Ultra Fast Kelvin waves in the equatorial upper atmosphere

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Abstract

Meteor radar wind measurement at Cariri (7.4°S, 36.5°W) and Ionosonde measurements at Fortaleza(3.9°S, 38.4°W) have been carried out in 2005. 3 to 5 days period oscillations in the mesospheric zonal wind and ionospheric F-layer bottom height (h'F) and the maximum frequency (foF2) were observed during a period from March 01 to 11, 2005. Atmospheric temperatures observed by the SABER/TIMED satellite also showed a similar periodic oscillations. From the characteristics of the downward phase propagation, longitudinal and latitudinal extension, we conclude that this oscillation must be a 3.5–day Ultra Fast Kelvin (UFK) wave. The observed amplitude of oscillation of the F-layer height caused by the UFK waves, 20–30 km, are significant, and worthwhile to investigate in terms of the day to day variability of the Spread F occurrence.

Introduction

There are several types of waves propagating in the equatorial upper atmosphere, such as, gravity waves, tidal waves, and planetary waves. Planetary scale waves are normally generated in the troposphere through meteorological activities, and propagate upwards. Depending on their wave characteristics (phase velocity and vertical wavelength) these waves could reach in the mesosphere and lower thermosphere, resulting some signatures in the mesospheric wind fields. Planetary waves in the ionosphere and coupling process with the lower atmosphere, *Pancheva and Lysenko* [1988] reported quasi-two-day waves in both mesospheric winds and in the F-region electron density. *Forbes* [1996] suggested that planetary waves potentially account for significant day-to-day variability of the F-region ionosphere. *Haldoupis et al.*[2004] suggested that interactions between planetary waves and tides in the lower ionosphere could be responsible for E-region variability. The role of planetary waves in the ionosphere and in coupling between the middle atmosphere and ionosphere, however, is still not well known.

The Ultra Fast Kelvin (UFK) wave in the stratosphere was first reported by *Salby et al.* [1984]. Due to the long vertical wavelength (>50 km), this wave could penetrate into the mesosphere and even above 100 km. *Forbes* [2000] called attention to this wave. The purpose of the present work is to investigate the presence of UFK waves in the equatorial upper atmosphere and to find out the influence in the ionosphere. In order to that, ionosonde data, meteor radar data from 4 different sites separated in longitude and latitude, and TIMED temperature data from the SABER instrument were compared.

Observations

A digital ionospheric sounder (DPS-4) is operated at Fortaleza (3.9°S, 38.4°W, Geomag. 2.1°S). Ionograms are taken with 10-minute intervals. The ionospheric parameters used in the present analysis are the maximum frequency of the F2 layer, foF2, and the minimum virtual height, h´F. SkiYmet meteor radars are operated at São João do Cariri (7.4°S, 36.5°W), Cachoeira Paulista (22.7°S, 45.0°W) and Santa Maria (29.7°S, 53.7°W). The zonal and meridional winds are estimated in one hour time bins for 7 (4-km thick) atmospheric layers, with a height overlap of 1 km between adjacent layers. The SkiYmet radar at Ascension Island (7.9°S, 14.4°W), operates at a frequency of 43.5 MHz. A description of the data processing for this radar has been presented elsewhere [*Pancheva et al.,* 2004]. The TIMED satellite has been in operation since 2002 and the SABER (Sounding of the Atmosphere by Broadband Emission Radiometer) instrument observes atmospheric temperature from 10 to 130 km altitude [*Russell et al.,*1999)]. In this study the level 2B kinetic temperature data from 30 to 100 km, are used.

For the present study, the first four months of 2005, from January 1 (day 1) to April 30 (day 120) are used. Cariri and Ascension are located in the same latitudinal zone but longitudinally separated by 2400 km. The three meteor radars in South America, located from 7° to 29° S, make it possible to investigate latitudinal effects. The longitudinal distance between the Fortaleza ionosonde and the Cariri meteor radar is about 430 km, negligible for our purpose. The locations of these observation sites are shown in **Figure 1**.

Results

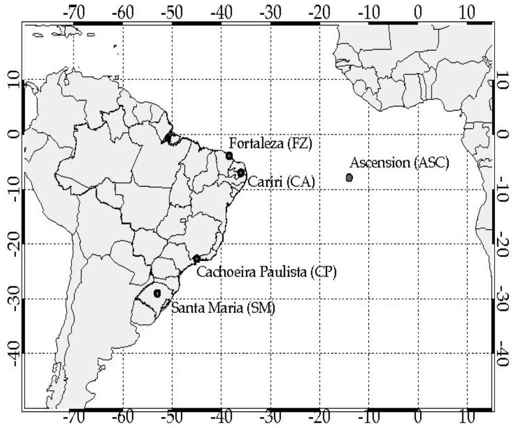

Figure 1. Geographic locations of the observation sites.

In the evening, the equatorial ionosphere F-layer is uplifted because of the F-region dynamo effect. In order to see day to day variability of the ionospheric h'F and foF2 parameters, we chose h'F at around 20:00 LT when the F-layer reaches the maximum height, and foF2 at around 19:00 LT before to start the Spread F condition. In order to study periodic oscillation, a wavelet spectral analysis was applied to the time series of the ionospheric foF2, h'F and 90-km mesospheric zonal wind. In **Figure 2** are shown Morlet wavelet power spectra for foF2, h'F and zonal wind, for periods from 2 to 16 days as a function of day of the year. The time series of the SABER temperature in the stratosphere (at 40 km) are also presented. Several kinds of wave packet with periods between 3 and 16 days can be seen. Among them a common periodic oscillation with a period of around 4 days can be seen for all of them, from day number 60 (March 1) to day 75 (March 16).

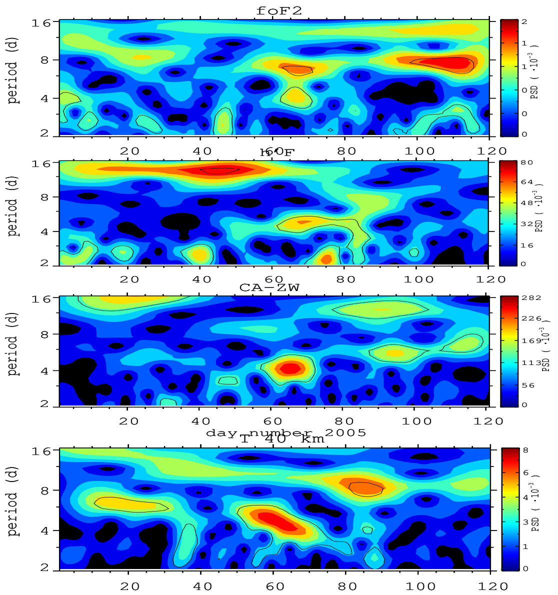

Figure 2. From top, wavelet analysis of ionospheric foF2, h'F observed at Fortaleza, Mesospheric zonal wind at 90 km observed at Cariri, and Temperature at 40 km altitude observed by SABER/TIMED satellite, during the period from January 1 to April 30, 2005.

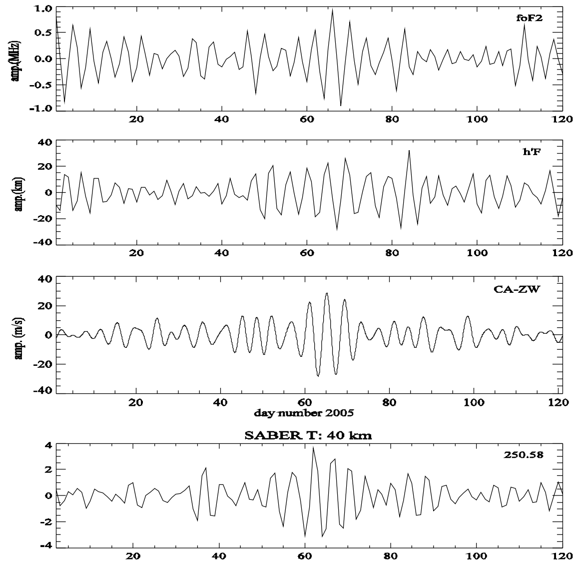

Figure 3. Amplitude and phase of the 4(±1) days filtered oscillations of, from top to down, ionospheric foF2, h'F observed at Fortaleza, Mesospheric zonal wind at 90 km observed at Cariri, and Temperature at 40 km altitude observed by SABER/TIMED satellite, during the period from January 1 to April 30, 2005.

In order to see the amplitude and phase of oscillation a band-pass filter with a width of 2 days, centered on 4 days, was applied to the time series. The results are shown in **Figure 3.** The wind shows a maximum amplitude of 25-30 m/s centered on day 66. A similar oscillatory feature can be seen in foF2 with an amplitude of 0.8 MHz. The amplitude of height variation of h'F reached 25 km (50 km peak-to-peak) at day 66. It is worth noting that h'F and the wind are almost in phase and there is a slight phase shift (1-2 days) between foF2 and h'F. The stratospheric temperature at 40 km also showed an amplitude of 3 K (6 K peak-to-peak). Vertical structure in the 3.5-day filtered wind oscillation for days 60-70 shows a downward phase propagation with a vertical wavelength of 39 ± 5 km. This indicates that the oscillation has the characteristics of a wave, with phase propagating downwards.

In order to investigate its longitudinal and latitudinal extensions, we used the wind data from 4 meteor radar stations in Brazil and the SABER temperature data. **Figure 4** shows the amplitude and phase of the 4(±1) days filtered oscillations of the SABER temperature at 90 km for different longitudinal zones, comparing with the data at Cariri (- 36°) and Ascension (- 15°), Africa (+36°), Indonesia (+108°) and Polinesia (- 144°). The phase difference between the two sites around the period of days-60 to 70, shows that the phase delay against Cariri increases as increasing the longitudinal distance. This indicates that the wave is propagating eastward and the wave number 1.

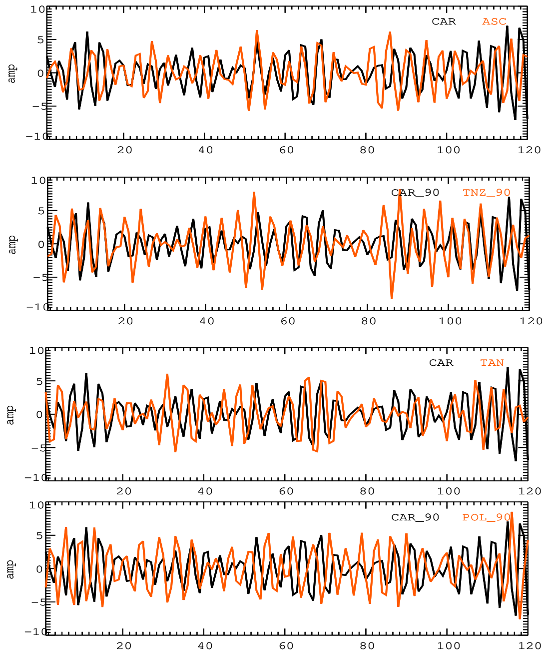

Figure 4. Amplitude and phase of the 4(±1) days filtered oscillations of the SABER temperature at 40 km for different longitudinal sites, (from top to down) between Cariri (black) and Ascension (red), Cariri and South Africa region, Cariri and Indonesia region, and Cariri and Polinesia region (bottom).

As to the latitudinal extensions of the 4-day oscillation in the meteor winds for Cariri, Ascension, Cachoeira Paulista and Santa Maria, **Figure 5** shows the 3-5 day filtered spectrum of the 4 sites. It is clear to see that the 4-day oscillation, its phase and amplitude, is almost identical for Cariri and Ascension. No significant phase lag between the two sites was found due to the short distance between them. If we compare Cariri with Cachoeira Paulista, the phase is almost the same but the amplitude of oscillation at Cachoeira Paulista is about a half of Cariri. The amplitude at Santa Maria is negligible. This latitudinal decrease of amplitude suggests us that this could be a wave trapped in the equatorial region.

4. Discussions

The observed evidence, ~4 day period, vertical phase propagation, longitudinal extension, and equatorial trapping, suggest that the observed wave might be a 3.5-day UFK wave generated in the troposphere and propagating upward. Signatures of the UFK wave at mesospheric heights were first reported by *Vincent* [1993] and later by *Liebermann and Riggin* [1997] and most recently by *Pancheva et al.* [2004]. *Takahashi et al.* [2006] showed simultaneous 3.5-day oscillations in the mesospheric zonal wind and ionospheric h'F and suggested that a UFK wave was present in the ionosphere. In the present work we find vertical and latitudinal extensions which agree with the characteristics of the UFK wave. *Forbes* [2000] predicted penetration of this wave into the ionosphere. Because of their long vertical wavelength (> 40 km), these waves could reach the lower thermosphere (100 – 150 km). Recently *Miyoshi and Fujiwara* [2006] showed, in their general circulation model, that the UFK wave could propagate upward to the lower thermosphere. Our present results agree with these previous works.

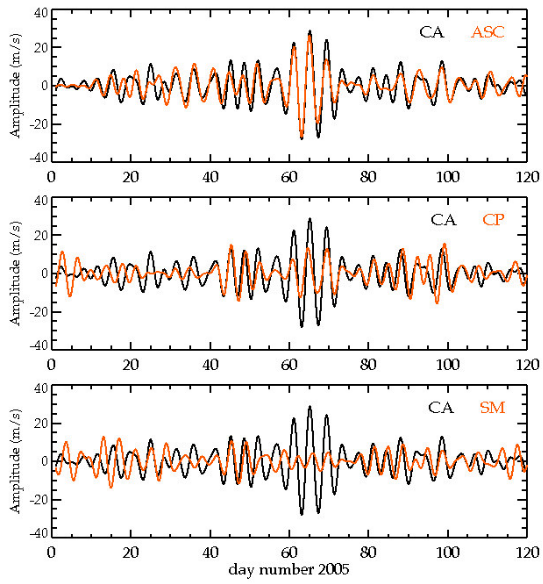

Figure 5. Amplitude and phase of 3-5 day filtered harmonic spectrum: Comparison of meteor radar zonal winds at 90 km between Cariri (CA) (7.4° S) and Ascension (ASC) (7.9° S) (top), Cariri and Cachoeira Paulista (CP) (22.7° S) (middle), and Cariri and Santa Maria (SM) (29.7° S) (bottom) during the period from January 1 to April 30, 2005. *(Fonte: GRL/AGU, 2007)*

The presence of 3-4-day modulation of the day-to-day variability in both h'F and foF2 suggests that the UFK wave could penetrate into the ionosphere. If the Kelvin wave reaches E-region heights (100 to 120 km), it could modulate the local diurnal tidal wind system (mainly zonal) resulting in a variation in the electron conductivity. If the wave penetrates even higher, to 150 to 200 km, it could directly modulate the lower thermosphere zonal wind speed, resulting in direct modulation of the F-region dynamo. From the present analysis, however, it is difficult to conclude which process is responsible. Since equatorial F-region plasma bubble formation depends directly on the upward drift velocity, the UFK waves might play an important role in the formation of such irregularities.

5. Conclusion

From the meteor radar wind and ionosonde h'F and foF2 measurements, we could identify propagation of a UFK wave in the ionospheric height during the period March 1 to 16, 2005. The estimated wave amplitude of the zonal wind at 90 km height was 28±3 m/s, h'F with 23±3 km, and foF2 with 0.8±0.1 MHz. These results strongly suggest that the UFK wave propagates from the troposphere to the ionosphere. The UFK wave could affect the post-sunset ExB uplifting of the F-layer via wave-induced changes in the E-region conductivity and/or the lower thermospheric neutral wind.

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References

Forbes, J.M.,1996, Planetary Waves in the Thermosphere-Ionosphere System, J. Geomag. Geoelectr., 48, 91.

Forbes, J.M., 2000, Wave coupling between the lower and upper atmosphere: case study of an ultra-fast Kelvin Wave, J. Atmos. Solar Terr. Phys., 62, 1603-1621.

Haldoupis, C., D. Pancheva, and N. J. Mitchell, 2004, A study of tidal and planetary wave periodicities present in midlatitude sporadic E layers, J. Geophys. Res., 109, A02302, doi:10.1029/2003JA010253.

Lieberman, R.S., and D. Riggin, 1997, High resolution Doppler imager observations of Kelvin waves in the equatorial mesosphere and lower thermosphere, *J. geophys. Res.*, 102 (D22), 26117-26130.

Miyoshi, Y. and Fujiwara, H., 2006, Excitation mechanism of intraseasonal oscillation in the equatorial mesosphere and lower thermosphere, J. Geophys. Res., 111*, D14108*, doi:101029/2005JD006993.

Pancheva, D. and I. Lysenko, 1988, Quasi-two-day fluctuations observed in the summer F region electron maximum, Bulgarian Geophys*. J., XIV*, 2.

Pancheva, D., N. J. Mitchell, and P. T. Younger, 2004, Meteor radar observations of atmospheric waves in the equatorial mesosphere/lower thermosphere over Ascension Island, Ann. Geophyscae, 2004 (22), 387-404.

Russell, J. M., Mlynczak, M. G., Gordley, L. L., Tansock, J., Esplin, R., 1999, An overview of the SABER experiment and preliminary calibration results, Proceedings of the SPIE, 44th Annual Meeting*,* Denver, Colorado, July 18– 23 , V. 3756, p. 277– 288.

Salby, M.L., Hartmann, D.L., Bailey, P.L. and Gille, J.C., 1984, Evidence for equatorial Kelvin modes in Nimbus-7 LIMS, J. Atmos. Sci., 41 *(2),* 220-235.

Takahashi, H., C. M. Wrasse, D. Pancheva, M. A. Abdu, I. S. Batista, L. M. Lima, P. P. Batista, B. R. Clemesha, K. Shiokawa, 2006, Signatures of 3-6 day planetary waves in the equatorial mesosphere and ionosphere, Ann. Geophys., 24 *(12),* 3343-3350.

Vincent, R.A., 1993, Long-period motions in the equatorial mesosphere*, J. Atmos. Terr. Phys., 55*, 1067-1080.