Occurrence of the main cloud types over Tomsk: data of ground-based observations in 1993–2004

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We present the data of ground-based observations of the occurrence of the main cloud types over Tomsk in 1993–2004. The obtained results are compared with data of many-year ground-based observations in Tomsk in 1936–1965.

Introduction

Clouds are one of the main sources of uncertainty in weather prediction and climate models. Since the cloud layers may be present simultaneously at different atmospheric levels, for simulation of the *spatial structure of multilayer clouds* it is necessary to have the information:

– on the total cloud amount and cloud amounts at different atmospheric levels;

– on the occurrence of the different cloud types and their combinations; and

– on the vertical structure of the cloud systems (the number of cloud layers and the heights of the cloud boundaries).

Large arrays of information on the vertical cloud structure, cloud types and their combinations over the territory of the former USSR were accumulated on the basis of aircraft studies in 1950s–1970s.[1–4] Despite the fact that these data were obtained for a limited time interval and individual points of the aircraft sensing, the obtained results (in conjunction with the data of ground-based observations) provided for a quite full insight into the statistical characteristics of the cloud fields over different regions of former USSR. At the beginning of 1990s these studies over the territory of Russia have practically stopped because of their high cost. At the present time, certain insight into the structure of the multilayer clouds can be derived form the data of ground-based observations, which also are used to validate the satellite data and more adequately describe the specific features of the regional cloud distribution.

Earlier, we have analyzed the data of daytime ground-based observations of the amount of total and low-level cloudiness over Tomsk for 1993–2004; these data were obtained at the Siberian Climatic and Ecologic Observatory of the Institute of Monitoring of Climatic and Ecologic Systems of SB RAS.[5] In this paper, we consider the occurrence of different cloud types for the same time period and compare the obtained results with the data of many-year ground-based observations in 1936–1965 in Tomsk.

Vertical cloud structure

For the period 1993–2004 in Tomsk, among the considered 16 784 daytime observations, the absence of clouds was recorded in 1335 cases (8% of the number of observations).

We will characterize the vertical cloud structure, based on information on the main cloud types[4]: at temperate latitudes the bottom height of the *high*-level clouds (*Ci*, *Cc*, *Cs*) usually exceeds 6 km, the bottom height of the *middle*-level clouds (*As*, *Ac*) lies within 2–6 km, while the *low*-level clouds (*St*, *Sc*, *Ns*) mainly occupy the atmospheric layer extending from the earth's surface to a height of about 2–2.5 km. Bottoms of the clouds of *vertical development* (*Cu*, *Cb*) are located at the height of the low-level clouds, while their tops are at height of the middle or high clouds. (In the subsequent analysis, in a number of cases we will attribute the clouds of the vertical development to the low-level clouds.) This means that the observation data on cloud types allow the estimation of the vertical distribution of clouds in the atmosphere at least in the first approximation.

When analyzing the cloud situations, it is necessary to keep in mind that the presence of low or middle *overcast* clouds makes it impossible to reliably determine the natural probability of low and/or high clouds from the ground-based observations, because they may be screened by the underlying clouds. This circumstance should be taken into consideration in interpretation of the subsequent statistical information about the cloud presence at different atmospheric levels. In the time period considered by us the overcast low-level clouds were observed in 16% of cases with the largest occurrence in October and November (32% of cases), while the overcast middle-level clouds were recorded in 6.7% of the total number of observations (Table 1).

According to the data, presented in Table 1, the probability of occurrence of low and middle *one-layer broken* clouds was small and equal to 4 and 1.4%, respectively. In the absence of other cloud types, the high-level clouds were observed quite

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frequently (18.6%), while the probability of their combination with low- or middle-level clouds was also considerable and equal to 18.6% on the whole. Note that, according to the High Resolution Infrared Radiation Sounder (HIRS) satellite data, the occurrence of such cloud systems, averaged over the latitude of Tomsk (55° N) was ≈ 25% in July, 1989 and ≈ 18% in January, 1990.[6]

Table 1. Occurrence of clear sky and clouds at the low, middle, and high levels in percent of the total number of the observations

Atmospheric level	Percent of total number of observations
Clear sky	7.9
Low level (overcast clouds)	16.0
Middle level (overcast clouds)	6.7
The presence of clouds at one level	24.0
Low level (broken clouds)	4.0
Middle level (broken clouds)	1.4
High level	18.6
The presence of clouds at two levels	34.6
Low + middle levels	16.0
Low + high levels	7.8
Middle + high levels	10.8
The presence of clouds at three levels	10.8

Clouds at the three atmospheric levels simultaneously were recorded in 10.8% of the total number of observations.

Occurrence of the main cloud types

In the processing of the data on the occurrence of the main cloud types, we used the method described in detail in Ref. 7. The method consists of the steps:

– the occurrence of the low-level clouds is calculated in percent of the total number of observations;

– the occurrence of middle-level clouds is calculated in percent of the number of observations when the low-level clouds were broken and middle-level clouds could be observed; and

– the occurrence of high-level clouds is calculated in percent of the number of observations when the low and middle clouds were broken and high-level clouds could be observed.

We included in the total number of observations the clear-sky cases. The initial data were used to calculate the occurrence of the groups of the main cloud types (*Ci–Cs–Cc*), (*As–Ac*), (*Ns*), (*Cu*), (*St–Sc*), and (*Cb*) for each season. The occurrence of each group was calculated independently of the presence of other cloud types.

Analysis of the results showed that the low- and middle-level clouds were present in 54% of cases, and high-level clouds in 75% of cases (Table 2).

Irrespective of the season, clouds in the groups (*As–Ac*) and (*Ci–Cs–Cc*) were most widespread. The high occurrence of the cloud group (*As–Ac*) is explained by the fact that the altocumulus clouds *Ac* are formed in a great variety of situations: during spread of the cumulus clouds at the different levels in summer, below the inversion layers, during atmospheric frontolysis; also, they can be associated with front occlusions, intrusions of cold air, and unstable state of the atmosphere. The occurrence of middle-level clouds in September was the most probable (66%), and their occurrence in March – the least probable (43%). High-level clouds accompanied practically all synoptic situations throughout the year. The occurrence of *other cloud types* had a pronounced seasonal behavior: the clouds of vertical development were most frequent in summer (31% for *Cu* and 25% for *Cb*) when the convective processes are most developed, whereas the clouds of the type (*St–Sc*) were most frequently observed in autumn (24%).

Table 2. Occurrence of the main cloud types over Tomsk (%), based on the data of daytime observations in 1993–2004

Season	*St–Sc*	*Ns*	*Cu*	*Cb*	*As–Ac*	*Ci–Cs–Cc*
Winter	11.7	11.6	1.6	12.4	57.5	78.5
Spring	13.5	4.0	12.4	15.6	46.6	73.3
Summer	11.3	1.9	31.4	24.6	52.3	74.5
Autumn	24.6	12.3	7.5	15.5	62.6	76.0
Year	15.3	7.3	13.5	17.1	54.2	75.3

Taking into account the importance of studying the radiation effects of the cirrus clouds (see, e.g., Ref. 8), we give information on the group (*Ci–Cc–Cs*) in more detail. These data concern the occurrence of high-level clouds in the absence of other cloud types, since these situations are most favorable for the study of the microstructure and optical and geometric characteristics of cirrus clouds.

In our region, according to the data of 1993–2004 observations, these situations relate to 29% of cases. On the average, they were distributed over year as follows: their occurrence was the largest from January to May with maximum in March (12%), and it was the smallest in the warm period with minimum in September (4.6%) (Fig. 1).

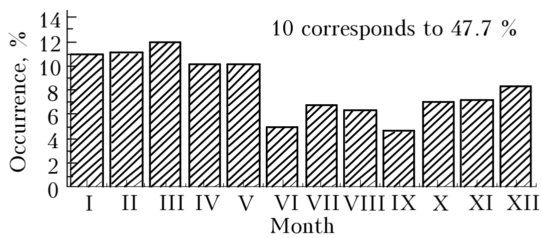

Fig. 1. Probability of distribution of cirrus clouds over Tomsk in 1993–2004 (other cloud types are absent).

Note that the overcast clouds were almost in half of cases; average cloud amount of one-layer high-level clouds was 7 with minimum in July (5.6) and maximum in December (8).

In Tomsk in the autumn–winter period, the low and middle overcast clouds occur in 45 to 56% of cases; while during a year, on average in 36% of cases the high-level clouds were not visible to the observer. As it was already noted above, this circumstance prohibits an adequate estimation of the degree of sky overcast by the cirrus clouds and their occurrence in the presence of the underlying cloud layers. Nonetheless, the results of Ref. 9 show that the information about high-level clouds, obtained from observations through gaps between low-level and middle-level clouds, is quite reliable for to be extended to all firmament.

Note that the data of marine (1965–1976) and ground-based (1971–1980) observations on the occurrence of different cloud types and their combinations are summarized by the group of American scientists from Naval Oceanographic and Atmospheric Research Laboratory, Monterey, California, in the form of the special atlases (with a spatial resolution of 5 × 5°). These results give a quite sufficient insight into the statistical characteristics of the global cloud field and are cited in Ref. 4.

Comparison with data of many-year observations over Tomsk

The authors of Ref. 7 present the monthly and yearly data on occurrence of main cloud types in Tomsk, based on results of the diurnal observations in 1936–1965 (the presented information concerns each cloud type separately, Fig. 2).

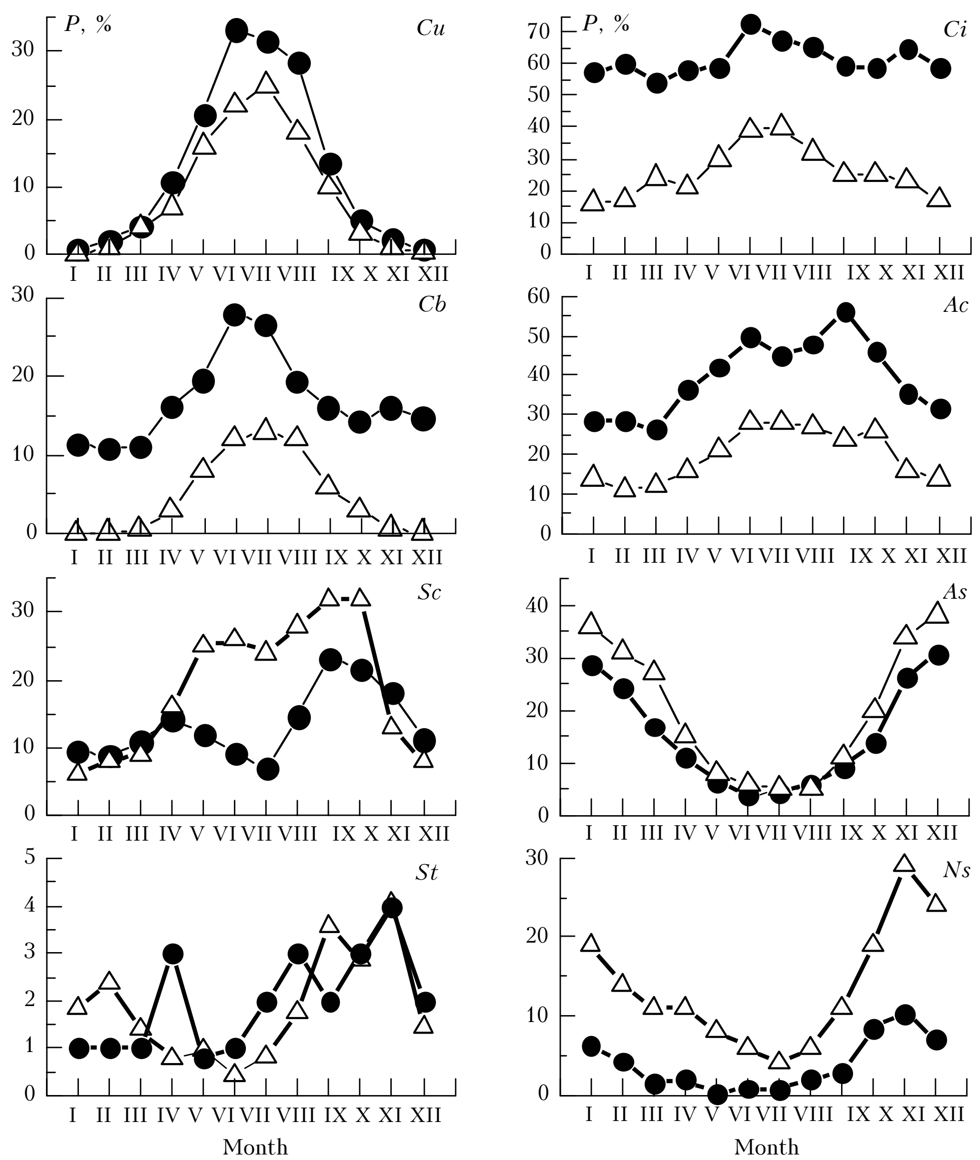

Fig. 2. Comparison of occurrence of the main cloud types in Tomsk, based on the data of observations in 1936–1965 (triangles) and 1993–2004 (circles).

This period was characterized by the following cloud distribution:

a) the occurrence of the main cloud types had an annual behavior;

b) the most probable during a year were clouds of the types: *Ci*, *Ac*, *As*, *Sc*;

c) the largest occurrence of cumulus, cumulonimbus, and altocumulus clouds was observed from May to September;

d) maximum occurrence of stratocumulus clouds was recorded in September and October (32%);

e) the annual behavior of altocumulus clouds corresponded to the annual behavior of the occurrence of cyclones and associated fronts; the occurrence of *As* was 3–8% in the warm period and 15–40% in the cold period.

In this paper, we analyze only the data of daytime cloud observations. Zhuravleva et al. [Ref. 5] showed that the data of diurnal observations of the total and low-level cloud amount in 1993–1996 and daylight observations in 1993–2004 practically coincide, both for individual seasons and for the period as a whole. We cannot assert that this conclusion is also true with regard to the occurrence of different cloud types; however, in the absence of other data, we use the results of daylight observations in the considered by us 11-year period for comparison with the many-year 1936–1965 data.

The results of the comparison show (see Fig. 2) that the annual behavior of the main cloud types (with exception of *Sc*) did not change. At the same time, the occurrence considerably increased: by 40% for cirrus throughout the year, and by 10% for clouds of the vertical development (for *Cu* only in summer period and for *Cb* throughout the year). The probability of occurrence of *Ac* has almost doubled, while the occurrence of *As* somewhat decreased in the autumn–winter period. In comparison with 1936–1965, there was also the decrease of the occurrence of *Ns* (throughout the year) and clouds of *Sc* (in the warm period of the year).

Conclusion

The presented analysis of the occurrence of the main cloud types over Tomsk, made on the basis of the data of daylight ground-based observations in 1993–2004, allows us to conclude that:

– the low-level overcast clouds and middle-level overcast clouds were observed in 16% and 6.7% of cases, respectively;

– the clouds in the groups (*As*–*Ac*) and (*Ci*–*Cs*–*Cc*) were most frequent during this period of observations, while the occurrence of other cloud types had pronounced a seasonal behavior;

– the occurrence of cirrus clouds in the absence of other cloud types was maximum in March (12%) and minimum in September (4.6%);

– in comparison with many-year 1936–1965 observations, the clouds of *Ci* and *Ac* types have been more frequent, while the stratiform clouds of *Sc* and *Ns* types were less frequent.

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