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Long-term variability in the mesospheric tidal winds observed by MF radar over Tirunelveli (8.7°N, 77.8°E)

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Abstract. Observations of mesospheric tidal winds in the 84-98 km height range over a period of five years with the MF radar at Tirunelveli (8.7°N, 77.8°E), India, are presented in this study. The emphasis is on describing the long-term variability in the tidal amplitudes. The results reported herein clearly indicate pronounced interannual variability in the tidal activity, and strengthen the earlier suggestion that this feature is linked to the stratospheric quasi-biennial oscillation (QBO).

Introduction

Atmospheric tides are one of the important means of transferring energy and momentum between different regions of the atmosphere. Tidal perturbations, generated in the lower and middle atmosphere, grow in amplitude as they propagate upwards, and participate in governing the heat and momentum budgets of the upper atmosphere [*Hines*, 1965]. Following the classical tidal theory by *Chapman and Lindzen* [1970], several theoretical calculations have been made in order to understand fully the propagation characteristics of the tides, their interactions with the background atmosphere, and their effects on the mesosphere and above [*Forbes and Garrett*, 1979; *Forbes*, 1982a, b; *Vial*, 1986; *Vial and Forbes*, 1989; *Hagan et al.*, 1995; to state a few]. Observational aspects of migrating tides have been reasonably covered by several studies using ground-based techniques [*Tsuda et al.*, 1983; *Vincent et al.*, 1988; *Manson et al.*, 1989; *Fritts and Isler*, 1994; *Chang and Avery*, 1997; *Raghava Reddi and Geetha Ramkumar*, 1997; to state a few] and satellite remote sensing [*Hays et al.*, 1994; *Burrage et al.*, 1995; *McLandress et al.*, 1996].

The experimental studies in the past brought out significant variabilities in the mesospheric tidal parameters over different timescales [*Vincent et al.*, 1998, and references therein], the principal among them being the semiannual timescale [*Burrage et al.*, 1995, for a more recent work]. *Vincent et al.* [1988] first noted variability in mesospheric tides over the interannual timescale with simultaneous radar observations from Adelaide and Kyoto. *Fritts and Isler* [1994] noted interannual variability over Kauai, a low latitude site, in the months of October and November. *Burrage et al.* [1995] reported interannual varibility in the amplitude of the (1,1) diurnal tide from observations of the mesosphere and lower thermosphere obtained by the High Resolution Doppler Imager on the Upper Atmosphere Research Satellite (UARS). The amplitudes were observed to change by nearly a factor of 2 over this timescale. Recently, *Vincent et al.* [1998] made a detailed study on the interannual variability in mesospheric tides from a comprehensive set of simultaneous radar observations over three equatorial and subtropical sites.

The long-term MF radar observations of mesospheric tidal winds made from the low latitude site, Tirunelveli (8.7°N, 77.8°E), India, are reported in the present work. The emphasis in the present study has been to examine the interannual variability in the observed tidal parameters. The seasonal varibilities in the vertical structure of tidal parameters are first examined, and the extent of interannual variability is noted. The long-term variability in the tidal amplitudes at 86 km is then examined, and the near-biennial variation in the amplitudes, which is pronounced in the zonal wind, is brought out. The results and the subsequent discussion presented herein support the earlier suggestion of *Vincent et al.* [1998] that the diurnal tide is linked to the equatorial QBO.

Observations

The wind data utilised in the present study were acquired by the spaced antenna MF radar operated at Tirunelveli. The system details, mode of operation and the method of wind determination, are the same as described by *Vincent and Lesicar* [1991]. Hourly values were obtained for each height in the sampling region (70-98 km) which were then examined for meaningful statistics before subjecting the data to further analysis [*Rajaram and Gurubaran*, 1998]. The data base available for the years 1993-1997 was used for the present work. The data acceptance rate, determined by the rejection criteria adopted in the method of wind determination, is quite low for altitudes below 84 km during nighttime. For this reason, wind measurements utilised for determining the tidal parameters are restricted to altitudes above 84 km. Some of the instrumental limitations, primarily the poor receiver signal strengths during nighttime, do not arise for the altitude region under consideration.

Results

The tidal parameters, namely, the amplitude and phase of the diurnal tide in zonal and meridional winds, over Tirunelveli, for different seasons and for the years 1993-1997, are depicted in Figs. 1 and 2. The amplitudes, in general, tend to show a minimum around 92 km and an increase with altitude above. As the scales indicate, the tidal amplitude in the meridional wind is always larger than the amplitude in the

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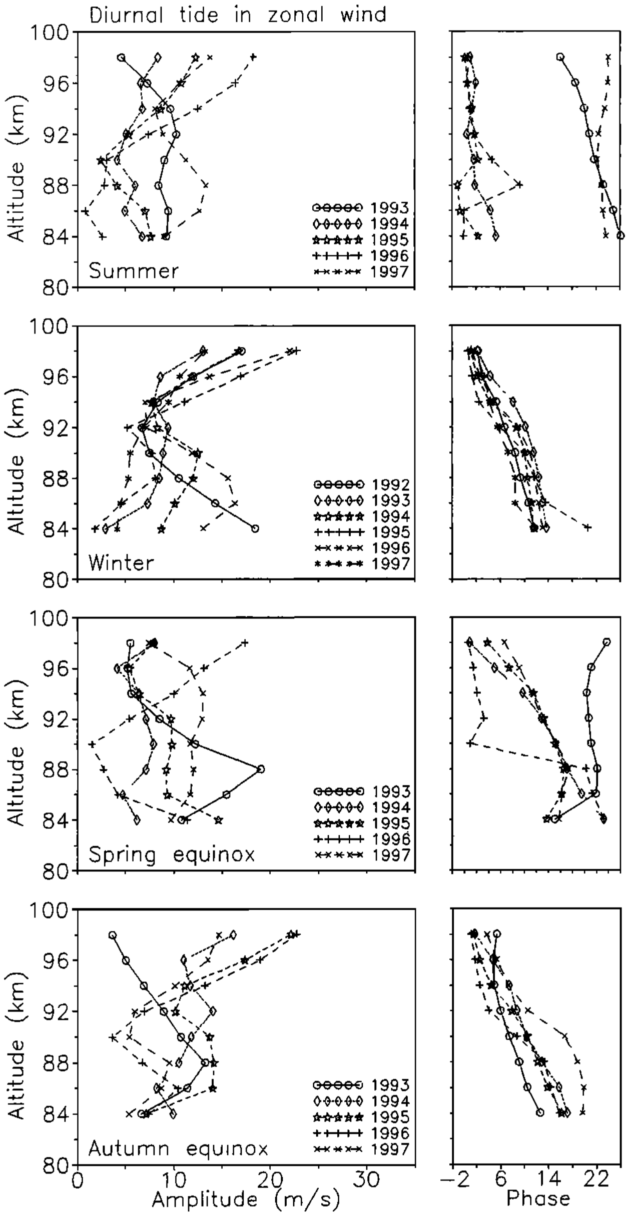

Figure 1. Altitude profiles of diurnal tide amplitude (zonal wind) over Tirunelveli for all seasons.

zonal wind. Largest amplitudes of ~ 30 m/s were observed in the meridional wind at 98 km during the spring and autumn equinoxes of 1995. The diurnal tide amplitude in the zonal wind increases above 92 km for all years during winter, summer and autumn equinox. In the latter two seasons, the amplitude decreases above 92 km in 1993. No systematic pattern in the profile is noticed in all spring equinoxes. The phase profiles reveal larger vertical wavelength (> 50 km) during summer when compared to other seasons.

The diurnal tide in the meridional wind reveals a greater variability during winter and the equinoxes. The interannual variability has been largest during autumn equinox in the years 1995 and 1996. The amplitude is reduced to a factor of 4 from 1995 to 1996. There is a factor of 2 increase from 1994 to 1995 at 94 km. The phase profiles reveal vertical wavelengths in the range 40-50 km.

In order to obtain a better representation of interannual variability, the tidal amplitudes at 86 km corresponding to 30-day mean winds are plotted at 15-day sliding intervals for every year in Figs. 3 and 4. The diurnal tide activity in the zonal wind depicted in Fig. 3 has been enhanced during the month of June in alternate years, namely, 1993, 1995 and 1997. The amplitudes are much smaller during 1994 and 1996. During the later half of 1994 and 1996, the diurnal tide gained strength, whereas during 1995 and 1997 it weakened. The phases in all years advance to later hours as the summer is approached, after which there is a slow recovery to their initial values.

The diurnal tide in the meridional wind at 86 km, depicted in Fig. 4, is least active during the winter solstice. For the years 1993 and 1995, larger amplitudes (~ 25 m/s) were observed in February, May, August, September and October. The amplitudes for the year 1997 were larger (20-35 m/s) than those for the other years in all months from January to July. The amplitudes were least (5-12 m/s) almost all through the year, 1996. The amplitude curve for 1994 tends to follow the 1995 curve except for enhanced activity during May and

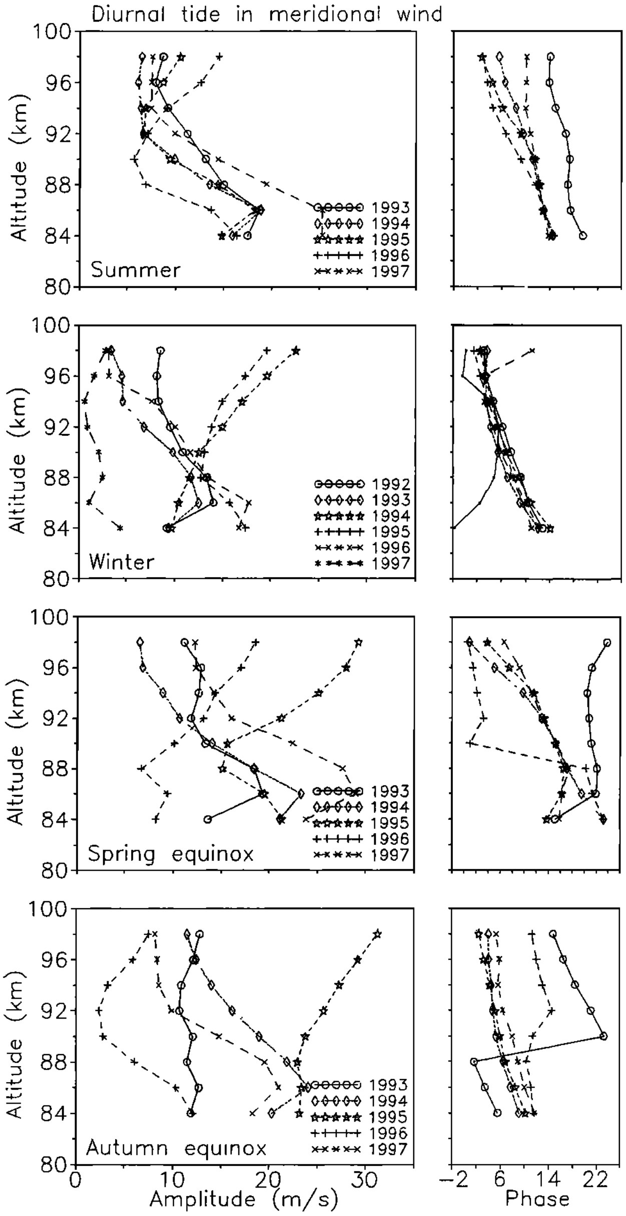

Figure 2. Same as in Fig. 1 but for meridional wind.

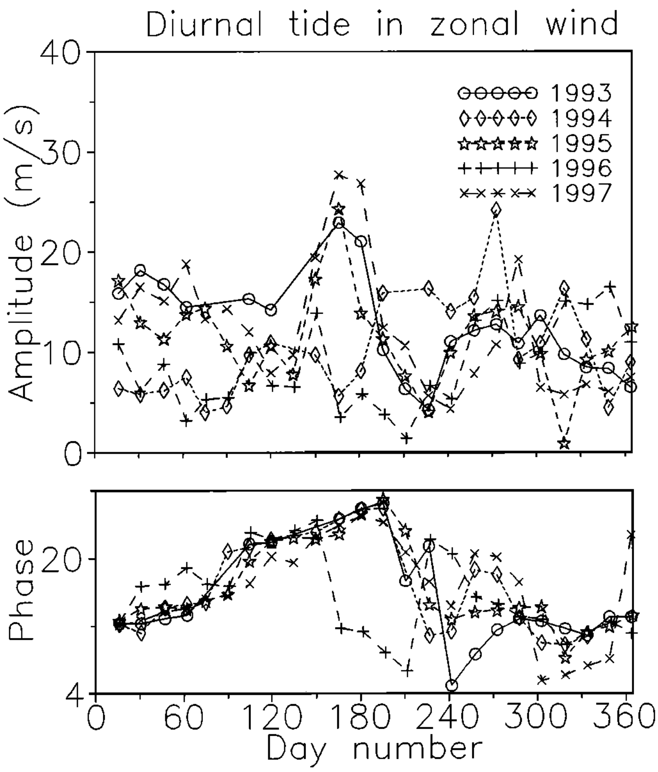

Figure 3. Temporal variation of diurnal tide amplitude and phase for the zonal wind presented yearwise.

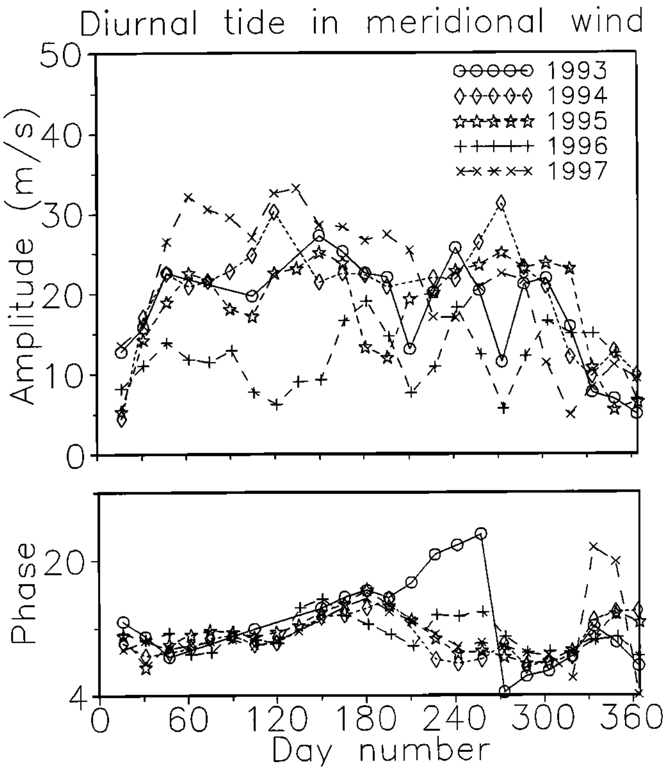

Figure 4. Same as in Fig. 3 but for meridional wind.

September. The phases had undergone similar variations in all years except for short durations in 1993, 1996 and 1997. The phase advances to later hours near the summer solstice, after which the phase retards.

In Fig. 5 the time series for the amplitude of the diurnal tide in the zonal wind is depicted representing the entire course of observations. The continuous curve is the result of an eighth order polynomial fit to the observed tidal amplitudes. The near-biennial variation is clearly present in the tidal activity. Amplitude minima are noticed in the beginning of 1994 and 1996, and near the end of 1997. Bursts of activity (amplitude of ~ 25 m/s) are observed during the month of June in 1993, 1995 and 1997.

Discussion

Using five years of mesospheric tidal observations, the long-term variability of tidal amplitudes and phases has been studied in detail, and some of the results are presented in this paper. The observed seasonal variabilities are rather complex, with largest amplitudes in the zonal wind appearing in June every alternate year. The diurnal tide in the meridional wind is characterised by minima in the winter solstices and intermittent maxima during rest of the seasons. The meridional wind component is almost always advanced in phase when compared to the zonal wind component as might be expected for a northern hemisphere site. The noticeable feature in the observations is the interannual variability in the tidal amplitudes which is pronounced in the zonal wind component, though this feature is observed in the meridional wind component also during the later half of the observation sequence.

The interannual variability in mesospheric tides reported in the present work has been studied with limited base earlier [*Vincent et al.*, 1988; *Fritts and Isler*, 1994; *Burrage et al.*, 1995] and quite extensively with a wider data base recently [*Vincent et al.*, 1998]. The 12-year data sequence from Adelaide revealed an approximately biennial variation in the amplitude of the diurnal tide. This feature was, however, observed only in March and April. *Vincent et al.* [1998] used 30 hPa wind data derived from Singapore radiosonde observations. When the QBO winds were eastward, the diurnal amplitudes in March/April were always larger than

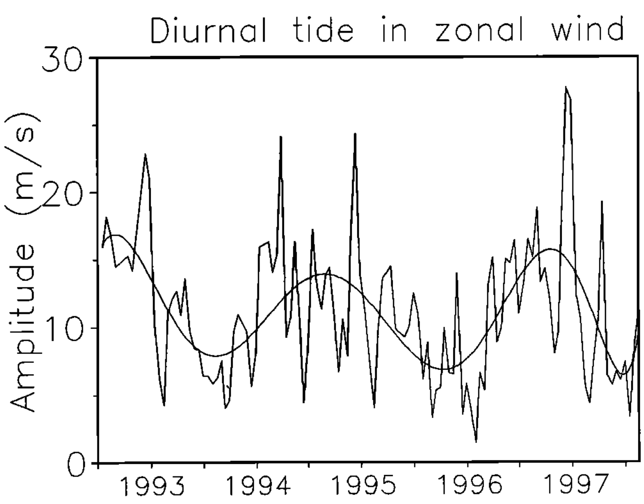

Figure 5. Temporal variation of diurnal tide amplitude (zonal wind) representing the entire sequence of observations (1993-1997). The continuous curve is the result of an eighth order polynomial fit to the observed points.

the 12-year average values, and in years of westward phase of the QBO the amplitudes were almost always smaller than the long-term average. This tendency was found to occur during the time of minimum amplitudes also. At Christmas Island, the zonal wind component was found to have such an association with the QBO in the stratospheric winds.

It may be noted that the zonal winds during 1993, 1995 and 1997, are characterised by pronounced westward maxima during the spring equinoxes, the semi-annual oscillation undergoing QBO variations [*Rajaram and Gurubaran*, 1998]. This is believed to be associated with the stratospheric QBO, the phases of the stratospheric and mesospheric mean zonal wind always being opposite [*Burrage et al.*, 1996]. Selective filtering of small-scale gravity waves by the underlying winds in the stratosphere has been shown to be the cause for the QBO variations in the mesospheric flow. Since the QBO variations in the mean zonal motion and the tidal activity are in phase, the suggestion by *Vincent et al.* [1998] that they are related is strengthened by the results reported in the present work. The principal agencies in producing the QBO effect on the tidal activity appear to be the variabilities associated with the tidal forcing and the interaction with the stratospheric winds. Gravity wave-tidal interactions may also be expected to contribute to the observed interannual variability. More long-term measurements from a set of widely spaced stations would help in understanding the causes for many of the observed tidal variabilities. Colloborative efforts under international programs like PSMOS (Planetary Scale Mesopause Observing System) and EPIC (Equatorial Processes Including Coupling), would yield valuable contribution to our current understanding of global scale tides and their influences on many of the ionospheric phenomena.

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