The impact of atmospheric blocking on spatial distributions of summertime precipitation over Eurasia

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Abstract. The correlation of precipitation anomalies over Eurasia with atmospheric blocking events was examined with ERA Interim reanalysis data. We found that, regardless of the frequency of the atmospheric blocking events, they significantly affect the distribution of rainfall over all Eurasian regions in summer, due to both the change in the westerly transport and the dominant dipole blocking structure. It is important that, depending on the blocking positions in Asia, there are heavy rainfalls in an arid zone which includes Kazakhstan, Mongolia, Northern China, and the Trans-Baikal Territory.

1. Introduction

Atmospheric blocking is a major large-scale phenomenon in the circulation of mid- and high-latitude atmosphere [1,2]. The mid-latitude westerly jet and the eastward progression of synoptic systems are often interrupted in long periods of atmospheric blocking. Thus, atmospheric blocking can significantly impact weather processes. The lifetime of blocking varies from a few days to a few weeks, and, therefore, they may be responsible for various extreme weather events. Blocking events (BEs) are normally associated with extreme summer droughts and snowless winter periods. In addition, they can cause heavy atmospheric precipitation, especially in summer.

The blocking formation processes and the associated weather anomalies over some areas of the Northern hemisphere have been studied in detail since the 1940s - 1950s. It has been found that strengthening of large-scale Rossby waves leads to the formation of a monopole Ω-blocking (a hot ridge in the center, cold troughs near the base) or to a dipole Rex-blocking (a closed cyclone from the equatorial side and a closed anticyclone from the polar side of the mean westerlies) [2]. Jet streams and the associated baroclinic disturbances are forced to bypass the blockings. Both factors, i.e. the change in the direction of motion of the synoptic disturbances and the descending and ascending flows in the blockings themselves, lead to the formation of both negative and positive atmospheric precipitation anomalies in the vicinity of the blockings. These anomalies are clearly visible on monthly average precipitation maps [3]. For instance, in the summer of 2003, a long-lasting blocking over Western Europe resulted in heavy rains in Eastern Europe. Also, in July 2010 a blocking over

Eastern Europe caused precipitation in Western Siberia. Besides, the significant meridional sizes of the blockings enables them to impact regions not only in the mid-latitudes but also those farther to the south [4,5].

The rainfall anomalies generated by blockings have been studied for some regions in Europe [6] and Asia [4]. In the present paper we analyze the impact of blocking processes on the atmospheric precipitation anomalies over the entire territory of Eurasia.

2. Method and data

In order to detect the blocking events, we used the Tibaldi and Molteni (TM) criterion [7], which is based on the estimation of the meridional gradient of the geopotential height at 500 hPa. This criterion allows us to detect blockings for a given longitude (equations (1) and (2)):

$$GHGS = \frac{Z(\varphi_0) - Z(\varphi_s)}{\varphi_0 - \varphi_s} \quad (1) \qquad GHGN = \frac{Z(\varphi_n) - Z(\varphi_0)}{\varphi_n - \varphi_0} \quad (2)$$

where Z is the geopotential height at 500 hPa, φ_n=80°N±Δ, φ_0=60°N±Δ, φ_s=40° N±Δ, Δ=-4°,0° or 4°.

The given longitude is then defined as "blocked" at some time if the following conditions are satisfied for at least one value of Δ: GHGS>0, GHGN < -10 m/deg lat.

To study the relationship between BEs and precipitation distributions, some local blocking estimates were used [2,8]. A blocking event was registered if the TM blocking condition was met at least for one day at some longitude. Some calculations of the TM criterion were performed using the ERA Interim data [9] from 1979 to 2015.

Figure 1 shows a time-longitude cross-section distribution of the blocking frequency (BF) over Eurasia in July obtained using the TM criterion. The July intensity of summertime blocking over Asia is most frequently at its maximum.

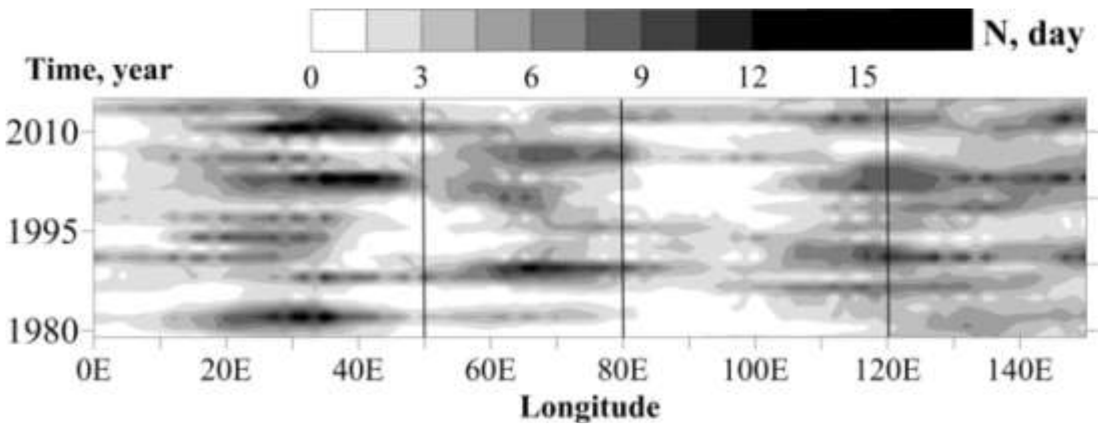


Figure 1. Time-longitude cross-section of BF (N) in July.

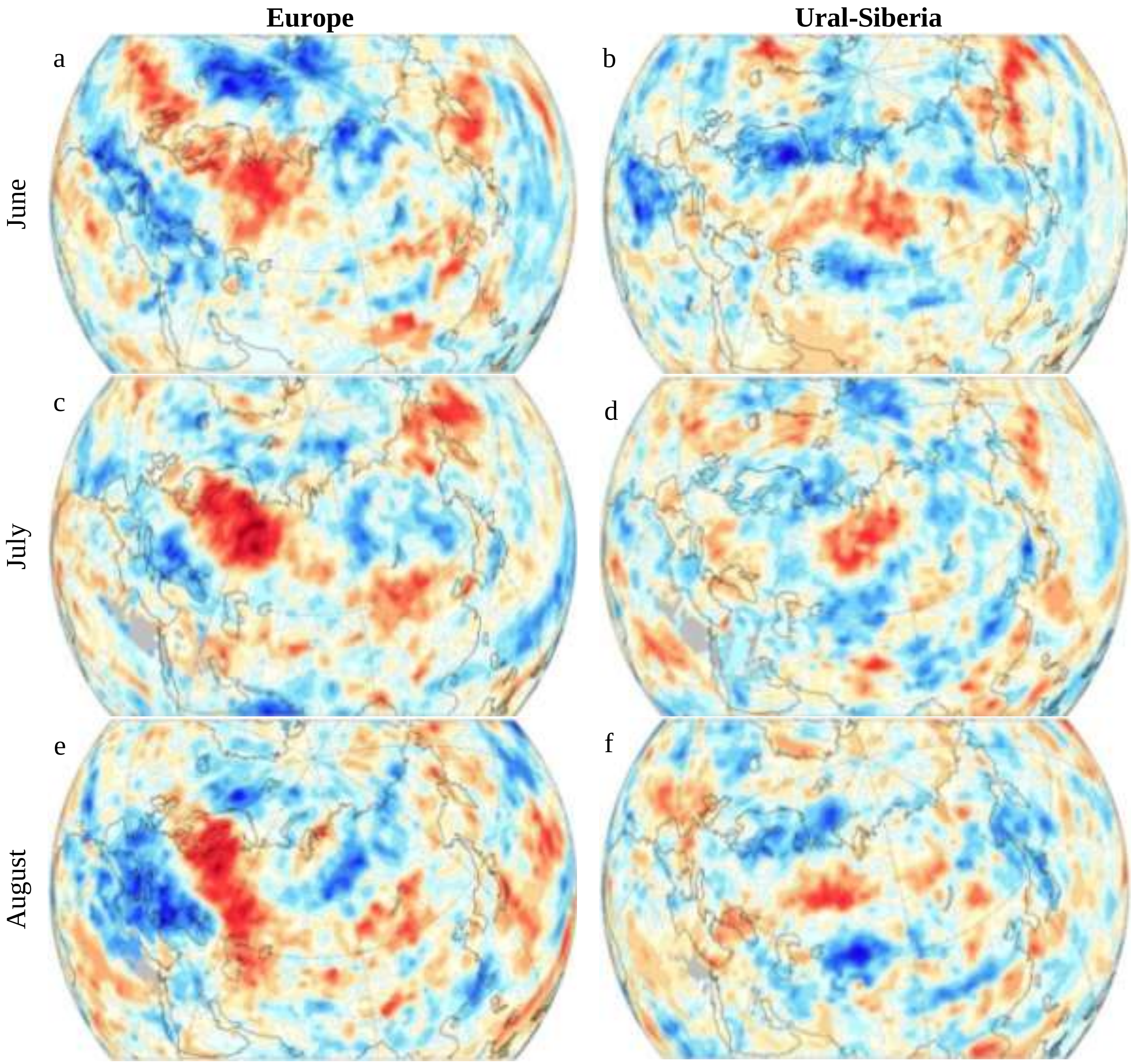
Normally, three blocking regions are distinguished over Eurasia [4]: 0-50E (E: Europe), 50-80E (US: Ural-Siberia) and 120-160E (OS: Okhotsk Sea). For these regions, the authors of [4] have investigated some characteristics of summertime blockings. For the OS and E regions, the correlations of blockings with atmospheric precipitation have also been studied [4,6]. The region from 80E to 120E, which has low BF, has been studied in much less detail. However, one can see that periods of high BF are observed even in this region (figure 1). That is why we investigated blockings in the region of 80E-120E (ES: East Siberia) too.

First we calculated the integral BF for each of the four regions, and then, the correlation coefficients between these four values and the total precipitation at a regular grid of the entire Northern hemisphere for each summer month.

3. Results

Figure 2 shows distributions of calculated correlation coefficients for various Eurasian regions. Positive and negative anomalies of precipitation (AP) caused by the structural features of blockings are more or less typical for all the regions. Dipole AP configurations are described in [6] for Europe and in [4] for the Okhotsk Sea region. In Europe, during the periods of blocking much precipitation falls in the south (figures 2a,c,e). During blockings in the Okhotsk Sea region, the atmospheric fronts in Japan and Korea are strengthened (figures 2h,j,l). Besides, during blocking periods in the Far East, a lot of precipitation falls over the Trans-Baikal Territory (figures 2h,j).

For the Siberian region, the correlation between blockings and precipitation anomalies has not been studied earlier, but a close examination of figure 2 shows that the impact of blockings on APs is as profound (figures 2g,I,k) as it is in the Ural-Siberian region (figures 2b,d,f). Due to the blocking process, the large-scale quadrupole anomaly structure in Eastern Siberia is even more evident than that in Europe; although the BF in Europe is much higher than that in Eastern Siberia [4]. In the course of blocking, much precipitation falls in the arid Mongolia which, basically, is anomalous. Thus, despite their low frequency, the blockings in Eastern Siberia play an important role in the region. Overall, it should be noted that the blockings in each region of Asia are accompanied by precipitation in the arid belt of Asia (Kazakhstan, Mongolia, Transbaikalia, and North China).



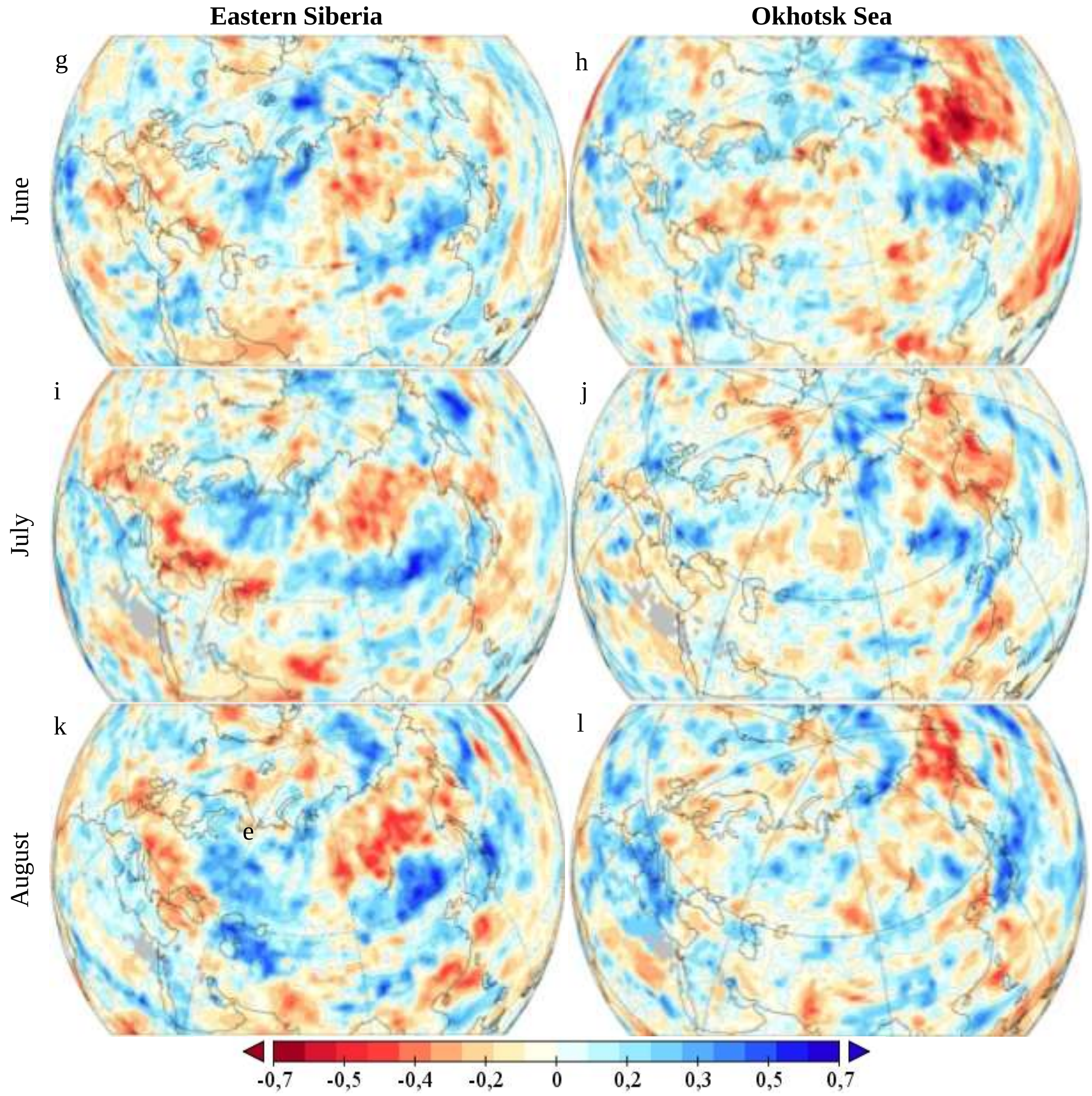


Figure 2. Distribution of correlations between BF and total precipitation for Europe (a-June, c-July, e-August), Ural-Siberia (b-June, d-July, f-August), Eastern Siberia (g-June, i-July, k-August), Okhotsk Sea (h-June, j-July, l-August).

All blockings in Eurasia are accompanied by positive precipitation anomalies at their north-western boundaries. These anomalies result from changes in the trajectories of baroclinic disturbances. The effect of this factor is evident in the case of East-Siberian blockings.

It is clearly seen that the northward shift of the cyclone series reduces precipitation in the southern regions of Europe. During blockings over Europe, much precipitation falls in Siberia due to the increased intensity of ultrapolar cold air intrusions. In the Far East region, special attention should be paid to the formation of positive precipitation anomalies northwards of the blocking anticyclone.

Despite the similarity of the correlation fields for specific regions in different summer months, there are some differences. These are not so evident over the entire Eurasia, but for some countries and regions they may play an essential role. For example, in August the negative anomalies resulting from a blocking anticyclone over Europe (figure 2e) are especially well-pronounced in the Volga region. When a blocking occurs in Eastern Siberia, the Central Asian republics (Kazakhstan, Uzbekistan and Turkmenistan) are areas of negative or positive anomalies in some months. For example, when a blocking takes place in July (figure 2i) a precipitation shortage is clearly seen, and, on the contrary, when a blocking takes place in August (figure 2k), positive precipitation anomalies prevail. Our main attention is focused on the arid and semiarid regions of Asia, because it was noted [10] that in the course of climatic changes of the recent decades the droughts of the arid and semiarid regions of Asia are among the most dramatic ones globally. Some changes in the atmospheric blocking may be one of the reasons of this phenomenon.

4. Conclusions

Atmospheric blockings can be responsible for both negative and positive atmospheric precipitation anomalies. It has been found that, regardless of frequency, atmospheric blockings have a pronounced effect on the distribution of atmospheric precipitation throughout all regions of Eurasia. The formation of positive and negative precipitation anomalies is associated both with changes in the trajectories of jet streams and with the dipole structure of blockings in summer. It is of special importance that the blockings in all regions of Asia are accompanied by large precipitation in an arid belt zone that includes Kazakhstan, Mongolia, North China, and the Trans-Baikal Territory.

5. Acknowledgments

This research was supported by the RAS Presidium (program no. 15), the Department of Earth Sciences, the Russian Foundation for Basic Research (grants no. 14-05-00526 and no. 14-05-00590), and the Presidential Program “Leading Scientific Schools of the Russian Federation” (grant NSh-6894.2016.5).

References

[1] Mokhov I I, Timazhev A V and Lupo A R 2014 Changes in atmospheric blocking characteristics within Euro-Atlantic region and Northern Hemisphere as a whole in the 21st century from model simulations using RCP anthropogenic scenarios *Global Planet. Change* **122** pp 265–270

[2] Pelly J L and Hoskins B J 2003 A new perspective on blocking *J. Atmos. Sci.* **60** pp 743–755

[3] https://kunden.dwd.de/GPCC/Visualizer

[4] Park Y-J and Ahn J-B 2014 Characteristics of atmospheric circulation over East Asia associated with summer blocking *J. Geophys. Res. Atmos.* **119** pp 726–738

[5] Hong Ch-Ch, Hsu H-H, Lin N-H and Chiu H 2011 Roles of European blocking and tropical-extratropical interaction in the 2010 Pakistan flooding *Geoph. Res. Let.* **38** pp 553–597

[6] Rimbu N, Stefan S, Busuoic A and Georgescu F 2016 Links between blocking circulation and precipitation extremes over Romania in summer *Int. J. Climatol.* **36** pp 369–376

[7] Tibaldi S and Molteni F 1990 On the operational predictability of blocking *Tellus* **42A** pp 343–365

[8] Masato G, Hoskins B J and Woollings T J 2012 Wave-breaking characteristics of midlatitude blocking *Q. J. R. Meteorol. Soc.* **138** pp 1285–1296

[9] Dee D P et. al. 2011 The ERA-Interim reanalysis: configuration and performance of the data assimilation system *Q. J. R. Met. Soc.* **137** pp 553–597

[10] Berezhnykh T V, Marchenko O Yu, Mordvinov V I and Abasov N V 2012 Changes in the summertime atmospheric circulation over East Asia and formation of long-lasting low-water periods within the Selenga river basin *Geogr. Nat. Resour.* **33** pp 223–229