ISSN 1024-8560, Atmospheric and Oceanic Optics, 2015, Vol. 28, No. 2, pp. 175–179. © Pleiades Publishing, Ltd., 2015.
Original Russian Text © V.S. Komarov, G.G. Matvienko, S.N. Il'in, N.Ya. Lomakina, 2014, published in Optika Atmosfery i Okeana.

OPTICAL MODELS AND DATABASES

Regional Features of Long-Term Changes in Cloud Cover in Siberian Sector of Northern Hemisphere for the Last 45 Years (1969–2013)

V. S. Komarov, G. G. Matvienko, S. N. Il'in, and N. Ya. Lomakina

V.E. Zuev Institute of Atmospheric Optics, Siberian Branch, Russian Academy of Sciences, pl. Akademika Zueva 1, Tomsk, 634055 Russia

e-mail: lnya@iao.ru

Received August 19, 2014

Abstract—We discussed the results of statistical analysis of regional features of long-term changes in cloud cover on the territory of Siberia according to data of climatic zoning of this region with respect to the total and low-level cloud regimes, using 45-year (1969–2013) time series of meteorological observations at 60 stations located in the Siberian sector of the Northern hemisphere. We found that there had been a clear trend toward increase in the total and low-level cloud amounts in all seasons and over the entire year after spatial averaging of data over the entire Siberian sector, as well as separately over the territory of Western and Eastern Siberia, during the base 45-year period (1969–2013), as well as in 1976–2005, when there was an intense global warming. The total and low-level cloud amounts substantially decreased in all seasons (except in fall) and over the entire year on the territory of the entire Siberian sector in recent years (2006–2013), when there was a trend toward a decrease in the intensity of global warming.

Keywords: low-level and total cloud amounts, long-term changes, trends, climatic zoning, Siberian region

DOI: 10.1134/S1024856015020050

INTRODUCTION

Clouds are known to be one of the key regulators of radiative fluxes that drive the thermal regime of the "Earth's surface – atmosphere" system; hence, the cloud characteristics (average values and spatiotemporal changes) have a determinant effect on climate state and change [1]. Long-term changes in the state of the cloud cover, which drive the variations in the near-surface temperature, play an especially important role in global and regional climate change [2, 3]. Moreover, cloud cover characteristics are among those most variable in space and time [4] and, as such, require permanent reevaluation as new synoptic observational data appear. Hence, studying the long-term climate changes in cloud cover with the incorporation of the newest data is of great scientific and practical interest.

Therefore, the problem of a long-term change in the state of cloud cover unsurprisingly attracts much attention both in Russia and abroad (see, e.g., [2, 3, 5–11]). However, the character of existing trends in the long-term change in the total and low-level cloud amounts is still uncertain for a number of reasons (e.g., the use of data pertaining to different periods of meteorological observations; inhomogeneities in statistical time series due to modifications in techniques and observation periods; lack of information about clouds in recent years, etc.), especially on the regional scale. This is especially true for data-sparse territories and, in particular, the Siberian sector of the Northern hemisphere (henceforth simply Siberian sector), located between 50 and 75° N and between 60 and 135° E. Moreover, the existing trends in long-term changes in cloud cover in the Siberian sector are studied using (in climate data analysis) different numbers of meteorological stations (from a few tens and more than a hundred [8, 12] to a few and even single stations [6, 11, 13]), thus complicating intercomparison of obtained results and providing no reliable information on the contemporary trends in these variations.

With this in mind, we performed a special study aimed to estimate the local features of long-term changes in the state of the cloud cover in the Siberian sector by using results of climatic zoning of this territory with respect to total and low-level cloud regimes (the method and results of this zoning were presented in [14, 15]; and these estimates of local features of long-term changes in these cloud types were considered in [16]).

However, in addition to local features, it would be certainly interesting (from the viewpoint of comparative analysis) to consider also the results of statistical estimation of long-term changes in total and low-level cloud amounts within the entire Siberian sector, which can be determined through area averaging of data of all trends,

determined for each of the homogeneous cloud regions, identified in the process of climatic zoning. The results of this estimation will be discussed in this work paper.

1. INITIAL DATA AND CERTAIN METHODICAL ASPECTS OF THEIR CLIMATIC PROCESSING

As in the case when local features of long-term changes in cloud cover were estimated [16], the main initial data, used to analyze the regional features of these changes over the territory of the whole Siberian sector and its separate parts (Western and Eastern Siberia), were annual values of seasonal and annual average total and low-level cloud amounts, obtained according to data of multiyear (1969–2013) eight-term observations at 60 meteorological stations (http:/www.ncdc.noaa.gov/). These data were used for climatic zoning of the territory of the Siberian sector [15], the results of which had been the basis for estimating the present-day trends in regional-scale variations in the total and low-level cloud amounts. It is noteworthy that the trends in long-term changes in cloud cover were analyzed within three observation periods:

—1969–2013, i.e., the period used to characterize the total (for the entire sector) trend in changes in cloud cover over the past 45 years and to compare it with results obtained elsewhere;

—1976–2005, characterized by intense global climate warming (see, e.g., [3, 17]);

—2006–2013, when researchers explicitly discerned not only the trend towards a decrease in the intensity of global warming, especially on a regional scale, but also a slow cooling on the entire Siberian territory [10, 18–21].

Based on these data, the yearly seasonal and annual average values of total and low-level cloud amounts, determined for every homogeneous cloud region accounting its area, were area averaged to estimate their spatially averaged values for the entire territory of the Siberian sector and its separate (western and eastern) parts. The results served a basis for calculating the common (for these territories) curves of interannual behavior, linear trends and intensities, which determine the main features of long-term variations in total and low-level cloud amounts on the territory of Western and Eastern Siberia and the Siberian sector, which had been apparent during the above three time periods.

2. DISCUSSION OF CLIMATIC ANALYSIS RESULTS

We will consider the proper results from climatic analysis of regional features of long-term changes in cloud cover over the territory of Western and Eastern Siberia and the entire Siberian sector, performed for three different periods (1969–2013, 1976–2005, and 2006–2013). For this, we will first investigate the specific features of long-term variations in the total and low-level cloud amounts, estimated according to the data for the entire 45-year period (1969–2013) considered here. As an example, Figs. 1 and 2 show the interannual behaviors and linear trends in long-tern variations in seasonal and annual average values of the total and low-level cloud amounts for these territories and periods of observations; and Table 1 gives the rates of these trends.

Analysis of Figs. 1 and 2 and data of Table 1 shows that a ubiquitous increase in the total and low-level cloud amounts at minor rates (respectively 0.04–0.10 and 0.04–0.15 cloud amount/decade in all seasons and 0.06–0.07 and 0.07–0.11 cloud amount/decade over the entire year) predominates over the territory of Western and Eastern Siberia and over the entire Siberian sector. It is noteworthy that this conclusion, drawn for low-level clouds and the entire Siberian sector, does not confirm the earlier findings [6, 8], which indicate that a low-level cloud amount predominately tended to decrease over the Asian part of Russia in the second half of twentieth century and early twenty first century.

In addition to the analysis of trends in climate variations in spatially averaged seasonal and annual average values of the total and low-level cloud amounts, estimated for the territories of Western and Eastern Siberia and the entire Siberian sector, according to data from the 45-year (1969–2013) period, it is also interesting to consider the specific features of these variations for intrinsically different periods, i.e., 1976–2005 (these years, as already indicated above, correspond to the period of most intense global climate warming) and 2006–2013, when there had been signs for an explicit trend toward weakening of this warming, and even toward climate cooling in certain (and, in particular, in Siberian [18–21]) regions.

Analysis of Figs. 1 and 2 and data of Table 1 shows that in 1976–2005 the character of linear trends of long-term variations in spatially averaged seasonal and annual average total and low-level cloud amounts, estimated for the entire territory of the Western (or Eastern) Siberia and the entire Siberian sector, is similar to trends characteristic for the entire 45-year period.

Indeed, in 1976–2005, as in the entire 45-year (1969–2013) period considered here, the seasonal average total and low-level cloud amounts increased at a rate of 0.03–0.09 and 0.09–0.18 cloud amount/decade, respectively, with the rate of the trends for low-level clouds being markedly larger in 1976–2005 than in the base 45-year period. The annual average total and low-level cloud amounts show a similar character of long-term variations (at rates of 0.04–0.06 and 0.11–0.14 cloud amount/decade).

In contrast to 1976–2006, the period from 2006 to 2013 over the territory of Siberian sector and its western and eastern parts was characterized by a substantial decrease (except in the fall) in seasonal and

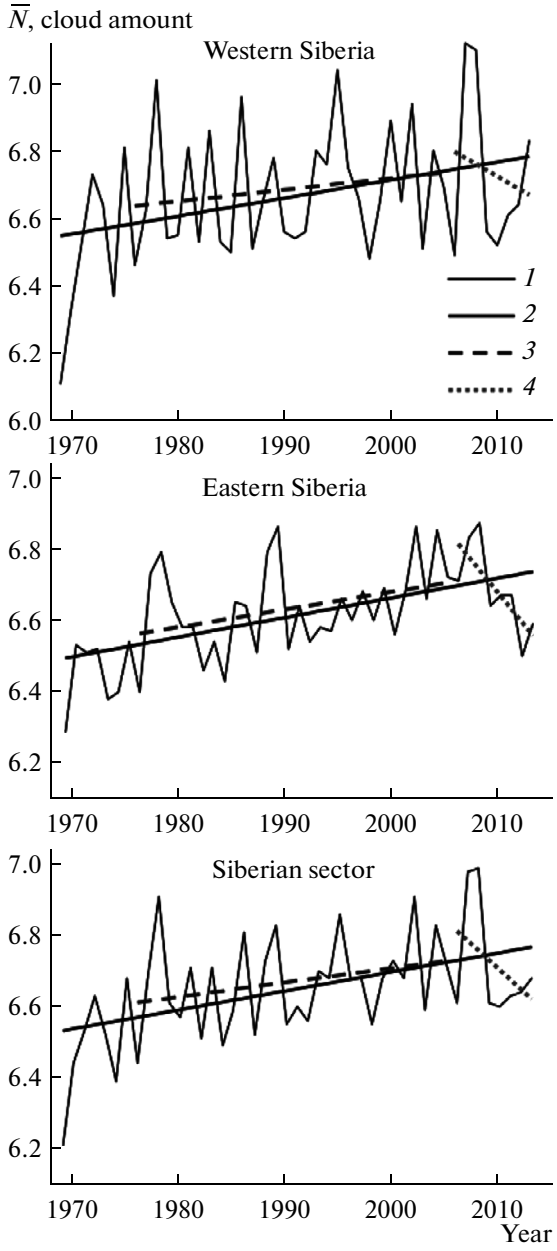

Fig. 1. Long-term variations in the annual average total cloud amount (curve *1*) and their linear trends, obtained according to data for 1969–2013 (curve *2*), 1976–2005 (curve *3*), and 2006–2013 (curve *4*) for the territories of the Western and Eastern Siberia, as well as for the entire Siberian sector.

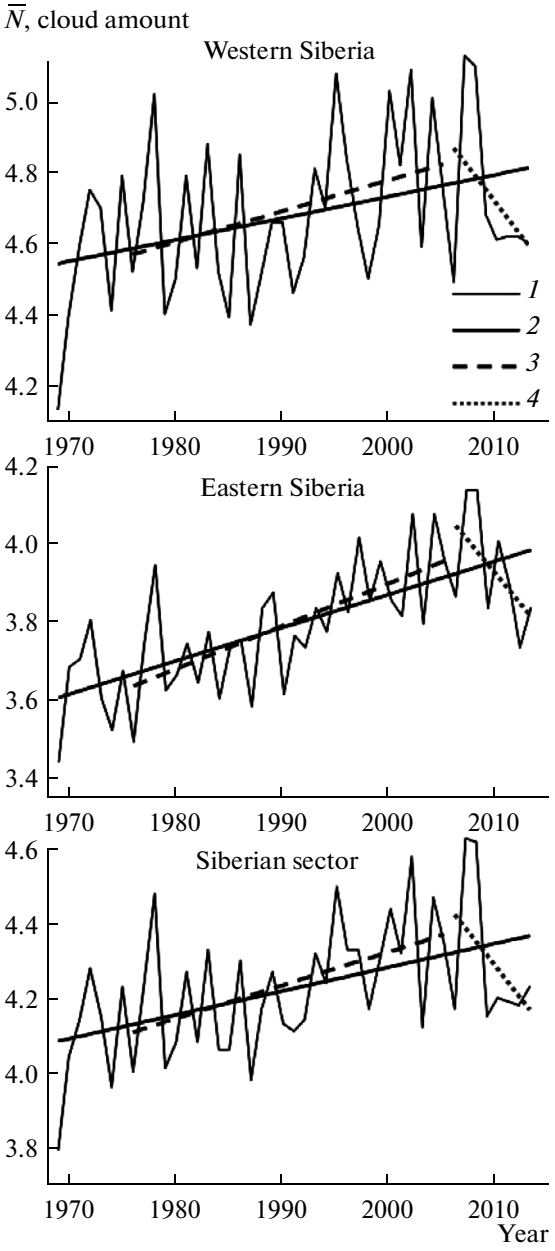

Fig. 2. Long-term variations in the annual average low-level cloud amount (curve *1*) and their linear trends, obtained according to data for 1969–2013 (curve *2*), 1976–2005 (curve *3*), and 2006–2013 (curve *4*) for the territories of the Western and Eastern Siberia, as well as for the entire Siberian sector.

annual average total and low-level cloud amounts at rates of −0.10 to −0.80 and −0.17 to −1.05 cloud amount/decade in all seasons (except in the fall), and at the rates of −0.18 to −0.36 and −0.34 to −0.40 cloud amount/decade, respectively, over the entire year.

This variation in the total and low-level cloud amounts from 1976–2005 toward 2006–2013, which was observed in the Siberian sector, is explained in [22] by a change from a latitudinal (westerly) circulation, which predominated in 1980–1990s, to a longitudinal (northerly) process, which plays a key role in early twenty first century and leads to a decrease in cloud cover.

In conclusion, we will consider the results of comparative analysis of the modern trends in long-term variations in annual average total and low-level clouds in the Siberian sector, presented in some recent publications [6, 8, 12, 13], and will compare them with data

Table 1. Rates in trends in the seasonal and annual average total and low-level cloud amounts in Western and Eastern Siberia and in the entire Siberian sector in different time intervals: 1969–2013, 1976–2005, and 2006–2013

Region	Total clouds					Low-level clouds				
	winter	spring	summer	fall	annual	winter	spring	summer	fall	annual
1969–2013										
Western Siberia	0.05	0.05	0.06	0.06	0.06	0.07	0.06	0.04	0.09	0.07
Eastern Siberia	0.04	0.06	0.08	0.10	0.07	0.11	0.13	0.07	0.15	0.11
Siberian sector	0.04	0.06	0.07	0.08	0.06	0.09	0.10	0.06	0.12	0.09
1976–2005										
Western Siberia	0.05	0.03	0.06	0.02	0.04	0.16	0.09	0.09	0.14	0.11
Eastern Siberia	0.03	0.07	0.07	0.09	0.06	0.13	0.18	0.09	0.17	0.14
Siberian sector	0.03	0.05	0.07	0.06	0.05	0.15	0.14	0.09	0.13	0.13
2006–2013										
Western Siberia	–0.80	–0.31	–0.10	0.50	–0.18	–1.05	–0.41	–0.52	0.39	–0.40
Eastern Siberia	–0.67	–0.53	–0.49	0.25	–0.36	–0.49	–0.17	–0.92	0.24	–0.34
Siberian sector	–0.74	–0.42	–0.30	0.38	–0.27	–0.77	–0.29	–0.72	0.32	–0.37

presented in this paper. The results of this comparison are given in Table 2.

From analysis of Table 2 it follows that, although different (as compared to our data) in length observation periods are used, these publications nonetheless elucidate certain specific features characteristic for the trends they present.

In particular, just one of these publication, namely, the work [13], indicates that the detected trends (according to data from just one station Tomsk over 1993–2004) toward an increase in the annual average total and low-level cloud amounts fully coincide with the results of the present study, where we took the most complete and homogeneous statistical time series of long-term (1969–2013) observations at 60 Siberian stations. They were used to estimate the trends in changes in the cloud cover within the entire Siberian sector.

Table 2. Comparative analysis of tendencies of long-term variations in the annually averaged total and low-level clouds, obtained for the Siberian sector by the authors of this work and other researchers

Literature source	Total clouds	Low-level clouds	Period
Present paper	Increase	Increase	1969–2013
	Increase	Increase	1976–2005
[6]	Increase	Decrease	1987–1995
[12]	Increase	Decrease	1936–1990
[13]	Increase	Increase	1993–2004
[8]	Decrease	Decrease	1961–2000
	Decrease	Increase	1976–2005

Moreover, authors of almost all works, mentioned above [6, 8, 12], conclude that the annual average low-level cloud amount decreased in the second half of the twentieth century, at odds with our data. It is noteworthy that Khlebnikova and Sall [8], who analyzed the modern change in cloud cover over the territory (and, in particular, over the Asian part) of Russia on the basis of more representative data of standard meteorological and actinometric observations, also indicate that low-level clouds explicitly tended to decrease in 1951–2000, despite the predominating minor growth in 1976–2005. However, the trends reported in [8] are negative in both time periods for the total clouds, inconsistent with our data.

These inconsistencies with our data are due to the authors of [8] neglecting the homogeneity of time series used, by incorporating four-term (for the period 1951–2000) and eight-term (starting from 1969) meteorological observations in one sample; moreover, they use six-term actinometric observations of cloud cover in 1976–2005.

CONCLUSIONS

Thus, analysis of long-term variations in the total and low-level cloud amounts over the entire base 45-year (1969–2013) period, as well as over 1976–2005 and 2006–2013, carried out for the Siberian sector of the Northern Hemisphere, using results from the climatic zoning of its territory with respect to the cloud cover regime, has allowed us to identify certain regional features of these variations in different time intervals.

In particular, it was found that:

—after spatial data averaging over the entire Siberian sector, as well as separately over the territory of Western and Eastern Siberia during the base 45-year (1969–2013) period, as well as in 1976–2005, when there was

an intense global warming, the total and low-level cloud amounts showed an explicit increasing trend;

—in contrast to these periods, in recent years (2006–2013), when there appeared a trend toward weakening of the intensity of global warming, and even toward climate cooling, such as over the territory of the entire Siberian sector, the total and low-level cloud amounts substantially decreased in all seasons (except in autumn) and over the entire year, which in [22] is attributed to a change from the westerly circulation, which predominated in 1980s–1990s over the Siberian sector, to the northerly circulation that played the key role in this region in the first years (2001–2012) of the twenty first century;

—results, presented in the given paper, substantially refine the data, presented in recent publications [6, 8, 12], which were aimed to estimate the present-day long-term changes in the cloud cover over the territory of the Siberian sector, primarily for low-level clouds, because in 1980s–1990s the low-level cloud amount markedly decreased, rather than increased, as indicated by our data.

REFERENCES

1. L. T. Matveev and Yu. L. Matveev, *Clouds and Vortices as a Basis of the Weather and Climate* (Russian State Hydrometeorological University, St. Petersburg, 2005) [in Russian].
2. S. G. Warren, R. M. Eastman, and C. J. Hahn, "A survey of changes in cloud cover and cloud types over land from surface observations 1971–96," J. Clim. **20** (4), 717–738 (2007).
3. B. G. Sherstyukov, *Climate Variations, Variability, and Oscillations* (RIHMI-WDC, Obninsk, 2011) [in Russian].
4. S. P. Khromov and M. A. Petrosyants, *Meteorology and Climatology* (MSU; Kolos, Moscow, 2004) [in Russian].
5. A. Henderson-Sellers, "Continental cloudiness this century," GeoJ. **27** (3), 255 (1992).
6. I. M. Baikova, N. A. Efimova, and L. A. Strokina, "Current change of cloud cover over the Russian territory," Rus. Meteorol. Hydrol., No. 9, 36–43 (2002).
7. A. Dai, T. R. Karl, B. Sun, and K. E. Trenberth, "Recent trends in cloudiness over the United States, A tale of monitoring inadequacies," Bull. Amer. Meteorol. Soc. **87** (5), 597 (2006).
8. E. I. Khlebnikova and K. A. Sall, "Peculiarities of climatic changes in cloud cover over the Russian Federation," Rus. Meteorol. Hydrol. **34** (7), 411–417 (2009).
9. R. Eastman and S. G. Warren, "A 39-yr survey of cloud changes from land stations world-wide 1971–2009: Long-term trends, relation to aerosols, and expansion of the tropical belt," J. Clim. **26** (4), 1286–1303 (2013).
10. Q. Tang and G. Leng, "Changes in cloud cover, precipitation, and summer temperature in North America from 1982 to 2009," J. Clim. **26** (5), 1733–1744 (2013).
11. G. M. Abakumova, "Trends in long-term variations in the air transparency, cloudiness, solar radiation, and underlying surface albedo in Moscow," Meteorol. Gidrol., No. 9, 5–62 (2000).
12. G. A. Zherebtsov, V. L. Kovalenko, and S. I. Molodykh, "Radiation budget of the atmosphere and climatic manifestations of solar variations," Atmos. Ocean. Opt. **17** (12), 891–903 (2004).
13. T. B. Zhuravleva, T. M. Rasskazchikova, T. K. Sklyadneva, and S. A. Smirnov, "Statistics of clouds over Tomsk: Data of ground-based observations for 1993–2004 period," Atmos. Ocean. Opt. **19** (10), 792–797 (1993).
14. V. S. Komarov, D. P. Nakhtigalova, S. N. Il'in, A. V. Lavrinenko, and N. Ya. Lomakina, "Climatic zoning of the Siberia territory according to the total and lower cloudiness conditions as a basis for construction of local cloud atmosphere models. Part 1. Methodical bases," Opt. Atmos. Okeana **27** (10), 895–898 (2014).
15. V. S. Komarov, D. P. Nakhtigalova, S. N. Il'in, A. V. Lavrinenko, and N. Ya. Lomakina, "Climatic zoning of the Siberia territory according to the total and lower cloudiness conditions as a basis for construction of local cloud atmosphere models. Part 2. The results of climatic zoning," Opt. Atmos. Okeana **27** (10), 899–905 (2014).
16. V. S. Komarov, G. G. Matvienko, S. N. Il'in, and N. Ya. Lomakina, "Evaluation of local features of long-term changes in cloud cover over the territory of Siberia from results of Climatic zoning according to total and low cloudiness conditions," Opt. Atmos. Okeana **28** (1), 59–65 (2015).
17. *Climate Change. The Physical Science Basis*, Ed. by S. Solomon, D. Qin, M. Manning et al. (University Press, New York; Cambridge, 2007).
18. B. G. Sherstyukov and R. S. Salugashvili, "New trends in variations in the climate of the Northern hemisphere of the Earth in the past decade," Trudy RIHMI-WDC, No. 175, 43–51 (2010).
19. V. S. Komarov, N. Ya. Lomakina, S. N. Il'in, and A. V. Lavrinenko, *Modern Variations in the Climate of Boudary Air Layer over the Siberian Territory*, Ed. by G.G. Matvienko (Publishing House IAO SB RAS, Tomsk, 2013) [in Russian].
20. K. A. Karimov, "Regional climate variations in the air temperature mode," in *Abstracts of the XX Intern. Symp. "Atmospheric Oceanic Optics. Atmospheric Physics"* (Publishing House IAO SB RAS, Tomsk, 2014) [in Russian].
21. URL: http//www/dailymail.co.uk/sciencetech/article-22172286/Global-warming-stopped-16-years-ago-reveals-Met-office-report
22. N. K. Kononova, "Seasonal features in variations in the atmospheric circulation in the Siberian sector of the Northern hemisphere in the XX–XXI century," in *Abstracts of the 10th Siberian Workshop on Climate-Environmental Monitoring*, Ed. by M.V. Kabanov (Agra-Press, Tomsk, 2013) [in Russian].

Translated by O. Bazhenov