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Empirical model of vertical structure of the middle atmosphere: Seasonal variations and long-term changes of temperature and number density

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Abstract

An empirical model of the mid-latitude (40°N–55°N, altitudes 25–110 km) monthly averaged vertical structure of temperature and number density is presented. It is based on the Soviet and Russian rocket, emission and radioionospheric temperature data and also aerologic pressure data, obtained during 1955–1995. The model reveals a long-term trend and solar activity effect in seasonal variations of temperature profiles. Here we present some new results for number density model vertical profiles and season–altitude and season–pressure maps of temperature for different years. Some conclusions concerning seasonal, solar activity and long-term variations in the vertical structure of the middle atmosphere are elaborated. The monthly averaged one-humped structure of temperature (one maximum and two minima) near the mid-latitude mesopause is found to be typical for all the seasons, both for periods of low and high solar activity. This structure is maintained despite the process of long-term changes at the second half of 20th century. The model confirmed the well-known fact that atmospheric density in lower thermosphere is greater in years of solar maxima. During the second half of 20th century, pressure and density decreased gradually. For altitudes around 100 km, lines of constant number density descended at a mean rate of 1–4 km per 10 years.

Keywords: Middle atmosphere; Seasonal variations; Long-term changes; Number density

1. Introduction

The paper develops a new approach to modeling of vertical structure of the middle atmosphere. The empirical model of the mid-latitude (40°–55°N, altitudes 25–110 km) monthly averaged vertical structure of temperature is prepared on the month-by-month base, covering 40 years 1955–1995 (Semenov et al., 2002). It is based on the Soviet and Russian rocket (rocket station Volgograd, 49°N, 44°E), emission (Zvenigorod, 56°N, 37°E; Abastumani, 42°N, 43°E) and radioionospheric (Moscow, 55°N, 37°E) temperature data and also aerologic pressure data, obtained during 1955–1995. The model revealed a long-term trend and solar activity effect in seasonal variations of temperature profiles. In this paper we present some new results for number density model vertical profiles and season–altitude and season–pressure maps of temperature for different years. Conclusions concerning the seasonal, solar activity and long-term variations in vertical structure of the middle atmosphere are given.

2. Vertical structure of temperature and number density

2.1. Monthly averaged temperature profiles and their seasonal variations

Reference models of the middle atmosphere in the latitude–altitude region considered provide smooth temperature profiles with two extrema: maximum (stratopause) and minimum (mesopause). Our model reveals a more

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complicated but, nevertheless, a very stable structure of temperature. The temperature gradients may change, and the altitudes of the extrema may ascend or descend from month to month and from year to year, without a change in the general behaviour. It may be characterized by four extrema: a maximum at the stratopause, a minimum at the main mesopause, an additional maximum, higher than the main mesopause and the higher minimum. For example, in Fig. 1, season–altitude maps of temperature for 1976 and 1986 are shown (the symbol corresponding to a month in the figures refers to the middle of the month). The dashed black and gray lines depict the temperature maxima and minima, correspondingly. Years 1976 and 1986 belong to periods of solar minimum. This general behaviour of temperature is maintained during the solar maximum (see Fig. 2 for years 1980 and 1991), however, in July, the two upper extrema merge.

2.2. Number density

Season–altitude maps for total number density were calculated according to

$$n(z) = \frac{N_A \cdot p_{25}}{\mu(z) \cdot g(z)} H^{-1}(z) \cdot \exp\left[-\int_{25\mathrm{km}}^{z} H^{-1}(z)\,\mathrm{d}z\right] \tag{1}$$

Using the monthly averaged temperature $T(z)$ profiles and the monthly averaged values of pressure p_{25} logarithm at a height of 25 km; the value

$$H^{-1} = \frac{\mu \cdot g}{R \cdot T} \tag{2}$$

is the reciprocal of the barometric scale height. It is approximated by a spline function. R is the universal gas constant, μ is the average molar mass of air, g is the gravitational acceleration, N_A is the Avogadro number. The pressure data were taken from results of the aerologic soundings accompanying the rocket soundings. Patterns of the number density maps for 1976 and 1986 are shown in Fig. 3. After obtaining the number density or pressure profiles, the temperature vs pressure variations may be computed The same data as shown in Fig. 1, but recalculated to the season-pressure grid, are presented in Fig. 4.

3. Results concerning long-term variations

3.1. Variations in solar cycle

Analyzing the EISCAT and some other data that provide annually averaged vertical structure of temperature, Lysenko et al. (1999), Semenov (2000), and Fadel et al. (2003) demonstrated an existence of the temperature maximum at the upper mesosphere with a temperature increase by 10–20 K and, consequently, the two temperature minima, upper and lower. The value of this maximum appears to be in correlation with solar activity. This was discovered earlier by She et al. (1993), however, they described it as an episodic rather than a permanent feature. Now based on the data considered in this paper (for the solar maximum years – 1980 and 1991, and for those of solar minimum – 1976 and 1986), we are able to formulate the more exact conclusion concerning a vertical structure of temperature near the mesopause. Such a one-humped picture of vertical structure of temperature (i.e. one maximum and two minima) does characterize the mesopause region both in the years of solar maximum and also those of solar minima. It is obvious from the temperature maps, shown in Figs. 1, 2.

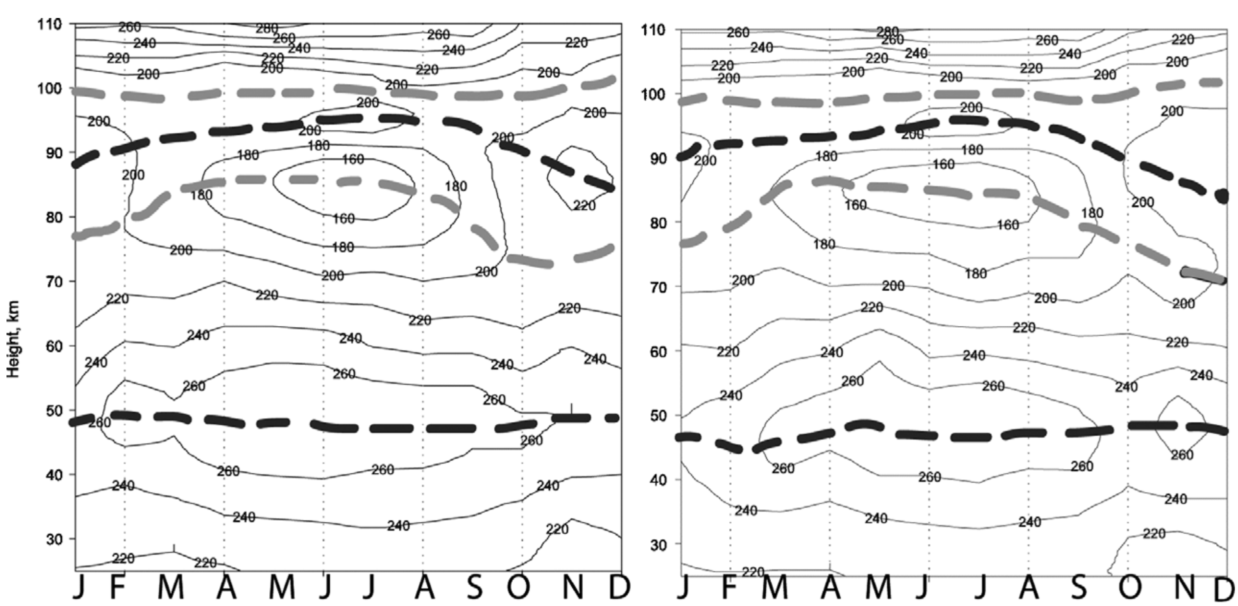

Fig. 1. Contours of constant temperature for 1976 and 1986. The dashed black and gray lines show the corresponding positions of the temperature maxima and minima.