Precipitation in the Selenga River basin during atmospheric blocking over Europe and the Russian Far East in July

O Yu Antokhina¹, P N Antokhin ¹, E V Devyatova ², V I Mordvinov ² and Yu V Martynova ³⁴

¹V.E. Zuev Institute of Atmospheric Optics of the Siberian Branch of the Russian Academy of Sciences, 1, Academician Zuev square, Tomsk, Russia
²Institute of Solar-Terrestrial Physics of the Siberian Branch of the Russian Academy of Sciences, 126a Lermontov st., Irkutsk, Russia
³Institute of Monitoring of Climatic and Ecological Systems of the Siberian Branch of the Russian Academy of Sciences, 10/3, Academichesky ave., Tomsk, Russia
⁴Siberian Regional Hydrometeorological Research Institute, 30 Sovetskaya st., Novosibirsk, Russia

olgayumarchenko@gmail.com

Abstract. We investigate the relationship between Eurasian blocking and summer precipitation in the basin of the Selenga River (Lake Baikal’s main tributary) in order to find the reasons of current low-water period in the Lake Baikal basin. In this paper, we study the development of blocking events over Europe and the Russian Far East (RFE) and anomalies in precipitation over the Selenga river basin. Blocking over Europe and the Russian Far East contribute to arid conditions over the southern (Mongolian) part of the Selenga basin and precipitation over the northern (Russian) part of the basin. We show that from 1979 to 2017 there were 10 years with joint blocking events over Europe and RFE in July: 1980, 1981, 1983, 1991, 1999, 2001, 2003, 2010, 2011 and 2014. Months with normal and higher than normal total precipitation in the basin were observed in 1983, 1991, and 2003. Months with lower precipitation were in 1980, 1981, 1999, 2001, 2010, 2011, and 2014. We conclude that simultaneous development of blocking over Europe and RFE for at least three days, along with intensity, duration and localization of blocking are important factors to form conditions favorable for intense precipitation over the northern part of the Selenga basin.

1. Introduction

Since 1996, a low-water period has been observed in the Lake Baikal basin, the longest-lasting one throughout the history of instrumental observations [1-3]. This low-water period has already caused a whole host of environmental and water economy problems in the lake basin, giving rise to many serious concerns in the future. Searching for the causes of this low-water period is very important. Previous studies showed that the decrease of inflow to Lake Baikal is related to reduce of the Selenga River discharge. The river basin comprises 83.4 % of the entire catchment area of the lake [1]. Major discharge of the river is formed by precipitation falling out from June through August [1, 4]. The decrease in the Selenga discharge within the last decades is mainly associated with the decrease in the amount of rainfall in its basin in the middle of summer-time [1, 4]. An important factor in determining the intensity of rainfall is the degree of involvement in the process of humid air of the East Asian summer monsoon, the observed low-water period the authors of [1] explain by the weakening of this
particular mechanism. It is noted in [5] that during the past decades decrease in the intensity of the East Asian summer monsoon has been observed. In [6], a conjecture was made that the cause of the monsoon variability should be searched in the features of atmospheric circulation in the middle and high latitudes of Eurasia. In particular, an important role can belong to large-scale long-lived structures – blocking. Depending on the pressure field configuration, two basic types of those are distinguished [7]: monopole and dipole. Monopole blocking (Omega (Ω)) represents an intensified high pressure ridge. At both sides of its bottom there are atmospheric troughs. Dipole blocking (Rex) resembles the symbol «8», it involves a blocking anticyclone in the north, and a cyclone in the south (in the Northern Hemisphere).

Figure 1 shows a map of the Selenga river basin. In [8] we showed features of forming July rainfall in the basin with a definite localization of blocking over Eurasia. We showed that precipitation tends to fall out in the Mongolian part of the river basin when the anticyclonic area (ridge, blocking anticyclone) is displaced from Western Siberia to Eastern Siberia. Such displacement forms a dipole blocking with anticyclonic part over Eastern Siberia and cyclonic part over Mongolia.

In [9] we demonstrated similarity between the negative phase of the spatial structure of the first empirical orthogonal function (EOF1-) and the positive phase of the second empirical orthogonal function (EOF2+) of the precipitation field over Eastern Siberia and Mongolia. In both cases precipitation tends to fall out in Eastern Siberia, and Mongolia tends to drought. In [10] we showed that the European and Russian Far East (RFE) blocking imposes similar effects on the precipitation distribution in the Selenga basin. They contribute to aridity in the Mongolian part of the river basin and precipitation in the Russian part of it. We made an assumption that EOF1 associated with blocking events over Europe and EOF2+, with blocking events over the Russian Far East.

The aim of this paper is to study features of the development of joint blocking events over Europe (0° – 50° E) and the Russian Far East (110° – 160° E) (we will call them «E+RFE») with different signs of anomalies in the precipitation over the Selenga river basin.

![Figure 1. Selenga river basin (blue color).](image-url)
2. Methods and data
To identify blocking events, we use a GHGS criterion from [11]:

\[ \text{GHGS} = \frac{Z(\phi_0) - Z(\phi_s)}{\phi_0 - \phi_s}, \]

where \( Z \) is the 500 hPa geopotential height, \( \phi_0 = 80° \text{N} \pm \Delta, \phi_s = 60° \text{N} \pm \Delta, \phi_s = 40° \text{N} \pm \Delta. \) Unlike in [11], we took the following values for \( \Delta: \Delta = -5°, -2.5°, 0°, 2.5° \) or 5°, which were first offered for use in [12].

We selected all events in July from 1979 to 2017 with blocking over Europe (0° – 50° E) and the Russian Far East (110° – 160° E) with a time interval between them of less than 5 days. The main criteria for the selection are as follows: duration of more than 5 days for at least one of «E+RFE» blocking and the absence of blocking more than 5-day long in other regions of Eurasia. We consider the situation as an «E+RFE» event until both blocking are over. Blocking events over one region if the time interval between them is less than 5 days are taken as one event, and if more than 5 days, as different ones. It was found that «E+RFE» blocking events were observed in 10 out of 39 Julys: 1980, 1981, 1983, 1991, 1999, 2001, 2003, 2010, 2011, and 2014. Then we divided the «E+RFE» events into two groups depending on the sign of anomaly of the total amount of precipitation in the Selenga basin. To calculate the total amount of precipitation over the river basin in July and deviations relative to normal, we used data from GPCC (The Global Precipitation Climatology Centre) on monthly amounts of precipitation at regular grid of 1º in longitude and latitude (GPCC Full Data Reanalysis Version 7 1979-2013, GPCC Monitoring Product Version 5 2014-2017) [13].

\[ P_{anom} = \frac{P_i - \bar{P}}{\bar{P}} - 1, \]

where \( P_i \) is the precipitation in a single month, \( \bar{P} \) is the July precipitation averaged for 1950 – 1990.

We analyzed the daily precipitation variations in the Russian part of the Selenga basin during the «E+RFE» events using the data from Russian weather stations (All-Russian Research Institute for Hydrometeorological Information-World Data Center (RIHMI-WDC)) [14].

To identify blocking events, we used 500 hPa geopotential heights from ECMWF Era-Interim data archive [15]. To figure out the origin of the air masses over the Selenga basin, we analyzed the potential temperature on the dynamic tropopause (PV–θ) [16] and 850 hPa wind velocity field stream lines from ECMWF Era-Interim [15].

3. Results
Figure 2 shows longitude-time cross-sections of the GHGS blocking index for «E+RFE» blocking events. Precipitation anomalies over the Selenga basin are given in brackets. The total precipitation is calculated for the entire Selenga basin, but keeping in mind that the arid conditions in the Mongolian part of the basin correspond to «E+RFE» blocking events, the major contribution to the change of anomaly sign must belong to precipitation falling out in the Russian part of the basin.

The months with total precipitation in the basin higher than normal include 1983 (0.2), 1991 (0.2), and 2003 (normal) Julys. The months with precipitation lower than normal are 1980 (-0.3), 1981 (-0.2), 1999 (-0.1), 2001 (-0.2), 2010 (-0.2), 2011 (-0.1), and 2014 (-0.3) Julys.

Figure 2 shows longitude-time cross-sections of the GHGS index for all ten Julys, we use those to determine the time of «E+RFE» events onset and termination. The time intervals of the «E+RFE» events are as follows: in 1980 from 21 to 31 July; in 1981 from 1 to 11 July; in 1983 from 5 to 27 July; in 1991 from 1 to 19 July and from 24 to 31 July (two events); in 1999 from 1 to 19 July; in 2001 from 3 to 31 July; in 2003 from 5 to 31 July; in 2010 whole July; in 2011 whole July; and in 2014 from 3 to 27 July. Thus, from 1979 to 2017 there were 11 «E+RFE» blocking events.

The red horizontal lines differentiate the blocking events and are drawn to help in the analysis of the dynamics of European and RFE-blocking within one blocking event. We can see that during strengthening of one of the blockings the other one is weakened, or the blockings develop in turn. For example, in 2010 the European blocking developed the whole month, and the blocking over the
Russian Far East was very weak and not lasting. The RFE blocking enhanced during the periods when the European blocking was weakening. Events in 2001 are a demonstrative example of alternating development of blocking over Europe and the Russian Far East. Based on analysis of Fig. 2, we divided all «E+RFE» events into two groups. The first group included events where the European and RFE blockings developed one by one. The second group subsumed events when the European and RFE blockings existed simultaneously for three days at minimum. One by one the «E+RFE» events were observed in: 1981 (-0.2), the second part of 1983 (0.2), 1999 (-0.1), 2001 (-0.2), and 2011 (-0.1). Simultaneous events «E+RFE»: 1980 (-0.3), the first part of 1983 (0.2), 1991 (0.2), 2003 (normal), 2010 (-0.2), and 2014 (-0.3).

Figure 2. Longitude-time cross-sections of GHGS blocking index for «E+RFE» events in July. Magnitude of anomaly in amount of precipitation over the Selenga basin in July relative to normal is shown in brackets. Blue rectangles depict time intervals of «E+RFE» blocking events. Red horizontal lines are drawn to help in analysis of the European and RFE blocking dynamics within one event.

It should be noted that the blocking form a large-scale structure of the atmospheric flows only, which control the direct sources of the precipitation of smaller scale: synoptic or mesoscale eddies and fronts. That is why we use information on the total amount of precipitation over the basin and the deviation of its amount relative to normal only as a preliminary assessment. Joint analysis of the development of «E+RFE» events and precipitation daily dynamics at stations is required, which we
carried out using PV–θ maps, streamlines at 850 hPa, and bar charts of daily precipitation fallout at stations in the Russian part of the basin. It turned out that during all 11 «E+RFE» events precipitation falls out in the Russian part of the Selenga basin with different intensity only. Figure 3 shows bar charts of daily precipitation at stations in the Russian part of the Selenga basin, which illustrate these differences. To find out the reasons of the difference in the precipitation intensity, we compared the dynamics of all 11 «E+RFE» events at the PV–θ and 850 hPa streamlines maps with Figure 3.

The results of the analysis of the blocking and precipitation dynamics have yielded the following conclusions on the role of the European and RFE blocking in forming conditions favorable for precipitation in the Selenga basin:

1) European blocking associated with advection of cold air mass to Siberia, including the northern part of Selenga basin. Advection of cold air mass is along the eastern flank of the European blocking.

2) RFE blocking contributes to the advection of warm humid air to the Selenga basin from the region of East Asian summer monsoon.

3) The RFE blocking stops the eastward propagation of moving cyclones, so frontogenesis and intensification of cyclone activity occurs directly over the basin, strengthening by temperature contrasts between the cold and monsoon air masses meeting over the basin.

Note that the mechanism of rainfall control is implemented most effectively when blocking events over Europe and the Russian Far East develop simultaneously (two «E+RFE» events with positive rainfall anomalies in the basin (1991, 2003) are subsumed under the group of simultaneous events, see Fig. 2 above). Analysis of PV–θ maps and stream lines at 850 hPa has shown that important factors of blocking control include intensity, duration, and localization of the European and RFE blocking. Obviously, the intensity and duration of blocking determine the intensity and duration of advection of air masses involved in the process. Localization of blocking determines the region of air advection. The quickest intrusion of cold air mass into the Selenga basin without loss of its initial properties takes place when an intense European blocking develops in a longitudinal interval of 25 – 50 E. For RFE blocking, an optimal longitudinal interval is 120 – 140 E.

1980 (-0.3) **simultaneous** blocking «E+RFE»

1983 (0.2) **simultaneous / one by one** blocking «E+RFE»

1981 (-0.2) **one by one** blocking «E+RFE»

1991 (0.2) **simultaneous** blocking «E+RFE»

1999 (-0.1) **one by one** blocking «E+RFE»

2003 (0.0) **simultaneous** blocking «E+RFE»

2001 (-0.2) **one by one** blocking «E+RFE»
To illustrate the above mechanism, we selected two blocking events shown in Figures 4 and 5. For comprehensive presentation of information, Figures show cross-sections of the GHGS index, bar charts of precipitation at stations of the Russian part of the Selenga basin, maps of anomalies in the July rainfall amount relative to normal, PV–θ maps and streamlines at 850 hPa for some days during relevant blocking events. Figure 4 shows the 1991 «Е+RFE» process, which represents a classic implementation of the mechanism of blocking impact with intense precipitation over the Selenga basin. Note that in 1991 two «Е+RFE» events were observed. They both developed in a similar way, both are related to abundant rainfall over the basin. For detailed analysis we selected the first of them (1 – 18 July 1991). Figure 5 shows the 2010 «Е+RFE» event (long-lasting blocking, from 1 to 31 July 2010), in which the mechanism is not fully implemented without intense precipitation.

In general, the two events (1991 and 2010) develop in a similar way. However, there are peculiarities causing, in our opinion, differences in the rainfall intensity over the Selenga basin. First of all, it is the velocity of cold air masses advection to the Selenga basin. On 2 July 1991 and 3 July 2010, the southern tips of the trough formed at the flank of European blocking are approximately at the same distance from the Selenga basin. In 1991, the trough reaches the Russian part of the Selenga basin in 5 days (02.07 – 06.07), and in 2010, in 12 days (03.07 – 14.07). In the second example, the air in the trough on its way to the Selenga basin transforms significantly and loses much of its initial properties. In 1991, intense rainfall at the stations started on 6 July, in 2010 – only on 14 July, and in general it was of far less intensity (see bar charts Figs. 4 and 5). It is quite fair to assume that different velocities of cold air advection in 1991 and 2010 are related to the intensity of European blocking. In 1991, the European blocking was shorter but stronger than in 2010. Second, there is a difference between events in the Russian Far East. In 1991, a strong blocking was observed there, in 2010 it was weak. Third, it is essential to note different activity of atmospheric fronts and cyclones over the basin.

Figure 3. Day-to-day amount of precipitation recorded at stations over Russian part of the Selenga River basin. Blue rectangles show time intervals of «Е+RFE» blocking events. Red horizontal line corresponds to a precipitation amount of 35 mm.
During the 1991 event, cyclonic vorticity is present for almost all the time over there. In 2010, in the first half month cyclones and atmospheric fronts were absent over the basin. In the middle of the month there were temperature contrasts and an atmospheric front over there. Then the basin was mainly in the southern air mass. In the last days of the month, cold air inflows again, but vorticity over the basin was anticyclonic.

Figure 4. July 1991. Map of anomaly of precipitation (a) (GPCC normals_v2015_10), longitude-time cross section of GHGS (b), day-to-day rainfall variations (c) (scales are shown above). PV-θ maps for 2, 4, 6, 8, 10, 12, 14, 16 July (d-k) (the first «E+RFE» event, the second one is not given, since it is similar to the first one in pattern).
Figure 5. July 2010. Map of anomaly of precipitation (a) (GPCC normals_v2015_10), longitude-time cross section of GHGS (b), day-to-day rainfall (c) (scales are shown above). PV-θ maps for 3, 7, 11, 14, 19, 23, 27, 31 July (d-k) (the first «E+RFE» event, the second one is not given, since it is similar to the first one in pattern).

4. Conclusions
We investigated the relationship between Eurasian blocking and regimes of summer precipitation in the basin of the Selenga river (Lake Baikal’s main tributary) in order to establish the reasons for the current low-water period in the Lake Baikal basin. In this paper, we investigated the development of joint blocking events over Europe (0°E – 50°E) and the Russian Far East (110°E – 160°E) with different sign of anomalies of precipitation over the Selenga river basin. Using ERA-Interim data we found that from 1979 to 2017 there were 10 years with such July events: 1980, 1981, 1983, 1991, 1999, 2001, 2003, 2010, 2011, and 2014. We divided the «E+RFE» events into two groups depending on the sign of the anomaly of total amount of precipitation in the Selenga basin. The years with total precipitation in the basin higher than the normal one are 1983 (0.2), 1991 (0.2) and 2003 (normal). Years with precipitation lower than normal are 1980 (-0.3), 1981 (-0.2), 1999 (-0.1), 2001 (-0.2), 2010
(-0.2), 2011 (-0.1), and 2014 (-0.3). Based on an analysis of longitude-time cross sections of the GHGS blocking index, we divided all «E+RFE» events into two groups. The first group included the events in which the European and RFE blocking events developed one by one: 1981 (-0.2), the second part of 1983 (0.2), 1999 (-0.1), 2001 (-0.2), and 2011 (-0.1). The second group consisted of the events in which the European and RFE blocking events existed simultaneously at least for three days: 1980 (-0.3), the first part of 1983 (0.2), 1991 (0.2), 2003 (normal), 2010 (-0.2), 2014 (-0.3).

The results of the above review led to the following conclusions concerning the role of the European and RFE blocking in forming conditions favorable for precipitation in the Selenga basin:

1) The European blocking causes the advection of cold air masses to Siberia, including the northern part of the Selenga basin. The advection of cold air masses takes place along the eastern flank of the European blocking.
2) The RFE blocking is responsible for the advection of warm air to the Selenga basin from the East Asian summer monsoon region.
3) The RFE blocking prevents the eastward propagation of the moving cyclones and confines them in the Selenga basin.

The intensity, duration, and localization of the European and RFE blocking are also important factors in forming precipitation in the Selenga basin area. In the future, a detailed description of each of the selected events will be made.

Acknowledgements

This study was supported by the Russian Scientific Foundation under project no. 17-77-10035. The authors are thankful to E.N. Osipchuk for preparing data on the boundaries of the water catchment area and the Selenga river network.

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