Remote Sensing of Atmospheric Gravity Waves (GWs) and Planetary Wave Type Oscillations (PWTOs) in the upper mesosphere-lower ionosphere system using the Very Low Frequency transmitter data

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Abstract

We present how the VLF radio data can be used to study the short-period (∼min to hrs) GWs and long-period (∼days) PWTOs. To show the presence of GWs, we analyse the VLF data from several places obtained by ICSP-VLF network during the solar eclipse of July, 2009. We find dominant wave periods ranging from 10 minutes to 1 hour around the time of maximum eclipse phase which could be associated with atmospheric gravity waves excited due to the solar eclipse. We also analyse nearly 4 years of VLF amplitude data received at ICSP, Kolkata from the VTX (18.2 kHz) transmitter and also from the NWC (19.8 kHz) transmitter for planetary wave type oscillations (PWTOs) in the mesosphere-lower ionosphere system. Fourier and wavelet analysis show the presence of PWTOs in both the radio paths having periodicity in the range 5-26 days. The PW spectrum of VLF data are also correlated with the PW spectrum of Ozone data.

1 Introduction

Continuous monitoring of very low frequency radio transmitters can be a very efficient tool for the study of atmosphere-ionosphere coupling (Latsovicka, 2001; Schmitter, 2011). The atmospheric waves (AGW, PW, tidal waves) transfer energy and momentum from lower atmosphere to upper atmosphere and maintain the atmospheric balance (Hines, 1960; Latsovicka, 1997). VLF waves (3-30 kHz) reflected from the upper mesosphere-lower ionosphere region (60-90 km) contain the information about all type of atmospheric forcing from below as well as with solar forcing from above.

In this paper, we shall show that the measurement of sub-ionospheric reflected VLF wave amplitude can be used to study the short-period atmospheric gravity waves as well as the longer period planetary waves. At mesosphere and thermosphere, the differential heating of the atmosphere at dawn and dusk terminator produces GWs regularly. Chimonas and Hines (1970) were the first to suggest that during a solar eclipse the disturbance of the heat balance along the supersonic travel of the trajectory of the moon's shadow could generate GWs. Subsequent studies show that the thermal cooling of the stratospheric Ozone layer during solar eclipses act as a main source of GWs. We use the VLF data collected by the Indian Centre for Space Physics (ICSP) during the solar eclipse of 22nd July, 2009 to find the wave-like oscillations associated with the solar eclipse.

Among the longer-period atmospheric waves, planetary waves (PWs) are characterized by periods of 2 to 30 days. Generally PWs are not able to penetrate to altitudes above 100–110 km due to atmospheric viscosity and other reasons (Lastovicka, 2006). Nevertheless, oscillations with PW periods were observed in all ionospheric layers (Pancheva et al., 2002) and some time they are referred to as planetary wave-type oscillations (PWTOs). The simultaneous occurrence of PW in the ionosphere and stratosphere is an indicator for vertical coupling between the middle atmosphere and the thermosphere/ionosphere system (Jacobi et al., 2007). We use 4 years of VLF amplitude data collected by the ICSP-VLF network to study the PWTOs in the the mesosphere-lower ionosphere system.

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2 Results

ICSP conducted a week long campaign all over India during the total solar eclipse of July 22, 2009 and received signals before, on and after the eclipse day from the VTX (18.2 kHz) transmitter. Data were collected from a dozen of places including Kathmandu and are reported in Chakrabarti et al., 2012. To analyze and to find the effects of the atmospheric gravity waves on the lower ionosphere during solar eclipse from these VLF data, we use the fourier and wavelet analysis method. For example, In Figure 1, we present the fourier spectrum of the VLF data from 05:00 AM to 08:00 AM IST on normal day (green curve) and on solar eclipse day (red curve) (eclipse started around 5:30 AM and continued up to $\sim$ 7:30 AM) for two places Kathmandu (96%) and Raiganj (100%).

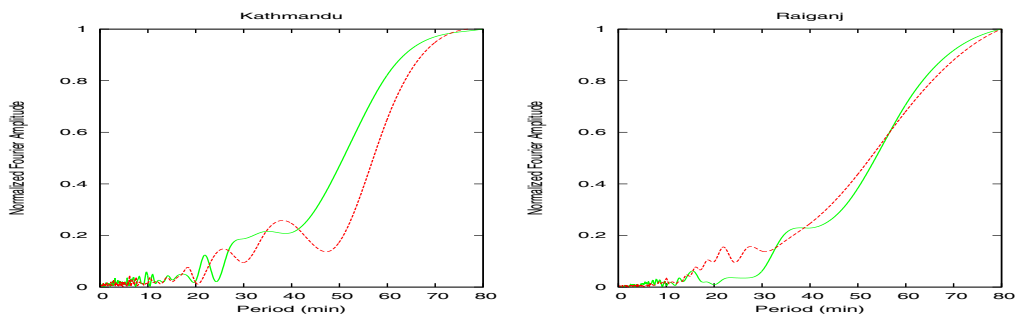

Figure 1: FFT spectrum on normal (green) and eclipse day (red). FFT spectrum show much higher wave activity on 22 July 2009 compared to normal days.

In Figure 2, we show the wavelet power spectrum of the deviation of VLF amplitude from normal values due to solar eclipse at Kathmandu. Here the presence of strong wave periods ranging from 10 minutes to 1 hour during the maximum solar eclipse phase ($\sim$ 06:30 AM) is very clear which could be associated with atmospheric GWs generated due to the movement of moon's shadow on Earth's atmosphere during the solar eclipse.

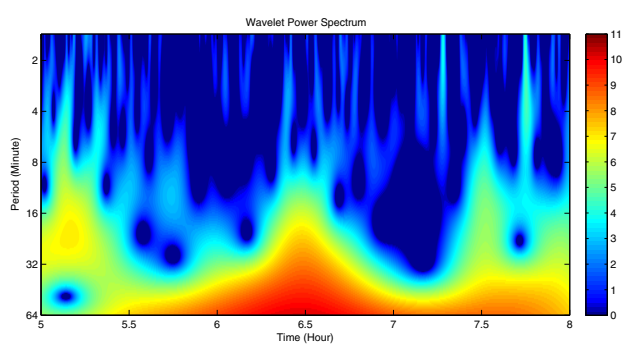

Figure 2: Wavelet power spectrum of the VLF amplitude deviation from normal values due to solar eclipse at Kathmandu receiving station. Note the strong wave-periods ranging from 10 minutes to 1 hour around the maximum eclipse phase (06:30 AM IST).

In Figure 3, we present the planetary wave spectrum obtained from the VLF absorption data (upper panel) and the total Ozone data over the receiver (lower panel) for the year of 2007. VLF absorption are defined as the difference between the mid-night amplitude and mid-day amplitude (2 h average) in the VLF diurnal pattern. With the VLF data clearly visible are 5, 13-15 and 25 days wave periods while with the Ozone data we find clear periods at 13, 16 and 22 days. From the wavelet spectrum of the Ozone data presented in Figure 4, we can see that almost all the PW type wave periods occurred in the winter time. With the VLF wavelet spectrum we see that the persistent 12-15 days PWTO periods are concentrated on April and November, while 25 days periods are concentrated on March and November. Near 5 days oscillations

are seen in mid January that could be associated with pre-seismic activities occurred in the Sumatra and Nicober region within the same time frame. (Pulinets & Davidenko, 2014 and references therein).

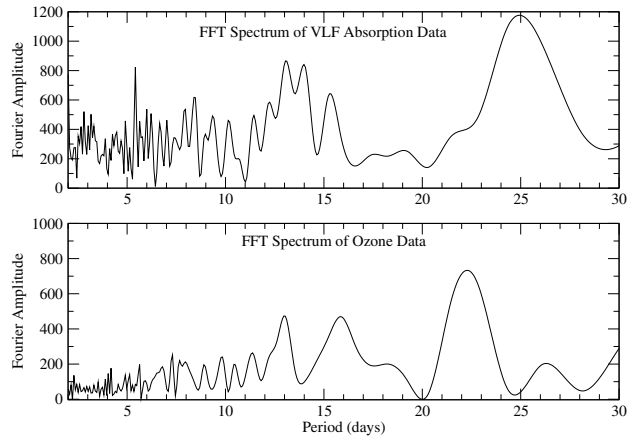

Figure 3: PW spectrum as obtained from the VLF absorption data (upper panel) and total Ozone data over the receiver (lower panel) for the year of 2007.

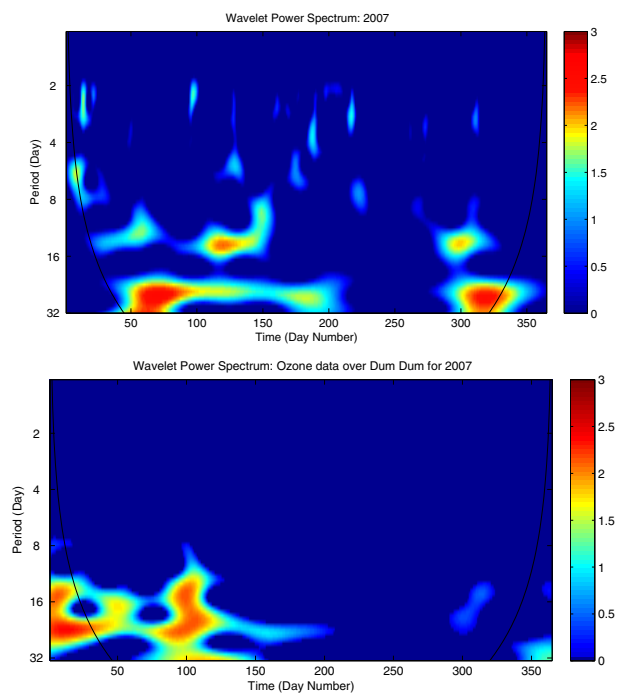

Figure 4: Wavelet power spectrum of the VLF absorption data (upper panel) and total Ozone data over the receiver (lower panel) for the year of 2007.

3 Conclusion

We presented the use of VLF amplitude data for the study of both short-period and longer-period atmospheric waves. The presence of GWs during the solar eclipse phase is very clear at the Kathmandu station which was $\sim$ 500 km away from the eclipse totality zone. Since the solar eclipse of July, 2009 was

just after the sunrise, clear identification of wave periods of GWs due to eclipse alone become very difficult for some of the receiving places because of interferences among the waves generated due to solar eclipse and solar terminator. On the other hand, wave periods associated PWTOs are mostly found in winter time, because summer troposphere is not transparent to PWs and their propagation is suppressed by summer stratospheric wind. To conclude we can say that continuous monitoring of VLF transmitter can be a very efficient remote sensing tool to study all kind of atmospheric forcing from below. More networking study should be done to extract more information about the atmospheric waves from VLF transmitter data.

4 Acknowledgements

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