Coherent and Non-Coherent Components of Mesoscale Variations of Hydroxyl Rotational Temperature near the Mesopause.

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Abstract

The method of digital difference filters was applied for the data analysis of the spectral observations of the rotational temperature of vibrationally excited hydroxyl at altitudes 85 – 90 km at the Zvenigorod scientific station of IAP RAS (56° N, 37° E) in 2004 – 2016, at the Tory observatory of ISTP SB RAS (52° N, 103° E) in 2012 – 2017, and Maymaga observatory of SICRA RAS (63° N, 130° E) in 2000 - 2015.

Semi-empirical formulas are used to separate coherent and non-coherent parts of mesoscale temperature perturbations.

Seasonal and interannual changes in the mean temperature and intensity of coherent variations having periods 0.4 – 5.4 h are studied. These variations may be associated with internal gravity waves (IGWs) propagating in the mesopause region.
Spectro-photometric measurements of the hydroxyl emission.

- Data on the hydroxyl emission, its intensity and rotational temperature, were derived from the spectroscopic observations in the 800 – 1000 nm spectral range. The spectroscopic measurements were performed during cloud-free nights. To obtain a good signal to noise ratio, the measurement integration time for one spectrum is 10 min. OH rotational temperature was determined using population distributions at three rotational levels of OH* molecule. In our study, the intensities of P1(2), P1(3), and P1(4) lines of the OH(6-2) band were used.
Method of data filtering.

To obtain the mesoscale variations, we used numerical filtration by taking differences between the sequential values of the OH rotational temperature, averaged over the intervals by duration from 0.17-2h.

\[ T'_i = \frac{(T_{i+1} - T_i)}{2} \]  

(1)

where \( i \) is the number of value with the middle time \( t_i \). This transformation is equivalent to a numerical filter with the transmission function

\[ H^2(\tau) = (r_1 r_2)^2 = \frac{\sin^4(\pi \Delta t / \tau)}{(\pi \Delta t / \tau)^2}. \]

where \( \Delta t \) is time step of the data.
Parameters corresponding to the maxima of $H^2$,
Periods of maxima, $\tau_m$, and to the high, $\tau_h$, and low, $\tau_l$, cutoff periods at the level 0.5 of the maxima of the transmission function (2) at different $\Delta t$.

<table>
<thead>
<tr>
<th>$\Delta t$, hr</th>
<th>$\tau_m$, hr</th>
<th>$\tau_h$, hr</th>
<th>$\tau_l$, hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>1.4</td>
<td>2.7</td>
<td>0.8</td>
</tr>
<tr>
<td>1</td>
<td>2.8</td>
<td>5.6</td>
<td>1.7</td>
</tr>
<tr>
<td>2</td>
<td>5.6</td>
<td>11</td>
<td>3.4</td>
</tr>
</tbody>
</table>
Standard deviation caused by the dark current fluctuations of the recording chamber matrix of the spectrograph

\[ \sigma_T = A_1 + A_2 T + A_3 T^2 + \frac{B_0 + B_1 T + B_2 T^2}{I} \]  

- \( \sigma_T \) – standard deviation in Kelvin (K)
- \( T \) – temperature, derived from OH(6-2)
- \( I \) – the intensity of OH(6-2) band
Coefficients of the formula (2) for Zvenigorod and Tory

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Zvenigorod</th>
<th>Irkutsk</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1, K$</td>
<td>-0.08</td>
<td>0.26</td>
</tr>
<tr>
<td>$A_2$</td>
<td>$1.01 \cdot 10^{-3}$</td>
<td>$1.713 \cdot 10^{-3}$</td>
</tr>
<tr>
<td>$A_3, K^{-1}$</td>
<td>$-3.44 \cdot 10^{-6}$</td>
<td>$-25.28 \cdot 10^{-6}$</td>
</tr>
<tr>
<td>$B_0, RI \cdot K$</td>
<td>1633.6</td>
<td>3896</td>
</tr>
<tr>
<td>$B_1, RI$</td>
<td>-20.23</td>
<td>-50.83</td>
</tr>
<tr>
<td>$B_2, RI \cdot K^{-1}$</td>
<td>0.08864</td>
<td>0.2474</td>
</tr>
</tbody>
</table>
Variances of Coherent and non-coherent mesoscale perturbations

Expansion of monthly temperature variance of differences (1) for small $\Delta t$:

$$s(t) = s_0 + qt + ..., \quad (3)$$

where $\sigma_0$ is variance of non-coherent in time component.

Variance of coherent component of difference (1) is equal to

$$s_c = s(\Delta t) - s_0. \quad (4)$$

For measurements at two time intervals $\Delta t$ and $2\Delta$

$$s_0 = 2s(\Delta t) - s(2\Delta t) \quad (5)$$
Examples of linear approximations (3) of mesoscale temperature variances
Seasonal changes in the variance of instrumental noise $\sigma_T$ in K – (1), and of incoherents variance $s_0$ determined using the least squares method – (2) and determined by the formula (5) – (3), for Tory (a), Zvenigorod (b) and Maimaga (c).
Gravity wave parameters

- Reasons for incoherent variance $s_0$ determined with Eq. (3) or (5) could be instrumental noise and atmospheric turbulence.

- Coherent temperature variance (4) may reflect internal gravity waves (IGWs) propagating near the mesopause. IGW polarization relations give the following formulae for the amplitude of horizontal velocity variations, $U$, and potential wave energy, $E_p$

$$ U = \frac{g}{N} \sqrt{\frac{T^2}{T_0^2}}; \quad E_p = \frac{U^2}{2} \quad (6) $$

where $g$ is the gravitational acceleration, $N$ is the Brund-Vaisala frequency, $T_0$ is the monthly-mean temperature.
Average monthly OH temperature in K (a), relative temperature standard deviations (b), IGW horizontal velocity variances in m/s (c), and specific wave potential energy in J/kg for filters $\Delta t = 0.5$ h (1), $\Delta t = 1$ h (2), and $\Delta t = 2$ h (3). Including incoherent variance (left) and for coherent variance only with (right).

Seasonal variations in Tory averaged for years 2012 - 2017
Seasonal variations in Maimaga averaged for years 1999 - 2015

Same as for Tory
Seasonal variations in Zvenigorod averaged for years 2004 - 2016

Same as for Tory.