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LONG-TERM VARIATIONS OF TEMPERATURE AND STRUCTURE OF THE MIDDLE ATMOSPHERE WITHIN THE LAST CENTURY

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Abstract. On the basis of the long-term data about the mesopause temperature (1955–2005) obtained by photometric of hydroxyl and atomic oxygen emissions and the analysis of data of the rocket and ionospheric temperature measurements of the atmosphere the distributions with height of temperatures have been constructed. They have allowed us to reveal the cooling of the middle and the upper atmosphere. For the mesopause region (~87 km) the tendency of long-term change of temperature has a non-linear character. The values of the temperature long-term trend for temporal intervals from 1955 up to 1990 and from 1990 up to present are –(0.7) K·year^{-1} and –(0.2÷0) K·year^{-1}, respectively.

Introduction

In recent decades the steadfast attention of scientists is directed to the problem of global change of the Earth climate. According to information of the World Meteorological Organization the temperature of air being a sensitive measure of climatic changes (the regular measurements of temperature are available since 1860), has increased in an atmospheric boundary layer by ~0.6 K over the last 100 years [WMO, 2002]. Moreover, over the last 2–3 decades, the rate of warming has appreciably exceeded its centennial mean value [WMO, 2002]. The results of numerical modeling have shown, that by the end of XXI century the increase of the air temperature in the surface layer can reach 1.4–5.8 K. This, in turn, can mean, that the air temperature in the surface layer will grow faster than ever during the last 10000 years. Such a rise in temperature can inevitably have an essential influence on the environment all over the world.

In connection with this problem a great deal of researchers' attention is attracted by studies of the condition of the upper layers of atmosphere. The reason of this is, on the one hand, the real opportunity of catastrophic consequences of anthropogenic change in the chemical composition of the atmosphere, such as ozone depletion. On the other hand, according to theoretical research, global changes in the thermal and dynamic regimes owing to increasing inflow of greenhouse gases are stronger in the upper layers of atmosphere than within the surface atmospheric layer [Rind et al., 1990].

In the recent decade many papers, dealing with the investigation of long-term temperature trend have been published. In these papers the tendencies of long-term behavior of the temperature regime of various layers of the Earth atmosphere are analyzed on the basis of more or less long series of observations of temperature and other characteristics of the middle and upper atmosphere obtained by rocket, satellite, lidar, radiophysical and optical methods. The quantitative estimations of such long-term changes obtained by various authors, considerably differ from each other [Beig et al., 2003; Laštovička, 2005]. In many respects it can be caused by the duration of temporal series of the measured parameters used for the analysis, by the helio and geophysical conditions, and also by the conformity to the temporal duration of the measured series of observations. Besides, the problem of revelation of long-term changes of any characteristics of geophysical processes demands to observe obligatory conditions connected to the preliminary exception from the analyzed data of all types of periodic and casual variations. The analysis of materials about the temperature trend at the height of the mesopause, obtained by hydroxyl emission (the duration of measurement of the hydroxyl emission is the longest) has shown, that the behavior of a trend has appreciable seasonal, latitudinal, altitude features, and also the dependence on what time interval it concerns (it is very essential). Non-observance of these conditions is the reason of absence of unambiguous representation about the character of long-term change of the condition of atmosphere at the level of the mesopause and lower thermosphere, and it results in a pointless discussion about the value of a trend.

Experimental results

The temperature in the region of the mesopause was determined by the distribution of intensity in vibrational structure of the bands of hydroxyl molecules [Chamberlain, 1961] as the emission layer has a maximum near 87 km [Shefov, 1978 b; Baker and Stair, 1988; Semenov and Shefov, 1996 a]. It is necessary to note, that observable variations of temperature should be carried to a layer of hydroxyl emission with halfwidth of ~ 8.5 km with the center near 87 km. These temperature data obtained in Abastumani (1957–1972) and in Zvenigorod (1957–1995) are presented in Fig. 1. The estimation of the behavior of temperature for the specified periods of time shows the presence of a negative trend for both stations, equal – (0.7 ± 0.1) K·year^{-1} [Givishvili et al., 1996] (Fig. 1).

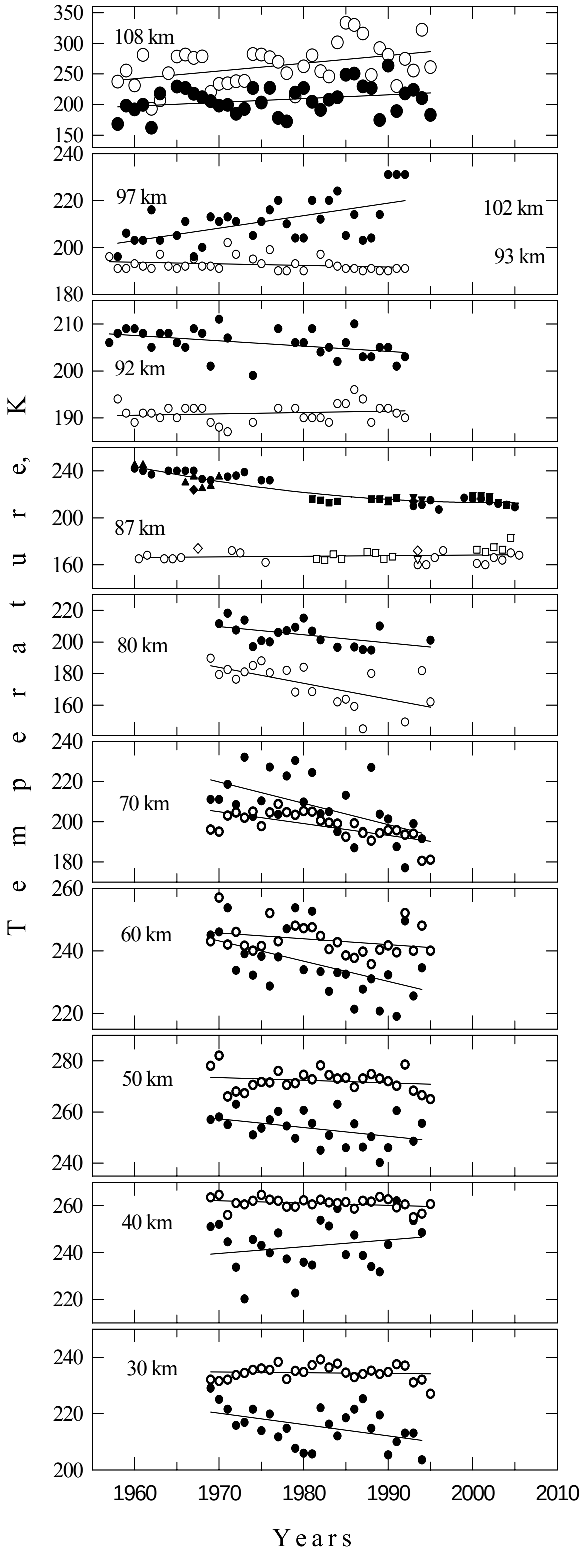

Fig.1. The long-term variations of the mean monthly temperatures for winter (December) and summer (June) at different heights (30-110 km) according to rocket (30-80 km) [Semenov et al., 2002], nightglow (87, 92 and 97 km) and radiophysical (110 km) [Semenov et al., 2002] measurements. Black symbols are December, hollow symbols are June. For the height of 87 km the circles are Zvenigorod, squares are Wuppertal, triangles are Yakutsk, inverted triangles are Maynooth, diamonds are Quebec and Delaware. The solid lines are regression lines.

Subsequently, when the data of observation for 1995÷2005 appeared, there was an opportunity to track a further tendency of the temperature behavior in the region of mesopause. Besides, the performance of recent special studies about the ratio between the rotational temperatures for spectral bands of hydroxyl molecules with various vibrational excitation [Bakanas and Perminov, 2003; Bakanas et al., 2003], has allowed to reveal that there are regular seasonal distinctions between temperatures for OH bands with various vibrational excitation, but the mean annual values differ insignificantly.

An important part of the discussed problem is used by various researchers at the calculation of rotational temperatures of various factors of intensity (line strengths). Unfortunately, this circumstance is not give enough concern. As a result of it there is a divergence in the measured temperatures up to 5÷14 K. The characteristic temperature for the region of hydroxyl emission is ~ 200 K (~87 km). In this connection, the change of the used factors of intensity during the long-term period of measurements will be inevitable to cause a distortion of character of the long-term changes of temperature of the mesopause. Besides, the comparison of absolute values of temperatures when using various types of factors of intensity will also cause a distortion of results [Shefov et al., 2006].

Therefore for 1984-1986 when the temperatures were obtained using the OH(8–3) band, the necessary correction (in Fig.1) of results of measurements of the temperature to the fifth vibrational level was made because earlier the temperature presented in the Figure was determined in the OH (5–2) band [Semenov and Shefov, 1996 a]. In the same Figure the black triangles show the behavior of temperatures data obtained at Wuppertal station [Offermann and Graef, 1992; Bittner et al., 2002; Offermann et al., 2004]. The presented data set for the first time has allowed to reveal in the recent years (beginning with the end of 1980) the occurrence of appreciable easing of the negative tendency of temperature change in the region of mesopause. It allows to suppose about the appreciable nonlinear character of long-term behavior of the temperature in this region of atmosphere heights. Thus, variations of the temperature trend during the considered period of observation break up as though to two parts: 1955÷1990 is practically a linear change of temperature with a rate of approximately – 0.6 K·year^{-1} and 1990÷2005 is a gradual decrease of the value of the trend up to (–0.2÷0) K·year^{-1}. Unfortunately, at present it is early to speak about the further tendency of behavior of the temperature trend. For this purpose the continuation of further observations of duration of at least, one – two cycle of solar activity is necessary. The analytical presentation of the line of approximation describing the behavior of long-term change of temperature for the period 1955÷2005 at heights of 87 km (Fig.1) can be presented as

$$T(t) = 214 - 0.50 \cdot (t - 1990) + 0.017 \cdot (t - 1990)^2, K$$

where t is the number of year. In Fig. 1 the variations of mean annual values of temperature of the atomic oxygen emission of 557.7 nm (~ 97 km) obtained by interferometric [Hernandez and Killeen, 1988] and lidar [She et al., 1993, 1995] measurements are also presented. In the same Figure the estimations of values of temperatures obtained on the basis of data on the behavior of 557.7 nm emission intensity [Semenov and Lysenko, 1996] are shown. We notice that in the entire data set (1924÷1992) there is a weak tendency of decrease of temperature at the height of ~ 97 km for the middle latitudes. The linear trend of temperature for this interval of years is approximately –0.1 K·year^{-1} (Fig. 1).

The estimations of temperature in ionospheric layer E (~ 110 km) [Givishvili and Leshchenko, 2000] are made on the materials of vertical sounding [Givishvili and Leshchenko, 1993, 1995] at stations of Moscow (55.5°N), Slough (52.5°N) and Juliusruh (55.6°N) and on the data of measurements of the incoherent scatter (1967-1975) at station of Saint-Santin (44.6°N, 2°E) [Alcaydé, 1979]. According to [Givishvili and Leshchenko, 1995, 2000] since 1931 till present time the regular growth of temperature of atmosphere at heights of about 110 km with an average speed of ~ +1 K·year^{-1} (Fig. 1) has been observed.

Conclusions

Thus, on the basis of the long-term data (1955–1995) about the temperature of the mesopause (~87 km), obtained using spectrophotometric measurements of the hydroxyl emission and the analysis of the published data of lidar, rocket (25–80 km) and ionospheric (105–110 km) measurements of the atmosphere temperature the cooling of the middle and upper atmosphere has been revealed. This cooling passed with the rate – (0.2÷0.8) K·year^{-1} (Fig. 1). The addition to the specified time period of the results of measurements of the mesopause temperature by hydroxyl emission during 1995–2005 has revealed the tendency of decrease of the rate of temperature change of the mesopause, which for this period was (0÷ – 0.2) K·year^{-1}.

Unfortunately, the absence of regular and long-term measurements of temperature at other heights of the middle and upper atmosphere do not allow to track the tendency of change of temperature at these heights during the period after 1995.

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