A comparative study of winds and tidal variability in the mesosphere/lower-thermosphere region over Bulgaria and the UK

D. Pancheva¹,², P. Mukhtarov¹, N. J. Mitchell³, A. G. Beard³, H. G. Muller³

¹ Geophysical Institute, Bulgarian Academy of Sciences, 1113 Sofia, Bulgaria
² The Department of Physics, The University of Wales, Aberystwyth, SY23 3BZ, UK
³ The University of Cranfield, The Royal Military College of Science, Shrivenham, Swindon, SN6 8LA, UK

Received: 17 January 2000 / Revised: 14 April 2000 / Accepted: 10 May 2000

Abstract. Meteor radars located in Bulgaria and the UK have been used to simultaneously measure winds in the mesosphere/lower-thermosphere region near 42.5°N, 26.6°E and 54.5°N, 3.9°W, respectively, over the period January 1991 to June 1992. The data have been used to investigate planetary waves and diurnal and semidiurnal tidal variability over the two sites. The tidal amplitudes at each site exhibit fluctuations as large as 300% on time scales from a few days to the intra-seasonal, with most of the variability being at intra-seasonal scales. Spectral and cross-wavelet analysis reveals closely related tidal variability over the two sites, indicating that the variability occurs on spatial scales large compared to the spacing between the two radars. In some, but not all, cases, periodic variability of tidal amplitudes is associated with simultaneously present planetary waves of similar period, suggesting the variability is a consequence of non-linear interaction. Calculation of the zonal wave number of a number of large amplitude planetary waves suggests that during summer 1991 the 2-day wave had a zonal wave number of 3, but that during January–February 1991 it had a zonal wave number of 4.

Key words: Meteorology and atmospheric dynamics (middle atmosphere dynamics; waves and tides)

1 Introduction

Over the last two decades, ground-based measurements of winds made by radar systems have proved to be a powerful tool in studies of the dynamics of the mesosphere/lower-thermosphere (MLT) region. An increasing element of such work has been co-ordinated studies that combine measurements made by radars at different geographical locations to investigate the spatial and temporal structure and variability of winds, waves and tides. A series of international campaigns such as the Dynamic Adapted Network (DYANA), the Mesosphere Lower Thermosphere Coupling Study (MLTCS) and the Planetary Scale Mesopause Observing System (PSMOS) have revealed that significant temporal variability occurs on short-term, intra-seasonal, seasonal and inter-annual time scales. Significant spatial variability with latitude, longitude and hemisphere is also apparent. These studies have generally involved observational campaigns of about 10 days to three months in duration.

For example, Singer et al. (1994) examined data from 14 radars recorded during the DYANA campaign of January 15 to March 15, 1990 and reported clear longitudinal differences between the prevailing winds over Canada, Central Europe, Eastern Europe and Asia. These authors also noted a close connection between the circulation of the stratosphere and the observed longitudinal structure in the MLT-region response to stratospheric warming events. An apparently related increase in MLT-region wave activity at wave periods of 8–15 days was also noted. A similar connection with stratospheric processes was noted by Pancheva and Mukhtarov (1994), who related wave activity at MLT heights to the presence of a strongly amplified planetary wave number 1 at the 30 hPa pressure level during the winter 1991/1992. Portnyagin et al. (1994) also examined the DYANA campaign data used by Singer et al. (1994) and concluded that the significant differences observed between monthly mean tidal parameters measured by the various radars could be explained by latitudinal and longitudinal structure in the tidal wind fields. In addition, well-defined fluctuations in tidal parameters over periods of 2–3 weeks were found to be typical of all the observational sites.

Characterising the global structure of the MLT-region tidal and planetary wave fields has also been a prime objective of the MLTCS programme (e.g.
Forbes, 1990; Manson et al., 1994; Deng et al., 1997), and as part of MLTCS a series of 10-day global observational campaigns have been conducted to study MLT-region coupling processes involving tides and planetary waves.

In this work, we consider the variability of winds and tides measured by two, very similar, meteor radars recording MLT-region winds; one sited near Yambol, Bulgaria and recording winds near (42.5°N, 26.6°E) and the other sited near Sheffield in the UK and recording winds near (54.5°N, 3.9°W). A detailed statistical study of the variability of tides over the UK has been presented elsewhere (Beard et al., 1999b), and so the focus of the work presented here is not to investigate tidal variability over each station in isolation, but rather to investigate the degree to which the variability over each station is correlated. In other words, we seek to assess some simple measure of the spatial coherence of the tidal variability occurring over both stations.

The data are for the 18-month interval January 1991 to June 1992. The similarity in the two radars’ modes of operation greatly reduces any biases that might otherwise complicate inter-comparisons between the two data sets. We therefore will make direct, statistical comparisons involving observations over the entire 18 months for which data are available from both radars. Such long-term studies provide a valuable complement to the results of short-term observational campaigns of the type discussed already.

The data used in this study covered areas of the northwestern and southeastern parts of Europe. The 30.5° longitudinal difference between the stations allows some investigation of the zonal wave numbers of planetary waves and the longitudinally dependent, long-term dynamical processes associated with stratospheric warmings and/or equinoctial transitions.

Three particular topics are addressed in this work. In Sect. 3.1 the longer-term seasonal and intra-seasonal variations in the background wind and tides are considered. In Sect. 3.2, the shorter-term, day-to-day variability of tides in particular is considered. This latter variability is now believed to include a substantial contribution that arises from a non-linear interaction between tides with planetary waves. In this process, which appears to function most conspicuously with the semidiurnal tide, a non-linear interaction generates a family of “secondary waves”, some of which have frequencies equal to the sum and difference of the frequencies of the planetary wave and tide (Teitelbaum and Vial, 1991). Because planetary waves have much lower frequencies than the tides, these secondary waves have frequencies near tidal frequencies and may beat with the tide, modulating the tidal amplitude at the planetary-wave period (e.g. Teitelbaum and Vial, 1991; Rüster 1992, 1994; Mitchell et al., 1996; Clark and Bergin, 1997; Kamalabadi et al., 1997; Beard et al., 1999a; Pancheva, 2000). Other studies have recently suggested that similar interactions may also occur between different members of the planetary-wave field (Jacobi et al., 1998; Pancheva et al., 2000). Finally, in Sect. 3.3 the zonal wavenumbers of some of the larger amplitude planetary waves observed are determined.

2 Measurements and data analysis

The meteor radar at Yambol operated at 27.7 MHz with a pulse repetition frequency of 100 Hz, and a peak power of about 10 kW. The radar operated without height finding and so provided a measure of winds across the meteor region with a weighting reflecting the distribution of meteor counts, which is believed to be strongly peaked at a height near 90 km. The winds derived from such systems are thus usually taken to represent an average over perhaps 6–10 km centred on this height. The measurements were obtained by sounding simultaneously in four geographical directions, however because of disturbances in two of them (east and north) during most of the day-time after April 1991, only the measurements of the western and southern antennae were used in processing and analysing the data. This fact is a reason why the level of noise for the measurements after April 1991 is higher than the previous ones when the north and south measurements were averaged together to produce a single data set corresponding to the meridional component of the neutral wind and similarly, the east and west measurements produce a single zonal component. The measurements of individual meteor drift velocities were averaged to produce hourly estimates of horizontal zonal and meridional winds. The main features of the monthly mean wind regime in the MLT region above Bulgaria have been described by Pancheva and Mukhtarov (1994, 1996).

The VHF meteor radar located near Sheffield operated at 36.3 MHz with a pulse repetition frequency of 300 Hz and a peak power of about 10 kW. The transmitted power was directed NW and SW in two narrow low-elevation beams. No height determination was employed during the time considered in this work. The hourly values of zonal and meridional velocities are obtained by the simple procedure described by Beard et al. (1999a).

The time series of hourly zonal and meridional winds from each radar were then subjected to a common analysis. For each 24-h section of data, a least squares best-fit analysis determined the amplitude and phase of the 8-, 12- and 24-h tides and mean wind. The derived characteristics are assigned to the centre of the section of data. No fit was attempted if less that 16 h of data were present in any 24-h segment. Then the 24-h segment was incremented in one-hour steps through each time series producing hourly estimates of these quantities. To estimate the confidence intervals we assume that the residual error can be described as Gaussian white noise and then the Student t-test is used to estimate the confidence intervals. This procedure is described in detail by Mukhtarov and Pancheva (1993). To obtain the hourly values of the tidal characteristics and prevailing wind we usually have to cope with the problem of filling the gaps. When the length of the