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A CASES STUDY OF MONGOLIAN CYCLOGENESIS DURING THE JULY 2018 BLOCKING EVENTS

ABSTRACT. Mongolia and Transbaikalia (M-TB) have experienced severe drought over the past 20 years due to the increased frequency of anticyclogenesis. However, in the summer of 2018, as a result of the formation of a series of cyclones over Mongolia and their move to the Transbaikalia, abnormally high precipitation was observed in the M-TB region. The dynamics of long Rossby waves and atmospheric blocking in the middle and upper troposphere were investigated to identify the causes of cyclogenesis over Mongolia. It was revealed that a sequence of events predefined the extreme precipitation in M-TB in the 2018 summer – the intensification of heat flux over the North Atlantic while maintaining cyclonic vorticity over Central Europe, the development of blocking ridges in the Urals and the Russian Far East, and an upper-level trough oriented to the eastern regions Mongolia. For a long time, the persistent advection of cold air in the rear part of the upper-level trough, as well as increased heat advection during the activation of the East Asian summer monsoon, caused meridional oriented upper-level front strengthening over the eastern regions of Mongolia and extreme precipitation.

KEY WORDS: Mongolia, Transbaikalia, rainfall, atmospheric blocking, cyclogenesis

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INTRODUCTION

Mongolia and Transbaikalia (M-TB) have experienced severe drought in recent decades due to a decrease in precipitation and an increase in air temperature in summertime (Davi et al. 2006, 2013; Berezhnykh et al. 2012; Erdenebat et al. 2015; Obyazov et al. 2015; Shubert et al. 2014; Hessl et al. 2018). A recent decade-long drought that exceeded the variability in the instrumental record (Hessl et al. 2018) caused economic, social, and environmental change (Karthe et al. 2014, Kasimov et al. 2017). The changes have affected the discharge of the Selenga River. In the last 20 years (1996-2017) it has decreased significantly (Berezhnykh et al. 2012; Frolova et al. 2017; Moreido and Kalugin 2017). Since the Selenga River is the main tributary of Lake Baikal (Berezhnykh et al. 2012), a decrease in its discharge has caused a reduction of the inflow into the lake, especially in 2014–2015 (Bychkov and Nikitin 2015).

The increase of the anticyclonic circulation over Mongolia is one of the reasons of the growth of aridity in M-TB (Iwasaki and Nii 2006; Zhu et al. 2012; Berezhnyukh et al. 2012; Shubert et al. 2014; Erdenebat and Sato 2015). We suppose that anticyclonic circulation is an attribute of air masses convergence weakening of the midlatitude and East Asia Summer Monsoon (EASM), which is typical for the M-TB region in midsummer (Berezhnykh et al. 2012). Several recent studies (Ding et al. 2008; Li et al. 2009; Chen et al. 2017) showed that EASM had been significantly weakened (decreasing of northward moisture transport). According to Khromov 1956; Yihui and Chan 2005; Chen et al. 2017, there is the evident linkage between cyclonic/anticyclonic activity around the M-TB and North China and intensity of moisture transport by EASM. Chen et al. 2017 have proved the relationship between EASM and East Asian cyclone activity. When the midlatitudes summer cyclone activity over East Asia is strong (weak), EASM tends to be intensified (weakened), and the weak cyclone activity after 1993 generally coincides with the decadal weakening of EASM.

The change in the spatial structure of long quasi-stationary Rossby waves (Iwasaki et al. 2006, Sato et al. 2006, Iwao et al. 2008; Shubert et. al. 2014; Li and Ruan 2018) and/or blocking over Eurasia (Antokhina 2019) are reasons for increasing the frequency of anticyclones over Mongolia. Li and Ruan, 2018 discovered the teleconnection, termed the Atlantic–Eurasian (AEA) teleconnection, which is a consequence of a large-scale Rossby wave train that originates in the subtropical North Atlantic Ocean. AEA has five centers of action, in the subtropical North Atlantic Ocean, the northeastern North Atlantic Ocean, Eastern Europe, the Kara Sea, and north China. A positive AEA index (AEAI) is an indicator of anomalously high 500 hPa geopotential heights over the subtropical North Atlantic Ocean, Eastern Europe, and Mongolia–north China, and low geopotential heights over the northeastern North Atlantic Ocean and the Kara Sea–northern Siberia, and vice versa. The AEAI shows that the AEA undergoes a high degree of variability from year to year, and the AEAI has an increasing trend over the last 30 years. Antokhina, 2019 established that during the high frequency of anticyclogenesis in Mongolia during 1996-2017, the change of Eurasian blocking patterns was observed.

The cause of global changes in circulation may be the weakening of the subtropical jet stream during the summer period (Kwon et al. 2007), due to a decrease in the north-south temperature gradient in the troposphere (Zhang and Zhou 2015). The Arctic amplification may explain the weakening of the north-south temperature gradient in recent decades (Coumou et al., 2018). Wirth et al. 2018 emphasized that ducting property of a jet waveguide (in a climate model) depends on the strength of the jet stream. The weakening of the jet stream can lead to the quasi-stationarity of waves and changing the structure and position of the blocking in midlatitudes. Antokhina, 2019 paid attention to the importance of the jet stream properties because it is waveguide for long Rossby waves. Using (Antokhina 2019) potential temperature on a dynamic tropopause (PV-θ) allowed the author to detect the link between cyclone activity over Mongolia and features of moving along the jet stream the air with high and low potential temperature. The traveling along waveguide of different disturbances can explain teleconnection of far apart regions.

Despite the duration of the drought period and the trend in precipitation change (decrease) and temperature (growth), the situation changed suddenly in July 2018. In July 2018, Mongolia and Transbaikalia were faced with extremal floods (floodlist.com; tass.com 2018). Floods were caused by intense precipitation from July 1 to July 22 (meteo.ru 2018). The greatest amount of precipitation fell in Chita (Transbaikalia), where the monthly norm was exceeded more than three times (from 1 to 31 July – 330 mm, 320%) (meteo.ru 2018). Extreme rainfall after decades of prolonged drought caused the question – what do these events mean? Is this event evidence of the end of a long drought? Synoptic analysis of the development of cyclogenesis over Mongolia in July 2018 and a comparison with processes causing a large amount of precipitation over M-TB in earlier years may partly shed light on this problem. The study is aimed at finding large-scale features of the atmospheric circulation that could affect the development of the situation in July 2018. Close attention was paid to the development of blocking processes in the middle troposphere since these processes are closely associated with extreme precipitation in Eastern Siberia and Mongolia (Antokhina et al. 2018a,b).

MONGOLIAN CYCLONES CHARACTERISTICS. THE LINKAGE BETWEEN THE MONGOLIAN CYCLOGENESIS AND THE FORMATION OF BLOCKING OVER EURASIA

According to the report of the weather forecasting center of the Chita (Hydrometcenter of Russia) (meteoinfo.ru 2018), the cause of extreme rain was a series of cyclones originating over Mongolia (also known as Southern cyclones, Mongolian cyclones – MC's). The cyclones originating over Mongolia have a high frequency as compared to all other cyclones in East Asia and have a significant influence on the weather in the Baikal region, Mongolia, and also in the areas located to the northeast (Chen et al. 1990, 1991; Wang et al. 2009). MC's are as a rule deep cyclones with high temperatures and absolute humidity of air masses. These air masses are related to conditions of forced convection, causing cloud cover formation and extreme precipitation. One of the most likely causes of the high frequency of cyclones in Mongolia is the role of a mountain barrier in cyclogenesis. A climatological analysis of cyclogenesis over East Asia revealed that one of the most active cyclogenesis areas is the lee sides of the Altai-Sayan, Stanovoi, and Great Xinganling mountains. Among these areas, the Altai-Sayan lee side is home to the most active cyclogenesis area in East Asia (Chen et al. 1991).

Weather forecasters extract MC's into a special group of cyclones that develop in the front part of a deep meridional tropospheric trough extending to the south of 50° N (Bukhalova 1959; Loschenko et al. 2010). Researches of synoptic conditions of Mongolian cyclones in Russia formation began in the middle of the 20th century (Arkhangelsky 1956; Bukhalova 1959). Bukhalova, 1959 identified the main trajectories of the Mongolian cyclones and investigated the structure of the upper-level pressure field. According to Bukhalova, 1959, during the formation of Mongolian cyclones in the troposphere, an upper-level trough is observed, oriented from the Ob Bay to the Ulan-Bator areas, characterized by increased advection of cold in the rear and advection of heat in the front. The region of the formation of MC's depends on the localization of the trough line and the associated ridges. If the line of the upper-level trough is oriented in the region of 43-50° N and 90-115° E, over Mongolia the strengthening of the jet stream (upper-level front) is possible. The strengthening of the jet stream causes the development of dynamically unstable baroclinic waves on the tropospheric front and, as a result, the formation of cyclones. Such conditions are more often observed in the summer season. An increase in horizontal geopotential gradients (≥20 dkm / 1000 km) on the jet stream axis, convergent advection of cold and heat (≥ 4-5 oC / day), respectively, to the rear and front parts of the cyclone (Loschenko et al. 2010) are considered as predictors of synoptic disturbances development. The structure and dynamics of Mongolian cyclones, as we have already noted, are strongly influenced by orography (large mountain chains) as well as the intensity of energy exchange processes between different layers of the troposphere.

Commonly in the atmospheric circulation researches, wave processes (Rossby long waves) (Wirth et al. 2018) and atmospheric blocking (Mokhov and Semenov 2016) are mentioned as large-scale circulation features responsible for the development of extremal synoptic processes. Rossby waves can be free or forced and maintained either by the energy of the mean flow or by orographic and/or thermal forcing by any region of the globe. In the northern hemisphere, such areas can be the North Atlantic and massive mountains – the Rocky Mountains, Tibet, and the Himalayas. The spatial structure of forced waves differs from the structure of free Rossby waves, which are mostly characterized by waveguide propagation along jet streams. At the nonlinear stage (breaking) Rossby waves can form large-scale quasi-barotropic and stationary pressure anomalies, often called blocking. Long-term intensive advection of heat and/or cold can be responsible for the formation of amplified ridges and troughs, which can block the mean flow in the troposphere. Probably, the wave and advective mechanisms of blocking formation are linked; however, this question, especially for East Asia, requires individual study. With the point of view clarifying the reasons for the activation of cyclonic processes in Mongolia, it is important that, regardless of the formation mechanism, the blocks are closely associated with intensive cold advection in the troughs related to the blocking. Palmen and Newton 1991; Schubert et al. 2014; Antokhina et al. 2018b showed that with the development of ridges and blocking over Europe (Europe-Urals, Europe-Urals-Western Siberia) to the east of the blocking anticyclone (ridge), an advection (intrusion) of polar air occurs, and a deep trough is formed. Under specific development scenarios of blocking over Europe, Urals and Western Siberia, these processes may contribute to the formation of Mongolian cyclones. An example of the development of synoptic and large-scale circulation processes accompanied by intensive precipitation in Mongolia in July 2018 is considered.

METHOD AND DATA

To identify blocking events, we use GHGS (geopotential height – gradient south) criterion is developed by Lejenäs and Øakland, 1983; Tibaldi and Molteni, 1991; Barriopedro et al., 2006:

$$GHGS = \frac{Z(\varphi_0) - Z(\varphi_S)}{\varphi_0 - \varphi_S} \quad ,$$

where Z is the 500 hPa geopotential height, φ0=60° N ±Δ, φs=40° N ±Δ, unlike in (Lejenäs and Øakland 1983; Tibaldi and Molteni 1991), we took the following values for Δ: Δ=-5°, -2.5°, 0°, 2.5° or 5°, which were first offered for use Barriopedro et al. 2006. The situation when GHGS>0 is referred to as blocking. A longitude is considered blocked when GHGS>0 for at least one of the five Δ values.

Atmospheric data used in this study are from the European Centre for Medium-Range Weather Forecasts ECMWF Era-Interim (Dee et al. 2011). To identify blocking events, we used 500 hPa geopotential heights. To reveal the origin of the air masses, we analyzed the potential temperature on the dynamic tropopause (PV–θ) (Hoskins 1991) and streamlines at 850 hPa, 500 hPa (The spatial resolution is 2.5×2.5 and 4-times-daily for July 2018). According to Hoskins 1991, Masato et al. 2011 PV–θ is a very good candidate to study the synoptic development of blocking as it is materially conserved in time, providing an excellent tracer for the air masses contributing to blocking formation, and can be inverted to give the balanced component of the flow. In addition, the reversal of the meridional gradient PV–θ is associated with Rossby wave-breaking (Masato et al. 2011).

We used daily precipitation data from GPCC (The Global Precipitation Climatology Centre), the spatial resolution is 1°×1° for July 2018, version GPCC First Guess Daily Product for July 2018 (Schamm et al. 2013). GPCC Precipitation Climatology Version 2018 (Meyer-Christoffer et al. 2018) was used for estimations of July's mean precipitation (1950-2000).

The Irkutsk Weather Administration provided surface and upper-level weather maps.

RESULTS

Precipitation anomalies and cyclogenesis periods in July 2018

Fig. 1 (a, b) shows maps of precipitation anomalies in July 2018 over Eurasia (Fig. 1a) and the M-TB (Fig. 1b). Two regions with positive precipitation anomalies are visible – Central Europe and most of East Asia (Fig. 1a). It is seen that the greatest amount of precipitation fell in Transbaikalia (Chita station is pointed in Fig. 1b). Over Northern Europe, the Urals and most of Western Siberia, the precipitation anomalies are negative. The spatial scale of the anomalies in Fig. 1a indicates that they are due to large-scale circulation processes.

Fig. 1 (c) shows the day-to-day histogram of the total daily precipitation in the Selenga basin in July 2018. For comparison, Fig. 1 (d) shows the same histogram for July 1990 – the highest in terms of precipitation in the Selenga River Basin. The calculations showed that July 2018 is in the top five years with the most precipitation in the Selenga basin during the observation period from 1934. At that time, the absolute record for the amount of precipitation in the history of

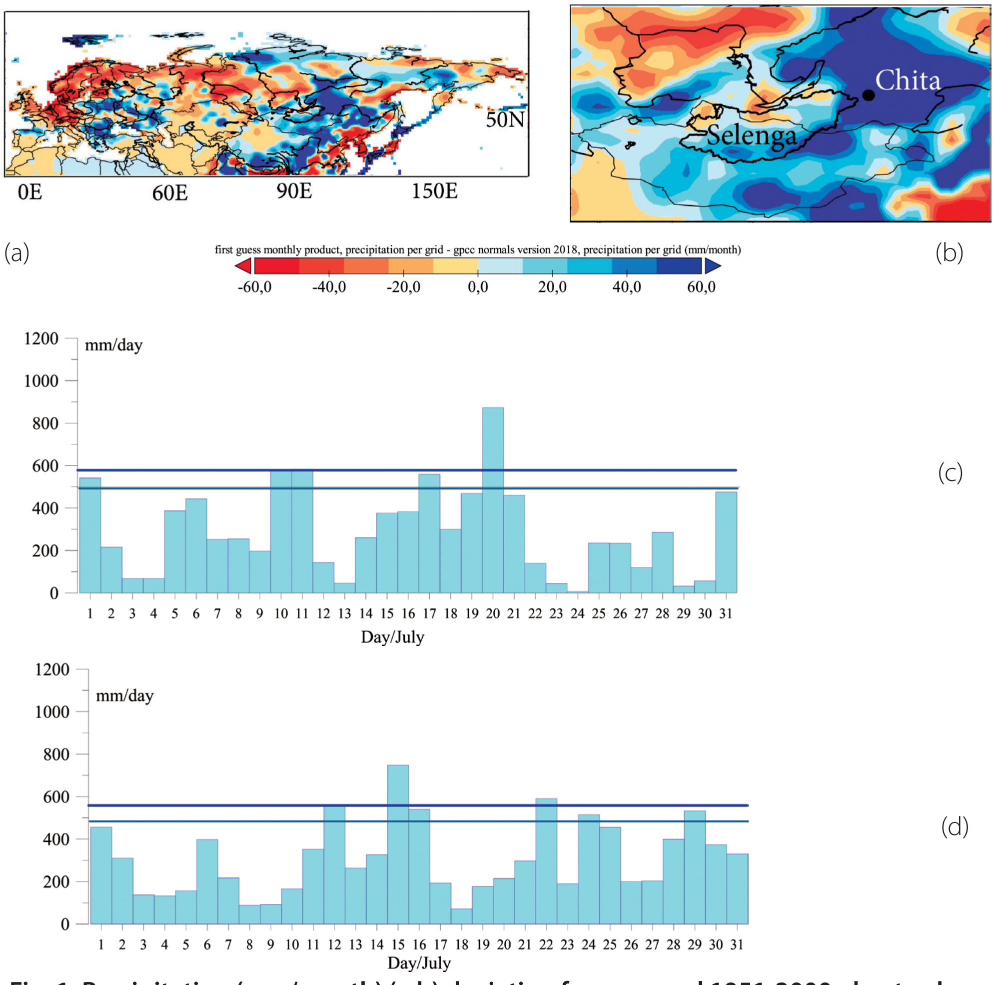

Fig. 1. Precipitation (mm/month) (a,b) deviation from normal 1951-2000, day-to-day total precipitation in Selenga River Basin in 2018 comparison to 1990 (2018 - c, 1990 - d) gray-blue – 90th percentile, deep-blue – 95th percentile. Event 20 July 2018 – 99th percentile. According to GPCC (Schamm et al. 2013)

instrumental observations was recorded at Chita station (Fig. 1b).

Fig. A1 (see Appendix A) on the left shows the maps of precipitation and streamlines at 850 hPa for each day from 1 to 20 July 2018. Fig. A1 on the right shows streamlines at 500 hPa and PV-Θ. The precipitation and streamlines at 850 hPa maps allow us to compare the dynamics of synoptic disturbances in the lower troposphere and the rainfall associated with them, maps in Fig. A1 on the right – to analyze the large-scale structure of the pressure fields in the period of formation and moving of the MC's. Based on the analysis of Fig. A1, we have identified four intervals, characterized by the formation and moving of the MC's, accompanied by precipitation in the longitude interval of 90-120°E: 4-8, 9-12, 14-17, 18-21 July. All of these cyclones originated in Mongolia and excluding the process of July 14-17, had moved to Transbaikalia.

Factors contributing to the development of cyclogenesis over Mongolia in July 2018

Fig. 2 shows the time-longitude diagram of the GHGS blocking index. Based on Fig. 2 and Fig. A1, we can more precisely describe the blocking associated with the formation of pressure anomaly. Fig. 3 shows an example of maps which were used to analyze the synoptic processes in July 2018 —AT-700 hPa (3 km) (a) and the surface pressure map (b) for 7th July 2018.

As shown by a synoptic analysis of a set of such maps, in July 2018, the Mongolian cyclones more often did not form in the west and north-west of Mongolia, where they most commonly develop in summer, but the east of Mongolia. The conditions of frequent strengthening of the jet stream (upper-level frontal zone) caused precipitation not only in the area of the primary and secondary atmospheric fronts but also in the rear part of the Mongolian cyclones after their moving.

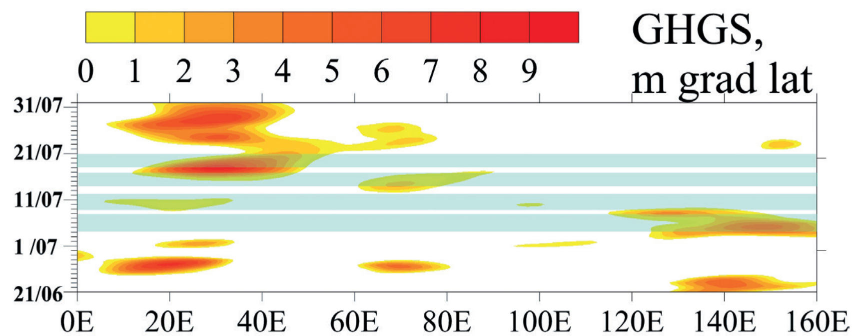

Fig. 2. The time-longitude diagram of the GHGS index (21 June - 31 July 2018), blue belt – periods of precipitation in the M-TB. According to Era-Interim (Dee et al. 2011)

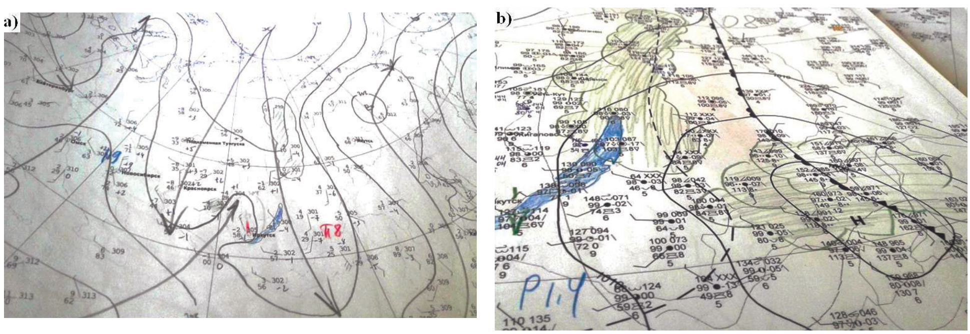

Fig. 3. Maps AT-700 hPa (3 km) (a) and surface pressure (b) for 7 July 2018. According to Irkutsk Weather Administration (https://www.irmeteo.ru/)

One of the critical factors that influenced the development of cyclogenesis was the formation of an upper-level trough of large amplitude (Fig 3a, Fig. A1 4-7 July). It can be seen that the orientation of the trough is exceptionally suitable for the formation of MC's (according to Bukhalova 1959 and Loschenko et al. 2010). The combination of intensive advection from the north, the stationary trough for a long time in July played a key role in the formation of the moving cyclogenesis and heavy precipitation in the region M-TB.

The formation of the trough, which was significant for the extreme precipitation over Mongolia in July 2018, was predefined by blocking in Europe (Fig. 2, Fig. A1). It can be seen in the period of displacement of the trough (7-9 July) the blocking over Europe is weakening, and then again is formed over Europe and Western Siberia. The blocking over Europe and Western Siberia persisted for a long time; as a result, the stationary upper-level trough with a line of about 105^0E, frontal zone and the development of wave disturbances on it, have been observed almost throughout the July 2018. Intense cold advection in eastern Mongolia and China was observed in the rear part of the trough (Fig. A1 – streamline at 850 hPa and PV-θ). The long-lasting heat advection in the front of cyclones contributed to the development and maintenance of a blocking process in the Russian Far East by the synoptic-scale waves. In turn, the blocking over the Far East further contributed to more intense and prolonged precipitation. It should be noted that the development of blocking covered not only the troposphere but also the lower stratosphere and propagated up to 50 hPa.

In general, July's 2018 blocking pattern (Fig. 2) is similar to the type studied earlier in (Antokhina et al. 2018b), which is characterized by the development of blocking over Europe and the Russian Far East (E-RFE). As shown in (Antokhina et al. 2018b), the E-RFE blocking pattern under specific scenarios can contribute to heavy precipitation in the Selenga River Basin. Several precipitation maxima can accompany the development of E-RFE blocking in July. The first maximum was caused by the strong baroclinicity due to the maximum temperature contrasts in front of the trough (Antokhina et al. 2018b, analysis of 1991 - 6-8 July). The second maximum of precipitation is associated with a northward shift of East Asia monsoon air due to traveling one cyclonic wave after another along the subtropical jet stream (Antokhina et al. 2018b, analysis of 1991 - 19-21 July). In July 2018 advection of moisture from the Pacific Ocean in a layer of 1000–500 hPa contributed to the development of tropospheric frontogenesis in the region of Mongolian cyclones development, especially when Pacific tropical cyclones moved to the coast of Eurasia. The total precipitable water in the eastern areas of the Selenga Basin on July 21 reached 40 kg/m^2. According to Marchenko et al. 2012, such precipitable water is common for the processes involving monsoon air.
The circulation over the North Atlantic, Western Europe, and the Mediterranean has played a significant role in the development of blocking over Europe, the Urals, and Western Siberia, which ultimately determined the anomalous rains over Mongolia. Formed as a result of the intrusion of cold air and deepening of the trough in the last decade of June 2018 (Fig. 4) thermal anomalies and intense cyclonic circulation over Central Europe have persisted until July 20.

The increasing of the North Atlantic heat fluxes could contribute to the amplification of the large-scale waves in the summer of 2018 and their displacement to the east. This is confirmed by the high AO (Arctic oscillation) and NAO (North-Atlantic oscillation) indices (cpc.ncep.noaa.gov 2018) and the positive anomalies of the surface pressure and geopotential at 500 hPa surface in Northern Atlantic, which, according to the Hydrometeorological Center of Russia, reached +7 hPa and +17 dkm (decameter, 1 dkm=10 m, in synoptic studies is commonly used for geopotential height) over the Atlantic

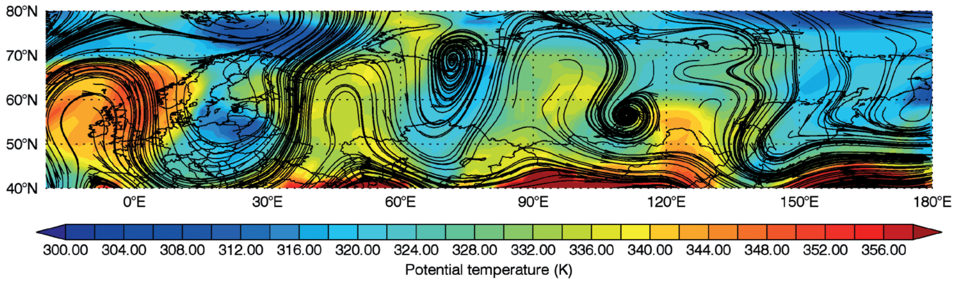

Fig. 4. Snapshot of the wave-like pattern in Eurasia, 24 June 2018 (PV-Θ and streamflow at 500 hPa), according to Era-Interim (Dee et al. 2011)

in July, 2018 (meteoinfo.ru 2018). The development of the thermal and pressure ridge over the North Atlantic has led to a deepening of the adjacent trough and determined the advective-dynamic factors of cyclogenesis over the Mediterranean, where the negative anomalies of the surface pressure in July 2018 reached maximum values in the Northern Hemisphere (-9 hPa). In turn, the heat advection in front of the trough has determined the development of the Urals-Western Siberia blocking ridge while the southern Mediterranean cyclones moved northward. The blocking area in western Eurasia occupied a longitudinal sector equal to 70 degrees (0-70° E Fig. A1, 4 July). The resulting configuration of the baric field in July from 1 to 20 was favorable to ensure that polar air masses were constantly advecting into the Mongolia area.

Fig. 5 shows the altitude-latitude diagrams of the position of the jet streams, dynamical tropopause (2PVU) (Hoskins 1991, Kunz et al. 2011, Masato et al. 2011) and vertical velocity for several days characterizing the different stages of the formation of Mongolian cyclones. On July 6, an extensive area of the upper-tropospheric jet stream formed by a convergence of subtropical and polar jet stream is visible. In the second half of July, mesojets were often observed in the middle and lower troposphere. The positions of the jet streams indicate the convergence of warm and cold air masses and the formation of dynamically significant high-altitude frontal zones over Mongolia and southern Transbaikalia regions with geopotential gradients exceeding 16 dkm / 1000 km.

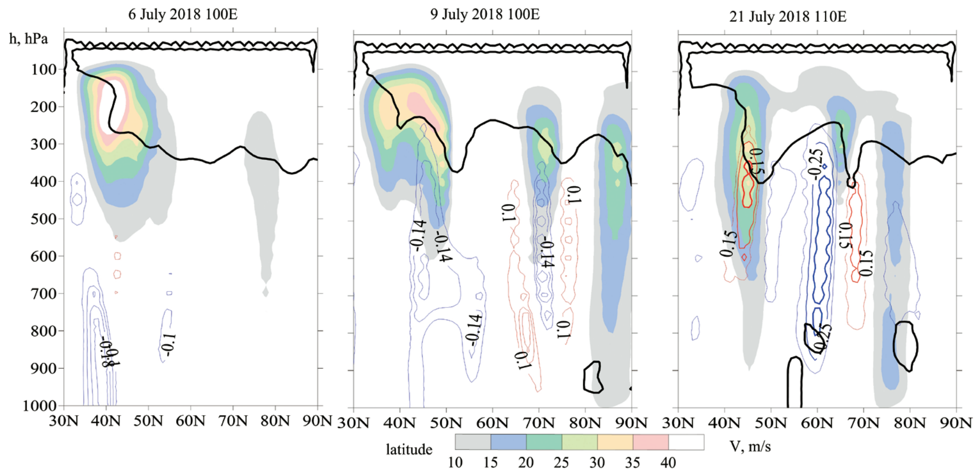

Fig. 5. Altitude-latitude diagram of the position of jet streams, vertical velocity for 6, 9 and 21 July 2018. The jet stream – rainbow color with color bare, dynamical tropopause position 2 PVU – black line, vertical velocity: blue line – ascending, red - descending (Pa/s). According to Era-Interim (Dee et al. 2011)

Thermally direct circulation, as evidenced by the ascending motion of the air, which reached the level of the tropopause, also indicates the development of powerful frontogenesis. In the second half of July 2018 (21 July), the strengthening of the ascending motion (up to -0.25 Pa/s) was supported by the descending motion of upper tropospheric air with an intensity of up to 0.15 Pa/s. Under such conditions, convection in the area of main and secondary cold atmospheric fronts intensifies, which determined the intense precipitation in the territory of Transbaikalia.

CONCLUSIONS AND DISCUSSION

After the prolonged drought during the last two decades, in July 2018, Mongolia and Transbaikalia (M-TB) experienced a period of heavy rain and flooding. The paper studied the development of the Mongolian cyclogenesis (MC's) in July 2018. Four intervals were identified associated with the formation of MC's and precipitation: 4-8, 9-12, 14-17, 18-21 July. The paper has shown that intense and prolonged rainfall in the summer of 2018 in M-TB was predefined by the abnormal development of wave processes in the middle troposphere. The abnormal development of wave processes was due to the intensification of heat flux over the North Atlantic, the stationing of a cyclone over central Europe, the development of blocking ridges in the Urals and the Far East, and the adjacent upper-level trough oriented towards the eastern regions of Mongolia. Lasting about twenty days advection of cold air in the rear part of the upper-level trough, and increased heat advection due to the summer East Asian monsoon caused the upper-level front strengthening in the eastern regions of Mongolia, activating cyclonic circulation and extreme precipitation in M-TB in July 2018.

As a discussion of the obtained results, we would like to note the following: we have compared the observed 2018 July blocking pattern to the previously studied (Antokhina et al. 2018a, 2018b; Antokhina 2019). Previous studies of the link between atmospheric blocking and precipitation in Eastern Siberia and Mongolia have suggested that the 2018 case is rather the exception. We have concluded that it was exceptional even though the development scenario of E-RFE blocking patterns is not exceptional and it was observed by us more than once. Our conclusion is mainly based on an analysis of the details of E-RFE blocking patterns scenario development. We suppose the main feature of circulation in July 2018 is the intensity of cold advection from the Arctic and its trajectory. The permanent cold advection was due to the unusual blocking configuration in western Eurasia. We suppose that further research of changing Rossby wave propagation and atmospheric blocking patterns over Eurasia is the key to figure out rainfall variability which will allow us to find out more about future trends in precipitation in the region M-TB.

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