the signal is highly affected
- The perturbed signal parameters are sometimes above the ambient ones and sometimes below
- Different signs of signal perturbation amplitude and phase

Due to the modal interference between perturbed and ambient propagating signals





VLF signal and Meteorological systems

Natural phenomena can lead to disturbance in the neutral atmosphere at altitudes of the VLF signal reflection height



Tsunami

We studied the VLF signal perturbations dues to Hurricanes and TS in the Atlantic Ocean during the cyclone activity of 2016

Some of the meteorological systems crossed the VLF path to Algiers and some of them had a stopping distances close to the VLF Path





The anomalies can be observed during low or high classification of the storm and were more frequent at nighttime

The anomalies were more important when the storm approached the GCP between the Tx and Rx

The anomalies were more frequent in the case of the powerful storms (Hurricane and MH stages)



The explanation of these observations is that the emitted GW will push the neutral species up and down which leads to the modification of the loss terms since they are function of the neutral densities

VLF signal anomalies dues to Earthquake

Several works were conducted to study the possibility of predicting the Earthquake days before.

Observation of enhancement of the VLF signal amplitude and phase

Supposed to be periodic Occur few days before EQ Used of the SR and SS transition times technic (widely used)

Showed that these times change a days before the EQ











This will gives a small deviation of the SR times because it is nearly the same each day over the years

Our results showed a clear displacement of the SR time below 3SD

- between July 20 and 22
- On July 25
- On July 31

After the EQ the SR Time recovered gradually to normal time





The comparison between NRK and GQD results gives:

- Similar shift of the SR Time from July 20 to 22
- Same wavy structure of the SR Time between 27 and 3 Aug



Conclusion

- \succ To study the solar flares effect it is important to select flares having the same χ angle
- It is also important to determine the ambient reflection of the VLF signal during the maximum of the solar cycle since it is different than at solar minimum
- > With our results we confirmed that not all early events are associated with TLE events
- The simulation with the LWPC code gives electron density increases of the same order like numerical simulations model of the atmospheric ionization
- > The sign of the perturbation in the VLF signal is attributed to the modal interference
- Our results confirmed that Hurricanes and Tropical Storms can produce anomalies in the VLF signals dues to the generated gravity waves
- Our results showed clearly that EQs can be predicted using the VLF technic some days before, especially when the EQ location is near the Rx or the Tx-Rx GCP
- In addition to the SR shifting, our results showed that a clear anomaly similar to the Night/Day is recorded when the Tx and Rx were at night

Thank you