# On the Effect of emerging solar active regions on the ambient VLF signal propagation

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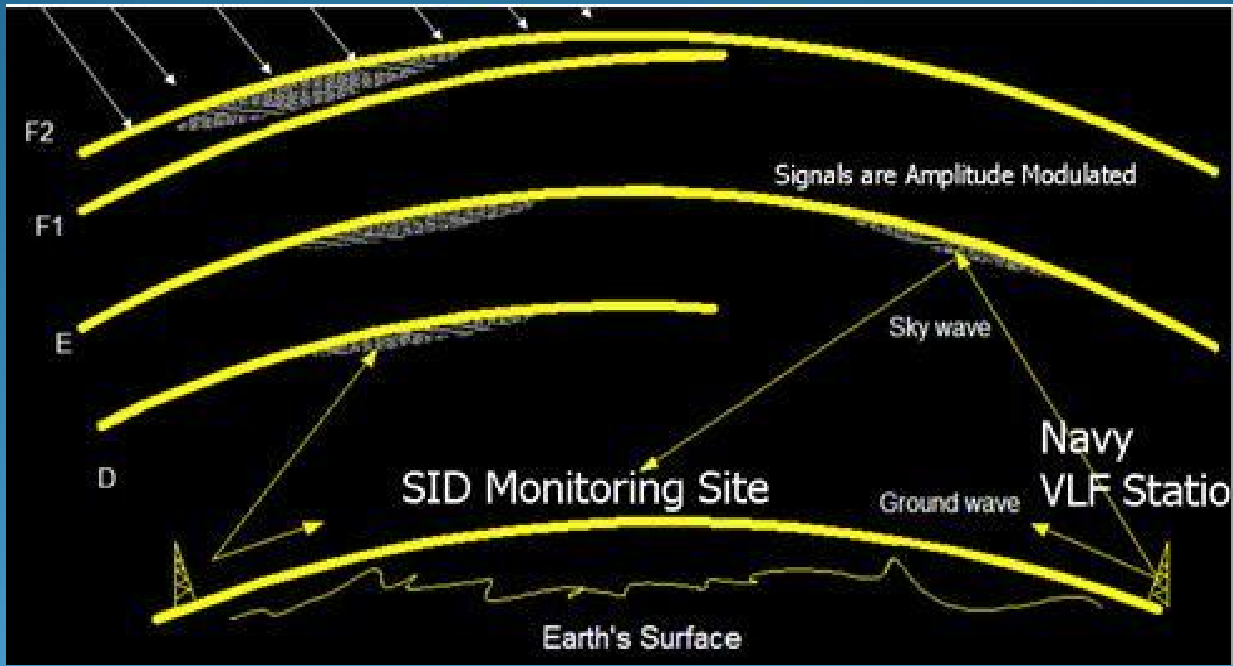
# INTRODUCTION

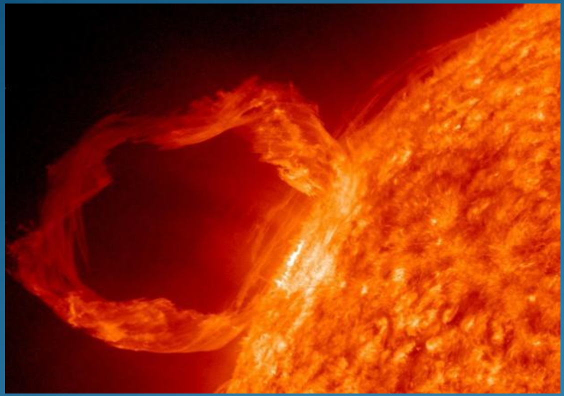
Very Low Frequencies propagate in Earth-ionosphere waveguide with an imperfect ground, and an anisotropic magnetized collisional plasma ionosphere for the upper boundary.



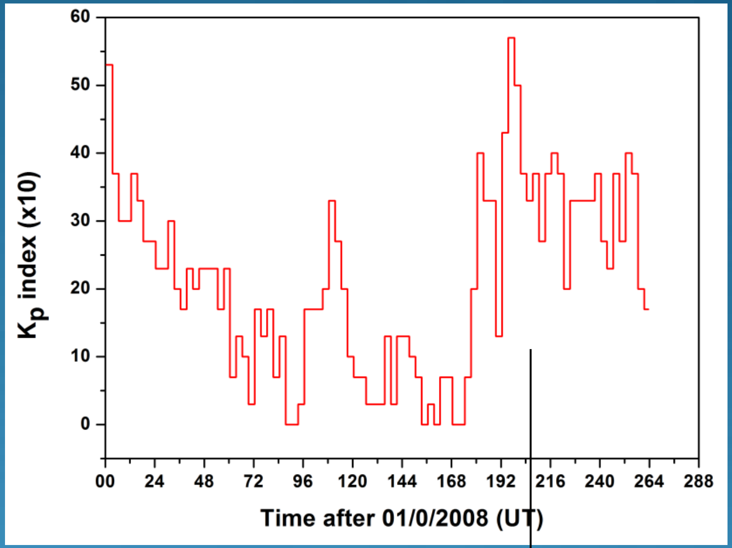

The waveguide properties vary with latitude and the ground conductivity

# Different sources of disturbances can modify the waveguide.

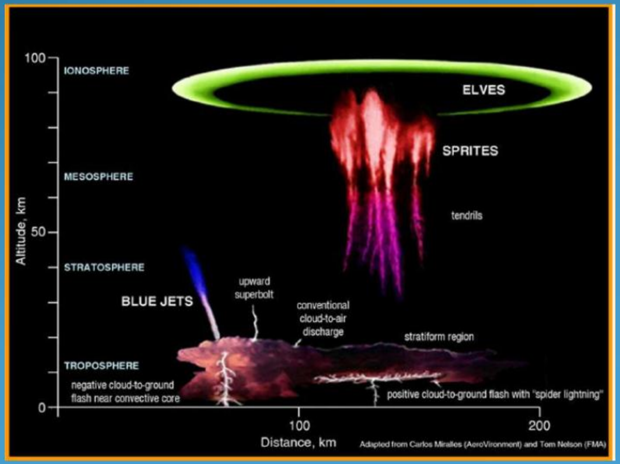
Solar Flares

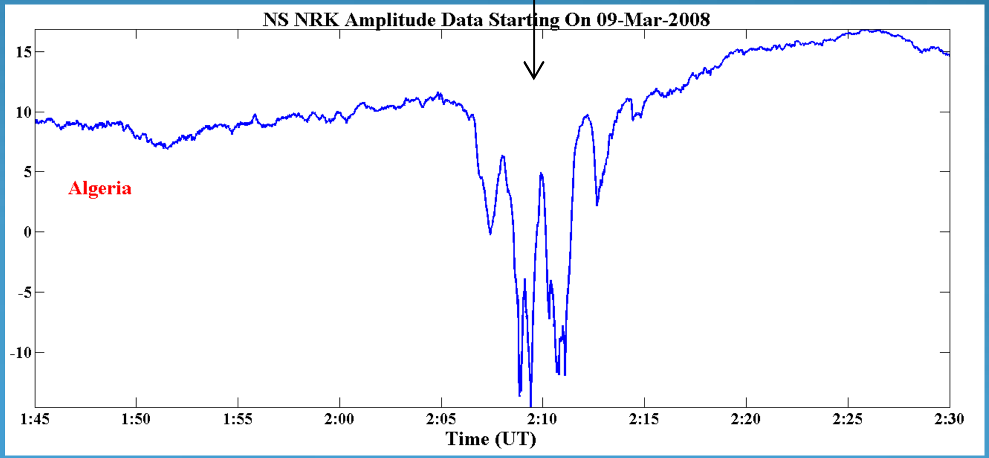


Geomagnetic Storms

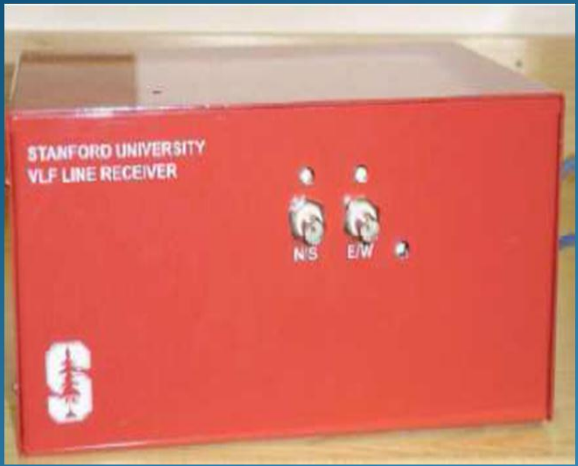



Transient Luminous Events

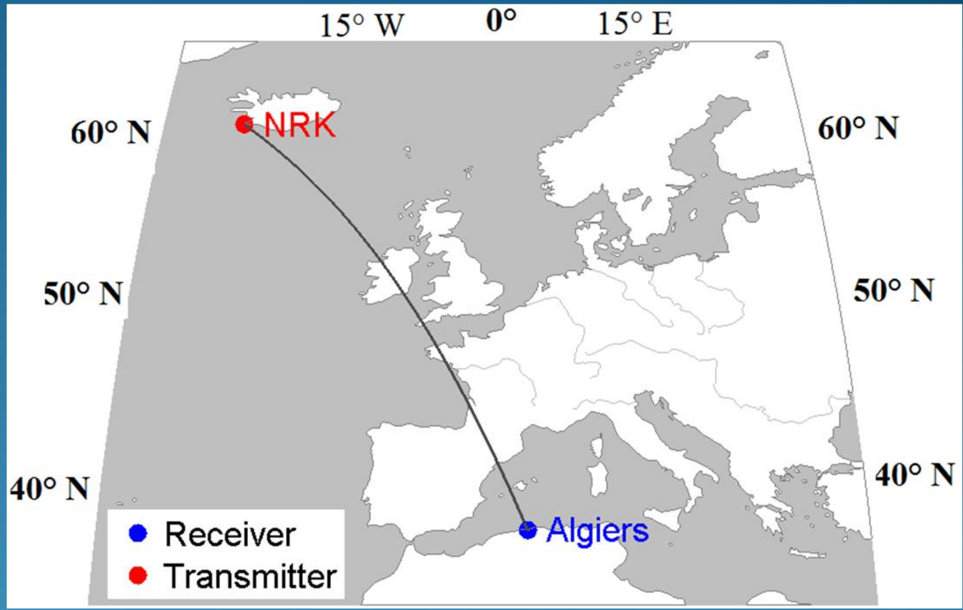


**In this case, we focused on the long term variability of the D region of the ionosphere at 10 UT by means of the NRK VLF signal recorded at Algiers receiver.**




Line receiver



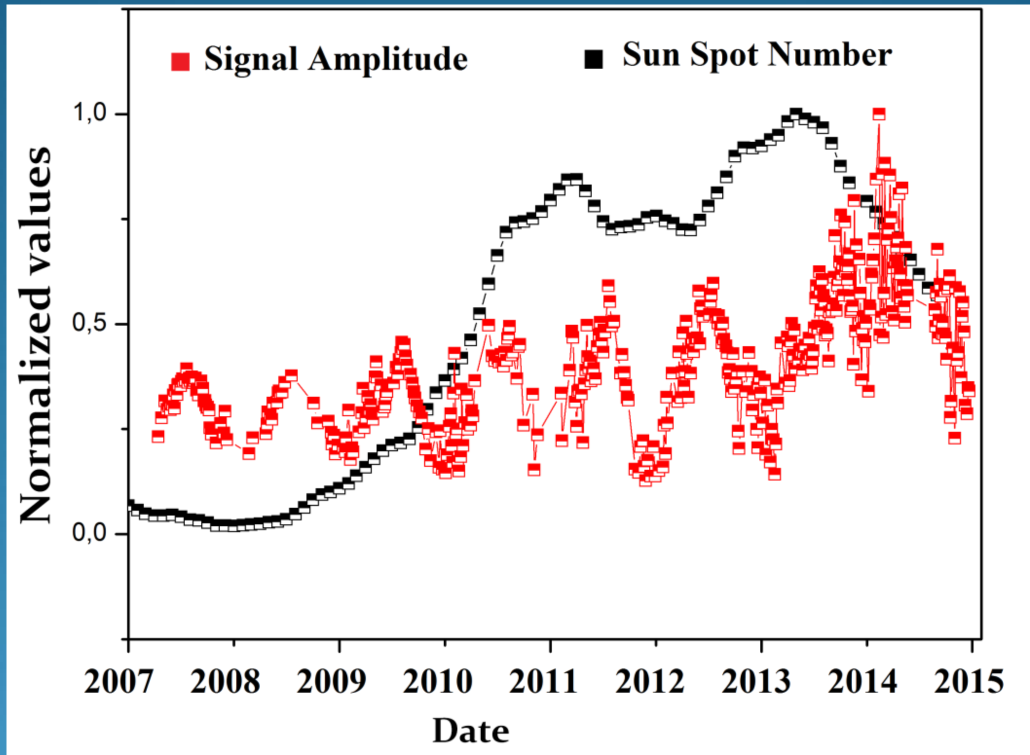

Antennas

GPS

Préamplificateur

# Data analysis results

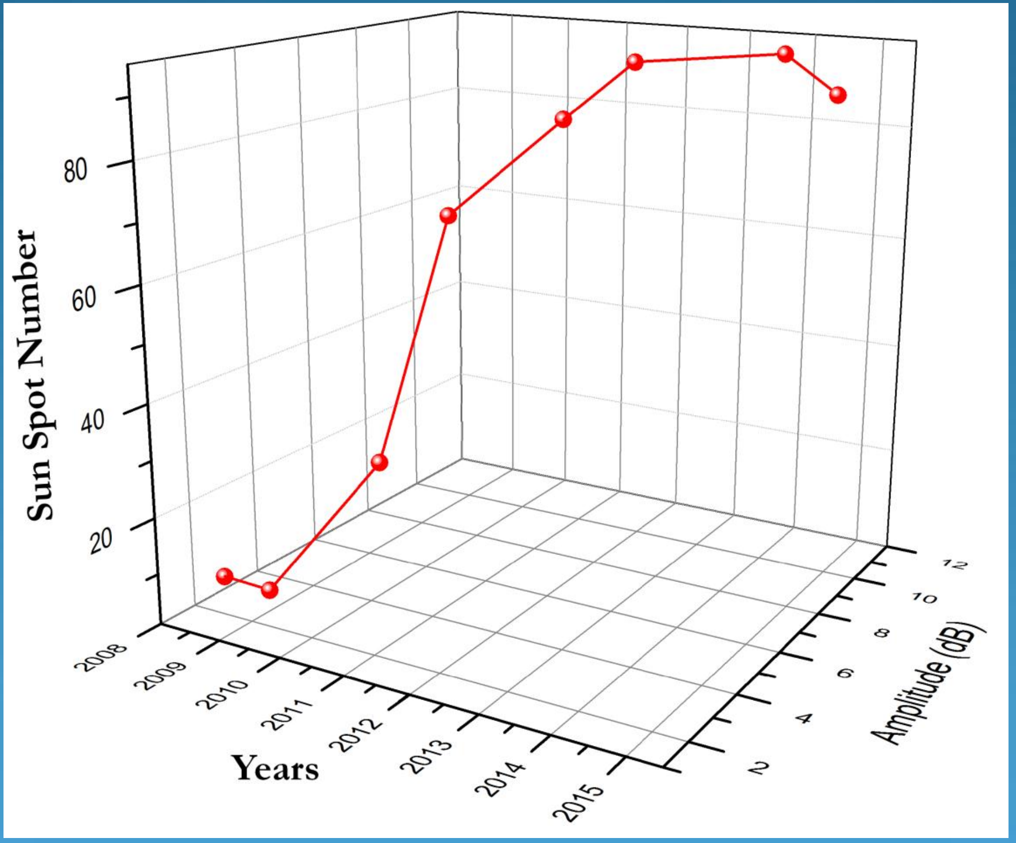
Along the year, the signal amplitude is function of the solar zenithal angle




**The important result is that the maximum amplitude from 2008 to 2010 is nearly the same**

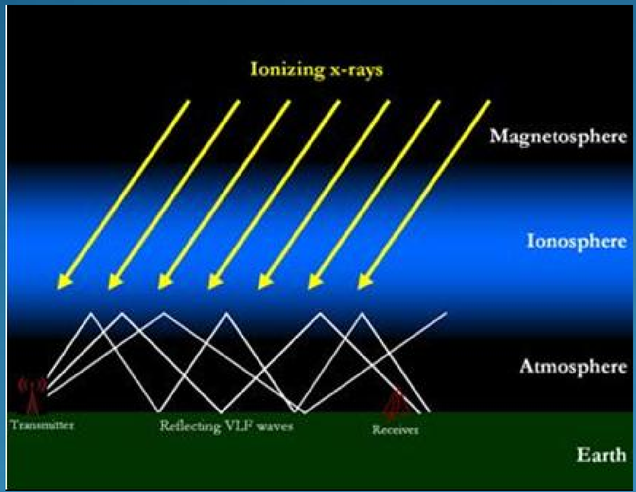
**After 2011 the maximum amplitude increases following the Sun Spot Number increases**

The yearly plot of the amplitude and the SSN shows good correlation between the signal amplitude increases and the SSN

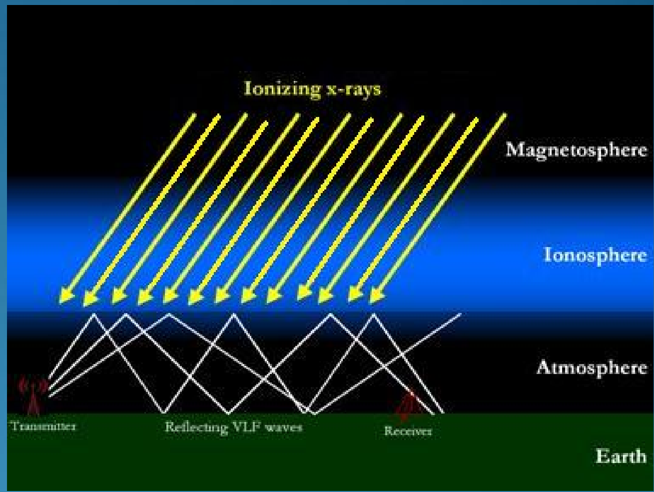


**The amplitude increases is due to the emergence of the active regions in the Earth side. Theses regions emit much more light in the EUV and X rays which leads to an increases of the electron density in the ionosphere. Therefore, the new reflection height is lowered.**

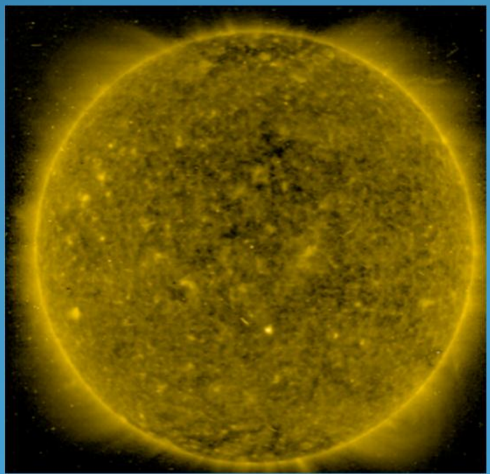
Quiet Sun



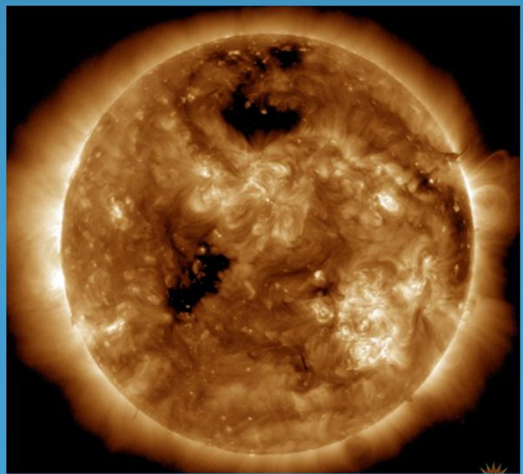

Active Sun



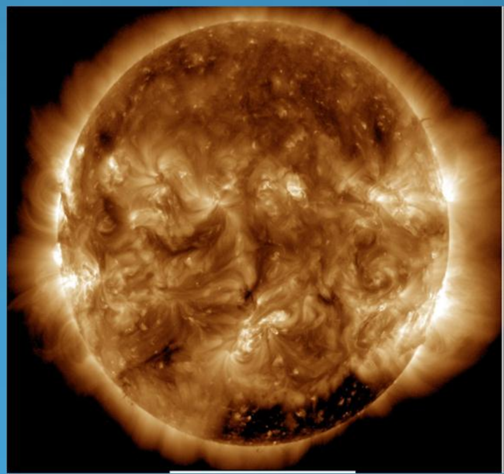

SOHO, 2008



SDO, 2013



SDO, 2014



## Determination of the new reflection height and the electron density enhancement

By means of the signal parameters (amplitude and phase) and the LWPC code (Long Wave Propagation Capability), the VLF technique allows to determine the new properties of the waveguide. Theses new waveguide parameters are important for the exact quantification of the ionization enhancement due to solar flares.

$$N_e(h', \beta, Z) = 1.43 \; 10^7 \exp(-0.15\, h') \exp[(\beta - 0.15)\,(Z - h')] \; (cm^{-3})$$

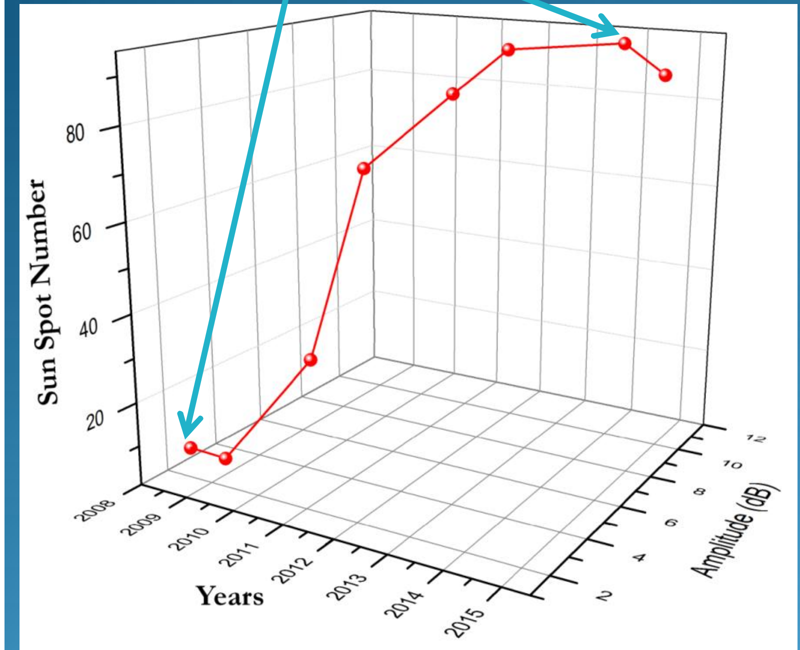
Where Z is the altitude in km h' is the reference height (km) and $\beta$ the sharpness factor ($km^{-1}$) known as the Wait parameters. The technique is to test several profiles by varying h' and $\beta$ untill we obtain the simulated amplitude and phase close to the measurement.

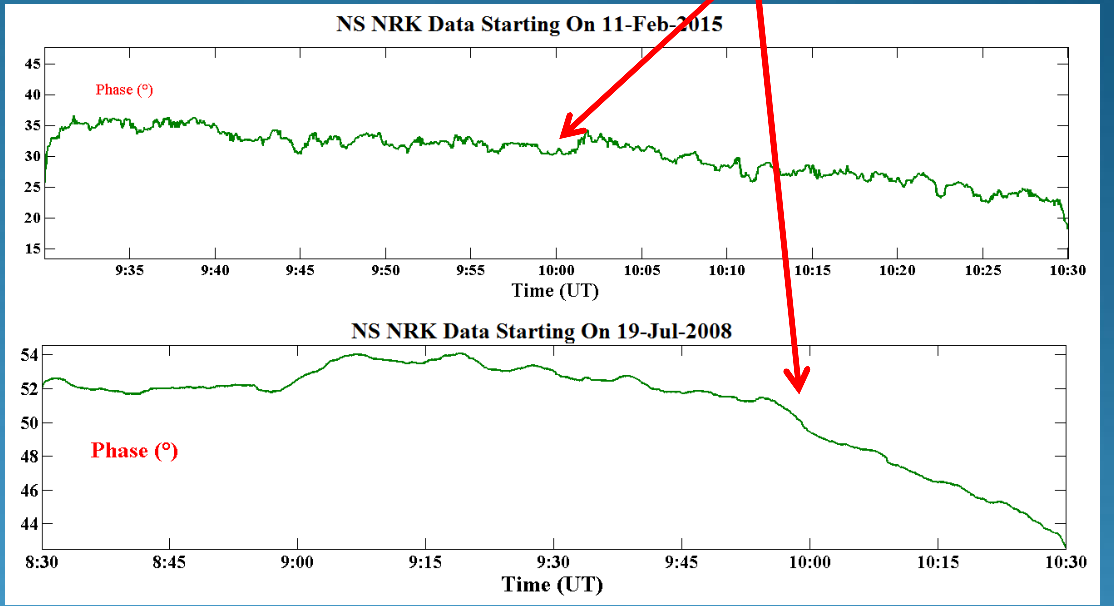
**At normal propagation conditions : h' = 74 km $\beta$ = 0.3 $km^{-1}$**

The measured difference in the VLF signal parameters during Quiet Sun and Active Sun at 10 UT are:

ΔAmp = 6 dB

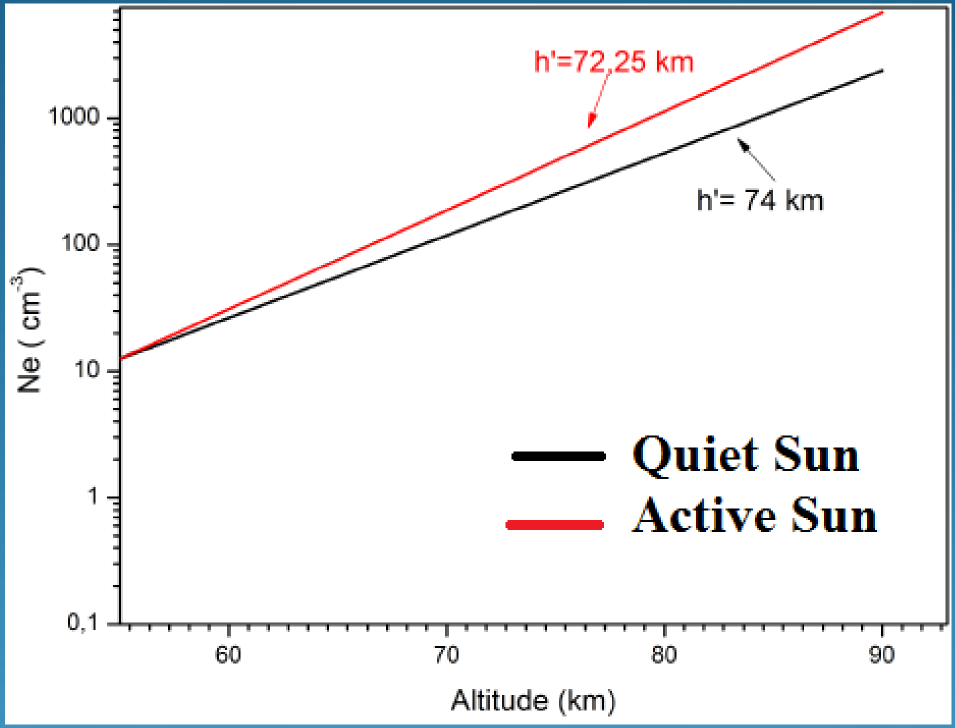
Δφ = 18.55°




The LWPC simulation gives : h' = 72.25 km β = 0.33 $km^{-1}$

From the simulation results, the electron density increases significantly during active Sun




**It is important to consider the ambient reflection height when analyzing the solar flare effect**

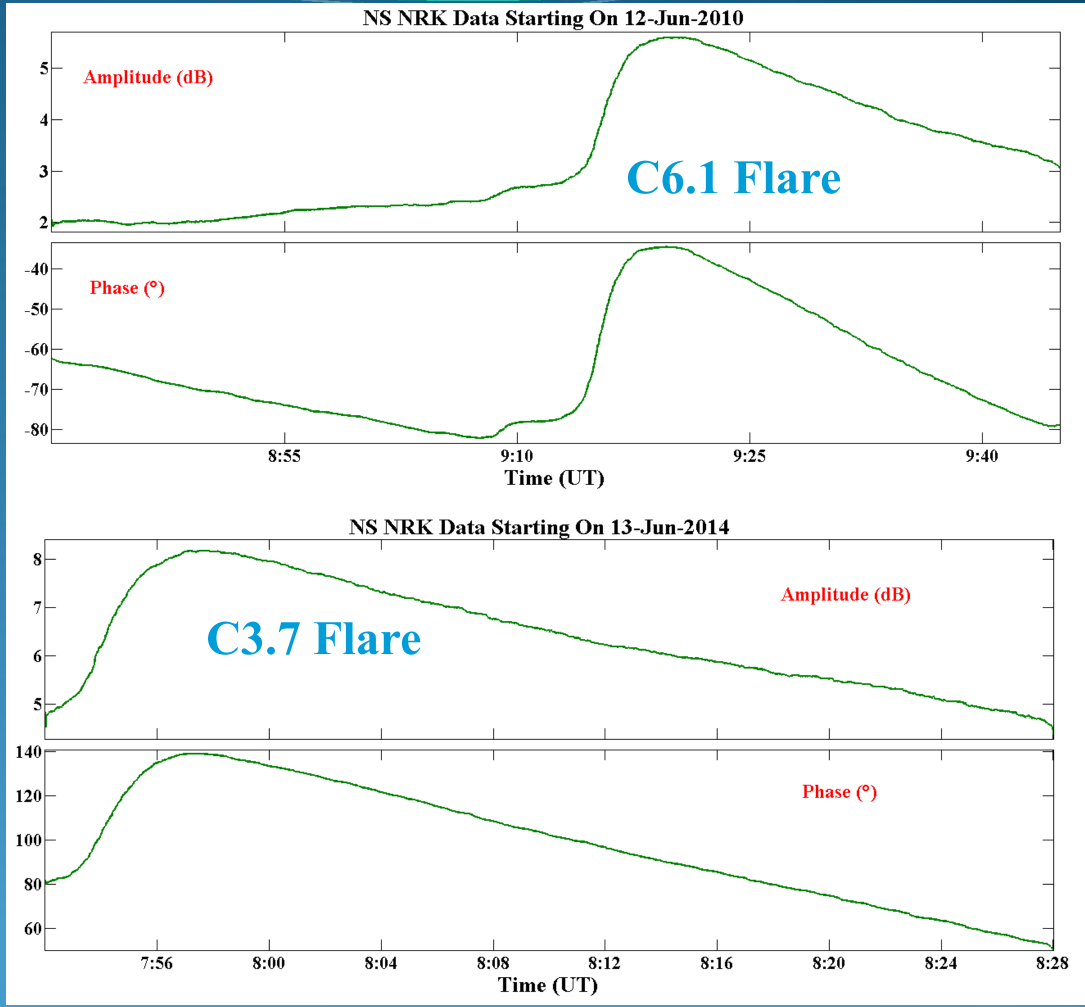
# Example of solar flare effect on the lower ionosphere (D region)

**At Quiet Sun, ambient ionosphere**
**h' = 74 km β = 0.3 km$^{-1}$**

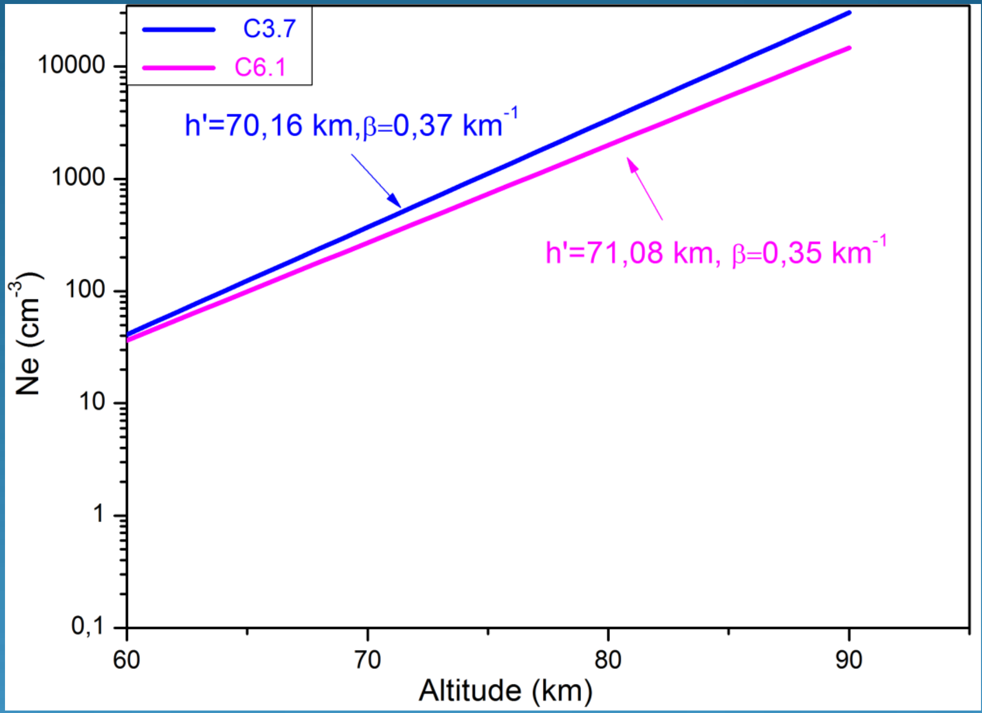
**LWPC code gives for disturbed ionosphere:**
**h' = 71.08 km β = 0.35 km$^{-1}$**

**At Active Sun, ambient ionosphere**
**h' = 72.25 km β = 0.33 km$^{-1}$**

**LWPC code gives for disturbed ionosphere:**
**h' = 70.16 km β = 0.37 km$^{-1}$**



## Even low, the C3.7 flare produced much ionization than C6.1




This is due to the fact that during active Sun, the ambient ionosphere is already disturbed by the emergence of the active regions in the visible disc.

Best quantification of the ionization in the Earth-Ionosphere wave guide changes due to solar flares needs a precise characterization of the ambient conditions

# Conclusion

The observation of the signal amplitude changes from 2008 to 2015 showed that:

The signal amplitude varies
With the Solar Zenithal Angle

**The maximum of the signal amplitude is well correlated to the SSN**

This is explained by the emergence of the active regions in the visible disc which increase the X and EUV rays flux toward the Earth

The ambient reflection height of the VLF signal is then lowered to 72.25 km during active Sun

Considering this fact, the C3.7 flare observed during active Sun was found to produce much more ionization than C6.1 flares that happened at quiet Sun

The VLF signal analysis is a fruitful technique to study and quantify the changes in the lower region of the ionosphere due to solar flares.

Thank you