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Recent variations of cloudiness over Russia from surface daytime observations

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Abstract
Changes of total and low cloud fraction and the occurrence of different cloud types over Russia were assessed. The analysis was based on visual observations from more than 1600 meteorological stations. Differences between the 2001–10 and 1991–2000 year ranges were evaluated. In general, cloud fraction has tended to increase during recent years. A major increase of total cloud fraction and a decrease of the number of days without clouds are revealed in spring and autumn mostly due to an increase of the occurrence of convective and non-precipitating stratiform clouds. In contrast, the occurrence of nimbostratus clouds has tended to decrease. In general, the ratio between the occurrence of cumulonimbus and nimbostratus clouds has increased for the period 2001–10 relative to 1991–2000. Over particular regions, a decrease of total cloud fraction and an increase of the number of days without clouds are noted.

Keywords: cloudiness changes, convective and stratiform clouds, regional and seasonal features

1. Introduction

Cloudiness is a significant atmospheric component of the global climate system (Wielicki *et al* 1995, IPCC 2007). The radiative effects of clouds depend on the season and time of the day (Warren *et al* 2007) as well as the type of cloud (Chen *et al* 2000). In particular, high-level clouds tend to warm the climate, while low-level clouds lead to a cooling effect (Ramanathan *et al* 1989). Changes in cloud cover can mitigate or exacerbate global warming (Mokhov 1981).

Following Sun *et al* (2001), this letter focuses on assessment of changes of different cloud types, particularly convective and stratiform clouds separately. The formation of these two cloud types depends on different processes. Convective clouds are driven primarily by atmospheric convection, while a relatively stable stratification determines the presence of stratiform clouds. Numerous studies have highlighted features of cloudiness changes over Northern Eurasia during the second half of the 20th century (Sun and Groisman 2000, Sun *et al* 2001, Warren *et al* 2007, Khlebnikova and Sall 2009). In particular, an increase of convective and high-level cloudiness and decrease of stratiform cloudiness were revealed. According to Khlebnikova and Sall (2009) the major changes in cloud cover occurred in the 1970s and 1980s. Therefore, we decided to limit our analysis to the 1990s and 2000s in order to capture the latest changes of cloud cover and to find out whether the previously mentioned tendencies of cloudiness changes are occurring now or not. Additionally, it is worth noting that previous studies were focused on analysis of cloudiness changes over extensive regions, for instance over the European and Asian part of Russia as a whole. Here, we present a more regionally detailed analysis on cloudiness changes during the most recent decades based on an extended dataset including information from more than 1600 meteorological stations. The station network is dense (except in some northern regions) and the observations are homogeneous in time. This is in contrast to Northern America where the introduction of the Automated Surface Observation System in the early 1990s broke this homogeneity (Sun *et al* 2001, Dai *et al* 2006). Thus, along with an assessment of recent cloud variations, observations from Russian meteorological stations can also be used as an alternative source for validating up-to-date satellite-based cloud observations over the northern midlatitudes. This is an additional argument for analyzing only the last two decades.

2. Data and method

In situ three-hourly visual observations from Russian meteorological stations were used in this study to estimate cloud variations during the two last decades. The comprehensive dataset was prepared at the All-Russian Research Institute of Hydrometeorological Information—World Data Center (RIHMI—WDC) where observations from meteorological stations were collected and subjected to an automated quality control (Veselov 2002). These data were presented for the first time by Razuvaev *et al* (1995) and contained information from 223 long-term high quality meteorological stations. Here we used an extended version of these data which contains information from more than 1600 stations over Russia.

The RIHMI—WDC dataset is based on routine visual observations which include information on total and low cloud cover (measured in tenths), and various morphological cloud types. All cloud types are separated into five groups: Ch, Cm, Cl1, Cl2 and Cl3. The group of high-level cloud (Ch) type with a base higher than 6 km includes cirrus, cirrocumulus and cirrostratus clouds and cases with their simultaneous presence. The middle-level cloud type (Cm) group includes altocumulus and altostratus clouds and cases with their simultaneous presence. Their base height is between 2 and 6 km. Nimbostratus (Ns) clouds are specified by the World Meteorological Organization as middle-level clouds, while in the RIHMI—WDC dataset they are classified as low-level clouds and together with fractonimbus (Fb) clouds form the Cl3 group. The Cl1 group combines convective cloud forms including cumulus (Cu) and cumulonimbus (Cb) clouds. The Cl2 group combines stratiform cloudiness including stratus and stratocumulus clouds. Low-level cloud types have base height below 2 km.

In this study, monthly means of total and low-level cloud fraction (TCF and LCF respectively) derived from three-hourly observations were assessed. The monthly percentage of the cloud type occurrence is defined as the ratio between the number of days with a given cloud type and the total number of days. To obtain the occurrence of high- and middle-level cloud types obscured by low-level cloudiness, the clouds at different levels are assumed to be randomly overlapped (Hahn and Warren 2003, Norris 2005). Seasonal means of TCF, LCF and the occurrence of cloud types were derived from monthly means. Their differences between the 2001–10 and 1991–2000 year ranges were evaluated and compared with interannual standard deviation to estimate more and less significant changes. In addition, linear trends of different cloud characteristics were obtained for the whole analyzed period for each station. Data from 1621 meteorological stations for the period from December 1990 to November 2010 were used. None of these stations changed their locations during this period. Stations with observational gaps are also taken into account. However, cloudiness changes for these stations are marked as ‘insignificant’ (small circles in the figures). To avoid uncertainties connected with poor quality of night observations (Hahn *et al* 1995, Warren *et al* 2007), only daytime observations from 8 am to 8 pm local standard time were chosen for analysis (this time period is not associated with daytime for several high-latitude stations during winter, so the results for these stations should be evaluated with caution). Possible biases due to observer-related uncertainties were not taken into account. Presumably, these biases are uniformly distributed and do not influence the results.

3. Results

Annual-mean magnitudes of TCF (not shown) vary between 0.8 on the Arctic coast (with the maximum in September–October and the minimum in January–February) and 0.6 in southern regions of the European part of Russia (with the minimum in summer) and the Far East (with the minimum in winter). The occurrence of days without clouds (NCO) varies between 1 and 2% in coastal regions and central regions of the European part and 10–20% in the continental part of the Far East (with the maximum in winter). The occurrence of days with overcast conditions (OO) is about 20–40%. In winter, it is up to 60–70% for central regions of the European part and down to 10–15% for East Siberia. In summer, OO has its maximum in coastal regions (40–50%) and its minimum in southern regions of the European part, Urals and Siberia (5–15%).

Changes of TCF for the period 2001–10 compared with 1991–2000 are shown in figure 1. Different tendencies of TCF changes are noted for different seasons and over different regions. In particular, in winter, TCF has increased by 0.05–0.1 over the southern regions of the European part, southern regions of East Siberia and over most of the Far East regions. An increase of TCF in these regions is accompanied by a decrease of NCO (by 10–15% over the Far East) (figure 2) and an increase of OO (by 10–15% over the European part of Russia) (figure 3). Over the Urals and West Siberia in winter, NCO has increased by 2–10% while OO and TCF have decreased by 10–20% and 0.05–0.1 respectively. At particular stations in the northern part of Siberia, TCF has decreased by more than 0.2. In spring, an increase of TCF (by 0.02–0.1) predominates in regions south of 60N except for very western regions of the European part where TCF tends to decrease mostly due to significant decrease of OO by 5–15%. NCO during spring has decreased over Russia as a whole with the largest changes in the southern part of the Urals and West Siberia (by 10–15%). In summer, the most significant changes have occurred over the Volga river basin where TCF has decreased by 0.1–0.2. In contrast, over the southern part of Siberia and the main part of the Far East, TCF has increased by 0.05–0.15. In general, changes of NCO are not significant in summer and changes of TCF are associated mostly with changes of OO. In autumn, TCF has decreased only over monsoon regions of the Far East. Over all other Russian regions, an increase of TCF and a decrease of NCO

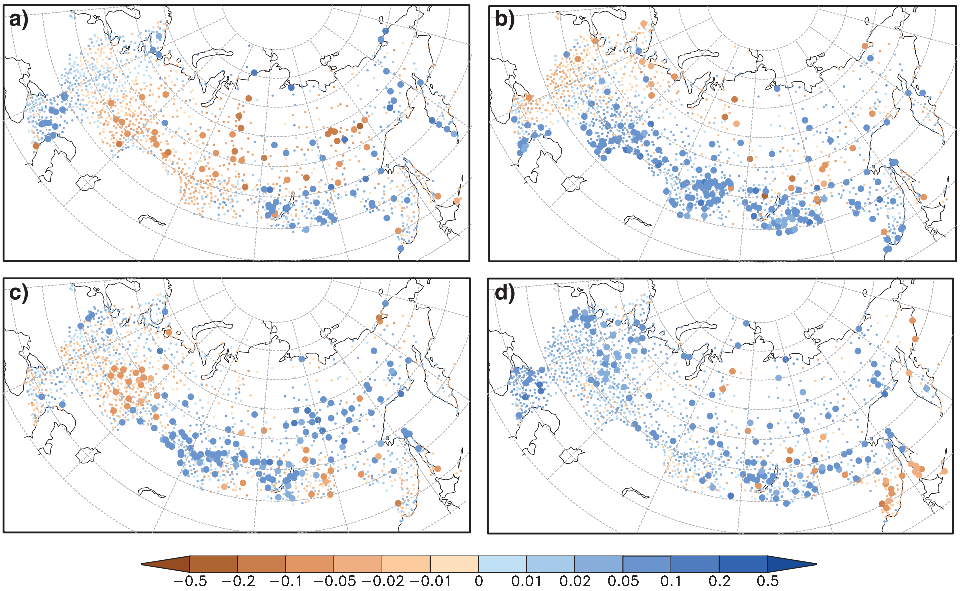

Figure 1. Changes of total cloud fraction between the periods 2001–10 and 1991–2000 in (a) winter (December–February), (b) spring (March–May), (c) summer (June–August) and (d) autumn (September–November). Large circles correspond to stations where the changes are higher than the interannual standard deviation.

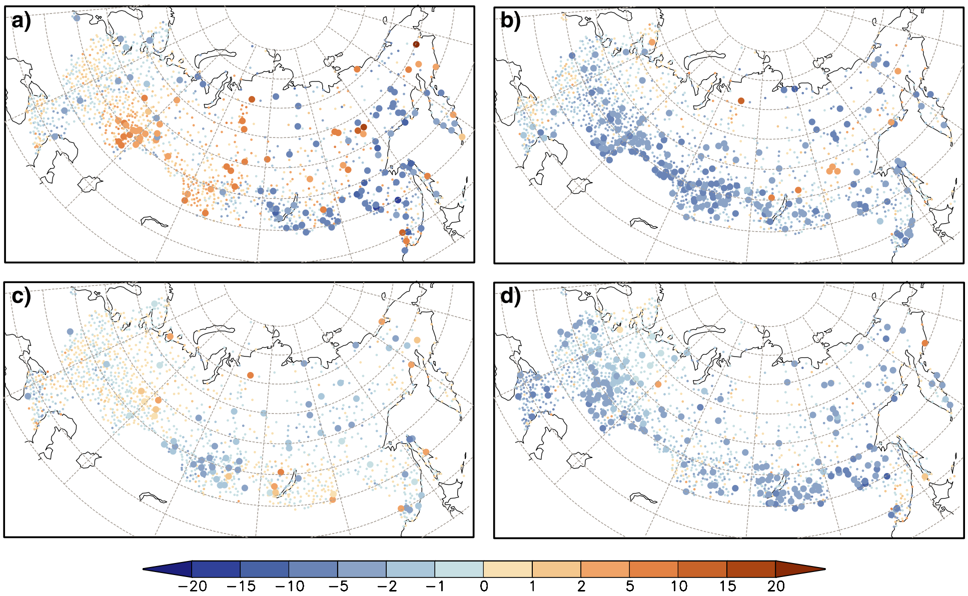

Figure 2. Changes of the occurrence of days without clouds (in %) between the periods 2001–10 and 1991–2000 in (a) winter (December–February), (b) spring (March–May), (c) summer (June–August) and (d) autumn (September–November). Large circles correspond to stations where the changes are higher than the interannual standard deviation.

are revealed. The largest changes are noted over the European part and southern Siberia. The linear trend analysis shows analogous results with similar regional features but all obtained trends are statistically insignificant at the 0.1 level.

Changes of TCF are caused primarily by changes of LCF (not shown). High- and mid-level clouds make less contribution to changes of TCF except a decrease of TCF over Siberia in winter, which is caused mostly by a decrease of mid-level clouds (not shown). In turn, changes of LCF are caused by changes of different cloud types, particularly, stratiform and convective-type clouds. Changes of the occurrence of cumulonimbus clouds (CbO) and nimbostratus clouds (NsO) are shown in figures 4 and 5 respectively. In winter, CbO is associated with atmospheric frontal systems and cyclonic activity. In general, CbO has increased over the southern part of Siberia and has decreased over the European part. In the rest of the year, air-mass convection becomes more significant in cumulonimbus formation. The increase of surface air temperature, which has been noted over Russian regions during recent decades (http://meteorf.ru/), leads to an increase of CbO. The most prominent increase of CbO (up to 20%) is noted in spring and autumn (figures 4(b) and (d)). As suggested

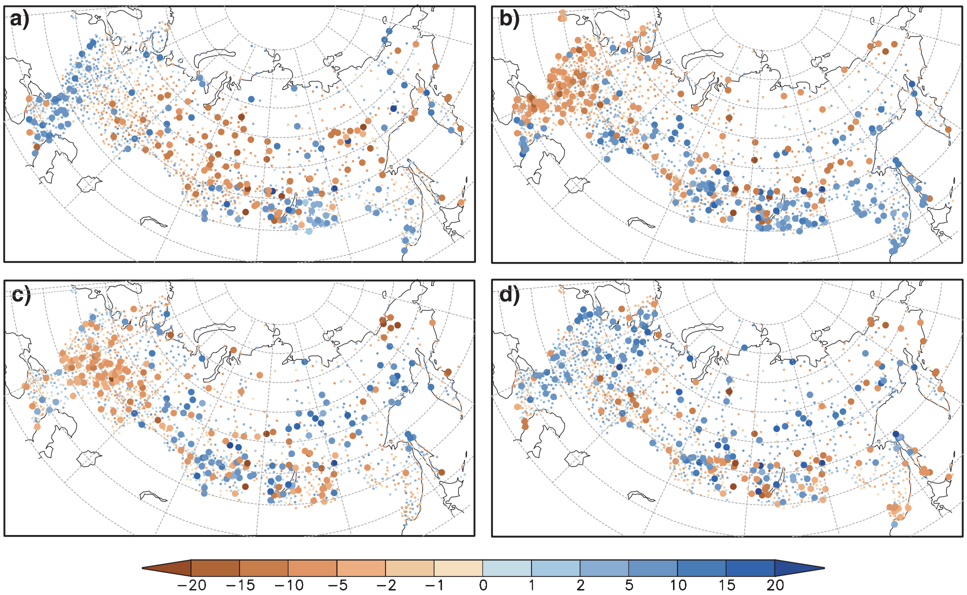

Figure 3. The same as figure 2 but for the occurrence of days with overcast conditions.

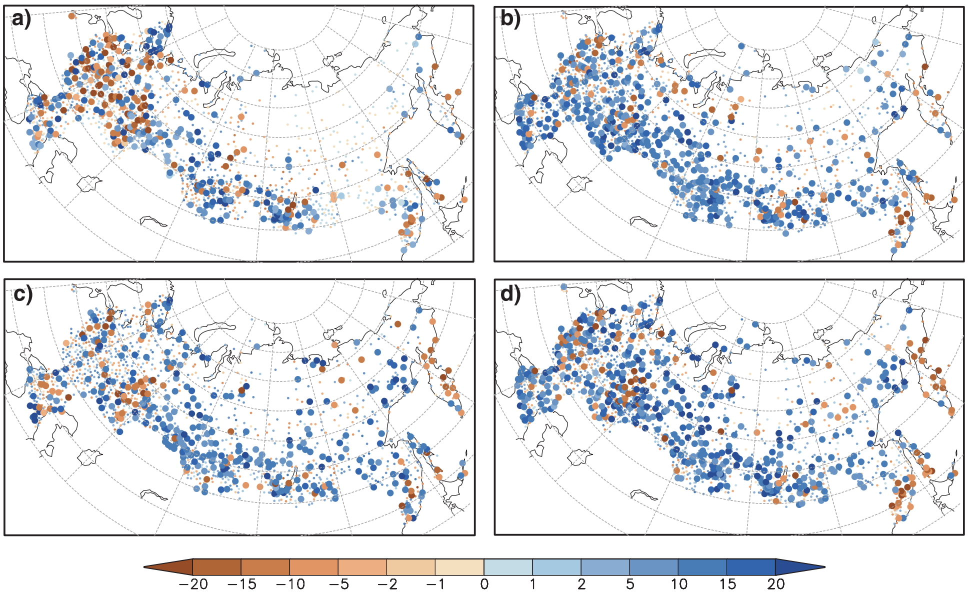

Figure 4. The same as figure 2 but for the occurrence of days with cumulonimbus clouds.

in Sun *et al* (2001), it is related to the prolongation of 'summer-type' cloudiness with a high occurrence of cumulus and cumulonimbus into spring (May and part of April) and into autumn (September and part of October). Two regions as exceptions should be highlighted: over the Urals and the coastal regions of the Far East (Kamchatka, Sakhalin and Primor'e). CbO has generally decreased during the whole year with the most prominent decrease in summer and autumn (by 15–20%). The changes in the occurrence of all convective clouds are similar to those for cumulonimbus only. Tendencies of NsO changes (figure 5) are more complicated than those of CbO. In general, NsO has decreased mostly in summer, particularly over western regions of the European part, where a decrease of OO is also revealed (figure 3(c)). Besides, many stations show an increase of NsO. Notwithstanding that NsO has generally decreased, the occurrence of days with low-level stratiform clouds (stratus and stratocumulus), which are associated with very low precipitation rate and can be considered as non-precipitating stratiform clouds (Matveev *et al* 1986), has generally increased over Russia during the whole year with the most prominent changes in spring and autumn (not shown).

4. Discussion and conclusions

Changes of the total and low cloud fractions and the occurrence of various types of clouds during the last 20 years by observations from surface stations were assessed for different

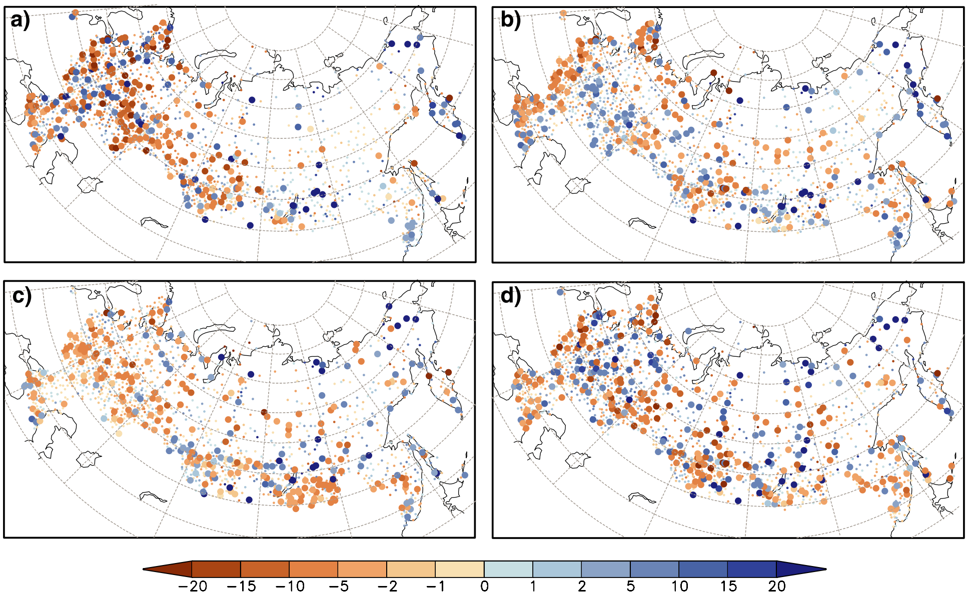

Figure 5. The same as figure 2 but for the occurrence of days with nimbostratus and fractonimbus clouds.

seasons. A major increase of total cloud fraction and a decrease of the occurrence of days without clouds are revealed in spring and autumn mostly due to an increase of convective and non-precipitating stratiform clouds. In contrast, nimbostratus clouds have tended to decrease. In general, the ratio between CbO and NsO has increased for the period 2001–10 compared with 1991–2000. These results are in agreement with previous studies (Sun and Groisman 2000, Sun *et al* 2001, Khlebnikova and Sall 2009) indicating precipitating cloud type (Cb and Ns) redistribution. At the same time, a few regional exceptions, omitted in previous studies, should be taken into account. In particular, over the Urals and coastal regions of the Far East the opposite tendency with a decrease of CbO and an increase of NsO was noted.

It should be noted that the visual observations did not provide information on the fraction of each cloud type. For many days various cloud types occurred simultaneously. Because of that, the quantitative contribution of different cloud types (e.g. contiguous stratiform clouds and sporadic convective clouds) to the TCF is difficult to assess. Changes in the occurrence of convective clouds mostly influence the occurrence of days without cloudiness. On the other hand, changes in the occurrence of stratiform clouds mostly influence the occurrence of days with overcast conditions.

An overall increase of convective cloud occurrence is an additional and independent evidence for the intensification of convective processes in recent decades over land in the northern midlatitudes. Along with an increase of heavy precipitation events (Groisman *et al* 1999, Sun *et al* 2001), an increase of the occurrence of cumulonimbus clouds leads to an increase of lightning occurrence (Gorbatenko *et al* 1999) and, in turn, leads to an increase of the risk of forest fire initiation. Together with the projected increase of fire danger indices in southern regions of the European part of Russia and Siberia (Mokhov *et al* 2006, Mokhov and Chernokulsky 2010), it can lead to a more fire hazardous regional climate.

The observed cloudiness changes can be related to changes of dynamic and thermodynamic processes (Mokhov and Khon 2005). In particular, an increase of surface air temperature can lead to a weakening of static stability, which in turn can lead to an increase of convective clouds and reduction of stratiform clouds (Weaver and Ramanathan 1997, Norris and Iacobellis 2005, Mokhov and Akperov 2006). A major part of midlatitude cloudiness is also associated with cyclonic activity (Norris 2000, Mokhov *et al* 2009). More detailed analysis is needed to estimate quantitatively the role of various factors in regional cloudiness changes in different seasons.

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