Impact of Rossby Waves Breaking on the Heavy Rainfall in the Selenga River Basin in July †

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Abstract: The Selenga is one of the crucial transboundary rivers of the semi-arid Northern Eurasia belt. The Selenga basin is located in Mongolia and Russia, and it is 83.4% of the Lake Baikal basin. Atmospheric precipitation is the primary source of the river supply; most of its amount falls like rain from June to August (about 70% of the annual). In the present paper, the relationship between the heaviest rains (HR) around the Selenga River basin in July (above 90th percentile) and Rossby wave breaking (both cyclonic and anticyclonic type, AWB and CWB) was examined. The total number of HR events from 1982 to 2019 was 83. For each event, the synoptic analysis and automatic detection of breaking based on potential vorticity from 2 to 9 PVU on the 350 K were utilized. In most cases (85%) of HR, events were accompanied to the RWB. It was revealed that waves propagating along the subtropical jet were the most important. Precipitation was observed both for the period of amplitude growth and period of waves breaking (CWB or AWB). CWBs on the subtropical jet stream that occurred east to Lake Baikal were observed in most HR events.

Keywords: Selenga River; wave breaking; precipitation; heavy rain; potential vorticity

1. Introduction

The present work is a continuation of the cycle of paper aimed at clarifying the reason for low and high water in the Lake Baikal basin [1–4]. First, highlight the main points concerning this issue [1–4]. Mongolia and Transbaikalia have experienced severe drought in recent decades due to decreased precipitation and increased air temperature in the summertime [1,5–9]. A recent decade-long drought that exceeded the instrumental record [9] caused economic, social, and environmental change [10]. The drought affected the discharge of the Selenga River. The Selenga is one of the crucial transboundary rivers of the semi-arid Northern Eurasia belt. The Selenga basin is located in Mongolia and Russia, and it is 83.4% of the Lake Baikal catchment area. Atmospheric precipitation is the primary source of the river supply; most of its amount (about 450 mm per year) falls like rain from June to August (about 70% of the annual). In the last 20 years (1996–2017), the Selenga’s discharge decreased significantly [1,11–13]. In the last years (2018, 2019), the water content in the Selenga basin exceeded the average [3,14]. By the end of September 2020, the Lake Baikal water level exceeded the critical point [https://www.urdupoint.com/en/world/lake-baikal-water-level-exceeds-critical-point-1037878.html] (accessed on 1 October 2020).

Clarification of the causes of fluctuations in the Selenga runoff is essential in the face
of increasing transboundary disputes and climate change [10]. In several papers [1,3–
4,15–17], authors tried to find the primary driver of precipitation during midsummer in the region, including the Selenga basin. The following mechanisms of precipitation are considered: dynamic of the northern convergence area of East Asian summer monsoon, the formation of the deep midlatitudes atmospheric troughs oriented to Mongolia, stationary Rossby wave along the Asian jet, as well as atmospheric blocking in a different part of Eurasia. So, the precipitation fluctuations over the basin are, first of all, driven by the atmospheric circulation dynamics, with the role of thermodynamic factors (local convective precipitation) less important.

The recent paper by Chyi et al. 2020 [18] showed the impact of wave breaking features of blocking on the precipitation over southeastern Lake Baikal. Wave breaking accompanied by the isentropic inverse of meridional potential vorticity (PV) gradient. Such dynamical processes such as high PV-streamers and cutoff low (CL) are associated with waves breaking (overturning). As a rule, the PV-streamers and CL are associated with high precipitation (and often extreme precipitation) [19–21]. In the front part of the slow upper-level trough (associated with PV-streamer and CL), the authors observed the intense ascending motions and transport, accumulation, and the ascent of water vapor. Additionally, convective precipitation can be observed for the central part of CL because the high PV (cold air masses) leads to high vertical instability in the troposphere [21]. In [18], it was shown that both AWB and CWB blocking events have an impact on precipitation over southeastern Lake Baikal. In addition, they are characterized by a cold trough deepening from the sub-Arctic region and a ridge amplifying toward its north over central Siberia and an evident Rossby wave train over mid-latitude Eurasia.

In the present paper, the relationship between the heaviest rains (HR) around the Selenga River basin in July (above 90th percentile) and Rossby wave breaking (RWB) (both cyclonic and anticyclonic type, AWB, and CWB) was examined. The HR events have a crucial role in annual water content formation as a whole.

2. Experiments

2.1. Data

Twelve UTC atmospheric data used in this study are from the European Centre for Medium-Range Weather Forecasts ECMWF Era-Interim [22]. We used daily precipitation data from GPCC (The Global Precipitation Climatology Centre), the spatial resolution is 1° × 1° for July 1982–2016 (version GPCC Full Data Daily Version 2018, [23]) and for July 2017–2019 (version First Guess Daily Product, [24]).

2.2. Method

Precipitation: For each day of July from 1982 to 2019, the total amount of precipitation within the Selenga River basin was calculated. For entire series (1178 values), were obtained days with precipitation above or equal the 90 percentile. These days were grouped into 83 events, which we named heavy rain events (HR events).

Wave breaking: We detected waves breaking using isentropic potential vorticity (PV) [25]. RWB is characterized by a poleward intrusion of low potential vorticity (or high potential temperature) air and an equatorward intrusion of high potential vorticity (or low potential temperature) air that is dictated by the shear environment associated with the incipient Rossby wave [26]. We detected breaking for isentropic surface 350 K. We selected 350 K due to reveal the exchange along subtropical tropopause [25], which is typical for the Siberia area only in summertime. We applied synoptic analysis and automatic algorithms searching for the overturning contour from 2 to 9 PVU (with interval 0.5 PVU).
The automatic detection of RWB events in this paper is based upon the overturning contour identification technique developed by Strong and Magnusdottir, 2008 [27]. For automatically detection centers of overturning areas, we used the identification technique developed by Barnes and Hartmann, 2012 [28].

The advantages of the method for estimation of the geometry of PV contours in comparison with the calculation of the gradient of potential temperature on the dynamical tropopause (PV-Θ) are as follows:

- First of all, the PV gradient around subtropical tropopause is stronger and visible compared to the PV-Θ gradient (Figure 1).
- Second, by using the approach to define the geometry of PV, there is no need to snap to the central longitude of breaking. Therefore, we can define shifted both northward and southward breaking.

![Figure 1. Wave breaking on 26–27 July 2019 based on PV-Θ (a,c) and PV on 350K (b,d). The blue contour is the Selenga basin.](image)

3. Results

In Table 1, are shown the date of HR events, type of breaking, its duration, and center.
Table 1. Data of HR events and breaking with start and end date.

| Date HR | Type of RWB | Period RWB, Center | Data HR | Type of RWB | Period RWB, Center |
|---------|-------------|--------------------|---------|-------------|--------------------|
| 27.07.2011 | CWB_on | 26–28.07, 124° E–61° N | 20.07.1987 | CWB_on | 19–21.07, 130° E–55° N |
| 29.07.2005 | WB | - | 03-04.07.2009 | AWB_I | 4–5.07, 128° E–56° N |
| 31.07.2018 | WB | - | 06.07.1985 | WB | - |
| 19.07.2012 | AWB_I | 20–21.07, 134° E–47° N | 13.07.1986 | CWB_on | 12–13.07, 95° E–65° N |
| 06.07.2002 | AWB_on | 16–23.07, 90° E–66° N | 20–21.07.1994 | CWB_on | 18–21.07, 107° E–64° N |
| 04.07.2012 | CWB_on | 4–5.07, 103° E–57° N | 28–30.07.1987 | CWB_I | 28–30.07, 115° E–55° N |
| 24.07.1990 | WB | - | 27.07.2000 | CWB_on | 27–28.07, 130° E–61° N |
| 20.07.2004 | AWB_I | 20–22.07, 128° E–55° N | 28.07.1993 | AWB_I | 27–30.07, 120° E–60° N |
| 23.07.1992 | CWB_on | 18–24.08, 124° E–60° N | - | - | - |
| 08.07.1996 | WB | - | 19.07.2000 | CWB_I | 19–21.07, 130° E–61° N |
| 02.07.2008 | WB | - | 08.07.1986 | CWB_on | 5–8.07, 95° E–65° N |
| 16.07.2009 | CWB_on | 16–17.07, 101° E–55° N | 22.07.2019 | CWB_on | 22–23.07, 113° E–56° N |
| 11–13.07.2002 | AWB_on | 15–17.07, 80° E–68° N | 30.07.2003 | CWB_on | 15–31.07, 117° E, 60° N |
| 27–28.07.1997 | WB | - | 25–26.07.1988 | CWB_on | 26–18.07, 114° E–61° N |
| 31.07.2007 | CWB_on | 30–31.07, 91° E–62° N | 21–23.07.1993 | CWB_on | 20–24.07, 86° E–60° N |
| 30.07.2012 | WB | - | 12.07.2015 | CWB_on | 11–13.07, 101° E–64° N |
| 17.07.1989 | CWB_on | 17–18.07, 124° E–54° N | 05–06.07.1991 | CWB_on | 5–7.07, 94° E–62° N |
| 12.07.1982 | CWB_on | 11–13.07, 91° E–69° N | 18.07.1983 | CWB_on | 20–21.07, 126° E–53° N |
| 12.07.2003 | CWB_on | 28–29.07, 115° E–52° N | 15–16.07.1990 | CWB_on | 12–15.07, 118° E–54° N |
| 09–10.07.2008 | CWB_on | 15–31.07, 117° E, 60° N | 17–20.07.1997 | CWB_on | 16–18.07, 124° E–65° N |
| 16.07.2012 | AWB_on | 16–22.07, 90° E–55° N | 22.07.1985 | CWB_on | 20–23.07, 107° E–55° N |
| 10–11.07.2018 | CWB_on | 16–14.07, 145° E–65° N | 21–22.07.2016 | CWB_on | 22–25.07, 140° E–60° N |
| 26–28.07.1999 | AWB_on | 26–28.07, 85° E–70° N | 28–29.07, 115° E–55° N | CWB_on | 27–28.07, 113° E–56° N |
| 22.07.2006 | AWB_on | 19–22.07, 89° E–68° N | 2.07.1997 | AWB_on | 1–3.07, 124° E–65° N |
| 17.07.2018 | CWB_on | 21–22.07, 105° N–52° N | 1.07.1999 | CWB_on | 3.06–2.07, 115° E–63° N |
| 12.07.1990 | AWB_on | 12–15.07, 118° E–54° N | 27–28.07.1983 | CWB_on | 27–29.07, 115° E–55° N |
| 14–15.07.1993 | CWB_on | 14–16.07, 127° E–50° N | 15–17.07.1991 | CWB_on | 15–17.07, 96° E–62° N |
| 22.07.1986 | AWB_on | 9–11.07, 135° E–54° N | 26.07.2008 | AWB_I | 26–27.07, 135° E–50° N |
| 04.07.1994 | CWB_on | 2–5.07, 107° E–64° N | 20.07.2018 | AWB I | 20–23.07, 150° E–48° N |
| 05–06.07.2011 | CWB_on | 5–6.07, 124° E–61° N | - | - | - |
| 13.07.2007 | AWB_on | 15–18.07, 163° E–57° N | 26.07.2008 | AWB I | 26–27.07, 135° E–50° N |
| 22.07.1990 | WB | - | - | - | - |

Propagating the low and high PV-disturbances along the area of maximal concentration of 2–6 PVU contours was observed in most of the cases. We found that several
main types associated with the growth of the amplitude of the PV-disturbances lead to precipitation in the Selenga basin and waves breaking:

- CWB_on (45 events)—precipitation accompanies by CWB; in the initial (CWB_I) and mature stage (CWB_on), the breaking is located on the Selenga River basin (Figures 2 and 3).
- CWB_I (11 events)—precipitation accompanies by CWB, but in the mature stage, the breaking is located eastward of the Selenga basin. The Selenga basin is located in the stage of growth wave (CWB_I).
- AWB_I (12 Events)—precipitation accompanies by AWB, but in the mature stage, the breaking is located eastward of the Selenga basin. The Selenga basin is located in the stage of growth wave (Figure 4).
- AWB_on—usually preceded by the abovementioned CWB or AWB (Figure 5) and located westward of the the Selenga basin. In 3 cases, AWB_on preceded by CWB, which took place far eastward of the Selenga basin (12.07. 1982, 1983, and 26.07.1991). Usually, the AWB_on occurred in northern regions of Eurasia (polar jet stream), whereas the CWB_on/I and AWB_I took place in the southern region of Eurasia (subtropical jet stream).
- WB (without breaking, 12 events)—propagating of PV-disturbances did not accompany wave breaking.

Figure 2. CWB (here and below cyclonic wave breaking) over the Selenga basin (blue contour). 6–8 July 2001. Here and below: blackline—PV counter from 2 to 9 PVU, red-blue fill—an anomaly of PV compared to the average for July 1979–2019.

Figure 3. CWB over the Selenga basin (blue contour). 13–15 July 1998.

Figure 4. AWB (here and belowanticyclonic wave breaking) over the Selenga basin (blue contour). 20, 22, 24 July 2018.
4. Discussion

The general scheme for precipitation in the Selenga basin and breaking looked the following way:

1. Propagating the low and high PV-disturbances along the area of maximal concentration of 2–6 PVU contours (Figures 2–5);
2. Sometimes, the structure of the low and high PV-disturbances looked like a wave train (Figure 3), but it was not regular;
3. Growth of the amplitude of the PV-disturbances lead to precipitation and waves breaking;
4. Breaking can have both AWB and CWB features; for example, it can be seen in Figure 5c, where eastward, the Selenga basin breaking (overturning) simultaneously signifies both cyclonic and anticyclonic overturning. The discovered type of breaking can prove that one type of air mass simultaneously forms both the cyclone processes from the west and anticyclone from the east.

A crucial role for extreme precipitation in the Selenga River has properties of wave propagation along the subtropical jet, determining the number of circulation processes, including the polar and subtropical jet stream interaction.

In future research, we will plane to reveal the feature of water vapor transport and vertical instability for discovered cases. Additionally, it is needed for the general scheme, which unites the outcome of this paper and earlier obtained in [3,4,29].

5. Conclusions

The Selenga is one of the crucial transboundary rivers of the semi-arid Northern Eurasia belt. The Selenga basin is located in Mongolia and Russia, and it is 83.4% of the Lake Baikal basin. Atmospheric precipitation is the primary source of the river supply; most of its amount falls like rain from June to August (about 70% of the annual). In the present paper, the relationship between the heaviest rains (HR) around the Selenga River basin in July (above 90th percentile) and Rossby wave breaking (both cyclonic and anticyclonic type, AWB and CWB) was examined. Atmospheric data used in this study are from the European Centre for Medium-Range Weather Forecasts ECMWF Era-Interim; precipitation data—from GPCC (The Global Precipitation Climatology Centre).

The total number of HR events from 1982 to 2019 was 83. We detected waves breaking using isentropic potential vorticity (PV). For each event, the synoptic analysis and automatic detection of breaking based on potential vorticity from 2 to 9 PVU on the 350 K were utilized. In most cases (85%) of HR, events were accompanied to the RWB. It was revealed that waves are propagating along the subtropical jet were the most important. Precipitation was observed both for the period of amplitude growth and period of waves breaking (CWB or AWB). CWBs on the subtropical jet stream that occurred east to Lake Baikal were observed in most HR events.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/ecas2020-08120/s1, Video S1: the height (hPa) of the dynamical tropopause (2PVU) for CWB on 27 July 2019.
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