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First results of meteor radar lower thermosphere wind measurements at Dixon, Arctic (73.5°N, 80°E)

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Abstract: Results of simultaneous wind measurements by the identical meteor radars at Dixon (73.5°N, 80°E) and Obninsk (55°N, 37°E) are presented for the time interval from November 12, 1999 to July 31, 2000. A number of features were observed which require comprehensive investigation on the basis of long-term wind measurements in the high-latitude lower thermosphere. The observed semidiurnal tide phases at Dixon are close to those published for Tromsø, providing some evidence for predominance of the migrating semidiurnal tide for semidiurnal oscillations at this latitude. Highly coherent oscillations in tidal amplitudes and prevailing winds were also revealed, as well as time intervals with non-significant semidiurnal tide during which oscillations with periods different from but close to 12 h were observed.

1. Introduction

There have been significant advances in our understanding of the mesosphere/lower thermosphere (MLT) dynamics over the last 20 years. However, most of these advances pertain to the middle and low latitudes where a vast majority of ground-based instruments have been deployed. Satellite observations (*e.g.* NIMBUS, UARS) have provided significant information about the global structure of the MLT winds. But these measurements are also confined to middle and low latitudes due to the orbital inclination of these satellites. While there have been regular MLT wind measurements in the Antarctic, including the unique meteor radar wind measurements at the Amundsen Scott station (South Pole), there is a dearth of wind measurements in the Arctic MLT region. The first MLT meteor radar wind measurements in the Arctic were carried out at Heiss Island (80.5°N, 58°E) during 1965–1985 (Portnyagin *et al.*, 1993a, b). MLT wind measurements in the Arctic were also carried out in 1967–1968 at College (65°N, 148°W; Hook, 1970), during 1974–1975 at Kiruna (68°N, 20°E; Massebeuf *et al.*, 1979), at Poker Flat (65°N, 147°W) in 1980–1984 (Avery *et al.*, 1989), and at Tromsø (70°N, 19°E) during 1987–1989. Avery *et al.* (1989) summarized what was known about the high-latitude MLT wind climatology based on wind measurements by radars, and further discussion of radar-based MLT Arctic dynamics was provided by Manson and Meek (1991) and Portnyagin *et al.* (1993a, b). Fraser *et al.* (1995) compared diurnal wind oscillations from several Arctic and Antarctic radar stations. New measurements of the Arctic wind circulation continue to be accumulated at a few of the above polar sites. Unfortunately the data have not been published by the time of the present work. Comprehensive comparisons of the new measurement data sets from the different sites are planned for the future.

New results on Arctic MLT dynamics have also been obtained through OH measurements of temperature. First of all, it seems to be well established that unusually large semidiurnal temperature variations exist near 78°N during winter (Myrabø, 1984; Walterscheid *et al.*, 1986). Since the observed temperature amplitudes of order 5–15 K are far larger than anticipated for the migrating semidiurnal tide (Forbes, 1982), Walterscheid *et al.* (1986) suggest that these oscillations might result from a pseudotide generated by gravity wave momentum fluxes modulated by the solar semidiurnal tide. It is also possible that they are connected with non-migrating tides without the major influence of gravity wave interactions. There also exist several measurements of a large terdiurnal (8-hour) oscillation (Oznovich *et al.*, 1995, 1997) at 80°N (Eureka Station); in at least one instance this oscillation is interpreted by the authors to be a zonally-symmetric tide. In addition, interannual aspects of the quasi-16-day oscillation in mesopause-region temperature were discussed by Espy *et al.* (1997).

Based upon the above collection of works we know that the main features of the MLT dynamics in polar region to have some similarities with, as well as significant differences from, those observed in the mid-latitude MLT region. And, while the above measurements and analyses have provided a significant enhancement to our basic understanding of the polar MLT dynamics, there is a consensus that much remains to be learned. In particular, there is serious lack of information about the main features of the day-to-day variability of the main Arctic MLT wind regime parameters and their global structure for different seasons. To investigate inter- and intra-diurnal wind variations in the high-latitude MLT region, the meteor radar COBRA-1 (Colorado-OBninsk-RAdar), which has been designed and built by collaborative efforts of the University of Colorado (USA) and Institute for Experimental Meteorology (Russia), was installed at Dixon (72°N, 80°E, Russian Arctic) in September 1999. This radar has operated practically continuously since November 1999. In this paper we present the first results of the analysis of winds measured at Dixon for the period from November 12, 1999 to July 31, 2000. We also compare the Dixon measurements with earlier Arctic data as well as simultaneous mid-latitude wind data which were obtained with the identical meteor radar COBRA-1 installed in Obninsk (55°N, 37°E, Russia). Diurnal tides are not included within the scope of this paper due to the large variability of these oscillations that need to be considered comprehensively in relation to numerical simulation results.

2. COBRA-1 meteor radar system

The COBRA-1 meteor radar system is a quasi all-sky VHF system that utilizes four Yagi T/R antennae pointed north, south, east and west. Each of these antenna are located a half wavelength above ground. This orientation puts the direction of maximum radiation at an approximate elevation angle of 30 degrees. With a custom designed antenna switch we can switch between antenna directions on a pulse-to-pulse basis. Using this feature the radar is operated in two specific modes, the "search" and "acquisition" modes. In search mode an RF pulse is transmitted in one direction; if a meteor echo is not detected in this direction then the system changes to the next antenna direction in the sequence until a meteor is detected. Once a meteor is detected the system stops switching directions and transmits pulses continuously in the direction where the echo was detected. This occurs until the echo power drops below a specified threshold and then the system returns to search mode. The advantage of this system over the conventional all-sky meteor radar system is that by using an Yagi antenna we can increase our power aperture product and by multiplexing the antennae we can cover most of the sky. Because meteor echoes are sporadic very few echoes are lost due to this multiplexing operation and we can see more echoes than a similarly powered all-sky system because of our increased power aperture product.

The COBRA-1 meteor radar system located in Obninsk operates at 33 MHz and the radar located at Dixon Island operates at 33.6 MHz. Each radar utilizes four 5-element Yagi T/R antennas with half-power fullwidth beam in the azimuthal direction of 60 degrees. The systems utilize a 100 μs wide pulse at a pulse repetition rate of 100 Hz in search mode and 300 Hz in acquisition mode. The peak RF power for these systems is 10 kW. Using a pulse width of 100 μs provides a range resolution of 15 km; therefore the data from these systems are all assigned to a nominal altitude of about 90 km–92 km. The effect of this assumption is minimal for waves with vertical wavelengths longer than 20 km (Palo *et al.*, 1998). At high latitudes there is also the possibility of auroral interference. Because auroral and meteor signals have significantly different spectral and temporal characteristics, there are procedures present in our processing that remove auroral contamination from our data.

3. Data analysis and results

The individual sporadic meteor wind velocities were averaged to obtain the hourly mean data for zonal and meridional wind components (positive wind directions are eastward and northward). Then, by applying a 1-hour step sliding harmonic analysis for basic intervals of 48 h, the parameters of mean winds and amplitudes and phases of the 48 h, 24 h, 12 h and 8 h tidal harmonics were found. The monthly vector-average values of these parameters were then calculated. To study non-stationary day-to-day wind variations we used the S-transform analysis (Stockwell *et al.*, 1996). Prior to analysis the data were interpolated (to fill some technical gaps in the data) and detrended for each time interval under investigation.

Figure 1 shows the seasonal variations of monthly mean values of the prevailing wind and semidiurnal tide parameters at Dixon during the period from November 1999 to July 2000. Vertical bars designate the double rms errors obtained for the parameters of the Dixon winds. For comparison the corresponding monthly mean values according to the measurement results at Tromsø (MF radar) during the period 1987–1989 are also shown in this figure. The Tromsø data are adapted from Fig. 2 and Fig. 4 of Manson and Meek (1991). As can be easily seen from Fig. 1a, in spite of the differences in the measurement techniques and the non-coincident observational periods, during practically all of the months the zonal prevailing winds at both observational sites

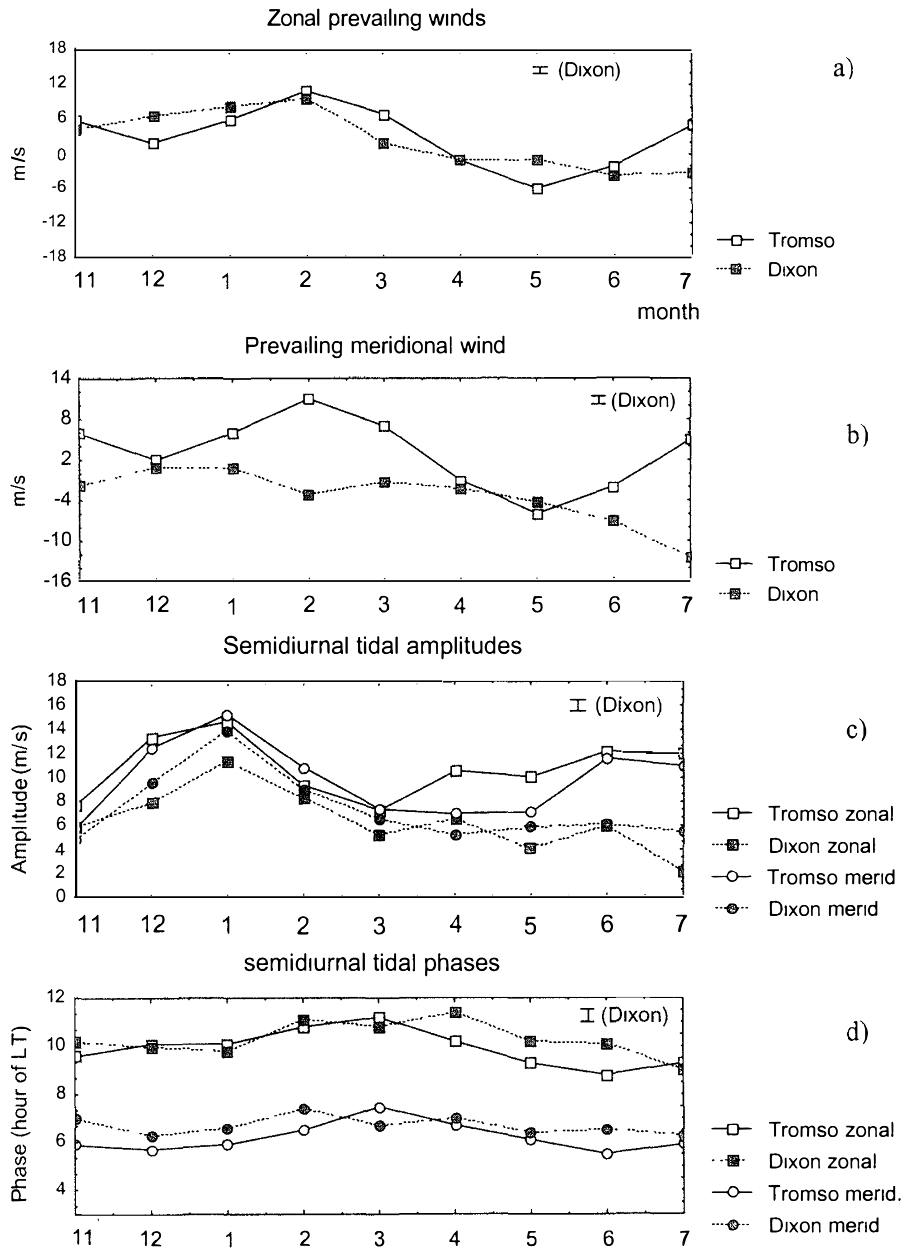

Fig. 1. Seasonal variations of prevailing and semidiurnal tidal winds at Tromsø (1987–1989) and Dixon (November 1999–July 2000).

demonstrate remarkably similar seasonal behavior. The sign of the zonal wind is only different for Dixon and Tromsø in July. The meridional prevailing wind (Fig. 1b) shows different seasonal variations for Dixon and Tromsø both in strength and in sign, thus indicating the possible existing of the longitudinal dependence of the summer MLT Arctic dynamics. Also this may be a result of the observations by the different techniques and for the different years.

The amplitudes of the semidiurnal wind variations for Dixon are generally smaller than that for Tromsø (Fig. 1c). However, the tendency for higher amplitudes in the winter season for the both sites is obvious. The absence of significant differences between the phases in local time for Dixon and Tromsø (Fig. 1d) may be interpreted as

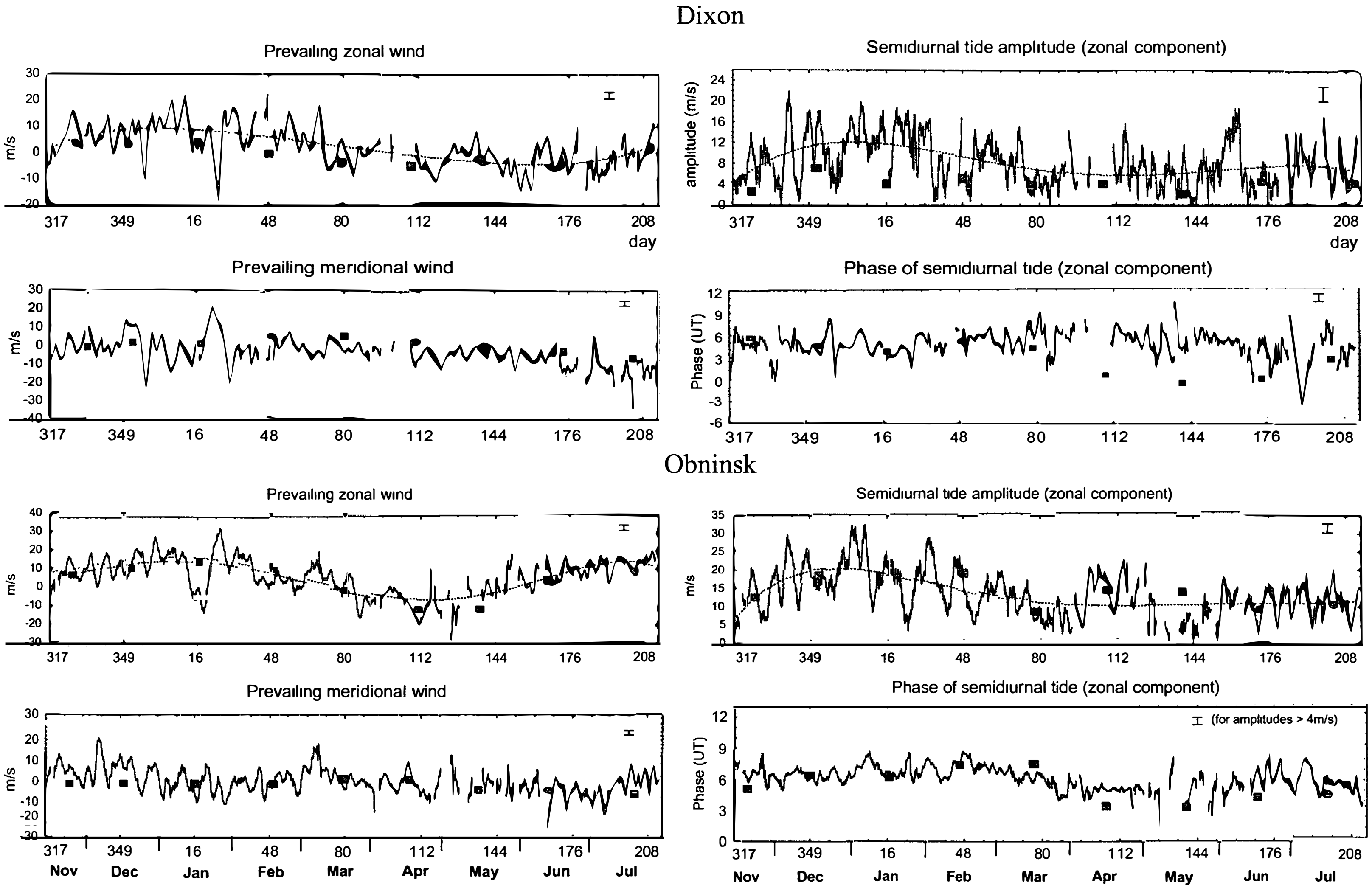

Fig. 2. Prevailing winds and semidiurnal tide parameters measured from November 13, 1999 at Obninsk and Dixon and compared with global semi-empirical models (solid squares). Thin curves present a least squares fit of the data by a 4-degree polynomial. The phases are in hours of UT.

a possible indication that the semidiurnal MLT wind variations at about 70°N are dominated by the migrating semidiurnal tide with the zonal wave number $s=2$. However, there are significant longitude differences in amplitude during some months, and moreover, it is possible that larger longitudinal variations in amplitude and phase exist outside the 19°E–80°E sector. Additional ground-based and/or satellite based measurements are needed to resolve this issue.

Figure 2 presents the series of the prevailing winds and the semidiurnal tides obtained from the harmonic analysis. Days are numbered from January 1 and the time is UT. Vertical bars designate the rms error of values presented in the figures. Additionally we show (with dark squares) the data from Global Empirical Wind Model (GEWM) of Portnyagin and Solovjova (2000) and the data from Empirical Semidiurnal Migrating Tide Model of Portnyagin and Solovjova (1998) for 72.5°N and 55°N of latitude. It is seen that the long-term trends of the prevailing zonal winds for Obninsk and Dixon are similar and each of them agrees with the GEWM. The Dixon prevailing zonal wind is slightly larger than the model prediction. For the semidiurnal tide the current version of the model gives significantly smaller values of the amplitudes than those measured at Dixon and properly reflects only the course of the phases at this site. Another well-expressed feature in Fig. 2 is the modulation of the semidiurnal tide amplitudes and phases. The modulation for Dixon is deeper than that for Obninsk, especially with regard to the phase. Namely the tidal amplitude at Dixon frequently decreases to values near zero, and the variations of phase have greater amplitude at Dixon than at Obninsk. Although the long-term trends of the semidiurnal tide amplitudes are similar for Obninsk and Dixon, the trends of the phases are different. This implies a transition to different tidal modes for Obninsk and Dixon after spring zonal wind reversal.

We can point out five common time intervals in relation to the prevailing zonal wind variations: 1.—before the stratospheric warming: from Day 316 (November 12, 1999) to Day 11; 2.—from Day 11 to Day 28, the stratospheric warming; 3.—till Day 87, it is after the warming and before the zonal wind reversal in spring 2000; 4.—time period with the zonal wind reversal; and 5.—summer months (June and July). During time interval 4 the Obninsk wind data contain a large number of gaps and below we will consider in detail only the time intervals 1–3 and 5.

In Fig. 3 S-transform spectrograms of the prevailing winds and the semidiurnal tides are shown. Days are numbered from 1 January. Right panels on the figure present squared amplitudes of oscillations in m^2/s^2. A marked feature of time interval 1 is the wave with period of 7 days. The oscillation is observed both in the prevailing winds and in the semidiurnal tide amplitudes except for the Dixon meridional prevailing wind. At the same time in the meridional prevailing winds at both stations there are 10–15 day oscillations. To further analyze the 7-day oscillations we will use the data before day number 357. The correlation between the zonal prevailing wind at Obninsk and that at Dixon is about 0.66 (at the confidence level 95% and at the lag of about 6 days) and between the meridional prevailing wind at Obninsk and the one at Dixon it is about 0.48 (non-significant). For the semidiurnal tide amplitudes the maximum value of the correlation is about 0.6 (at the confidence level 95% and at a lag of about 1.5 days) for both components.

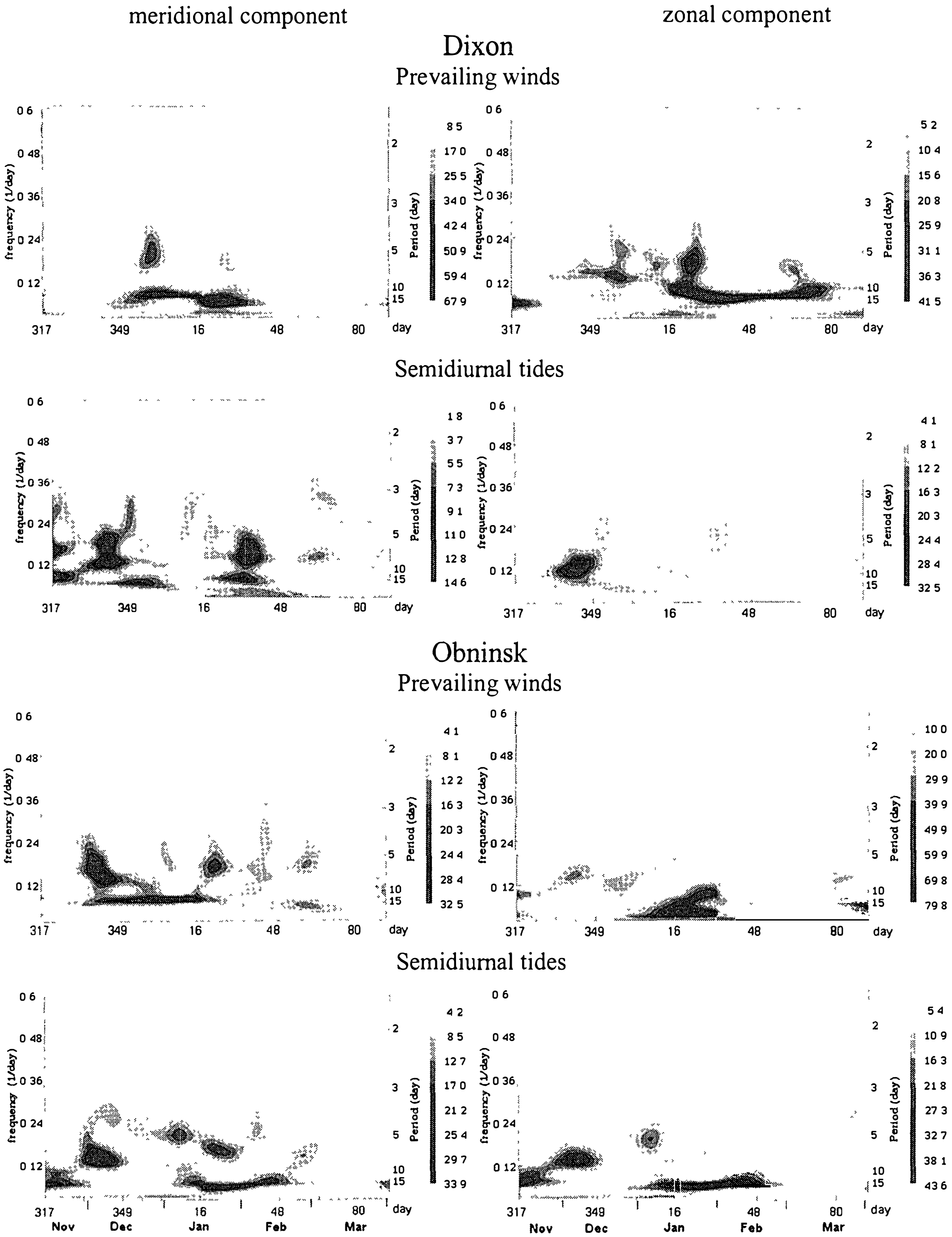

Fig. 3. S-transform spectrograms of prevailing winds and semidiurnal tide amplitudes obtained from November 13, 1999. Right scales present squared amplitudes in m^2/s^2 for each picture.

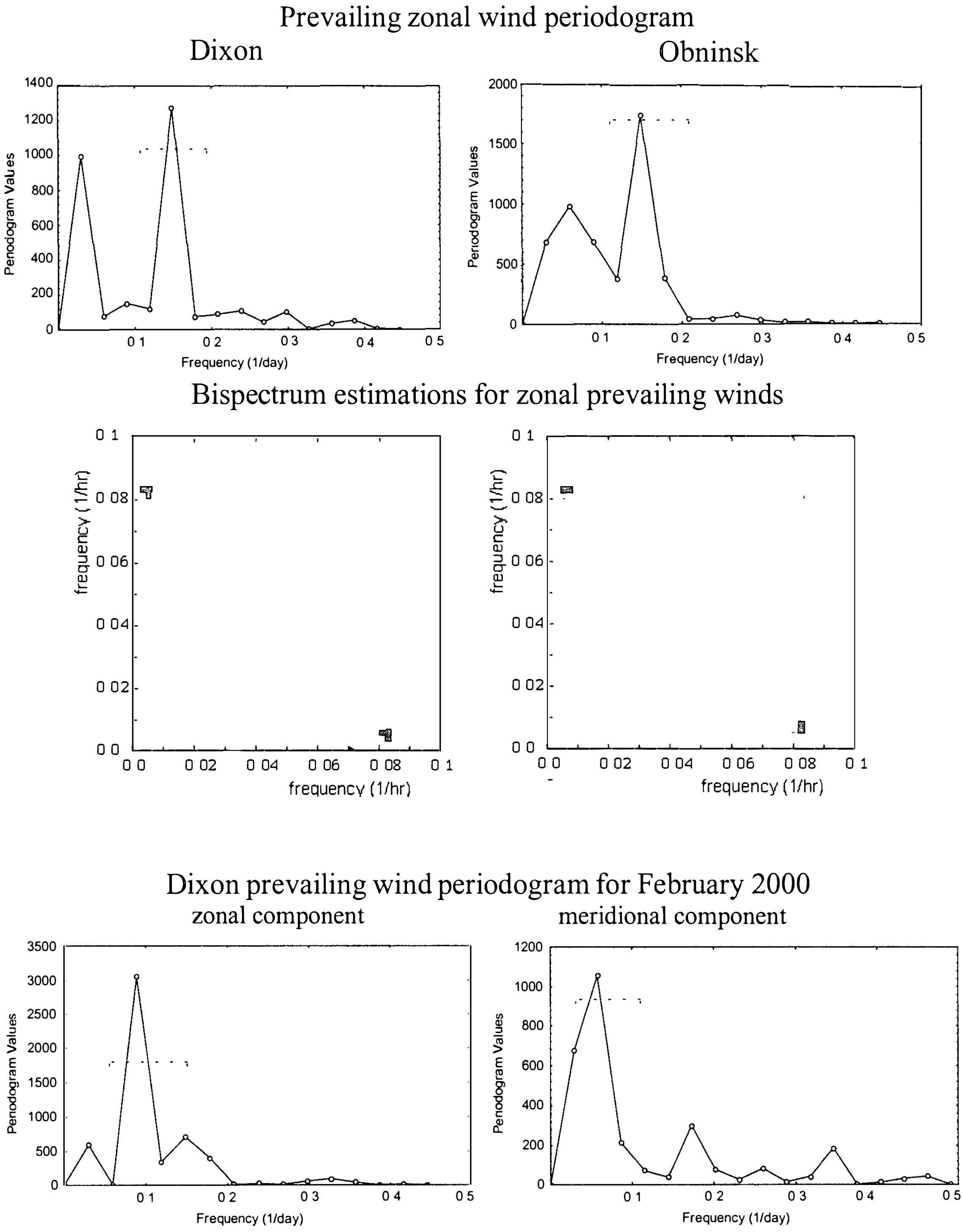

Fig. 4. Prevailing zonal wind periodograms for the time interval from 28 November until 19 December, 1999 (top). Bispectrum estimations for hourly mean zonal winds, measured during the same time interval (middle). Periodograms for zonal and meridional wind components, measured at Dixon during February 2000

In Fig. 4 (top) the periodogram for the zonal prevailing winds is shown. There is the common significant peak for both the Dixon and Obninsk sites at period of 7 days (0.143 day^{-1}). To estimate the significance level we applied Fisher's test (Fisher, 1929). Using a sliding least squares fit filters the initial data set as a lower-frequency filter with the cutoff period close to 48 h. We suggest the spectrum peaks with longer periods retained and we took for the level estimation only these peaks. The same method shows the significance of semidiurnal tide modulations with a period of about 7 days. In the middle of Fig. 4 bispectra for zonal wind components of both sites are presented. With their help we may limit the frequencies of oscillations involved in a non-linear interaction. The significant responses exist exactly for the semidiurnal tide and 7-day wave. For the considered time interval the correlation between meridional and zonal components of the semidiurnal tide is about 0.83 (at the lag 0) for Obninsk and 0.7 (at the lag 0) for Dixon, respectively.

Estimation of the significance levels for the bispectra is based on a Monte-Carlo simulation. We considered the semidiurnal tide as a stable oscillation with fixed amplitude and phase. The rest of variance is suggested to be Gaussian noise. One thousand artificial series were used in the analysis.

Strong zonal wind reversals in January occur at nearly the same time interval at both sites (see Fig. 2), and are interpreted as an effect of the stratospheric warming. These events are reflected in non-identical variations of semidiurnal tide amplitudes at the different sites (Fig. 3). After the warming (time interval 3) quasi 15-day oscillations are observed in the prevailing winds and in the semidiurnal tide amplitudes (see Fig. 3). However the oscillation exists in the Dixon zonal wind and is absent in the Obninsk zonal wind. For the semidiurnal tide amplitudes the picture is opposite. The correlation between the zonal prevailing wind at Obninsk and the zonal prevailing wind at Dixon is non-significant. The same is true for the meridional prevailing winds.

The bottom panel of Fig. 4 shows spectra of the prevailing winds measured during time interval 3. Only the oscillations with periods greater than 2 days are included. To estimate the 5% significance level we have used again the Fisher's test (Fisher, 1929) for the corresponding peaks and have determined that the peak corresponding to a period of 12 days is significant for Dixon. From least square fitting we have obtained the following wind parameters for the Dixon 12-day wave: amplitude of the zonal component $=10.4\pm1.4$ m/s and of the meridional component $=9.7\pm2$ m/s; the phase of maximum (the unit is day) for the zonal component $=7\pm0.3$ and for the meridional component $=9.9\pm0.4$. If one considers the latitude $\varphi=73.5^\circ$ sufficiently high to apply an approximation $\varphi\sim\pi/2$, then the obtained values of the phases would imply eastward propagation of the oscillation. A simplified way to see it is to use an approximation of the Hough's functions near a pole and substitute the approximation in expressions for velocities (see formulas (2.7) and (2.8) in Longuet-Higgins, 1968). From the analytical investigation of Longuet-Higgins (1968) such waves are possible as forced waves.

During summer at mid-latitudes the most prevailing wind variations, apart from tides, are quasi-two-day waves. The S-transform spectrograms for the period from 20 June 2000 are shown in Fig. 5. At Obninsk the quasi-two-day waves were observed in July 2000. The period of the basic harmonic is close to 48 hr. At Dixon one can also observe quasi-two-day waves. However they are of different periods for zonal and

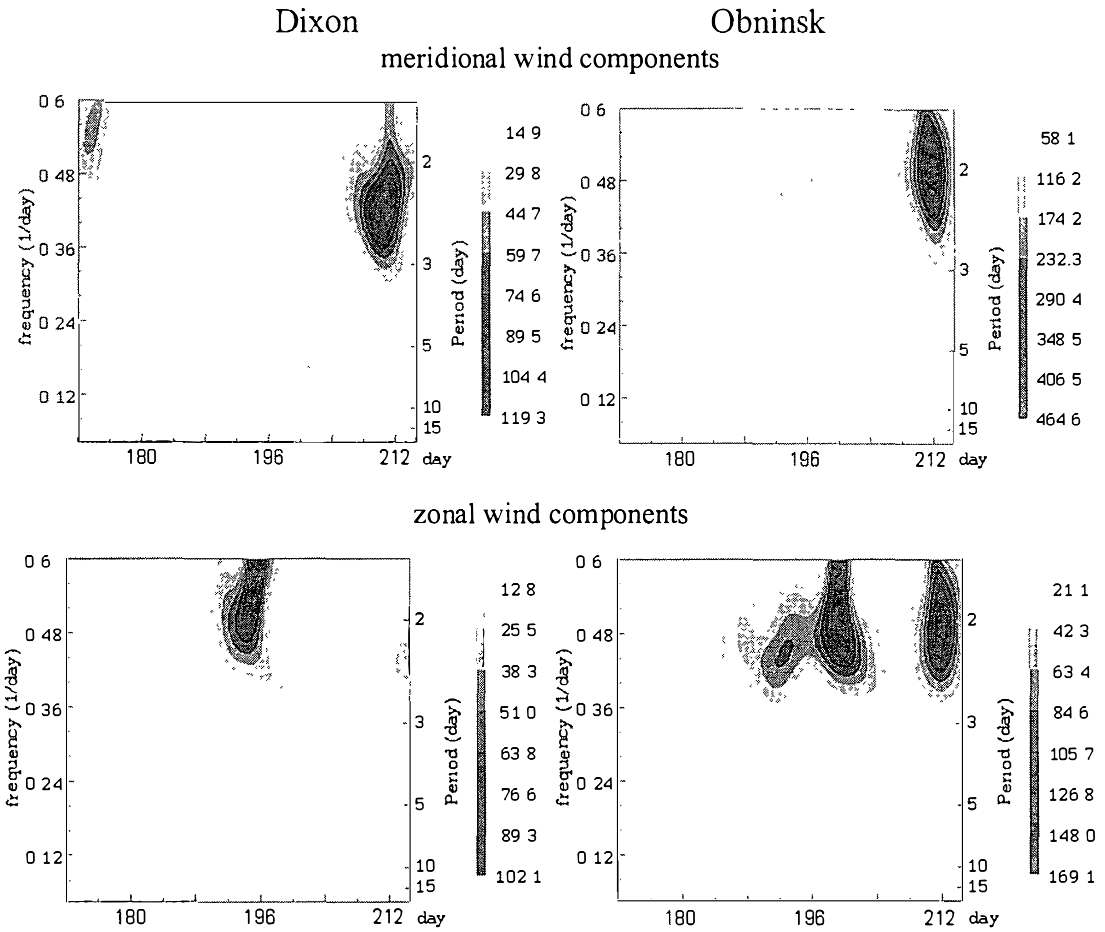

Fig. 5. Quasi-two-day waves observed in July 2000 at Obninsk and Dixon. S-transform spectrograms are presented for the time interval from June 20, 2000.

meridional components (see Fig. 5). These oscillations enhance during the same time interval as at Obninsk. For the both sites the waves have definite lifetimes and hence are characterized by a broad spectrum (Fig. 5). The waves observed at Dixon relate to different parts of the quasi-two-day spectrum. The correlation between the prevailing winds at Obninsk and Dixon is not high, but has a significant value. For the zonal components it is equal to -0.38 and for the meridional component the value is about 0.55. There is no significant correlation between the two series of semidiurnal tide amplitudes. As was mentioned above, the Dixon semidiurnal tide is characterized by deep variations of the phase and the amplitude. These dips in amplitude are suitable time intervals to ascertain the possible existence of non-tidal oscillations with the period different from but close to 12 h. At middle latitudes the semidiurnal tide usually has a rather large amplitude to distinguish from it an oscillation with close period in short time intervals. The periodograms presented in Fig. 6 demonstrate the appearance of several oscillations during the time interval from July 1 to July 4 with periods that differ from 12 h. During this interval the data gaps amount to 7 hours for the meridional component and 3 hours for the zonal component. The observed 10 h oscillations may be normal planetary-scale atmospheric Lamb waves (Forbes *et al.*, 1999) or inertial-gravity waves.

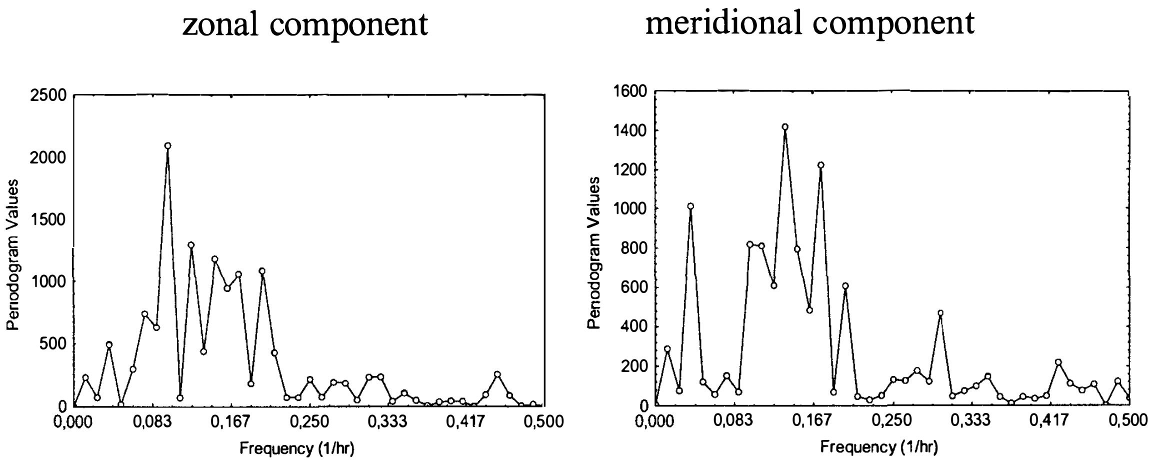

Fig. 6. Periodograms of hourly mean wind measured at Dixon for the time interval from July 1, 2000 to July 4, 2000.

4. Conclusions

Features of the high-latitude MLT wind variations revealed by our analysis may be summarized as follows:

1) Semidiurnal tide phases at Dixon (80°E) are close to those observed at Tromsø (19°E). Therefore, there is no evidence for predominance of nonmigrating semidiurnal tides in this longitude sector and at this latitude.

2) The long-term behavior of the prevailing winds and semidiurnal tide parameters are in general agreement with the empirical models of Portnyagin and Solovjova (1998, 2000).

3) Significant correlations between amplitudes of semidiurnal tide and simultaneously between prevailing zonal winds is measured at Obninsk and Dixon. This event may represent evidence for a global non-linear interaction between the semidiurnal tide and the planetary wave.

4) The high-latitude semidiurnal tide is characterised by a strong day-to-day variability (transience) in amplitude and the phase.

5) There are time intervals of non-significant semidiurnal tide in the high-latitude MLT region. Hence there is an opportunity to investigate the atmospheric non-tidal oscillations with the periods close to 12 h. One such interval reveals existence of a 10 h wave, thought to be a Lamb wave.

6) Possible evidence of an eastward-propagating oscillation with period of 12 hours is presented.

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