A high-latitude 8-hour wave in the mesosphere and lower thermosphere

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Received 17 January 2005; revised 6 June 2005; accepted 8 June 2005; published 1 September 2005.

[1] We used simultaneous multimission Fabry Perot interferometer neutral wind, airglow intensity, and temperature observations at Resolute (75°N) and meteor radar neutral wind observation at Esrange (68°N) to study a wave event with a period of close to 8 hours. On the basis of two days’ worth of observations in October, we were able to show that during this event the 8-hour wave only appeared at Resolute (75°N) and damped from 87- to 97-km altitude with a vertical wavelength of ~35 km. The OH emission temperature 8-hour oscillation was leading that in the OH emission brightness, resulting a negative phase of Krassovsky ratio, which may be related to the damping of the wave. The 8-hour wave also appears to be affected by planetary waves, resulting in a small phase shift for the wave from the first to the second day.


1. Introduction

[2] The 8-hour wave in the mesosphere and lower thermosphere winds and temperatures has been observed from middle to high latitudes [Smith, 2000; Pendleton et al., 2000; Taylor et al., 2001; Younger et al., 2002; She et al., 2002; Ozovich et al., 1997a, 1997b; Akmaev, 2001]. The 8-hour wave at high latitudes tends to be transient and not uncommon [Walterscheid and Sivjee, 1996; Ozovich et al., 1997a, 1997b]. Younger et al. [2002] summarized the seasonal variation of the 8-hour wave near Esrange (68°N) based on meteor radar data. Their results appear to suggest that at some occasions, the 8-hour wave may be a result of the 24- and 12-hour wave nonlinear interaction. They also found that on other occasions, the 8-hour wave seems to be inconsistent with this generation mechanism. They also showed that the amplitude of the 8-hour wave is largest during the fall season and the wave amplitude increases with altitude from 80 to 100 km. Direct solar forcing and nonlinear interaction between the 12-hour semiidiurnal tide and the 24-hour diurnal tide all are suggested as possible sources for the 8-hour wave. Smith [2000] used UARS HRDI measurements to examine the latitudinal distribution of the 8-hour wave at 95 km and noted that its maximum amplitude occurs during the fall and winter seasons at midlatitudes. Smith and Ortland [2001] used the ROSE model and a linear model to study the effects of the direct solar forcing and nonlinear interaction between the diurnal and semiidiurnal tide on the terdiurnal tide and found that the former is the dominant source at high latitudes. They were able to reproduce many of the features observed in the UARS HRDI data [Smith, 2000]. Moreover, they provided a latitude and altitude map of nonpropagation regions for various terdiurnal tide modes. According to the map, only Hough modes with higher mode numbers can propagate in the winter hemisphere and these modes are even more restricted in the summer hemisphere.

[3] The changes in the mesospheric airglow intensity and temperature induced by the 8-hour wave have been the focus of many past studies, in part, because they were often observed by ground-based Michelson interferometers monitoring the OH emission intensity and rotational temperature. The ratio of relative changes in the brightness and temperature (Krassovsky ratio $\eta$) is calculated based on observations and compared with theoretical predictions [Ozovich et al., 1997a, 1997b; Taylor et al., 2001; Schubert et al., 1991; Walterscheid and Schubert, 1995]. The $\eta$ value is a complex number and its phase reflects the phase difference between the brightness and temperature oscillations. A positive phase means the brightness oscillation leads that of the temperature. Model calculations [Schubert et al., 1991; Walterscheid and Schubert, 1995] show that the phase for various terdiurnal tide modes should be positive. Only gravity waves appear to be able to produce negative phases [Schubert et al., 1991; Tarasick and Hines, 1990]. On the other hand, various observations showed negative phases for the 8-hour oscillation as summarized by Taylor et al. [2001]. These results seem to add weight to a gravity wave explanation. Yet the persistent occurrence of the 8-hour wave appears to favor a tidal wave interpretation. While Krassovsky ratio is an important parameter, one should be cautious when use the ratio to interpret wave parameters [Hines and Tarasick, 1987]. Wave saturation and breaking may change the Krassovsky ratio in an unexpected ways. We should also point out that Walterscheid and Schubert [1995]
calculation was made with assumption of isothermal and inviscid atmosphere and zero mean wind. These assumptions may affect their results.

To further examine the high latitude mesosphere and lower thermosphere 8-hour wave and its optical, neutral wind and temperature signatures, we analyzed a recent data set from a newly installed highly sensitive Fabry-Perot interferometer (FPI) at a Canadian polar cap station and a simultaneous neutral wind data set from a Scandinavia high latitude station. The combined data set allows us to examine the vertical and horizontal structures of the 8-hour wave more closely and shed more light on some unresolved issues from various 8-hour wave observational results in the past [Taylor et al., 2001]. The paper is organized as follows. Observational results and analysis are given in the next section, followed by discussions in section 3. Finally, our new findings are summarized.

2. Observations

On 10–11 October 2003 (283 and 284 day of year), we observed a wave with period very close to 8 hours in the mesosphere and lower thermosphere neutral winds using the Early Polar Cap Observatory FPI in Resolute, Canada (74.68°N, 94.90°W). Simultaneous meteor radar observations of neutral winds from another polar station Esrange, Sweden (68°N, 21°E), located at slightly lower latitude were examined to study the latitudinal extent of the 8-hour wave.

2.1. Resolute Fabry-Perot Interferometer Observation

2.1.1. Instrument

An FPI was deployed at the Resolute, in the summer of 2003. In early October of 2003, the instrument started its daily routine observations. The instrument consists of a sky scanner, an 8-position filter wheel, a 4-inch diameter effective area etalon with 2 cm gap and 80% reflectivity, a back illuminated 1024 × 1024 25-micron pixels CCD (SiTe03) detector. The CCD is cooled to −55°C to reduce the dark count. The etalon is enclosed in a sealed and temperature controlled chamber to reduce the instrument drift. In this study we use data from the OH (7–3) P3 8920 Å (~87 km) and O(1S) 5577 Å (~97 km) nightglow emissions. The instrument takes measurements with a 3-min integration time at 4 cardinal directions (45° elevation angle) and at vertical direction for each emission in sequence. Because of measurements of other nightglow emissions, the duty cycle of the instrument is about 1 hour. The main focus lens has a focal length of 54.2 cm. The wind error is about 6 m/s for the OH emission and 1 m/s for the 5577 Å. The instrument is controlled by a Pentium-4 computer with the Windows 2000 operation system. Data acquisition software turns on the instrument automatically when the Sun is 10 degrees below the horizon. The computer clock is synchronized to GPS time on a daily basis. The timing error is about a few seconds. Overall the instrument is designed to study upper atmosphere waves with timescales of several hours and amplitudes of a few tens of meters per second. More information about the instrument is provided by Wu et al. [2004].

2.1.2. Data

On 10 and 11 October 2003 a strong wave with period close to 8 hours was observed in the neutral winds from the OH 8920 Å and O(1S) 5577 Å emissions as shown in Figures 1 and 2, respectively. Local noon is at about 18 UT and the nighttime coverage lasts for about 12 hours during this time of year at Resolute. The sky was slightly hazy but stars and the moon are visible based on a colocated all sky...
camera data. The upper panels of the figures are for the meridional winds and the lower for the zonal winds. The meridional winds are from the northward and southward directions as indicated by different symbols in the figure. Similarly the zonal winds are from the eastward and westward viewing directions. There are no major differences between the wind values from the opposite directions for both the meridional and zonal components implying the wave has a large horizontal wavelength (the sampling location of the opposite viewing direction is separated by about 150 km). Daily least squares fit curves with an 8-hour oscillation for the meridional and zonal winds are also plotted in the figures. The fitting results are listed Table 1. The 8-hour wave amplitude in the OH emission winds is about 2 times that in the 5577 Å emission. Because of the high sensitivity of the instrument, we are able to extract the wave parameters from the 5577 Å emission data, even though the wave amplitude was small (\(|v| \leq 10 \text{ m/s}\)). On the basis of the phase and known peak altitude difference (10 ± 2 km) differences between the OH and 5577 Å emissions, the estimated vertical wavelength for the 8-hour wave is about 35 km (see Table 2). Figure 3 shows the OH emission brightness and uncalibrated Doppler temperatures. Although the absolute values of the temperature are not available, the relative changes are the reflection of true changes in the mesosphere temperature. The temperature level shift between the two days was due to adjustments to the instrument. We were still testing the instrument shortly after installation. The daily least squares fit curves are also plotted in the figure. The 8-hour oscillation in the brightness and temperature are apparent. It is also clear that the temperature oscillation is leading that in the brightness as the figure and the least squares fit results show (see Table 3). Because of uncertainties in the temperature and brightness values, the magnitude of the \(h\) value was not calculated. The phases of the \(h\) are negative for both days. The oscillation in the 5577 Å emission brightness and temperature is too small to be detected by the FPI instrument (not shown here). We should point out that the exact period of the wave is difficult to obtain because of the length of the data set and its transient nature. Although an 8-hour oscillation appears to fit the data very well, the phases for the wave in different parameters (Table 1) shifted from day 2003283 to day 2003284.

![Resolute FPI neutral winds from the 5577 emission at 97 km from day 2003283 to 2003284.](image)

The figure is in the same format as Figure 1.

### Table 1. Eight-Hour Wave Parameters From Least Squares Fit

<table>
<thead>
<tr>
<th>Date, yyyyddm</th>
<th>Emission</th>
<th>Direction</th>
<th>Amp, m/s</th>
<th>Phase, UT</th>
<th>Background Wind, m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003283 8920</td>
<td>meridional</td>
<td>18.39 ± 1.8</td>
<td>0.13 ± 0.1</td>
<td>−2.60 ± 1.2</td>
<td></td>
</tr>
<tr>
<td>2003283 8920</td>
<td>zonal</td>
<td>14.27 ± 1.6</td>
<td>1.66 ± 0.2</td>
<td>−0.49 ± 1.2</td>
<td></td>
</tr>
<tr>
<td>2003283 5577</td>
<td>meridional</td>
<td>8.46 ± 2.0</td>
<td>6.06 ± 0.3</td>
<td>8.81 ± 1.4</td>
<td></td>
</tr>
<tr>
<td>2003283 5577</td>
<td>zonal</td>
<td>8.49 ± 2.5</td>
<td>7.20 ± 0.3</td>
<td>−0.29 ± 1.3</td>
<td></td>
</tr>
<tr>
<td>2003284 8920</td>
<td>meridional</td>
<td>17.26 ± 2.5</td>
<td>1.25 ± 0.3</td>
<td>14.39 ± 1.9</td>
<td></td>
</tr>
<tr>
<td>2003284 8920</td>
<td>zonal</td>
<td>8.70 ± 2.9</td>
<td>3.54 ± 0.4</td>
<td>−0.88 ± 2.0</td>
<td></td>
</tr>
<tr>
<td>2003284 5577</td>
<td>meridional</td>
<td>11.65 ± 1.6</td>
<td>7.01 ± 0.2</td>
<td>7.92 ± 1.2</td>
<td></td>
</tr>
<tr>
<td>2003284 5577</td>
<td>zonal</td>
<td>6.43 ± 4.0</td>
<td>0.83 ± 0.8</td>
<td>−1.49 ± 2.9</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2. Eight-Hour Wave Vertical Wavelength and Amplitude Ratio

<table>
<thead>
<tr>
<th>Date, yyyyddm</th>
<th>Direction</th>
<th>Vertical Wavelength, km</th>
<th>Amplitude Ratio 5577/OH</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003283</td>
<td>meridional</td>
<td>38.6 ± 10</td>
<td>0.46</td>
</tr>
<tr>
<td>2003283</td>
<td>zonal</td>
<td>35.5 ± 9</td>
<td>0.59</td>
</tr>
<tr>
<td>2003284</td>
<td>meridional</td>
<td>35.7 ± 9</td>
<td>0.67</td>
</tr>
<tr>
<td>2003284</td>
<td>zonal</td>
<td>30.7 ± 12</td>
<td>0.73</td>
</tr>
</tbody>
</table>
which could be an indication that the wave period may not be exactly 8 hours. We will discuss the possible cause for the phase shift in section 3.

2.2. Esrange Meteor Radar Observation

2.2.1. Instrument

The meteor radar at Esrange is a “SKYmet” all-sky VHF system produced commercially [Hocking et al., 2001]. The radar uses a 6 kW peak power transmitter with a 15% duty cycle at 32.5 MHz frequency. The pulse repetition frequency is 2144 Hz. The radar has a five-element antenna and routine data processing produces hourly meridional and zonal wind values at 6 different altitudes (81.0, 84.6, 87.5, 90.4, and 93.4 km). More information is provided by Mitchell et al. [2002].

2.2.2. Data

The neutral winds from the Esrange meteor radar are plotted as contours in Figure 4. The dashed lines mark the altitudes (87 and 97 km) of the OH and 5577 Å emissions, respectively. The upper panel is for meridional winds and the lower for zonal winds. Both components display a clear periodicity of 12 hours. The Fourier spectra of the two components (Figure 5) show a strong peak at 12 hours. There is no sign of the 8-hour oscillation on these data. The vertical wavelength of the 12-hour wave is about 35 km, which is comparable with that of the 8-hour wave at Resolute. The similar vertical wavelength appears to suggest the 12-hour wave has a similar modal index.

3. Discussion

3.1. Discrepancies With Esrange Monthly Average Results

Because of the short data set we could not do a monthly average calculation of the current data to compare with past monthly average results from Esrange [Younger et al., 2002]. As Younger et al. [2002] have pointed out, specific 8-hour wave event can behave quite differently from the monthly averaged results. Major differences between this October event at Resolute and the monthly averaged results at Esrange are the vertical profile and wave amplitude. The monthly averaged wave amplitude is much smaller and increases from 80 to 100 km. The vertical wavelength during the fall season (September) is 61.2 ± 2.8 km and 91.4 ± 2.9 km for the zonal and meridional winds at Esrange [Younger et al., 2002]. During this October Resolute event the wave amplitude is much larger than previous Esrange monthly results and the wave amplitude decreases from 87 km to 97 km. The vertical wavelength is shorter than that observed at Esrange in the same season. While there are many reasons for the differences, latitudinal, longitudinal, and instrumental differences between the two data sets are all possible causes. The vertical wavelength for the Esrange seasonal 8-hour observations are longer than that observed at Resolute. It could mean that Esrange meteor radar saw a different mode of the 8-hour wave with lower mode numbers 4 or 5 [Smith and Ortland, 2001].

3.2. Wave Parameters and . Phase Estimation

Assuming that the scale height is 6 km, the 8-hour wave amplitude would increase by a factor of 2 from 87 to

<table>
<thead>
<tr>
<th>Date, yyyyddm</th>
<th>Temperature Phase, UT</th>
<th>Brightness Phase, UT</th>
<th>Temperature Phase Difference, Deg</th>
<th>Brightness Phase Difference, Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003283</td>
<td>3.70 ± 0.62</td>
<td>5.19 ± 0.37</td>
<td>−1.49 ± 0.72</td>
<td>−67.1 ± 32</td>
</tr>
<tr>
<td>2003284</td>
<td>1.45 ± 0.53</td>
<td>3.93 ± 0.22</td>
<td>−2.48 ± 0.57</td>
<td>−1.16 ± 25</td>
</tr>
</tbody>
</table>

Table 3. Temperature and Brightness Phases

Figure 3. Resolute FPI OH emission brightness and Doppler temperature (uncalibrated) from day 2003283 to 2003284. The least squares fit are also plotted.
97 km, if there were no damping. In reality, the observed 8-hour wave amplitude decreases by a factor of 2 from 87 to 97 km. We do not know the cause or causes for the wave amplitude to decrease; eddy diffusion and gravity wave forcing are all possible reasons. We are having the same issue facing Taylor et al. [2001], which is to interpret the meaning of a negative phase for Krassovsky ratio, whereas the model results suggest a positive phase for terdiurnal tide [Schubert et al., 1991; Walterscheid and Schubert, 1995]. Perhaps, by coincidence, Schubert et al. [1991] have shown that, by introducing damping to a gravity wave, they were able to change the phase of the $\eta$ value from positive to negative for a wave with a vertical wavelength about 30 km. It is still unclear why most of the observations of 8-hour wave in the past including this one have shown negative phase of Krassovsky ratio. We should point out that Taylor et al. [2001] did not rule out the possibility that some of the 8-hour waves might be long-period gravity waves.

To explore this issue further, we reexamine the analytical results from Tarasick and Hines [1990]. Assuming the wave has the form [Tarasick and Hines, 1990, equation (44)],

$$Ae^{-f H^\gamma}$$

where, $A$ is the amplitude, $H$ is the scale height, $\omega$ is the wave frequency, $k_x$, $k_y$, $k_z$, are wave numbers in three directions.

[11] They have the equation for the phase of Krassovsky ratio for vertical viewing as follows (equation (52)). $\phi$,

$$\phi = \tan^{-1} \left( \frac{-\nu}{\chi - \mu} \right),$$

[3] where

$$\nu = \frac{-\gamma k_z H}{1 - \omega^2/k_y^2 g^2},$$

$\gamma$, the ratio of specific heats, $k_h$, the horizontal wave number, $g$, acceleration due to gravity, $\chi$ (~2.2) [Tarasick and Hines, 1990, equation (34)] and $\mu$ (between 0.22 and 0.78) [Tarasick and Hines, 1990, equations (53) and (56)] are real numbers.

If the wave phase progresses downward (most likely), then $k_z$ is negative. For an 8-hour wave, with horizontal wavelength greater than 500 km (FPI wind data appear to suggest a long horizontal wavelength section 2.1.2), we have,

$$\nu \approx -\gamma k_z H.$$

Figure 4. Esrange meteor radar neutral winds from day 2003283 to 2003284. The meridional winds are in the upper panel and zonal in the lower. See color version of this figure at back of this issue.
If the wave grows with altitude we have a positive $H$. Since $k_z$ is negative, we have a positive $n$, which means a positive phase for the Krassovsky ratio. On the other hand, if the wave amplitude reduces with altitude, we have a negative $H$ and a negative phase for the Krassovsky ratio. We can write the tidal wave in the same form as (1), with different wave numbers and scale heights. The calculation for the Krassovsky ratio should be similar. We may still obtain a negative phase of Krassovsky ratio for a damping tidal wave according to this simple analytical calculation, which is based on isothermal assumption. Because of the short data string, we have a large uncertainty about the 8-hour wave frequency. The wave we observed could be a long period gravity wave or a terdiurnal tide. Wave damping appears to be the cause for the negative Krassovsky ratio.

3.3. Vertical Wavelength, Latitudinal Variation, and Longitudinal Variation

Because of the short vertical wavelength, it appears that, although severely damped, the 8-hour wave is not evanescent. The vertical wavelength of 35 km corresponds to a mode with very high modal index, if the wave is a migrating terdiurnal tide or a zonally symmetric tide. The large amplitude decrease from Resolute and Esrange appears to be consistent with high modal indices, which entail more rapid latitudinal changes. On the other hand, it is possible that the 8-hour oscillation is a nonmigrating tide (other than the zonally symmetric tide). Given the large longitudinal difference between Esrange and Resolute, it should not be a surprise that there is a large difference in 8-hour wave amplitude between the two stations. Such interpretation, however, may not work for the 12-hour wave, which was observed at Esrange and not at Resolute. We would like to think the 12-hour wave is a migrating tide, because the migrating semidiurnal tide tends to be stronger. If the 12-hour wave were a migrating tide then only the latitudinal variation would be able to explain the interstation difference. The same may be true for the 8-hour wave.

3.4. Phase Shift and Possible Interaction With Planetary Waves

Phases of the 8-hour wave in the meridional, zonal components, temperature, and OH emission intensity are all shifted from day 2003283 to 2003284 (see Tables 1 and 3). One of possible causes for these phase shifts may be the nonlinear interactions between the 8-hour wave and planetary waves. While we cannot observe planetary wave directly, however, the background wind level shift in the OH emission
meridional wind from day 283 to 284 (Figure 1) appears to imply the presence of the planetary wave.

4. Summary

[17] On the basis of combined simultaneous multialtitude and multialtitude observation, we summarize our findings as follows.

[18] 1. The high latitude 8-hour wave while prominent at Resolute was absent at Esrange. The interstation difference could be due to rapid latitudinal changes in amplitude or longitudinal variation if the 8-hour wave was a nonmigrating tide. At the same time, the 12-hour wave appeared strongly at Esrange and did not occur at Resolute.

[19] 2. The 8-hour wave amplitude decreased from 87 to 97 km altitude and had a vertical wavelength of ~35 km.

[20] 3. The OH temperature 8-hour oscillation leads of that in the brightness resulting a negative phase for the Krassovsky ratio, which is consistent with many past observations.

[21] 4. Analytical calculation from Tarasick and Hines [1990] seems to show that the growth or decay rate of the wave can change the sign of the phase of Krassovsky ratio. The calculated phase appears to be consistent with our observation of damped 8-hour wave.

[22] We hope that future multistation observations will help to determine the horizontal wavelength or zonal wave number of the wave.

[23] Acknowledgments. The Fabry-Perot interferometer operation in Resolute is supported by the National Science Foundation grant ATM 0334596 to the National Center for Atmospheric Research (NCAR). The Fabry-Perot interferometer instrument development effort was supported by the NCAR new initiative program and by internal funding from the High Altitude Observatory (HAO). The National Center for Atmospheric Research is sponsored by the National Science Foundation. R. Kerr and J. Noto of Scientific Solution, Inc., have provided both technical and material support for the instrument development. This work was also supported in part by the International Collaboration Research Team Program of the Chinese Academy of Sciences. We would like to thank A. Burns for helpful comments and suggestions.

[24] Shadia Rifai Habbal thanks Anne K. Smith and another referee for their assistance in evaluating this paper.

References


Figure 4. Esrange meteor radar neutral winds from day 2003283 to 2003284. The meridional winds are in the upper panel and zonal in the lower.
Figure 5. Neutral wind spectra for days 2003283 and 2003284. Same format as Figure 4 for the wind spectra.