Influence of atmospheric circulation on precipitation in Altai Mountains

MALYGINA Natalia[1*] http://orcid.org/0000-0001-6358-7273; e-mail: natmgn@gmail.com

PAPINA Tatiana[1] http:// orcid.org/0000-0002-8388-7289; e-mail: tanya.papina@mail.ru

KONONOVA Nina[2] http:// orcid.org/0000-0001-5241-0704; e-mail: NinaKononova@yandex.ru

BARLYAEVA Tatiana[3] http://orcid.org/0000-0001-6562-594X; e-mail: tvbarlyaeva@gmail.com

** Corresponding author*

1 Institute for Water and Environmental Problems, Siberian Branch of the Russian Academy of Sciences, Barnaul 656038, Russia

2 Institute of Geography, Russian Academy of Sciences, Moscow 117312, Russia

3 Laboratoire d'Astrophysique de Marseille UMR 7326, CNRS-INSU, Marseille, 13388, France

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Abstract: We analyzed the changes in precipitation regime in the Altai Mountains for 1959-2014 and estimate the influence of atmospheric circulations on these changes. Our study showed that during last 56 years the changes in the precipitation regime had a positive trend for the warm seasons (April-October), but weakly positive or negative trends for the cold seasons (November-March). It was found that these changes correspond to the decreasing contribution of "Northern meridional and Stationary anticyclone (Nm-Sa)" and "Northern meridional and East zonal (Nm-Ez)" circulation groups and to the increasing contribution of "West zonal and Southern meridional (Wz-Sm)" circulation groups, accordingly to the Dzerdzeevskii classification. In addition, it was found that the variation of precipitation has a step change point in 1980. For the warm seasons, the precipitation change at this point is associated with the reduced influence of "West zonal (Wz)", "Northern meridional and Stationary anticyclone (Nm-Sa)" and "Northern meridional and Southern meridional (Nm-Sm)" circulation groups. For the cold seasons, a substantial increase of "Wz-Sm" and a decrease of "Nm-Sa", "Nm-Ez" circulation groups are responsible for the precipitation change in the two time periods (1959-1980 and 1981-2014).

Keywords: Altai Mountains; Precipitation; Atmospheric circulation

Introduction

Climate changes in various regions of the Earth have different manifestations. In mountain areas, one of the best evidences of such changes are the melting glaciers (Kohler and Maselli 2009; Kohler et al. 2014; Hewitson et al. 2014). Mountains occupy very different territories on the globe and they differ in shape, extension, altitude, vegetation cover, and climate regime. They are therefore affected by climate change in various ways and the results obtained for one mountain region cannot be immediately applied to another (Kohler and Maselli 2009; Hewitson et al. 2014).

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Unfortunately, climate changes have been studied mostly in highly populated zones such as the Alps, Scandinavian Mountains, Rocky mountains, which possess a dense network of meteorological stations allowing to get a trusty information on climate variations in the region (Gilbert and Vincent 2013; Cramer et al. 2014; Kohler and Maselli 2014; Kovats et al. 2014; Romero-Lankao et al. 2014). The meteorological networks covering some of the Asian mountain regions are of low spatial resolution (Williams and Konovalov 2008; Kohler and Maselli 2009; Hijioka et al. 2014), so that the data of climate observations in these zones are limited. It makes difficult to estimate the regional climate, to understand its peculiarities, and to forecast the trends in the climate change.

The main reasons for climate change at different time and spatial scales are the following: changes of the Earth orbital parameters, variations of solar activity, volcanic eruptions, anthropogenic factors, and atmosphere circulation (Wanner et al. 2008; Wanner et al. 2011). During the past decades some attempts to establish relation between the observed regional climate variability and the large-scale patterns of atmospheric circulation were undertaken in the Asian Mountain regions. A few studies were devoted to quantitative estimation of the influence of the atmospheric circulation patterns on climate variations in these regions (Aizen et al. 2001; Immerzeel et al. 2010; Li et al. 2013; Bothe et al. 2012; Huang et al. 2013; Chen et al. 2014; Hijioka et al. 2014; Wang et al. 2014; Zhang et al. 2015; Geng et al. 2016; Li et al. 2016; Yao et al. 2016). However, the northern periphery of Central Asia, in particular, the Altai Mountains remains the least studied region (Groisman and Gutman 2013).

The Altai Mountains are distinguished by high biological diversity in complex ecosystems: from semi-deserts to humid landscapes (Kokorin 2011). The contrasting climate, associated with seasonal changes in atmospheric circulation, and the great biological diversity lead to the existence of many paleoarchives (ice cores, peat bogs, tree rings) in this region (Eichler et al. 2009; Kokorin 2011; Herren et al. 2013). The study of precipitation changes under the influence of atmospheric circulation in the Altai Mountains, especially using the daily data, could give results which can be helpful in doing forecasts of regional climate changes, predicting changes in Altai glaciation and semi-desert landscapes of this region as well as performing reliable paleoreconstructions.

1 Study Area

The Altai Mountains are located in the central part of Eurasian continent, at the northern periphery of the Central Asia. They stretch from the West-Siberian plain in the north-west to the Gobi desert in the south-east. The length of the Altai massif is about 1500 km, whereas its width varies from 600 km in the north to about 100 km in the south. This mountain region consists of a set of high ridges and plateaus achieving 4500 m of altitude, forming watersheds of the biggest Siberian Rivers the Ob, Irtysh, and Yenisei, and rivers of the Central Asia basin (Egorina 2003). The Altai Mountains stretch over four countries (China, Kazakhstan, Mongolia and Russia); a significant part of the Altai belongs to Russia and Mongolia.

The Altai acts as a barrier for most of the humid air masses transported by the Westerlies, resulting in a strong northwest to southeast precipitation gradient (Klinge et al. 2003). These mountain areas have a high seasonal temperature range (from +41°C in summer to -47 °C in winter). The Siberian High is an anticyclone, centered over Eurasia (40°-65°N, 80°-120°E) (Sahsamanoglou et al. 1991), which controls the winter weather in the Altai (Klinge et al. 2003). The Siberian High is maintained by radiative cooling over snow-covered Asia, associated with the large-scale descending motion (Ding and Krishnamurti 1987). The anticyclone prevents winter precipitation in the Mongolian part of the Altai Mountains, whereas few intrusions of Westerlies can result in precipitation in the Russian part of the Altai Mountains (Klinge et al. 2003). In summer, most of the precipitation is transported by humid air masses of the Westerlies (Egorina 2003).

For the Altai Mountains, the circulation regime of the atmosphere was described by Popova et al. (1986), but only for the warm period of the year; and the study was limited in time (till mid 1980-ies). Hydrometeorological conditions and circulation patterns for winter seasons in the Altai Mountains were classified and described by

Narozhnyj et al. (1993). Later, Subbotina (1995) identified fourteen types of macrosynoptic processes for the northern part of Central Asia based on the data derived from synoptic maps for 1970-1980. Based on the types of macrosynoptic processes, Aizen identified region-sources of precipitation in the Siberian Altai for the period 1984-2000 (Aizen et al. 2005), analyzed the patterns of climatic and atmospheric circulation variability in the Altai, Tien Shan and Tibet (Aizen at al. 2006), and studied a coupling between large-scale atmospheric patterns and modifications of regional precipitation regimes at seasonal and annual time scales in different areas of mid-latitudes in Asia, including Western Siberia Aizen et al. (2001). Using precipitation data, he also studied the relation between atmospheric circulation patterns and firn-ice core records from the Inilchek glacierized area (central Tien Shan, Asia) (Aizen et al. 2004).

Variations in circulation processes of Western Siberia, including the areas adjacent to the Altai Mountains, and their impact on climate change were studied by Gorbatenko et al. (2011), Volkova et al. (2015), however, only using the monthly and annual data. In contrast to the previous studies of the Altai Mountains, we used the daily data on precipitation and atmospheric circulation which allowed us to reveal the mechanism of direct influence of the atmospheric circulation on the precipitation. The use of daily data is advantageous comparing to the monthly and annual averages, since the latter characterize the synoptic situation only in average and include, in particular, all time intervals even those without precipitation.

2 Materials and Methods

2.1 Data

We use the data of (Figure 1, Table 1) meteorological stations in the Altai Mountains which have different locations with respect to the humid air masses transported by Westerlies. The meteorological station Kara-Tyurek (2600 m asl) operates in the Katun range and the station Ust-Coksa (978 m asl) is situated in the Uymon depression. Both stations are located on the windward slopes of the Altai Mountains. The stations Kyzyl-Ozek (331 m asl) and Yailu (480 m asl) are situated in the Mayma river valley and the Lake Teletskoye valley. They are located on the northern periphery of the Altai Mountains (which is to the north of the Westerlies). Three stations are located on the leeward slopes of the Altai Mountains. The station Kosh-Agach (1760 m asl) is situated in the Chuya depression. The meteorological stations Hovd (1400 m asl) and Ulgii (171 m asl) are located in the Hovd river valley.

To have a reliable starting point, for the stations located in the Russian part of the Altai, we used the data from the official site of the All-Russian Research Institute of Hydrometeorological Information – RIHMI-WDC (http://meteo.ru/english/data/). These meteorological data sets were automatically processed for quality as well as homogeneity control before being stored at the RIHMI-WDCThe RIHMI is the major source of official information of the Russian meteorological stations. The precipitation series of Mongolian

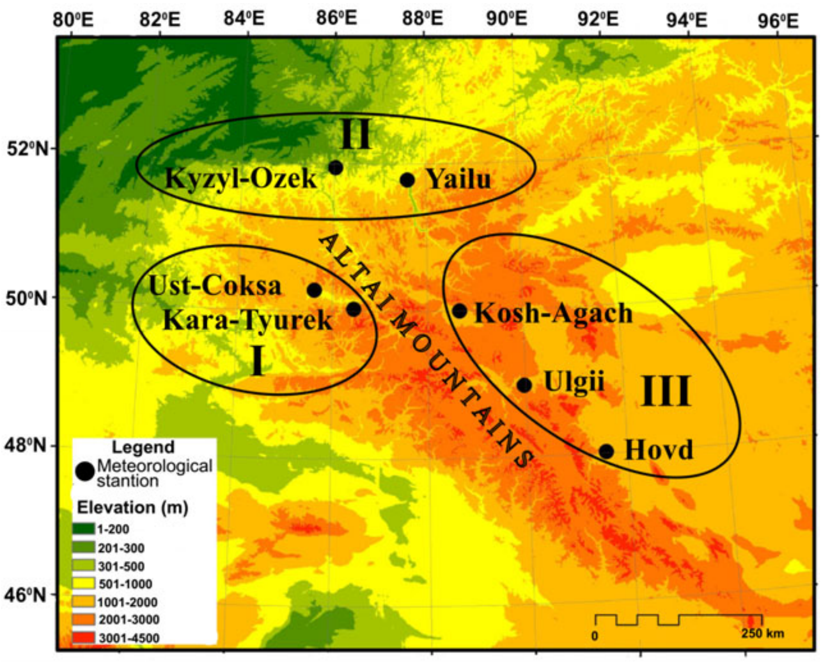

Figure 1 Location of meteorological stations (*black points*) on the windward slopes of the Altai Mountains (Kara-Tyurek and Ust-Coksa – *group I*), on the northern periphery of the Altai Mountains (Kyzyl-Ozek and Yailu – *group II*) and on the leeward slopes of the Altai Mountains (Kosh-Agach, Hovd and Ulgii – *group III*).

weather stations – Hovd and Ulgii – were provided by Mongolian Hydrometeorological Institute. To identify the missing data and to provide the homogeneous data for Mongolian stations, we used the Methods of State Hydrological Institute and Voeikov Main Geophysical Observatory (Bulygina et al. 2013).

2.2 Dzerdzeevski's classification

Elementary Circulation Mechanisms (ECMs), proposed by B. L. Dzerdzeevskii in the 1960-ies (Dzerdzeevskii 1962, 1966, 1969), form the basis for classification of atmospheric processes in the northern hemisphere. Based on the analysis of maps of baric topography at the 500 hPa level, the dynamical state of the atmosphere was assigned to one of the defined ECMs types depending on 1) whether the atmospheric pressure in the Arctic was high or low; 2) the number of blocking processes varied from 0 to 4; 3) the number and trajectories of southern cyclones varied from 2 to 4. Dzerdzeevskii distinguished 41 subtypes of ECMs (Table 2). The first letters of the alphabet (a, b, c, d) distinguish the ECMs within the same subtype, differing by the number of blocking processes and the number of cyclones. Letters "w" (winter) and "s" (summer) indicate seasonal differences in ECMs pressure in the Arctic. The daily data on 41 subtypes of ECMs are presented in the "Calendar of successive change of Elementary Circulation Mechanisms (ECMs)" by B. L. Dzerdzeevskii (http://atmospheric-circulation.ru/about-us/). For the northern hemisphere, these 41 subtypes of ECMs were further organized into 13 types according to certain common similarities. (Table 2) (Dzerdzeevskii 1962; Kononova 2009, 2010). The classification by B. L. Dzerdzeevskii was adopted by the World Meteorological Organization (Mitchell et al. 1966) and described by Barry and Perry (1973), Przybylak (2003) and Brencic (2016).

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 (Dzerdzeevskii 1962; Kononova 2009, 2010; http:// atmospheric-circulation.ru/ about-us/). The change of dominating circulation groups allowed them to recognize a circulation epoch for each sector. Since the Altai Mountains belong to the Siberian sector, our study deals with Circulation Groups in the Siberian Sector (CGSS) of the northern hemisphere (see Table 3). Figure 2 shows one subtype of ECMs for each circulation group of the Siberian sector. B. L. Dzerdzeevskii, and then N. K. Kononova identified three circulation epochs for the Siberian sector starting from 1899: 1) meridional (1899-1931), 2) fluctuation near the

Table 1 Meteorological in the Altai Mountains

Meteorological station	Location	Elevation (m asl)	Mean precipitation for period 1959-2014 (mm)		
			Warm period	Cold period	Year
Kyzyl-Ozek	51.90°N, 86.0°E	331	569.3	160.2	729.5
Yailu	51.77°N, 87.6°E	480	749.5	57.7	807.2
Ust-Coksa	50.30°N, 85.6°E	978	385.5	74.7	460.3
Kosh-Agach	50.00°N, 88.4°E	1760	105.3	16.5	121.7
Kara-Tyurek	50.00°N, 86.4°E,	2600	486.0	106.2	592.2
Ulgii	48.90°N, 91.9°E	171	114.1	5.9	120.1
Hovd	48.00°N, 91.4°E	1400	121.6	7.0	128.6

Table 2 Types and Subtypes of ECMs according to B.L. Dzerdzeevskii for the northern hemisphere (Dzerdzeevskii 1962; Kononova 2009, 2010)

Circulation group of ECMs	Types of ECMs	Subtypes of ECMs	Atmospheric pressure in the Arctic	Number of blocking processes	Number of southern cyclones
Zonal circulation	1, 2	1a,1b, 2a, 2b, 2c	High	0	2–3
Disturbance of zonal circulation	3–7	3, 4a, 4b, 4c, 5a, 5b, 5c, 5d, 6, 7aw, 7as, 7bw, 7bs	High	1	2–3
Meridional northern	8–12	8a, 8bw, 8bs, 8cw, 8cs, 8dw, 8ds, 9a, 9b, 10a, 10b, 11a, 11b, 11c, 11d, 12a, 12bw, 12bs, 12cw, 12cs, 12d	High	2–4	2–4
Meridional southern	13	13w, 13s	Low	0	3–4

Table 3 Circulation groups of ECMs for the Siberian sector (Kononova 2009)

Circulation Groups for the Siberian sector (CGSS)		Subtypes of ECMs
West zonal and Southern meridional	Wz-Sm	2a, 2b, 3, 7as, 8a, 9a, 10a, 13s
Northern meridional	Nm	12a
West zonal	Wz	2c, 4b, 6, 7bs
West zonal and Stationary anticyclone	Wz-Sa	1a, 1b, 4a, 7aw, 7bw, 9b, 13w
Northern meridional and Stationary anticyclone	Nm-Sa	5a, 5c, 8cw, 8dw, 11a, 11b, 11d, 12bw, 12cw
Northern meridional and East zonal	Nm-Ez	5b, 5d, 11c, 12d
Northern meridional and West zonal	Nm-Wz	8bw, 8bs, 8cs, 10b
Northern meridional and Southern meridional	Nm-Sm	4c, 8ds, 12bs, 12cs

average (1932-1980), 3) zonal (1981 - 2014) (Kononova 2009; Kononova 2010).

Thus, the Dzerdzeevski's classification describes in detail the changes in atmospheric processes both in the whole northern hemisphere and in the Siberian sector, which is the one that includes the Altai Mountains. N. Kononova further elaborated it and her work resulted in "Calendar of successive change of ECMs", which has an advantage comparing to the other completed regional classifications of atmospheric circulation patterns developed for the Central Asia, in particular, the Altai (Popova et al. 1986; Narozhnyi et al. 1993; Subbotina 1995). An analysis of classification by B. L. Dzerdzeevskii (Kononova 2009) showed the correlation between the annual average duration of individual ECMs and NAO teleconnection pattern which indicates a high level of applicability of Dzerdzeevskii's classification. It should be noted that this classification was efficiently used for estimating the relation between isotopic composition of precipitation and atmospheric circulation patterns, for example in Slovenia (Brencic et al. 2015) as well as for evaluation of the variability of precipitation and glacier mass balance over the Tuyuksu Glacier in the Tien Shan Mountains, Russia (Kononova et al. 2015). Tursunova (2014, 2015) reported interrelation of the atmospheric circulation processes, by B. L. Dzerdzeyevskii, with the change of runoff in the basins of rivers of South Kazakhstan and Central Asia.

2.3 Methods

We used the classical Mann-Kendall test to check whether there is a trend in a precipitation time series (Mann 1945; Kendall 1975). In addition, the nonparametric Mann–Kendall–Sneyers test (Mann 1945; Kendall 1975; Sneyers 1975) was applied to determine the occurrence of step change points of precipitation.

Let x_1, ..., x_n be the data points. Then one defines n_i as the number of elements x_j preceding x_i ($j<i$) and such that $x_j < x_i$, and introduces the test statistic:

$$t_k = \sum_{i=1}^{k} m_i \qquad 2 \leqslant k \leqslant n. \qquad (1)$$

Under the null hypothesis (no step change point), t_k are normally distributed with the mean and the variance given by:

$$\bar{t}_k = E(t_k) = k(k-1)/4 \qquad (2)$$

$$\bar{\sigma} t_k^2 = var(t_k) = k(k-1)(2k+5)/72 \qquad (3)$$

Finally, one calculates u_k, the normalized statistic variables defined as follows:

$$u_k = (t_k - \bar{t}_k)/\sqrt{(\bar{\sigma}\, t_k^2)} \qquad (4)$$

In this work, long-term trends of precipitation were determined as the slope of linear regression line of the mean precipitation during the studied time interval by using the method described by Li et al. (2013). Then we divided the study interval into two time subintervals at the step change point and compared them between each other.

To explain the changes observed in the precipitation of the two periods, we compared the daily calendar of successive change of ECMs with daily precipitation, and calculated the contribution (in %) of each identified ECM to precipitation. To this end, we calculated the total amount of the daily precipitation (in mm) happened at each of the 41 ECMs in the considered time interval. The obtained values allowed us to calculate the distribution (in %) of the precipitation by ECMs subtypes (Malygina et al. 2013; Malygina et al. 2014a, 2014b). Then we grouped the results obtained for 41 types of ECM into 8 CGSS. Thus, we calculated the contributions (in %) of 8 CGSS to precipitation for the whole

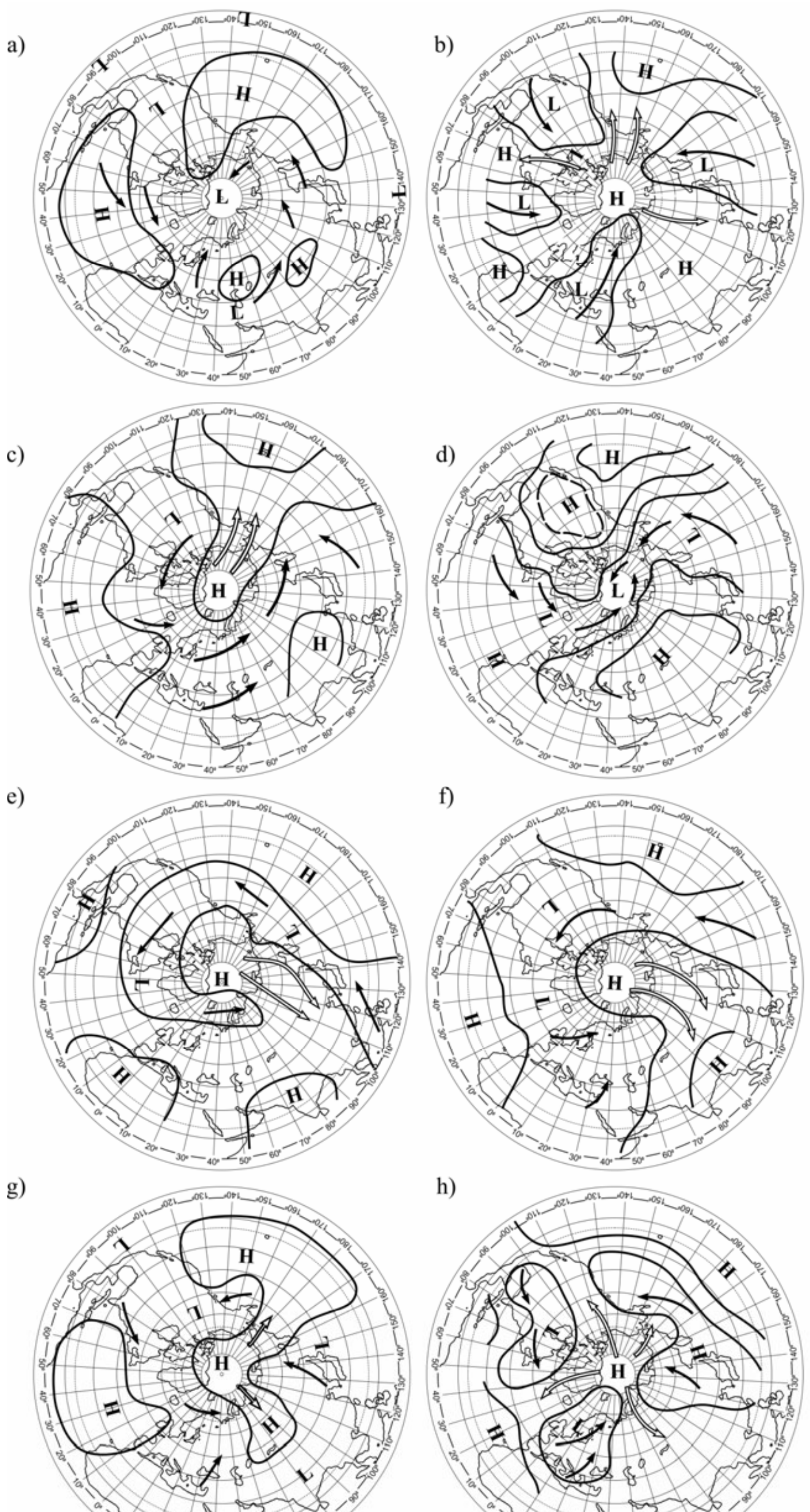

Figure 2 Dynamical scheme of subtypes of Elementary Circulation Mechanisms (ECMs) circulation groups for the Siberian sector: a) 13s; b) 12a; c) 6; d) 13w; e) 5a; f) 5d; g) 8cs; h) 12bs *(arrows indicate generalized trajectories of cyclones in the extratropical latitudes, double light - blocking processes, L and H - low and high pressure)* (Kononova 2009).

considered time interval as well as for the two subintervals separated by the step change, and for warm and cold seasons.

To group stations with similar ECMs causing a precipitation there, we used Agglomerative Hierarchical Clustering (AHC) which is a simple iterative classification method. First, we calculated the dissimilarity between *N* objects. Then two objects are clustered together if this clustering leads to a minimization of a given agglomeration criterion. In this way, we created a class comprising these two objects. Then we repeated the procedure for this class and *N-2* remaining objects. The process continues until all the objects are clustered (Everitt et al. 2010). These successive clustering operations produce a binary clustering tree (dendrogram), whose roots represent the class that contains all the observations. Such dendrogram represents a hierarchy of partitions.

3 Results and Discussion

3.1 Trends of precipitation

The Mann–Kendall test has shown that during the interval 1959-2014 the precipitation had different trends for the various seasons. Table 4 demonstrates significant increasing trends of precipitation at all stations for the warm (April - October) season (1959-2014). For the cold season (November – March), negative trends were found except for Ulgii station, where the trend was weakly positive. In contrast, it was found that the trends of annual precipitation were different. A high positive trend was observed at the stations located on the windward slopes of the Altai Mountains (Kara-Tyurek and Ust-Coksa), a positive or weakly negative trend was found for the stations located on the leeward slopes (Kosh-Agach, Hovd and Ulgii), and a negative one for the stations located on the northern periphery of the Altai Mountains. All these results are statistically significant ($P<0.01$).

The Mann–Kendall–Sneyers test has found in addition the dates of the step change points of precipitation. Figure 3 illustrates that for all stations it occurred in 1980. On the basis of these results the considered time interval (56 years) was divided into two subintervals: 1959-1980 and 1981-2012. Similarly to the whole interval, each sub-interval was studied using the analysis of the precipitation trend by the Mann-Kendall test. As a result, for the warm season, during the first interval (1959-1980) positive trends were observed at all stations (from +4 to +39 mm per decade) (Table 4). In contrast, during the second time interval (1981-2012) only negative trends were found at all stations during the warm season. For the cold season, during the first interval (1959-1980) a negative trend was observed only at the stations located on leeward slopes (Kosh-Agach, Hovd and Ulgii), while during the second interval (1981-2012) the opposite results were obtained for all stations. The trends of the total precipitation from the first interval to the second one changed similarly to the warm season (Table 4) except for the negative trend during the first interval at Kosh-Agach station (Figure 3c).

This result is perfectly consistent with the results of the studies of the precipitation changes in Western Siberia presented in the Second Assessment Report (2014), the results of regional studies (Bezuglova and Zinchenko 2009; Litvinova and Gulyaeva 2010; Volkova et al. 2015), and the results for the northwest China including the mountain region adjacent to the Altai (Zhou and Huang 2003; Li et al. 2013; Chen et al. 2014; Wang

Table 4 The precipitation trend (mm/10 years) at Altai Mountains meteorological stations during 1959-2014

Meteorological station	1959-2014			1959-1980			1981-2014		
	Warm season	Cold season	Year	Warm season	Cold season	Year	Warm season	Cold season	Year
Kara-Tyurek	15	-2	14	16	1	14	-9	-17	-23
Ust-Coksa	3	-1	4	8	2	10	-10	-1	-8
Kosh-Agach	2	2	-1	10	-8	-2	-4	2	-4
Hovd	2	0	3	4	-3	3	-7	1	-5
Ulgii	2	1	4	10	-1	6	-11	2	-8
Yailu	1	-1	-3	15	1	12	-21	-9	-15
Kyzyl-Ozek	4	-6	-12	39	4	30	-16	-7	-9

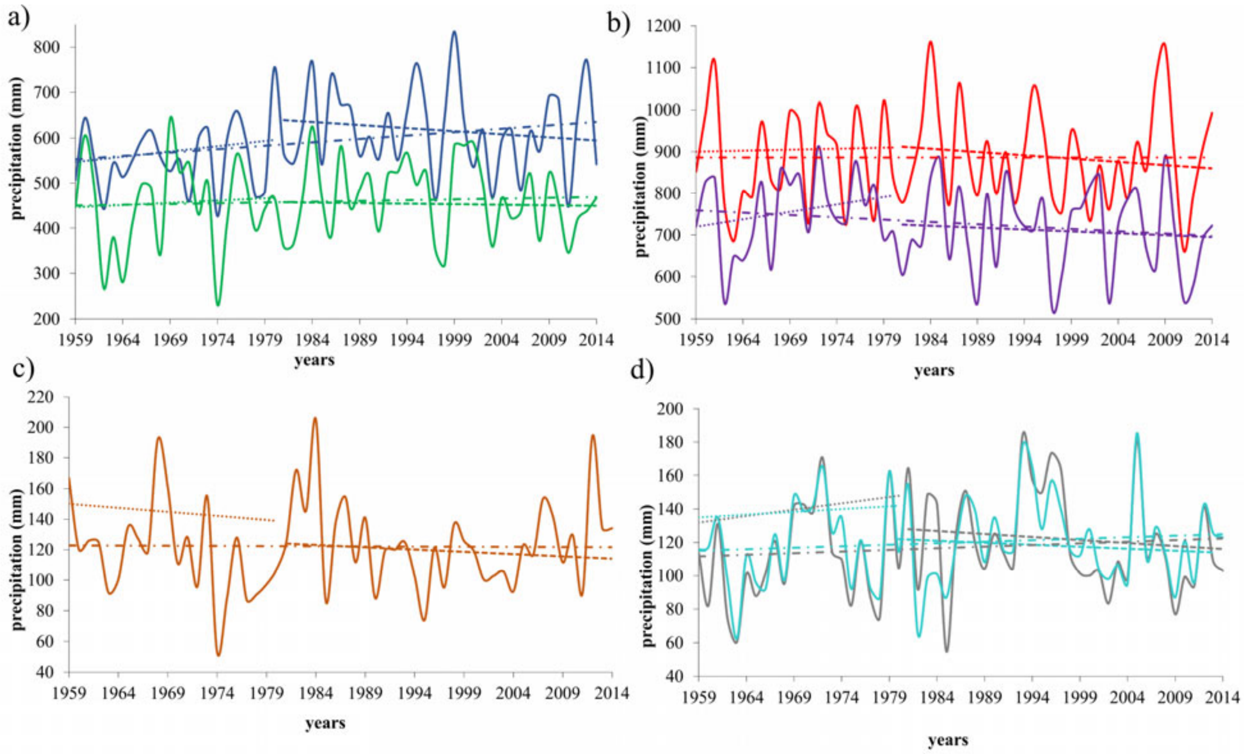

Figure 3 The total precipitation trends at meteorological stations: on windward slopes of the Altai Mountains (*a*) – Kara-Tyurek (*blue*) and Ust-Coksa (*green*); on northern periphery of the Altai Mountains (*b*) – Yailu (*red*) and Kyzyl-Ozek (*lilac*); on leeward slopes of the Altai Mountains – (*c*) Kosh-Agach (*orange*), (*d*) Hovd (*turquoise*) and (*d*) Ulgii (*gray*) during the period 1959-2014 (*dashed-dotted lines*), 1959-1980 (*dotted lines*), 1981-2014 (*dashed lines*).

et al. 2014).

To clarify the reasons of the sign change of the precipitation trend between different intervals and seasons, we estimate the relation of precipitation variation and teleconnection pattern, as well as the relations of precipitation and ECMs. As the original data, we use mainly the daily data since the data with such resolution allow to better describe the relation between the observed precipitation change and atmospheric circulation.

3.2 Dzerdzeevski's classification and precipitation

To assess the role of ECMs in precipitation regime change, we calculated the change in the total number of days in each out of eight groups of circulation, the number of days with precipitation and the contribution (%) of each group to precipitation. This was done for two time intervals within the period 1959-2014 for different dominated CGSSs (Table 5). The calculation of the average number of days in the year with predominance of one out of eight CGSS in each of the studied time intervals provides an evidence that the largest contribution comes from the Wz-Sm, Wz-Sa and Nm-Sa groups. During the second interval, the number of days increased in the Wz-Sm and Wz-Sa and decreased in the Nm-Sa groups. The analysis of change in the average number of days with precipitation done for seven Altai meteorological stations, gives a similar pattern for both subintervals (1959-1980 and 1981-2014), whereas the contribution of the Nm-Sa group demonstrates a great (2-fold) decrease. The analysis of the number of days with precipitation in various CGSS does not allow us to estimate accurately the change in the precipitation regime. The calculation of the average (for 7 stations) precipitation amount for each CGSS shows that the maximum precipitation occurs in the Wz-Sm group both during the first (36%) and the second (47%) time intervals; in the second interval the contribution of this group increases up to 9% (Figure 4).

To assess the effect of CGSS on precipitation change in the region, we calculated the contributions (%) of eight CGSS for three time

Table 5 CGSS duration and contribution to precipitation in Altai Mountains during 1959-1980 and 1981-2014

CGSS	Average number of days per year		Average number of days with precipitation per year		CGSS contribution to precipitation	
	1959-1980	1981-2014	1959-1980	1981-2014	1959-1980	1981-2014
Wz-Sm	93 (25%)	111 (30%)	42 (27 %)	62 (31%)	36%	47%
Nm	20 (5%)	36 (10%)	10 (6%)	16 (8%)	7%	9%
Wz	17 (5%)	16 (4%)	9 (6%)	14 (7%)	10%	7%
Wz-Sa	65 (18%)	77 (21 %)	24 (15%)	33 (17%)	11%	11%
Nm-Sa	73 (20%)	63 (17%)	39 (24 %)	23 (12%)	12%	7%
Nm-Ez	29 (8%)	21 (6%)	12 (8%)	8 (4%)	6%	3%
Nm-Wz	17 (5%)	18 (5%)	10 (6%)	19 (10%)	7%	7%
Nm-Sm	52 (14%)	23 (6%)	12 (8%)	23 (12%)	11%	10%
Total	366 (100%)	366 (100%)	159 (100%)	199 (100%)	100%	100%

Figure 4 Duration and mean contribution of CGSS to precipitation in the Altai Mountains for 1959-1980 (*first value*) and 1981-2014 (*second value in brackets)* (Table 2 and 3).

intervals (the whole and two subintervals) for a whole year and separately for two seasons for all seven stations (Tables 6-8). The maximum contribution (from 41% to 56%) for the whole period (1959-2014) and the two time intervals for the warm season comes from the Wz-Sm group (Table 6), by significantly increasing 13s subtypes ECM from 12% to 38%. During the second interval, the growth of the Wz-Sm contribution for some stations increased to 10%. We observed the growth of Nm and Nm-Wz contribution from the first to the second interval. In contrast, three groups (i.e. Wz, Nm-Sa, and Nm-Sm) showed a reduced contribution and led to the sign change from positive to negative in the precipitation trend during the second period.

It is seen that the Nm-Sa group made a significant contribution to the precipitation at Kosh-Agach, Ulgii and Hovd stations located on leeward slopes of the Altai Mountains during the cold season at first subinterval, whereas in the second subinterval its contribution dropped (Table 7). A similar situation was observed in the Nm-Ez group for all stations. The second important Wz-Sa group showed an increase in the precipitation amount from the first to the second interval; however, the values of CGSS contribution for the weather stations located on leeward slopes remained unchanged. More than 3-fold precipitation increase comes from the Wz-Sm group from Kosh-Agach, Ulgii and Hovd stations that caused the sign change from negative during

Table 6 Contribution (%) of CGSS to precipitation for the warm season in Altai Mountains during 1959-2014

Period	CGSS	Kara-Tyurek	Ust-Coksa	Kyzyl-Ozek	Yailu	Kosh-Agach	Hovd	Ulgii
1959-2014 1959-1980/1981-2014	Wz-Sm	47	47	47	48	53	53	53
		44/49	41/51	41/49	43/50	46/55	46/56	46/56
	Nm	10	10	10	10	6	6	6
		8/10	9/10	7/10	8/10	8/6	8/6	7/5
	Wz	9	9	8	9	10	10	10
		10/8	11/7	10/7	11/7	15/8	14/8	15/8
	Wz-Sa	8	8	8	8	5	5	5
		9/8	8/8	8/8	7/7	5/5	5/5	5/5
	Nm-Sa	5	5	5	5	3	4	4
		6/5	6/4	7/4	6/4	4/3	3/3	4/3
	Nm-Ez	2	2	3	3	1	1	1
		3/2	4/1	5/2	4/2	2/1	2/1	2/1
	Nm-Wz	8	8	8	8	8	8	8
		8/8	8/8	8/8	8/8	7/9	7/8	7/9
	Nm-Sm	11	11	12	11	13	13	13
		12/11	13/10	15/11	13/10	15/12	15/12	14/12

Table 7 Contribution (%) of CGSS to precipitation for the cold season in Altai Mountains during 1959-2014

Period	CGSS	Kara-Tyurek	Ust-Coksa	Kyzyl-Ozek	Yailu	Kosh-Agach	Hovd	Ulgii
1959-2014 1959-1980/1981-2014	Wz-Sm	10	9	10	10	9	9	97
		6/13	6/10	7/11	7/12	4/13	4/14	4/14
	Nm	8	7	7	7	8	7	8
		6/9	4/10	5/8	6/9	7/9	7/9	7/10
	Wz	2	1	1	1	1	2	2
		1/2	1/1	1/2	1/2	1/3	1/3	1/3
	Wz-Sa	34	33	33	34	32	32	32
		31/35	30/32	29/36	31/36	32/32	32/32	32/32
	Nm-Sa	31	33	32	32	34	34	34
		38/26	39/30	38/27	39/27	41/27	41/27	41/27
	Nm-Ez	12	13	13	12	15	15	15
		14/10	14/12	17/11	13/10	14/14	14/13	14/13
	Nm-Wz	2	3	2	2	1	1	1
		4/2	5/2	3/2	2/1	1/1	1/2	1/2
	Nm-Sm	2	2	2	2	1	1	1
		1/2	1/2	1/2	2/2	1/1	1/1	1/1

Table 8 Contribution (%) of CGSS to total precipitation in Altai Mountains during 1959-2014

Period	CGSS	Kara-Tyurek	Ust-Coksa	Kyzyl-Ozek	Yailu	Kosh-Agach	Hovd	Ulgii
1959-2014 1959-1980/1981-2014	Wz-Sm	42	42	39	43	47	47	47
		37/43	36/45	33/45	37/42	38/51	37/51	38/51
	Nm	9	9	9	10	6	6	6
		8/10	7/10	6/11	8/10	7/6	7/6	7/6
	Wz	7	7	7	7	9	9	9
		7/6	8/6	8/6	8/6	9/8	8/8	9/8
	Wz-Sa	13	12	13	11	9	9	9
		12/13	12/12	13/12	11/14	11/8	10/8	12/8
	Nm-Sa	10	9	11	9	8	8	8
		13/8	12/8	15/7	12/9	12/6	11/6	11/6
	Nm-Ez	4	4	5	4	3	3	3
		6/3	7/3	8/3	6/4	6/3	6/3	5/2
	Nm-Wz	7	7	7	7	7	7	7
		8/7	7/7	7/8	7/7	7/8	6/8	7/8
	Nm-Sm	10	10	10	10	11	11	12
		10/10	12/8	11/9	12/9	12/11	12/11	11/12

the first period to positive during the second one.

The Wz-Sm group made a considerable contribution to the annual precipitation and, in particular, to the precipitation during the warm season; the growth of its contribution was observed in the second period (Table 8). However, a sharp decrease in the Nm-Sa and Sa-Ez contribution was recorded from the first to the second period that had a great effect on the change of the trend sign from positive in the first period to negative in the second one.

Obviously, the CGSS contribution to the precipitation regime in Altai Mountains is related to the change in circulation epochs in the Northern hemisphere, i.e. in the Siberian sector. Kononova (2009) has shown that in 1981 the new circulation epoch (called “Zonal”) started. This seems to be consistent with our findings. It is worth to note that similar results were obtained for the south of Western Siberia (Litvinova and Gulyaeva 2010; Volkova et al. 2015) and Central Asia (Anisimov et al. 2009), where changes in precipitation (monthly data) are associated with the increase of W-type circulation by the Vangengeim-Girs classification.

We compared our results with the data published by Aizen (Aizen et al. 2005), who identified the sources of atmosphere precipitation in the area of the Belukha glacier (the Altai Mountains) for the years 1984-2000. Since the Kara-Tyurek station is located near the Belukha glacier (the Altai Mountains), we calculated the relative contribution of precipitation here for 1984-2000 applying the same interval used by Aizen et al. (2005), who estimated the contribution of the southwestern cyclone as 33%±8%. If we assume that the Wz-Sm group corresponds to southwestern cyclones, we obtain 41% that is consistent with the previously published results (Aizen et al. 2005). Our findings provide more accurate calculations of circulation effects on precipitation because we have used only the days with precipitation but not all days of the month.

To estimate the influence of CGSS on precipitation for different stations, we applied the method of AHC. It allowed us to specify three classes of stations, differing from each other by various CGSS with the dominant influence on precipitation.

For the first time interval (1959-1980), we determined three groups of stations: the first one comprises Hovd, Ulgii and Kosh-Agach, the second one consists of Kara-Tyurek and Ust-Coksa, and the third one includes Yailu and Kyzyl-Ozek stations. For the second time interval (1981 - 2012) the grouping remained the same (Figure 5).

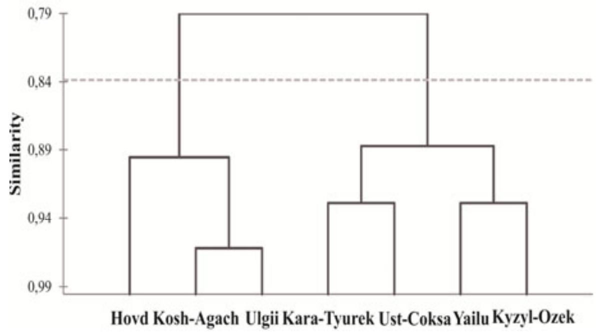

Figure 5 Dendrogram of meteorological stations by CGSS influence on precipitation in the Altai Mountains.

In each class, CGSS have a similar influence on the regional precipitation. Note that the first class consists of the stations located on leeward slopes, the second one includes the stations situated on the windward slopes, and the third class – the stations on the periphery of the Altai Mountains. Thus, the clustering is based on the station position and the CGSS influence on precipitation in the region.

4 Conclusion

In 1959-2014, the changes of the precipitation regime in the Altai Mountains had different trends for various stations and seasons. Only positive trends were revealed for the warm season, while for the cold period - both negative and slightly positive ones. It was found that the variation of precipitation had a step change point occurred in 1980. The maximum contribution (from 41% to 56%) for the whole period (1959-2014) and for two subintervals separately for the warm season comes from the Wz-Sm group circulation (the Dzerdzeevskii’s classification), by significantly increasing 13s subtypes ECM from 12% to 38%. During the second interval (1981-2014), the growth of the Wz-Sm contribution for some stations increased to 10%. Accordingly to the data from the stations located on leeward slopes of the Altai

Mountains, the Nm-Sa group circulation made a significant contribution to the annual precipitation during the cold season, whereas in the second period its contribution has dropped. A similar situation was observed in the Nm-Ez group for all stations. The second important Wz-Sa group showed an increase in precipitation amount from the first to the second interval; however, the values of the CGSS contribution for the weather stations located on leeward slopes remained unchanged. The Wz-Sm group made a considerable contribution to the annual precipitation and, in particular, to the precipitation during the warm season; the growth of its contribution was observed in the second period. However, a sharp decrease in the Nm-Nm and Sa-Ez contribution was recorded from the first to the second period which had a great effect on the change of the trend sign from positive in the first period (1959-1980) to negative in the second one (1981-2014).

When analyzing the influence of different CGSS on precipitation, we specified three groups of stations with similar patterns of atmospheric circulation. These groups characterize the predominant influence of atmospheric processes causing precipitation in different parts of the region. Note that the data on precipitation for the Mongolian part of Altai (Khovd and Ulgii station) as well as for the Kosh-Agach station located in the Russian part of Altai (nearby Mongolia) are available. It should be noted that the observations (daily data) were made during 72 years at the Kosh-Agach station, and over 50 years at the Mongolian stations. It is clear that, for example, for determination of the origin of bio-objects found in the ice cores, it is crucial to have data as long as possible. Thus, this problem for the Tsambagarav glacier massif in Mongolia can be resolved for the longer time interval using the data registered by Kosh-Agach station, as it was previously done for the Belukha glaciers in Russia (Papina et al. 2013).

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