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Ionosphere, Mesosphere and Lower Thermosphere

Latitudinal - seasonal model of the temperature response of the middle atmosphere to solar activity

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ABSTRACT:

Based on rocket and nightglow measurements at middle atmosphere heights covering several cycles of low solar activity, characteristics of seasonal response of mean monthly atmospheric temperature to solar activity are obtained at different heights of the atmosphere at middle and high latitudes. These results are used in the development of an empirical model. which allows the determination of the atmospheric temperature response as a function of latitude, month of the year and level of solar activity at heights of 30-90 km.

Keywords: Middle Atmosphere, Temperature Response, Solar Activity, Model.

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1. Introduction

A lot of attention has been paid recently to studying the response of the middle atmosphere to solar activity [1]. In many respects this is caused by the fact that for correct estimation of the observed long-term temperature variations at different altitudes using data obtained for different periods, it is necessary to reduce these data to uniform conditions in order to eliminate the effect of solar activity. However, available models of the middle atmosphere cannot be used for this purpose since the effect of solar activity at altitudes of 30–95 km is not represented. Some estimates of the effect of solar activity on the character of vertical temperature distribution were considered in review [1]. In this review the results of the measurements performed using the hydroxyl emission and the method of falling spheres [2,3] at high latitudes and a lidar [4,5] at midlatitudes were summarized. The authors of the review indicate that the results can not be explicitly used to understand the observed trends at different latitudes because short periods of observations used in analyses hinders reliable separation of the effects of solar activity and long-term trends. The present work studies the response of the average monthly temperatures of the middle atmosphere to solar activity based on long-term data obtained using rocket measurements [6] and spectrophotometry of the natural atmospheric emissions during several 11-year solar cycles at low, middle, and high latitudes [7]. In addition to the long-term rocket measurements the results of the spectrophotometric measurement of the hydroxyl emission, obtained on Spitsbergen (81º*N* [8]) were used to analyze the response of the average monthly temperatures of the high-latitude middle atmosphere to solar activity.

2. Results of measurements and the analysis

The response of temperature to solar activity at midlatitudes was revealed using the vertical temperature profiles (30–110 km) [9] obtained from rocket measurements at altitudes of 30–80 km and spectrophotometric measurements of the hydroxyl (87 km), sodium (93 km), and atomic oxygen (97 km) emissions. The vertical temperature distributions at midlatitudes are presented in [10] for all months for the years of maximal (1980, $F_{10.7}$=198, and 1991, $F_{10.7}$=208) and minimal (1976, $F_{10.7}$=73, and 1986, $F_{10.7}$=75) solar activity.

It should be noted that the errors in individual rocket temperature measurements varied from ~3 K at altitudes of 20–45 km to 6 K at 65–80 km altitude. The average monthly temperature profiles were constructed using the data of not less than ten rocket launches in a month, which considerably decreased the errors of the average monthly temperature profiles (1–2 K depending on altitude) [7]. The error of the spectrophotometric temperature measurements was 2 K. For low, middle, and high latitudes, the average monthly vertical temperature profiles at altitudes of 20– 80 km for the considered years of maximal and minimal solar activity (Fig. 1) were constructed based on the rocket measurements at the Thumba (8.5°*N*), Volgograd (48°*N*), and Heiss Island (80.6°*N*) stations. The data of spectrophotometric temperature measurements for the middle and high latitudes have been taken into consideration.

Based on these data and using the temperature difference for different altitudes of the average monthly profiles corresponding to

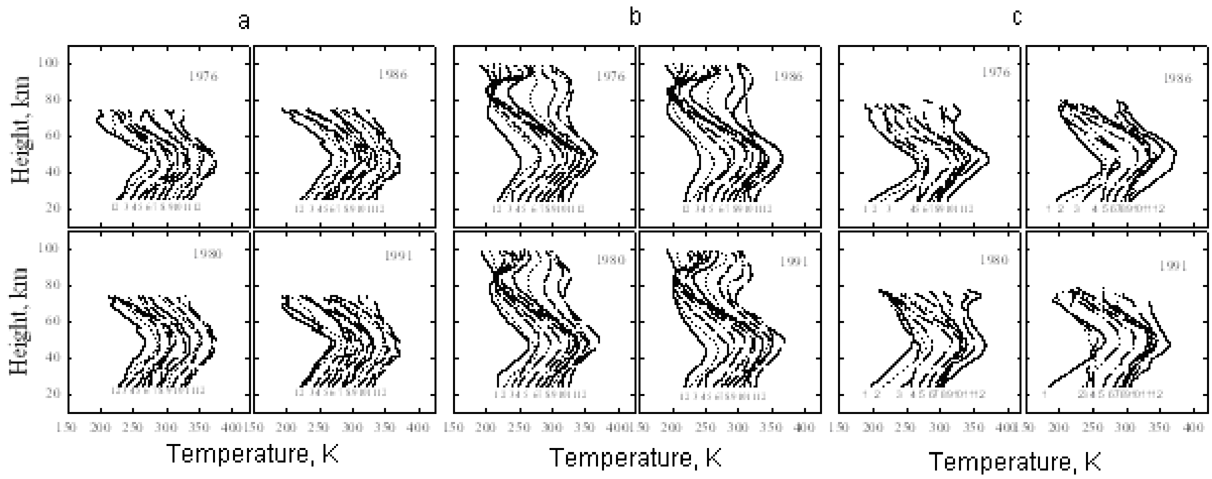

Fig. 1: Vertical distributions of the average monthly temperatures in the middle atmosphere at (a) low, (b) middle, and (c) high latitudes for the years of solar activity minimums (1976, $F_{10.7}$=73, and 1986, $F_{10.7}$=75) and maximums (1980, $F_{10.7}$=198, and 1991, $F_{10.7}$=208). The temperature profiles for each month are shifted to the right relative to the previous profile by 10 K. The first profile on the left corresponds to January.

the years of high and low solar activity, the rate of temperature rise due to solar activity can be found in the following form using a linear approximation [9]: under the action of solar activity can be found in the following form in a linear approximation [9]:

$$\Delta T(Z) = \delta T_F(Z)\frac{F_{10,7}-130}{100}K, \quad (1)$$

where $\delta T_F(Z) = dT/dF$ is the temperature change at altitude Z for $F_{10,7}$=100 sfu. The seasonal variations were constructed upon determining $\delta T_F(Z)$ for different altitude levels. These dependences were approximated by the sum of four harmonics in order to reveal regular patterns. Thus,

$$\delta T_F(Z) = A_0 + \sum_{n=1}^{4} A_n(Z)\cos\left[\frac{2\pi n}{T_{an}}\left[t_d - t_n(Z)\right]\right], \frac{K}{100}\text{sfu}, \quad (2)$$

where T_{an}=365.2425 days is the duration of a year, and t_d is one day of a year.

The vertical variations in the amplitude $A_n(Z)$ and phase $t_n(Z)$ were approximated using the polynomials as functions of altitude Z:

$$A_n(Z) = \sum_{k=1}^{9} a_{nk}\left(\frac{Z}{100}\right)^k, \frac{K}{100}\text{sfu}, \quad (3a)$$

$$t_n(Z) = \sum_{k=1}^{9} b_{nk}\left(\frac{Z}{100}\right)^k. \quad (3b)$$

The results of the approximation $\delta T_F(Z)$ for the equatorial, middle, and high latitudes are shown in Fig. 2 (solid lines); dots are the data of measurements smoothed by three-month moving averages in order to eliminate random outliers. These data represent insignificant temperature differences (~2–10 K), which are determined for different levels of solar activity between vertical profiles. It should be noted that the average temperature value for the considered altitudes was ~200 K.

The authors of [1] presented the $\delta T_F(Z)$ values ($K/100$ sfu) for different latitudes, not indicating seasons. Therefore, it is very difficult to compare their results with one another and with the results presented in Fig. 2. For example, based on the measurements at altitudes about 80 km during the summer period (69°N) [2] and 87 km during winter (78°N) [3], the conclusion was drawn that the temperature does not respond to solar activity at high latitudes in the Northern Hemisphere. At the same time, a positive response (5 $K/100$ sfu) was obtained at high latitudes of the Southern Hemisphere (69°S) [11]. For lower latitudes, the authors of [12] (59°N), [13] (43°N), and [14] (43°N) presented the response estimates varying from 1.5 to 2.6 $K/100$ sfu. Figure 2 indicates that, during these periods, the atmospheric response to solar activity at height of the midlatitude mesopause is most pronounced in autumn, winter, and spring. For summer months, the atmospheric response remains almost unchanged, although it has a maximal value. Therefore, the spread in the values is apparently caused by the seasonal character of observations. Nevertheless, it should be noted that the results obtained in Wuppertal (midlatitudes) [13] almost coincide with the average response values at midlatitudes shown in Fig. 2. The lidar midlatitude measurements (1978–1989) at altitudes of 33–75 km [4] also indicated that the response changes its sign in winter and summer depending on altitude. These researchers obtained that the response values at altitudes of 60–70 km were ∼5 and ∼3 $K/100$ sfu in winter and summer, respectively. For altitudes about 40 km, these authors obtained that the values were about −6 and −1 $K/100$ sfu in winter and summer, respectively.

In order to extend the analysis over a range of latitudes, an assumption has been made that the variability in the response of the atmospheric temperature in the Southern hemisphere is similar to that observed in the Northern hemisphere. Naturally, the difference in the seasons for Southern and Northern hemispheres was taken into account.

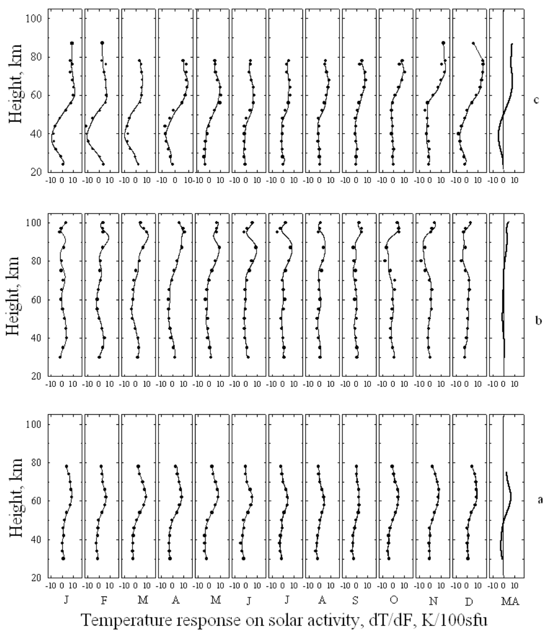

Fig. 2. Vertical distributions of the temperature response $\delta T_F(Z)$ to solar activity for different months of the year at (a) polar, (b) middle, and (c) low latitudes. Dots are data of measurements; solid lines, approximations. For polar latitudes, the $\delta T_F(Z)$ values at an altitude of 87 km are presented according to [8,15]. MA is the average annual vertical distribution.

Figure 3 shows the altitude distribution of the atmospheric temperature response to solar activity over the latitude range from 80 S up to 80 N for all months of year. Apparently, the temperature response is observed for all months of the year ranging from -10 up to +10 $K/100$ sfu. At heights above 55 km for the entire latitude range, the response is practically always positive, reaching the highest values in the polar and equatorial regions. Below 55 km, the response is negative during the equinoctial periods for the considered latitude range. During winter and summer the response is negative in polar and equatorial regions while at middle latitudes the response exhibits weak positive values (up to +4 $K/100$ sfu) in both hemispheres. Such a behavior of seasonal change of temperature response in the middle atmosphere is obviously associated with features of the altitude distributions of chemically active gas components and the influence of the solar UV radiation, in many respects defining the altitude distribution of temperature.

3. Conclusion

The obtained profiles of the temperature response of the middle atmosphere at various heights on solar activity for the equatorial, middle and polar latitudes show altitude nonlinearity.

At low latitudes, a positive reaction of a temperature regime to solar activity at heights of 50-70 km (up to +10 $K/100$ sfu) is observed. For the height range of 30-50 km, the temperature response is practically absent for winter period and negative for summer (-2 $K/100$ sfu). Above 70 km, a tendency for a negative monthly temperature response is observed.

At the middle latitude at heights of 55-70 km, the changes of the response are usually small (+2 $K/100$ sfu for winter and -1 $K/100$ sfu for equinoxes). At stratospheric heights of 30-55 km, noticeable changes exist in winter and spring (+5 $K/100$ sfu). The greatest seasonal variations are found at heights of 80-95 km (-5 $K/100$ sfu for winter conditions and +8 $K/100$ sfu for summer).

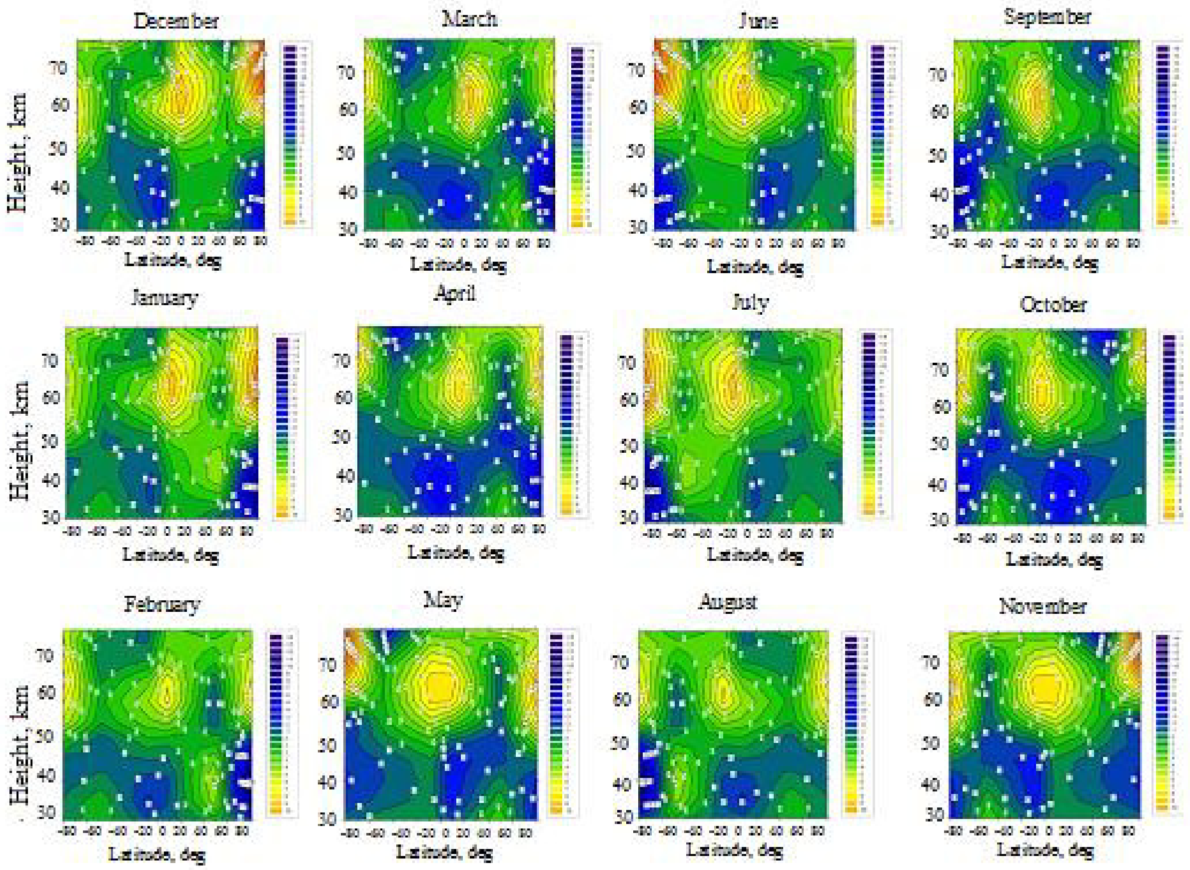

Fig. 3. The altitude distribution of the temperature response of an atmosphere on solar activity in the latitudinal range from 80 S up to 80 N for all months of year.

The negative response of the temperature regime to solar activity at altitudes of the stratosphere and the positive response at altitudes of the mesosphere, with no insolation during the prolonged period of the polar night, are typical for high latitudes. In summer, when the polar atmosphere is sunlit around the clock for several months, the temperature behavior up to altitudes of 50 km changes insignificantly. The difference becomes pronounced above 50 km, when the positive response to solar activity is considerable (up to 10 K/100 sfu).

The presented results highlight the importance of accounting for solar activity variation impacts in the analysis of long-term behavior of the temperature regime of the middle atmosphere at the different heights and latitudes. Without considering these effects, one can misinterpret the results of long-term temperature regime changes obtained at different stations and for the various heliogeophysical conditions.

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