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Isotope composition of macrocirculation processes responsible for precipitation in the Altai mountains

N S Malygina¹, A N Eirich¹, T V Barlyeva², and T S Papina¹

¹Institute for Water and Environmental Problems SB RAS, 1 Molodezhnaya Street, Barnaul, 656038, Russia

²CITEUC, University of Coimbra, Almas de Freire, Sta. Clara, Coimbra, 3040-004, Portugal

E-mail: natmgn@gmail.com

Abstract. An estimation of changes in the precipitation over the Altai mountains in 1959-2016 was carried out using the Mann-Kendall-Sneyers test. It was found that the precipitation has a step change in 1980. The step change point of precipitation in the Altai mountains coincides with the beginning of «zonal epoch of elementary circulation mechanisms» for the Siberian sector according to Dzerdzeevskii's classification. B.L. Dzerdzeevskii considered 41 subtypes of elementary circulation mechanisms (ECMs) based on analysis of maps of baric topography at the 500 hPa level. To reveal the role of various ECMs in the Altai precipitation, we calculated the contribution of the ECMs which correspond to the Siberian sector to the precipitation. It was found that the most significant contribution to the precipitation regime of the Altai mountains was provided by the «West zonal and southern meridional» circulation group. The maximal contribution to the precipitation of 2016 was given by the «West zonal and southern meridional» circulation group (26.8%). The precipitation of this ECM group is characterized by the heaviest isotope composition ($\delta^{18}\text{O}$ -9.85‰ and δD -78.65 ‰) relatively to the values obtained for the other circulation groups. In the ECM of this group of circulations the precipitation is most often caused by southern cyclones coming from the Aral-Caspian region, the waters of which have the heaviest isotope composition.

1. Introduction

The Fifth Assessment Report presents the major highlights on climate change in Asia: warming trends, including higher extremes, are strongest over the continental interiors of Asia, and warming in the period 1979 onward was strongest over China in winter, and northern and eastern Asia in spring and autumn. However, most areas of the Asian region lack sufficient observational records to draw conclusions about trends in annual precipitation over the past century. Precipitation trends, including extremes, are characterized by strong variability, with both increasing and decreasing trends observed in various parts of Asia in different seasons. In northern Asia the observations indicate some increasing trends of heavy precipitation events, but in central Asia no spatially coherent trends were found [1]. At the same time, on the vast territory of Russia an increase of annual means of precipitation has been observed since the second part of the 1980th. The biggest values of trends are found for the Middle (3.3%/10 years) and Eastern (3.7%/10 years) Siberia [2].

To make a reliable estimate of climatic trends, one needs to take into account the influence of atmospheric circulation on climate changes in each specific region [3]. This information is also important for prediction of climate changes both at global and regional scales. During the recent



decades a set of models of global atmospheric and oceanic circulation (ECHAM-wiso, COSMOiso, LMDZ-iso, EMAC etc.) started to use as additional input parameters the data on stable isotopologues HDO (δD) and H₂¹⁸O ($\delta^{18}O$) obtained from the Global Network of Isotopes in Precipitation, GNIP. Unfortunately, in Russia, especially in its Asian part, the data of GNIP are very limited both temporally and spatially [4].

In Asia, the Altai mountains is a «white spot», i.e. for this region climatic data are limited, but at the same time this region is of great climatological and ecological importance. The Atlantic air masses from the west have interacted with the Arctic air masses from the north in the Altai. It is not only a climatic conjunction, but the important ecological transition where the taiga forests have interacted with the steppes. Thus, the main goal of our investigation is the analysis of macrocirculation processes and the estimation of their influence on changes in regime and isotope composition of the precipitation in the Altai mountains.

2. Data and Methods

In Altai, about ten weather stations have continuous data for more than 50 years (Figure 1). In this study, we used the data from the All-Russian Research Institute of Hydrometeorological Information, RIHMI-WDC [5] and Mongolian Hydrometeorological Institute. Additionally we investigate the climate changes from data NCEP/NCAR Reanalysis to understand spatial climate changes in Altai. The NCEP/NCAR Reanalysis project uses a state-of-the-art analysis/forecast system to perform data assimilation using past data from 1948 to the present [6]. We applied the nonparametric Mann–Kendall–Sneyers test [7, 8, 9] to determine the occurrence of step change points of precipitation.

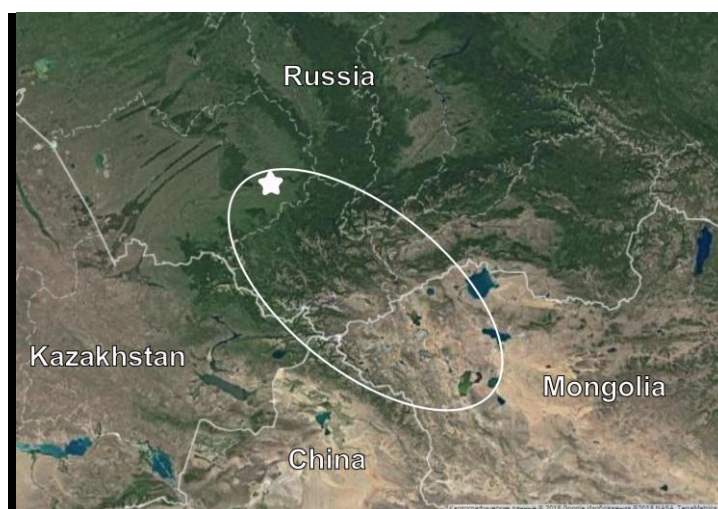


Figure 1. Study area: Altai (*white oval*) and precipitation sampling point (*white star*).

To assess the changes in macrocirculation processes in Altai, we apply elementary circulation mechanisms (ECMs) forming the basis for the classification of atmospheric processes in the Northern Hemisphere proposed by B. L. Dzerdzeevskii [10]. The daily data on 13 types including 41 subtypes of ECMs are presented in the «Calendar of Successive Change of Elementary Circulation Mechanisms by B. L. Dzerdzeevskii» [11]. For each of the sectors in the Northern Hemisphere (Atlantic, European, Siberian, Far East, Pacific, and American sectors), B. L. Dzerdzeevskii identified the circulation groups by the prevalence of subtypes of ECMs [10, 11, 12]. The change of dominating circulation groups allowed to recognize a circulation epoch for each sector. Since Altai belongs to the Siberian sector, our study deals with circulation groups in the Siberian sector of the northern hemisphere. N. K. Kononova identified since 1899 three circulation epochs for the Siberian sector: 1) meridional (1899-1931), 2) fluctuation about the average (1932-1980), 3), and zonal (1981 - 2014)

[11, 12]. This classification was effectively used for estimating the relation between the isotopic composition of precipitation and atmospheric circulation patterns, for example, in Slovenia [13]. The sampling of precipitation, in accordance with the GNIP requirements and recommendations, was carried out in the northern part of Altai in 2016 for further isotope analysis. The isotope analysis of water samples was performed at the Chemical-Analytical Centre of the Institute for Water and Environmental Problems of the Siberian Branch of the Russian Academy of Sciences with IR-laser absorption spectroscopy on a device PicarroL2130-i equipped with a WS-CRDS system (Wavelength-Scanned Cavity Ring Down Spectroscopy). The detection limits were 0.4 ‰ and 0.1 ‰ for δD and $\delta^{18}O$, respectively. The analysis was performed according to the V-SMOW-2 (Vienna Standard Mean Ocean Water 2) standard. The obtained data on the isotope composition of the precipitation were analyzed and correlated with the ECMs data.

3. Results and Discussion

The estimation of the precipitation in the Altai mountains during 1959-2016 performed with the NCEP/NCAR reanalysis data by the Mann-Kendall-Sneyers test has shown that the precipitation regime is characterized by a step change in the early 1980s (Figure 2). This result is in good agreement with the previously estimated changes in the precipitation done using the data from meteorological stations both in Russian and Mongolian Altai for 1959-2014 [14], the estimates obtained for the dataset extended till 2016, done within the framework of the present study, and with the results on the north-west of China, in particular, in the areas adjacent to Altai [15, 16]. It is worth noting that the time limit (1980) of precipitation changes in Altai coincides with the beginning of the «Zonal ECMs epoch» for the Siberian sector according to the Dzerdzhevsky classification [8], as recently shown by the estimations done using the data of meteorological stations [14].

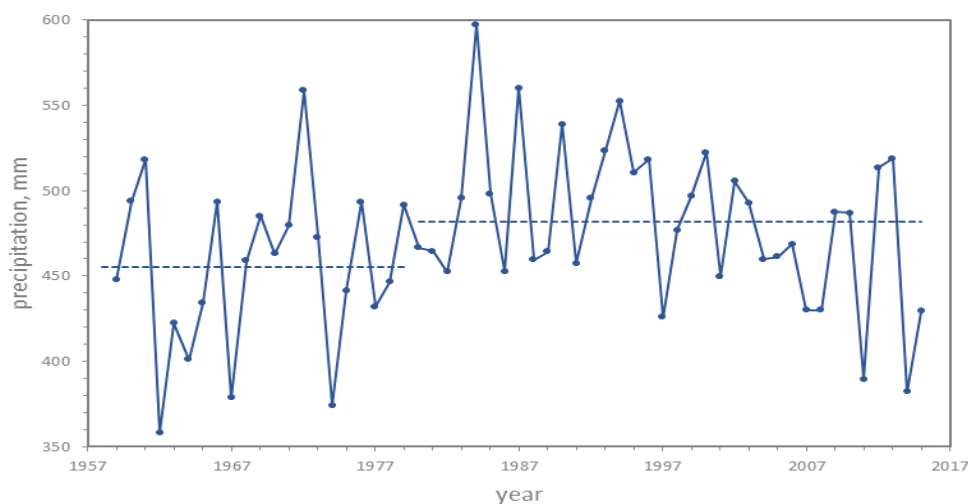


Figure 2. Precipitation in Altai (reanalysis NCEP/NCAR).

Thereupon we used an already tested approach that allows estimating the influence of macrocirculation processes on the changes in the precipitation regime in Altai [14]. Thus, estimation was made of the contribution of various types of macrocirculation processes - ECM circulation groups found for the Siberian sector - to the precipitation in the Altai. The contributions during the two chosen periods (period I: 1959-1980, period II: 1981-2016) showed the following. The maximal contribution to the precipitation during both periods I and II was by the «West zonal and Southern meridional» ECMs group (Table 1). The contribution of the other circulation groups is in the range of

4-12%. Wherein during period II (1981-2016) the contribution of the leading group to the precipitation considerably increased (by more than 10 %).

Table 1. The contribution (in %) of various circulation groups found for the Siberian sector to the precipitation in Altai during 1959-2016, 1959-1980 (period I) and 1981-2016 (period II).

Circulation group of ECMs	ECMs	1959-2016	I period	II period
West zonal and Southern meridional	2a, 2b, 3, 7as, 8a, 9a, 10a, 13s	43	38	49
Northern meridional	12a	8	7	8
West zonal	2c, 4b, 6, 7bs	8	10	6
West zonal and Stationary anticyclone	1a, 1b, 4a, 7aw, 7bw, 9b, 13w	11	11	11
Northern meridional and Stationary anticyclone	5a, 5c, 8cw, 8dw, 11a, 11b, 11d, 12bw, 12cw	10	12	7
Northern meridional and East zonal	5b, 5d, 11c, 12d	5	5	5
Northern meridional and West zonal	8bw, 8bs, 8cs, 10b	5	6	4
Northern meridional and Southern meridional	4c, 8ds, 12bs, 12cs	10	11	10

In the northern part of the study area during the period from January to December 2016, 130 samples of the precipitation were taken for isotope analysis. The results of the isotope analysis have shown a significant variation in the composition of the precipitation, namely, a bit more than 30‰ for $\delta^{18}\text{O}$ and 225 ‰ for δD . The obtained results on the precipitation and the isotope composition formed the basis for the calculation of the ECM circulation groups contribution to the precipitation in Altai in 2016 and of the induced isotope composition of the precipitation (Table 2).

Table 2. Weighted average isotope composition of precipitation and its contribution (%) to the total precipitation in the north of Altai in 2016.

Circulation group of ECMs	$\delta^{18}\text{O}$ (‰)	δD (‰)	Contribution (%)
West zonal and southern meridional	-9.85	-78.65	26.8
Northern meridional	-13.78	-104.16	19.7
West zonal and stationary anticyclone	-19.93	-153.05	20.2
Northern meridional and stationary anticyclone	-21.16	-160.26	15.3
Northern meridional and west zonal	-20.92	-159.40	5.9
Southern meridional	-11.85	-92.11	12.1

The results of the estimations of the contributions of various ECM circulation groups found for the Siberian sector to the precipitation in 2016 have shown that the maximal contribution was by the «West zonal and southern meridional» circulation group (26.8%) causing a significant contribution to the precipitation in the region. The precipitation of this ECM group was characterized by the heaviest isotope composition ($\delta^{18}\text{O}$ -9.85‰ and δD -78.65 ‰) relative to the obtained estimation values for the other circulation groups, which is natural. During the ECM from this group of circulations, for instance, ECM 13s (Figure 3a), the precipitation is most often caused by southern cyclones coming from the Aral-Caspian region, the waters of which are characterized by the heaviest isotope composition. To verify the obtained result, for all dates in 2016, when the precipitation in Altai occurred during ECM 13s, a map of the average wind directions at an altitude of 700 mb was constructed on the basis of the NCEP/NCAR reanalysis (Figure 3b). The analysis of the results obtained on the basis of NCEP/NCAR data has shown that in 2016 the precipitation in Altai during the

«West zonal and southern meridional» circulation group was determined by south-western and western air masses.

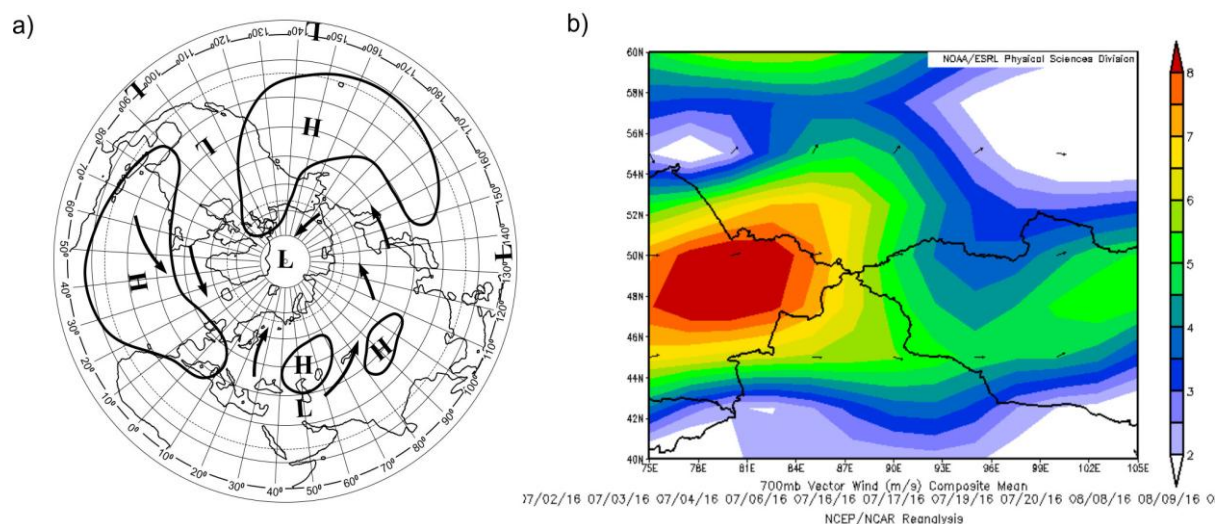


Figure 3. ECM 13s and average wind speed in Altai, days with precipitation during ECMs 13s.

4. Conclusions

Estimation of data on the precipitation in Altai in 1959-2016 using the Mann-Kendall-Sneyers test has shown that the precipitation regime had a step change in the early 1980s. Wherein the time limit of the change of precipitation sign trend in Altai coincides with the beginning of the «Zonal ECM epoch» for the Siberian sector according to Dzerdzhevsky's classification. The most significant contribution to the precipitation regime in Altai during 1980-2016 was made by the atmospheric processes of the «West zonal and southern meridional» circulation group, which determined the heaviest isotope composition of the precipitation of 2016.

Acknowledgements

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