Morphological characteristics of the atmosphere temperature regime in the south region of East Siberia

M.A. Chernigovskaya

Institute of Solar-Terrestrial Physics,
Siberian Branch of the Russian Academy of Sciences, Irkutsk

Received July 16, 2008

The temporal and altitude temperature variations in troposphere, stratosphere, and mesosphere for the Irkutsk region (52°N, 104°E) over the period from August, 2004 to March, 2008 have been analyzed. We used satellite data of the vertical temperature distribution obtained with MLS (Microwave Limb Sounder) aboard the satellite EOS Aura. Diurnal, inter-diurnal, and seasonal variations of the temperature were considered for height levels of 11, 50, and 80 km. The annual mean temperature variations at given heights were obtained by averaging for each day of year for the investigated period. The temporal variations of the temperature and the height of the stratopause and mesopause for day and night conditions were studied. We have plotted and analyzed altitude-temporal maps of the atmospheric temperature distribution for each month of the period under consideration.

Introduction

Temperature plays central role in atmospheric physics. It is the key parameter in radiative budget of the atmosphere. The atmospheric temperature is the parameter, which determines or affects many other parameters (for example, density, rate of chemical reactions) and processes (dynamical, chemical, heat transfer) in the atmosphere and ionosphere. Temperature is especially important in hydrological cycle, because it governs the cloud formation and distribution of the atmospheric humidity.

Main features of the stratified structure of the atmosphere are determined first of all by the peculiarities of the temperature vertical distribution.[1,2] Temperature decreases with height. Then, in the stratosphere temperature increases, because ozone absorbs solar radiation and heats the stratosphere. Heating due to ozone decreases above 50 km, and temperature decreases again. Above 80 km, the solar radiation of very high energy again heats the atmosphere.

When studying the Earth atmosphere as a unified system, the vertical sensing is very important instrument. The methods of vertical sensing are various[3]: optical sensing by a laser beam, acoustic sensing by sound, as well as radiosonde, radar, rocket, and satellite sensing.

Since the ground-based sensing methods provide for only 20% of the information, necessary for meteorological and climatic forecast of the weather[4] leaving uncovered vast oceanic polar and mountain regions, the sensing of the atmosphere from artificial satellites of the Earth, capable of collecting data over all regions, plays the most important role.

The important advantage of the remote sensing from space is the real-time determination of the field of vertical profiles of the Earth's atmosphere (chemical composition, wind, humidity, temperature, etc.)[5]. The vertical profile of temperature can be calculated from measurements of the spectral distribution of the outgoing thermal radiation of the "Earth – atmosphere" system, because its intensity definitely depends on the temperature. Measurements are carried out in narrow spectral regions corresponding to the absorption bands of gases, the vertical distribution of which in the atmosphere is stable and well studied.

As the methods of sensing of the atmosphere, especially satellite sensing, are developed and improved, the interest of researchers to the study of spatial-temporal structure of the atmospheric temperature at different height levels is resumed.[6–15] A lot of papers are published, in which periodicities of different temporal scales are analyzed (from inner gravitational waves, flood-tides, and planetary waves to half-year, annual, quasi-biannual, etc.).[10–13] The works on revealing many-year trends of temperature of the Earth's atmosphere both in lower atmosphere (troposphere) and in the middle atmosphere (stratosphere and mesosphere)[14] are carried out.

In this paper we study temporal and altitudinal variations of temperature in the troposphere, stratosphere, and mesosphere during the period from August, 2004 to March, 2008 in the region of Irkutsk (52°N, 104°E) from the satellite data.

Data under analysis

Data on the vertical profiles of the atmospheric temperature, obtained by means of the Microwave Limb Sounder (MLS) installed onboard the satellite Aura EOS[15] were used for analysis. The Aura satellite was launched in July 15, 2004.

0235-6880/08/12 962-07 $02.00

The Aura EOS satellite is a part of the "A-Train" mission. These satellites, intended for observation of the Earth and situated on the orbits with close parameters make it possible to carry out unique comprehensive investigations. They fly one after another above the same regions of the Earth with an interval of 15 min, and form the database for creation of a common image of the global climate changes.

The satellites have a polar orbit (a period of rotation is about 100 min, and a height of 705 km). The spatial coverage is almost global (from –82° to 82° by the latitude). Vertical profiles are measured with an interval of ~25 s every 1.5° (~165 km) along the orbital trajectory. About 15 flies of the satellite are carried out during a day. The MLS scans the Earth limb in the flight direction, recording the microwave emission in five spectral bands (at frequencies of 118, 190, 240, and 640 GHz and 2.5 THz). The data of MLS measurements are used for retrieval of profiles of the chemical composition, relative humidity and temperature of atmospheric areas from the troposphere and stratosphere up to the upper mesosphere as functions of height of isobaric surfaces represented in hPa.

The MLS Aura data on temperature are shown in the form of vertical profiles from the ground surface to a height of 10^{-5} hPa (0–130 km).[15] The working area is height range 316–0.001 hPa (approximately 9–92 km), the error in measuring temperature is 0.5–1 ÷ 1–2 K, and the vertical resolution is about 3 km.

The database on atmospheric temperature assessed from the satellite MLS Aura data from August, 2004 up to now is formed. The initial data files contain information about the global distribution of temperature for each day of the considered time interval. The computer code is developed, which enables obtaining the vertical profile of temperature for the preset input parameters:

– geographical coordinates (latitude and longitude);

– local time (day or night), i.e., a choice of ascending or descending satellite orbit;

– distance to the satellite orbit.

Analysis of the observational results and discussion

To analyze the temporal and altitudinal variations of the atmospheric temperature, the diurnal, inter-diurnal, seasonal (annual) and annual average variations of temperature at height levels of about 11, 50, and 80 km were used, which approximately corresponded to heights of tropopause, stratopause, and mesopause.

A strong inter-diurnal temperature variability is observed at all considered heights. Daily mean values of the temperature under daytime conditions at the considered height levels are shown in Fig. 1 as an example (symbols), as well as the curves of one-month sliding mean temperature under daytime (approximately 14 LT) and nighttime (approximately 03 LT) conditions for the whole considered time interval.

The well pronounced annual (seasonal) temperature behavior is observed. The annual variation at heights of the troposphere and stratosphere has a maximum in summer and a minimum in winter. Temperature at heights of the mesosphere varies in opposite phase with the stratosphere and troposphere: with minimum in summer and maximum in winter. Diurnal variations of temperature are observed in the majority of cases as the temperature decrease at night as compared to daytime values. This is best pronounced at heights of the upper mesosphere.

A strong difference in atmospheric temperature variations at heights of stratopause under summer ($V_x \approx 1.4 \div 1.5\%$) and winter ($V_x \approx 3.8 \div 4.3\%$) conditions is observed (see Table).

Height, km	$\bar{X}$, K		σ, K		$V_x = \sigma/\bar{X} \cdot 100\%$	
	day	night	day	night	day	night
summer						
11	219	218.2	4.1	4.0	1.9	1.8
50	269.5	268.9	3.7	4.1	1.4	1.5
80	172.5	164.3	8.9	8.5	5.2	5.2
winter						
11	211.4	212.5	5.1	5.2	2.4	2.4
50	256.7	254.4	9.8	10.9	3.8	4.3
80	206.3	203.5	8.9	9.8	4.3	4.8

Possibly, this difference is caused by the fact that the abrupt stratospheric warmings, i.e., anomalous warmings of air in the stratosphere by tens of degrees, are observed in the considered region of the south of East Siberia almost each winter. Sometimes the temperature can exceed the summer maximum. Geographical inhomogeneity of the distribution over the Earth is characteristic of stratospheric warmings, and their concentration over Asia is high[16].

Annual mean temperature variations at the considered height levels were calculated by means of averaging the initial data for each day of an year over all years and then they were smoothed by the one-month sliding mean (Fig. 2).

The mean seasonal variation of the greatest amplitude is observed at heights of mesopause (about 40°) and stratopause (up to 20°). The amplitude of seasonal variation at tropopause heights is about 10°. Mean maximal temperature in winter (December, January) at mesopause heights (~ 80 km) is approximately equal to the mean minimal temperature at tropopause heights (about 11 km) and equals 210°K.

Temporal variations of temperature and heights of the stratopause and mesopause were analyzed separately, and their seasonal, diurnal and inter-diurnal variability was also observed.

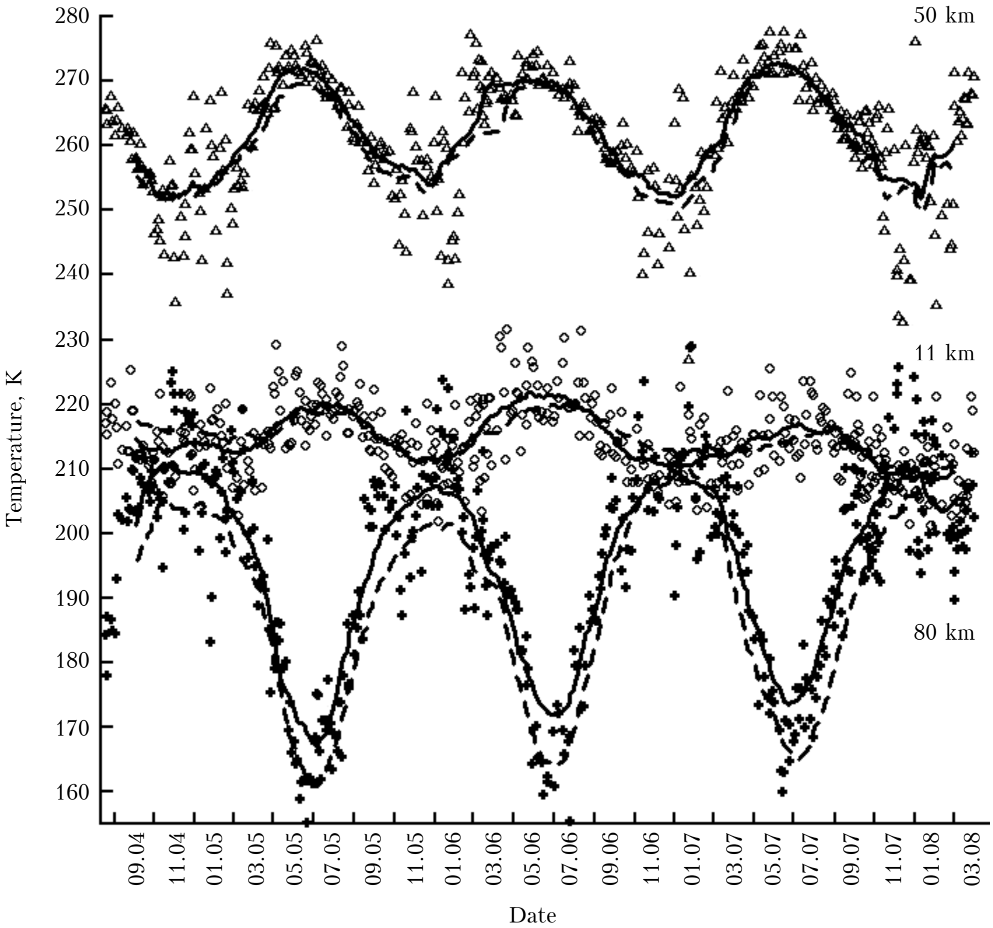

Fig. 1. Diurnal daytime values of temperature (symbols) and one-month-smoothed sliding mean temperature curves for daytime (solid line) and nighttime (dot line) conditions at the considered height levels.

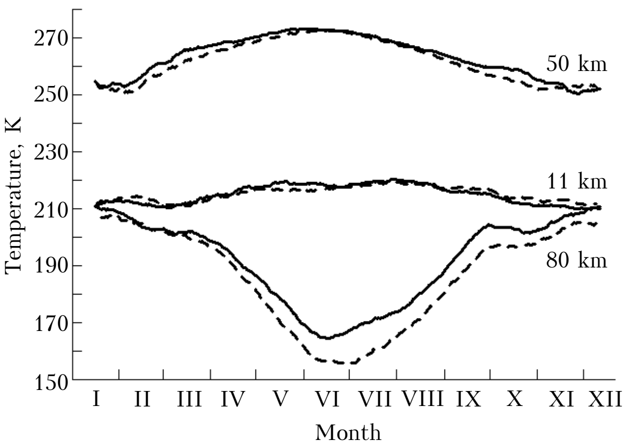

Fig. 2. Annual mean variations of temperature at the considered height levels under daytime (solid line) and nighttime (dot line) conditions.

Seasonal temperature variation in stratopause in summer (April – October) has a regular manner, but in winter (November – March) these variations are extremely irregular. Temperature of the winter stratopause very often reaches summer values and even exceeds them (top in Fig. 3).

The histograms confirm this fact: the most probable temperature for summer and winter is about 260–270°K (Fig. 4*a*).

Most probable stratopause height is 48–52 km throughout a year (Fig. 4*c*), however, a wide scatter of heights is observed in winter period. Temperature of the mesopause shows a better pronounced seasonal variation, although the inter-diurnal variations are also great (Fig. 3, bottom). The winter mesopause (the most probable $T_{\text{mes}} = 180 \div 190$ K) is warmer than the summer one ($T_{\text{mes}} = 170 \div 180$ K) (Fig. 4*b*).

The most probable height of the mesopause in winter is 88–96 km, and in summer it decreases to 80 km (Fig. 4*d*).

The built and analyzed altitudinal-temporal distributions of atmospheric temperature for each month of the considered time period made it possible to confirm the conclusion about essentially different temperature regimes in the middle atmosphere in summer and winter. They are shown for June, 2007 and January, 2008 in Fig. 5, as well as the vertical profiles of temperature for June 15, 2007 and January 7, 2008 (see website of Aura satellite (http://disc.sci.gsfc.nasa.gov/Aura/MLS/).

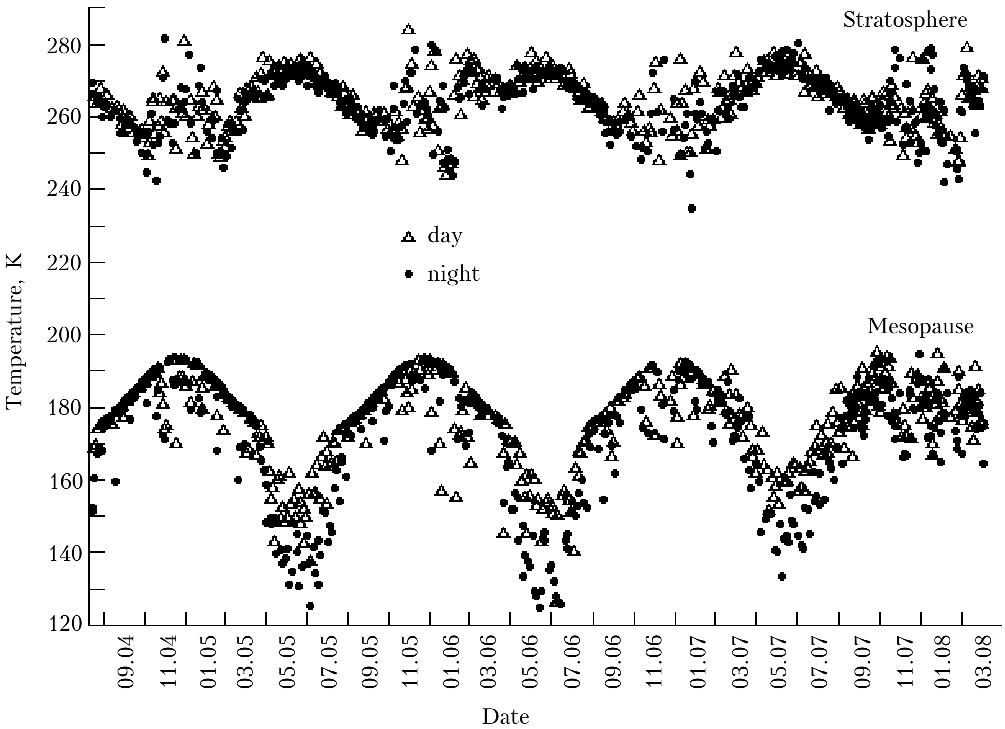

Fig. 3. Temporal variations of stratopause and mesopause temperature under daytime and nighttime conditions.

The temperature regime of the atmosphere in summer is irregular with well pronounces warm stratopause and cold mesopause (Fig. 5*a*). The altitudinal-temporal distributions of the temperature in winter in the considered height interval have irregular structure; well pronounced stratopause and mesopause are absent. Range of enhanced temperature values of stratopause is extended to 10 km and more, and decreases to heights of about 30 km. Several maxima are observed in the vertical temperature profiles (Fig. 5*b*).

These peculiarities of winter temperature regime of the middle atmosphere can be related, in our opinion, with the appearance of the known effect of enhanced winter variability of the parameters in stratosphere and mesosphere.[17,18] This effect lies in intensification of the wave activity of different temporal scales in the middle and upper atmosphere and, as a rule, is accompanied by a complex of phenomena: the abrupt winter stratospheric warming, intensification of vertical transport, turbulent processes, break of atmospheric circulation, etc. Some of the aforementioned phenomena can be observed as regional or longitudinal peculiarities of the characteristics of the middle and upper atmosphere. To date, the longitudinal (or regional) effects were observed for components of prevalent wind and flood-tides at heights of ~ 80–100 km,[18,19] for radiance of the upper atmosphere at a line of 557.7 nm (the radiance at 85–115 km heights).[20,21]

These effects are explained by quasi-stationary planetary waves, the sources of which can be temperature contrasts of the Earth surface and orographic effects. Peculiarities of the planetary waves lie in their global length during cold periods and very small amplitudes in summer.[2,3] This gives a reason to assume that the longitudinal effects can also be observed for temperature distributions at heights of the mesosphere and lower thermosphere. Regional effects of the temperature regime can be the subject of an independent study.

Variations of the atmospheric parameters at heights of the troposphere, stratosphere, mesosphere, and lower thermosphere with periods of several (2–40) days are mostly related with moving planetary waves.[2,3,17,18,22] Temporal variations with periods of several (3–10) days are quite often observed in winter period and can be found in the analyzed MLS Ayra temperature data, in particular, at heights of mesosphere.

Such temperature disturbances have been noted earlier in the papers:

– on the study of the effect of atmospheric processes on ionization of the F2-layer of ionosphere, using data on slant and vertical sensing at the Irkutsk station[23];

– on revealing the regression between the intensity of the upper atmosphere green emission from data of the Geophysical observatory of ISTP SB RAS at the atmospheric temperature at height levels of 30 and 95 km [Ref. 24];

– on the study of simultaneous intensifications of atmospheric emission at 557.7 nm [OI] and formation of sporadic layers during the periods of temperature disturbances in strato- and mesosphere.[25]

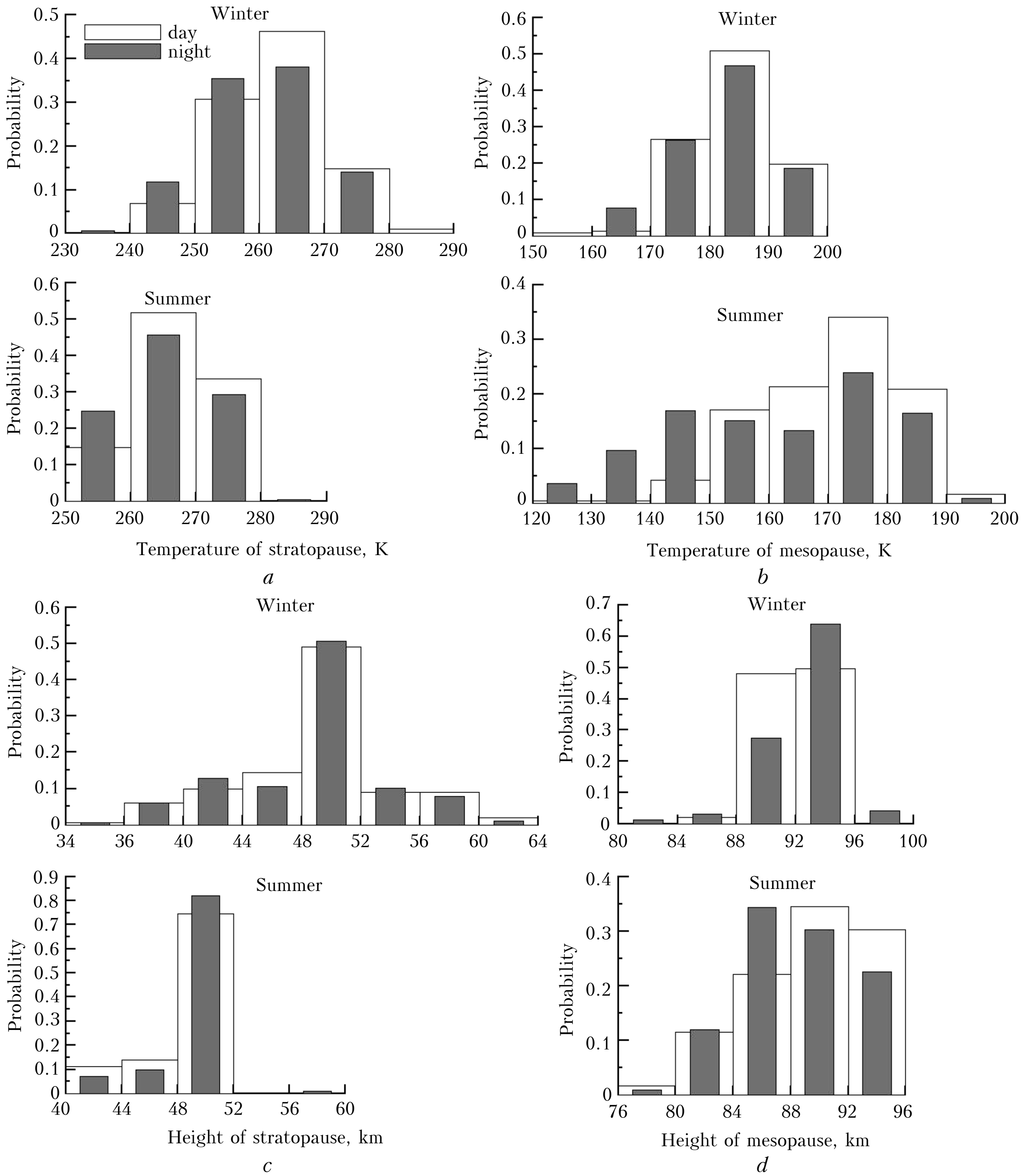

Fig. 4. Histograms of the stratopause (*a*) and mesopause (*b*) temperature distribution, as well as heights of stratopause (*c*) and mesopause (*d*) in winter and summer.

Conclusions

In the course of investigation of temporal and altitudinal temperature variations by the MAL Aura satellite data on vertical profiles of atmospheric temperature between August, 2004 and March, 2008 over Irkutsk region (52°N, 104°E), the diurnal, inter-diurnal, and seasonal (annual) variations of temperature at height levels of tropopause, stratopause, and mesopause have been analyzed, as well as temporal variations of the temperature and the height there in summer and winter.

Based on the performed analysis, the presence of essentially different temperature regimes in the middle atmosphere in summer and winter has been noted. In summer, temporal-altitudinal variations of temperature in the considered height range are regular with well pronounced warm stratopause and cold mesopause.

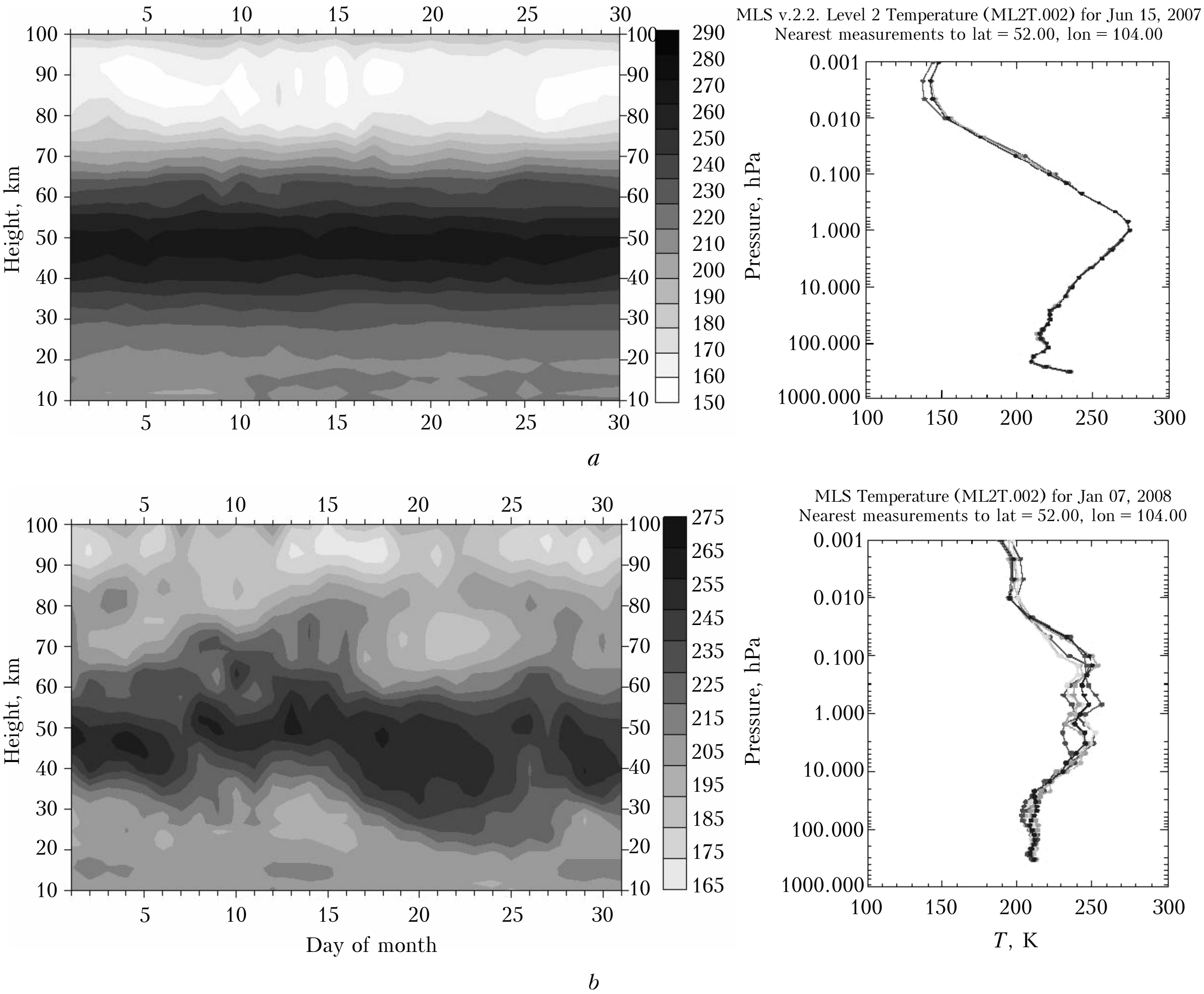

Fig. 5. Temporal-altitudinal distributions and vertical profiles of atmospheric temperature in June, 2007 (*a*) and January, 2008 (*b*).

Temperature distribution in winter has an irregular structure, the pronounced stratopause and mesopause are absent.

Acknowledgements

Author thanks A.V. Mikhalev for discussion of the paper and useful remarks.

This work was supported in part by the Program of Presidium RAS No. 16 (Part 3).

References

1. A.Kh. Khrgian, *Atmospheric Physics. Meteorology* (Gidrometeoizdat, Leningrad, 1969), 647 pp.
2. G.A. Kokin and S.S. Gaigerov, eds., *Meteorology of the Upper Atmosphere* (Gidrometeoizdat, Leningrad, 1981), 270 pp.
3. S.S. Gaigerov, *Study of Synoptic Processes in High Layers of the Atmosphere* (Gidrometeoizdat, Leningrad, 1973), 252 pp.
4. K.Ya. Kondratyev and Yu.M. Timofeev, *Meteorological Sensing of the Atmosphere from Space* (Gidrometeoizdat, Leningrad, 1978), 279 pp.
5. V.B. Kashkin and A.I. Sukhinin, *Remote Sensing of Earth from Space. Digital Image Processing* (Logos, Moscow, 2001), 264 pp.
6. R.J. States and C.S. Gardner, J. Atmos. Sci. **57**, No. 1, 66–77 (2000).
7. G.A. Gavrilyeva and P.P. Ammosov, J. Atmos. and Sol.-Terr. Phys. **64**, Nos. 8–11, 985–990 (2002).
8. C. Jacobi and D. Kürschner, Adv. Radio Sci., No. 4, 351–355 (2006).
9. D.L. Wu, W.G. Read, Z. Shippony, T. Leblanca, T.J. Duckb, D.A. Ortlandc, R.J. Sicad, P.S. Argalld, J. Oberhaidee, A. Hauchecornef, P. Keckhutf, C.Y. Sheg, and D.A. Krueger, J. Atmos. and Sol.-Terr. Phys. **65**, No. 2, 245–267 (2003).
10. D.Y. Wang, W.E. Ward, B.H. Solheim, and G.G. Shepherd, J. Atmos. and Sol.-Terr. Phys. **62**, No. 11, 967–979 (2000).
11. A.A. Svoboda, J.M. Forbes, and S. Miyahara, J. Atmos. and Sol.-Terr. Phys. **67**, No. 16, 1533–1543 (2005).
12. F.T. Huang, H.G. Mayr, C.A. Reber, J.M. Russell, M. Mlynczak, and J.G. Mengel, Ann. Geophys. **24**, No. 8, 2131–2149 (2006).

13. J.M. Forbes and Wu Dong, J. Atmos. Sci. **63**, No. 7, 1776–1797 (2006).
14. G.V. Givishvili, L.N. Leshchenko, E.V. Lysenko, S.P. Perov, A.I. Semenov, N.P. Sergeenko, L.M. Fishkova, and N.N. Shefov, Izv. Ros. Akad. Nauk. Fiz. Atmosf. i Okeana **32**, No. 3, 329–339 (1996).
15. M.J. Schwartz, A. Lambert, G.L. Manney, W.D. Read, N.J. Livesey, L. Froidevaux, C.O. Ao, P.F. Bernath, C.D. Boone, R.E. Cofield, W.H. Daffer, B.J. Drouin, E.J. Fetzer, R.A. Fuller, R.F. Jarnot, J.H. Jiang, B.W. Knosp, K. Krüger, J.-L.F. Li, M.G. Mlynczak, S. Pawson, J.M. Russell III, M.L. Santee, W.V. Snyder, P.C. Stek, R.P. Thurstans, A.M. Tompkins, P.A. Wagner, K.A. Walker, J.W. Waters, and D.L. Wu, J. Geophys. Res. **113**, D15S11, doi: 10.1029/2007JD008783 (2008)
16. I.V. Medvedeva, A.B. Beletskii, A.V. Mikhalev, M.A. Chernigovskaya, N.A. Abushenko, and S.A. Tashchilin, Atmos. Oceanic Opt. **20**, No. 2, 130–133 (2007).
17. A.D. Danilov, E.S. Kazimirovskii, G.V. Vergasova, and G.V. Khachikyan, *Meteorological Effects in Ionosphere* (Gidrometeoizdat, Leningrad, 1987), 271 pp.
18. E.I. Ginsburg, V.T. Gulyaev, and L.V. Zhalkovskaya, *Dynamical Models of the Free Atmosphere* (Nauka, Novosibirsk, 1987), 292 pp.
19. E.S. Kazimirovsky, V.D. Kokourov, and G.V. Vergasova, Surv. Geophys. **27**, No. 2, 211–255 (2006).
20. A.V. Mikhalev, I.V. Medvedeva, E.S. Kazimirovsky, and A.S. Potapov, Adv. Space Res. **32**, No. 9, 1787–1792 (2003).
21. D.Y. Wang, W.E. Ward, B.H. Solheim, and G.G. Shepherd, J. Atmos. and Sol.-Terr. Phys. **64**, Nos. 8–11, 1273–1286 (2002).
22. N.N. Shefov, A.I. Semenov, and V.Yu. Khomich, *Radiation of the Upper Atmosphere – Indicator of its Structure and Dynamics* (GEOS, Moscow, 2006), 741 pp.
23. V.I. Kurkin, N.M. Polekh, M.A. Chernigovskaya, and N.A. Abyshenko, Atmos. Oceanic Opt. **19**, No. 12, 979–983 (2006).
24. I.V. Medvedeva, M.A. Chernigovskaya, and A.V. Mikhalev, Atmos. Oceanic Opt. **20**, No. 12, 983–986 (2007).
25. A.V. Mikhalev, K.G. Ratovskii, A.V. Medvedev, M.A. Chernigovskaya, and I.V. Medvedeva. Atmos. Oceanic Opt. **20**, No. 12, 978–982 (2007).