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SUN-EARTH INTERACTION AND ITS IMPACT IN THE UPPER ATMOSPHERE

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The upper atmosphere has been monitored to study the external forcing importance in the variations of its physical and chemical properties. The main external forcing are the solar phenomena, such as: flares, flux of energetic particles (winds) and giant bubbles of gas expelled from its atmosphere (coronal mass ejection, CME). All these solar phenomena strongly affect the ionized layer of our atmosphere, the ionosphere, especially during the periods the Sun is active. The ionosphere is also a very sensitive flare detector during solar minimum activity, when it is possible to detect weak flares. In the periods the Sun is calm, the forcing from below is competitive with solar forcing. The main forcing from below has been attributed to atmospheric waves mostly of tropospheric origin, especially the planetary waves because of the period similarities. Thus, long term studies are important to improve our understanding of the external forcing of the ionosphere as well its coupling with lower atmospheric layers, which are essential to understand their role in the climate changes.

The base of ionosphere (< 100 km altitude), the D-region, is essentially maintained during quiet conditions by the solar Lyman-alpha radiation, which ionizes the minor neutral atmospheric constituent nitric oxide. Variations in the Lyman-alpha produce changes in the ionization rates, and consequently in the D-region state. The disturbances of the lower ionosphere have been monitored by very low frequency (VLF) waves propagating within the waveguide formed between the ground and the ionosphere base. The amplitude and phase of VLF waves depend sensitively on the waveguide electrical conductivity, so they can be used as a proxy to estimate the Lyman-alpha solar radiation during periods of low solar activity. During periods the Sun is active, the base of ionosphere is strongly affected by the excess of X-ray emission from the active regions and from solar flares. The X-ray emission of solar flares is detected as VLF phase abrupt variations called sudden phase anomalies (SPAs). Studies of the incidence of SPAs have shown that the ionosphere reference height is lower (about 1 km) at solar maximum (McRae and Thomson, 2004; Raulin *et al.*, 2006), which means the decrease of electron density in the base of ionosphere during solar minimum, becomes possible the detection of weaker X-ray events (Raulin *et al.*, 2010). Long term analysis of diurnal VLF amplitude detected at Brazilian Antarctic Station Comandante Ferraz (EACF, 62.1° S and 58.4° W) from NPM transmitter at Hawaii (Lualualei), shows an overall decrease from 2005 through 2009 that accompanies the decay phase of the 23 rd solar cycle (Figure 1). The greater attenuation rate of VLF amplitude at solar minimum was also found by Thomson and Clilverd (2000) during the decay phase of previous solar cycle, which was explained by the competition between the reduction of solar Lyman alpha in the height range 65-80 km and an increase of the cosmic ray intensity at lower heights.

The solar origin forcing could also be due space weather effects, which govern the lower ionosphere

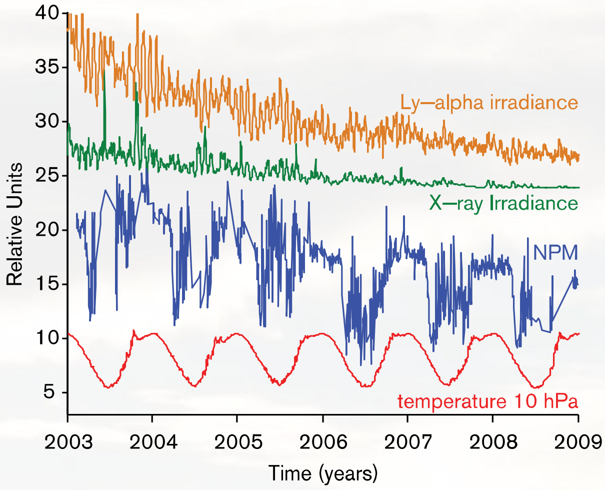

Figure 1. Long term diurnal VLF amplitude detected at Brazilian Antarctic Station Comandante Ferraz (EACF) from NPM transmitter at Hawaii. Figure also shows the solar irradiances at Lyman-alpha and X-ray, and the stratosphere temperature at southern latitudes between 55° and 75°. It shows the decrease of VLF amplitude has a close association with the decrease of solar irradiance, which occurs in the minimum of solar cycle.

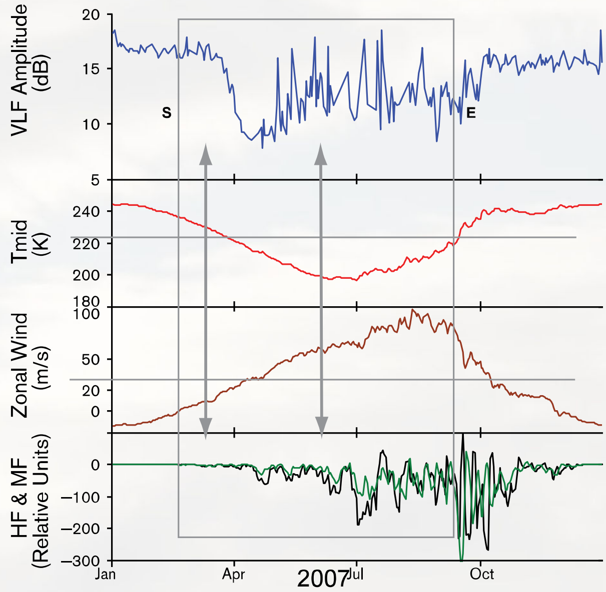

Figure 2. Example of the annual variation of VLF amplitude. From topo to bottom figure shows: NPM VLF amplitude detected at EACF, the stratosphere temperature at southern latitudes, the zonal wind speed, and the stratosphere parameters heat flux (HF) and Momentum flux (MF), the last ones indicators of disturbed stratosphere. It shows the lower ionosphere is very sensitive to the stratospheric disturbances that occur during the winter polar vortex.

variability especially at high latitudes, particularly at night. The most important space weather phenomenon that disturbs the lower ionosphere is strong geomagnetic storms, which are produced by the impact of solar wind and CMEs. Their effects are more pronounced in the lower ionosphere at high and middle latitudes, where the income energetic particles mostly precipitate and cause large increase of electron density. This densification of the lower ionosphere produces substantial increase of radio wave absorption, sometimes with blackouts of telecommunication.

On the other hand, during the minimum of solar activity the lower ionosphere is also affected by meteorological processes, which are predominantly upward propagating waves of tropospheric origin. The detailed analysis of VLF amplitude detected at EACF from the end of 2005 through 2009, shows an annual variation (Figure 2) in close association with the temperature and wind speed variations in the stratosphere, especially during the winter polar vortex (winter anomaly), which is from April through the end of September in southern hemisphere. During winter anomaly VLF amplitude shows faster fluctuations with quasi-periods similar the ones of planetary waves originated in the troposphere (few days). So, these results show the planetary waves are important forcing of the ionosphere by waves from below as previously obtained from different approaches (Dunkerton, 2000, Lastovicka, 2006).

Thus the long term studies of the lower ionosphere are important to better determine the relative role and importance of various external forcing and to try to define more reliable predictions methods of its state. The understanding of ionosphere coupling with lower-lying levels of atmosphere is also important to define its role in the climate changes.

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