Comparison subpolar mesopause OH(6-2) temperature over Yakutia with the calculated data of NRLMSISE-00 model for 1999-2015

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Abstract. The analysis of changes in temperature of mesopause region based on fluctuation measurements of rotational temperature and intensity of molecular emission of hydroxyl OH (6-2) excited at ~87 km altitude is presented. Observations were carried out at the Maimaga station (63°N, 129.5°E), at a distance of 120 km to the north from Yakutsk. Measurements were conducted with a digital infrared spectrograph. The temperature was determined from the distribution of the emission intensity in the different branches of the molecular hydroxyl band. Comparison OH(6-2) temperature with the calculated data of NRLMSISE-00 model was defined based on the data received from 1999 to 2015. 2320 midnight temperature values of hydroxyl OH (6-2) suitable for comparison were obtained at the Maimaga station over 16 years of measurements. The NRLMSISE-00 model describes temperature changes at the height of the mesopause region from October to April within the experimental fluctuations with a seasonal temperature variation of ~ 35 K, deviations from the experimental values are no more than 7 ± 4 K. A correlation analysis was performed to compare the rotational temperature OH (6-2) and the NRLMSISE-00 model calculations. When the number of observations at the station Maimaga more than 180 days (about six months) correlation coefficient R> 0.7. This means that the NRLMSISE-00 model accurately describes the temperature changes of the subauroral mesopause.

1. Introduction
The optical remote measurement of the temperature of the upper atmosphere is based on a ground-based recording of the intensity of the intrinsic radiation of the night sky. The rotational temperature, determined from the intensity distribution of the hydroxyl (OH) band, corresponds to the kinetic temperature of the neutral gas at the radiation height. The radiating layer of OH according to numerous rocket measurements is quite thin (7-10 km) and is located at the level of the mesopause (about 87 km). The mesopause region is a boundary region (80-100 km) between the mesosphere and the thermosphere, in which the temperature minimum is located. Despite variations in the height of the emission layer, this method of measuring the temperature of the mesopause region is the most convenient way of studying seasonal variations, the response of temperature to solar activity, and the long-term changes in the temperature of the upper atmosphere.

Various empirical atmospheric models, such as MSIS-90, have been constructed based on experimental data obtained by both terrestrial and satellite methods. Comparison with measurements
taken at different latitudes, even after their creation, shows that there are significant deviations in the behavior of the temperature regime of the mesopause region from model ones [1].

The aim of this paper is to compare the temperature of the subpolar mesopause with the empirical model NRLMSISE-00 calculations. The study is based on the mesopause temperature data during 16-year observations of OH hydroxyl radiation (6-2) obtained at Maimaga station (63°N, 129.5°E).

2. Infrared digital spectrograph and data processing method
The results of the analysis of the mesopause temperature data obtained by an infrared digital spectrograph (ICS) made based on the SP–50 spectrograph are presented. The device is installed at the optical station Maimaga (63°N, 129.5°E), which is located 120 km north of Yakutsk. Observations were made at night, at an angle of immersion of the Sun> 9° in cloudless weather. For the analysis, the data obtained in the moonless time and in the absence of auroras were selected. From 1999 to the present, a digital CCD camera is used to record the spectrum at the output of the spectrograph, which makes it possible to use the whole spectrum for the estimation of the rotational temperature [2]. The method for estimating the rotational temperature of molecular emission is based on fitting the model spectra constructed with allowance for the apparatus function of the instrument for various predetermined temperatures to the actually measured spectrum by the method of least squares. The model spectrum whose deviation from the real does not exceed the recording noise is considered the most appropriate one and that the rotational temperature of the hydroxyl molecule, which is determined from the spectrum, corresponds to the temperature at the height of the mesopause. As estimates show, random errors in temperature measurement lie within the range of 2-5 K, depending on the level of the signal-to-noise ratio. The infrared spectrograph is calibrated twice a year using a gas discharge lamp (Ne).

Recording of the spectrum of the night sky is conducted from the middle of August to the middle of May. The longest night rows of data are recorded in the winter months. The number of measurements per month varies from 10 to 25 nights. To compare the temperature of the subauroral mesopause with empirical models, the mean nighttime temperatures of the hydroxyl were calculated. In total, from August 1999 to April 2015, there were 2320 average night values of OH (6-2) meeting the above sampling criteria. They are shown in Figure 1.

![Figure 1. The OH (6-2) temperature series obtained at the Maimaga station from 1999 to 2015.](image_url)

3. Comparison with the empirical NRLMSIS-00 model
To calculate the temperature and chemical composition of the atmosphere, the MSIS (Mass-Spectrometer-Incoherent-Scatter) model is widely used. The first version of this model appeared in 1977. As a result, of the accumulation of experimental atmospheric data updated versions of this model were created: MSIS-83, MSIS-86, MSIS-90, NRLMSISE-00 [3]. At the moment, the latest version of
the model is NRLMSISE-00 based on the MSISE90 model. NRLMSISE-00 uses rocket, satellite and non-coherent radar data. The model calculates the concentrations of He, O, N₂, O₂, Ar, H, N, total mass density, neutral temperature at altitudes from the Earth's surface to 1000 km.

The model uses the temperature profile, as a function of the geopotential height for the upper thermosphere, for the lower thermosphere is the inverse polynomial of the same variable. Atmospheric characteristics are expressed as functions of geographic and solar / magnetic parameters. To describe the main variations of the atmosphere, including latitudinal, annual, and semiannual and longitude, spherical harmonics of low orders are used.

MSIS-90 and NRLMSISE-00 models allows calculating the parameters of a neutral medium in magnetic storms. The NRLMSISE-00 model makes it possible to calculate the concentration of excited atomic oxygen. The input parameters of the NRLMSISE-00 model are the day of the year, altitude, latitude and longitude, UT local or global time. Also this model contains averaged solar activity index F10.7, index F10.7 on the day preceding the simulation day, a set of magnetic index values Ap. More precisely the average values of the index Ap on the simulation day, the three-hour values for 3, 6, 9 hours before the time of calculating the model values, as well as the average values of the index from 12 to 33 hours and from 36 to 57 hours to the specified time.

Figure 2 shows the temperature values from the NRLMSISE-00 model calculations and the hydroxyl band (6-2) with standard errors obtained at the Maimaga station averaged over a period of 16 years. The comparison was made for all months, except for June and July, at which time observations at the station are not conducted due to geographical location. The measurements at the Maimaga station are carried out from the 20th of August to the 10th of May, therefore in these months there are very few measurements suitable for conducting the comparison.

Figure 2. Average monthly NRLMSISE-00 model and OH(6-2) temperatures for 16 years.

There is a sufficient agreement between the values of OH (6-2) and NRLMSISE-00 from October to April, the difference is not more than 7 ± 4 K. In September, the temperature differences are greatest, with the hydroxyl temperature being higher, than the data of model NRLMSISE-00. This can be explained by a smaller amount of experimental data in September compared to other months, since in the autumn months there are more cloud nights. Such features of the distribution of experimental data
can affect the evaluation when compared with model calculations. It should be taken into account that the subpolar mesopause is characterized by a larger temperature variation in comparison with the models during the transition from winter to summer, which is associated with seasonal circulation of the atmosphere.

To determine the dependence of the accuracy of the NRLMSISE-00 model on the variation of the temperature of the mesopause region from each year, a correlation analysis was performed, in which model calculations were made only on the days when measurements were taken at the Maimaga station. The results of the correlation analysis are presented in Table 1 in the form of the correlation coefficient R by years and the number of experimental measurements of the rotational temperature OH (6-2) for each individual year. As can be seen from the table, the number of measurements at the Maimaga station varies depending on the year. When the number of observations at the Maimaga station is more than 180 days (approximately six months), the correlation coefficient R is greater than 0.7. This means that the NRLMSISE-00 model accurately describes the temperature changes of the subauroral mesopause.

### Table 1. R calculated by years the number of experimental measurements of the temperature OH (6-2)

| Years         | Number of measurements | R   | Years         | Number of measurements | R   |
|---------------|------------------------|-----|---------------|------------------------|-----|
| 1999-2000     | 139                    | 0.7 | 2007-2008     | 173                    | 0.64|
| 2000-2001     | 109                    | 0.65| 2008-2009     | 169                    | 0.68|
| 2001-2002     | 180                    | 0.78| 2009-2010     | 168                    | 0.19|
| 2002-2003     | 158                    | 0.65| 2010-2011     | 122                    | 0.55|
| 2003-2004     | 133                    | 0.38| 2011-2012     | 123                    | 0.45|
| 2004-2005     | 190                    | 0.71| 2012-2013     | 183                    | 0.82|
| 2005-2006     | 144                    | 0.47| 2013-2014     | 100                    | 0.71|
| 2006-2007     | 167                    | 0.62| 2014-2015     | 62                     | 0.61|

### 4. Conclusions
To compare the temperature of the subauroral mesopause with the empirical model NRLMSISE-00, from August 1999 to April 2015, 2320 average night values of OH (6-2) were obtained that satisfy the above-described sampling criteria. Difference between OH(6-2) temperature and NRLMSISE-00 model data from October to April is not more than 7 ± 4 K. To determine the dependence of the accuracy of the NRLMSISE-00 model on the variation of the temperature of the mesopause region from each year, a correlation analysis was performed, in which model calculations were made only on the days when measurements were taken at the Maimaga station. NRLMSISE-00 model accurately describes the changes in subpolar mesopause temperature obtained at the Maimaga station if the number of OH (6-2) measurements is more than 180 days (the correlation coefficient R is greater than 0.7).

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