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Long-term trends in temperature, precipitation and snow conditions in Northern Russia

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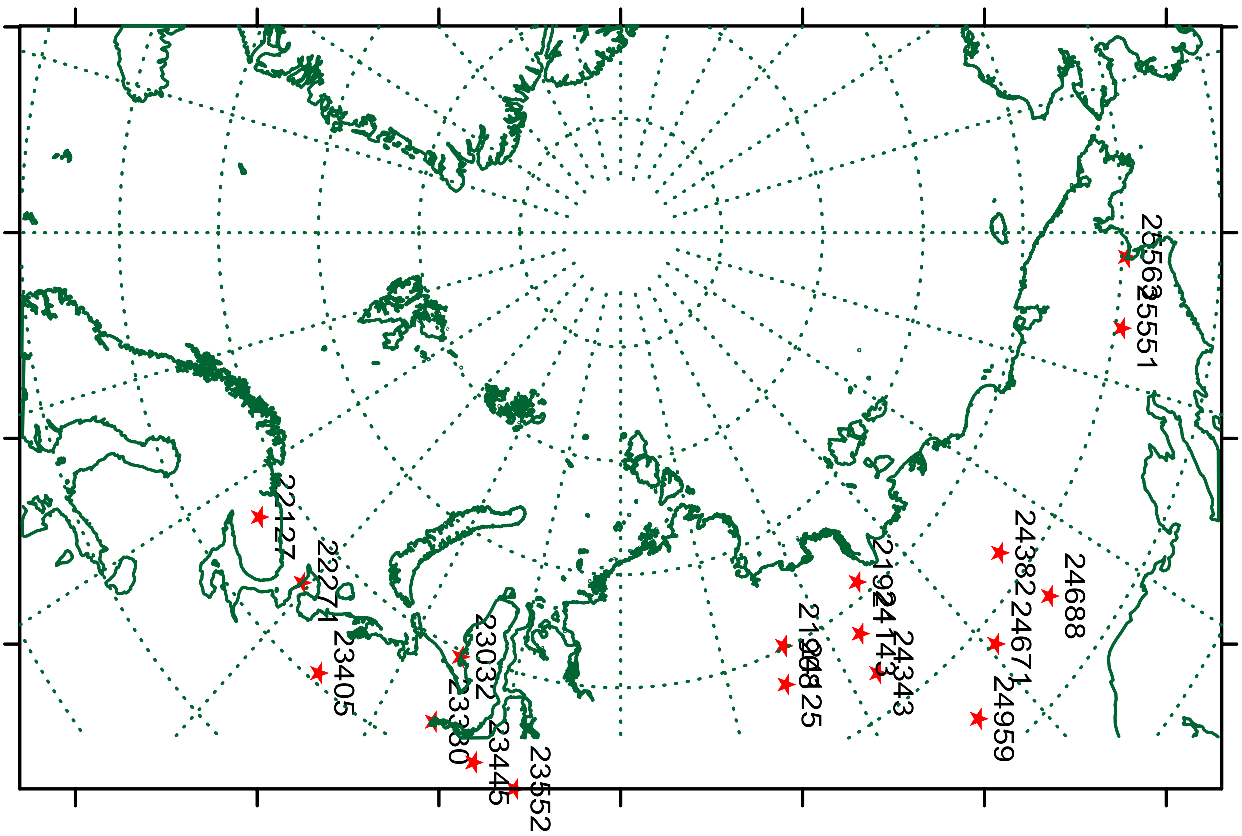

report

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Abstract

Long-term variability in temperature, precipitation and snow conditions has been studied for 18 localities in northern Russia. An overview is given of station metadata and of methodology to study long-term trends and shifts in various climate series. For **temperature** no statistically significant trends (1938-2008) were found in the annual average series for Kola Peninsula, Nenets AA and Yamalo-Nenets AA, Komi republic, while there are significant positive trends in the data for Sakha republic and Chukci AA. At most stations there are a significant warming after 1990. A negative trend (1943-2008) was found in number of days with very low temperatures (daily mean temperature <-30 °C). In the Chukci district there was an increase in number of days with mean temperature above 0 and +10 °C. Also for the Kola Peninsula there has been an increase in number of days with mean temperatures > 0°C. For **precipitation** significant positive trends (1943-2008) were found for all seasons except summer,- with strongest trends during winter and spring. The strongest trends were found for the Lovozero station at the Kola Peninsula. The precipitation trends are however influenced by inhomogeneities caused mainly by changes in precipitation gauges during the period 1946-1960. For duration of **snow cover** two stations (Mare-Sale and Gigansk) had significant trends. At both stations the trends were positive, i.e. increased length of the period with continuous snow cover. The highest **snow depths** in northern Russia are usually observed in April. For 4 stations significant positive trends were found in snow depths for April;- the strongest increase is observed at Tarko-Sale and Ust'Cilma. The reason for the increase in snow duration and maximum snow depths despite increasing temperatures is probably increased amounts of solid precipitation during the cold season.

Keywords

Temperature, precipitation, snow, trends, Northern Russia

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Contents

1. Introduction

The Arctic land areas have over the latest 2–3 decades experienced more warming than any other region on earth, and the sea-ice cover has decreased in the order of 10% in the same period (ACIA, 2005; IPCC, 2007). The Arctic climate conditions show large variability, both from year-to-year, but also on a decadal scale. A warm period, almost as warm as the present, was observed in the Arctic from 1925 to 1945, but its geographical distribution appears to have been different from the recent warming since the extent was not global (IPCC, 2007).

IPCC (2007) states that most of the observed increase in globally-averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations, and that it is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica. Climate models furthermore indicate that anthropogenic global warming will be enhanced in the northern high latitudes due to complex feedback mechanisms in the atmosphere – ocean– ice system.

The climate changes seen in the Arctic have already led to major impacts on the environment and on economic activities. If the present warming continues as projected, these impacts are likely to increase, greatly affecting ecosystems, cultures, lifestyles and economies across the Arctic. The Arctic climate is a complex system and has multiple interactions with the global climate system. Changes in the Arctic climate are thus very likely to have significant impacts on the global climate system.

These changes considerably influence the living conditions of the indigenous people in the northernmost regions and for reindeer husbandry in particular. While looking into the issues of the native population vulnerability and adaptation due to the climate change, the traditional reindeer herders' experience is going to be used as well as the international climatic observation data network. (Tyler et. al. 2007).

To estimate the vulnerability and the possibilities of the native population's adaptation to the climate change, we need looking into the temporal variability of the relevant climate parameters. Extreme climatic conditions are of specific interest.

Other important issues for the vulnerability and community adaptation research are the projections of possible climate changes using climate models, and to describe the distribution of the meteorological parameters on a local scale.

The objective of this report is to describe the metadata and meteorological observation data made available from AARI for the EALAT and CAVIAR projects, and to outline the temporal tendencies of the climatic parameters which are most important for indigenous people in northern Russia, and particularly for reindeer husbandry.

2. Observations and data

To analyze the long-term climate variability in the main reindeer husbandry areas of Russia (see fig.1); a dataset was created, containing the observations of air temperature, precipitation and snow depth. The dataset covers the whole period of observations from the end of the 19th century (or the station starting point) up to 2008, and the temporal resolution was 1 day or 1 month. As outlined below, there were several changes and shifts in the observation system of observations.

2.1 Temperature

The types of thermometers in use at each station remained the same throughout the period of record (Table 1). Minimum temperature was consistently measured with an alcohol thermometer, whereas hourly and maximum temperatures were measured by separate mercury thermometers. When the air temperature approached the freezing point of mercury (-38.9 C), either an alcohol thermometer, or in some cases a minimum thermometer alcohol column, was used in place of the mercury thermometer.

The type of shelter or screen surrounding the thermometers varied considerably before 1930. In 1912, official instructions recommended sheltering thermometers with the Stevenson-type screen (before 1912, no such guidelines existed). However, it is likely that at many stations Stevenson screens were not implemented. From 1920-30, Stevenson screens were replaced with the current screens at all stations. In 1928, additional guidelines regarding the exact dimensions of the shelters and their heights above the ground were issued (before 1928, no such specifications had been defined). Therefore, from 1930 on, most stations had their thermometers sheltered in roughly the same fashion.

Major changes in the time of observation occurred in 1936 and 1966. Prior to 1936 measurements for computing daily mean temperature were taken at 07, 13, and 21 Local Mean Time (LMT) (minimum and maximum thermometers were checked at one of these hours or at 09 LMT, see Table 1). Because of the lack of nighttime observations, daily mean temperature was probably overestimated by some location-dependent amount during this period. Beginning in 1936, all thermometers (hourly, minimum, and maximum) were checked at 01, 07, 13, and 19 LMT at most stations. As a result, the bias in daily mean temperature dropped to ~0.2 ºC. From 1966 to present, all thermometers were checked at 3-h intervals beginning at midnight Moscow winter Legal Time (MLT) (MLT being three hours later than Greenwich Mean Time). This rendered the bias in daily mean temperature insignificant.

Table 1. Temperature recording methods and instrumentation

Year	Recording method/instrumentation implemented
1881	Measurements for computing daily mean temperature taken at 07, 13, and 21 LMT; mercury thermometer used; because of lack of nighttime observations, daily mean temperature probably overestimated
1881	Daily minimum temperature thermometer checked at 09 LMT; alcohol thermometer used.
1881	Daily maximum temperature thermometer checked at 09 LMT; mercury thermometer used.
1881	No regulations regarding type of shelter surrounding thermometers.
1883	Daily minimum temperature thermometer checked at 07 and 21 LMT (lower value chosen); multiple measurements taken only to determine approximate time of occurrence of minimum.
1891	Daily maximum temperature thermometer checked at 13 and 21 LMT (higher value chosen); multiple measurements taken only to determine approximate time of occurrence of maximum.
1912	Official meteorological instructions recommended use of Stevenson screen to shelter thermometers; practice not implemented at all stations.
1920	Official meteorological instructions recommended use of current screen to shelter thermometers; practice implemented over next ten years.
1928	Official meteorological instructions specified exact size/height of screens.
1936	Measurements for computing daily mean temperature taken at 01, 07, 13 and 19 LMT (or at 07, 13, 19, and 21 LMT); bias in daily mean temperature dropped to ~0.2 °C; daily maximum and minimum thermometers may or may not have been checked each hour.
1966	Measurements for all temperature variables collected at 3-h intervals beginning at midnight MLT; bias in daily mean temperature eliminated.

2.2 Precipitation

The type of rain gauge used at each station changed at least once during the period of record (Table 2). In particular, the old-style gauge (type unknown) was replaced with the Tretyakov-type gauge over the period 1946-60. Whether or not other gauge replacements occurred at each station is not currently known. The type of shielding surrounding the rain gauges varied considerably over time. For example, in 1883, official instructions recommended that cross-shaped zinc strips be inserted into the gauge to prevent snow from drifting. Other shielding guidelines were issued at various times over the next half-century, up until the Tretyakov-type gauge was introduced. However, exact information on wind shields at each station is not currently known.

Changes in the time of observation occurred in 1936, 1966, and 1986 (see Table 2). Before 1936, rainfall was measured only at 07 LMT. From 1936-65, gauges were checked at 07 and 19 LMT. Beginning in 1966, the time of observation became time-zone dependent (the USSR comprised 11 time zones).

Table 2. Precipitation recording methods and instrumentation

Year	Recording method/instrumentation implemented
1881	Rain gauge measurements taken at 07 LMT; snowfall converted to a liquid total by melting snow in gauge; type of gauge and shielding not standardized.
1883	Official meteorological instructions recommended that cross-shaped zinc strips be inserted into the gauge to prevent snow from blowing out of the gauge; change probably not implemented at all stations.
1887	Official meteorological instructions recommended surrounding the gauge with the funnel-shaped Nifer's shield; change probably not implemented at all stations.
1892	Official meteorological instructions recommended erecting a fence around the gauge; change probably not implemented at all stations.
1902	Official meteorological instructions recommended erecting a double fence around the gauge; change probably not implemented at all stations.
1936	Rainfall measurements taken at 07 and 19 LMT; daily total rainfall obtained by summing all measurements for the calendar day.
1946-60	Old-style gauge replaced with the Tretyakov-type gauge.
1966	Rainfall measurements taken at 03, 09, 15 and 21MLT in time zone 2; at 03, 06, 15 and 18 MLT in zones 3-5; at 03 and 15 MLT in zones 6-8; at midnight, 03, 12, and 15 MLT in zones 9-11; and at 21, 03, 09 and 15 MLT in zone 12; wetting corrections <=0.2 mm applied to each hourly measurement.(Because 4 observations per day were collected at stations in time zones 2-5 and 9-12, four corrections were counted in the daily total; therefore, total daily corrections are higher for stations in these areas.)
1986	Rain gauge measurements at 03 and 15 MLT discontinued at all stations except those in time zone 2.

2.3 Snow cover

Snow depth measurement at the meteorological stations was carried out once a day. The value of the snow depth is assessed as an arithmetic average of measurements from three snow-measuring rods, which are usually placed on the meteorological measurement site. The measurements are influenced by the site's sheltering from the wind.

Snow cover on the ground is estimated visually. Definition of a day with snow cover is when more than a half of the visible surface is covered with snow, regardless of its depth. The snow cover is considered as stable if it is observed continuously all winter or with no more than 3 days gaps in each 30 days of its observation. It is also assumed that a daily gap in the beginning of the winter is to be preceded by at least 5 days with snow covering, while 2 or 3 days gaps – by at least 10 such days.

2.4 Homogeneity

A relocation of a station, as well as a change in the observation procedures or in the gauges type can lead to inhomogeneities in the climate series. Main causes of inhomogeneities are: tendencies of station relocation to more open space in the 1930s. In 1936 a shift in the number of daily temperature measurements (4 times instead of 3 before) revealed that the mean daily values were overestimated before the shift. The change to Tretyakov precipitation gauge in the 1950s led to increased catch efficiency; especially for solid precipitation. The homogeneity of the snow depth series is influenced by relocations of the rods to sites with different wind sheltering.

The influence of possible inhomogeneities should be considered when analyzing the long-term variability.

Table 3. Station relocations and rain gauge replacement dates.

Station name	WMO number	Station relocation	Rain gauge replacement
Lovozero	22127		1953.-.01
Sojna	22271		1953.-07
Ust'Cilma	23405	1899 10,1904 -,1915 08, 1918 11, 1930 06, 1933 10, 1950 08	1952.26.06
Salekhard	23330	1973 -	1956.-.02
Mare-Sale	23032		1951 29.08
Nadym	23445		-
Tarko-Sale	23552		1953.-.06

Kusur	21921		1952.-.01
Djalinda	21908		1953.-.03
Gigansk	24343	1957 09, 1960 09, 1964 07, 1973 06	1953. -.01
Djardan	24143		1955.-.09
Ust-Moma	24382		1953.-.11
Olenek	24125	1965 06	1955.01.08
Tompo	24671		1953.-.01
Oimakon	24688	1942 -	1953 01.02
Yakutsk	24959	1964 11	1953 09.01
Markovo	25551	1904 -, 1911 -,1940 - ,1942 10	1952 01.07
Anadyr	25563	1913 -, 1935 12	1951 18.12

Metadata for the stations are presented in Table 4.

Table 4. Survey of meteorological stations used in this report

Aria	WMO number	Station name	Distance (km) to nearest settlement	Latitude, degrees	Longitude, degrees	Elevation (m a.s.l.)	Start (year)
Kola peninsula	22127	Lovozero	9.4	68.08	34.80	161	1936
Nenets AA	22271	Sojna	-	67.88	44.13	8	1936
Republic Komi	23405	Ust'Cilma	9.2	65.43	52.17	68	1889
Yamalo-Nenets AA	23552	Tarko-Sale	4.2	64.92	77.82	27	1936
	23330	Salekhard	7.7	66.53	66.53	35	1882
	23032	Mare-Sale	0.4	69.72	66.82	24	1914
	23445	Nadym	8.5	65.53	72.52	15	1943
Republic Sakha	21921	Kusur	7.0	70.68	127.40	33	1886
	24343	Gigansk	7.1	66.77	123.40	92	1935
	24143	Djardan	9.3	68.73	124.00	39	1936
	21908	Djalinda	5.5	70.13	113.97	62	1942
	24382	Ust-Moma	-	66.45	143.23	196	1937
	24959	Yakutsk	13.5	62.08	129.75	103	1829
	24125	Olenek	0.6	68.50	112.43	127	1936
	24671	Tompo	1.5	63.95	135.87	400	1936
	24688	Oimakon	33.6	63.27	143.15	726	1930
Chukci AA	25551	Markovo	6.8	64.68	170.42	25	1894
	25563	Anadyr	18.0	67.78	177.57	61	1895

Location of the stations is shown in Figure 1.

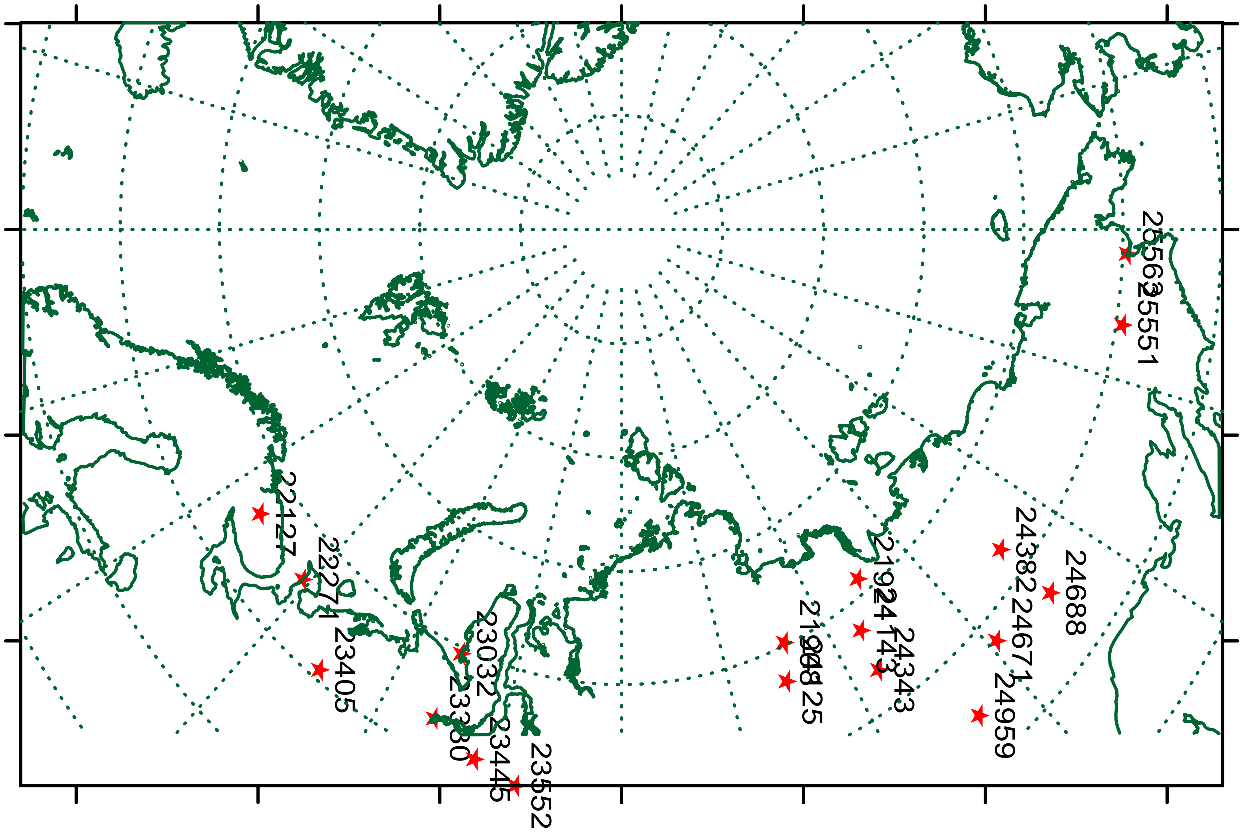

Figure 1. Meteorological stations location. Numbers on the map are WMO numbers.

The meteorological observations data were taken from the following sources: USSR climate handbooks, Meteorological monthly and annual summaries released by the Main Geophysical observatory, All-Russian hydrometeorologial University, Arctic and Antarctic Research Institute. We also used the information from the following websites: All-Russian Research Institute website, The Royal Netherlands Meteorological Institute, Carbon Dioxide Information Analysis Center (USA), National Climate Data Center (USA), National Snow and Ice Data Center (USA) websites. Partly the information was received directly from the Murmansk and Tiksi meteorological services administration, as well as from the Arctic and Antarctic Research Institute archives.

Table 5 gives an overview of observation periods for each parameter included in the dataset.

Table 5. Available climate series for the analysis.

Station Name	WMO	Temperature monthly	Temperature daily	Precipitation monthly	Precipitation daily	Snowdepth monthly	Snowdepth period	Snowdepth daily
Lovozero	22127	1936-2008	1936-2008	1936-2008	1936-2008	1937-2008	1973-2008	1973-2008
Soina	22271	1936-2008	1958-2008	1936-2008	1958-2008	1936-2008	1973-2008	1973-2008
Ust-Cilma	23405	1889-2008	1892-2008	1891-2008	1892-2008	1936-2008	1914-2008	1936-2008
Tarko-Sale	23552	1937-2008	1957-2008	1936-2008	1936-2008	1937-2008	1966-2008	1966-2008
Salekhard	23330	1883-2008	1951-2008	1891-2008	1891-2008	1962-2008	1882-2008	1973-2008
Mare-Sale	23032	1914-2008	1966-2008	1936-2008	1928-2008	-	1914-2009	-
Nadym	23445	1954-2008	-	1943-2008	-	-	-	-
Kusur	21921	1911-2008	1962-2008	1910-2008	1909-2008	1931-2008	1917-2008	1970-2008
Gigansk	24343	1935-2008	1936-2008	1936-2008	1936-2008	1936-2008	1936-2008	1936-2008
Djardjan	24143	1936-2008	1950-2007	1936-2008				
Djalinda	21908	1942-2008	1959-2008	1942-2008	1942-1998	1942-2008	1982-2008	1982-2008
Ust-Mona	24382	1937-2008		1937-2008		1937-2008		
Yakytsk	24959	(1830)-2008	1888-2008	1888-2008	1888-2008	1922-2008	1922-2008	1922-2008
Olenek	24125	1936-2008	1936-2008	1936-2008	1937-2008	1936-2008	1936-2008	1936-2008
Tompo	24671	1936-2008	1960-2007	1933-2008	-			
Oimakon	24688	1930-2008	1943-2008	1930-2008	1943-2008	1943-2008	1943-2008	1943-2008
Markovo	25551	1894-2008	1894-2008	1894-2008	1894-2008	1943-2008	1943-2008	1943-2008
Anadyr	25563	1895-2008	1898-2008	1898-2008	1898-2008	1929-2008	1931-2008	1931-2008

3. Methods

The statistical methods used in this study were focusing on the long-term variability and possible climate regime shifts assessment. Non-parametrical approaches which do not require a priori restrictions for the analyzed series were preferred, as parametrical methods require a specific distribution type of the series. Due to lack of data it was difficult to determine whether the distribution type of the series obey the parametric approach conditions.

To test the statistical hypothesis of an existing monotonous trend the Mann-Kendall test was used (Mann 1945, Kendall 1975).

The value of a trend's bias, assuming its linearity, was determined using the Sen's slope test (Gilbert 1987, Sirois 1998).

The year of trend shifts were assessed using the Pettitt test (Pettitt 1979), as well as the wavelet analysis. A continuous expansion by the orthogonal Daubechis 4th degree wavelet was used (Solonia & Arbuzov, 2008).

In addition, mean value series shift detection was carried out using the Rodionov tool (Rodionov 2004), which includes bilateral T-criteria and Huber weight parameter to estimate the deviation between the mean values. The moving averages were assessed by 10 values with the temporal shift equal to 1. What made the analysis complicated was the large number of gaps in the observation data. To make the results for each element comparable, an observation period with no gaps was chosen for most stations.

4. Temporal variability of air temperature

Seasonal and annual temperature averages were calculated using the mean monthly data: March - May for spring, June – August for summer, September – November for autumn and December (of the previous year) – February for winter. The calculated averages were analyzed for the period 1938-2008. The estimates of years with a tendency shift using Petitt test are seen in Table 6. A tendency of decreasing temperature in the first part of the series was replaced by an increasing tendency in the later decades. According to all studied stations data, a winter shift occurred earlier than a summer shift. Meanwhile, when looking into the spring and fall data, it is clear that at the stations west of Yakutsk the shift was observed earlier than at the stations east of Yakutsk.

Table 6. Temperature change point detection (based on Pettitt's test)

station	Annual	Spring	Summer	Autumn	Winter
Lovozero	1988	1981	1998	1963	1988
Sojna	1988	1988	1987	1954	1963
Ust-Cilma	1987	1972	1987	1951	1970
Tarko-Sale	1980	1988	1981	1976	1980
Salekhard	1987	1985	1987	1951	1962
Mare-Sale	1956	1985	1988	1954	1957
Kusur	1992	1970	1996	1952	1987
Gigansk	1987	1970	1996	1951	1979
Djardan	1987	1987	1996	1951	1988
Ust-Moma	1979	1983	1986	1984	1975
Yakutsk	1982	1973	1985	1987	1979
Olenek	1966	1970	1997	1982	1966
Tompo	1979	1970	1979	1982	1975
Oimakon	1979	1965	1987	1977	1975
Markovo	1994	1977	1989	1993	1987
Anadyr	1994	1977	1988	1993	1955

Estimates of linear temperature trends are shown in Table 7. Statistically significant monotonous trends were defined using Mann-Kendall criteria with the significance level equal to 0.05. It is clear from Table 7 that there are no statistically significant trends in the annual average series for Kola Peninsula, Nenets AA and Yamalo-Nenets AA, Komi republic, while there are significant trends in the data for Sakha republic and Chukci AA. The same tendency is seen for the seasonal data as well, significant trends for winter data are found only for Sakha. Remarkable are the negative trends for autumn and winter, indicating decreasing air temperatures, although these trends are not statistically significant. However, the fact that the stations with negative trends are situated close to each other gives a reason to assume it is not a coincidence.

Table 7. Linear temperature trends (degC/year) during 1938-2008 (**bold** indicate trends significant at the 0.05 level)

station	Annual	Spring	Summer	Autumn	Winter
Lovozero	0.0114	**0.0300**	0.0057	-0.0077	0.0118
Sojna	0.0083	0.0173	**0.0172**	-0.0037	-0.0025
Ust-Cilma	0.0170	**0.0283**	0.0150	0.0000	0.0150
Tarko-Sale	0.0137	0.0242	**0.0189**	0.0047	0.0158
Salekhard	0.0088	0.0146	0.0058	0.0000	0.0000
Mare-Sale	0.0030	0.0026	0.0156	0.0000	-0.0121
Kusur	0.0091	0.0179	0.0083	-0.0091	0.0180
Gigansk	0.0030	**0.0258**	0.0051	-0.0057	**0.0330**
Djardan	0.0042	0.0143	0.0045	-0.0130	0.0150
Ust-Moma	**0.0324**	**0.0300**	**0.0220**	**0.0292**	**0.0490**
Yakutsk	**0.0340**	**0.0447**	0.0102	0.0167	**0.0727**
Olenek	**0.0397**	**0.0343**	0.0085	0.0250	**0.0833**
Tompo	**0.0200**	**0.0308**	**0.0167**	0.0063	0.0188
Oimakon	**0.0206**	**0.0250**	**0.0160**	0.0235	0.0170
Markovo	0.0091	0.0209	**0.0154**	**0.0212**	-0.0111
Anadyr	**0.0154**	0.0216	0.0059	**0.0324**	0.0074

With the use of the Rodionov tool, the climate regime shift dates were investigated. Each climate regime was characterized by the long-term annual temperature averages for a specific period of time, where temperature values were averaged seasonally or annually. The shifts dates are shown in Table 8, as well as the deviations between the mean values, considering $\Delta = T_k - T_{k-1}$. The calculations were provided for each station for different periods depending on the duration of observation and the number of gaps.

Table 8. Change dates and differences (°C) in shifts in average values of air temperature

Lovozero: (Obs. period 1937-2008). Winter: 1989/+1.5, spring: 2003/+1.6, Summer: 1975/-0.8 and 1999/+1.6, annual: 2003/+1.5
Sojna: (1933-2008). Winter: 1965/-1.3, summer: 2004/+1.5, autumn: 1964/-0.9 and 2003/+1.8
Ust'Cilma: (1920-2008). Spring: 1989/+1.5, summer: 2003/+1.3, autumn: 1952/-1.2 and 2003/+2.5, annual: 1963/-1.2, 1972/+1.2 and 2003/+1.7
Tarko Sale: (1938-2008). Spring: 1957/-1.5 and 1990/+2.6, summer: 2000/+1.7, autumn: 1957/ -1.6 and 1977/+1.4, annual: 1957/-1.2 and 1980/+1.5
Salekhard: (1884-2008). Spring: 1943/+5.2, 1957/-2.2, 1989/+2.9 and 2004/-4.3, summer: 1904/+1.3, 1968/-1.3 and 1981/+1.8, autumn: 1895/+2.4 and1964/-0.7, annual: 1903/+1.6, 1963/-1.3 and 1981/+1.5
Mare-Sale: (1928-2008). Spring: 1943/+2.3, 1957/-2.0, 1989/+3.0 and 1998/-3.0, summer: 1953/+1.5, 1963/-1.5 and 1989/+1.3, autumn: 1956/-2.0 and 2004/+3.0, annual: 1963/-1.4, 1981/+1.1 and 2005/+2.0
Kusur: (1926-2008). Winter: 1941/-2.2, spring: 1955/-1.4 and 1971/+1.5, summer: 2005/+1.3 Autumn: 1953/-1.7 and 2001/+1.8, annual: 1958/-0.7 and1993/+1.0
Gigansk: (1937-2008). Winter: 1989/+1.5, spring: 2000/+1.8, autumn: 1952/-1.2, annual: 1950/ -0.6 and 1988/+0.9
Djardan: (1938-2008). Winter: 1989/+1.3, spring: 1955/-1.4 and 1971/+1.4, summer: 1997/+1.0, autumn: 1952/-2.0, 2005/+1.6, annual: 1950/-1.0, 1988/+0.7 and 2005/1.0.
Ust'Moma: (1949-2008). Winter: 1976/+2.4, spring: 2000/+2.4, summer: 1997/+1.2, autumn: 1994/+2.2, annual: 1985/+1.5 and 2005/+1.4
Yakutsk: (1883-2008). Winter: 1990/+3.1, spring: 1895/+0.7, 1974/+1.5 and 2002/+2.1, Summer: 1893/+0.7, autumn: 2005/2.2, annual: 1988/1.5
Olenek: (1936-2008). Winter: 1967/+3.5, spring: 1955/-2.1 and 1965/+2.7, Annual: 1950/-1.4, 1967/+2.0 and 2005/+1.7
Tompo: (1937-2008). Spring: 1954/-1.3 and 1968/+2.2, Summer: 1997/+1.0, Autumn: 2005/+2.4, Annual: 1980/+0.9
Oimakon: (1936-2008). Spring: 1954/-1.7 and 1966/+2.1, Summer: 1995/+1.1, Autumn: 1955/ -0.8 and 2002/+2.5, Annual: 1980/+0.9 and 2005/+1.0
Markovo: (1895-2008). Winter: 1978/+2.2 and 1989/-2.8, Spring: 1935/+2.7, 1944/-1.8, 1996/+3.0 and 2005/-2.3, Summer: 1920/+1.2, 1946/-1.8, 1953/+1.5 and 2002/+1.5, Autumn: 1921/+1.4, 1954/-2.1, 1970/+0.8 and1995/+2.2, Annual: 1921/+1.5, 1946/-0.6 and1995/+1.0
Anadyr: (1896-2008). Winter: 1978/+2.0, 1989/-3.0 and 2004/+4.0, Spring: 1935/+2.6, 1944/ -1.8, 1996/+3.0 and 2005/-2.1, Summer: 1920/+1.2, 1946/-1.8, 1953/+1.6 and 2005/-1.6, Autumn: 1921/+1.4, 1954/-2.1, 1970/+0.8, 1995/+2.2 and 2005/+3.5, Annual: 1921/+1.5, 1946/ -0.6 and 1995/+1.2

Table 8 reveal the repeated shifts (positive and negative); both in the annual and seasonal averages. The changes in the mean mainly correspond the mean temperature for the whole hemisphere, although the range of the change points is rather wide. Most stations see a significant warming in the late 1990s – 2000s. Some peculiarities are remarkable. For the stations situated in Nenets AA and Yamalo-Nenets AA and Komi republic no shift in the mean is found in winter. In 1965 Sojna had a negative change of 1.3^{0}C in annual temperature.

Also in Yamalo-Nenets AA negative temperature changes are found in spring (-4^{0}C for Salekhard in 2004 and -3^{0}C for Mare-Sale in 1998), although there is an obvious warming for the whole year. Also in Chukci AA negative changes are found during the spring season: -2,1^{0}C for Anadyr in 2005 and -2.3^{0}C for Markovo in 2005.

An additional analysis of the change tendencies using the same tests was carried out on the number of days when the daily mean daily air temperature was above/below certain thresholds. Because of missing data, it was only possible to perform this analysis for 6 stations covering the period from 1943 to 2008. Based on information from indigenous people, number of days with daily mean temperature below -30 ^{0}C, above 0 ^{0}C and above +10 ^{0}C is especially important for the native population's living conditions. Trends in frequencies of temperatures above /below these limits are presented in Table 9. The negative trend in the number of the days with extremely low temperatures (corresponding to the observed warming) is observed in the data for Yakutsk;- the rest of the stations have no such a trend. Chukci district had an increase in number of days with temperatures above + 10^{0}C as well as above 0^{0}C, which confirms the assumption of a summer warming in this area. Kola Peninsula also has an increase in number of days with mean temperatures above 0 ^{0}C.

Table 9. Linear trends (days/year) during 1943-2008 in number of days with temperatures above/below given thresholds (**bold** indicate trends statistically significant at the 0.05 level)

Station	T<-30°C	T>10°C	T>0°C
Lovozero	0.000	0.000	**0.186**
Ust'Cilma	0.000	0.040	0.132
Gigansk	-0.123	-0.016	0.000
Yakutsk	**-0.243**	0.000	0.084
Markovo	0.000	**0.214**	**0.154**
Anadyr	-0.020	**0.189**	**0.150**

5. Temporal variability of precipitation

Changes in precipitation amount were studied in the same way as for air temperature. The analysis was carried out for the stations with no more than one gap for the period 1943-2008. The results of the change points study are shown in the Table 10. In comparison with the temperature data, the change points for precipitation data are observed earlier on most stations, mainly 1950-60s. Such an outcome in some cases might be caused by the change in gauge types (see Table 3)

Table 10. Precipitation change points detection

Station	Annual	Spring	Summer	Autumn	Winter
Lovozero	1961	1960	1961	1961	1954
Sojna			1984	1962	1965
Ust-Cilma	1951	1979	1972	1966	1943
Tarko-Sale		1984	1994		1973
Salekhard	1958	1955	1964	1949	1980
Mare-Sale		1964	1958	1950	
Kusur		1993		1975	1962
Gigansk					1956
Djardan		1951	1953	1987	
Yakutsk	1958	1965	1973	1955	1965
Olenek		1966		1965	1965
Markovo	1958	1961	1999	1964	1955
Anadyr					1955

Table 11 shows that significant positive trends in precipitation are revealed in all seasons but summer;- the strongest trends are found in spring and winter. For all stations except Yakutsk (negative trend for winter season) the precipitation amount is increasing. No significant trends are revealed for Ust-Cilma, Salekhard and Sojna. The strongest significant trends are found for Lovozero in winter and for the whole year, at Mare-Sale for the whole year, and at Anadyr in winter. The analysis reveals the strong influence of inhomogeneities in precipitation series caused by the introduction of the Tretyakov gauge (cf. Table 3).

Table 11. Linear trends in precipitation amount (mm/year) during 1943-2008. (**bold** indicate trends statistically significant at the 0.05 level)

Station	Annual	Spring	Summer	Autumn	Winter
Lovozero	**2.142**	**0.607**	0.298	**0.567**	**0.665**
Sojna	0.444		-0.014	0.150	0.104
Ust-Cilma	-0.082	-0.095	0.124	-0.378	0.095
Tarko-Sale		**0.440**	0.000		**0.585**
Salekhard	0.133	-0.155	0.239	-0.022	0.170
Mare-Sale	**1.860**	**0.458**	-0.058	**0.597**	
Kusur		-0.131	0.282	-0.018	**0.232**
Gigansk		**0.328**			0.123
Djardan		**0.306**	-0.067	**0.675**	
Ust-Moma					
Yakutsk	**0.889**	0.084	0.127	**0.345**	**-0.162**
Olenek		**0.213**		**0.427**	**0.160**
Tompo					0.184
Oimakon					
Markovo	0.850	**0.374**	-0.348	0.465	**0.465**
Anadyr					**1.663**

Figures 2-13 illustrate the temporal variability of the annual precipitation sums for the period from 1930-40s up to 2008, as well as the spectrograms of the first coefficient of the continuous wavelet expansion with the use of Daubechis 4 degree wavelet. The values of the coefficient are depicted by its absolutes, with colour scaling. The light stripes on the spectrograms correspond the moments of abrupt precipitation sum changes. Fig. 4 and 13 depict the winter and annual precipitation tendencies at Mare-Sale station. It is clear from the figures that there is an inhomogeneity in the temporal series caused by the new rain gauge introduction in 1951.

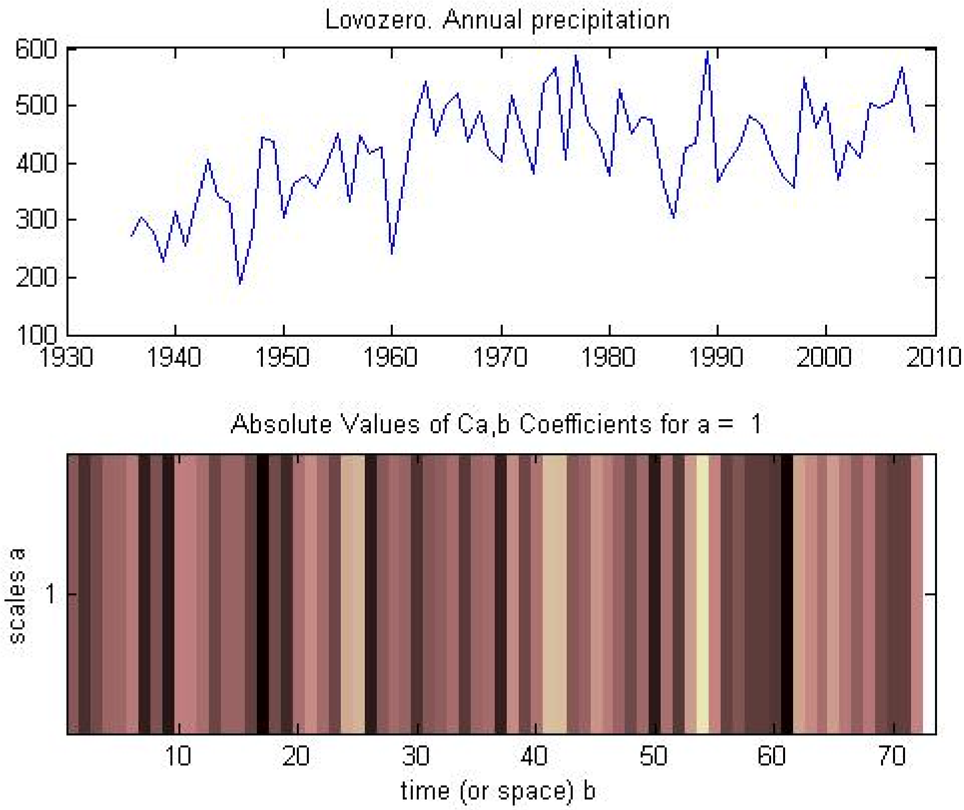

Figure 2. Temporal variability and spectrogram of the 1st coefficient of annual precipitation sum at Lovozero station.

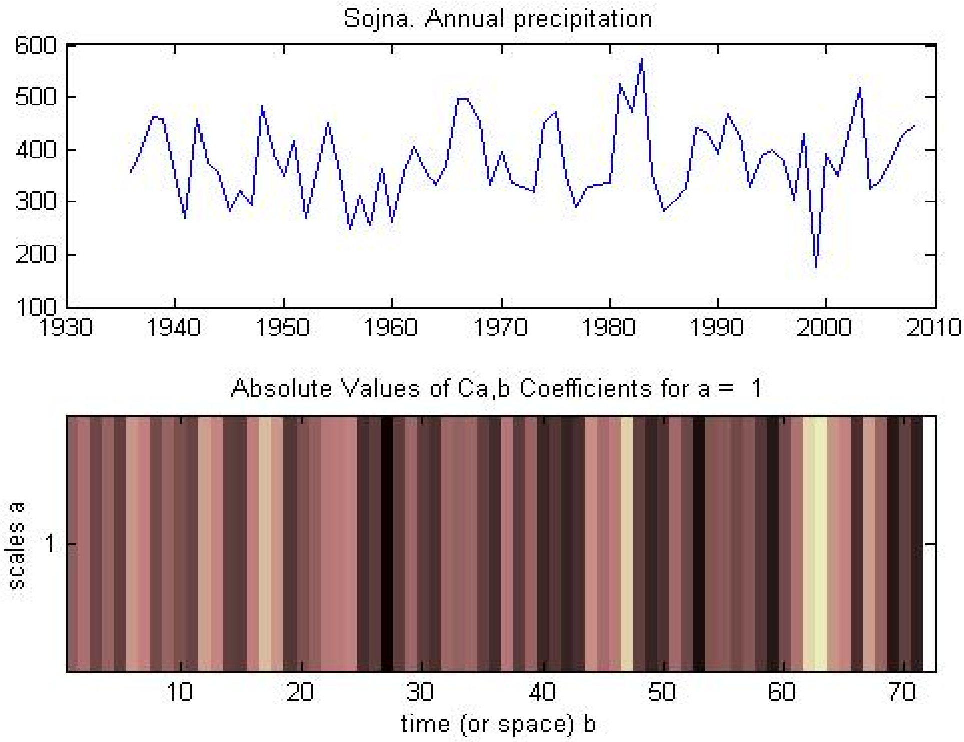

Figure 3. Temporal variability and spectrogram of the 1st coefficient of annual precipitation sum at Sojna station.

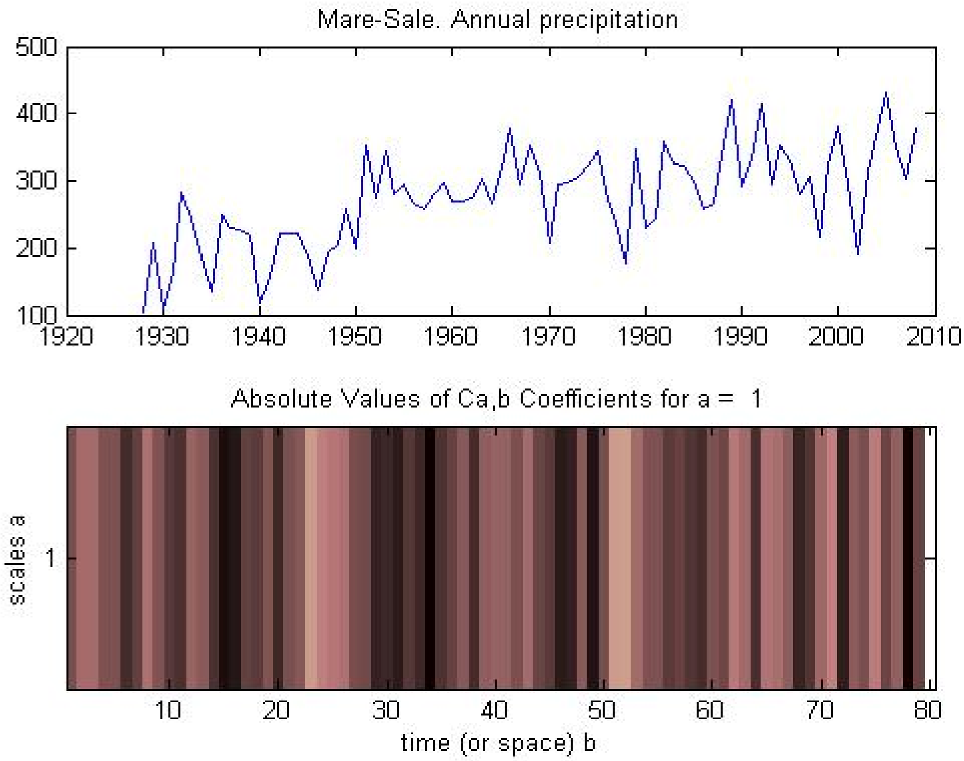

Figure 4. Temporal variability and spectrogram of the 1st coefficient of annual precipitation sum at Mare-Sale station.

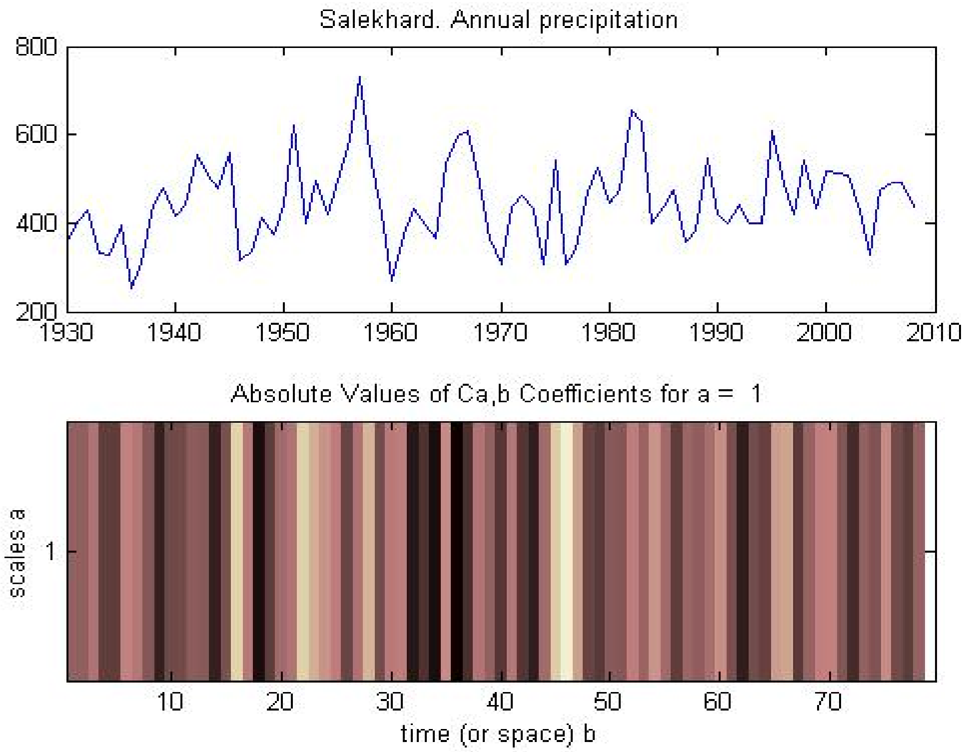

Figure 5. Temporal variability and spectrogram of the 1st coefficient of annual precipitation sum at Salekhard station.

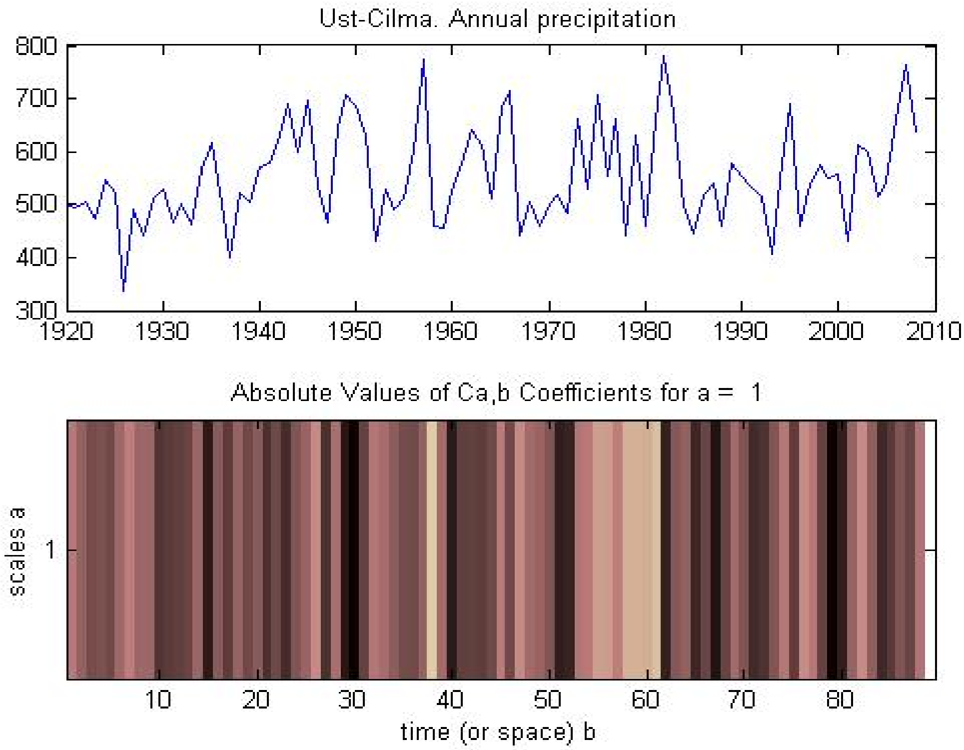

Figure 6. Temporal variability and spectrogram of the 1st coefficient of annual precipitation sum at Ust' Cilma station.

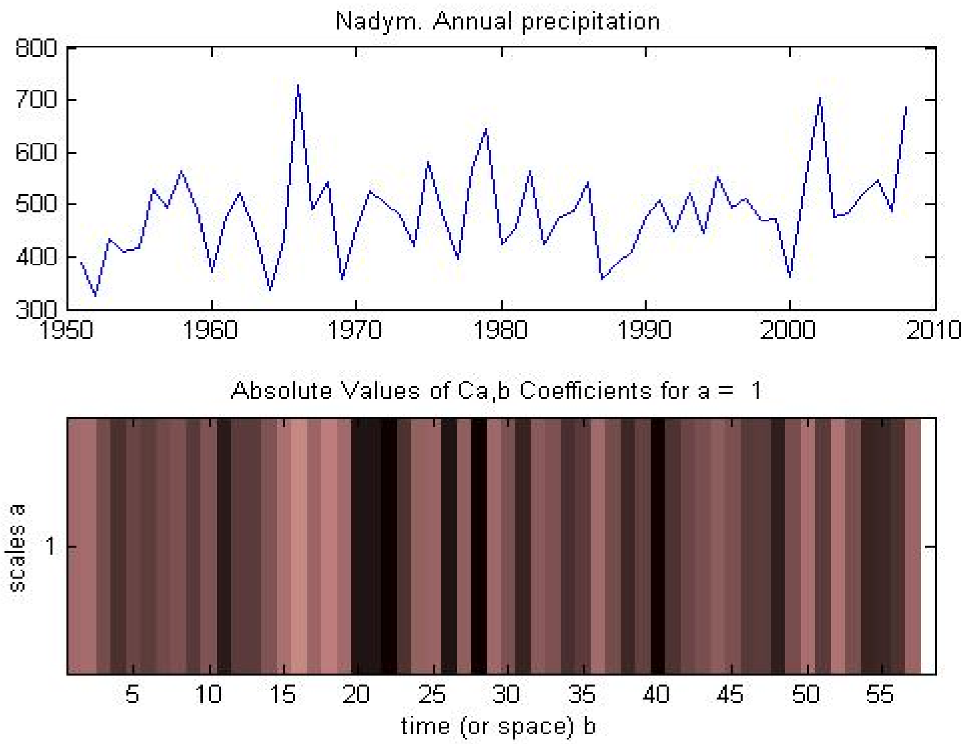

Figure 7. Temporal variability and spectrogram of the 1st coefficient of annual precipitation sum at Nadym station.

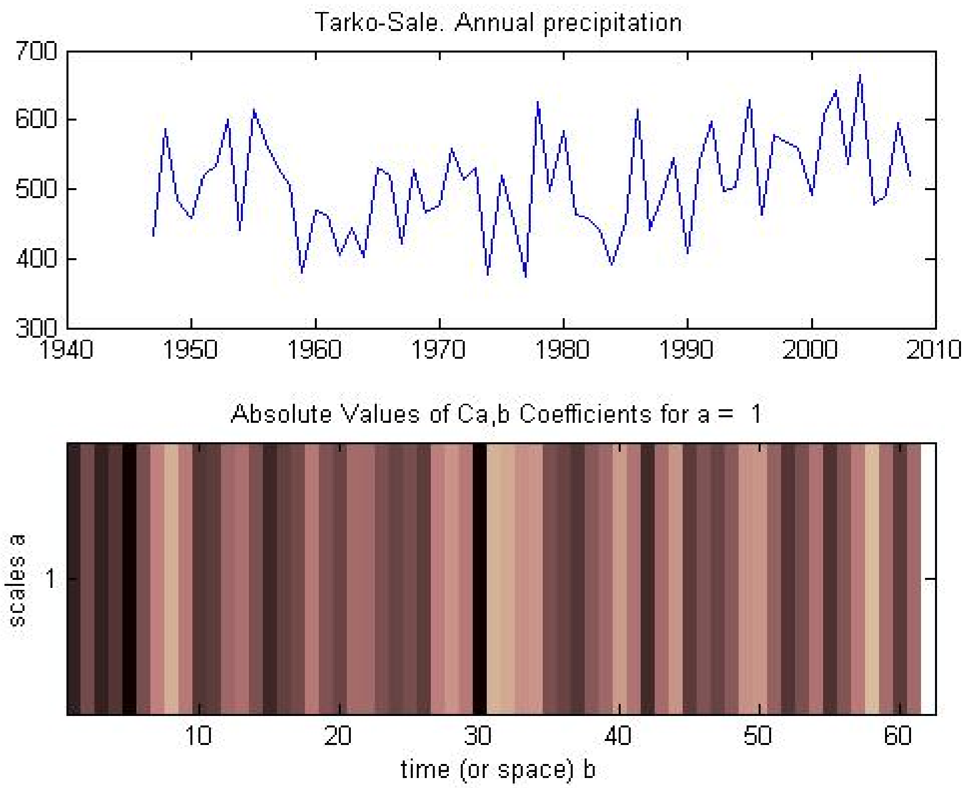

Figure 8. Temporal variability and spectrogram of the 1st coefficient of annual precipitation sum at Tarko-Sale station.

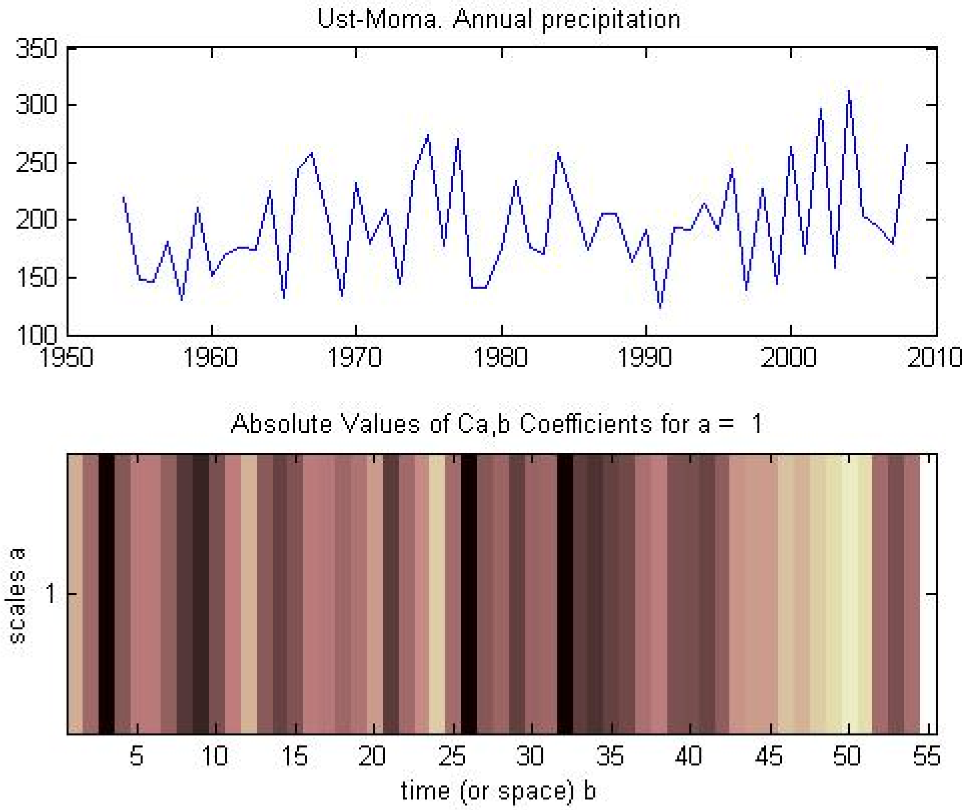

Figure 9. Temporal variability and spectrogram of the 1st coefficient of annual precipitation sum at Ust-Moma station.

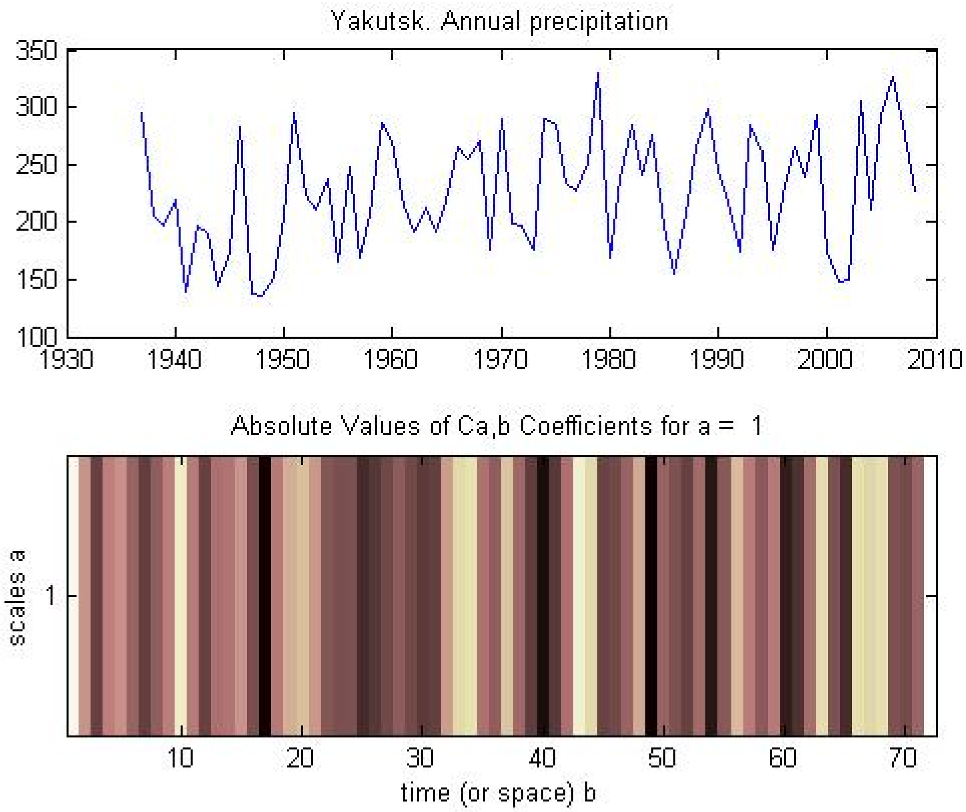

Figure 10. Temporal variability and spectrogram of the 1st coefficient of annual precipitation sum at Yakutsk station.

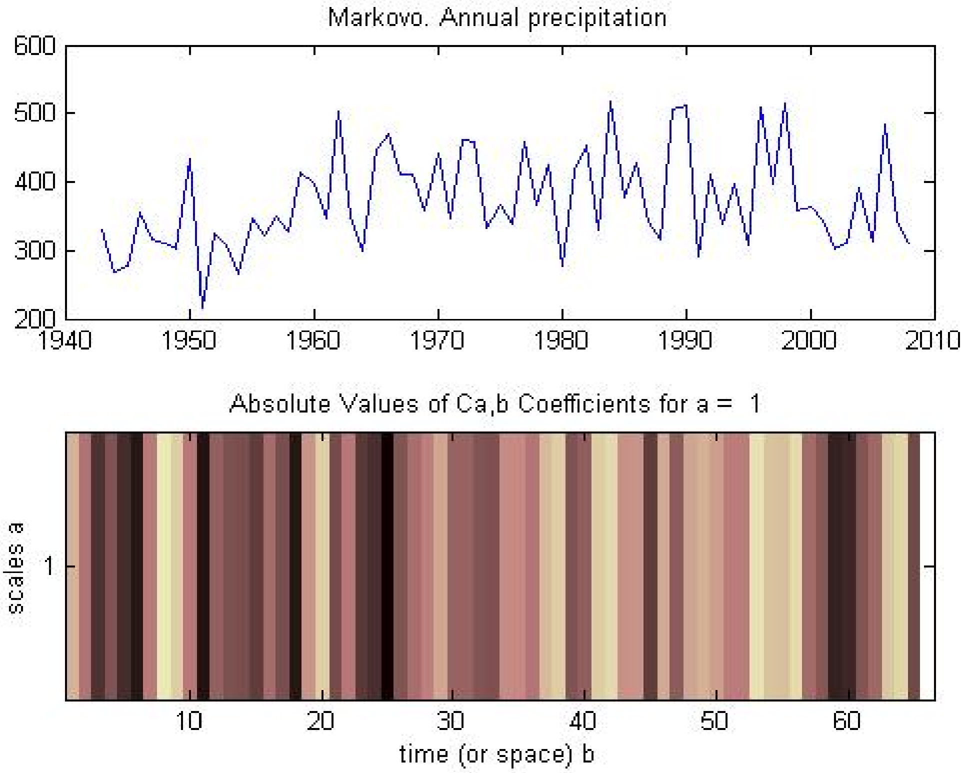

Figure 11. Temporal variability and spectrogram of the 1st coefficient of annual precipitation sum at Markovo station.

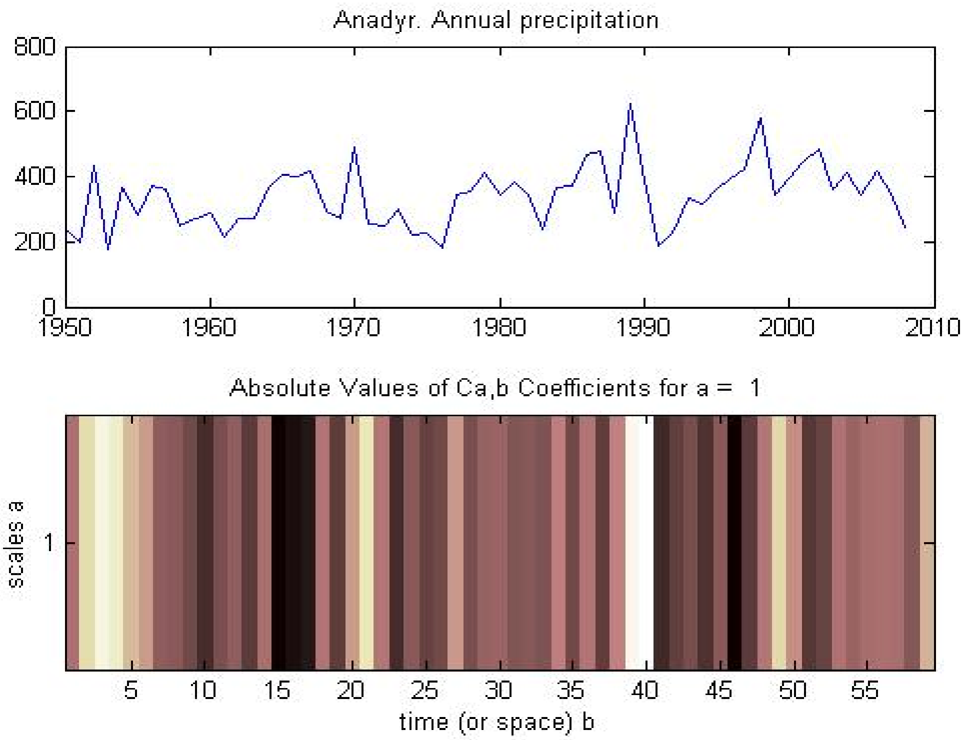

Figure 12. Temporal variability and spectrogram of the 1st coefficient of annual precipitation sum at Anadyr station.

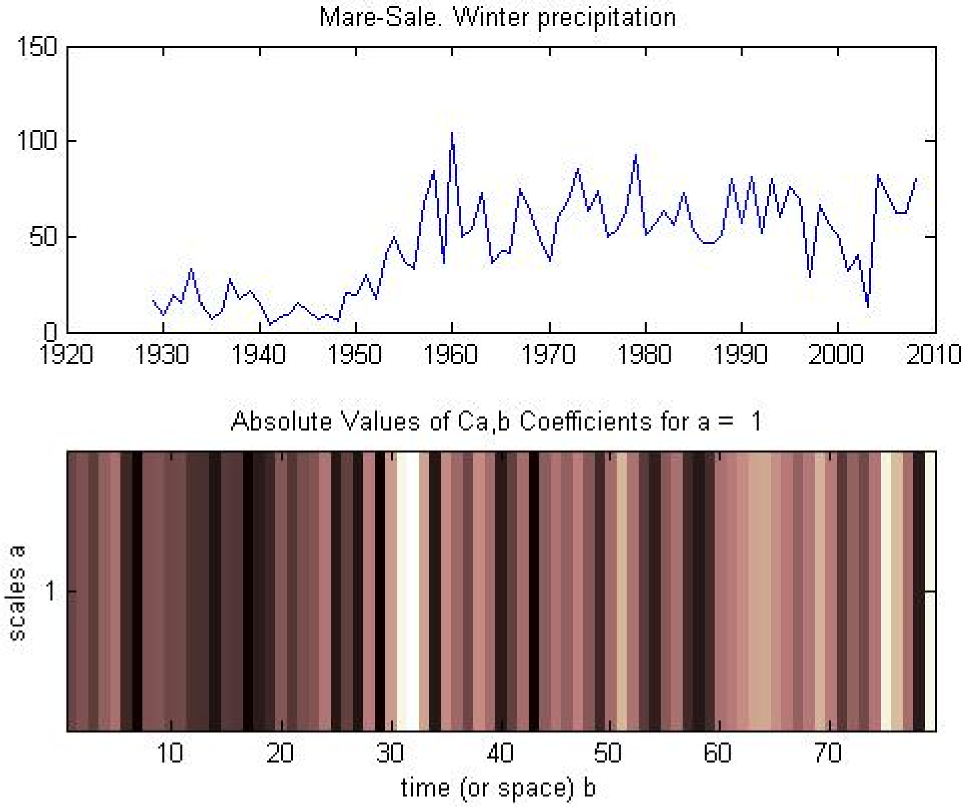

Figure 13. Temporal variability and spectrogram of the 1st coefficient of precipitation sum in winter at Mare-Sale station.

The analysis of time changes of precipitation has been performed by means of comparison of averages by the Rodionov's method. Results are presented in Table 12. The analysis is performed for the longest possible period for each station. On the majority of the 11 stations numerous changes of average values are found; - both positive and negative.

Table 12. Change dates and differences (mm) in shifts in average values of precipitation sums

Lovozero (1937-2008), Winter: 1952/+37, Spring: 1948/+23 and 1966/+20, Autumn: 1962/+28, 1986/-18 and 2004/+27, Annual: 1948/+88 and 1961/+76
Sojna (1954-2008) No changes
Ust'Cilma (1920-2008), Winter:1944/+31 and 1965/-8, Spring: 1943/+14, Autumn:1938/+40 and 1967/-30, Annual:1940/+125, 1952/-67 and 2006/+135
Tarko-sale (1947-2008), Winter: 1974/+19, Spring: 1985/+31, Summer:1957/-60 and 1997/+70, Autumn: 2004/+30, Annual:1959/+47 and 1991/+77
Salekhard (1931-2008), Winter: 1951/+26 and 1964/-15, Autumn: 1951/+63 and1960/-50,
Mare-Sale (1929-2004), Winter: 1953/+39, 1972/+8 and 2001/-34, Spring: 1950/+23, 1965/+14 and 1998/-14, Autumn: 1951/+28 and 2003/+25, Annual: 1951/+103 and 2002/-50
Kusur (1952-2008), Summer: 1988/+35, Autumn:1962/+37, 1974/-96 and 1985/+21, Annual: 1988/+87, 1995/-110 and 2002/-115
Gigansk (1964-2008), Winter:1976/+10 and 2002/+19, Autumn: 1992/+26, Annual: 1978/-44 1988/-85 and 2005/+45
Djardan (1968-2008), Winter: 2002/+10, Autumn: 1978/-25 and 2000/+28, Annual:1988/+78
Ust' Moma (1954-2008), Winter: 1966/+4 and 1987/-9, Summer: 1970/+23, Autumn: 2004/+18
Yakutsk (1938-2008), Winter: 1954/+8, Spring:1966/+18 and 1973/-15, Summer:1974/+30, 1985/-32 and 2005/+45, Autumn: 2006/+18, Annual: 1974/+27 and 2005/+46
Olenek (1969-2008), Spring: 1988/+14 and1995/-10
Tompo (1939-1994), Winter: 1991/+5
Oimakon (1960-2008), Winter:1981/-9, Spring: 1971/-5, Summer: 1975/+15, Autumn:2006/+16
Markovo (1944-2008), Winter: 1956/+53 and 1973/-26, Spring:1954/+22, Summer: 2000/-39, Annual: 1959/+77
Anadyr (1950-2008), Winter: 1965/+66, 1971/-85, 1979/+104, 1990/-73 and 2000/+49, Autumn: 1997/+45 and 2006/-56, Annual: 1997/+88

Figures 14-18 reveal that inhomogeneities are found in precipitation series from Mare-Sale in all seasons except summer.

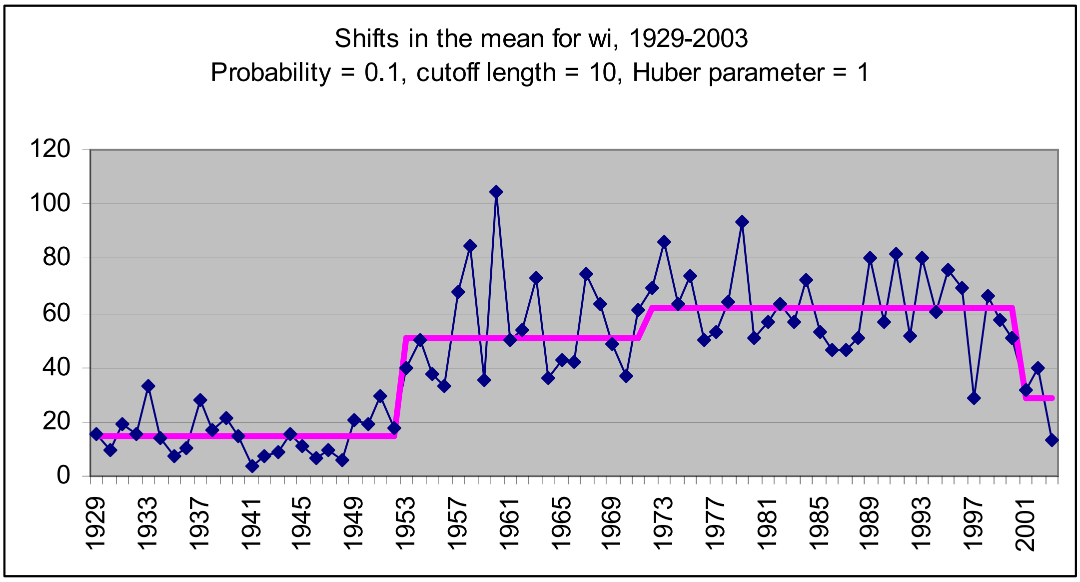

Figure 14. Shifts in mean precipitation sums at Mare-Sale in winter for the period 1929-2003

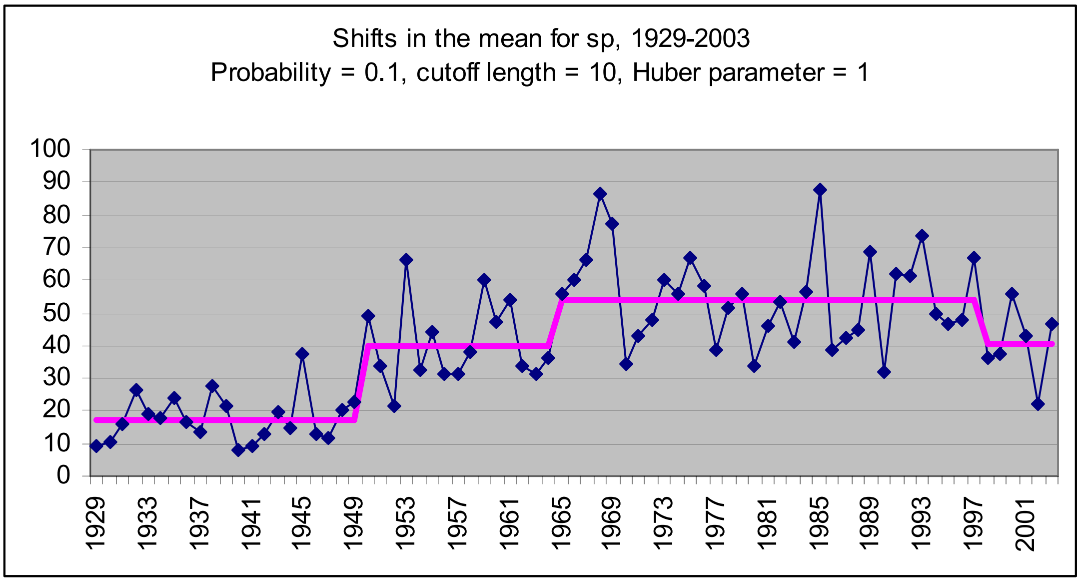

Figure 15. Shifts in mean precipitation sums at Mare-Sale in spring for the period 1929-2003

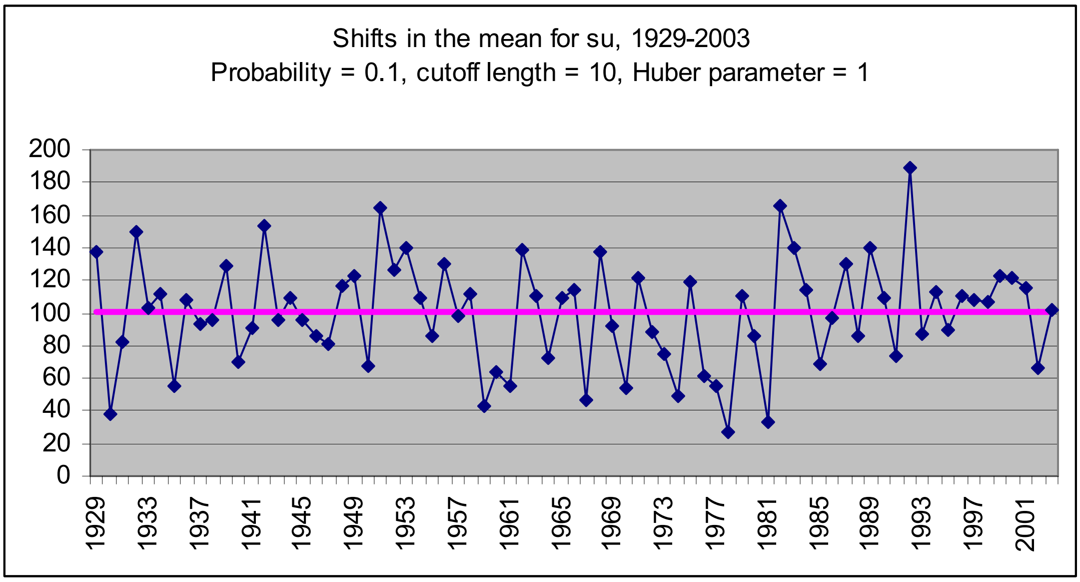

Figure 16. Shifts in mean precipitation sums at Mare-Sale in summer for the period 1929-2003

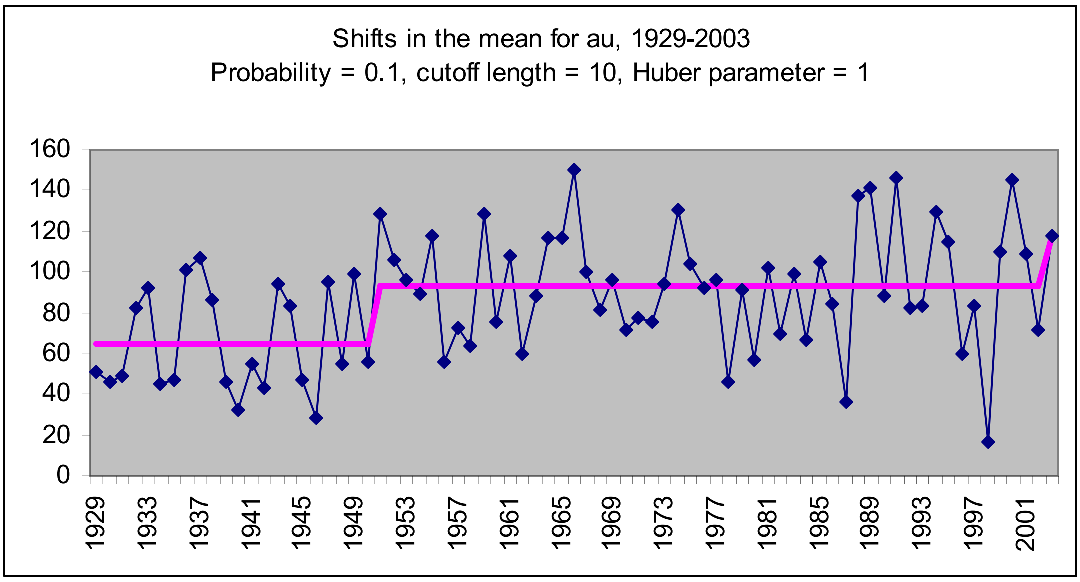

Figure 17. Shifts in mean precipitation sums at Mare-Sale in autumn for the period 1929-2003

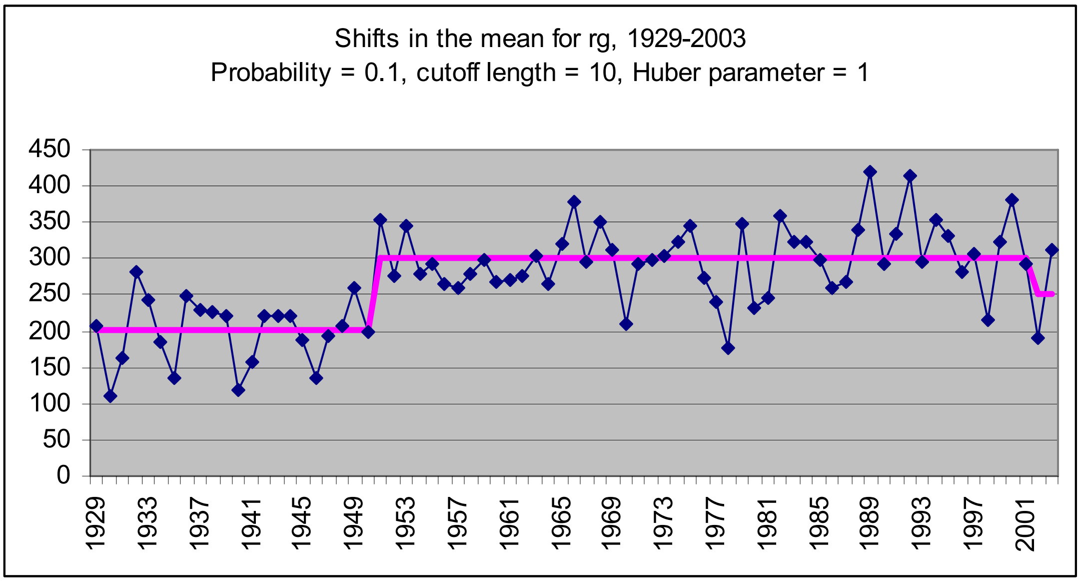

Figure 18. Shifts in mean precipitation sums at Mare-Sale for annual values during the period 1929-2003

The analysis of the precipitation intensity is provided for the period 1938 – 2008. The change in annual maximum of daily precipitation was calculated, as well as intensive (over 10mm/day) and moderate (over 1mm/day) precipitation frequency. The trends of these parameters are outlined in Table 13.

Table 13. Linear trends (1938-2008) in maximum 1 day precipitation (mm/year) and number of days with precipitation >1 & 10 mm (days/year). **Bold** indicate trends statistical significant at the 0.05 level.

Station	**Daily max**	**R>10 mm**	**R>1 mm**
Lovozero	0.045	**0.036**	**0.432**
Ust'Cilma	0.014	0.020	**0.224**
Tarko-Sale	0.020	0.000	**0.386**
Salekhard	-0.076	0.000	**0.132**
Mare-Sale	0.068	0.000	**0.438**
Kusur	0.072	0.019	**0.634**
Gigansk	-0.034	0.000	**0.413**
Yakutsk	0.101	0.000	**0.130**
Oimakon	-0.017	0.000	0.036
Markovo	-0.083	0.000	0.083
Anadyr	**0.100**	**0.074**	**0.556**

An increasing trend in daily precipitation maximums is observed only for Anadyr, while increase in precipitation frequency is found for Anadyr and Lovozero. Almost all stations except Oimakon and Markovo have an increase in moderate precipitation frequency. The most significant increase is observed at Kusur, Anadyr, Lovozero and Mare-Sale stations, which is clear from the trend biases analysis.

6. Temporal variability of snow depth and snow cover duration

In this section we are looking into the changes of the snow cover characteristics, which are important for the reindeer breeding. Most analyzed stations experience the highest value of snow depth in April. Linear trends for snow depth for April and in duration of snow cover (from autumn till spring) are presented in Table 14 and 15.

Table 14. Linear trends and change points (Pettitt) in duration of stable snow cover (1943-2008). **Bold** indicate trends statistical significant at the 0.05 level.

Station	Trend slope	Pettitt test
Kusur	-0.107	1988
Mare-Sale	**0.283**	1955
Salekhard	0.000	1985
Ust'Cilma	0.097	1967
Gigansk	**0.192**	1976
Oimakon	-0.076	1968
Yakutsk	0.025	1967
Markovo	-0.053	1987
Anadyr	-0.111	1950

Table 15. Linear trends and change points (Pettitt) in snow depth for April (1943-2008). **Bold** indicate trends statistical significant at the 0.05 level.

Station	Trend slope	Pettitt test
Lovozero	0.176	1967
Tarko-Sale	**0.586**	1970
Ust'Cilma	**0.573**	1989
Kusur	**0.227**	1963
Gigansk	-0.210	1990
Oimakon	-0.062	1958
Yakutsk	0.083	1992
Markovo	**0.398**	1957
Anadyr	0.038	1992

According to the outcome depicted in Table 14, significant trends are observed only for 2 stations – Mare-Sale and Gigansk, and the trend is positive, which indicates an increase of the continuous snow cover duration. Data from Table 15 indicate increase in snow depth for 4 stations. The strongest increase is observed at Tarko-Sale and Ust'Cilma. The increase in snow duration (Table 14) and snow depths (Table 15) despite increasing temperatures (Table 7) is probably due to increased precipitation during the cold season (Table 11).

7. Summary and conclusions

Long-term variability in temperature, precipitation and snow conditions have been studied for 18 localities in the Kola Peninsula, Nenets AA, Komi Republic, Yamalo-Nenets AA, Sakha Republic and Chukci AA in northern Russia. An overview is given of station metadata (length of series, relocation of stations, observing hours, instrumentation etc.) and of methodology to study long-term trends and shifts in various climate series.

For **temperature** no statistically significant trends (1938-2008) were found in the annual average series for Kola Peninsula, Nenets AA and Yamalo-Nenets AA, Komi republic, while there are significant positive trends in the data for Sakha republic and Chukci AA. The same tendency is seen for the seasonal data as well, significant trends for winter data are found only for Sakha. Some negative trends are found for autumn and winter, but these trends are not statistically significant. At most stations there are a significant warming after 1990. A negative trend (1943-2008) was found in number of days with very low temperatures (daily mean temperature below -30 °C). In the Chukci district there was an increase in number of days with mean temperature above 0 and +10 °C. Also for the Kola Peninsula there has been an increase in number of days with mean temperatures > 0°C.

For **precipitation** significant positive trends (1943-2008) were found for all seasons except summer, - with strongest trends during winter and spring. The strongest trends were found for the Lovozero station at the Kola Peninsula. The precipitation trends are however influenced by inhomogeneities caused mainly by changes in precipitation gauges during the period 1946-1960.

For duration of **snow cover** two stations (Mare-Sale and Gigansk) had significant trends. At both stations the trends were positive, i.e. increased length of the period with continuous snow cover. The highest **snow depths** in northern Russia are usually observed in

April. For 4 stations significant positive trends were found in snow depths for April;- the strongest increase is observed at Tarko-Sale and Ust'Cilma. The reason for the increase in snow duration and maximum snow depths despite increasing temperatures is probably increased amounts of solid precipitation during the cold season.

8. Acknowledgements

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