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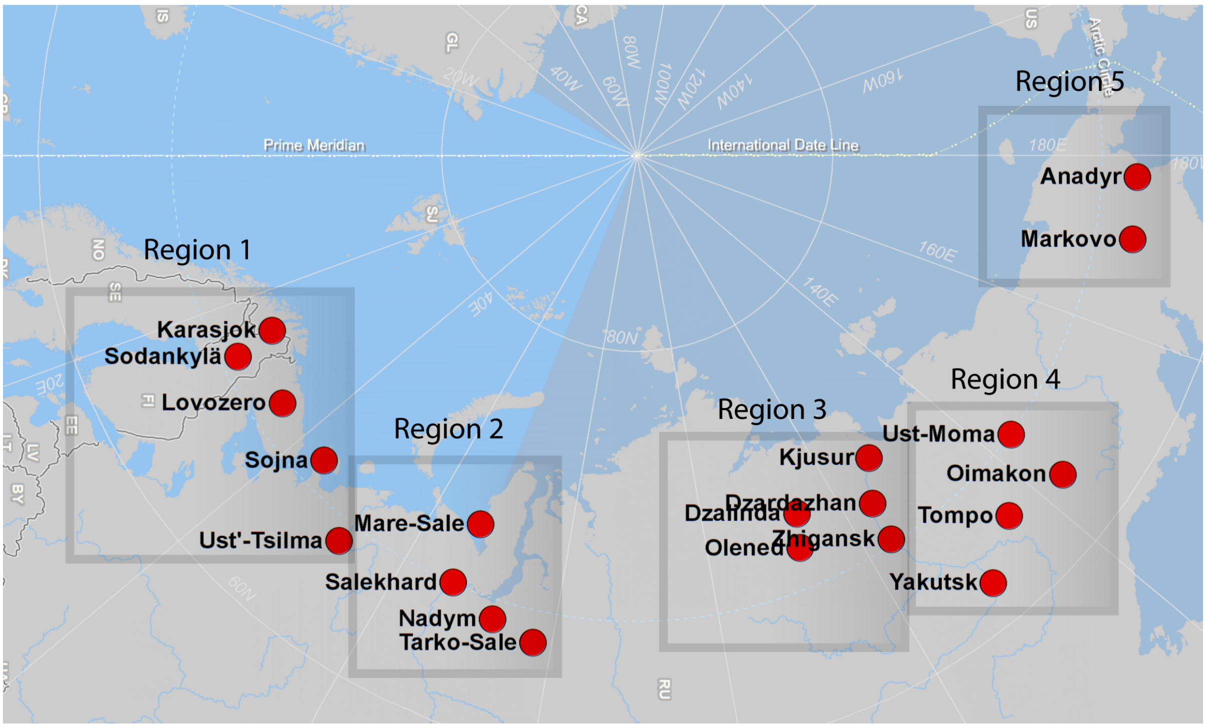
**Climate**

# Arctic communities and reindeer herders' vulnerability to changing climate:

# Climate conditions in northern Eurasia since year 1900


Dagrun Vikhamar-Schuler, Eirik J. Førland, Inger Hanssen-Bauer, Hans Olav Hygen, Øyvind Nordli and Pavel Svyashchennikov

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# report

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**Abstract**

This report provides background data on current climate and historical climate development (1900-2008) in five selected regions in northern parts of Fennoscandia and northern Russia. The main climate elements studied are temperature, precipitation and snow conditions. In addition derived climate products are studied, i.e. degree days, growing season and cold season. The long-term development is studied by use of low-pass Gaussian filters, linear trends and by comparison of changes from the standard normal period 1961-90 to the recent 30-year period 1979-2008. Atmospheric circulation indices are used to explain the observed long-term temperature variability.

**Keywords**

Temperature, Precipitation, Snow, NAO, Northern Eurasia.

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# Contents

# 1 Introduction

This report has been written as a contribution to the climate description in the Norwegian Research Council projects EALAT ($http://icr.arcticportal.org/en/ealat$) and CAVIAR ($http://www.ipy.org/news-a-announcements/item/2097-caviar-community-adaptation-and-vulnerability-in-arctic-regions$). Both EALAT and CAVIAR are interdisciplinary projects with partners from the Arctic nations. The aims of the projects are to increase understanding of how Arctic communities are affected by climate and other changes and to contribute to the development of adaptive strategies and policies. For EALAT a particular emphasis is put on identification of local climate conditions important for reindeer herding.

This report provides background data on current climate and historical climate development in five selected regions in northern parts of Fennoscandia and northern Russia. The main climate elements studied are temperature, precipitation and snow conditions. In addition derived climate products are studied, i.e. degree days, growing season and cold season. Finally, atmospheric circulation indices are used to explain the observed long-term temperature variability.

# 2 Dataset and analysis

This section gives an overview of the meteorological dataset used in the analysis in this report. Furthermore, it contains a description of how the various climate parameters were computed.

## 2.1 Meteorological stations in Russia, Finland and Norway

In this report we have analysed data from twenty weather stations in Russia, Finland and Norway (Table 1). These stations are spatially distributed in five regions from the Finnmarksvidda area in the west to Markovo and Anadyr near the Bering Strait in the east (Figure 1). The survey of time periods covered by observations for the different climate elements (Table 1) shows that the observation period for each station varies widely. It is also important to notice that although observations have been carried out, not all data are available in digital formats. Some of the data are only available in analogue archives. There are a few gaps in the time-series. Further metadata for the Russian stations are presented by Svyashchennikov and Førland (2010).

| Station number (met.no/ARIO) | Station name | Elevation m a.s.l. | Start | Temperature monthly | daily | Precipitation monthly | daily | Snow depth monthly | daily |
|---|---|---|---|---|---|---|---|---|---|
| **Region 1** | | | | | | | | | |
| 97250 | Karasjok, Norway | 129 | 1875 | 1877-2009 | 1877-2009 | 1877-2009 | 1877-2009 | 1904-2009 | 1904-2009 |
| 7501 | Sodankylä, Finland | 179 | 1891 | 1908-2008 | 1908-2008 | 1908-2008 | 1908-2008 | - | 1911-2008 |
| 22127 | Lovozero, Russia | 161 | 1936 | 1936-2008 | 1964-2008 | 1936-2008 | 1936-2008 | 1936-2008 | 1973-2008 |
| 22271 | Sojna, Russia | 8 | 1936 | 1936-2008 | 1969-2008 | 1936-2008 | 1958-2008 | 1936-2008 | 1973-2008 |
| 23405 | Ust-Tsilma, Russia | 68 | 1889 | 1889-2008 | 1892-2008 | 1891-2008 | 1892-2008 | 1936-2008 | 1936-2008 |
| **Region 2** | | | | | | | | | |
| 23552 | Tarko-Sale, Russia | 27 | 1936 | 1937-2008 | 1957-2008 | 1936-2008 | 1936-2008 | 1937-2008 | 1966-2008 |
| 23330 | Salekhard, Russia | 35 | 1883 | 1883-2008 | 1951-2008 | 1891-2008 | 1891-2008 | 1962-2008 | 1973-2008 |
| 23032 | Mare-Sale, Russia | 24 | 1914 | 1914-2008 | 1966-2008 | 1928-2008 | 1928-2008 | - | - |
| 23445 | Nadym, Russia | 15 | 1943 | 1954-2008 | - | 1943-2008 | - | - | - |
| **Region 3** | | | | | | | | | |
| 21921 | Kjusjur, Russia | 33 | 1888 | 1911-2008 | 1962-2008 | 1910-2008 | 1909-2008 | 1931-2008 | 1970-2008 |
| 24343 | Zhigansk, Russia | 92 | 1935 | 1935-2008 | 1936-2008 | 1936-2008 | 1936-2008 | 1936-2008 | 1936-2008 |
| 24143 | Dzhardzhan, Russia | 39 | 1936 | 1936-2008 | 1950-2008 | 1936-2008 | - | - | - |
| 21908 | Dzalinda, Russia | 62 | 1947 | 1942-2008 | 1959-2008 | 1942-2008 | - | 1942-2008 | 1982-2008 |
| 24125 | Olenek, Russia | 127 | 1936 | 1936-2008 | 1936-2008 | 1936-2008 | 1937-2008 | 1936-2008 | 1936-2008 |
| **Region 4** | | | | | | | | | |
| 24382 | Ust-Moma, Russia | 196 | 1937 | 1937-2008 | - | 1937-2008 | - | 1937-2008 | - |
| 24959 | Yakutsk, Russia | 103 | 1888 | (1830)-2008 | 1888-2008 | 1888-2007 | 1888-2008 | 1959-2008 | 1922-2008 |
| 24671 | Tompo, Russia | 400 | 1936 | 1936-2008 | 1960-2008 | 1933-2008 | - | - | - |
| 24688 | Oimakon, Russia | 726 | 1930 | 1930-2008 | 1952-2008 | 1930-2008 | 1943-2008 | 1943-2008 | 1943-2008 |
| **Region 5** | | | | | | | | | |
| 25551 | Markovo, Russia | 26 | 1894 | 1894-2008 | 1894-2008 | 1894-2008 | 1894-2008 | 1943-2008 | 1943-2008 |
| 25563 | Anadyr, Russia | 61 | 1895 | 1895-2008 | 1898-2008 | 1898-2008 | 1898-2008 | 1929-2008 | 1931-2008 |

Table 1: *Meta data for the Russian, Finnish and Norwegian meteorological stations within the five defined regions.*

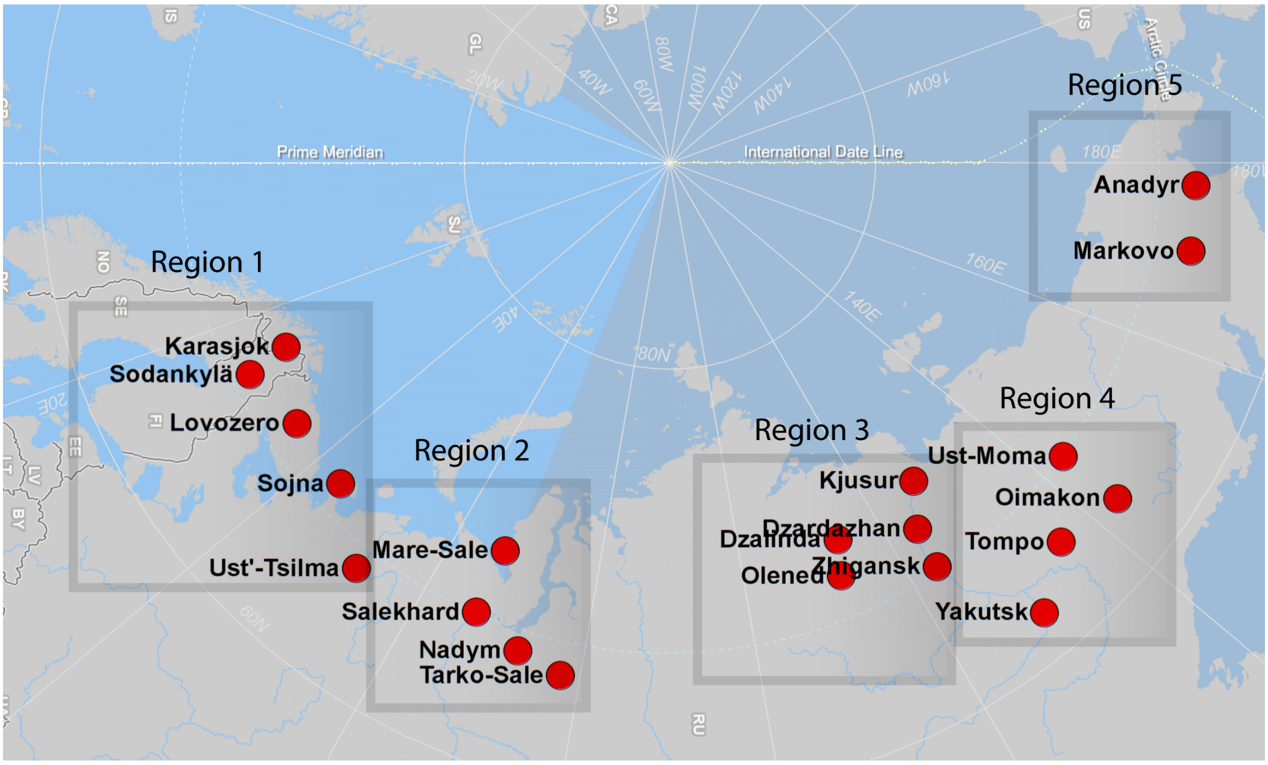


Figure 1: Location of the selected meteorological stations located in Russia, Karasjok (Norway) and Sodankylä (Finland).

## 2.2 Time-series analysis

In this Section we describe how the different climate parameters were computed. Decadal scale variability in the dataset are studied by applying a 10 year gauss filter. Results from the analysis are presented in Chapter 3. The homogeneity of the Russian series used in this report is discussed in brief by Svyashchennikov and Førland (2010). They concluded that there have been both screen changes and changes of the time of observation, so when analysing the data one should have in mind possible inhomogeneities.

### 2.2.1 Mean temperature

The mean annual temperature is computed from the mean monthly temperatures of a calendar year. Decadal-scale variability is illustrated in the figures by computing the deviation from the mean temperature during the normal period (1961-1990) (Table 2).

Seasonal mean temperature has also been computed according to standard season definitions. Autumn consists of the months September, October and November. Winter consists of the months December, January and February, spring consists of the months March, April and May, while summer consists of the months June, July and August.

For computing annual values a minimum of ten months of data was required within the same year. A stricter criterion was applied to compute seasonal values by requiring observations for all three months.

The homogeneity of the Russian series used in this report is discussed in brief by Svyashchennikov and Førland (2010). They concluded that there have been both screen changes and changes of the time of observation, so when analysing the data one should have in mind possible inhomogeneities.

### 2.2.2 Annual precipitation sum

The annual precipitation sum is the sum of monthly precipitation during a calendar year. Decadal scale variability is studied by computing the deviation from the mean annual precipitation sum during the normal period (1961-1990) (Table 2).

To examine seasonal variations, this parameter has also been computed for autumn, winter, spring and summer.

| Station number | Station name | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Region 1** | | | | | | | | | | | | | |
| 97250 | KARASJOK | -17.1 | -15.2 | -9.8 | -3.0 | 4.0 | 10.4 | 13.4 | 10.8 | 5.5 | -1.3 | -9.4 | -15.3 |
| 7501 | SODANKYLÄ | -15.1 | -13.6 | -8.6 | -2.1 | 5.0 | 11.5 | 14.1 | 11.2 | 5.8 | -0.3 | -7.4 | -13.1 |
| 22127 | LOVOZERO | -14.4 | -14.1 | -9.5 | -3.6 | 2.7 | 9.4 | 12.9 | 10.4 | 5.6 | -0.5 | -7.2 | -11.7 |
| 22271 | SOJNA | -12.6 | -13.1 | -9.6 | -5.9 | -0.3 | 5.9 | 10.9 | 9.8 | 6.4 | 1.2 | -4.3 | -8.6 |
| 23405 | UST'-TSILMA | -17.6 | -15.9 | -8.7 | -3.4 | 3.3 | 10.6 | 15.3 | 11.8 | 6.3 | -1.3 | -9.0 | -13.0 |
| **Region 2** | | | | | | | | | | | | | |
| 23552 | TARKO-SALE | -25.7 | -24.3 | -16.2 | -9.2 | -1.3 | 9.7 | 16.3 | 12.0 | 5.6 | -5.6 | -16.2 | -22.0 |
| 23330 | SALEKHARD" | -24.8 | -23.9 | -16.2 | -9.9 | -2.0 | 7.9 | 14.3 | 11.0 | 5.1 | -4.8 | -15.3 | -20.9 |
| 23032 | MARE-SALE | -22.6 | -22.6 | -18.2 | -13.9 | -5.9 | 1.4 | 7.2 | 6.7 | 3.3 | -5.1 | -13.9 | -17.9 |
| 23445 | NADYM | -24.4 | -23.1 | -15.1 | -8.7 | -1.0 | 9.1 | 15.8 | 11.7 | 5.7 | -5.1 | -15.3 | -20.6 |
| **Region 3** | | | | | | | | | | | | | |
| 21921 | KJUSJUR | -38.7 | -34.6 | -26.4 | -15.7 | -3.8 | 7.7 | 12.2 | 9.2 | 1.8 | -12.5 | -30.1 | -35.3 |
| 24343 | ZHIGANSK | -38.8 | -34.4 | -23.2 | -11.3 | 1.3 | 11.8 | 15.8 | 12.1 | 3.5 | -10.6 | -29.7 | -36.5 |
| 24143 | DZHARDZHAN | -38.9 | -34.2 | -23.7 | -12.7 | -0.5 | 10.4 | 14.7 | 10.8 | 2.8 | -11.6 | -30.2 | -35.9 |
| 21908 | DZALINDA | -39.9 | -35.0 | -27.1 | -15.2 | -3.5 | 8.5 | 13.9 | 9.5 | 1.2 | -13.3 | -31.3 | -36.0 |
| 24125 | OLENEK | -38.4 | -34 | -24.1 | -12.7 | -1.7 | 9.1 | 14.7 | 10.7 | 2.3 | -11.9 | -30.0 | -34.8 |
| **Region 4** | | | | | | | | | | | | | |
| 24382 | UST-MOMA | -44.4 | -40.3 | -28.8 | -12.7 | 3.2 | 13.3 | 15.0 | 10.9 | 2.5 | -14.9 | -34.9 | -42.3 |
| 24671 | TOMPO | -44.3 | -38.6 | -26.7 | -10.9 | 3.6 | 12.7 | 15.5 | 11.7 | 3.1 | -13.4 | -34.2 | -41.6 |
| 24688 | OIMAKON | -47.0 | -42.9 | -32.2 | -14.4 | 1.9 | 11.6 | 13.8 | 10.1 | 1.7 | -16.1 | -37.2 | -45.6 |
| 24959 | YAKUTSK | -40.8 | -35.9 | -22.3 | -6.3 | 6.7 | 15.4 | 18.6 | 15.1 | 5.7 | -8.5 | -29.2 | -38.9 |
| **Region 5** | | | | | | | | | | | | | |
| 25551 | MARKOVO | -24.1 | -25.4 | -22.2 | -14.2 | -0.7 | 10.9 | 13.9 | 10.7 | 3.7 | -9.4 | -20.6 | -25.7 |
| 25563 | ANADYR | -19.5 | -22.5 | -20.5 | -13.8 | -2.7 | 5.4 | 10.6 | 9.6 | 3.8 | -6.3 | -15.2 | -20.0 |

Table 2: *Mean monthly temperature for the normal period 1961-1990.*

| Station number | Stationname | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Region 1** | | | | | | | | | | | | | |
| 97250 | KARASJOK | 17.9 | 12.4 | 13.8 | 14.7 | 22.9 | 41.6 | 71.4 | 57.6 | 40.4 | 32.9 | 22.4 | 16.7 |
| 7501 | SODANKYLÄ | 30.7 | 25.5 | 25.2 | 23.6 | 34.5 | 55.9 | 64.6 | 62.7 | 55.4 | 50.9 | 39.4 | 30.9 |
| 22127 | LOVOZERO | 23.4 | 19.0 | 22.8 | 27.1 | 34.9 | 52.5 | 65.7 | 68.5 | 47.1 | 39.4 | 33.7 | 25.4 |
| 22271 | SOJNA | 27.3 | 20.3 | 19.1 | 20.8 | 22.8 | 33.7 | 41.2 | 44.9 | 46.7 | 48.3 | 32.0 | 31.0 |
| 23405 | UST'-TSILMA | 34.3 | 27.1 | 29.0 | 32.8 | 44.1 | 55.9 | 65.9 | 70.6 | 59.6 | 59.8 | 45.4 | 42.2 |
| **Region 2** | | | | | | | | | | | | | |
| 23552 | TARKO-SALE | 26.2 | 18.7 | 24.9 | 25.4 | 35.5 | 48.9 | 61.5 | 65.0 | 58.3 | 47.9 | 37.9 | 29.8 |
| 23330 | SALEKHARD | 20.7 | 18.5 | 20.4 | 24.6 | 34.9 | 51.9 | 71.2 | 64.0 | 50.8 | 40.4 | 28.0 | 26.1 |
| 23032 | MARE-SALE | 20.1 | 17.3 | 15.5 | 16.4 | 20.1 | 25.4 | 30.2 | 37.9 | 40.8 | 28.7 | 23.4 | 22.2 |
| 23445 | NADYM | 24.2 | 17.8 | 21.5 | 25.5 | 38.1 | 55.0 | 68.5 | 61.9 | 61.1 | 45.8 | 33.4 | 26.5 |
| **Region 3** | | | | | | | | | | | | | |
| 21921 | KJUSJUR | 14.5 | 16.6 | 18.7 | 15.7 | 20.9 | 34.0 | 48.5 | 48.7 | 43.3 | 43.7 | 24.4 | 19.5 |
| 24343 | ZHIGANSK | 8.4 | 12.0 | 12.2 | 13.1 | 20.6 | 33.4 | 46.5 | 41.0 | 34.8 | 32.5 | 17.1 | 13.3 |
| 24143 | DZHARDZHAN | 11.5 | 10.5 | 13.7 | 14.8 | 19.4 | 35.3 | 46.6 | 43.2 | 39.9 | 40.5 | 20.3 | 15.5 |
| 21908 | DZALINDA | 8.3 | 6.8 | 10.3 | 13.8 | 18.0 | 40.3 | 42.1 | 38.4 | 36.5 | 25.8 | 14.8 | 11.1 |
| 24125 | OLENEK | 10.5 | 8.4 | 11.1 | 12.8 | 21.5 | 39.6 | 51.1 | 38.9 | 30.3 | 27.9 | 18.0 | 14.0 |
| **Region 4** | | | | | | | | | | | | | |
| 24382 | UST-MOMA | 8.5 | 7.1 | 5.0 | 5.2 | 11.8 | 26.4 | 40.7 | 40.7 | 20.6 | 12.0 | 10.3 | 8.6 |
| 24671 | TOMPO | 4.8 | 5.0 | 4.4 | 11.8 | 26.8 | 47.8 | 58.7 | 53.6 | 28.4 | 18.2 | 11.7 | 7.1 |
| 24688 | OIMAKON | 8.3 | 7.5 | 5.1 | 6.4 | 11.1 | 30.6 | 49.4 | 37.9 | 21.3 | 16.3 | 11.4 | 9.8 |
| 24959 | YAKUTSK | 8.5 | 6.7 | 5.9 | 9.6 | 17.8 | 36.5 | 38.8 | 36.3 | 28.1 | 19.2 | 15.4 | 12.0 |
| **Region 5** | | | | | | | | | | | | | |
| 25551 | MARKOVO | 34.1 | 22.7 | 18.7 | 19.8 | 17.3 | 30.5 | 53.1 | 59.9 | 38.2 | 34.7 | 41.8 | 31.6 |
| 25563 | ANADYR | 41.0 | 24.4 | 22.1 | 16.4 | 9.6 | 19.2 | 36.3 | 42.6 | 28.8 | 16.8 | 25.7 | 29.9 |

Table 3: *Monthly precipitation sum for the normal period 1961-1990.*

For computing annual values a minimum of ten months of data was required within the same year. A stricter criterion was applied to compute seasonal values by requiring observations for all three months.

### 2.2.3 Maximum snow depth

Maximum snow depth (cm) was computed for every winter season from *daily* snow measurements. A winter season is defined to follow the hydrological year (from 1 September to 31 August).

### 2.2.4 Snow season duration

We here define the snow season duration as the period during a hydrological year with permanent snow cover. The daily snow depth data from some of the stations have been observed irregularily in periods. Most of the time daily observations have been carried out, but in certain periods snow depth have been measured approx. every 14 days (Figure 2). This makes it difficult to identify the start and end of the snow season directly from the snow depth data. Therefore, we applied a snow period data set provided by the Arctic and Antarctic Research Institute (AARI), St. Petersburg, Russia (Svyashchennikov and Førland, 2010). This data set consists of dates of start and end of the season with permanent snow cover, as well as number of days in between (snow season duration). The definition used for determining these dates is based on two criterions: 1) at least 50% of the ground around the station should be covered by snow; and 2) snow depth observations at the station. Maximum three snowfree succeding days are allowed within this period of permanent snow cover. Furthermore, the snow season duration was computed as the number of days between the first and the last day. These days constitute the period of the hydrological year with permanent snow cover, and thereby excludes short periods with snow fall followed by melt episodes.

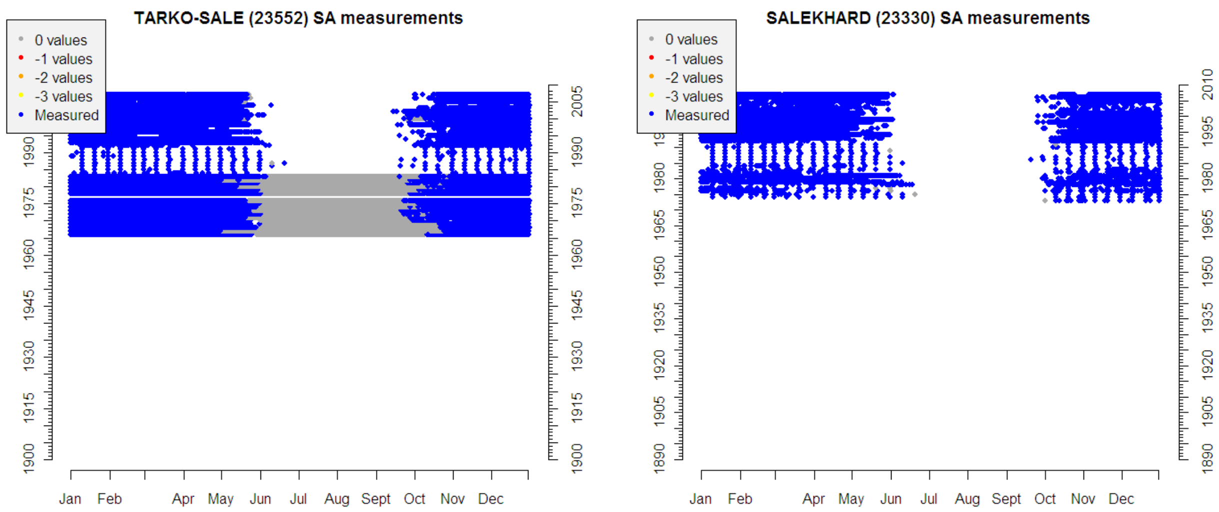


Figure 2: Example of the daily snow depth data which in some periods are observed with certain days interval. Illustration of the difficulties with determining start and end of the snow season.

### 2.2.5 Cold periods

We have studied degree days as a measure of how cold it has been and how long it has been cold. We have counted the number of days with temperatures below 0°C, -15°C and -30°C for each hydrological year (1 September-31 August). Additionally, we have computed the cumulated degree days. This is the sum of average daily degrees for days with temperatures below the applied threshold temperature. We computed degree days for hydrological years and not for calendar years. To avoid misinterpretation of trends introduced by missing data, we excluded years with more than 15 days with missing data.

Loose snow structures (depth hoar crystals) are favourable for reindeer for accessing the food below the snow pack. Depth hoar crystals form preferentially in cold, continental type climate. The higher the temperature gradient between the snow surface and the ground surface is, the more efficient the formation of depth hoar crystals is. This gradient depends on the snow surface temperature, the ground surface temperature and the snow depth. Hence, long periods with cold weather favours the generation of depth hoar crystals, and are therefore favourable for the reindeers access to food through the snow.

#### 2.2.6 Growing season

Growing degree days is an indicator for the growth and development of plants during the growing season. Development does not occur at this time unless the temperature is above a minimum threshold value (base temperature). The base temperature varies for different organisms, but is often set to +5°. Growing degree days is not of importance for reindeer winter pastures, but is included to show some historical climatic aspects of the summer pastures.

We have counted the number of days with temperatures above +5°C for each calendar year (1 January-31 December). Additionally, we have computed the cumulated growing degree days. This is the sum of of the differences between mean daily temperature (TM) and the reference temperature 5°C for days with TM>5°C (Førland et al., 2004).

# 3 Comparison of the climate at the meteorological stations within the regions 1-5

## 3.1 Temperature

The area that is subject for this report covers the sector of the northern Eurasian continent from about 30°E to 180°E, or almost the half of the circle around the pole. A large part of the area has permafrost characterised by cold winters and little precipitation. The area contains also the part of the globe that has the largest difference between summer and winter temperature. Although near to the Arctic Ocean the winter climate is continental due to the sea ice. Covered with snow, the sea ice act as an effective barrier for the heat flux from the ocean to the air during winter.

According to Köppen's classification scheme no station has Arctic climate but one, Mare-Sale, which is situated near the Kara Sea in the Poluostrov Yamal region (Region 2). The mean temperature during July (warmest month) is only 7.2°C (Table 2). For the Yakutsk station on the other hand, the mean July temperature is as high as 18.6°C, which is the highest among the series here presented.

### 3.1.1 Annual temperature

When analysing the data we will have in mind two important spatial temperature gradients, one meridional (North-South) and one latitudinal (West-East). The western areas, in particular Region 1, but also Region 2 are somewhat influenced by North Atlantic air masses, and have higher annual temperature than the other regions (Figure 4). The annual mean temperatures for the series in Region 1 are between -5°C and 0°C, whereas for those in Region 3 (Western Siberia) for example are between -15°C and -10°C (Table 5).

Annual temperature is probably the weather element that is most often referred to when anthropogenic influence on climate is discussed. Globally the mean temperature has increased by about 1°C for the whole globe the latest 100 years (IPCC, 2007), due to anthropogenic influence and in the first half of the 20th century also by increased radiation from the sun. However, temperature varies spatially so therefore there might be regions that deviate from the global trends of warming.

For all stations in the study area the temperature trends are inferred since the start of the 20th century (Table 4). Temperature at all stations has increased, but significant increase is only detected in the Yakutsk series. None of the series has a negative trend. However, the analysis is hampered by the fact that only 6 out of 19 stations have data coverage for the whole period under analysis.

Annual temperature is inferred further with the help of a Gaussian low pass filter where variations on shorter time scales than decades are smoothed out in order to visualise variations on longer time scales (Figure 3). One striking feature is the strong decadal variations in Region 1 and 2, the two European regions. The early local maximum on the curves are the well known Early 20th Century Warming (ETCW) that is present in the European sector on latitudes higher than about 60°N (Overland et al., 2004, e.g.). For some of the series in the two regions this is still the absolute maximum (Figure 3) and linear trends are weak. The series from the Sápmi Region in northern Norway (continental Finnmark) differ from those of the coastal regions, which have steeper trends (Hanssen-Bauer and Førland, 1998).

For the western Siberia (Region 3) the ETCW maximum show values as high as or even higher than the present day maximum. Thus all regions from Finnmark to western Siberia are characterised by high temperature in the 1930s, thereafter a decrease that ended in the 1960s or 1970s when another increase started (Figure 3). In Region 3 the series from Olenek deviates from this pattern but this might be due to an inhomogeneity in this particular series. Further to the east in Regions 4 (Eastern Siberia) and Region 5 (Chuci) temperature increase is larger than in the other regions. In Region 4, this was mainly caused by a significant temperature increase after the 1960s, and the present temperature in this region is higher than in the 1930s (Figure 3). In Region 5, however, the ETCW is still the most pronounced period of warming, and present temperatures are approximately at the same level as the temperatures in the 1930s.

The temperature increase in the latest parts of the series may also the illustrated by a comparison between the standard normal temperatures, 1961-1990, and the temperature during the latest 30 year period, 1979-2008 (Table 5). For all stations the latest 30 years have been warmer than the standard normal period by from 0.4°C to 1.1°C.

| Station number | Station Name | Linear trend (°C per decade) | | | | |
|---|---|---|---|---|---|---|
| | | Annual | Autumn | Winter | Spring | Summer |
| **Region 1** | | | | | | |
| 97250 | Karasjok | 0.07 | 0.04 | -0.05 | 0.15* | **0.13*** |
| 7501 | Sodankylä | 0.05 | 0.05 | -0.05 | 0.14* | 0.02 |
| 22127 | Lovozero | - | - | - | - | - |
| 22271 | Sojna | - | - | - | - | - |
| 23405 | Ust'-tsilma | 0.07 | 0.02 | 0.04 | 0.14 | 0.10 |
| **Region 2** | | | | | | |
| 23552 | Tarko-sale | - | - | - | - | - |
| 23330 | Salekhard | 0.05 | -0.01 | -0.04 | **0.18** | 0.06 |
| 23032 | Mare-sale | - | - | - | - | - |
| 23445 | Nadym | - | - | - | - | - |
| **Region 3** | | | | | | |
| 21921 | Kjusjur | - | -0.11 | 0.18 | 0.12 | 0.02 |
| 24343 | Zhigansk | - | - | - | - | - |
| 24143 | Dzhardzhan | - | - | - | - | - |
| 21908 | Dzalinda | - | - | - | - | - |
| 24125 | Olenek | - | - | - | - | - |
| **Region 4** | | | | | | |
| 24382 | Ust-moma | - | - | - | - | - |
| 24671 | Tompo | - | - | - | - | - |
| 24688 | Oimakon | - | - | - | - | - |
| 24959 | Yakutsk | **0.14*** | -0.02 | **0.30*** | **0.23*** | 0.04 |
| **Region 5** | | | | | | |
| 25551 | Markovo | 0.12* | 0.06 | 0.07 | **0.23*** | **0.10*** |

Table 4: *Least squares linear trends in annual and seasonal temperature series (°C per decade) during the period 1900-2008. Trends significant at the 1% level according to the Mann-Kendall test are shown in* **bold** *type, while trends significant at the 5% level are marked with a "*". Temperature series starting later than 1900 are excluded from the analysis.*


Figure 3: *Normalized temperature: Comparison of all stations within the regions 1-5. 10 year Gauss filter.*

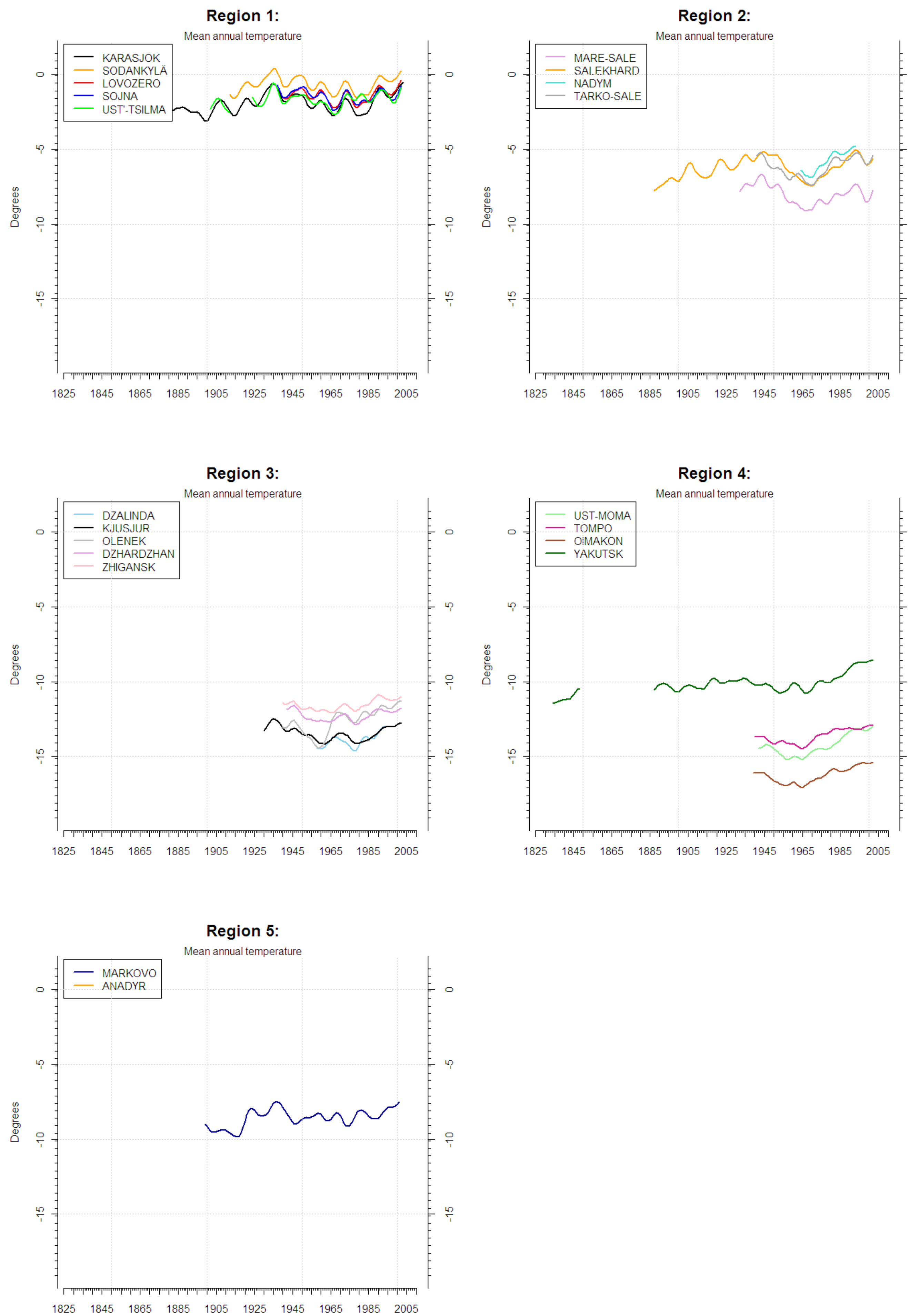


Figure 4: *Absolute temperature: Comparison of all stations within the regions 1-5. 10 year Gauss filter.*

| | | 1961-90 | 1979-08 | Difference |
|---|---|---|---|---|
| **Region 1** | | | | |
| 97250 | Karasjok | -2.2 | -1.5 | 0.7 |
| 7501 | Sodankylä | -1.0 | -0.5 | 0.5 |
| 22127 | Lovozero | -1.7 | -1.1 | 0.6 |
| 22271 | Sojna | -1.7 | -1.3 | 0.4 |
| 23405 | Ust'-tsilma | -1.8 | -1.3 | 0.5 |
| **Region 2** | | | | |
| 23552 | Tarko-sale | -6.4 | -5.5 | 0.9 |
| 23330 | Salekhard | -6.6 | -5.7 | 0.9 |
| 23032 | Mare-sale | -8.5 | -7.8 | 0.7 |
| 23445 | Nadym | -5.9 | -5.1 | 0.8 |
| **Region 3** | | | | |
| 21921 | Kjusjur | -13.8 | -13.3 | 0.5 |
| 24343 | Zhigansk | -11.7 | -11.2 | 0.5 |
| 24143 | Dzhardzhan | -12.4 | -12.0 | 0.4 |
| 21908 | Dzalinda | -14.0 | -13.1 | 0.9 |
| 24125 | Olenek | -12.5 | -11.8 | 0.7 |
| **Region 4** | | | | |
| 24382 | Ust-moma | -14.5 | -13.4 | 1.1 |
| 24671 | Tompo | -13.7 | -13.1 | 0.6 |
| 24688 | Oimakon | -16.4 | -15.6 | 0.8 |
| 24959 | Yakutsk | -10.0 | -9.1 | 0.9 |
| **Region 5** | | | | |
| 25551 | Markovo | -8.6 | -8.1 | 0.5 |

Table 5: *Mean annual temperature for the periods 1961-1990 and 1979-2008, and change in temperature.*

### 3.1.2 Seasonal temperature

Using just the same Gausian filter that smooths out variations on time scale less than decades the analyses are continued for seasonal values (Figure 5- 8).

In the autumn (Figure 5) the variations along the east-west direction are much like those for the whole year with appreciably higher temperatures in the European sectors (Regions 1 and 2) than in the Asian ones (Regions 3-5). The relatively high temperatures in the European sectors are also present during winter, but now there is a difference between Region 1 and 2 of almost 10°C (Figure 6). The coldest region is eastern Siberia (Region 4) with mean winter temperatures between -50°C and -40°C. In Chuci (Region 5), where the station is somewhat influenced by the Pacific Ocean winter temperatures are somewhat higher, but well below those in Region 1.

During spring (Figure 7) the differences between the regions diminish, but still Region 1 is the warmest one, whereas Region 3 and 4 both have stations where the average spring temperature is about -15°C. For the other regions mean spring temperatures are about -10°C. In summer the east-west gradient further diminishes, now the North-South gradient is the important one. The warmest place in this analysis is Yakutsk in Region 4 with mean summer temperature well above 15°C. In contrast to this the Mare Sale station adjacent to the Kara Sea has a mean summer temperature of approximately 5°C (Figure 8). These differences are established by the cold surface of the Kara Sea compared to the warm Eurasian continent.

From the Guassian curves in Figures 5- 8 it is also seen that the long-term trends vary from season to season. Generally the trends are positive for spring and summer seasons, where ETCW is not present, whereas for the winter season the trends vary more between the regions. Thus, the Regions 1 and 2 have small negative trends, while positive trend in winter temperature tends to be more common in the eastern regions.

During autumn trends seem to be very weak (Figure 5). The trends from 1900 to 2008 in the few long-term series confirm this picture (Table 4).

As for the annual values the seasonal temperature during the latest 30 years, 1979-2008, are compared with the standard normal period, 1961-1990 (Tables 6 and 7). Except for a small decrease in winter temperature at the one station in Region 5; the temperature has increased in all seasons at all stations. For the seasons the magnitude of the differences seem to vary much also within the same region so that a broad picture of spatial variations is not easily seen. However, in autumn the increase in Region 1 seems to be smaller than in the other regions, whereas the temperature increase is largest in the two easternmost regions (Table 6).

During spring and summer temperature increase is seen in all regions and variations within the regions are more striking than between the regions. It is interesting to note that the increase for the Markovo station in Region 5 is not small in spite of the decrease in winter for this station.

| **Station number** | **Station name** | **Autumn** | | | **Winter** | | |
|---|---|---|---|---|---|---|---|
| | | **1961-90** | **1979-08** | **Difference** | **1961-90** | **1979-08** | **Difference** |
| **Region 1** | | | | | | | |
| 97250 | Karasjok | -1.7 | -1.5 | 0.2 | -16.0 | -14.6 | 1.4 |
| 7501 | Sodankylä | -0.6 | -0.4 | 0.2 | -14.0 | -13.1 | 0.9 |
| 22127 | Lovozero | -0.7 | -0.5 | 0.2 | -13.5 | -12.6 | 0.9 |
| 22271 | Sojna | 1.1 | 1.3 | 0.2 | -11.4 | -11.0 | 0.4 |
| 23405 | Ust'-tsilma | -1.3 | -0.8 | 0.5 | -15.5 | -15.3 | 0.2 |
| **Region 2** | | | | | | | |
| 23552 | Tarko-sale | -5.4 | -4.9 | 0.5 | -24.0 | -23.1 | 0.9 |
| 23330 | Salekhard | -5.0 | -4.2 | 0.8 | -23.2 | -22.4 | 0.8 |
| 23032 | Mare-sale | -5.2 | -4.3 | 0.9 | -20.9 | -20.7 | 0.2 |
| 23445 | Nadym | -4.9 | -4.3 | 0.6 | -22.7 | -22.2 | 0.5 |
| **Region 3** | | | | | | | |
| 21921 | Kjusjur | -13.6 | -13.1 | 0.5 | -36.2 | -35.2 | 1.0 |
| 24343 | Zhigansk | -12.3 | -12.0 | 0.3 | -36.6 | -35.9 | 0.7 |
| 24143 | Dzhardzhan | -13.0 | -12.9 | 0.1 | -36.4 | -35.7 | 0.7 |
| 21908 | Dzalinda | -14.5 | -14.0 | 0.5 | -36.9 | -35.7 | 1.2 |
| 24125 | Olenek | -13.2 | -12.7 | 0.5 | -35.7 | -34.2 | 1.5 |
| **Region 4** | | | | | | | |
| 24382 | Ust-moma | -15.8 | -14.4 | 1.4 | -42.4 | -40.8 | 1.6 |
| 24671 | Tompo | -15.2 | -14.3 | 0.9 | -41.5 | -40.9 | 0.6 |
| 24688 | Oimakon | -17.2 | -16.0 | 1.2 | -45.1 | -44.5 | 0.6 |
| 24959 | Yakutsk | -10.7 | -9.9 | 0.8 | -38.6 | -36.9 | 1.7 |
| **Region 5** | | | | | | | |
| 25551 | Markovo | -8.7 | -7.6 | 1.1 | -25.0 | -25.6 | -0.6 |

Table 6: *Mean autumn and winter temperature for the periods 1961-1990 and 1979-2008, and change in temperature.*

| Station number | Station name | Spring | | | Summer | | |
|---|---|---|---|---|---|---|---|
| | | 1961-90 | 1979-08 | Difference | 1961-90 | 1979-08 | Difference |
| **Region 1** | | | | | | | |
| 97250 | Karasjok | -2.9 | -2.1 | 0.8 | 11.5 | 11.9 | 0.4 |
| 7501 | Sodankylä | -1.9 | -1.2 | 0.7 | 12.3 | 12.7 | 0.4 |
| 22127 | Lovozero | -3.5 | -2.6 | 0.9 | 10.9 | 11.1 | 0.2 |
| 22271 | Sojna | -5.3 | -4.8 | 0.5 | 8.8 | 9.1 | 0.3 |
| 23405 | Ust'-tsilma | -2.9 | -2.2 | 0.7 | 12.6 | 13.0 | 0.4 |
| **Region 2** | | | | | | | |
| 23552 | Tarko-sale | -8.9 | -7.7 | 1.2 | 12.7 | 13.5 | 0.8 |
| 23330 | Salekhard | -9.4 | -8.1 | 1.3 | 11.1 | 11.8 | 0.7 |
| 23032 | Mare-sale | -12.7 | -12.1 | 0.6 | 5.1 | 5.7 | 0.6 |
| 23445 | Nadym | -8.2 | -7.0 | 1.2 | 12.2 | 13.0 | 0.8 |
| **Region 3** | | | | | | | |
| 21921 | Kjusjur | -15.3 | -14.9 | 0.4 | 9.7 | 10.0 | 0.3 |
| 24343 | Zhigansk | -11.1 | -10.5 | 0.6 | 13.2 | 13.5 | 0.3 |
| 24143 | Dzhardzhan | -12.3 | -11.9 | 0.4 | 12.0 | 12.3 | 0.3 |
| 21908 | Dzalinda | -15.3 | -14.4 | 0.9 | 10.6 | 11.3 | 0.7 |
| 24125 | Olenek | -12.8 | -12.2 | 0.6 | 11.5 | 12.0 | 0.5 |
| **Region 4** | | | | | | | |
| 24382 | Ust-moma | -12.8 | -12.0 | 0.8 | 13.1 | 13.7 | 0.6 |
| 24671 | Tompo | -11.3 | -10.8 | 0.5 | 13.3 | 13.7 | 0.4 |
| 24688 | Oimakon | -14.9 | -14.3 | 0.6 | 11.8 | 12.3 | 0.5 |
| 24959 | Yakutsk | -7.3 | -6.4 | 0.9 | 16.4 | 16.8 | 0.4 |
| **Region 5** | | | | | | | |
| 25551 | Markovo | -12.4 | -11.3 | 1.1 | 11.8 | 12.4 | 0.6 |

Table 7: *Mean spring and summer temperature for the periods 1961-1990 and 1979-2008, and change in temperature.*

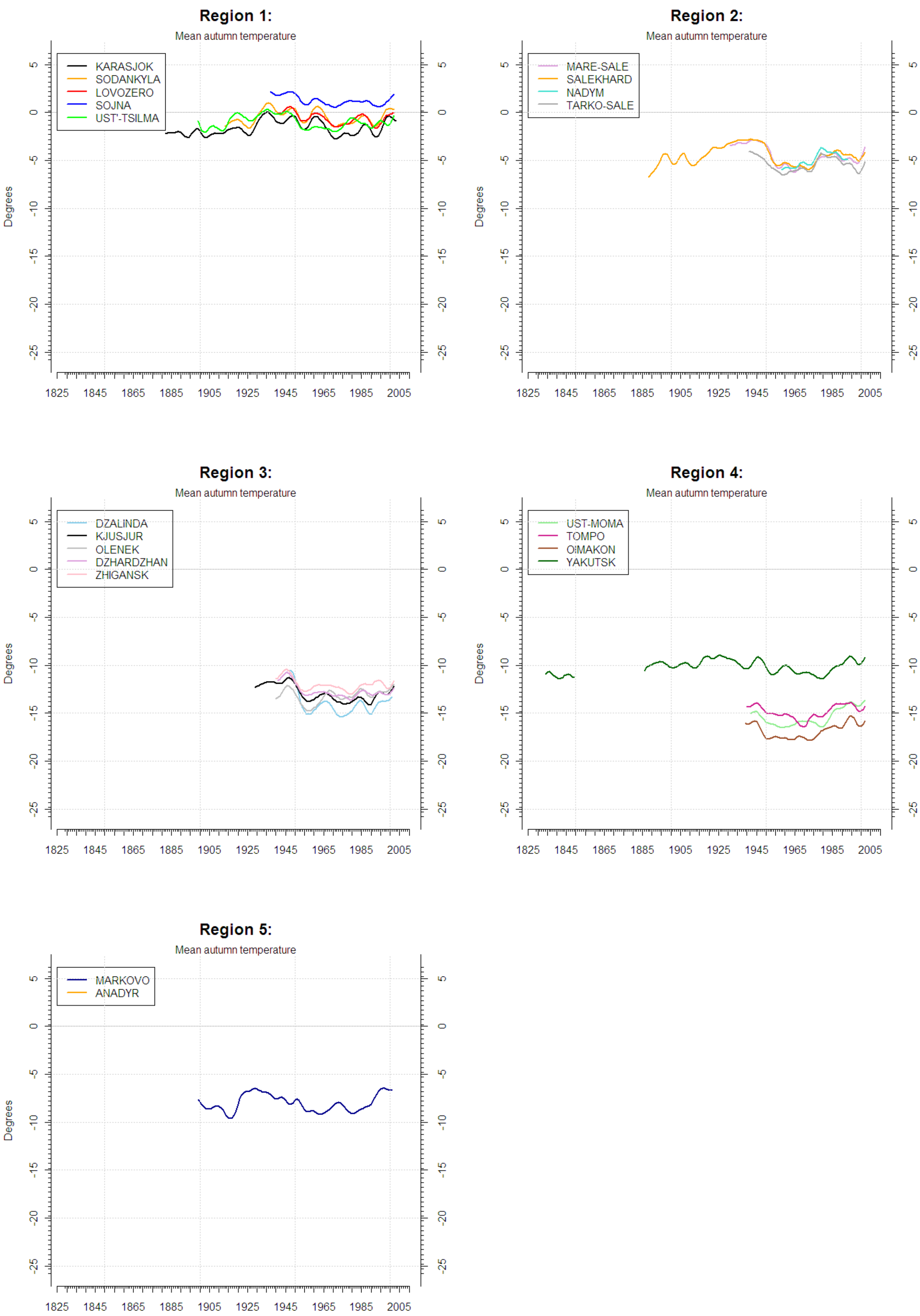


Figure 5: *Autumn temperature: Comparison of all stations within the regions 1-5. 10 year Gauss filter.*

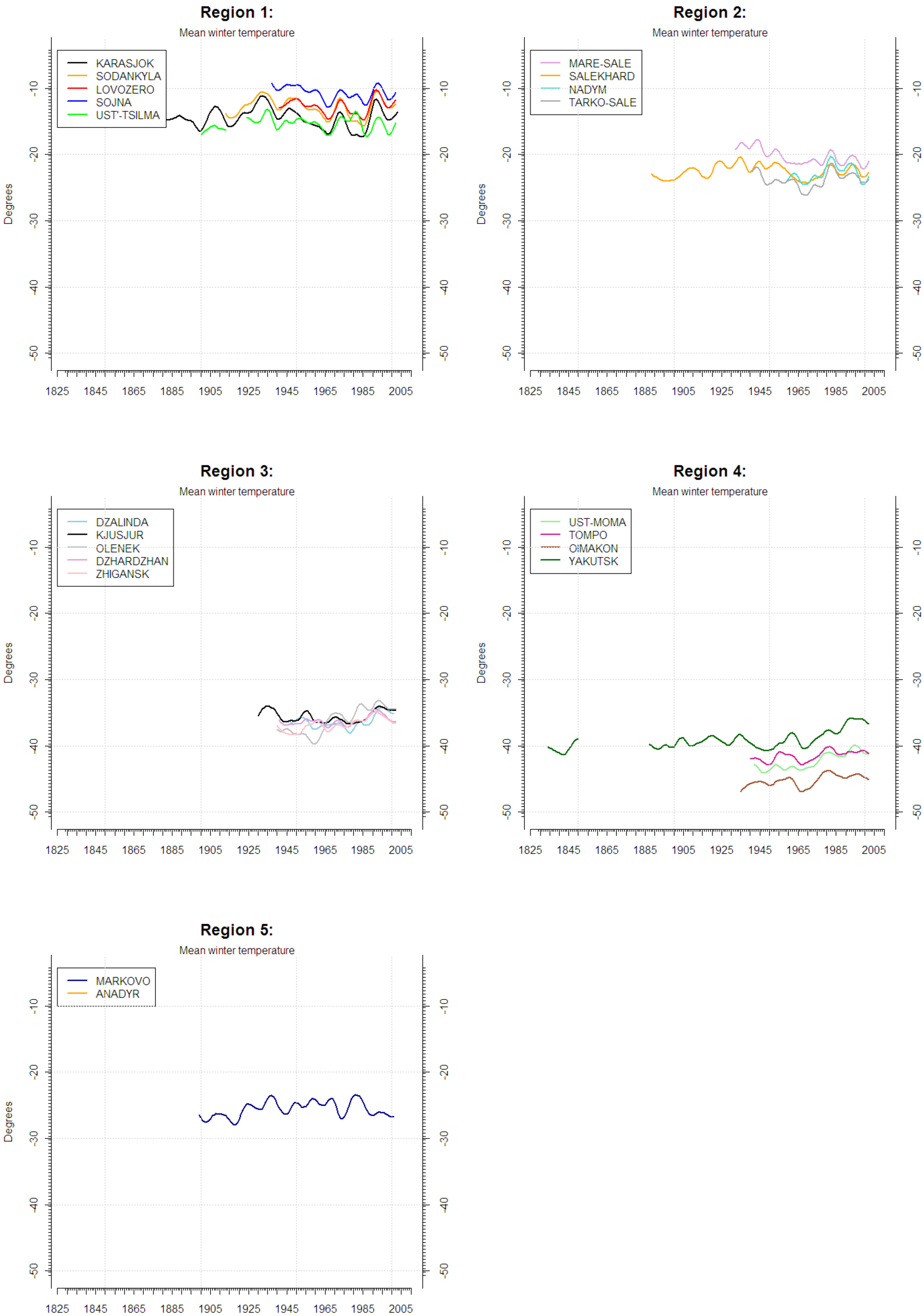


Figure 6: *Winter temperature: Comparison of all stations within the regions 1-5. 10 year Gauss filter.*

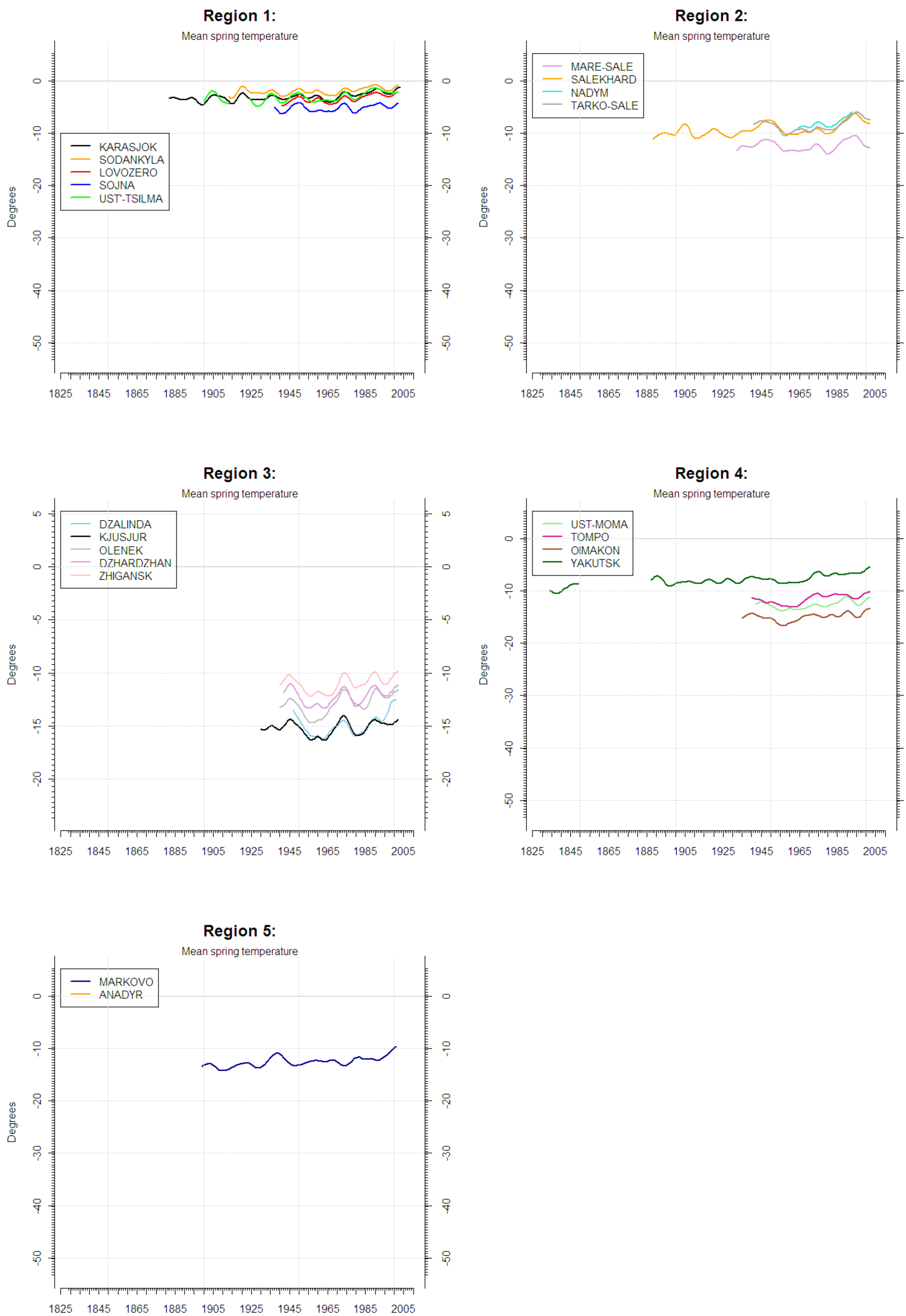


Figure 7: *Spring temperature: Comparison of all stations within the regions 1-5. 10 year Gauss filter.*

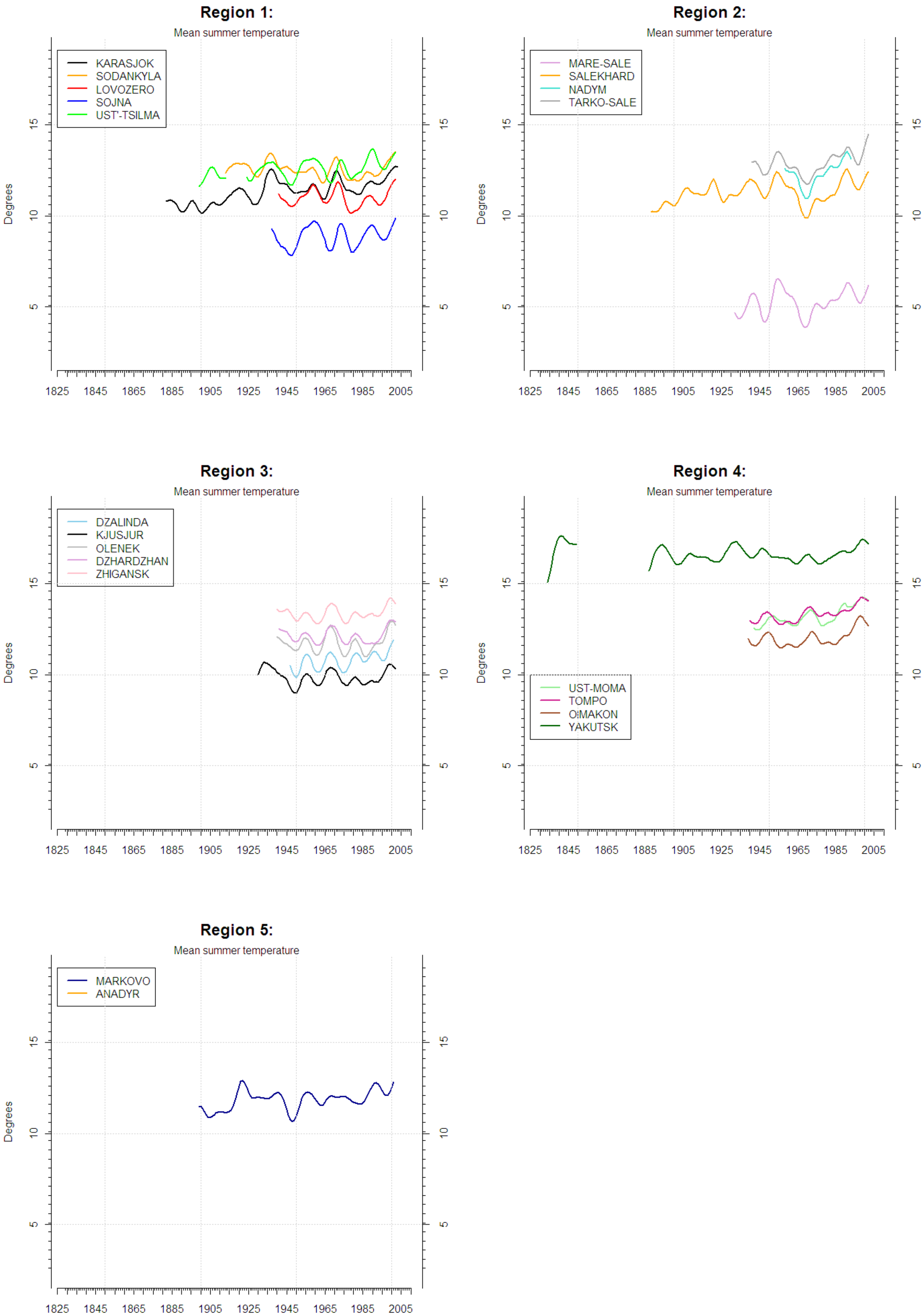


Figure 8: *Summer temperature: Comparison of all stations within the regions 1-5. 10 year Gauss filter.*

### 3.1.3 Cold season and degree days

The cold season has been described by the number of days with mean temperature below the thresholds of 0, -15, and -30°C, and “degree-days” (see definitions in Chapter 2.2.5). A comparison of the last normal period (1961-1990) and the period of 1979-2008 have been performed for 11 stations from Karasjok in the west to Anadyr in the east (Tables 8 and 9).

Number of days below 0°C indicates a clear decrease in the whole region with the stronger signals at maritime influenced stations like Karasjok (-7.2 days) and Anadyr (-6.4 days), while stations in continental regions like Zhigansk (-0.7) and Oimakon (-1.1) hardly have any decrease at all. The decrease in number of days below -15 and -30°C does not show the same spatial pattern. The three stations to the west, Karasjok (-6.3 days), Sodankylä (-6.8 days), Lovozero (-7.8), show the greater decrease while Zigansk (-1.9 days) and Anadyr (-1.8 days) has the least reduction of days below -15°C. The three stations with the greater reduction are also the three stations with the least number of days below -15°C. The 4 stations, Zhigansk (-3.9 days), Olenek (-8.2 days), Oimakon (-5.7 days), and Yakutsk (-7.1 days) with the greater number of days below -30°C show the greater reduction in number of days. Converting the number of days in Table 8 to percentages shows again that the westerly stations have great reductions with Karasjok loosing 27% of the days with temperature below -30°C.

The sets of Figures 9- 14 show the long term development of degree days and number of cold days for the sites. Unfortunately only a few of the stations do contain a continuous series of measurements for longer periods of time. In Region 1 this include Karasjok, Sodankylä, and Ust-Tsilma, Region 2 does not contain any stations with this long-term development. Region 3 has some fractions of series at Dzhardansk and Olenek, while Oimakon and Yakutsk indicates the long term development in Region 4. Both Anadyr and Markovo has series reaching back to the 1940s.

In Figure 9 is the degree days for the Regions 1 and 2 presented. The tendency in Region 1 is a warming period culminating in the 1930s. From about 1930 to about 1970 there is a period where the degree days number decrease, e.g. at Sodankylä does the number of degree days with threshold 0°C go from ca -1500 to ca -2000. From ca 1960 to today does the number increase to approximately the same numbers as in the 1930s. The same tendency might be tracked at Karasjok and Ust-Tsilma. The figures also give a clear indication of large variations on annual and decadal scale. The series in Region 2 are too short for proper investigations.

Region 3 (Figure 10) indicates a change resulting in increasing degree days, unfortunately the series are too fractioned to give a complete picture of the development. Yakutsk in Region 4 (Figure 10) show an increase in degree days from about -5800 in the 1950s to about -5100 for degree days with threshold of 0°C. The datasets before 1940 are too incomplete to reveal anything about the development. The same pattern emerges for the other thresholds.

Region 5 is presented in Figure 11. For degree days with threshold 0°C there are small increases, e.g. at Markovo the degree days change from about -4500 to about -4100. For the other thresholds there are no significant changes.

Figure 12 shows the development of the duration of the cold season. Region 1 is still the region with the longest continuous dataset. Here a steady decrease of number of days below 0°C is revealed. The other regions show a similar trend, but have got shorter series of data.

Figure 13 shows the number of days with temperature below -15°C. There are sign of decreasing number of days, but the signal is not quite as strong as for days with temperature below 0°C. The really cold days are shown in Figure 14 where the threshold is -30°C. Region 1 shows a small decrease, but the small number of days makes it hard to se any trend. The only region that displays a trend in the graphs is Region 4 where Yakutsk drops from 100 days with temperatures below -30°C to about 85 days.

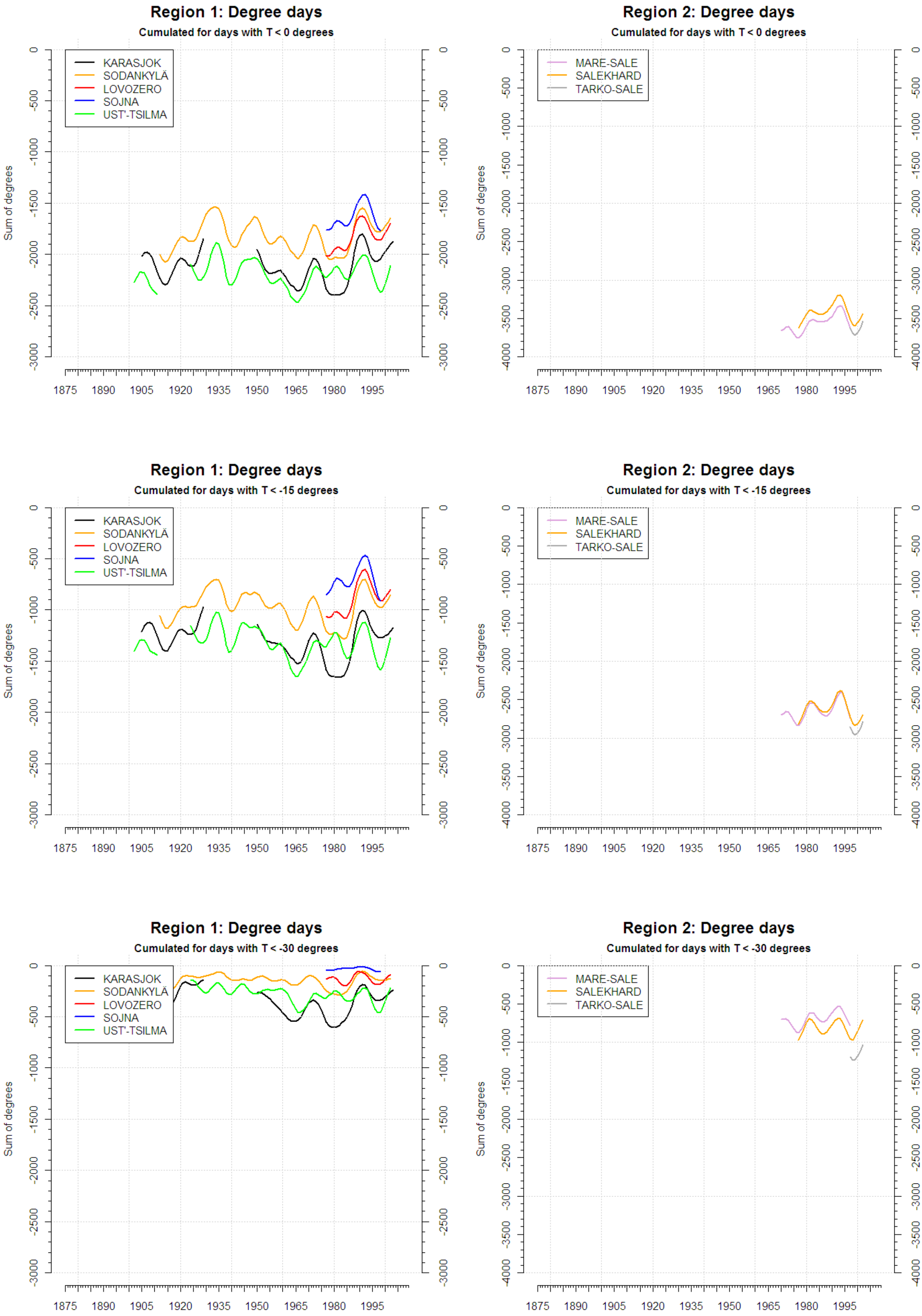


Figure 9: *Degree days: Comparison of all stations within the regions 1 and 2. 10 year Gauss filter.*

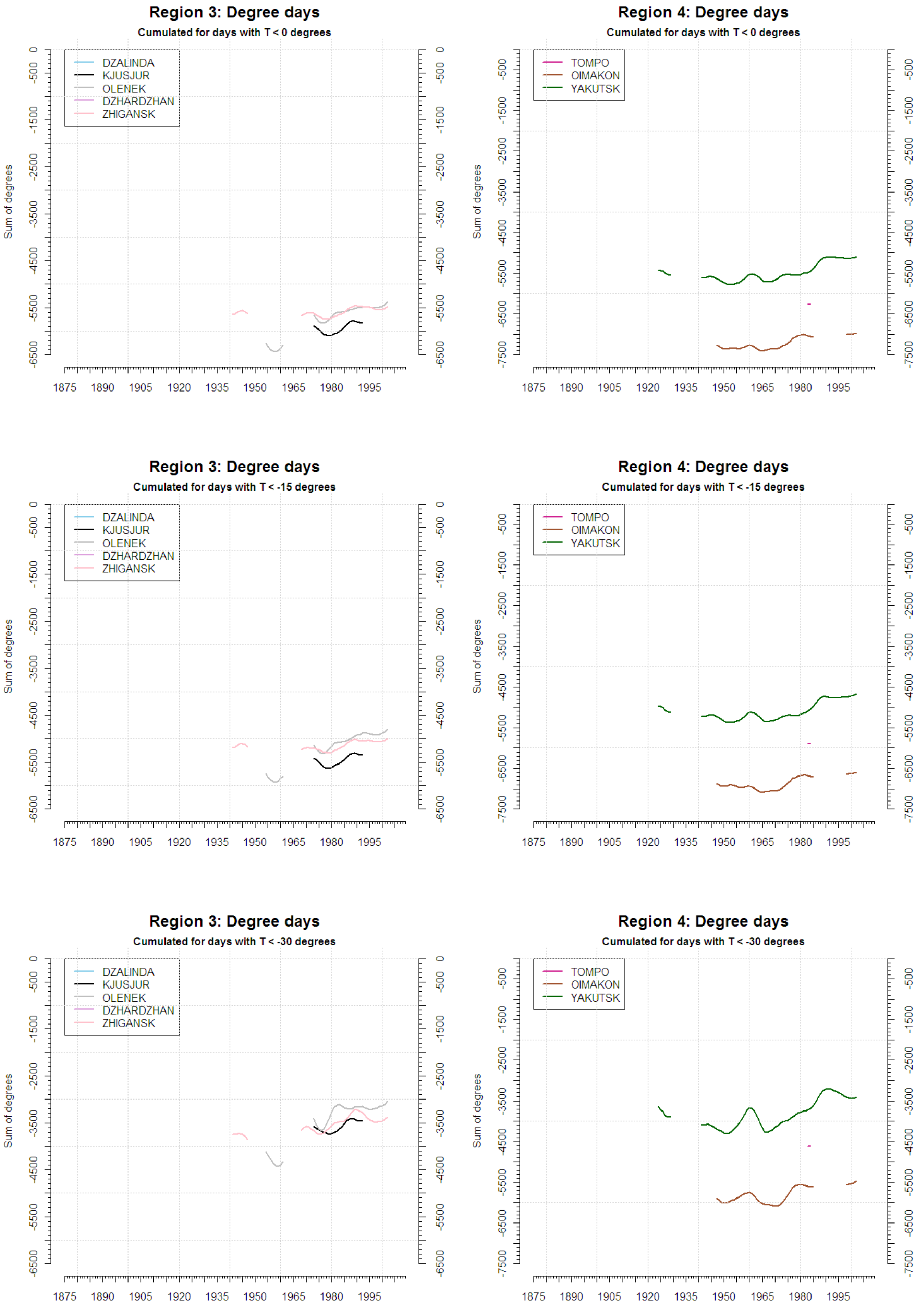


Figure 10: *Degree days: Comparison of all stations within the regions 3 and 4. 10 year Gauss filter.*

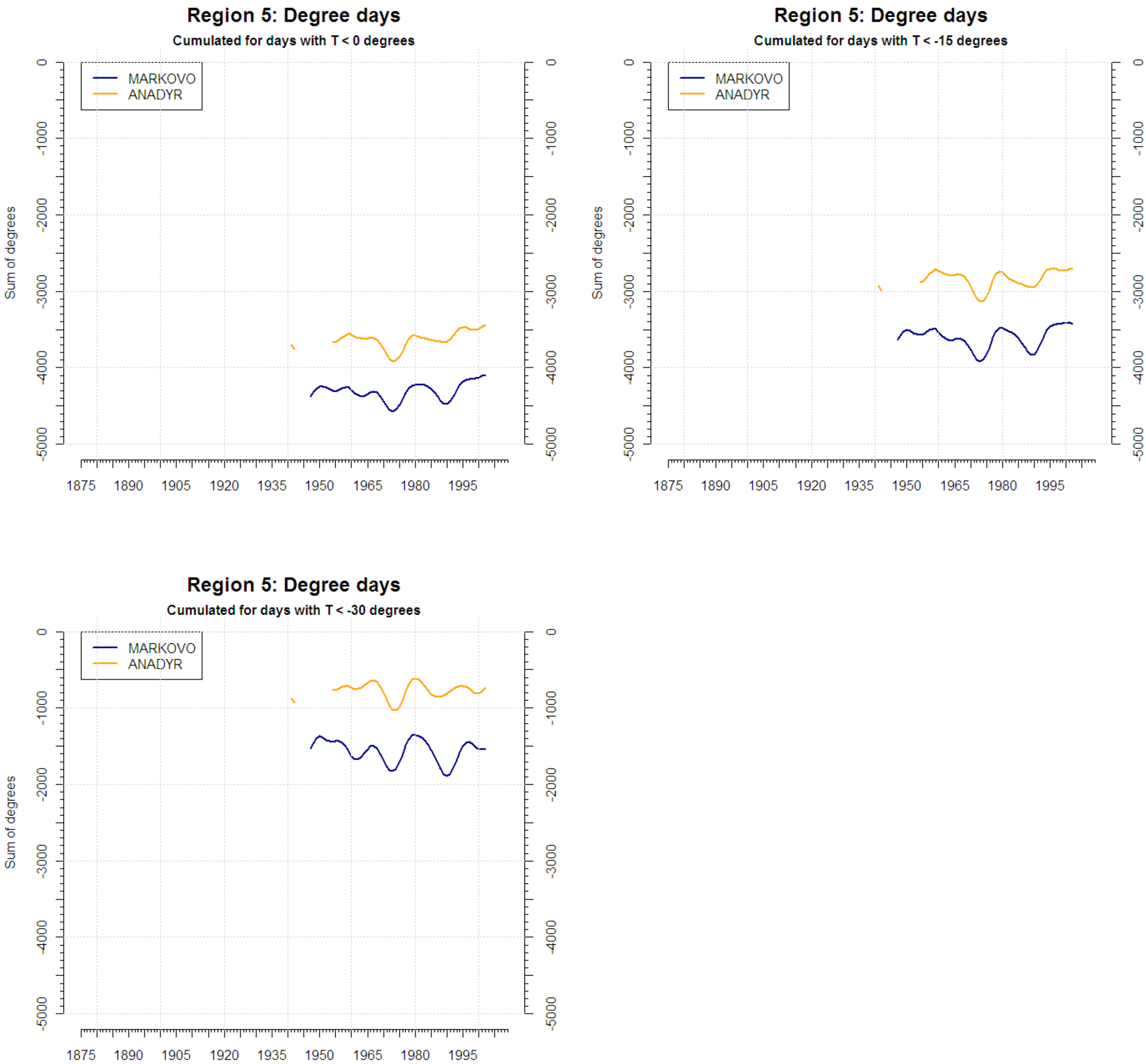


Figure 11: *Degree days: Comparison of all stations within the region 5. 10 year Gauss filter.*

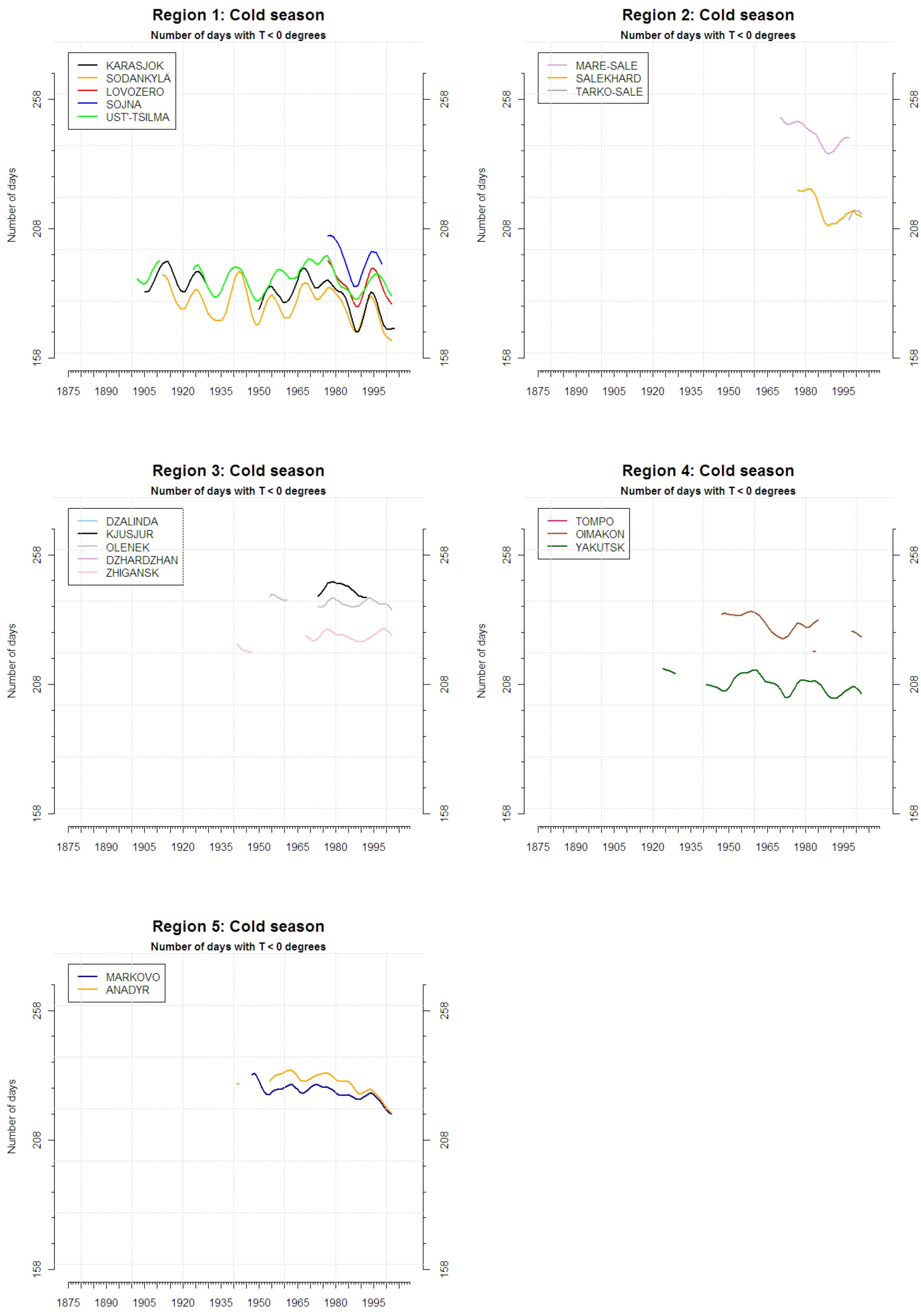


Figure 12: *Cold season: Comparison of all stations within the five regions. 10 year Gauss filter.*

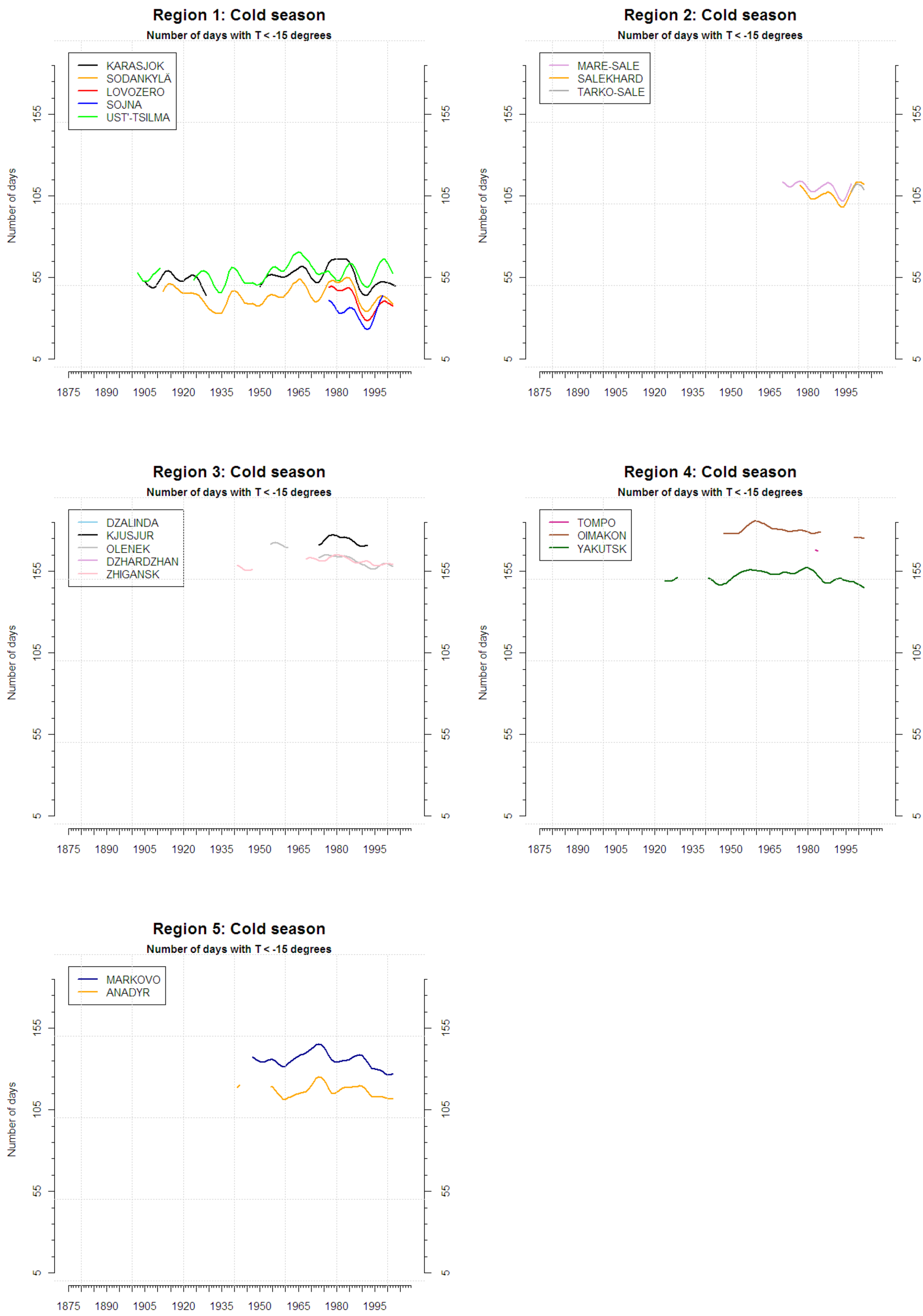


Figure 13: *Cold season: Comparison of all stations within the five regions. 10 year Gauss filter.*

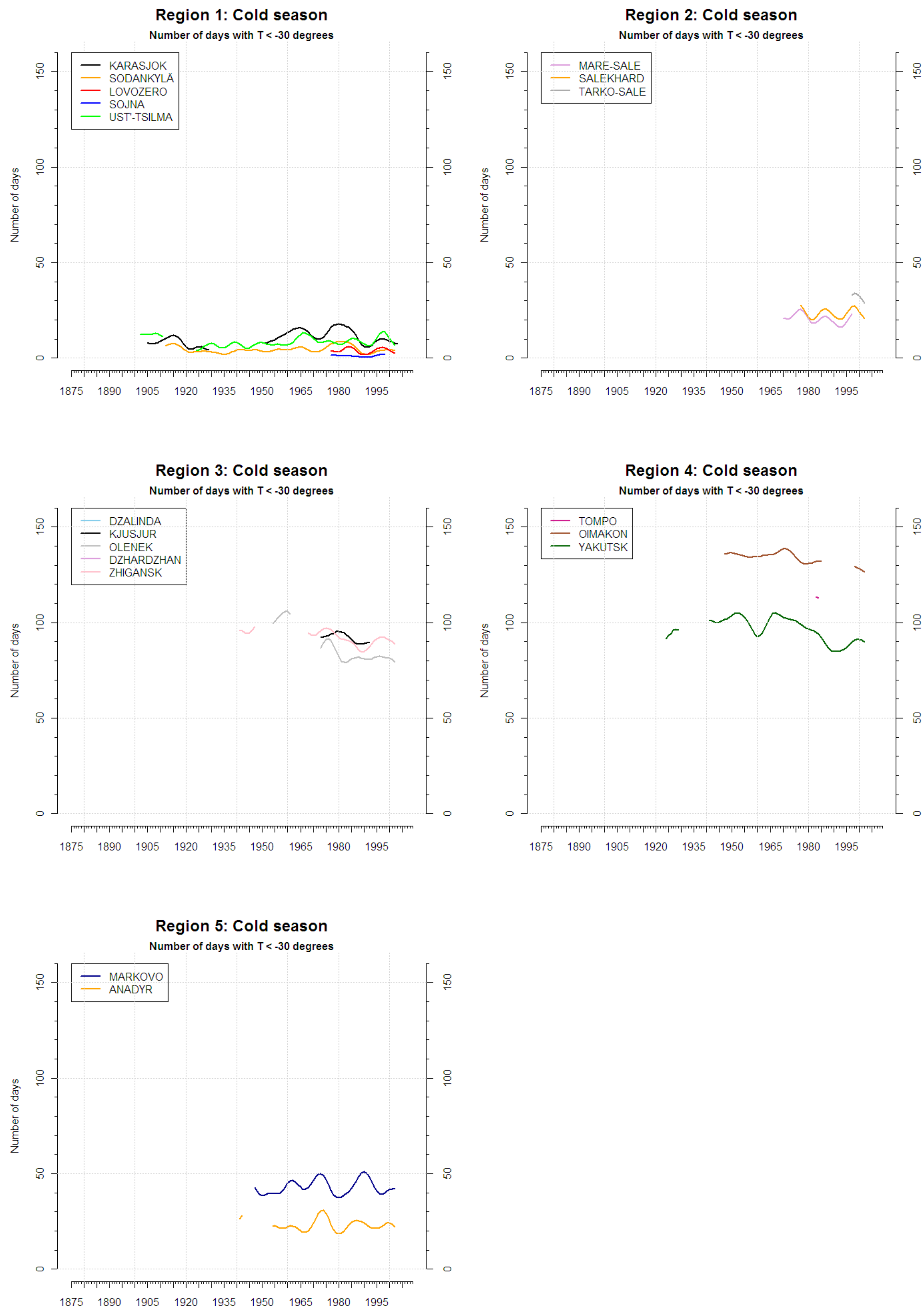


Figure 14: *Cold season: Comparison of all stations within the five regions. 10 year Gauss filter.*

| | | 1961-90 | 1979-08 | Difference |
|---|---|---|---|---|
| **Region 1** | | | | |
| 97250 | Karasjok | 182.7 | 175.5 | -7.2 |
| 7501 | Sodankylä | 178.8 | 172.6 | -6.2 |
| 22127 | Lovozero | 187.3 | 183.9 | -3.4 |
| 22271 | Sojna | - | 193.2 | - |
| 23405 | Ust'-tsilma | 189.1 | 184.6 | -4.5 |
| **Region 2** | | | | |
| 23552 | Tarko-sale | - | - | - |
| 23330 | Salekhard | 220.7 | 214.6 | -6.1 |
| 23032 | Mare-sale | 246.1 | - | - |
| 23445 | Nadym | - | - | - |
| **Region 3** | | | | |
| 21921 | Kjusjur | - | 241.8 | - |
| 24343 | Zhigansk | 226.7 | 226.0 | -0.7 |
| 24143 | Dzhardzhan | - | - | - |
| 21908 | Dzalinda | - | - | - |
| 24125 | Olenek | 239.6 | 238.0 | -1.6 |
| **Region 4** | | | | |
| 24382 | Ust-moma | - | - | - |
| 24671 | Tompo | - | - | - |
| 24688 | Oimakon | 230.4 | 229.3 | -1.1 |
| 24959 | Yakutsk | 207.6 | 205.7 | -1.9 |
| **Region 5** | | | | |
| 25551 | Markovo | 227.2 | 223.2 | -4.0 |
| 25563 | Anadyr | 231.9 | 225.5 | -6.4 |

Table 8: *Number of days with temperatures below 0°C for the periods 1961-1990 and 1979-2008, and change in number of days.*

| Station number | Station name | -15 degrees | | | -30 degrees | | |
|---|---|---|---|---|---|---|---|
| | | 1961-90 | 1979-08 | Difference | 1961-90 | 1979-08 | Difference |
| **Region 1** | | | | | | | |
| 97250 | Karasjok | 60.0 | 53.7 | -6.3 | 14.0 | 10.2 | -3.8 |
| 7501 | Sodankylä | 49.7 | 42.9 | -6.8 | 5.7 | 4.6 | -1.1 |
| 22127 | Lovozero | 46.4 | 38.6 | -7.8 | 3.8 | 3.6 | -0.2 |
| 22271 | Sojna | - | 32.4 | - | - | 1.0 | - |
| 23405 | Ust'-tsilma | 61.2 | 55.9 | -5.3 | 9.4 | 8.0 | -1.4 |
| **Region 2** | | | | | | | |
| 23552 | Tarko-sale | - | - | - | - | - | - |
| 23330 | Salekhard | 110.8 | 105.5 | -5.3 | 25.4 | 22.2 | -3.2 |
| 23032 | Mare-sale | 111.3 | - | - | 21.1 | - | - |
| 23445 | Nadym | - | - | - | - | - | - |
| **Region 3** | | | | | | | |
| 21921 | Kjusjur | - | 171.7 | - | - | 89.6 | - |
| 24343 | Zhigansk | 162.5 | 160.6 | -1.9 | 92.8 | 88.9 | -3.9 |
| 24143 | Dzhardzhan | - | - | - | - | - | - |
| 21908 | Dzalinda | - | - | - | - | - | - |
| 24125 | Olenek | 164.6 | 160.0 | -4.6 | 87.5 | 79.3 | -8.2 |
| **Region 4** | | | | | | | |
| 24382 | Ust-moma | - | - | - | - | - | |
| 24671 | Tompo | - | - | - | - | - | - |
| 24688 | Oimakon | 180.1 | 176.7 | -3.4 | 133.8 | 128.1 | -5.7 |
| 24959 | Yakutsk | 153.0 | 149.2 | -3.8 | 96.8 | 89.7 | -7.1 |
| **Region 5** | | | | | | | |
| 25551 | Markovo | 138.4 | 133.3 | -5.1 | 43.9 | 42.4 | -1.5 |
| 25563 | Anadyr | 117.8 | 116.0 | -1.8 | 23.4 | 22.2 | -1.2 |

Table 9: *Number of days with temperatures below -15 and -30°C for the periods 1961-1990 and 1979-2008, and change in number of days.*

### 3.1.4 Growing season and degree days

The same 11 stations as in Section 3.1.3, with an addition of Sojna and Mare-Sale, is analysed regarding growing season and growing degree days (see definition in Chapter 2.2.6).

A comparison of the normal period and the period of 1979-2008 (Table 10) reveals an increase in growing season. Region 2 has the greater increase with 5.9 days at Salekhard and Mare-Sale, while Region 3 and 4 has the least change with e.g. 1.7 days at Zhigansk and 2.0 days at Olenek. For Region 1 Sojna deviates from the others with only 1.1 day increase while the other stations in the region varies from 3.3 to 6.5 days increase.

Looking at the development over a longer period of time (Figure 15) reveals a steady increase in growing season since the 1960s for Region 1. Before the 1960s the growing season seems to be fairly stable with decadal variations. The present lengths of growing season in Region 1 seem slightly longer than previous peaks in the 1940s and 1950s. Region 2 has fairly short series, but shows a clear increase. Region 3 and 4 does not show any clear change in growing season. Region 5 reveals a clear increase in the growing season, e.g. Markovo had less than 100 days in the 1950s and about 110 days now.

Figure 16 shows the long-term development of growing degree days (GDD). Region 1 has fairly stable number of growing degree days from start of the century to 1980s. After the 1980s, the GDD does clearly increase, e.g. Sodankylä changes from about 1400 to 1600. Region 2 indicates a small increase, but the series are too short to be conclusive. Again there are no clear sign of change in Region 3 and 4. Region 5 has a clear increase since the 1940s. For Markovo, the GDD changes from about 1050 to about 1400.

| | | | | |
|---|---|---|---|---|
| **Region 1** | | | | |
| 97250 | Karasjok | 118.1 | 121.4 | 3.3 |
| 7501 | Sodankylä | 124.6 | 128.4 | 3.8 |
| 22127 | Lovozero | 113.2 | 117.2 | 4.0 |
| 22271 | Sojna | 105.5 | 106.6 | 1.1 |
| 23405 | Ust'-tsilma | 118.0 | 124.5 | 6.5 |
| **Region 2** | | | | |
| 23552 | Tarko-sale | - | - | - |
| 23330 | Salekhard | 99.1 | 105.0 | 5.9 |
| 23032 | Mare-sale | 49.0 | 55.8 | 6.8 |
| 23445 | Nadym | - | - | - |
| **Region 3** | | | | |
| 21921 | Kjusjur | - | 84.2 | - |
| 24343 | Zhigansk | 105.2 | 106.9 | 1.7 |
| 24143 | Dzhardzhan | 95.8 | - | - |
| 21908 | Dzalinda | - | - | - |
| 24125 | Olenek | 91.8 | 93.8 | 2.0 |
| **Region 4** | | | | |
| 24382 | Ust-moma | - | - | - |
| 24671 | Tompo | - | - | - |
| 24688 | Oimakon | 103.7 | 107.1 | 3.4 |
| 24959 | Yakutsk | 128.6 | 130.9 | 2.3 |
| **Region 5** | | | | |
| 25551 | Markovo | 101.2 | 105.4 | 4.2 |
| 25563 | Anadyr | 86.1 | 93.1 | 7.0 |

Table 10: *Growing season: Number of days with temperatures abowe $+5°$ for the periods 1961-1990 and 1979-2008, and change in number of days.*

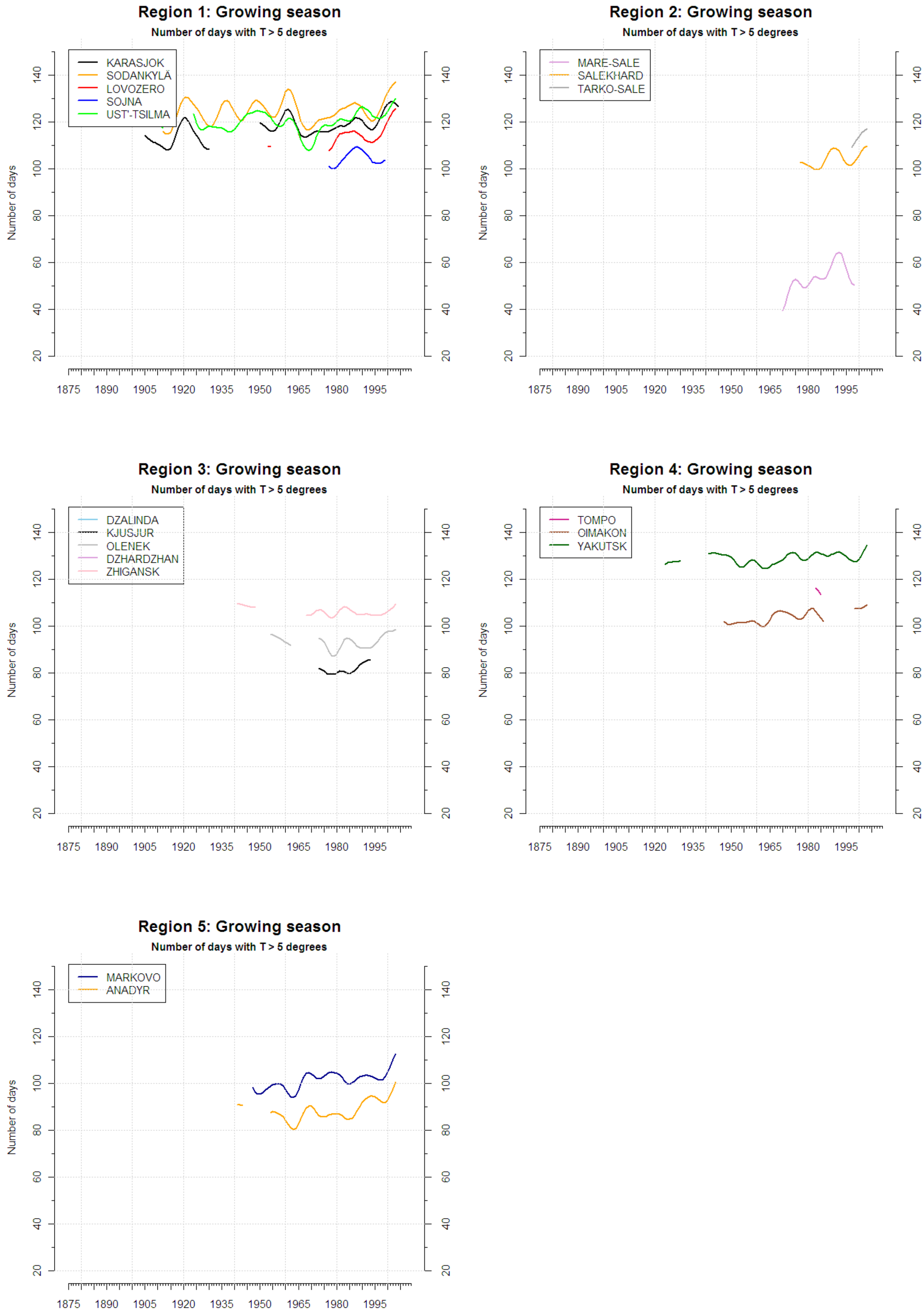


Figure 15: *Growing season: Comparison of all stations within the regions 1-5. 10 year Gauss filter.*

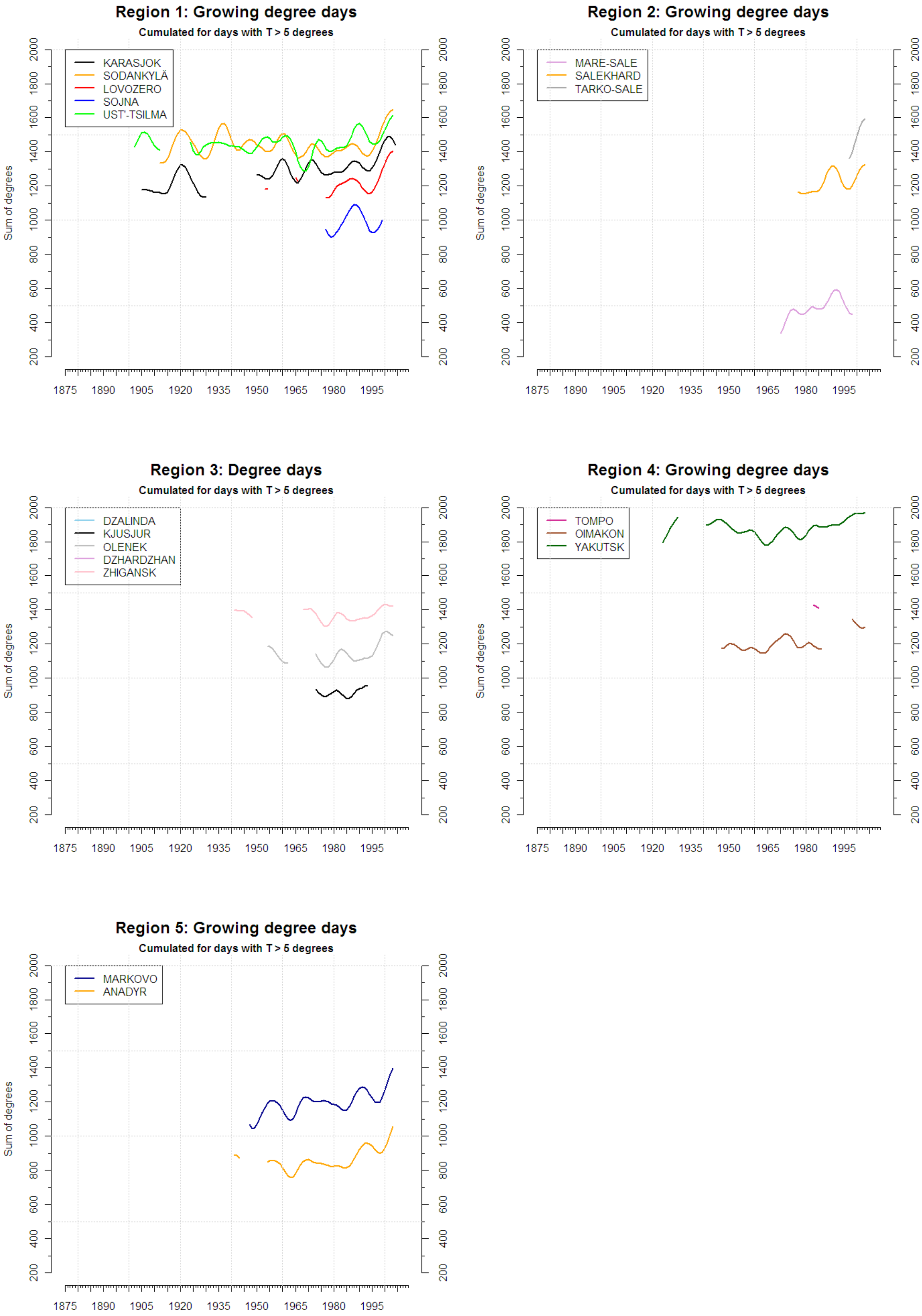


Figure 16: *Growing season: Comparison of all stations within the five regions. 10 year Gauss filter.*

## 3.2 Precipitation

Observations suggest that it is probable that total annual precipitation has increased by roughly 14% in the Arctic north of 60°N over the past century (ACIA, 2005). The greatest increases were observed in autumn and winter. However, uncertainties in measuring precipitation in the cold Arctic environment (Førland and Hanssen-Bauer, 2000) and the sparseness of data in parts of the region limit confidence in these results. There are large regional variations in precipitation across the Arctic, and also large regional variations in the changes in precipitation. According to ACIA (2005) the precipitation increased by about 2% per decade during the Arctic warming in the first half of the 20th century (1900-1945), with significant trends in the Nordic region. During the two decades of Arctic cooling (1946-1965, cf. Chapter 3.1.1), the high latitude precipitation increase was roughly 1% per decade. Since 1966, annual precipitation has increased at about the same rate as during the first half of the 20th century. Also IPCC (2007) states that there has been a widespread increase in precipitation over northernmost Europe during 1900-2005. For Northern Norway and the Svalbard region the annual precipitation has increased by ca. 2-3% per decade during the latest 100 years (Førland et al., 2009).

Details of instrumentation, gauge types, relocation of stations and inhomogeneities in the Russian precipitation series discussed in this report are given by Svyashchennikov and Førland (2010).

### 3.2.1 Annual precipitation

Table 12 shows that the measured annual precipitation for the normal period 1961-90 varies from below 200 mm at Ust-Mona in Region 4 to more than 550 mm at Ust-Tsilma in Region 1. Generally the lowest annual values are found for Region 3 and 4.

Trend analysis for the long-tem variability of annual precipitation is hampered by periods of missing data, and is just performed for eight stations (Table 11). The two stations (Markovo and Anadyr) in Region 5 have experienced a strong and statistically significant increase of 5-8% per decade in annual precipitation. Also in the other four regions, significant increases (2-3% per decade) in annual precipitation are found. These trends are thus on the same level as for Northern-Norway and Svalbard (Førland et al., 2009) and for the Arctic as a whole (ACIA, 2005). For the period 1943-2008, Svyashchennikov and Førland (2010) found statistically significant positive trends in annual precipitation for Lovozero, Mare-Sale and Yakutsk. For the other stations they found no significant trends during this period. The precipitation series are not tested for possible inhomogeneities, and particularly the change from Nifer to Tretyakov type gauge during 1946-1960 (Svyashchennikov and Førland, 2010) may have influenced the trends through changed catch efficiency of the precipitation gauges.

The long-term decadal-scale variability in annual precipitation is outlined by Gaussian low-pass filters in Figure 17 and 18. The figures illustrate that even on decadal scale there are large local differences in the long-term variability. However, for most stations there is a tendency to increasing annual precipitation during the latest decades.

These features are supported by Table 12;- indicating that most stations have higher annual precipitation in the recent 30-year period 1979-2008 compared to the standard normal period 1961-90. In Region 2 all stations have higher values in the most recent 30-year period, while in Region 4 there are only minor changes.


Figure 17: *Normalized annual precipitation sum: Comparison of all stations within the regions 1-5. 10 year Gauss filter.*


Figure 18: *Annual precipitation sum (absolute values): Comparison of all stations within the regions 1-5. 10 year Gauss filter.*

| Station number | Station Name | Linear trend (% per decade) | | | | |
|---|---|---|---|---|---|---|
| | | Annual | Autumn | Winter | Spring | Summer |
| **Region 1** | | | | | | |
| 97250 | Karasjok | **2.1*** | 0.8 | 2.9* | 3.3* | 2.3* |
| 7501 | Sodankylä | 0.5 | -1.0 | **3.0*** | 1.5 | -0.3 |
| 22127 | Lovozero | - | - | - | - | - |
| 22271 | Sojna | - | - | - | - | - |
| 23405 | Ust'-tsilma | **1.5*** | 1.2 | 3.2 | 1.9* | 0.6 |
| **Region 2** | | | | | | |
| 23552 | Tarko-sale | - | - | - | - | - |
| 23330 | Salekhard | **3.3*** | **2.9*** | **5.3*** | **4.5*** | 2.7* |
| 23032 | Mare-sale | - | - | - | - | - |
| 23445 | Nadym | - | - | - | - | - |
| **Region 3** | | | | | | |
| 21921 | Kjusjur | 2.7* | 1.7 | 5.0 | 0.2 | 3.3* |
| 24343 | Zhigansk | - | - | - | - | - |
| 24143 | Dzhardzhan | - | - | - | - | - |
| 21908 | Dzalinda | - | - | - | - | - |
| 24125 | Olenek | - | - | - | - | - |
| **Region 4** | | | | | | |
| 24382 | Ust-moma | - | - | - | - | - |
| 24671 | Tompo | - | - | - | - | - |
| 24688 | Oimakon | - | - | - | - | - |
| 24959 | Yakutsk | **2.6*** | **4.8*** | **3.9*** | 2.9* | 1.1 |
| **Region 5** | | | | | | |
| 25551 | Markovo | **5.3*** | **6.7*** | **8.4*** | **9.8*** | 1.8 |
| 25563 | Anadyr | **7.6*** | **8.0*** | **11.8***| **12.4*** | 0.2 |

Table 11: *Least squares linear trends in annual and seasonal precipitation series (% per decade) during the period 1900-2008. Trends significant at the 1% level according to the Mann-Kendall test are shown in* **bold** *type, while trends significant at the 5% level are marked with a "*". Precipitation series starting later than 1900 are excluded from the analysis.*

| | | 1961-90 | 1979-08 | Difference |
|---|---|---|---|---|
| **Region 1** | | | | |
| 97250 | Karasjok | 364.8 | 379.6 | 14.8 |
| 7501 | Sodankylä | 499.3 | 524.5 | 25.2 |
| 22127 | Lovozero | 459.5 | 447.7 | -11.8 |
| 22271 | Sojna | 388.3 | 387.6 | -0.7 |
| 23405 | Ust'-tsilma | 566.5 | 561.8 | -4.7 |
| **Region 2** | | | | |
| 23552 | Tarko-sale | 480.1 | 525.1 | 45.0 |
| 23330 | Salekhard | 450.8 | 470.1 | 19.3 |
| 23032 | Mare-sale | 297.7 | 310.0 | 12.3 |
| 23445 | Nadym | 479.3 | 489.2 | 9.9 |
| **Region 3** | | | | |
| 21921 | Kjusjur | 348.7 | 360.0 | 11.3 |
| 24343 | Zhigansk | 281.4 | 316.8 | 35.4 |
| 24143 | Dzhardzhan | 310.5 | 302.2 | -8.3 |
| 21908 | Dzalinda | 266.1 | 265.4 | -0.7 |
| 24125 | Olenek | 283.2 | 296.6 | 13.4 |
| **Region 4** | | | | |
| 24382 | Ust-moma | 196.7 | 198.7 | 2.0 |
| 24671 | Tompo | 278.4 | 281.9 | 3.5 |
| 24688 | Oimakon | 215.0 | 211.0 | -4.0 |
| 24959 | Yakutsk | 234.8 | 239.4 | 4.6 |
| **Region 5** | | | | |
| 25551 | Markovo | 402.4 | 390.3 | -12.1 |
| 25563 | Anadyr | 341.4 | 383.2 | 41.8 |

Table 12: *Annual precipitation sum (mm) for the periods 1961-1990 and 1979-2008, and change in precipitation.*

### 3.2.2 Seasonal precipitation

Precipitation is normally low during the winter season in this region because air masses usually are stable stratified and contain small amounts of water vapour. For most stations in Region 4, the measured monthly precipitation is lower than 10 mm both in December, January, February, March and April (Table 3). Because of undercatch in the gauges during snowfall combined with low temperatures and strong winds (Førland and Hanssen-Bauer, 2000), the "true" precipitation is probably higher than the uncorrected measured values. However, in this region blowing and drifting snow may also influence the precipitation measurements.

At most stations in the region, the highest monthly precipitation values (cf. Table 3) are found in July and August. The only exceptions are Mare-Sale (September) and Sojna (October).

The long-term decadal-scale variability in seasonal precipitation is outlined by Gaussian low-pass filters in Figure 19- 22. The figures illustrate that even on decadal scale there are large local and regional differences in the long-term variability. For most stations there is a weak tendency to increasing precipitation values during the latest decades, but this picture is not clear-cut. However, as mentioned in Chapter 3.2.1, inhomogeneities caused by changes in gauge types may influence the long-term precipitation variability.

Changes in mean seasonal precipitation from the standard normal period 1961-90 to the most recent 30-year period are outlined in Table 13 and 14. For the spring season most stations have a tendency of increasing precipitation. In Region 5 both stations have increasing values, while in Region 4 most stations have (small) negative changes. For the summer season, all stations in Region 2 and 3 have higher values in the most recent 30-year period, while both stations in Region 5 have lower values. For region 1 both positive and negative differences are found. For the autumn season, all stations in Region 4 have higher values in the latest 30-year period, while most stations in Region 1 have lower values. For the winter season there is a majority of positive changes, but in all regions there are stations with negative and positive changes.

Trend analysis for the period 1900-2008 (Table 11) indicate indicate that all trends found statistically significant (1% and 5% level) are positive for all seasons. For Markovo and Anadyr (Region 5) there is a remarkably strong increase in seasonal precipitation (7-12% per decade) during both autumn, winter and spring. For the period 1943-2008, also Svyashchennikov and Førland (2010) found statistically significant positive trends in seasonal precipitation during autumn, winter and spring for several stations in the region. Table 11 shows that for the summer season no precipitation trends are significant at the 1%-level. Similarly in their study, Svyashchennikov and Førland (2010) found no significant trends during the summer season.

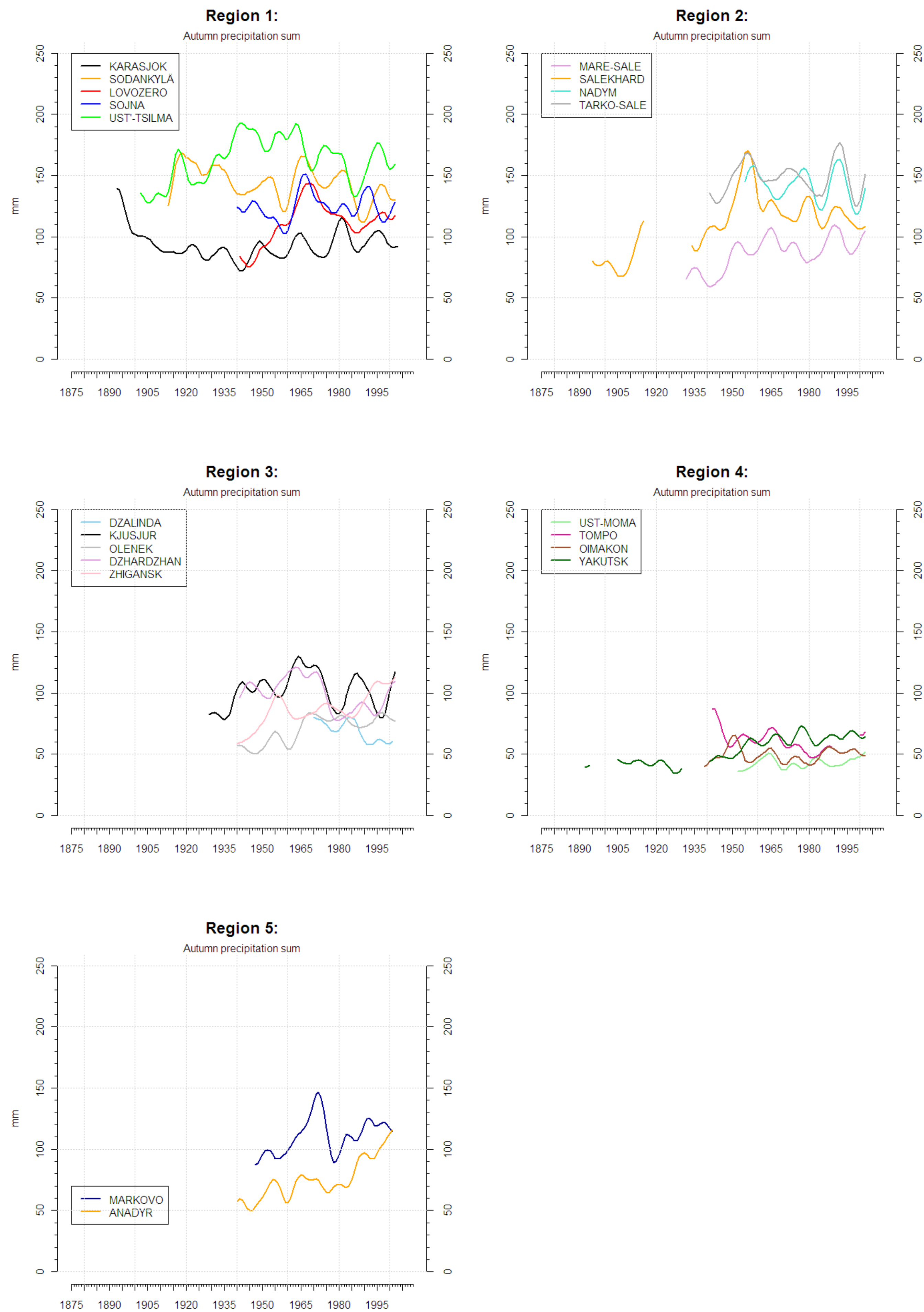


Figure 19: *Autumn precipitation sum (absolute values): Comparison of all stations within the regions 1-5. 10 year Gauss filter.*


Figure 20: *Winter precipitation sum (absolute values): Comparison of all stations within the regions 1-5. 10 year Gauss filter.*

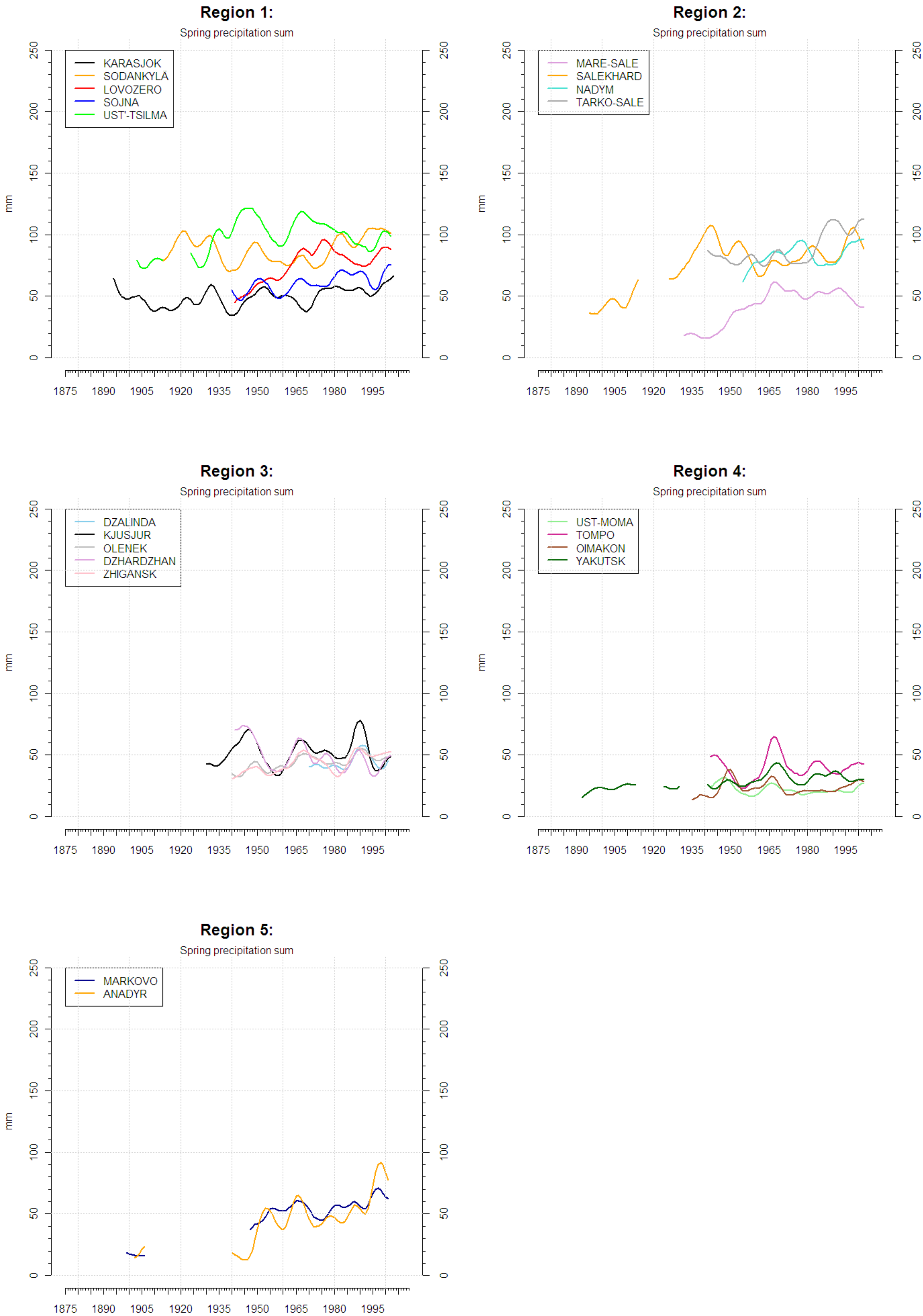


Figure 21: *Spring precipitation sum (absolute values): Comparison of all stations within the regions 1-5. 10 year Gauss filter.*

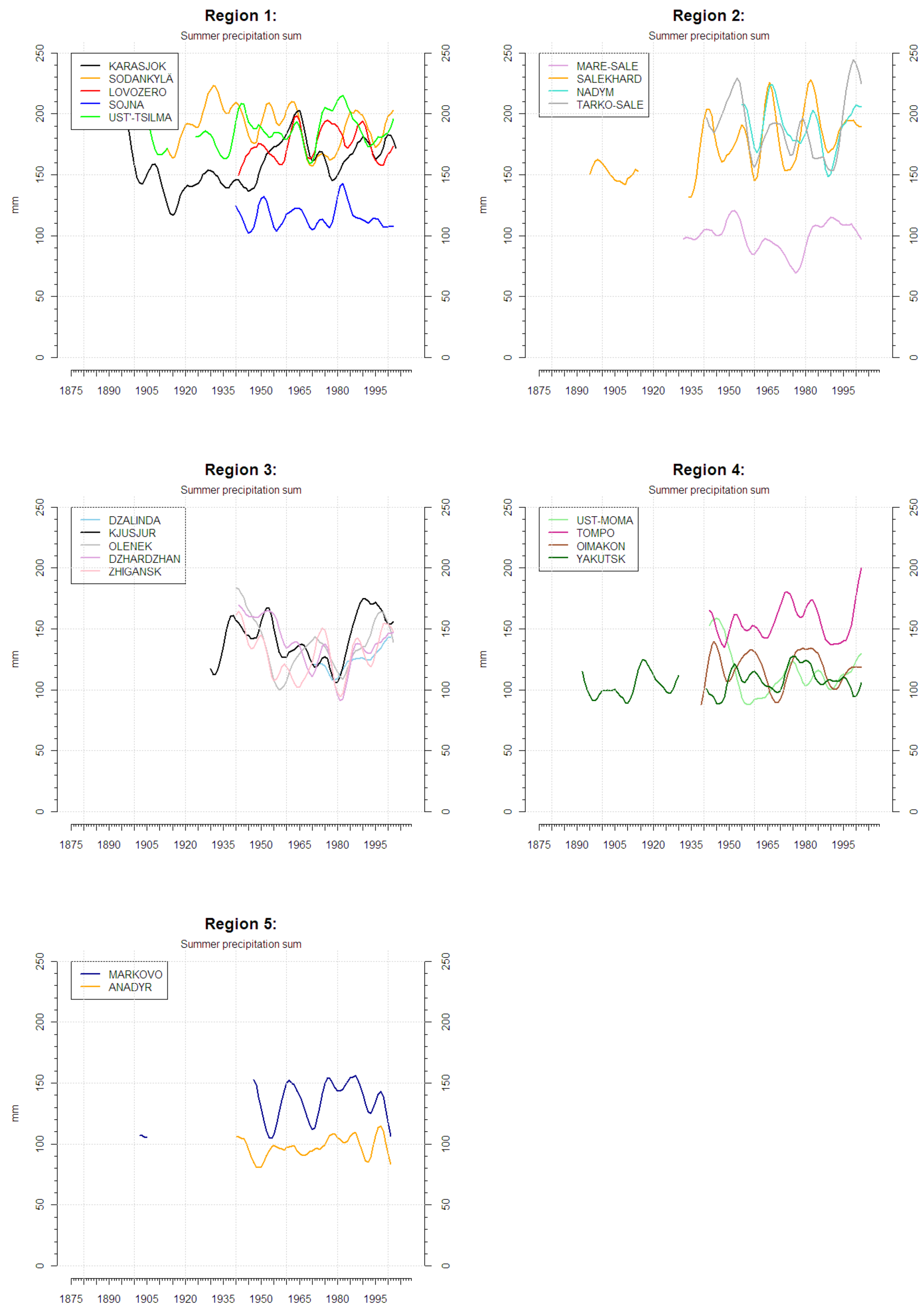


Figure 22: *Summer precipitation sum (absolute values): Comparison of all stations within the regions 1-5. 10 year Gauss filter.*

| Station number | Station name | Autumn | | | Winter | | |
|---|---|---|---|---|---|---|---|
| | | **1961-90** | **1979-08** | **Difference** | **1961-90** | **1979-08** | **Difference** |
| **Region 1** | | | | | | | |
| 97250 | Karasjok | 95.6 | 98.5 | 2.9 | 47.8 | 53.8 | 6.0 |
| 7501 | Sodankylä | 145.7 | 136.3 | -9.4 | 87.4 | 99.7 | 12.3 |
| 22127 | Lovozero | 120.2 | 115.6 | -4.6 | 68.3 | 71.6 | 3.3 |
| 22271 | Sojna | 127.0 | 125.5 | -1.5 | 77.8 | 77.5 | -0.3 |
| 23405 | Ust'-tsilma | 164.8 | 160.9 | -3.9 | 103.7 | 103.5 | -0.2 |
| **Region 2** | | | | | | | |
| 23552 | Tarko-sale | 144.1 | 148.5 | 4.4 | 74.3 | 83.4 | 9.1 |
| 23330 | Salekhard | 119.2 | 117.7 | -1.5 | 64.8 | 69.9 | 5.1 |
| 23032 | Mare-sale | 92.8 | 97.0 | 4.2 | 58.9 | 57.4 | -1.5 |
| 23445 | Nadym | 140.3 | 141.9 | 1.6 | 67.9 | 73.5 | 5.6 |
| **Region 3** | | | | | | | |
| 21921 | Kjusjur | 111.5 | 102.4 | -9.1 | 50.1 | 51.5 | 1.4 |
| 24343 | Zhigansk | 84.4 | 99.6 | 15.2 | 29.8 | 38.1 | 8.3 |
| 24143 | Dzhardzhan | 100.6 | 91.6 | -9.0 | 37.2 | 36.6 | -0.6 |
| 21908 | Dzalinda | 77.1 | 66.8 | -10.3 | - | 23.7 | - |
| 24125 | Olenek | 76.2 | 78.4 | 2.2 | 32.9 | 36.3 | 3.4 |
| **Region 4** | | | | | | | |
| 24382 | Ust-moma | 42.9 | 46.0 | 3.1 | 24.1 | 19.4 | -4.7 |
| 24671 | Tompo | 58.3 | 63.1 | 4.8 | 16.4 | 16.7 | 0.3 |
| 24688 | Oimakon | 49.0 | 50.7 | 1.7 | 25.6 | 19.3 | -6.3 |
| 24959 | Yakutsk | 62.6 | 65.3 | 2.7 | 26.7 | 28.1 | 1.4 |
| **Region 5** | | | | | | | |
| 25551 | Markovo | 114.6 | 113.8 | -0.8 | 88.3 | 81.5 | -6.8 |
| 25563 | Anadyr | 76.4 | 94.1 | 17.7 | 113.7 | 130.0 | 16.3 |

Table 13: *Autumn and winter precipitation sum (mm) for the periods 1961-1990 and 1979-2008, and change in precipitation.*

| Station number | Station name | Spring | | | Summer | | |
|---|---|---|---|---|---|---|---|
| | | 1961-90 | 1979-08 | Difference | 1961-90 | 1979-08 | Difference |
| **Region 1** | | | | | | | |
| 97250 | Karasjok | 51.3 | 59.3 | 8.0 | 170.7 | 167.7 | -3.0 |
| 7501 | Sodankylä | 83.3 | 98.9 | 15.6 | 183.2 | 188.8 | 5.6 |
| 22127 | Lovozero | 84.8 | 82.6 | -2.2 | 186.7 | 177.8 | -8.9 |
| 22271 | Sojna | 62.8 | 68.2 | 5.4 | 119.8 | 116.3 | -3.5 |
| 23405 | Ust'-tsilma | 105.8 | 97.7 | -8.1 | 192.4 | 198.7 | 6.3 |
| **Region 2** | | | | | | | |
| 23552 | Tarko-sale | 85.8 | 102.0 | 16.2 | 175.5 | 191.1 | 15.6 |
| 23330 | Salekhard | 79.2 | 87.5 | 8.3 | 187.1 | 194.3 | 7.2 |
| 23032 | Mare-sale | 51.9 | 49.2 | -2.7 | 93.5 | 105.4 | 11.9 |
| 23445 | Nadym | 85.1 | 85.5 | 0.4 | 185.4 | 188.3 | 2.9 |
| **Region 3** | | | | | | | |
| 21921 | Kjusjur | 55.4 | 51.1 | -4.3 | 131.2 | 156.1 | 24.9 |
| 24343 | Zhigansk | 45.7 | 47.1 | 1.4 | 120.9 | 131.9 | 11.0 |
| 24143 | Dzhardzhan | 47.9 | 43.6 | -4.3 | 124.3 | 130.7 | 6.4 |
| 21908 | Dzalinda | 42.1 | 47.1 | 5.0 | 120.8 | 126.5 | 5.7 |
| 24125 | Olenek | 45.6 | 48.2 | 2.6 | 129.0 | 133.6 | 4.6 |
| **Region 4** | | | | | | | |
| 24382 | Ust-moma | 21.8 | 21.4 | -0.4 | 107.8 | 111.8 | 4.0 |
| 24671 | Tompo | 43.1 | 39.9 | -3.2 | 160.1 | 163.3 | 3.2 |
| 24688 | Oimakon | 22.6 | 23.5 | 0.9 | 117.9 | 117.5 | -0.4 |
| 24959 | Yakutsk | 33.4 | 32.4 | -1.0 | 111.6 | 113.7 | 2.1 |
| **Region 5** | | | | | | | |
| 25551 | Markovo | 55.8 | 61.9 | 6.1 | 143.4 | 133.5 | -9.9 |
| 25563 | Anadyr | 49.8 | 64.1 | 14.3 | 102.6 | 98.0 | -4.6 |

Table 14: *Spring and summer precipitation sum (mm) for the periods 1961-1990 and 1979-2008, and change in precipitation.*

## 3.3 Snow

Snow cover extent over higher northern latitudes has declined by about 10% over the past 30 years, and model projections suggest that it will decrease an additional 10-20% before the end of this century (ACIA, 2005). Also the latest IPCC report (IPCC, 2007) concluded that the snow cover has decreased in most regions, especially in spring. The Northern Hemisphere snow cover observed by satellite over the 1966-2005 period decreased in every month except November and December, with a stepwise drop of 5% in the annual mean in the late 1980s (IPCC, 2007).

For Norway, Dyrrdal and Vikhamar-Schuler (2009) found that the snow season has decreased during the latest hundred years at most of the 41 long-term snow series they analysed. At most stations there was a clear tendency to a later start and an earlier end of the snow season. Also for maximum annual snow depth they found a majority of negative trends. However, for maximum daily increase in snow depth (i.e. an indicator for heavy snowfalls) they found a tendency to increasing values in North Norway.

### 3.3.1 Snow season: start, end and duration

At most stations in the region there are in average more than 200 days per year when the ground is covered by snow, and at some stations there is a snow cover in around 2/3 of the year. The long-term graphs in Figure 23 reveal substantial decadal scale variability in snow season duration. For some stations the difference between highest and lowest decadal values of snow cover duration are more than 30 days. Figure 24 shows that the snow accumulation on the ground starts in the first part of October at most stations, but in Region 3 the snow season often starts in the end of September. Even on a decadal scale there are large temporal variations in the end of the snow season (Figure 25);- from late April till mid-June.

Event though there is a large variability on a decadal scale in Figure 23, the values in Table 15 show that there are only minor differences in snow season duration between the most recent 30-year period (1979-2008) and the normal period 1961-90. For the period 1943-2008 Svyashchennikov and Førland (2010) found statistically significant trends in snow cover duration at two stations (Mare-Sale and Zhigansk). At both these stations the trends were positive; i.e. there is a tendency to an increase in the duration of the period with continuous snow cover. Also in Table 15 there is a positive difference in snow duration for these two stations.

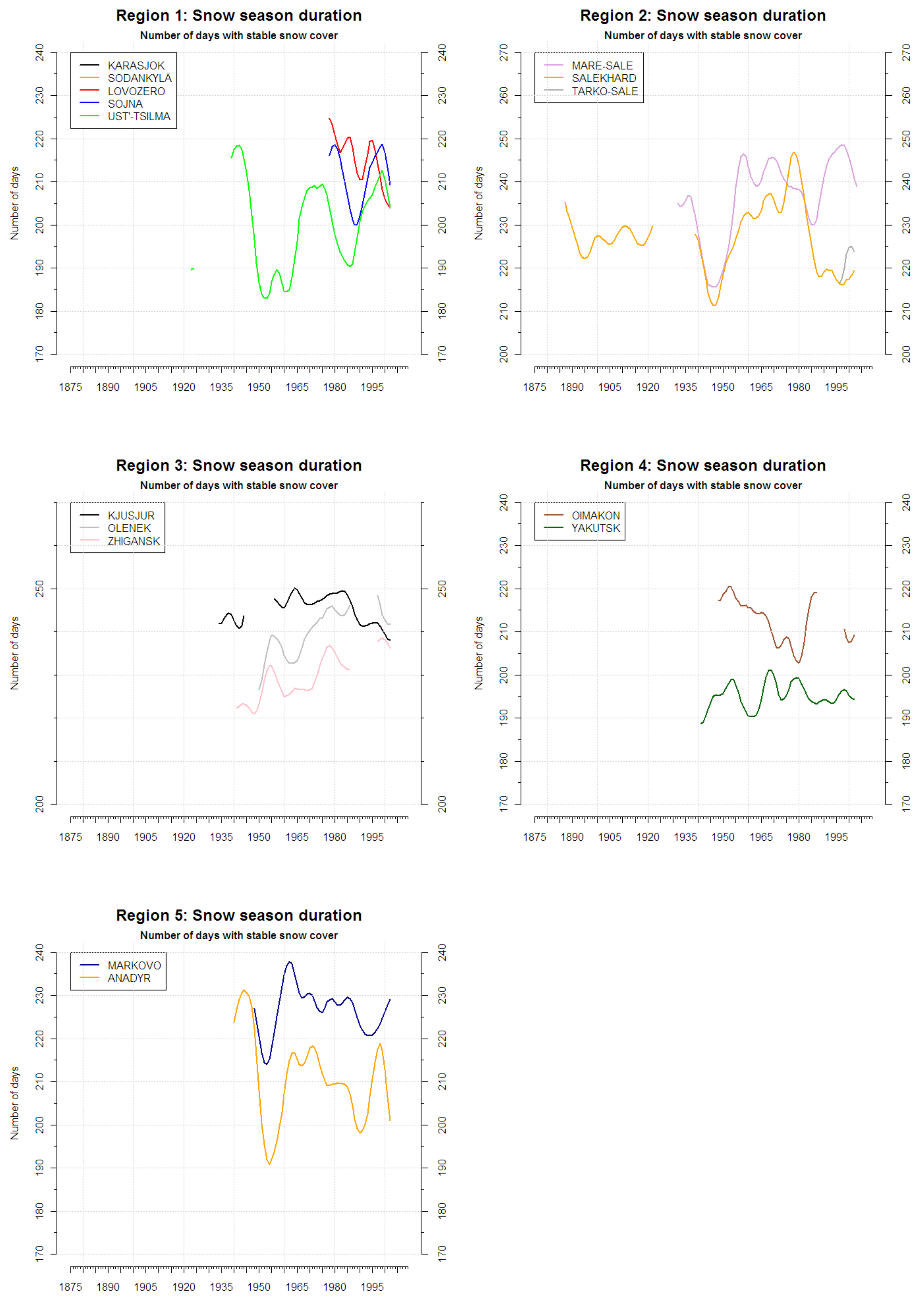


Figure 23: *Snow season duration: Comparison of all stations within the regions 1-5. 10 year Gauss filter.*

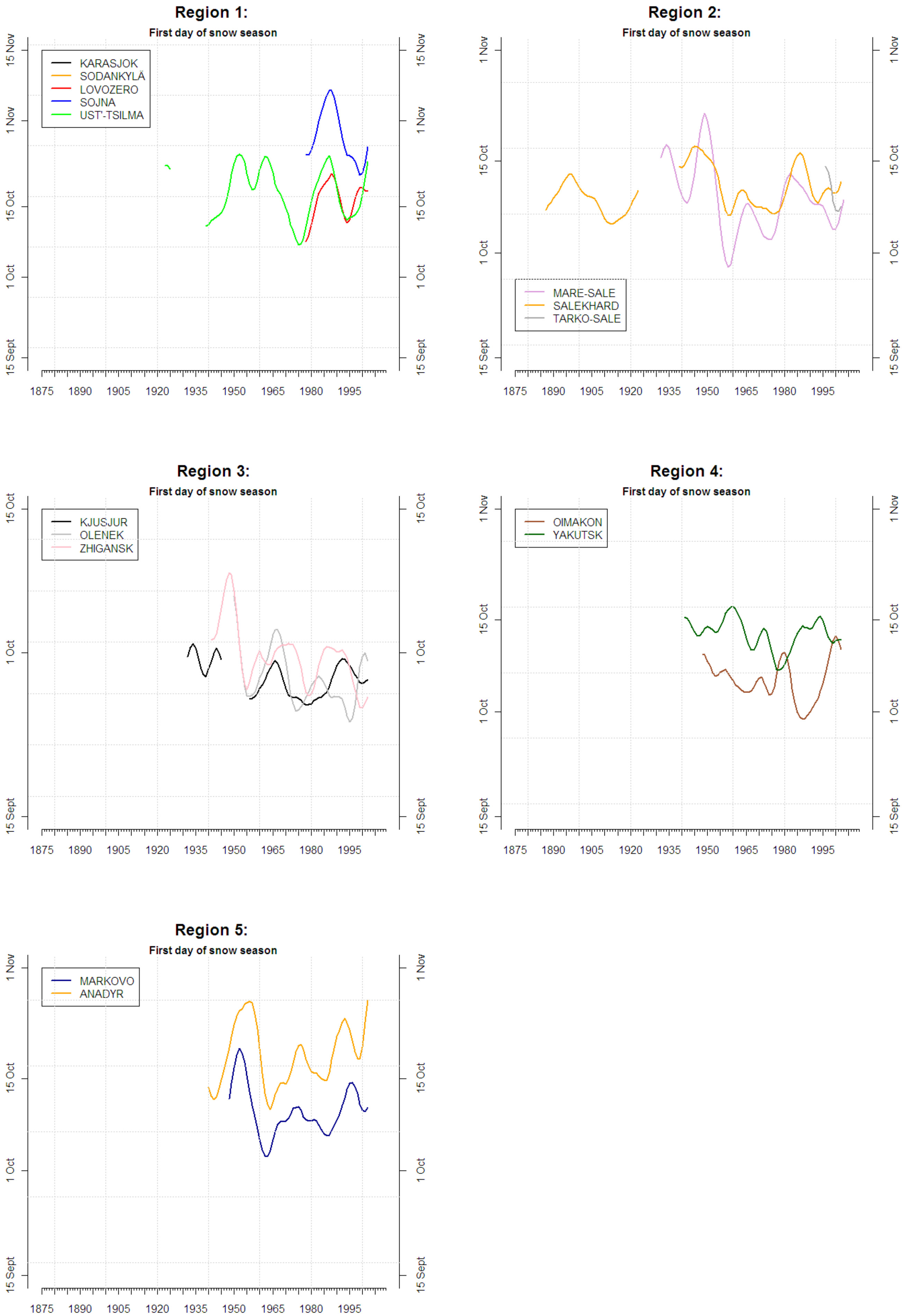


Figure 24: *Start of snow season: Comparison of all stations within the regions 1-5. 10 year Gauss filter.*

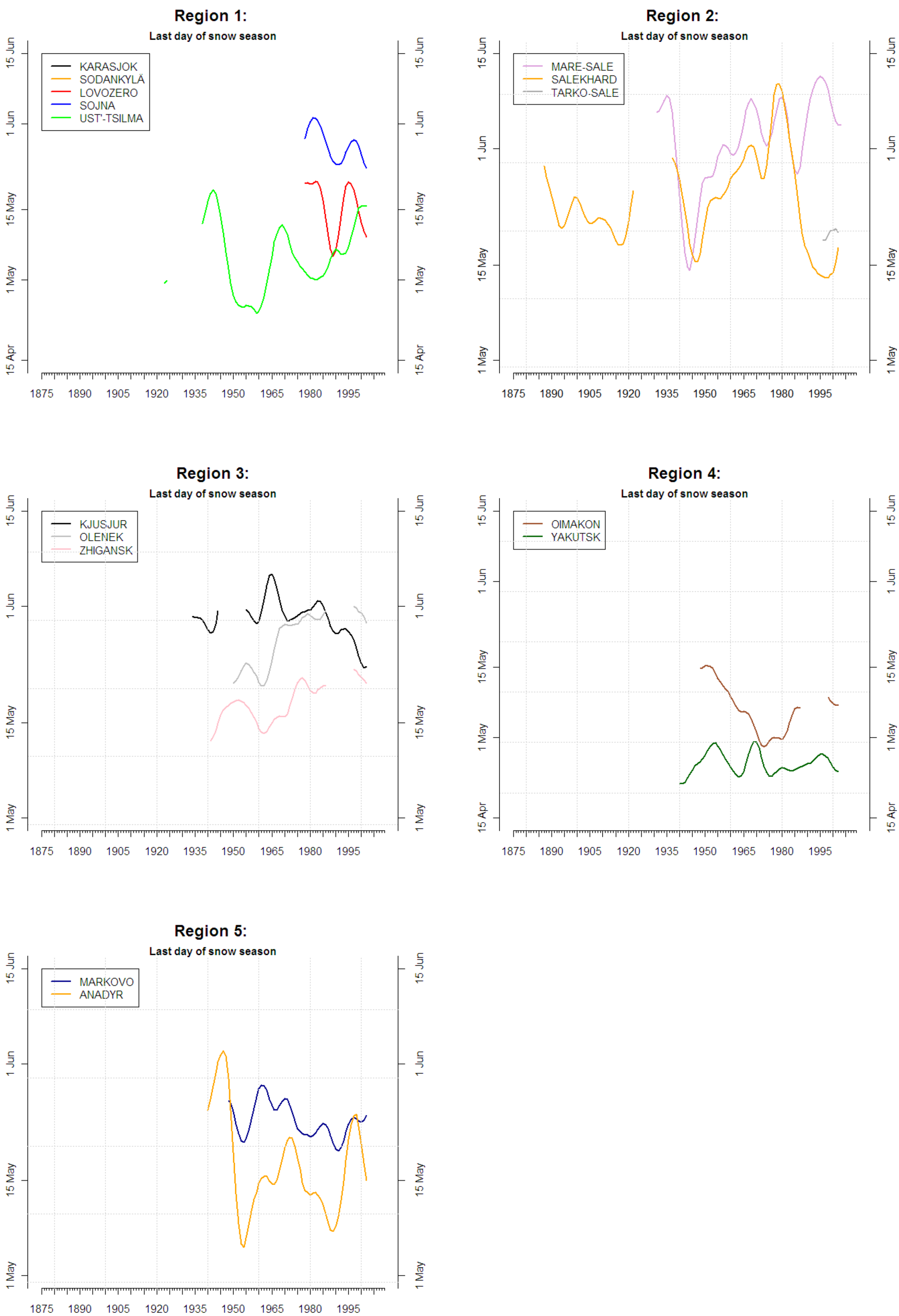


Figure 25: *End of snow season: Comparison of all stations within the regions 1-5. 10 year Gauss filter.*

| | | 1961-90 | 1979-08 | Difference |
|---|---|---|---|---|
| **Region 1** | | | | |
| 97250 | Karasjok | | | |
| 7501 | Sodankylä | | | |
| 22127 | Lovozero | - | 213.0 | - |
| 22271 | Sojna | - | 209.5 | - |
| 23405 | Ust'-tsilma | 197.2 | 200.2 | 3.0 |
| **Region 2** | | | | |
| 23552 | Tarko-sale | - | - | - |
| 23330 | Salekhard | 232.6 | 223.8 | -8.8 |
| 23032 | Mare-sale | 238.3 | 240.2 | 1.9 |
| 23445 | Nadym | - | - | - |
| **Region 3** | | | | |
| 21921 | Kjusjur | 247.6 | 242.8 | -4.8 |
| 24343 | Zhigansk | 230.6 | 233.6 | 3.0 |
| 24143 | Dzhardzhan | - | - | - |
| 21908 | Dzalinda | - | - | - |
| 24125 | Olenek | 242.1 | 245.8 | 3.7 |
| **Region 4** | | | | |
| 24382 | Ust-moma | - | - | - |
| 24671 | Tompo | - | - | - |
| 24688 | Oimakon | 211.5 | 212.1 | 0.6 |
| 24959 | Yakutsk | 195.9 | 195.5 | -0.4 |
| **Region 5** | | | | |
| 25551 | Markovo | 230.2 | 226.0 | -4.2 |
| 25563 | Anadyr | 212.3 | 207.2 | -5.1 |

Table 15: *Snow season duration: Number of days with permanent snow cover for the periods 1961-1990 and 1979-2008, and change in number of days.*

| | | 1961-90 | 1979-08 | Difference |
|---|---|---|---|---|
| **Region 1** | | | | |
| 97250 | Karasjok | 58.2 | 60.8 | 2.6 |
| 7501 | Sodankylä | 83.6 | 87.7 | 4.1 |
| 22127 | Lovozero | - | 61.0 | - |
| 22271 | Sojna | - | 89.6 | - |
| 23405 | Ust'-tsilma | 61.6 | 80.8 | 19.2 |
| **Region 2** | | | | |
| 23552 | Tarko-sale | - | 88.9 | - |
| 23330 | Salekhard | - | 66.0 | - |
| 23032 | Mare-sale | - | - | - |
| 23445 | Nadym | - | - | - |
| **Region 3** | | | | |
| 21921 | Kjusjur | - | 55.7 | - |
| 24343 | Zhigansk | 66.6 | 56.0 | -10.6 |
| 24143 | Dzhardzhan | - | - | - |
| 21908 | Dzalinda | - | - | - |
| 24125 | Olenek | 54.6 | 57.1 | 2.5 |
| **Region 4** | | | | |
| 24382 | Ust-moma | - | - | - |
| 24671 | Tompo | - | - | - |
| 24688 | Oimakon | 38.5 | 34.2 | -4.3 |
| 24959 | Yakutsk | 34.0 | 36.5 | 2.5 |
| **Region 5** | | | | |
| 25551 | Markovo | 86.4 | 89.6 | 3.2 |
| 25563 | Anadyr | 26.8 | 30.7 | 3.9 |

Table 16: *Maximum annual snow depth (cm) for the periods 1961-1990 and 1979-2008, and change in maximum annual snow depth.*

### 3.3.2 Snow depth

The highest snow depths in northern Russia are usually observed in April (Svyashchennikov and Førland, 2010). The mean maximum annual snow depths (Table 16) vary from below 40 cm in Region 4 to close to 90 cm at some stations in Region 1, 2 and 5. There is no clear regional pattern in decadal scale variability in snow depths (Figure 26 and 27). For most stations there is a tendency to higher maximum snow depths in the latest 30-year period compared to the normal period 1961-90 (Table 16). Exceptions are Zhigansk (Region 3) and Oimakon (Region 4). Also Svyashchennikov and Førland (2010) found tendencies to increasing snow depths in Northern Russia. During the period 1943-2008, statistically significant positive trends for snow depths in April were found for 4 stations (Tarko-Sale, Ust´Cilma, Kusur and Markovo). They found the strongest increase at Tarko-Sale and Ust´Cilma.

The results above are apparently in contradiction to the conclusions referred (Chapter 3) above from ACIA (2005), IPCC (2007) and Dyrrdal and Vikhamar-Schuler (2009). The reason may be difference in geographical regions and time periods studied. However, the reason why there is no clear decrease in snow duration (Chapter 3.3.1) and even a tendency to increase in snow depths (Chapter 3.3.2) despite increasing temperatures (Chapter 3.1) is probably that the precipitation amounts have increased during the cold season (Table 11 and 13).


Figure 26: *Maximum annual snow depth: Comparison of all stations within the regions 1-5. 10 year Gauss filter.*


Figure 27: *Normalized mean annual snow depth: Comparison of all stations within the regions 1-5. 10 year Gauss filter.*

# 4 Atmospheric circulation indices and winter temperatures

Atmospheric circulation indices are often used to explain variability in climate and also in ecological variables. In the present study, we use the NAO index (Hurrell, 1995) to represent the north-south pressure gradient and thus the strength of the westerlies in the Atlantic sector. To represent the meridional pressure gradient, we use MI 3 and MI 4 as defined by Wood and Overland (2009). These three indices are all based upon normalized sea level pressures (SLP) at specific sites (NAOI: Ponta Delgada, Azores and Stykkisholmur/Reykjavik, Iceland; MI 3: Arkhangels, Russia and Stykkisholmur/Reykjavik, Iceland; MI 4: Bodø, Norway + Edinburgh/Aberdeen, Scotland and Stykkisholmur/Reykjavik, Iceland.) The SLP pattern associated with the indices are similar to those given respectively by the first, third and fourth EOF of the SLP field for the northern hemisphere north of 20°N (Wood and Overland, 2009).

## 4.1 The NAO index

Figure 28 shows the correlation coefficients between winter (Dec-Feb) NAO and winter temperatures at the different weather stations. In regions 1 and 2 (Figure 1, Table 1), all stations show positive correlation coefficients ranging from +0.35 to +0.55. Also in Region 3, the correlation coefficients are positive, except from at Kjusjur which is situated in the north-eastern part of this region. In Region 4 and Region 5, the correlation is negative, except from the station Yakutsk in the south-western part of Region 4. Thus, Regions 1-3 mainly tend to be warmer than usually when NAO is in its high phase. This does not necessarily imply that the north-westward heat transport, which is connected to a high NAO, directly affects these areas. There may also be indirect effects; e.g. winters with high NAO tend to have less sea ice in the Barents Sea (Sander et al., 2005), and possibly also the Kara Sea, which again may lead to milder winters in the area.

## 4.2 Meridional indices

The correlation coefficients between the meridional indices MI 3 (Figure 29) and MI 4 (Figure 30) and winter temperatures at the different weather stations, show more complex spatial variability than we can see in Figure 28, and the correlation coefficients are generally less significant. Both indices are mainly positively correlated to winter temperatures in Region 1 and 5. For MI 3, the western part of Region 2 is also positively correlated, while the other stations mainly are negatively correlated. For MI 4, Region 2 is negatively correlated, while Regions 3 and 4 mainly are positively correlated.

Both these indices are, in their positive phase, connected to SLP-fields where the Siberian high tends to spread westward toward Europe, for MI 3 to western Siberia; for MI 4 even into Scandinavia. In their positive phase, they will thus indicate increased south-north advection in the western part of the area and increased north-south advection in the east. However, southerly wind is no guarantee for mild weather in the northern Siberian winter: Some areas in the Siberian inland are among the northern hemispheres coldest sites during the winter season. Very cold air is produced in these areas because the topography prevents advection of heat, humidity and clouds from the ocean south of the continent. The low correlation coefficients and the rather complex geographical patterns in Figures 29 and 30 are thus explainable.

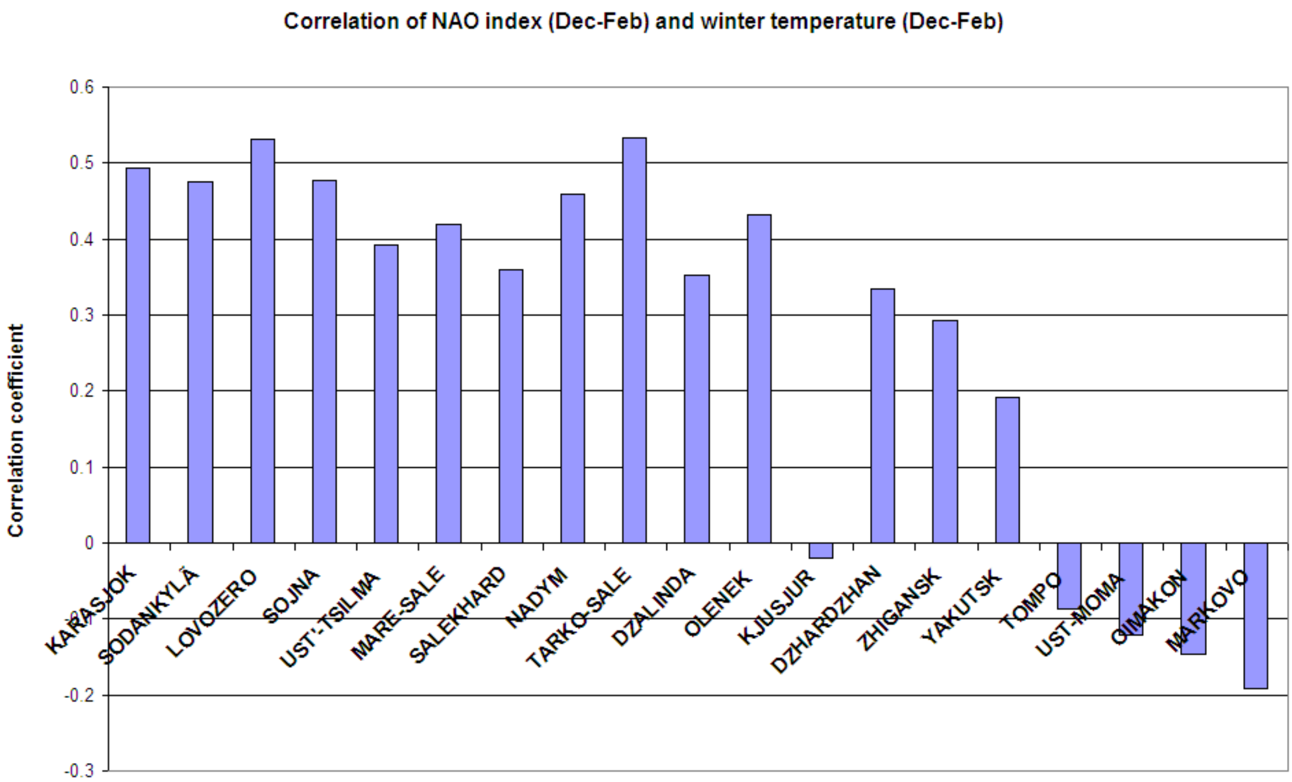


Figure 28: *Correlation of the NAO winter index and mean winter temperature.*

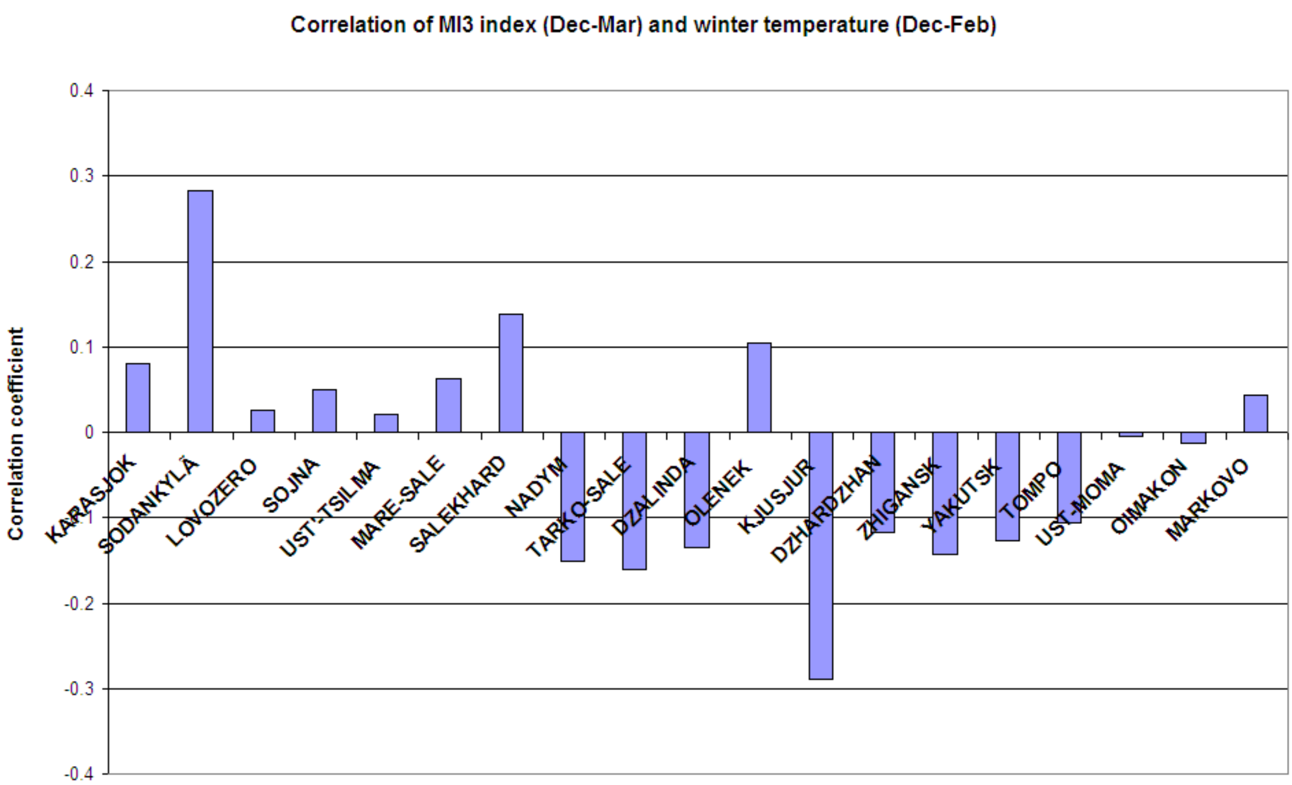


Figure 29: *Correlation of the MI 3 winter index and mean winter temperature.*

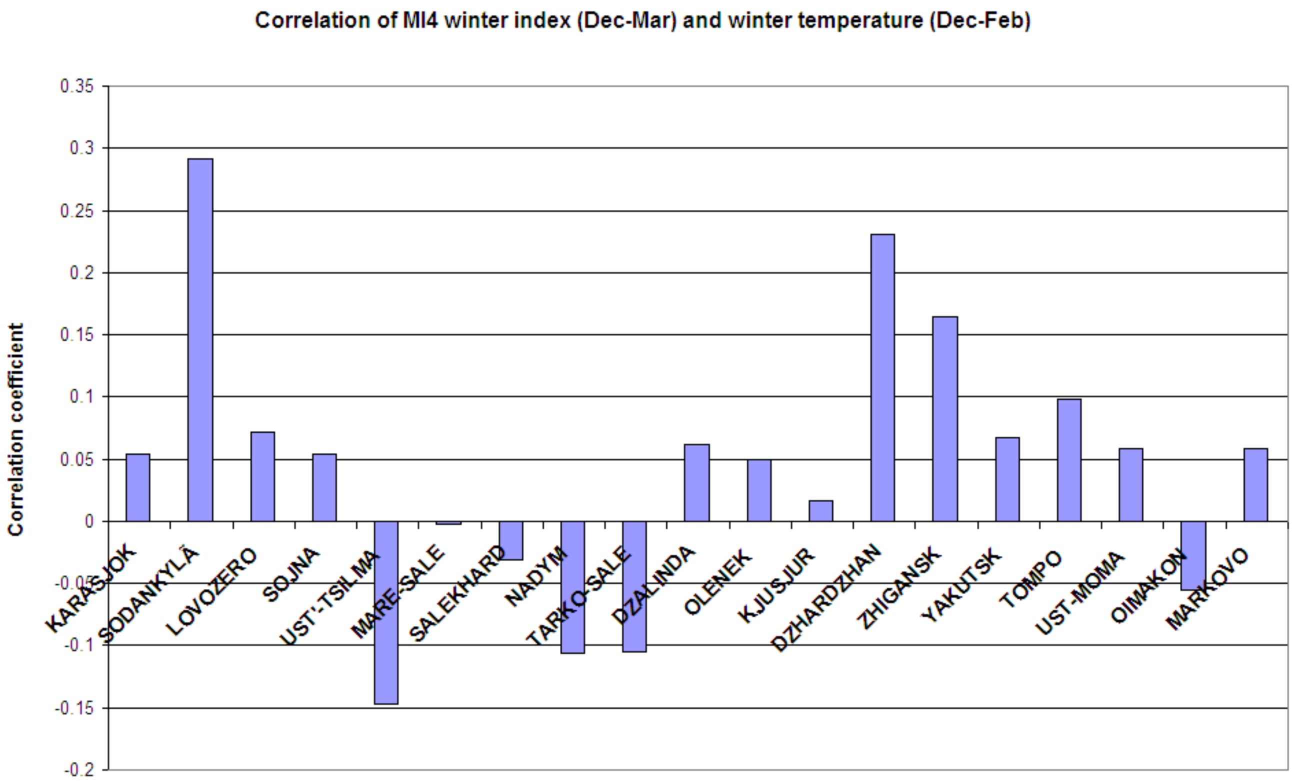


Figure 30: *Correlation of the MI 4 winter index and mean winter temperature.*

# 5 Summary

This report provides information on current climate and climate development during the latest hundred years in five selected regions in northern parts of Fennoscandia and northern Russia. The focus area covers the northern Eurasian continent from about 30°E to 180°E, or almost half of the circle around the North-Pole. A large part of the area has permafrost and is characterised by cold winters and little precipitation.

The annual **temperature** (1961-90) varies from -1.0°C at Sodankylä in Region 1 to -16.4°C at Oimakon in Region 4. The annual temperature has increased at all stations, but significant increase is only detected in the Yakutsk series. None of the series has a negative trend. All regions from Finnmark to western Siberia are characterised by high temperatures in the 1930s ("Early 20th Century Warming"), thereafter a decrease that ended in the 1960s or 1970s when another increase started. Further to the east in Regions 4 and 5 the temperature increase is larger than in the other regions. For all stations the latest 30 years have been warmer than in the standard normal period 1961-90.

During summer, the warmest place in this analysis is Yakutsk (Region 4) with mean temperature of well above 15°C. In contrast, the Mare Sale station adjacent to the Kara Sea has a mean summer temperature of approximately 5°C. Except for a small decrease in winter temperature at the one station in Region 5; the seasonal temperatures during 1979-2008 have been higher than in 1961-90 in all seasons at all stations.

The **cold season** is described by number of days with mean temperature below the thresholds of 0, -15, and -30°C. For number of days below 0°C there is a clear decrease in the whole Region. The decrease in number of days below -15 and -30°C does not show the same spatial pattern. The **degree days** during winter in Region 1 show that from ca 1960 to today there is an increase to approximately the same level as in the 1930s.

Concerning length of the **growing season**, a comparison of the two periods 1961-90 and 1979-2008 reveals an increase. Region 2 has the greatest increase with 6 days at Salekhard and Mare-Sale. Looking at the development over a longer time period, reveals a steady increase in growing season since the 1960s for Region 1. Region 2 has fairly short series, but shows a clear increase. Region 3 and 4 do not show any clear change in growing season. Region 5 reveals a clear increase in the growing season, e.g. Markovo had less than 100 days in the 1950s and about 110 days now. Region 1 has a clear increase in **growing degree days** after the 1980s, and Region 5 has a clear increase since the 1940s.

The measured **annual precipitation** (1961-90) varies from below 200 mm at Ust-Mona in Region 4 to more than 550 mm at Ust-Tsilma in Region 1. Generally the lowest annual values are found for Region 3 and 4. The annual precipitation has increased in all five regions, and for most stations the tendency to increasing annual precipitation is enhanced during the latest decades. This is supported by the fact that most stations have higher annual precipitation in the period 1979-2008 than during 1961-90.

Precipitation is normally low during the winter season, and in Region 4 most stations even have monthly precipitation lower than 10 mm both in December, January, February, March and April. Because of undercatch in the gauges during snowfall combined with low temperatures and strong winds, the "true" precipitation probably is higher than the uncorrected measured values. At most stations the highest monthly precipitation values are found in July and August. For most stations there is a weak tendency to increasing seasonal precipitation during the latest decades, but this picture is not clear-cut. The long-term precipitation trends may be influenced by change of gauge types during 1946-1960.

The ground is covered by **snow** more than 200 days per year at most stations, and at some stations there is a snow cover in around 2/3 of the year. The snow accumulation on the ground starts in the first part of October at most stations, but in Region 3 the snow season often starts in the end of September. On a decadal scale there are large temporal variations in the end of the snow season;- from late April till mid-June. Even though there is a large variability on a decadal scale, there are only minor differences in snow season duration between the most recent 30-year period and the period 1961-90.

The highest **snow depths** in northern Russia are usually observed in April. The mean maximum annual snow depths vary from below 40 cm in Region 4 to close to 90 cm at some stations in Region 1, 2 and 5. There is no clear regional pattern in decadal scale variability in snow depths. For most stations there is a tendency to higher maximum snow depths in the latest 30-year period compared to the period

1961-90. The reason why there is no clear decrease in snow duration, and even a tendency to increase in snow depths despite increasing temperature;- is probably that the precipitation amounts have increased during the cold season.

**Atmospheric circulation indices** are often used to explain variability in climate and also in ecological variables. The North Atlantic Oscillation (NAO) index is here used to represent the north-south pressure gradient and thus the strength of the westerlies in the Atlantic sector. To represent the meridional pressure gradient, i.e. south-north air mass transport, the MI 3 and MI 4 indices are used.

In Regions 1 and 2 all stations show positive correlation coefficients between winter (Dec-Feb) **NAO** and winter temperatures. In Region 4 and 5, most correlations are negative. Thus, Regions 1-3 mainly tend to be warmer than usually when the NAO index is in its high phase. This does not necessarily imply that the north-westward heat transport, which is connected to a high NAO index, directly affects these areas. There may also be indirect effects; e.g. winters with high NAO index tend to have less sea ice in the Barents Sea, and possibly also the Kara Sea, which again may lead to milder winters in the area.

The correlation coefficients between the meridional indices **MI 3 and MI 4** vs. winter temperatures, show more complex spatial variability than for the NAO index, and the correlation coefficients are generally less significant. Both these indices are, in their positive phase, connected to SLP-fields where the Siberian high tends to spread westward toward Europe. In their positive phase, they will thus indicate increased south-north advection in the western part of the area and increased north-south advection in the east. However, southerly winds are no guarantee for mild weather in the northern Siberian winter.

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