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Study of the semidiurnal tide derived from observations of OH(6,2) and O_2(0-1) nightglow at high latitudes.

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Abstract. The investigation is based on ground-based measurements of fluctuations in airglow brightness and rotational temperature, taken in the station Maimaga (63°N, 129.5°E) which is situated about 200 km northward from Yakutsk. The database consists of intensities and rotational temperatures of the OH(6,2) and O_2(0-1) molecular bands which are emitted at approximately 87 km and 95 km respectively. The data were collected from August to April during 5 years (2000-2005). The amplitude and phase of the 12-hours tide were computed by the least square method. The cases of downward phase propagation were selected to obtain the parameters of the clear semidiurnal tide. The analysis shows a growth in the mean amplitude of the temperature from the OH layer (6.6K) to the O_2 layer (8.7K). The maximum of the tide in temperature of the OH layer is at 7 h which is 2 h later than the time of the O_2 temperature maximum. A comparison of tide parameters obtained at a high subauroral latitude with tide properties at the mid-latitude mesopause shows that the amplitude is not changed. The derived phases of both layers are about 8 h ahead of the semidiurnal tide at mid-latitudes.

Keywords. Semidiurnal tide, Nightglow, Hydroxyl emission, Mesopause

1 Introduction

Solar atmospheric tides appear as stationary and large-scale variations of the temperature, wind, pressure, density and geopotential height with periods which are harmonics of the solar day. At the mesopause (89-110 km) the daily variations of atmospheric parameters mainly occur under the influence of propagating diurnal (24 hours) and semidiurnal (12 hours) tides, which are forced by ozone and water vapor absorption of solar energy in the stratosphere and troposphere. The existence of tides and their properties at the mesopause are most widely investigated by radar measurements of their effects on winds (Manson et al., 1989; Portnyagin et al., 1994; Jacobi et al., 1999) and by optical and satellite instruments (Takahashi et al., 1984; Walterscheid et al., 1986; McLandress et al., 1996; Reisin and Sheer, 1996; Taori et al., 2005; López-González et al., 2005). For the study of mesopause dynamics, temperature measurements play an especially important role. Temperature is a fundamental parameter, which provides direct information on the structure of the atmosphere and its changes under the influence of wave processes. For examination of the thermal state of the mesopause the most frequently used methods are lidar measurements and satellite limb soundings (Russell et al., 1993; McLandress et al., 1996; Mertens et al., 2001). On the basis of such measurements seasonal and latitudinal dependences of diurnal and semidiurnal tides have been studied. However, the naturally occurring airglow emissions in the upper mesosphere can also be used for examination of the dynamics and thermal state. The first study on the influence of tides on the upper mesosphere airglow emissions were initially conducted by Fukuyama (1976). It is known, that the relative intensity of branches in an atmospheric band under thermodynamic equilibrium depends on the temperature weighted by the emission layer width. Thus, measurements of nightglow molecular bands are a simple and reliable way to study the thermal state of the upper mesosphere. There are numerous papers, in which the diurnal, semiduirnal, and terdiurnal tides are studied using results from nightglow measurements (Oznovich et al., 1995; Reisin and Sheer, 1996; Pendleton et al., 2000; López-González et al., 2005). However, in spite of the fact that during the last years there has been a growing number of studies of the influence on the luminescence of the night sky by tidal oscillations, many unanswered questions remain. Most measurements are carried out at low- and mid-latitudes and in the polar cap. The finite length of mid-latitude night-

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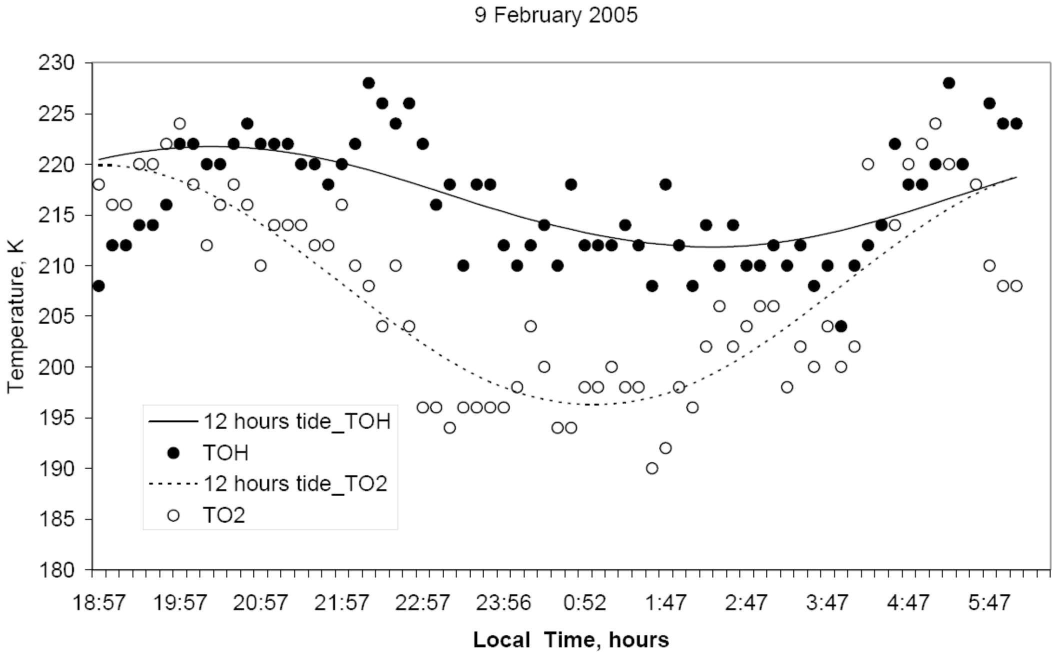

Fig. 1. Example of temperature data showing a fit of the semidiurnal tide amplitude to the raw data. The data were obtained on 9-10 February 2005. Solid circles correspond to the OH(6,2) rotational temperature (TOH), open circles show O_2(0-1) rotational temperature (TO2). The curves depict a best fit of the semidiurnal model to the data. The wave amplitude in the OH layer is equal to 4.8K and in the O_2 layer 10K.

glow data sets, less than 24 hours, limits their interpretation regarding tides. In the polar cap the emission bands are often blended by aurora lines during times of high geomagnetic activity. In this paper nightglow measurements conducted in the East Siberia region are analyzed. The observation site is placed at high latitude (62°N, 129°E), but far from the auroral oval because of the difference between the positions of the geographic and geomagnetic poles.

2 Instrument and observations

Measurements of the molecular bands OH(6,2) and O_2 (0-1), which are emitted at approximately 87 km and 95 km respectively, are used. The observations were carried out by an infrared spectrograph, that exposes both molecular bands simultaneously. The near infrared spectral band 830-880 nm is exposed with a time resolution of 10 min.

The method used to determine the rotational temperature of the molecular emission is based on least squares fits of the measured spectrum to a set of model spectra, constructed by taking into account different preassigned temperatures. The model spectrum, whose deviation from the real one is not higher than the recording noise, is considered to be the best fit, and its rotational temperature corresponds to the temperature at the mesopause altitude. With this method rotational temperature estimates with systematic errors exceeding random ones are eliminated from the processing. The estimates indicate that the random errors in temperature measurements are within 2-10 K, depending on the signal-to-noise ratio (Ammosov and Gavrilyeva, 2000, 2002).

The semidiurnal tide properties have been deduced from the mesopause temperature data obtained in 2000-2005 with the infrared spectrograph. The instrument was installed at the optical station Maimaga (63°N, 129.5°E) located 150 km north of Yakutsk. The observations were performed during nighttime at a solar declination of $>9^\circ$ in cloudless weather in the absence of the moon and airglow. The location of the observational point makes it possible to perform measurements only from the middle of August until the middle of May, since the summer mesopause is constantly sunlit at the Yakutsk latitude. The maximum duration of observations was 14 hours. The station is located far from the auroral oval because of the displacement of the geomagnetic pole from the geographic pole, and auroral lines contribute to the registered molecular bands only during high geomagnetic activity. The observations cover only part of the day and the diurnal tide can not be deduced from our data. Moreover according to model and experimental data (She et al., 2004) the amplitude of the diurnal tide at high latitude is small, so its influence on an estimate of semidiurnal tide parameters can be neglected. For the analysis, the observations from October until March were chosen, when the duration of time series was not less than 8 hours. During 5 seasons 381 measurement nights were obtained, allowing investigation of seasonal variation

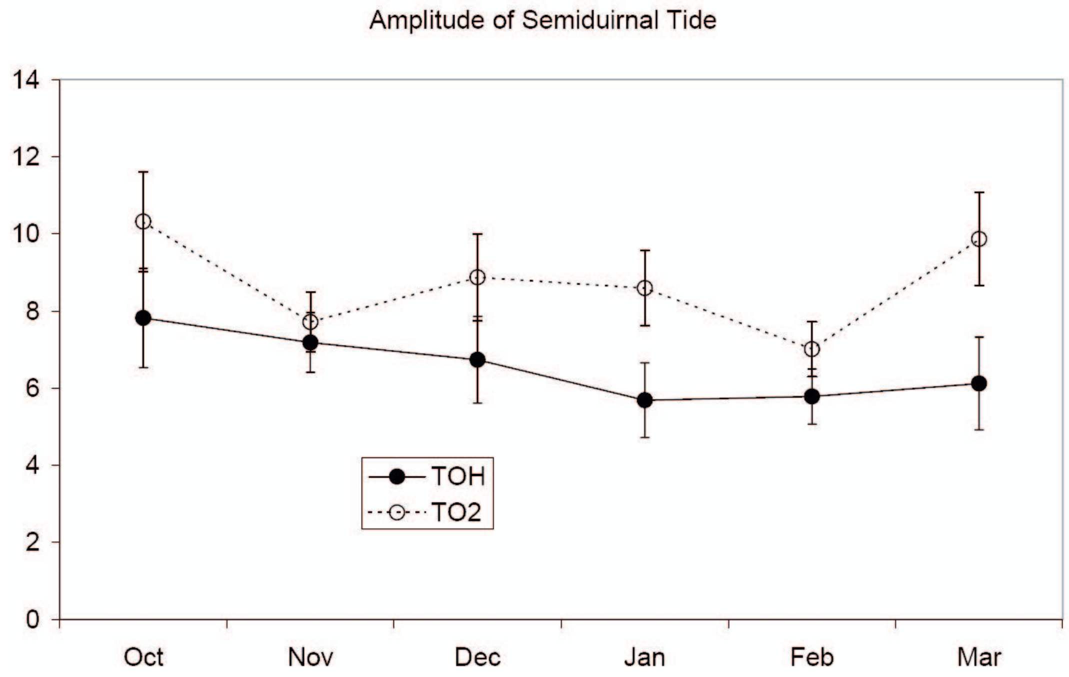

Fig. 2. Mean monthly variation of the semidiurnal tide amplitude at the OH (solid circles) and O_2 (open circles) emission heights. Wave amplitude growth with altitude is clearly seen. The mean amplitude at 87 km (TOH) is about 6.6K. The amplitude of the tide at 95 km (TO2) is about 8.7K.

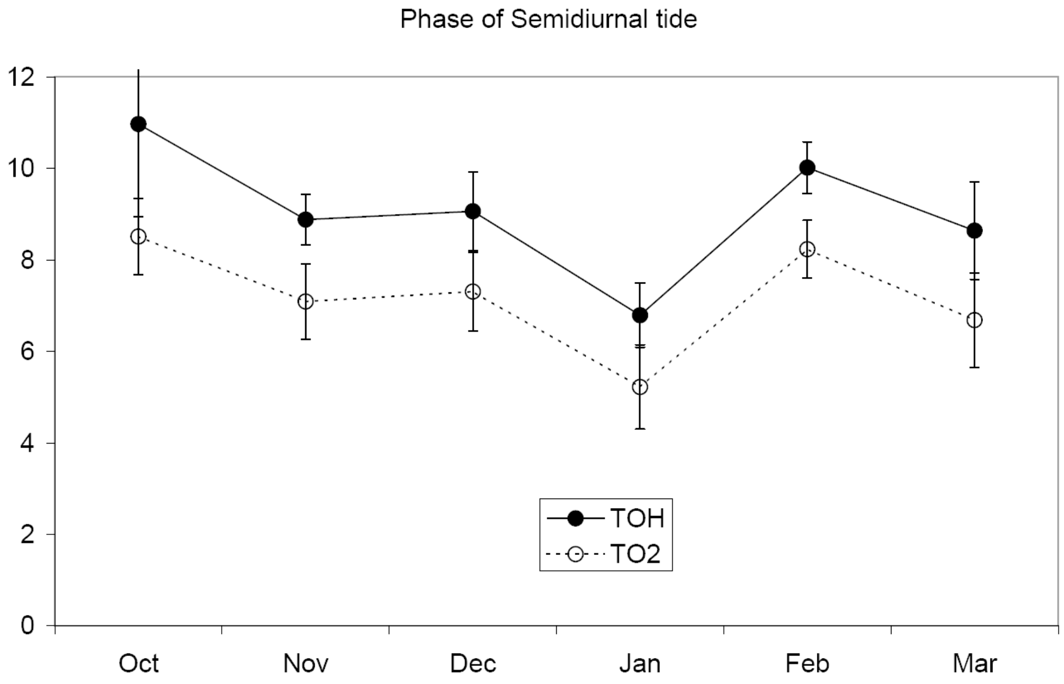

Fig. 3. Monthly averaged semidiurnal tide phase at the OH(6,2) and O_2(0-1) emission heights. The tide phase at the O_2 height leads the phase at the OH height by 2 hours.

of the semidiurnal tide. The temperatures were averaged into bins of 1 hour solar time. The averaging by local time largely reduces the influence of short-period internal gravity waves. The amplitude (A) and phase (θ, defined to be the time of maximum) plus a constant term (A_0) were estimated by a least square fit of the model $A_0 + A \cos \Omega(t - \theta)$) to the measured temperature time series. Here Ω is equal to $2\pi/12$ hr and t is local solar time.

In Fig. 1 an example of a fit of a semidiurnal variation to rotational temperature is given. This night the duration of observations was about 11 hours. It is known, that in the winter at high latitude the mesopause is located at an height of about 100 km and therefore the temperature at the O_2 radiation height (∼95 km) should be lower, than at the height of the OH layer (∼87 km). In Fig. 1 it is seen, that on the average the rotational O_2 temperature is lower, than the OH temperature. The amplitude of the semidiurnal tide in the OH layer is equal to 4.8K and in the O_2 layer 10K. The phase of the wave in O_2 temperature leads the phase of the wave in OH temperature by approximately 1 hour, which corresponds to downward phase progression. The error in the amplitude estimate was ∼1K and in the phase estimate ∼0.5 hour in both emissions. The growth of wave amplitude with height and the downward directed phase progression allows us to interpret it as a semidiurnal tide, whose source is located in the low atmosphere.

To investigate the semidiurnal tide behavior during the winter the calculated amplitudes and phases were grouped into months. Monthly averaged values of amplitudes and phases were derived in both emissions. The measurement errors in each group were calculated as monthly averaged values. The amplitude of tidal modulation is about 8K for the O_2 temperature and about 6K for the OH temperature. No significant phase discrepancy between the OH layer (87 km) and O_2 layer (95 km) exceeding the measurement error was found. Therefore the cases of upward wave were explored. Only 105 nights with clear downward phase progression were found in our data. A possible reason for such a small amount of upward tide can be connected with complex vertical thermal structure of the winter mesopause above our region.

Calculated monthly mean amplitudes of the 12-hour tide in rotational temperatures of both emissions are plotted in Fig. 2. From this figure we notice that the amplitude of the wave at the height of the excitation of the O_2 emission (95 km) is larger, than at the height of OH (87 km) at all times. The tide amplitude in rotational temperatures of OH is about 6K. The amplitude of the tide in the O_2 layer is about 8K. The monthly averaged tide phases in both emissions are drawn in Fig. 3. The mean tide phase at the height of molecular oxygen is 7 h. The mean phase of the OH temperature tide is equal to 9 h.

3 Discussion

The seasonal dependence of tide property variations is most widely investigated by radars and lidars at mid-latitude. The climatology of the semidiurnal tide is now better investigated by its influence on the wind in the mid-latitude mesosphere. Results based on mid-latitude radar network data are presented in the papers of Manson et al. (1989); Portnyagin et al. (1994); Jacobi et al. (1999). As is shown in these works, the seasonal behavior of tide amplitude in the wind has minima during the seasonal turnaround of the general circulation of the atmosphere in the spring and autumn. The tide amplitude in October and March is approximately one third of its maximum value in December - January. In our measurements the variation of monthly average amplitude in temperature tide from October until March is much less. Comparing amplitudes of the temperature tide in October and March with values in the winter time, the changes do not exceed 30 %.

The wave amplitudes at the OH and O_2 emission heights are equal to 6K and 8K respectively, which corresponds to amplitude growth with increasing height. The seasonal change of semidiurnal tide properties in the mesopause temperature was investigated by sodium resonance lidar sounding of the vertical structure of the atmosphere in Fort Collins, Colorado (46.6° N, 105° W) (Williams et al., 1998). On the basis of the change of tide parameters, the authors have grouped lidar data according to seasons. Measurements from November to March are shown in one group of winter months. According to the lidar measurements the wave amplitude in this group at the height of 87 km is equal to 7K, and at the height of 95 km approximately 9K. Our monthly mean temperatures taken from November to March are a little less but the amplitude increase with height in both measurements is equal to 2K. The monthly average amplitude of the tide during the autumn equinox (September, October) calculated from lidar measurements is actually less than the amplitude in winter. However, in another study based on observations in Fort Collins during September 2003, the semidiurnal tide amplitude is about 10K (Zhao et al., 2005). This amplitude is not different from the winter amplitude. According to the tide theory the greatest semidiurnal oscillation amplitudes should appear at low- and mid-latitude and in the process of propagation to a pole the tide should disappear (Walterscheid and Schubert, 1995). However results of numerous experiments show that tides are global in scale. Even in the upper atmosphere of the polar cap there are fluctuations, which can be attributed to tides (Walterscheid and Sivjee, 1996; Oznovich et al., 1997; Fisher et al., 1999). The semidiurnal tide influence on the OH and O_2 rotational temperature has been much investigated by López-González et al. (2005). Airglow observations with a Spectral Airglow Temperature Imager (SATI), installed at the Sierra Nevada Observatory (37.06° N, 3.38° W) , have been used to investigate the presence of tidal variations at mid-latitudes in the mesosphere/lower thermosphere region. The derived semidiurnal parameters from the SATI OH and O_2 temperature data have been compared with the semidiurnal parameters obtained by us. The temperature semidiurnal tide amplitudes obtained at both stations agree very well. The OH semidiurnal amplitudes above Yakutia of about 6.6K are in excellent agreement with the amplitudes of about 5-6K at the mid-latitude station. The O_2 semidiurnal tide amplitudes at Maimaga are about 8.7K, which is only 1-2K less than the semidiurnal tide amplitudes at the Sierra Nevada station.

The derived phases of the temperature semidiurnal tide differ from those obtained at the mid-latitude station. The OH semidiurnal phases of about 9 h local time are less than the semidiurnal tide of about 15-16 h in the Sierra Nevada Observatory. Similarly, the O_2 semidiurnal tide phases of about 7 h local time differ by 7-8 hours from the mid-latitude phases of 14-15 h.

Unfortunately our study did not cover the equinoxes. So the seasonal variation of semidiurnal tide parameters can not be derived. It can be only noted that the amplitude variations from October to March do not exceed 30% whereas at mid latitudes the discrepancy between the equinoxes tide amplitudes are less than winter tide amplitudes by a factor 2 -3 (Williams et al., 1998; López-González et al., 2005). From Fig. 3 it is easy to see that the time of the OH temperature maximum is about 2 h later than the time of the maximum in O_2 temperature, This discrepancy is retained from October to March. Possibly this is a result of choosing the upward propagated tide. According to measurements at midlatitude (Jacobi et al., 1999; She et al., 2004; Zhao et al., 2005; López-González et al., 2005) the semidiurnal tide phase difference at approximately 85 km and 95 km is more than 1 hour. Our measurements are in good agreement with their conclusion.

4 Summary

The amplitude of thermal semidiurnal tides measured from October to March above East Siberia, is comparable to the amplitude of tides at mid-latitude. The semidiurnal tide phase in the East Siberia mesopause region is ahead of the tide phase above mid-latitude stations by about 8 hours. The time of the OH temperature maximum is about 2 h later than the time of the maximum in O_2 temperature, in good agreement with the upward propagation tide phase difference at the mesopause above mid-latitude stations.

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