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Peculiarities of the atmospheric blocking events over the Siberia and Russian Far East region during summertime

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ABSTRACT

We study the atmospheric blocking event evolution peculiarities over the Siberia and Far Eastern region (Russia) during summertime. Compared are two methods to identify blockings: from the 500 hPa (Z500) isobaric surface height distribution, and from the potential temperature at the dynamic tropopause (PV-θ) for every July 1979 through 2016. We revealed the situations, where blockings are identified only in one of the characteristics. Blocking identification by the PV-θ characteristics is complicated in the cases, when its cyclonic part appears to be filled with air masses of the southern origin, due to which there is no meridional gradient reversal in the PV-θ region. In the Z500 region, the difficulties to identify blocking events may arise in those cases, when the baric field fails to adapt to rapid changes in the temperature field associated with the air mass advection. For example, such events often occur over the ocean surface.

We performed a synoptic analysis for several blocking events from the data on the velocity field dynamics at 850 hPa and PV-θ supplemented by the analysis of the observational rainfall data at the stations during those events. Distinguished were several stages of the blocking evolution over the Siberia and Far Eastern region that involved air masses from the East Asian summer monsoon region: 1. The formation of a blocking over Western Siberia; 2. Cold inflow on the blocking eastern periphery, the East Asian summer monsoon front activation, and a cyclone formation (east of Lake Baikal), in whose system the monsoon air was actively involved. Such monsoon cyclones, as a rule, are deep long-living formations, and they bring abnormal precipitations; 3. The formation of a ridge or anticyclone east of the monsoon cyclone, caused by the advection of the same monsoon flow, whose part is involved in a cyclone system.

In general, the East Asian summer monsoon influence comes to the effects of regeneration and intensification of the blocking circulating systems. Those effects are often accompanied by strong droughts in some regions and floods in others.

Keywords: atmospheric blocking, geopotential, potential temperature on the dynamic tropopause, objective criteria, East Asia summer monsoon.

1. INTRODUCTION

Atmospheric blocking events (blocking) have recently drawn increasing attention. One of the main reasons is frequent natural disasters related to this phenomenon to this or that extent [1]. As the basis of the mechanism for blocking formation, one often regards instability of Rossby long waves. The produced baric anomalies are then maintained by a flux of the quasi-stationary Rossby wave vorticity, and/or of synoptic formations [2]. In some regions, however, in particular, in Eastern Asia, blocking formation during summertime is closely related to the warm air mass advection from the tropics/subtropics. When moving northward, due to maintaining the absolute vorticity, flow lines obtain additional anticyclonic curvature. In the mid troposphere, a barotropic atmospheric anticyclone (or a high-pressure ridge) forms. The size of those formations depends on the advection scale. Subject to the degree, at which cold air from high latitudes is involved in the process, and to the degree of its penetration southward, one identifies two main types of blocking: monopole and dipole [3,4]. The monopole blocking looks like an intensified high-pressure ridge, at whose basis atmospheric troughs are located on either side. The dipole blocking resembles a meridionally-oriented numeral "8" comprising a blocking anticyclone from the polar side, and a cyclonic region from the equatorial side.

To study the blocking long-term variations, one should develop techniques to autodetect those events. Such a technique should base on the knowledge of blocking peculiarities, blocking configurations, and their life cycle. One of

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the most popular techniques in detecting blocking events is the one based on the analysis of the 500 hPa geopotential field distribution [5,6]. Besides, to identify blockings, one often uses the analysis of the potential temperature distribution at the dynamic tropopause (PV - θ) [3]. A dynamic (isoertelic) tropopause, with some assumptions [3], may be regarded as a quasi-material surface, along which air mass transport occurs. On average, of lower latitudes, characteristic are higher values of Z500 and PV-θ, than those of high latitudes. At a blocking formation, we observe a meridional reversal (inverse) of both characteristics. It is the estimate for the meridional gradient, that underlies the two above techniques to identify blocking events.

2. COMPARING THE RESULTS OF BLOCKING AUTOMATIC IDENTIFICATION BY USING Z500 AND PV-Θ

To implement blocking automatic identification based on the Z500 data analysis (Tibaldi and Molteni criterion [6] and PV-θ (Pelly and Hoskins criterion [3]), we developed a program algorithm [7]. In this study, we use this algorithm to identify blockings during summertime over the Asian-Pacific region. We built and analyzed time-longitude cross-section for the blocking event intensity from the Z500 and PV-θ data for every July 1979 through 2016, as well as synoptic charts for these characteristics (over 12 hours UTC). Both techniques appeared to be able to identify blockings in the most of the studied cases. However, there are also special situations, when only one of the techniques identifies blocking. As example, Figure 1 shows time-longitude cross-section diagrams for the blocking event intensity in July of 1990 (a,b) and 1997 (c,d).

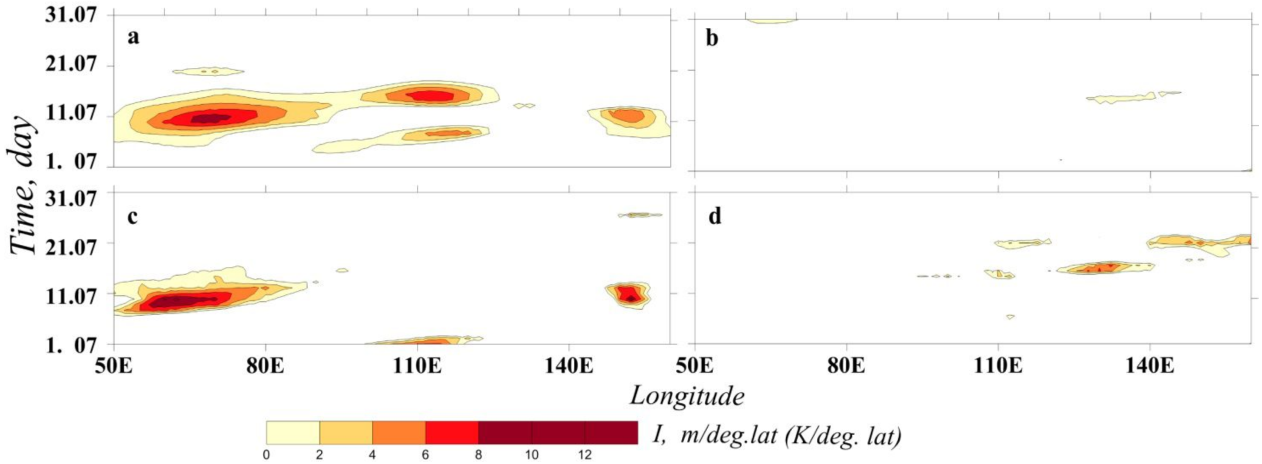

Figure. 1. Time-longitude cross-section for the blocking event intensity (I) in 1990 (a,c) and 1997 (b,d) built from the Z500 (a,b) and PV-θ (c,d) data. The blocking central latitude in calculations is 50°N. Based on the ECMWF Era-Interim archive data [8].

One can see on the diagrams that, both in 1990 and in 1997, in all the cases, the Z500-detected blockings are not identified in PV-θ, and vice versa. We analyze explicitly some events: 1) 1990 July 11-14, the blocking is detected in the Z500 characteristic over the Ural-Siberian region (80°E - 120°E) (Fig. 2a); 2) 1997 July 14, 15, 20, 21, the blocking is detected in the PV-θ characteristic in in the Russian Far East (120°E - 140°E) (Fig. 2b).

In 1990, in the geopotential, starting with July 11, one can clearly see a large-scale blocking over the Ural-Siberian region. By July 14, the high-pressure area displaces to Eastern Siberia, and two "cut-off" cyclones north-west and south-east of Lake Baikal form. The geopotential field configuration over Eastern Siberia meets the geopotential reversal condition on July 14 (Fig. 1a). In the potential temperature field, the July 12-14 geopotential low values east of Lake Baikal correspond to the PV-θ high values. It is rather a curious fact, because in other regions the Z500 high values correspond to the PV-θ high values. The potential temperature distribution indicates that the air in the cyclone south-east of Lake Baikal has a "tropical" origin, arriving into region from East Asian summer monsoon region.

Let us address an inverse situation. On 1997 July 14-15 (Fig. 2b), one can see an evolution of a weak ridge that did not reflect on the diagram (Fig. 1c) in the geopotential field over the Far East. On July 20-21, in the geopotential field, there is no even weak ridge. But, in the potential temperature field, one can clearly see air advection from the East Asian summer monsoon region (Fig. 2b). And on the Fig. 1d diagram, blockings are identified on those days. This situation is less contrasting, than that in 1990, nevertheless, in this case also the difference in the Z500 and PV-θ behaviors is rather indicative. These differences may substantially complicate the detection of blockings in the Asian-Pacific region, and, consequently, they require a more detailed study.

a b

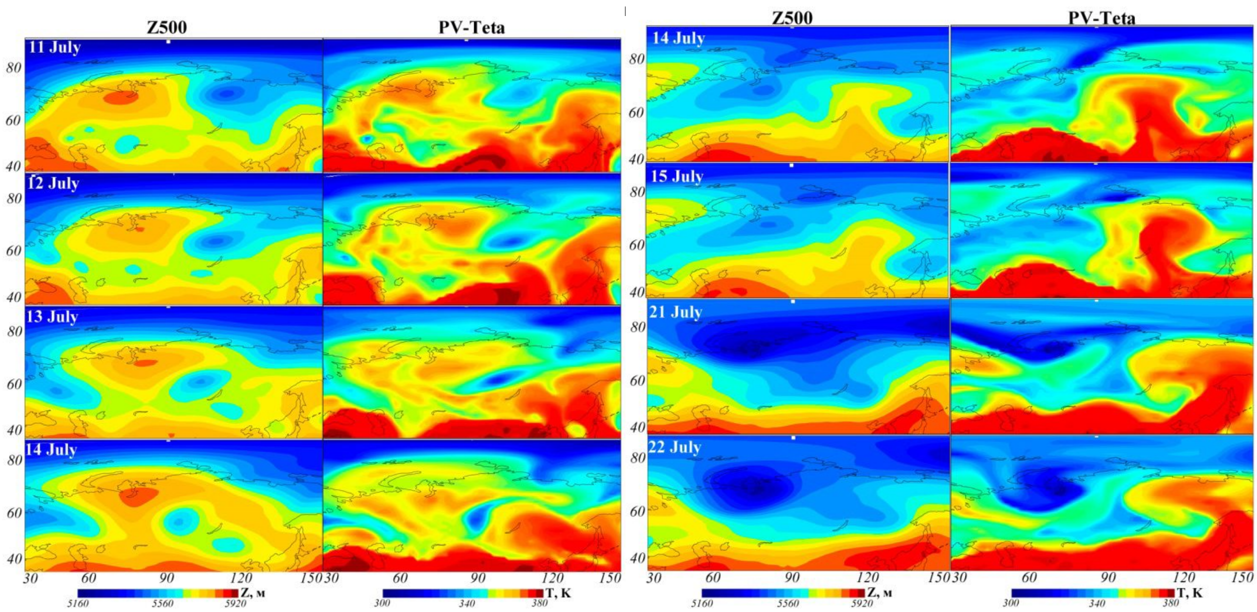

Figure. 2. Distribution of geopotential height (Z500) and of potential temperature (PV-θ) for 12 UTC on 1990 July 11-14 (a) and 1997 July 14-15 and 1997 July 21-22 (b). Based on the ECMWF Era-Interim.

3. BLOCKINGS FORMATION WHEN INVOLVING EAST ASIAN SUMMER MONSOON (EASM) AIR MASSES

We saw, while analyzing Fig. 2 that the air masses from the East Asian summer monsoon (EASM) region participate actively in the processes of forming and maintaining blockings over Asia during summertime. To realize, how the EASM air is involved in the baric formations, we analyzed some cases of summer blocking over Asia from the data on the velocity field dynamics at 850 hPa [9] and PV-θ [8]. The 850 hPa level is convenient for the analysis, because both monsoon transfers and locking vortex formations are well seen on it. We addressed four blocking events: one in 1982, one in 2013, and 2 events in 1998. Additionally, we used observational precipitation data recorded at meteorological stations within the Siberia and Far East region during the addressed events [10].

Figs. 3 (a-e) illustrate blocking evolution over Siberia and the western part of the Pacific Ocean in 1982 mid-July. The figure also presents the time-longitude cross-section for the blocking intensity over the Euro-Asian-Pacific region in July (Fig. 3f), and the precipitation dynamics for two stations located in the Far East in July (Fig. 3g). According to the Fig. 3f diagram, blocking evolves over Western Siberia first (60°E - 80°E), and, then, in the East-Asian-Pacific sector (110°E - 160°E). The Fig. 3 (a-e) distributions of the potential temperature and of the streamlines visually illustrate the blocking evolution. One can see, how the atmospheric trough caused by the cold air inflow on the eastern periphery of the blocking anticyclone over Western Siberia, gradually deepens and is cut off. At the same time, there is a gradual ridge increase east of Lake Baikal. This increase was caused by advection of the warm monsoon air. On the eastern periphery of the ridge, another cold cyclonic vortex forms that, later, is filled with the East Asia warm monsoon air masses from the east (Fig. 3 c-e). A part of the warm air flow directs northward, thus forming an anticyclone (Fig. 3e). Already on July 12, one can see, how monsoon air masses reach the Asian northern boundaries.

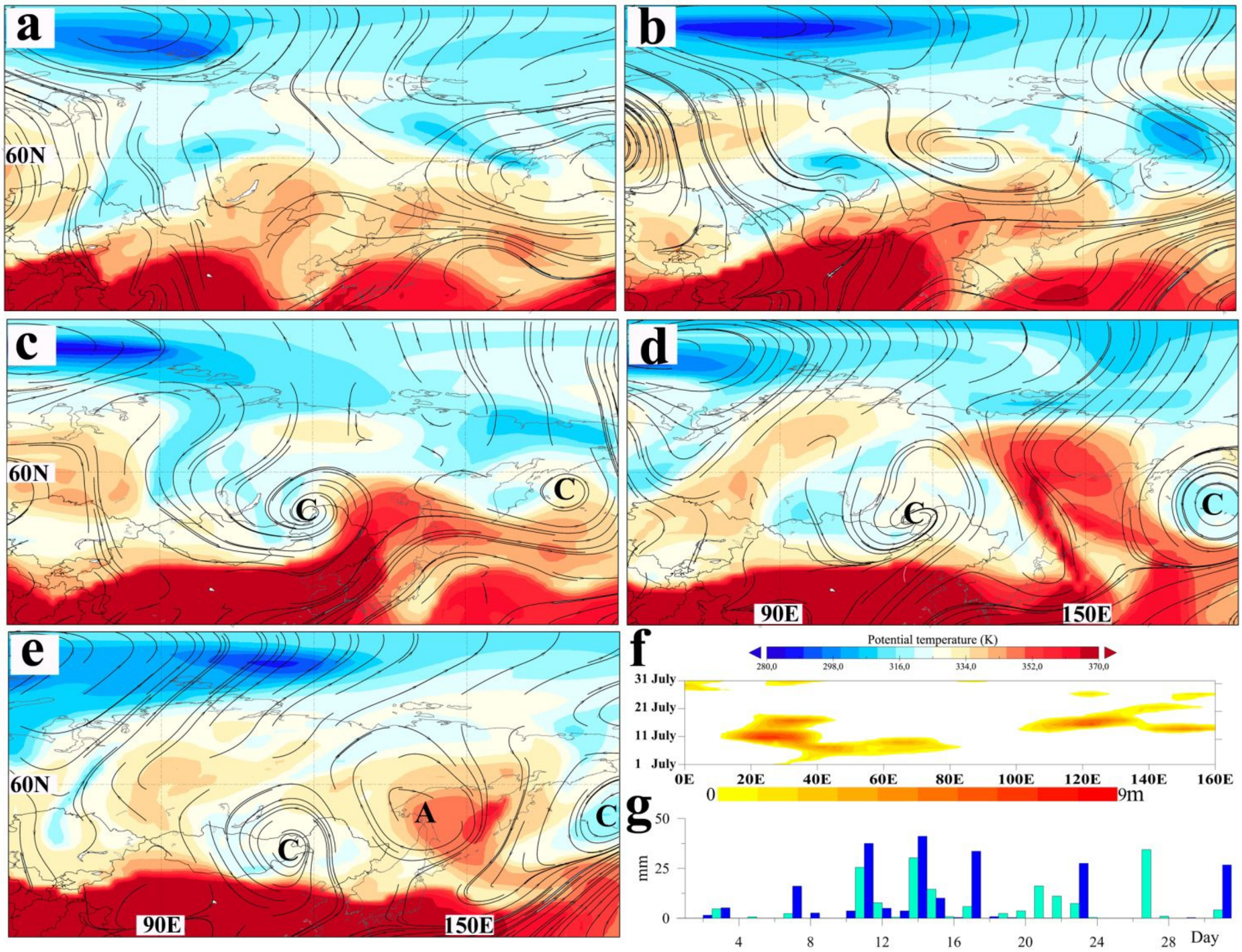

Figure. 3. Velocity field dynamics at 850 hPa and PV-θ 1982 July 6-14 (every other day, for 12 UTC) (a-e), the time-longitude cross-section for the 1982 July blocking (f), precipitations at the Dzhalinda (dark blue) and Skovorodino (light blue) Weather stations located in the 53°N, 123°E area (g).

A "chain" of cyclonic and anticyclonic vortices formed by July 14 due to the advection of warm and cold air masses exists for several more days. As long as one examines the precipitation dynamics at the Far East stations (Fig. 4g) and the blocking duration within 100°E - 160°E, one may draw a conclusion that, generally, the described process took about 10 days. This surpasses the standard synoptic period a little, and, as a rule, explains anomalous precipitations at a number of stations in the Far East.

The next event that we address is related to extreme flood in the Far East in 2013 [1]. The precipitations in that region had an anomalous character May through August, but they possessed a particularly impressive span in 2013 July (Fig. 4). The distributions of PV-θ and of streamlines in Figs. 5a-e show that involving the monsoon air masses in cyclogenesis process in the Far East, and in the subsequent anticyclogenesis process over the Sea of Okhotsk were much more significant, than those in 1982. The comparison between the blocking indices in Figs. 3f and 5f also indicate that, in 2013, the blocking process over Western Siberia was more intensive, than that in 1982. Especially, its initial stage is important, because one may assume that how powerful the cold air intrusion into Eastern Siberia and the monsoonal flow dynamics during the subsequent period depend on the initial intensity of warm air inflow over Western Siberia. The further anticyclone stationing over Western Siberia and its intensity variations illustrate, at a greater extent, the processes inside the blocking formation. Formally, in Figs 5d-e, one can see an omega blocking in its ripe stage (anticyclone and two cyclones at its basis). By the potential temperature difference between July 16 and 17, one can see that the anticyclone's filling with warm air from the south came to an end. And, had it been an individual anticyclone, it would have collapsed within a day or two. But the situation with an omega-blocking is absolutely different. After the anticyclone's filling from the south came to an end on July 16, it had been stationed for 10 days more.

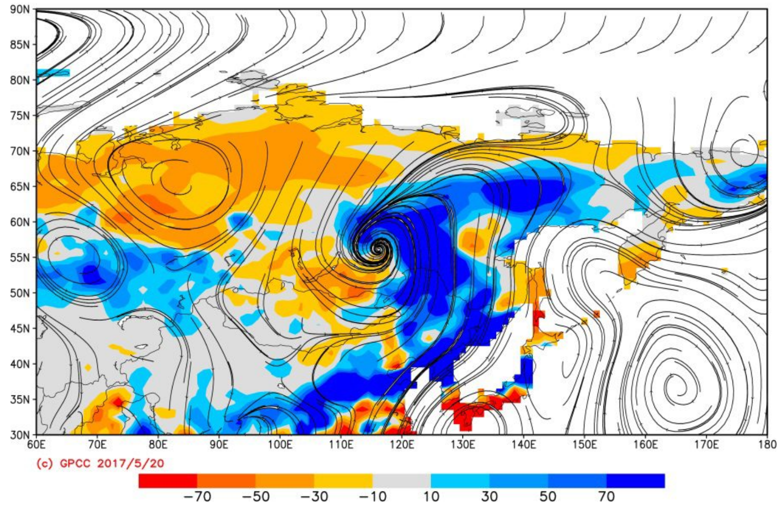

Figure 4. Anomalies of precipitation in July 2013 and streamlines at 850 hPa (16 July). Distribution of precipitation anomalies was obtained using GPCC data [11] (https://kunden.dwd.de/GPCC/Visualizer).

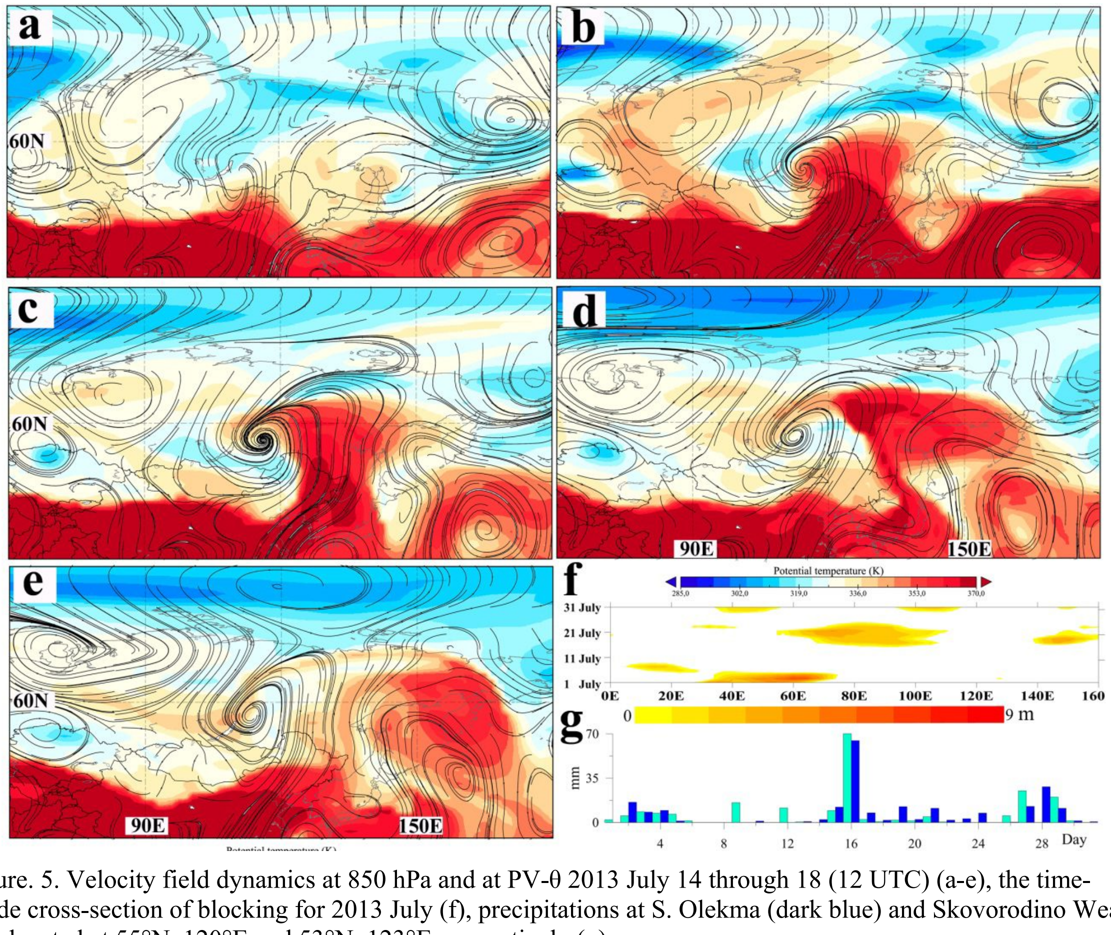

Figure. 5. Velocity field dynamics at 850 hPa and at PV-θ 2013 July 14 through 18 (12 UTC) (a-e), the time-longitude cross-section of blocking for 2013 July (f), precipitations at S. Olekma (dark blue) and Skovorodino Weather stations located at 55°N, 120°E and 53°N, 123°E, respectively (g).

One of possible explanations for the blocking large duration may be that, after the end of usual "swap" from the south, warm monsoon air masses started to arrive through the cyclone system from the east into the anicyclone system on July 17-19 (Figs. 5d). Probably, this was the reason, why the anticyclone had practically stationed until the end of July. Simultaneously, the cyclone that caused the precipitations over the Far East had also stationed (Fig. 5g).

Two more blocking events accompanied by active involvement of monsoon air masses occurred in 1998 late July - first half of August (Fig. 6). During these events, a great amount of precipitations fell over Mongolia and Northern China. Figs. 6a-b show the situations on July 31 and on August 1. Figs. 6c-d present the situations for August 8 and 11. We address in detail, what they are especially interesting for. First of all, the following fact makes itself conspicuous: like in two previous cases (1982 and 2013), a blocking event over the Ural - Western Siberia region (diagram in Fig. 2f), ultimately determining the north inflow intensity, precedes those processes. Yet, unlike 2013, this event has a very weak intensity. And it is, probably, this fact (the West Siberian blocking intensity) that determines all further peculiarities of the process behavior to the east.

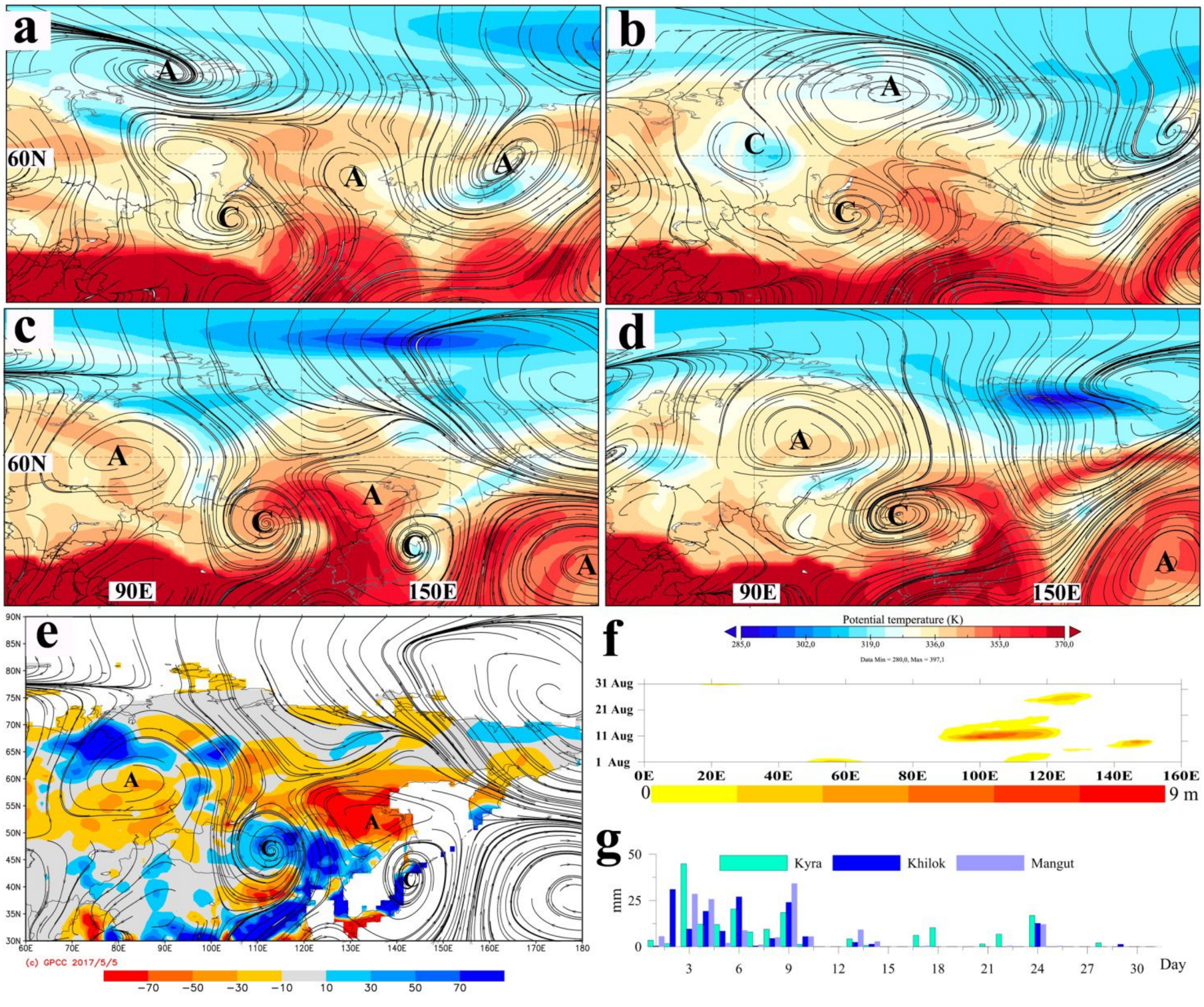

Figure. 6. Velocity field dynamics at 850 hPa and PV-θ over 1998 July 31 - August 1 (a, b), August 8 (c), and August 11 (d) (12 UTC), anomalies of precipitations (August) and of streamlines at 850 hPa (August 8) (e); the time-longitude cross-section of blocking for 1998 August (f), the interdiurnal precipitation (August) variability at Kyra, Khilok, and Mangut Weather stations located at (49°N, 111°E), (51°N, 110°E), and (49°N, 112°E) (g), respectively.

On July 31, there was a cyclone over East Mongolia and Northern China. Like the precipitation plot shows, there are almost no precipitations at the stations under the influence of the cyclone over East Mongolia by July 31. However, during the same period, on the eastern periphery of the anticyclone located north of Siberia, there occurs a cold air intrusion into the western part of the cyclone that we address. The cyclonic activity becomes more active again, and the precipitations at a number of the stations located at the border between Russia, Mongolia, and China (Fig. 6g) evidence this. Note that a distinctive feature of the 1998 blocking events is a very active participation of the monsoon air at a relatively weak northern inflow intensity. And like Figs. 6a-b show, for such precipitations, necessary is the participation of air masses not only from the south, but also from the north. The 1998 situations that we address show almost complete filling of the blocking cyclonic parts by monsoon air, which produces technical difficulties for blocking identification through the PV-θ characteristic (there is no reversal of this characteristic gradient).

The same as Fig. 3e, Figs. 6 (c,d) show a "chain" of cyclonic and anticyclonic vortices. In Figs. 6 (c,d), we see anticyclones over Western Siberia and the Far East, and cyclones over Mongolia/Northern China, and Sakhalin/Japan. On August 11, the anticyclone over Western Siberia displaces eastward, involving cold air, the blocking situation in the Far East disappears, because the monsoon anticyclone collapses. In its turn, there appears a rex-blocking in its ripe stage in the geopotential field. Like in the 2013 omega-blocking case, between August 8 and 11 (the figure is not cited), there occurs a double swap of the blocking anticyclone from the south and from the east. In the precipitation distribution anomalies (Fig. 6e), one can well see an influence of the anticyclonic (over the Far East) and cyclonic (Mongolia/China) monsoon regions.

4. CONCLUSION

In this study, we investigated some peculiarities of the atmospheric blocking evolution within the Siberia and Far East region in summertime. We compared two most common techniques to identify blocking: from the isobaric surface (Z500) height distribution, and from the potential temperature at the dynamic tropopause (PV-θ) for every July 1979 through 2016. The comparison was performed for the Siberia and Far East region. Both techniques appeared to be able to identify blockings in the most of the addressed cases. However, there are also special situations, in which only one of the techniques identifies a blocking. The PV-θ characteristic blocking identification is complicated in the cases, when the blocking cyclonic part appears completely filled with air masses of the southern origin. For this reason, in the PV-θ field, there is no gradient reversal. In the Z500 field, the blocking identification difficulties may originate in the cases, when the baric field fails to adapt to rapid changes in the temperature field associated with the air mass advection. For example, such events often occur over the ocean surface.

We also revealed that, during the blocking formation and maintenance over Siberia and the Far East during summertime, air masses from the East Asian summer monsoon region participate actively. The synoptic analysis of several blocking events from the velocity field dynamics data at 850 hPa and at PV-θ, supplemented by the analysis of the observational rainfall data at the stations during these events, enabled to identify several stages of blocking evolution in the Asian-Pacific sector:

1. The formation of a blocking over Western Siberia.

2. Cold inflow on the blocking eastern periphery, activation of the East Asian summer monsoon front, and formation of a cyclone east of Lake Baikal, whose system actively involves the monson air. Such monsoon cyclones, as a rule, are deep, long-living formations, and bring anomalous precipitations. Probably, it is monsoon cyclones that are the key link in maintaining the chain of blocking anomalies over the Asian-Pacific region, because they advect the monsoon air into the moderate and high latitudes.

3. The formation of a ridge or anticyclone east of the monsoon cyclone. This formation is caused by the advection of the same monsoon flow, whose part is involved in the cyclone system.

That the warm monsoon air may simultaneously fill both cyclonic and anticyclonic formations is the main reason for a complex identification of blockings according from the PV-θ data, because different baric formations may correspond to the same mass in the geopotential field. On average, apparently, the East Asian summer monsoon influence comes to the effects of regeneration and intensification of the blocking circulating systems that are often accompanied by severe droughts in some regions and floods in others.

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