A Climatology of Cloud Amount of Midlatitude Continental Clouds in Tomsk Region: Preliminary Results

T.B. Zhuravleva, T.M. Rasskazchikova, and T.K. Sklyadneva
Institute of Atmospheric Optics SB RAS
Tomsk, Russia

S.V. Smirnov
Institute of Monitoring of Climatic and Ecological Systems SB RAS
Tomsk, Russia

The Atmospheric Radiation Measurement (ARM) Program provides concentrated measurements of surface radiative budget as well as measurements of the atmospheric constituents including clouds, aerosols, water vapor, etc. at the Southern Great Plains (SGP), the Tropical Western Pacific and the North Slope of Alaska (NSA) sites. The data obtained allow studying a wide, but not the full range of climatologically relevant possibilities, and thus additional investigations are needed to provide the completeness of the coverage.

We present the data of ground-based observations of the state of cloudiness (total and low cloud amount, sunshine duration) over Tomsk (56.5N, 85.1E) carried out at the Institute of Monitoring of Climatic and Ecological Systems (IMCES) SB RAS, Tomsk, Russia, since 1993. This region, situated in the zone of *Siberian boreal forests*, takes intermediate place between SGP and NSA sites of ARM Program, and is characterized, in particular, by underlying surface, features of seasonal variability, regularities of the airmass change, etc different from SGP and NSA.

Background

Ground-based cloud observations are performed at the Siberian Climatic and Ecological Observatory IMCES SB RAS (56°29′N, 85°04′E), Tomsk, Russia, from 1993 to the present. Until 1996, the observations were performed in commonly accepted synoptic terms 8 times a day; and since 1997 only daytime observations are conducted. For storage and use of the accumulated data, the database created at Institute of Atmospheric Optics SB RAS (Tomsk) is employed; it contains information on cloud types, total and low cloud amounts, sunshine duration, as well as the synoptic situation in Tomsk, obtained on the basis of daily synoptic maps.

The time interval 1993-2004, considered by ourselves, pertains to period of global warming (second half of the twentieth century), which is characterized by growth of air temperature in the lower layers of the atmosphere for the whole globe and the northern hemisphere (http://www.cru.uea.ac.uk). Beginning of the modern warming in most regions of Russian Federation, including West Siberia, has taken place in early 1970s (http://climate.mecom.ru). Time series of the averaged anomalies of annually mean temperature and precipitation (deviations from standard base period 1961-1990) for West Siberia and Tomsk (Barashkova et al. 2002) are presented in Figure 1.

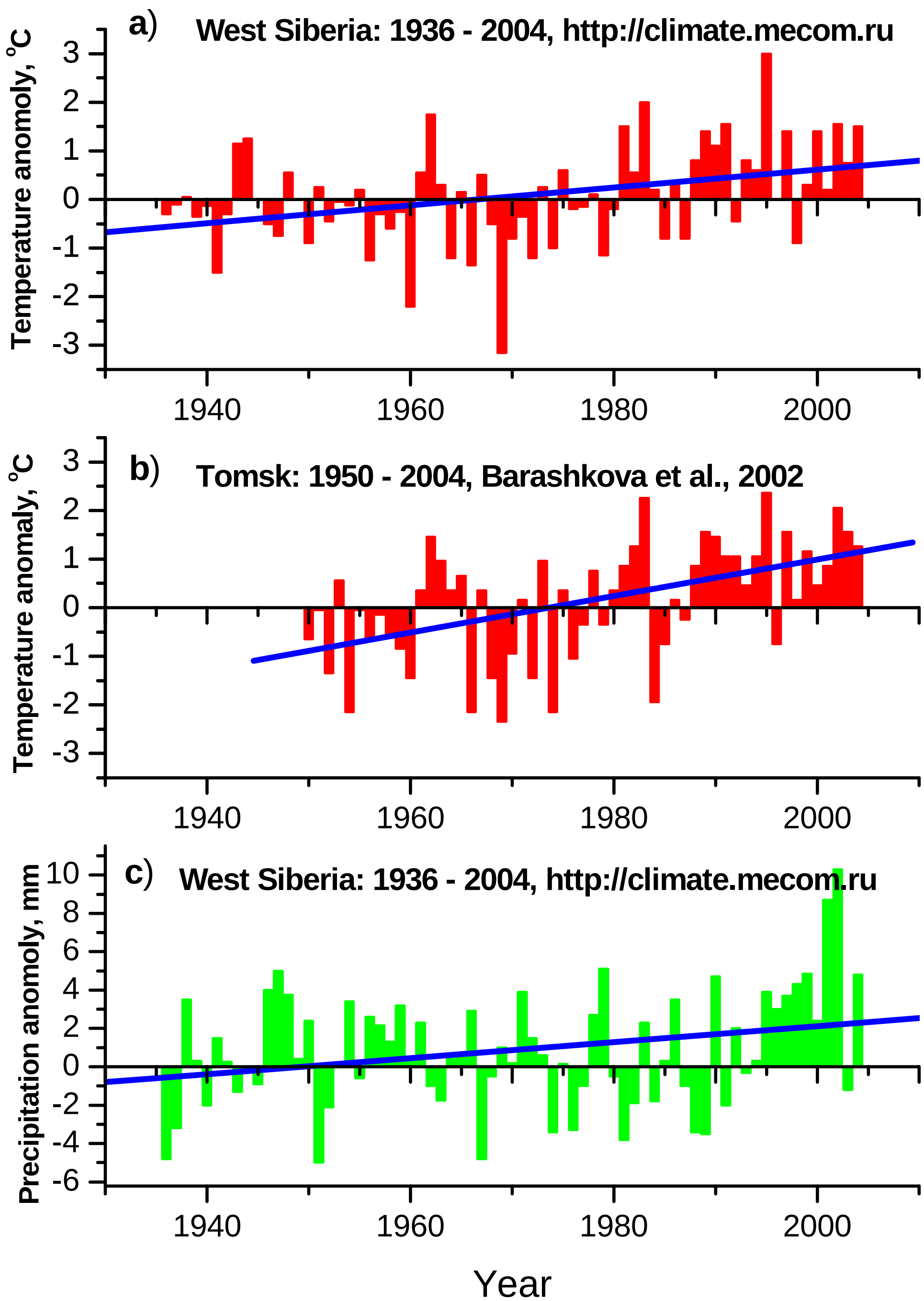

Figure 1. Averaged anomaly of annually mean air temperature and precipitation (deviation from the mean temperature of the base period 1961-1990) and their linear trends.

The specific feature of the chosen period is a considerable change of atmospheric circulation regime both in entire hemisphere and in the region of Tomsk. We use as the characteristics of synoptic situation the number of observation periods during which the territory of Tomsk was under influence of fronts or their zones $N(F)$, cyclones $N(Zn)$, and anticyclones $N(Az)$. During 1993-2004, the number of $N(F)$ has increased, while the number of $N(Zn)$ has decreased by approximately a factor of 2; at the same time, $N(Az)$ has remained almost unchanged (Belan et al. 2005).

Interannual Variations of Cloud Amount

We will consider the *interannual variations* of total N_{tot} and low N_{low} cloud amounts and their standard deviation over Tomsk. In the observation period, the minimum annually average total cloud amount N_{tot} (7.4 cloud amount) was observed in 1996-1997, while the maximum cloud amount (8.6) correspondingly in 2002 (Figure 2). The standard deviation σ_{Ntot} was quite stable and varied in the range 2.9-3.5 cloud amount. The minimum of annually average N_{low} (2.8 cloud amount) was observed in 1994, while the maximum value (4.3 cloud amount) took place in 2002 and 2004. The variations of low cloud amount were larger than those of N_{tot} and reached 3.2-4.1 cloud amount, depending on the year. We note that in 2002, when total and low cloud amounts were maximum, in West Siberia the largest value of precipitation anomaly over almost 60-year period of observations was observed (Figure 1c). During 1993-2004, there were a weak positive N_{tot} trend and a more considerable N_{low} increase; the average total and low cloud amounts over 11-year period were 8.0 and 3.7 cloud amounts respectively.

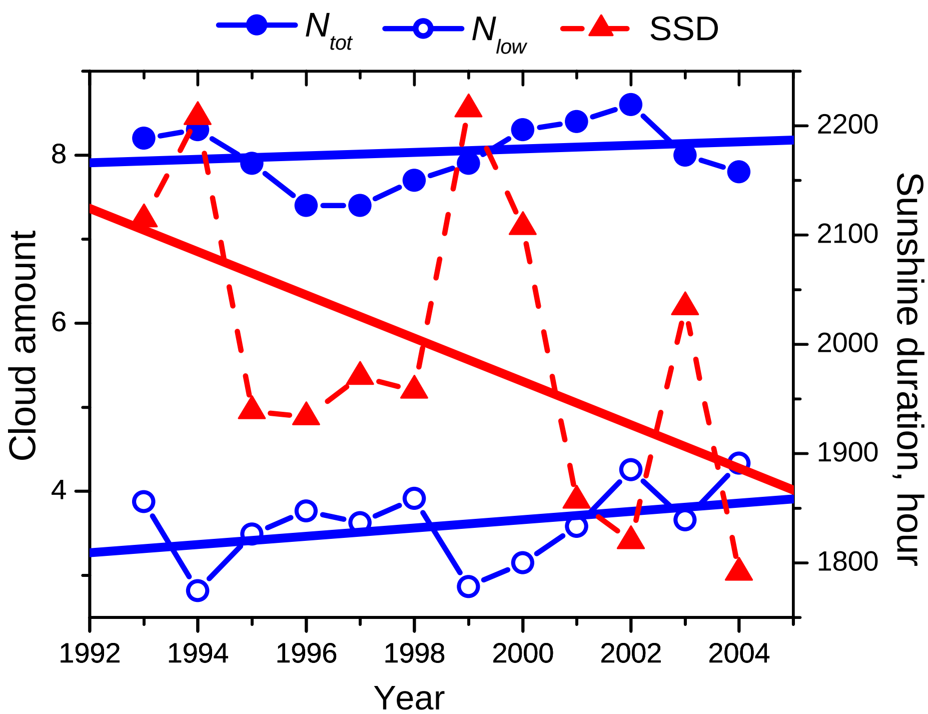

Figure 2. Interannual variations of total and low cloud amounts (daytime observations) and sunshine duration over Tomsk based on data of Siberian Climatic and Ecological Observatory IMCES SB RAS.

The increasing tendency of cloud amount also takes place in other regions of Russia. The data of Meteorological Observatory of Moscow State University (55°42′N, 37°31′E), located at almost the same latitude as Tomsk, show that from 1958 to 1997, the annually average N_{tot} value increased by approximately 0.7, while N_{low} by 1.1 cloud amount (Abakumova 2000). For period 1967-1990, the increase of N_{tot} and N_{low} was also observed on the territory of the European part of the former USSR, West Siberia, and Far East (Efimova et al. 1994).

One of the characteristics frequently employed in analysis of cloud amount variations is the sunshine duration (SSD). As data of Belan et al. (1999) suggest, the sunshine duration over Tomsk increases starting from 1958; whereas the considered period 1993-2004 is characterized by considerable SSD decrease. The observed negative SSD trend agrees with increase of cloudiness over Tomsk, with significant anticorrelation dependence taking place between SSD and low cloud amount (Figure 2). We note that the SSD decrease for positive trend of cloud amount is also observed in other regions of the globe: Ireland (Palle and Butler 2001), and USA (Angell 1990). More detailed consideration of correlations between cloud amount and sunshine duration is planned to be made by incorporating information on distribution of clouds over atmospheric levels.

Annual Variations of Cloud Amount

According to 1993-2004 data, the largest cloud amount N_{tot} was observed in fall-winter months with maximum in November equaling 8.7 cloud amount (Figure 3). In annual behavior of cloud amount of total clouds N_{tot} there are 2 minima: in March and July, reaching 7.3 cloud amount. Local maxima of cloud amount of low clouds N_{low} are observed in July (3.7) and October (5.1). As to the March minimum of N_{low} and N_{tot}, we note that this month has been unusually dry: data of Barashkova et al. (2002) indicate that for period 1950-1998, no cases of excessive wetting were recorded.

Analysis of synoptic situation over the territory of Tomsk has shown (Belan et al. 2005) that the annual behavior of frequency of occurrence of cyclones is poorly defined and has 3 local minima (strongest in July). The frequency of anticyclones becomes increasingly more significant from month to month (with minimum in summer period). Fairly well defined annual behavior of the clouds best agrees with seasonal variations of location of planetary frontal zones (Figure 3).

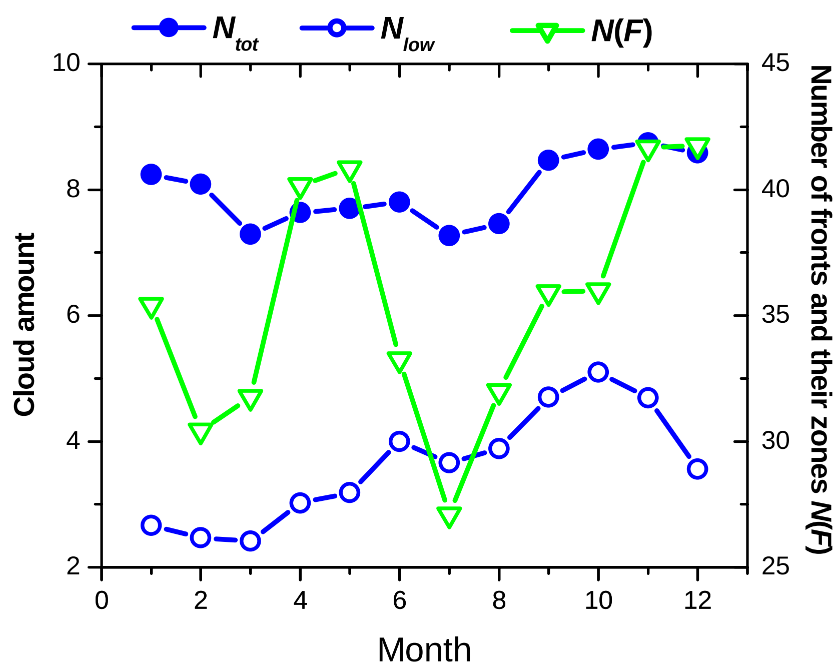

Figure 3. Monthly mean values of cloud amount and planetary frontal zones *N*(*F*) according to data of multiyear observations of 1993-2004.

Comparison with Data of Multiyear Observations in 1936-1965

Let us compare the frequency of occurrence of clear-sky (cloud amount $N_{tot} = 0 – 2$), cloudy ($N_{tot} = 3 – 7$), and overcast ($N_{tot} = 8 – 10$) weather in 1993-1996 with data of multiyear diurnal observations during 1936-1965 in Tomsk (Handbook of Climate of USSR 1970). The climatically significant 30-year period of observations (1936-1965) fell into the period of comparatively small cooling between two periods of warming (1910-1940 and 1970- …) and was characterized by the following features (Figure 4):

- Most probable was overcast weather (more than 50% in all months); clear-sky weather was observed in more than 20-25% of cases (except in October, 15%); clouds with $N_{tot} = 3 – 7$ were least probable;

- Probability of sky overcast with clouds was minimum in July (51%), maximum in October (76%); while clear sky was most probable in February (35%), and least probable in October (14%);

- Frequency of cloudy days increased from January (7-8%) to July (23%), with subsequent symmetric decrease toward December (7%).

Can we use the available information to estimate the frequency of occurrence of clear, semi-clear, and overcast weather for the time period considered by ourselves? A problem is that we have data on *diurnal* cloud variations only for 4-year observation period (1993-1996). Analysis revealed that the data of *daytime* observations of total cloud amount in 1993-1996 and 1993-2004 practically coincide both for

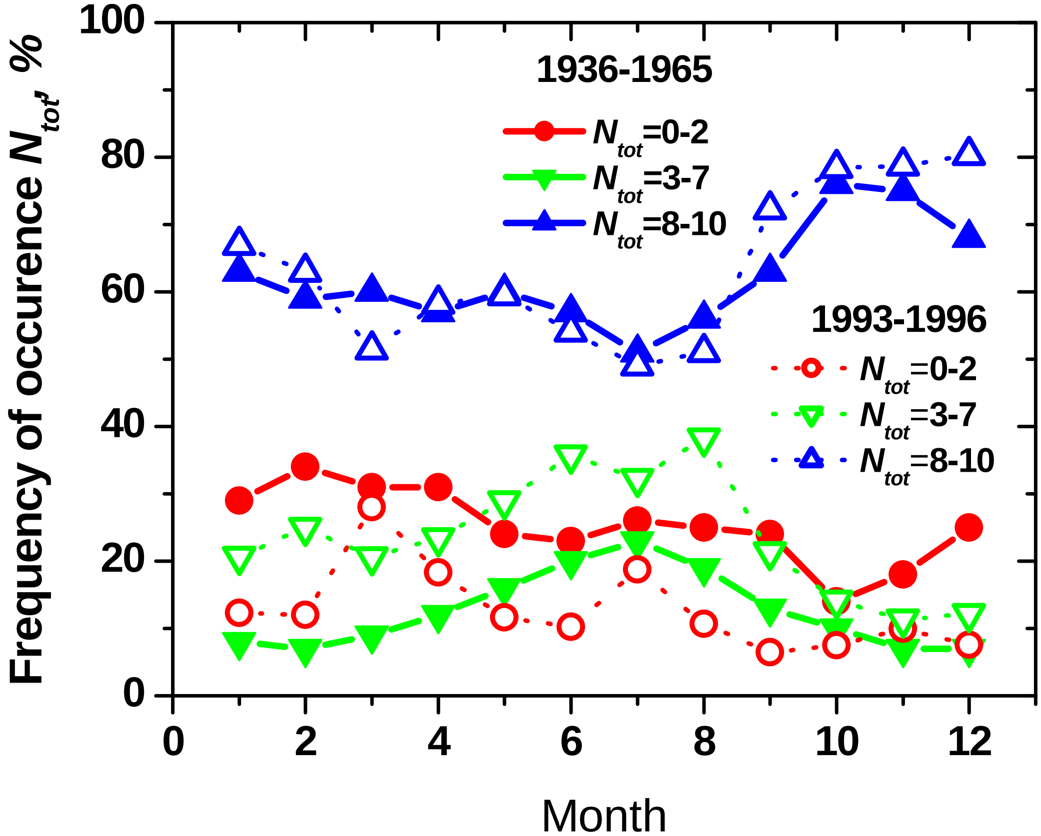

Figure 4. Comparison of frequency of occurrence of clear, semi-clear, and overcast weather based on diurnal observations of 1993-1996 and 1936-1965.

separate seasons and for the whole periods. Therefore, it can also be expected that the results of *diurnal* N_{tot} observations, obtained over 1993-1996, are characteristic, to some or another degree, for entire 11-year observation period, considered by ourselves.

We use the data of *diurnal* 1993-1996 observations for comparison with data of multiyear 1936-1965 observations with respect to the frequency of occurrence of clear, semi-clear, and overcast weather. The results of comparison showed (Figure 4) that the probability of presence of overcast weather remained the largest; whereas the number of clear days decreased, especially in winter months (by ≈ 20%). The frequency of occurrence of semi-clear days ($N_{tot} = 3 – 7$) increased; while the annual behavior (with maximum in summer months) remained the same.

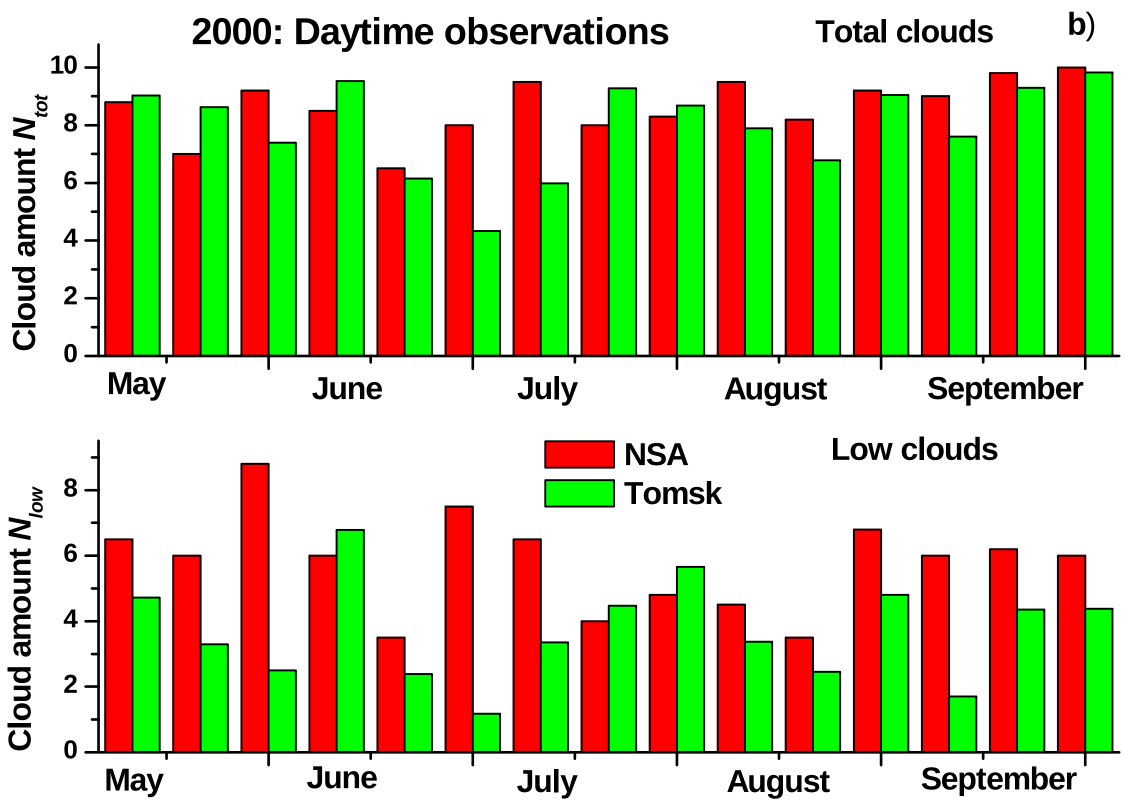

Figure 5. Comparison of cloud amounts over SGP, NSA, and Tomsk.

Comparison of Clouds Over SGP, NSA, and Tomsk

We compared our data with results of observations of cloud amount, obtained at the ARM SGP and NSA sites in the same period of observations.

ARM SGP Central Facility (36.6N, 262.5E): observation period 1997-2002 (Dong et al. 2005). After averaging over 6-year period 1997-2002, cloud amounts of *low clouds* in Tomsk are higher than N_{low} at SGP Central Facility; maximum (more than a factor of 3) differences are observed in summer months (Figure 5a).

ARM NSA (71.3N, 156.6W): observation period is May-September 2000, averaging period is 10 days (Dong et al. 2003). Cloud amount of *total clouds* at Barrow and Tomsk are comparable (except in two first decades of July); cloud amount of *low clouds* in Tomsk is somewhat lower almost throughout the entire period of observations (Figure 5b).

Conclusions

1. Cloud amount over Tomsk was estimated based on regular ground-based observations in 1993-1996 during full day, and from 1997 to the present at daytime. The results of daytime observations have demonstrated a *positive trend of cloud amounts of total and low clouds*, with more significant growth observed for low clouds. In comparison with multiyear observations performed in 1936-1965, the number of days with small cloud amount decreased, while the number of days with $N_{tot} = 3 - 7$ increased.

2. SSD, observed in Tomsk since 1958, increased; while in time period 1993-2004 the SSD was characterized by *negative trend*. In period 1993-2004, the interannual SSD variations were well anticorrelated with cloud amount of low-level clouds.

3. Comparison of data of observations in Tomsk and at ARM SGP and NSA sites has shown that, in the considered time periods, the averaged cloud amounts of low-level clouds in these geographic regions differ. To understand the factors determining the specific features of cloud and, hence, radiation regime, further studies in each geographic location are required.

Because the 1993-2004 time series considered here is short compared with the scale of climate changes, the obtained results correspond only to this observation period. We can say nothing about if the revealed tendencies of cloud variations will persist into the future or it is just a phase of long-period cloud variations.

Acknowledgments

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