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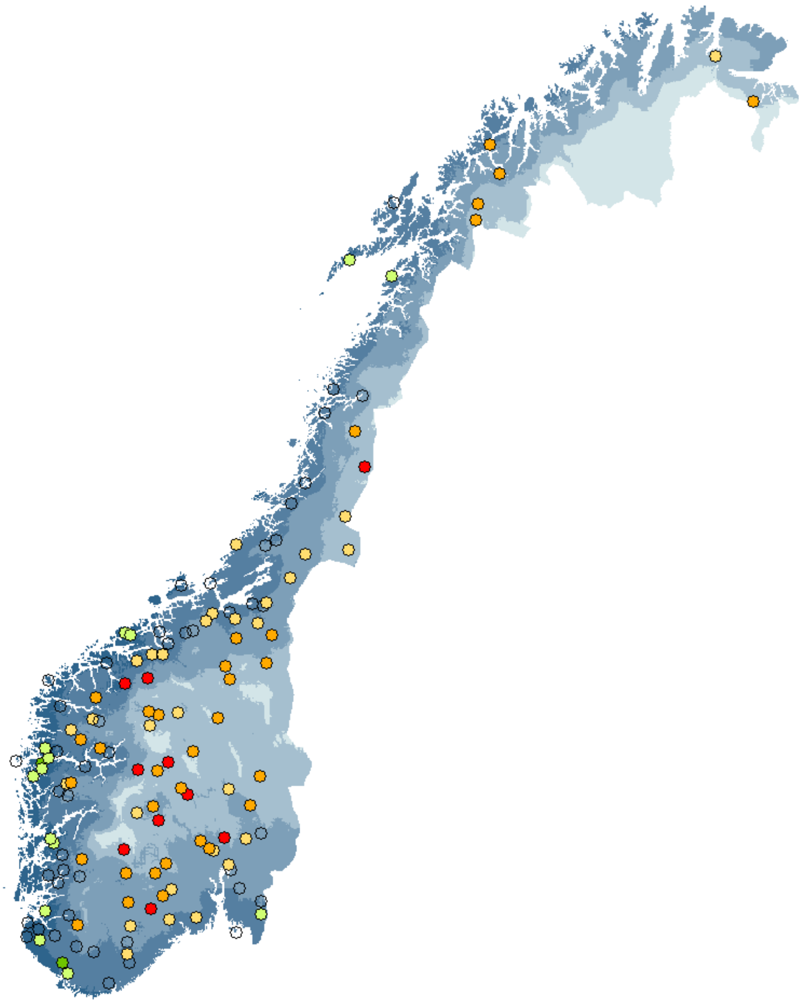
no. 10/2010
Climate

Analysis of past snow conditions in Norway
- Time periods 1931-60, 1961-90 and 1979-2008

Anita Verpe Dyrrdal



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Abstract

Observed trends in number of snow days and annual maximum snow depth have been evaluated for three 30-year periods in Norway; 1931-60, 1961-90 and 1979-2008. Trends in snow parameters are evaluated for statistical significance, and their relationship to winter precipitation and temperature is examined. Period I has a limited amount of stations, but there is a tendency to positive trends along the southern coast. Period II and III show more and more negative trends in number of snow days, while there are some positive trends in max snow depth in the coldest areas. Correlation analysis between snow parameters and winter climate indicates that number of snow days is greatly sensitive to temperature changes in all parts of the country. The same dependency applies to max snow depth in warmer regions, while in colder regions max snow depth is also very sensitive to precipitation changes.

Keywords

snow, Norway, SWE, snow days, snow depth

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Contents

1. Introduction

Snow is an important part of the climate system and changes in snow conditions are of hydrological significance, such as in hydropower production or as a threat related to flooding and avalanches etc. Hanssen-Bauer et al. (2009) compared mean winter precipitation and temperature for the international reference period 1961-90 and the most recent 30-year period 1979-2008. They found that winter precipitation has increased by 5-25 % (17 % on average for the entire country), and that winter temperature has increased by 0.91–1.34 ºC (0.98 ºC on average for the entire country). These changes have had and will continue to have a great effect on snow in Norway. However, changes in snow conditions are more complex due to their strong dependence on both before mentioned parameters, and the balance between these. Thus, studying variations in past snow conditions is essential to understanding expected future development. In Dyrrdal (2009) a trend analysis on number of snow days was performed, and negative trends were found all over the country, indicating a shorter snow season. The period of study varied from station to station depending on available observations, and the results were most likely influenced by this.

In the present study we have analysed trends in mean annual maximum snow depth (max snow depth) and mean number of days with snow on ground (number of snow days) for three 30-year periods, with the purpose of gaining a better understanding of variations in past snow conditions in Norway in the different periods, and possibly relate these to variations in temperature and precipitation.

2. Data and methods

2.1 Observations

In January 2010 the met.no observational network consists of 672 stations in total, and snow depth is measured at 354 of these stations (Kielland, personal communication). Observations are quality checked, and in this study we extract time series that are relatively continuous and of good quality. Maximum annual snow depth is taken as the maximum snow depth for each snow season, and is often used as a proxy for accumulative winter precipitation. Number of snow days is the average number of days with snow on ground (here defined as snow depth > 0 cm), and is here used as a measure of snow season duration.

2.2 Climate grids

Observational series at the meteorological stations are of different lengths, and as most stations where snow is observed are precipitation stations, temperature is normally not observed. To get a more consistent dataset we extract values of precipitation and temperature from the gridded dataset at www.seNorge.no (Engeset et al., 2004). We consider the extended winter climate, here taken as the average November through March (NDJFM) climate. Thus NDJFM temperature refers to the extended winter mean temperature, and NDJFM precipitation refers to the extended winter total precipitation. In the text we refer to winter climate as the average December through February (DJF) climate.

Values are taken from a 1 x 1 km grid point which contains the coordinates of the station in question. Although the grid values are not completely accurate due to interpolation errors and erroneous correction for gauge undercatch (Førland et al., 1996), as well as elevation differences, we believe that they conserve the overall trend and the variability reasonably well.

2.3 Time periods

Analyses are carried out for the three following time periods: 1931-60 (period I), 1961-90 (period II), and 1979-2008 (period III). Thus, periods II and III overlap by 11 years. The number of stations with complete digitised observations varies between the different time periods. In period I there are 55 stations, in period II there are 298 stations, and in period III there are 225 stations. Only 27 stations have complete observations throughout all three periods, while periods I and II share 45 of the same stations, and periods II and III share 138 of the same stations. Fig.1 shows all stations and in which period or periods they have complete observations. In the same figure we notice that the station network is denser in the south, apart from the higher elevated areas in the west. We also see that there exist very few long-term snow series (yellow dots). Due to the limited number of stations in the first period, we concentrate this study on the two last periods. In the second part of the study we take out the 138 shared stations in period II and III (hereafter, the mutual stations), so as to make a direct comparison between the two periods and detect any shift in snow conditions.

2.4 Trend analysis

2.4.1 Mann Kendall trend test

Like most hydro-meteorological time series, snow parameters studied here are not considered to be normally distributed. Non-parametric statistical tests, such as the Mann-Kendall test, is thought to be more suitable to study trends in these types of data (Yue et al., 2002). We have applied the Mann-Kendall test to compute trends, and a 95% confidence level is used to evaluate the significance of trends for the three time periods.

2.4.2 Linear trend test

Linear trend slopes are computed and plotted against long-term average NDJFM temperature (mean NDJFM temperature) extracted from the climate grids, with the intention of illustrating the relationship between temperature and nature of trends in snow parameters. The climate grids only go back to 1957, and so a 1x1 km gridded data set of monthly temperature (Hanssen-Bauer et al., 2006) is used to compute NDJFM temperature for period I. This data set is established by spatial interpolation of monthly anomalies and goes back to 1900.

Figs.2-3 show mean winter climate in Norway for the normal period 1961-90, and is used as reference to colder/warmer and dryer/wetter regions.

2.5 Correlation analysis

To further investigate snow parameters sensitivity to variations in winter climate, we extracted time series of NDJFM temperature and precipitation from the climate grids and performed a correlation analysis. The degree of correlation between time series was quantified by specifying the correlation coefficient *R*. Analysis of correlation was only performed on the mutual stations, so as to correlate the entire period 1961-2008, and in this way arrive at a more robust result.

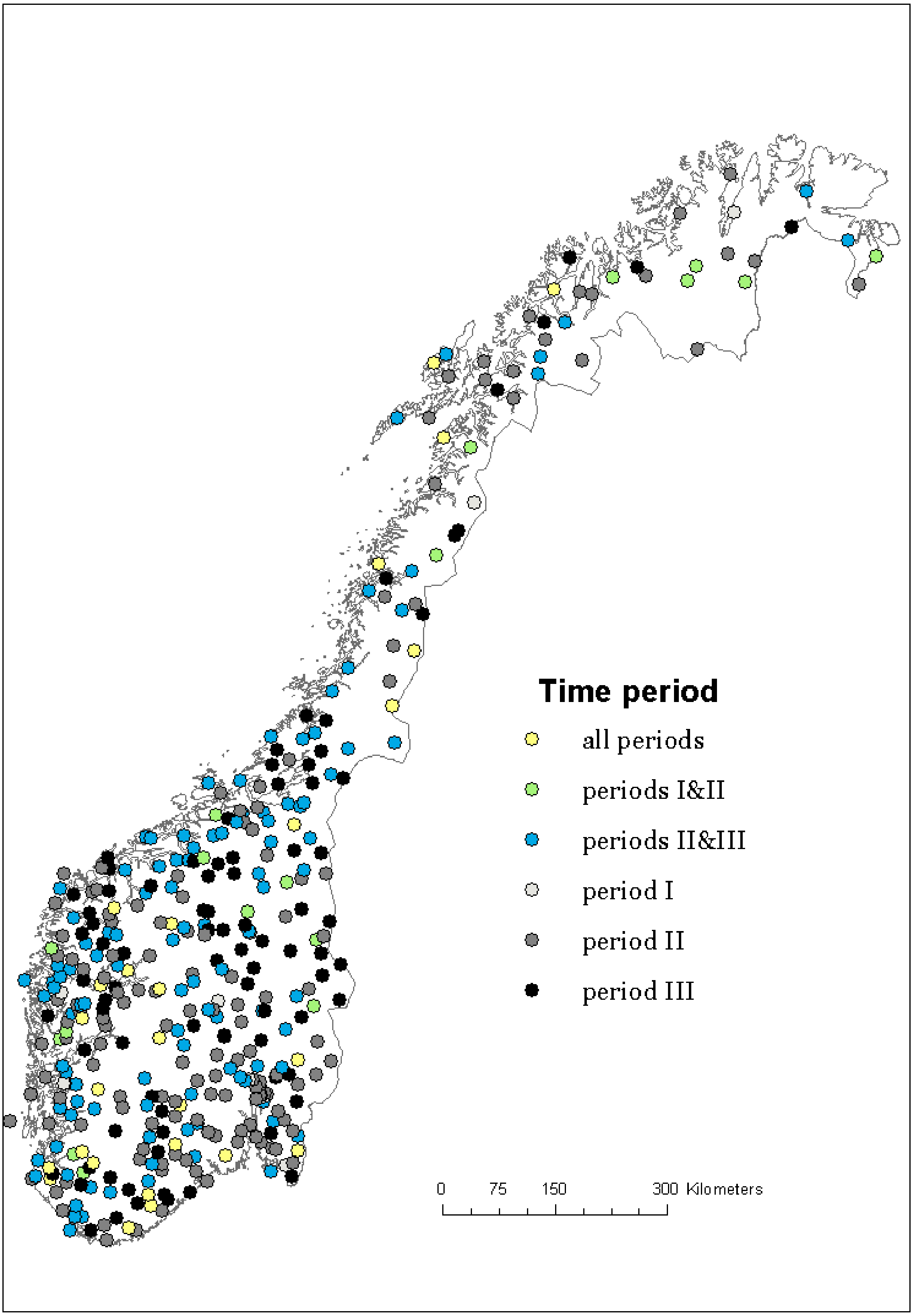

Fig.1: All stations included in this study. Colors represent the period or periods with complete digitised observations at each station.

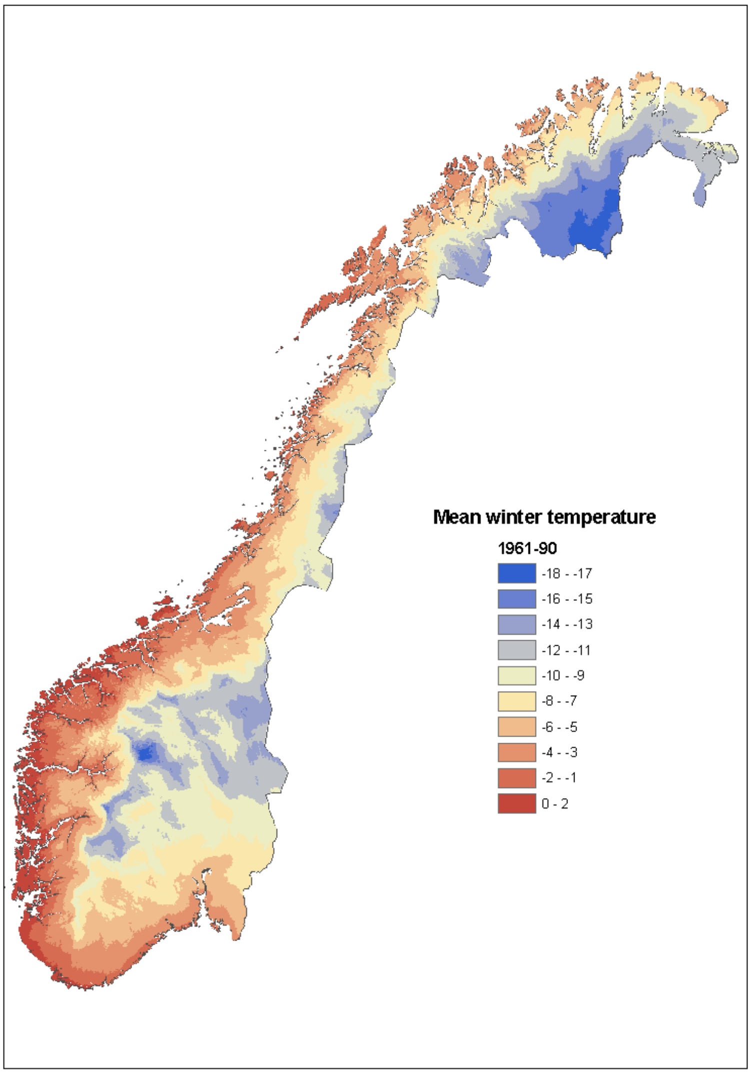

Fig.2: Mean 1961-90 winter temperature.

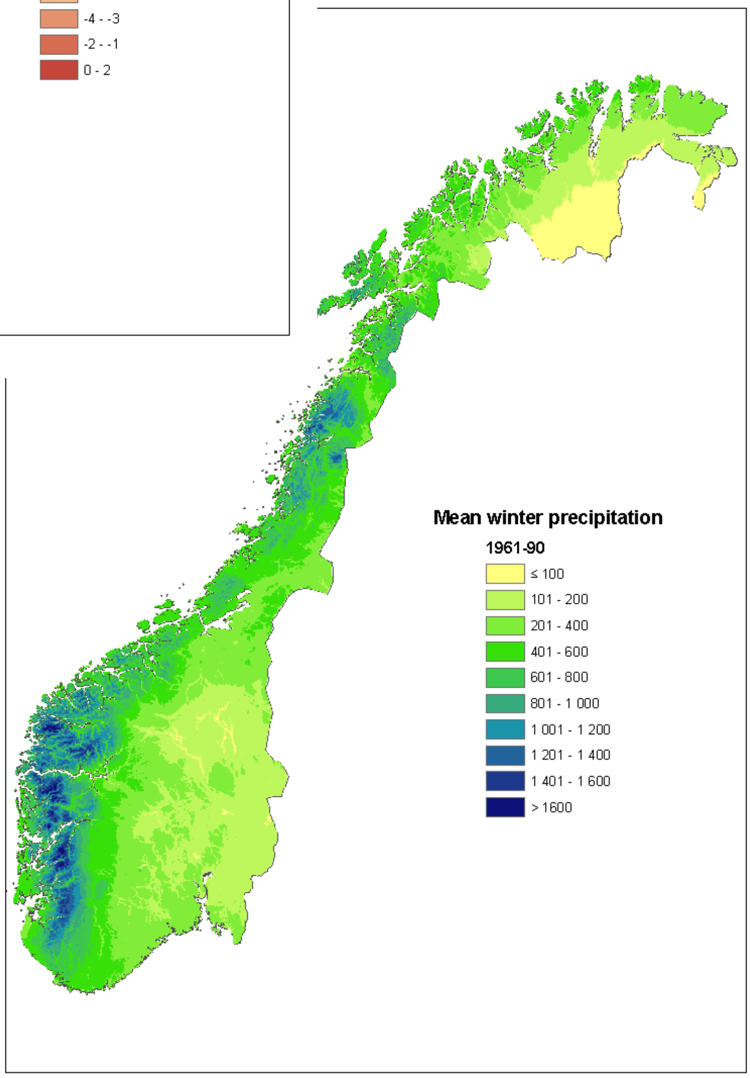

Fig.3: Mean 1961-90 winter precipitation.

3. Results

3.1 Period I (1931-1960)

In this period the number of stations with complete digitised snow observations is limited, which makes it difficult to conclude on a general pattern (Figs.4b-5b). However, along the southern coast there is a tendency to positive trends in both max snow depth and number of snow days. We also see that there is a larger number of positive trends in max snow depth. In Figs.4a-5a we see that for both parameters mostly negative trends are found in colder regions, while mostly positive trends are found in warmer regions.

The country as a whole experienced decreasing temperatures from the relatively warm 1930's and to the relatively cool 1960's (Fig.6a), which might explain the increasing snow amounts along the southern coast, or in warmer regions in general, where decreasing temperatures in this period would have given more precipitation as snow instead of rain and reduced snow melt. In areas governed by colder winters, however, a cooling would not make a great difference. From Fig.6b we see that winter precipitation was slightly reduced throughout the period, which is in accordance with the more negative trends in colder regions. Still, these are only indication and cannot be generalized due to the limited amounts of data.

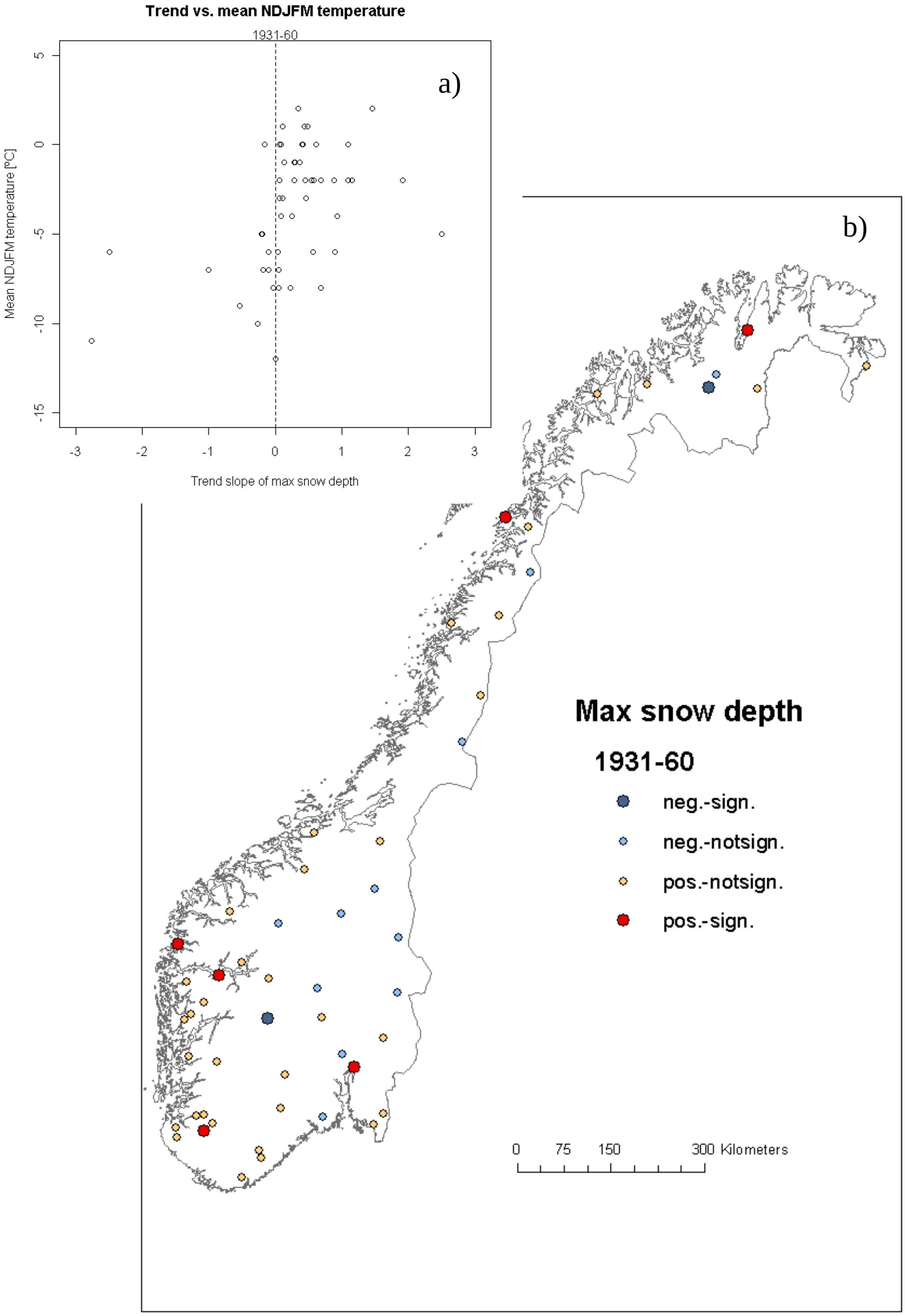

Fig.4: a) Trend in max snow depth versus mean NDJFM temperature for period I.
b) Trend in max snow depth for period I.
neg. (pos.) = negative (positive) trend, sign. (notsign.) = trend is (not) significant at the 95% confidence level.

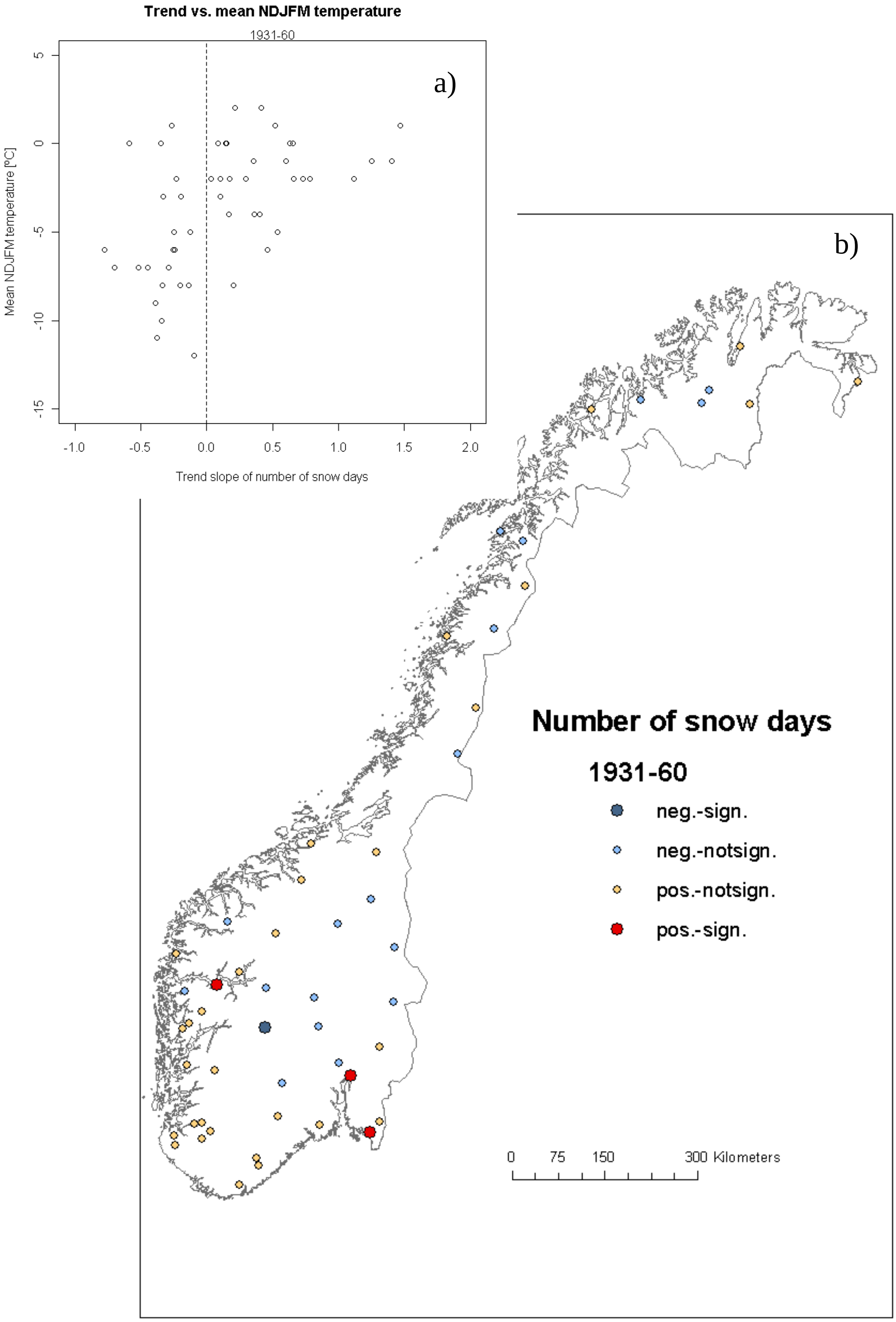

Fig.5: a) Trend in number of snow days versus mean NDJFM temperature for period I.
b) Trend in number of snow days for period I.
neg. (pos.) = negative (positive) trend, sign. (notsign.) = trend is (not) significant at the 95% confidence level.

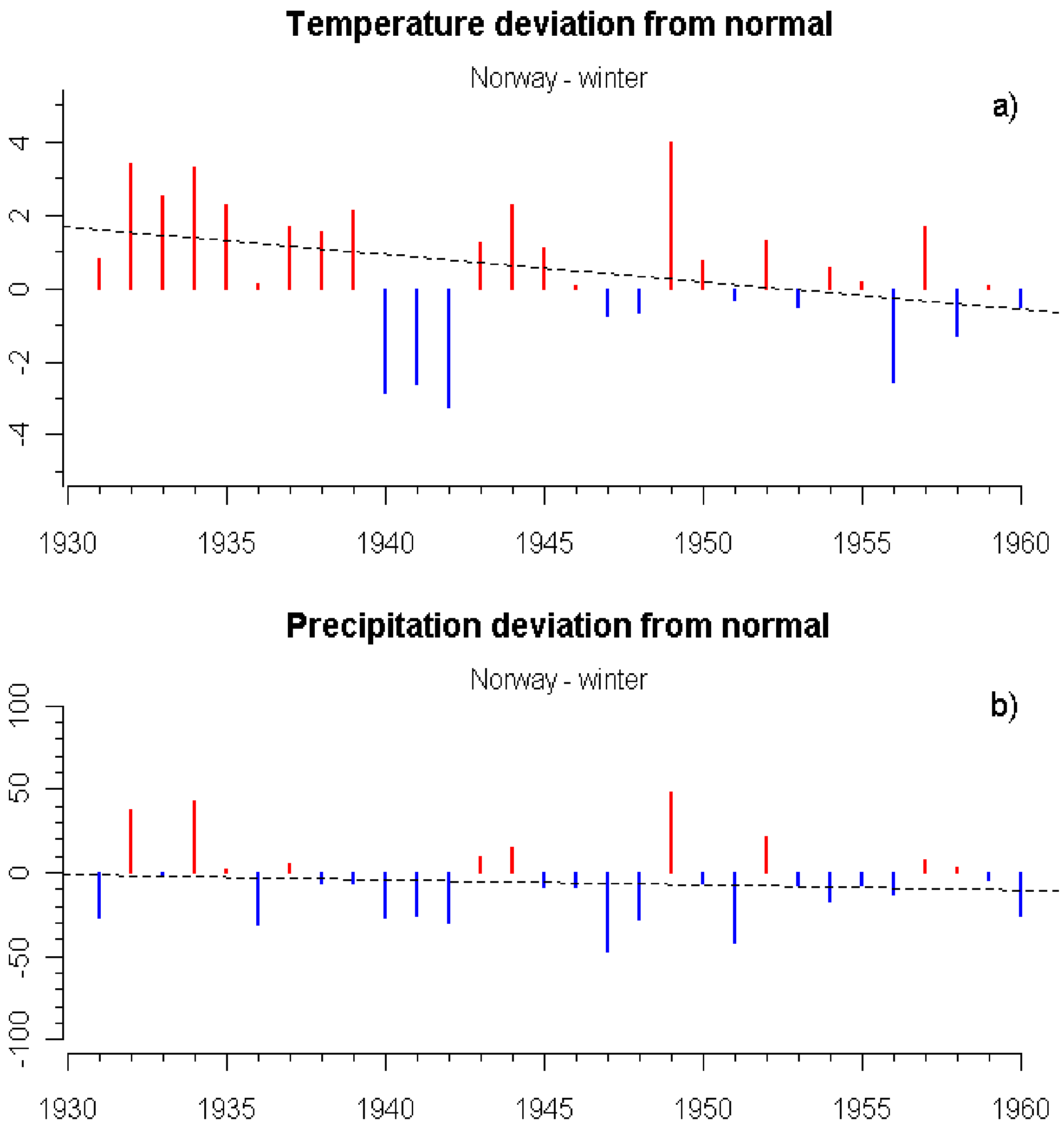

Fig.6: Average gridded values for Norway in period I including linear trend.
a) Winter (DJF) temperature anomaly (ºC)
b) Winter (DJF) precipitation in percent of normal

3.2 Period II (1961-1990)

Both max snow depth and number of snow days show a general negative trend in the entire country in this period (Figs. 7b and 8b), except in a few locations. Number of snow days show a greater amount of significant negative trends, and only one significant positive trend, compared to five significant positive trends in max snow depth. However, trends in max snow depth are generally weak. Figs.7a and 8a indicate that the locations with significant positive trends are characterized by relatively low mean NDJFM temperatures, and we also see more negative trends in warmer areas in general. There are no obvious geographic differences in the distribution of trends.

Winter climate varies throughout the period and precipitation and temperature show only weak positive trends for the country as a whole (Fig.9). Although we don't see significant changes in average winter climate, there might have been stronger trends in certain regions. It's possible that the overall negative trends in both parameters, and particularly for number of snow days, is related to increasing temperatures, while increasing winter precipitation might explain some of the positive trends in max snow depth in colder regions.

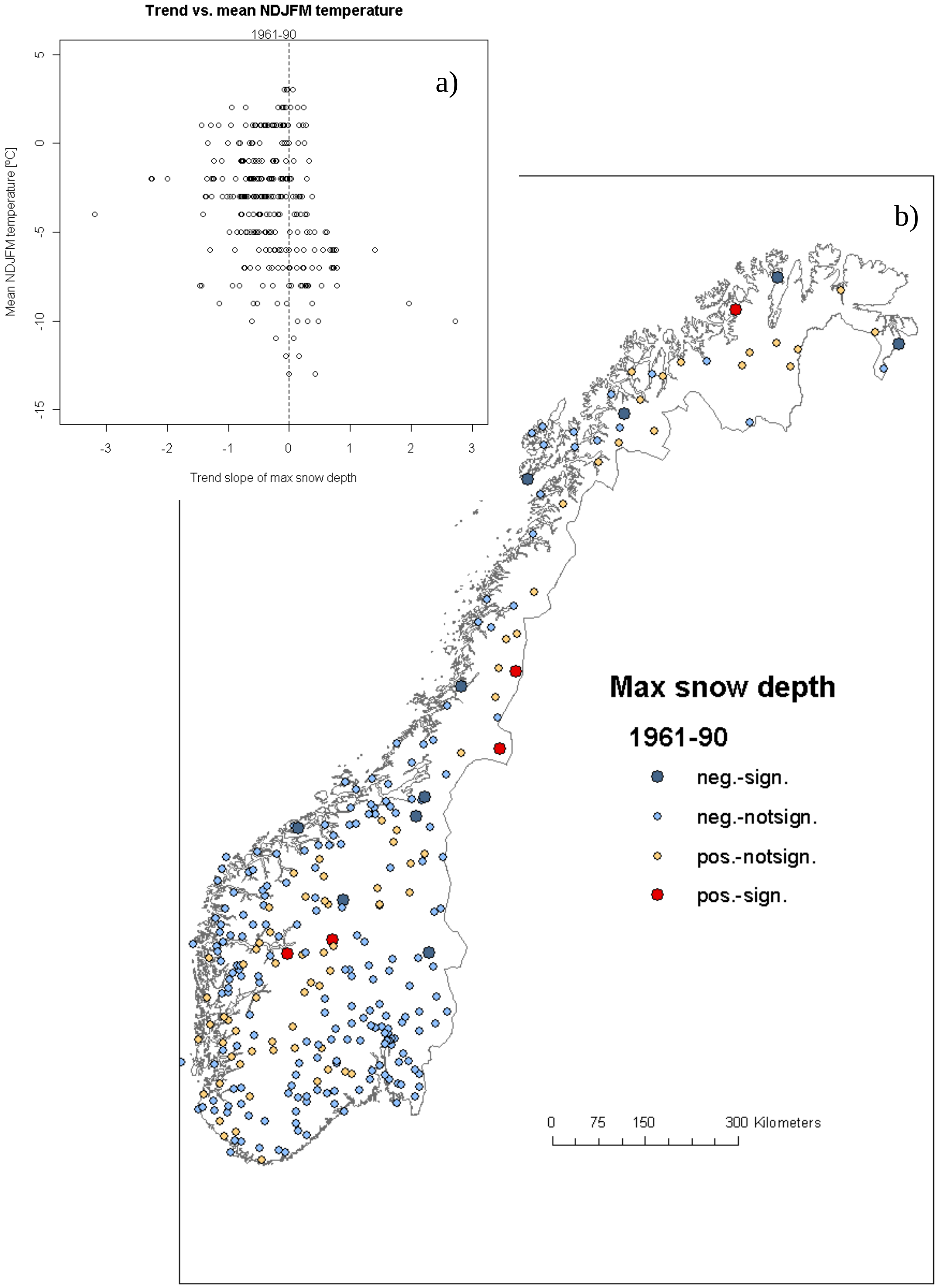

Fig.7: a) Trend in max snow depth versus mean NDJFM temperature for period II.
b) Trend in mean annual maximum snow depth for period II.
neg. (pos.) = negative (positive) trend, sign. (notsign.) = trend is (not) significant at the 95% confidence level.

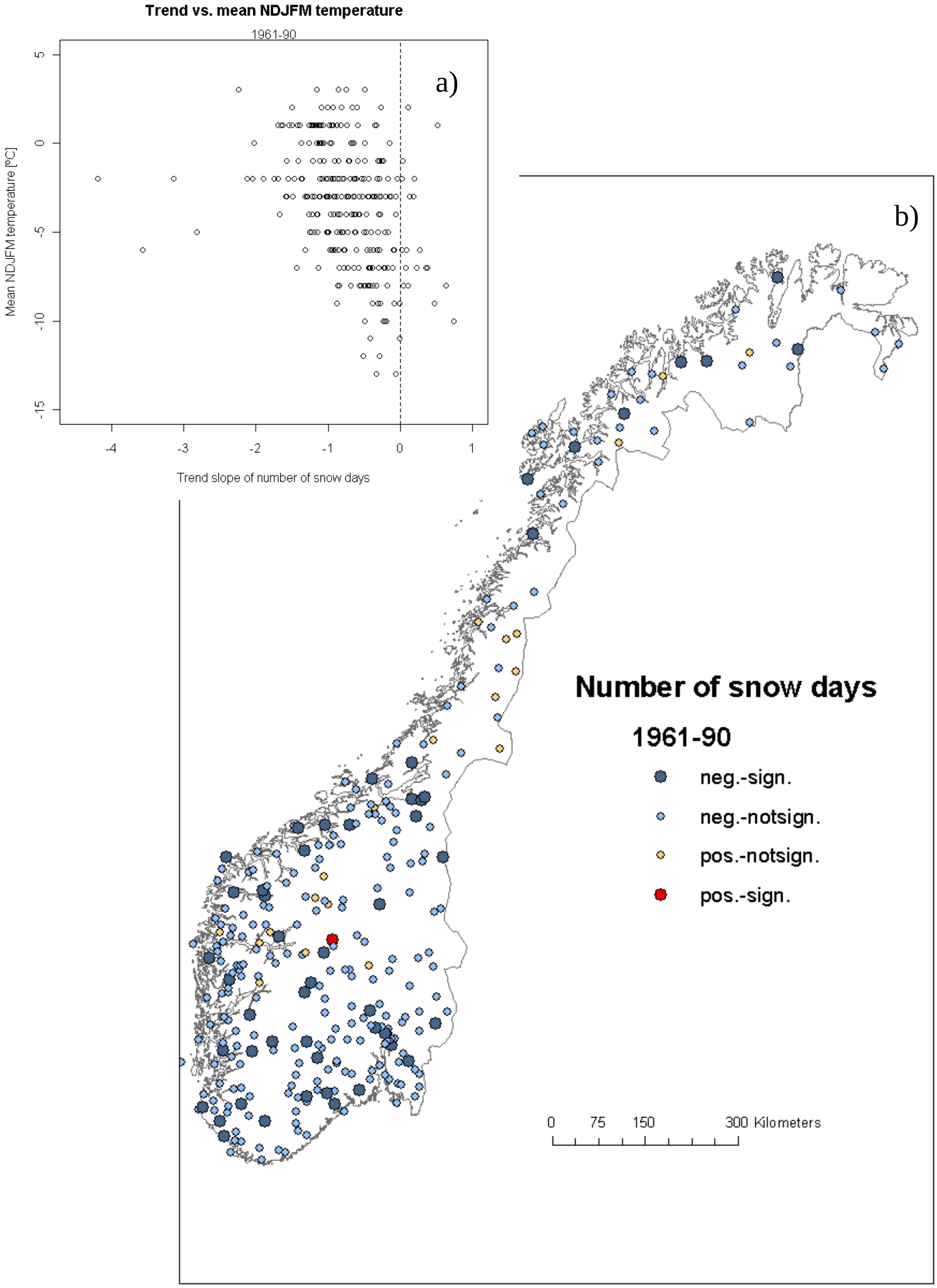

Fig.8: a) Trend in number of snow days versus mean NDJFM temperature for period II.
b) Trend in number of snow days for period II.
neg. (pos.) = negative (positive) tren, sign. (notsign.) = trend is (not) significant at the 95% confidence level.

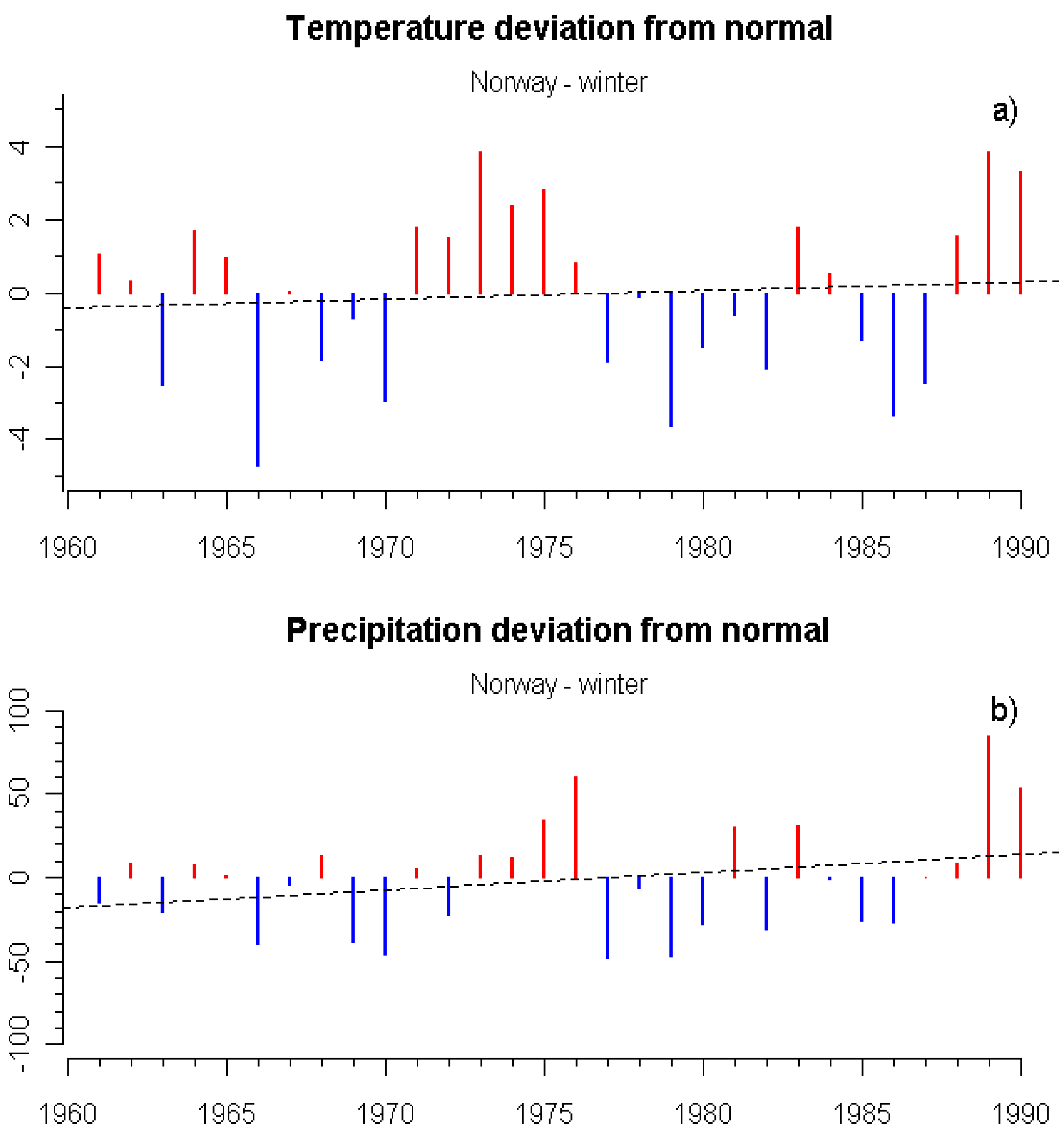

Fig.9: Average gridded values for Norway in period II including linear trend.
a) Winter (DJF) temperature anomaly (ºC)
b) Winter (DJF) precipitation in percent of normal

3.3 Period III (1979-2008)

Also in this period there is an overload of negative trends in both parameters, and the amount of significant negative trends is greater for number of snow days. In addition, trends are stronger than in the previous period. Significant negative trends in both parameters are found along the south-western coast. For max snow depth we detect a small geographic region in the inner northern parts of South Norway, where most trends are positive (Fig.10b). This region has a continental climate and is characterized by relatively low winter temperatures. In North Norway we get ambiguous results for max snow depth, and trends are weak. Figs.10-11a again indicate that trends generally become more negative in warmer areas.

Both winter temperature and precipitation is well above normal (1961-90) for most years in this period, especially for the last 20 years (Fig.12), and linear trends are strongly positive.

It is likely that the increase in temperatures can explain the overall negative trends, especially in warmer areas (see Fig.2), while increasing winter precipitation might explain the few positive trends in max snow depth seen in colder regions.

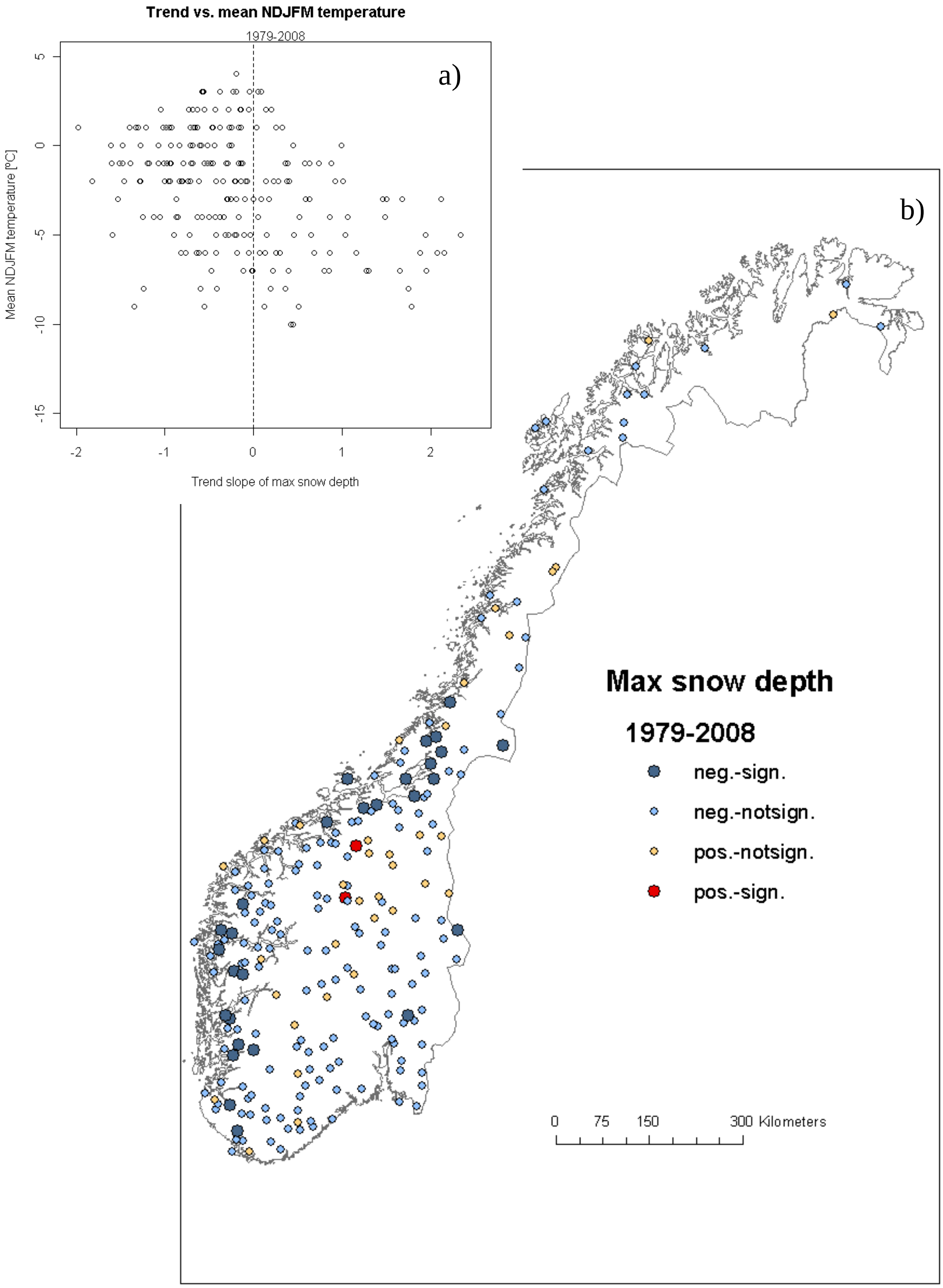

Fig.10: a) Trend in max snow depth versus mean NDJFM temperature for period III.
b) Trend in max snow depth for period III.
neg. (pos.) = negative (positive) trend, sign. (notsign.) = trend is (not) significant at the 95% confidence level.

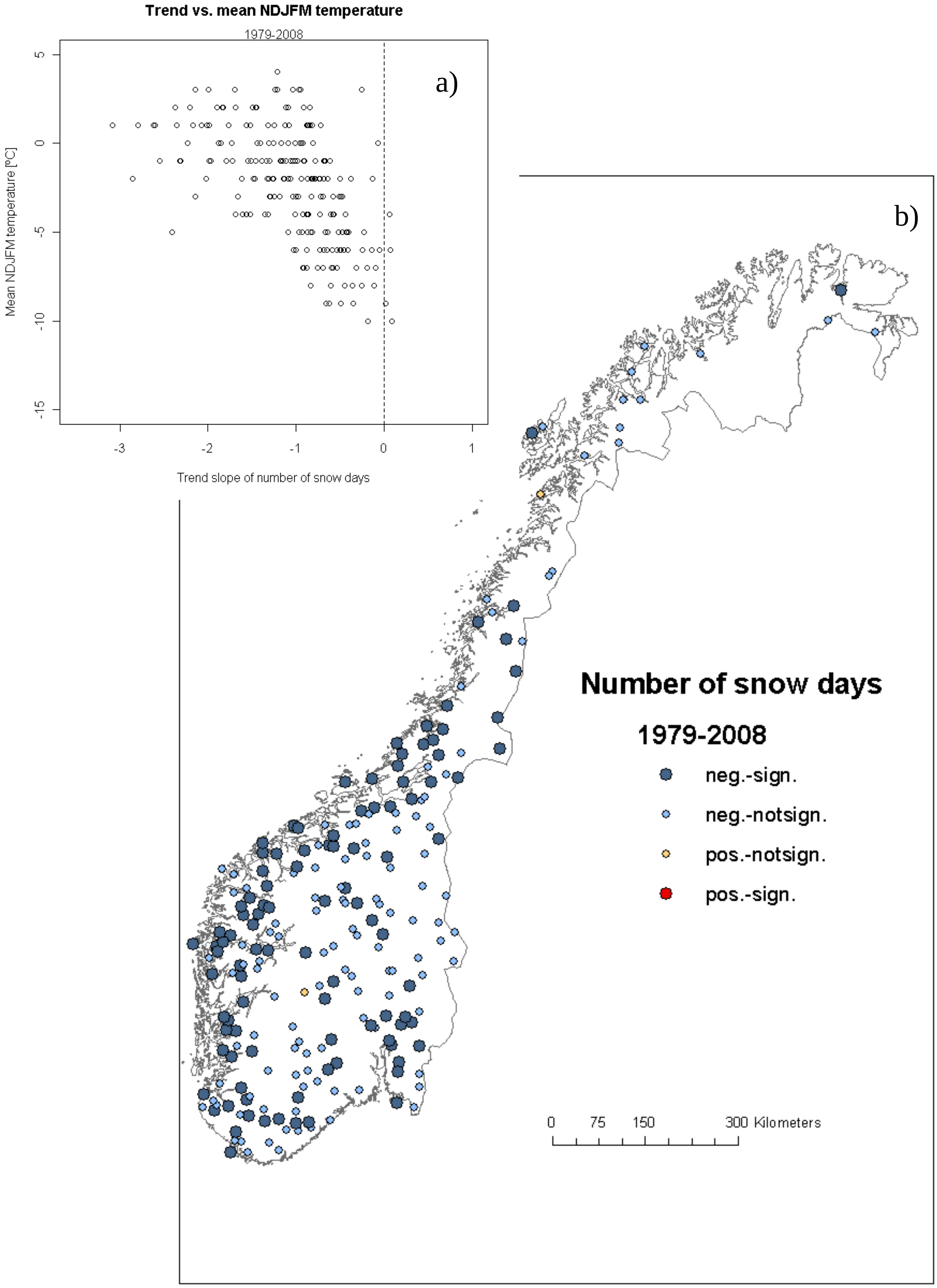

Fig.11: a) Trend in number of snow days versus mean NDJFM temperature for period III.
b) Trend in number of snow days for period III.
neg. (pos.) = negative (positive) trend, sign. (notsign.) = trend is (not) significant at the 95% confidence level.

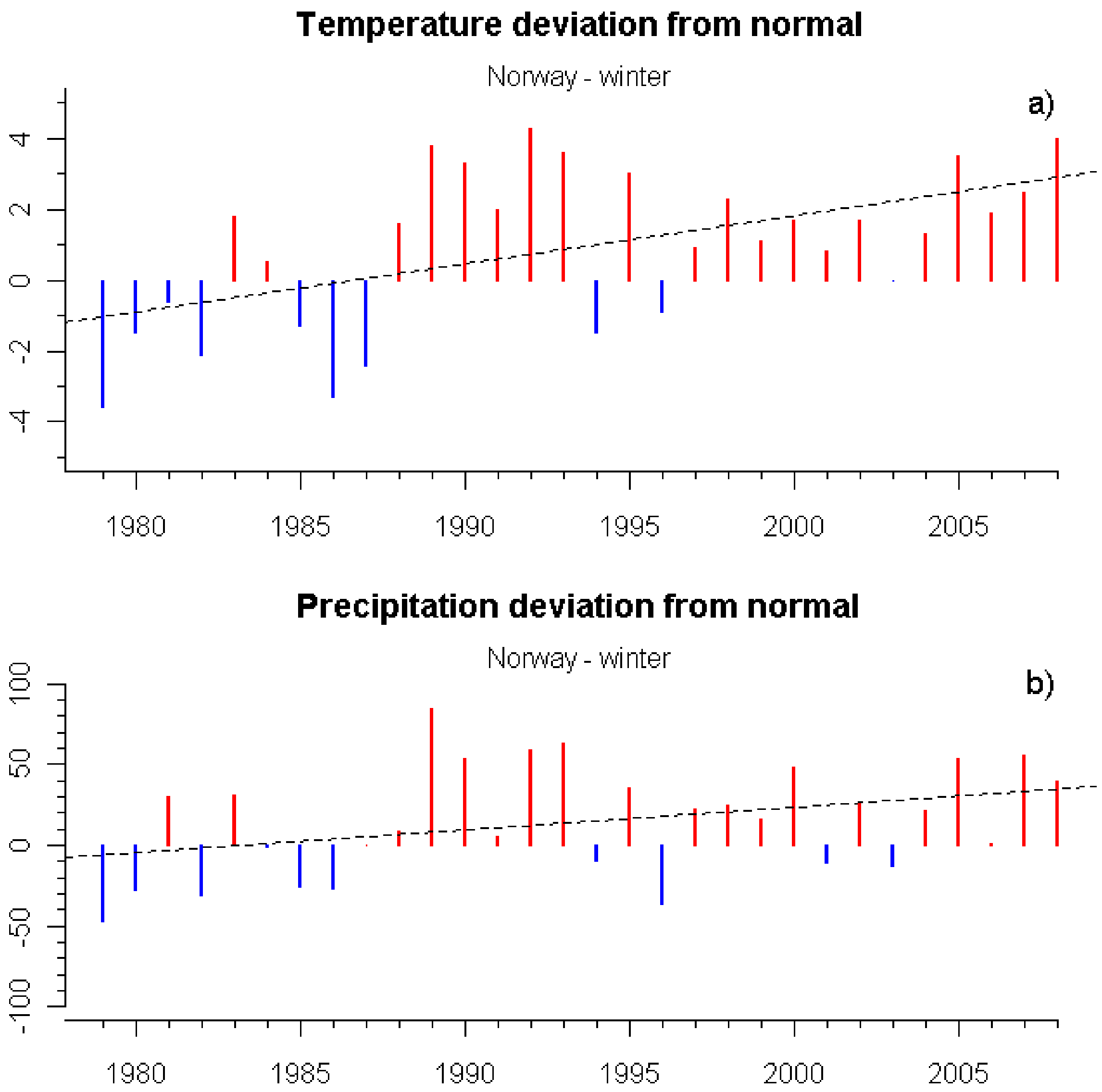

Fig.12: Average gridded values for Norway in period III including linear trend.
a) Winter (DJF) temperature anomaly (ºC)
b) Winter (DJF) precipitation in percent of normal

3.4 Comparison of periods II and III

When studying the mutual stations in the two most recent periods, we detect a larger spread in max snow depth trend slopes in period III, meaning both negative and positive trends are stronger (Fig.13a-b). For number of snow days there rather seems to be a shift towards more negative trends in period III (Fig.13c-d). In Fig.14 we find that both parameters decrease in general from period II to period III. The decrease is stronger for number of snow days, especially in warmer regions where snow season duration is shorter on average.

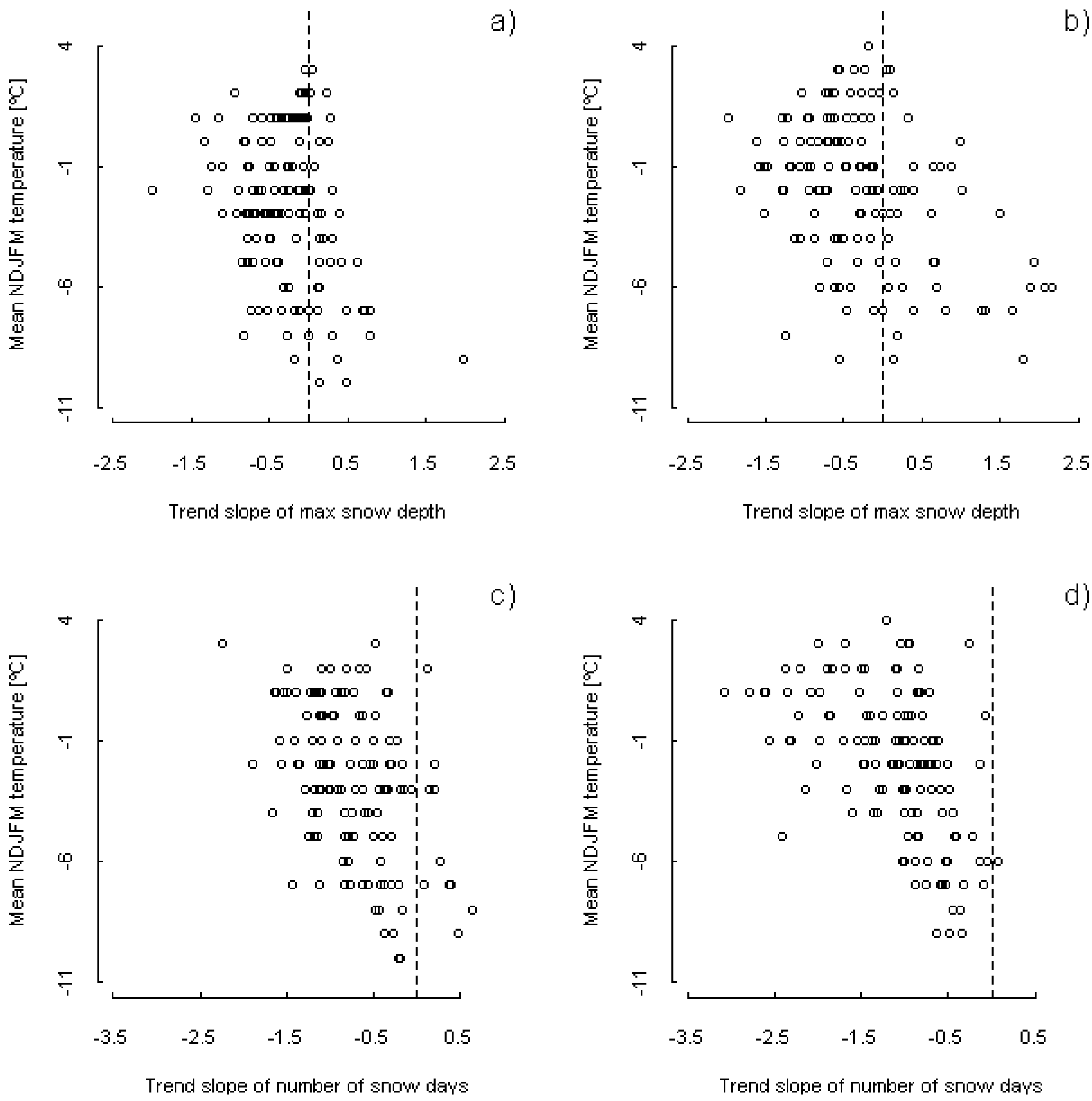

Fig.13: Trend versus mean NDJFM temperature (mutual stations)
a) Max snow depth in period II, b) Number of snow days in period II
c) Max snow depth in period III, d) Number of snow days in period III

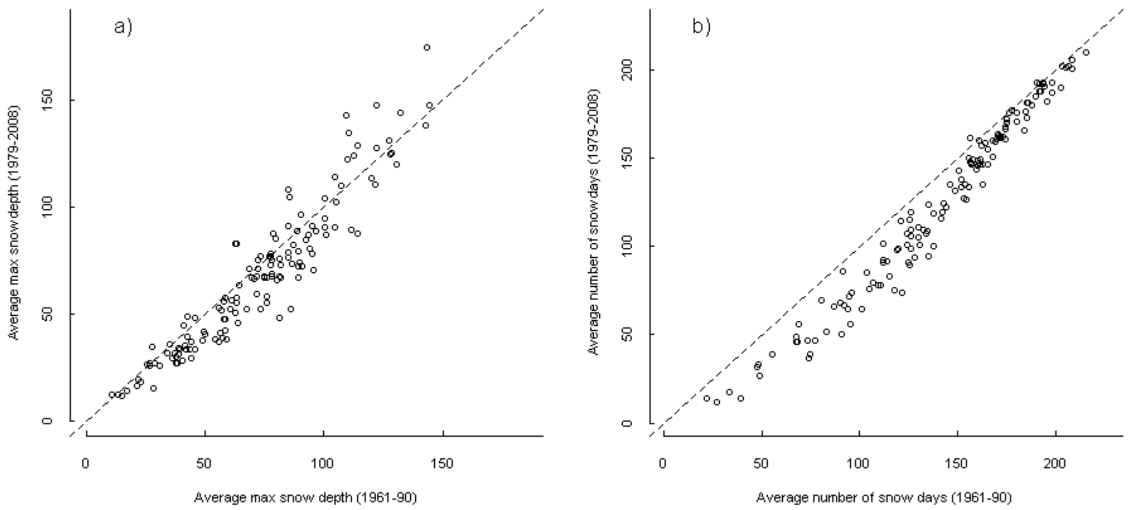

Fig.14: a) Average max snow depth in period II (x-axis) and period III (y-axis)
b) Average number of snow days in period II (x-axis) and period III (y-axis)

3.5 Correlation analysis

Max snow depth and NDJFM temperature for the entire period 1961-2008 (Fig.15b) are in general negatively correlated all over the country except at a couple of locations. From Fig.15a we see that these locations are characterized by lower NDJFM temperatures, and that the correlation generally becomes more negative with higher temperatures.

Max snow depth and NDJFM precipitation are negatively correlated along the southern coast and positively correlated inland and in the north (Fig.16b). Especially in the southern inland these positive correlations are relatively strong. Fig.16a indicates that negative correlations are found in warmer areas where some winter precipitation comes as rain, while the strongest positive correlations are found in colder areas.

Number of snow days and NDJFM temperature (Fig.17b) are negatively correlated all over the country, and stronger correlations are seen along the coast. This is confirmed by Fig.17a, which suggests that these negative correlations are stronger in warmer areas. They are also generally stronger than the correlations between max snow depth and NDJFM temperature.

Correlations between number of snow days and NDJFM precipitation (Fig.18b) are mostly negative along the coast and weakly positive inland. Negative correlations are found in warmer areas, while positive correlations are found in colder areas (Fig.18a). However, correlations are relatively weak overall.

These results clearly demonstrate that both number of snow days and max snow depth are greatly sensitive to variations in winter temperature in warmer regions, while in colder regions max snow depth is also very sensitive to variations in winter precipitation

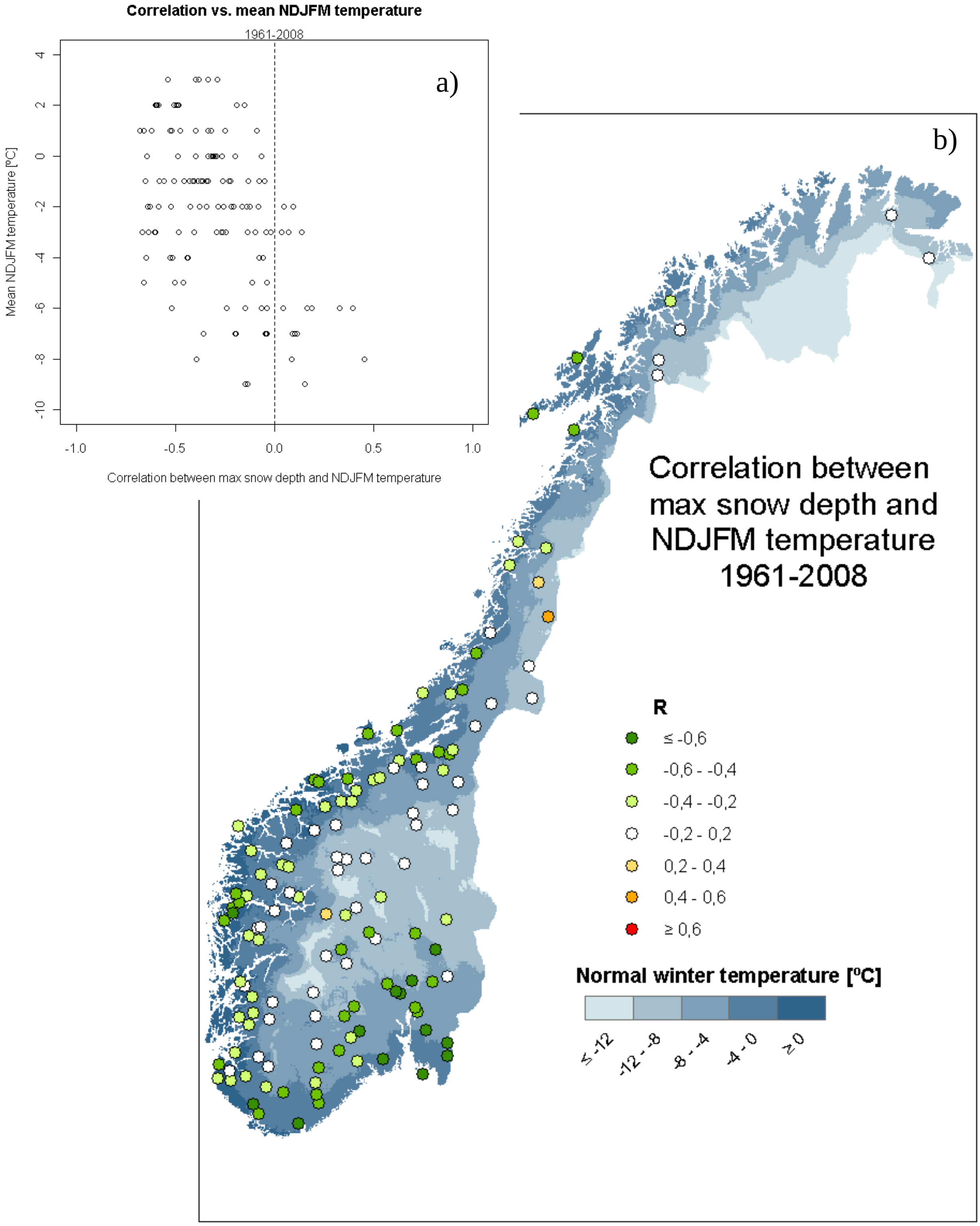

Fig.15: a) Correlation (R) between max snow depth and NDJFM temperature versus mean NDJFM temperature in the period 1961-2008 (mutual stations).
b) Correlation (R) between max snow depth and NDJFM temperature in the period 1961-2008 (mutual stations). Blue background indicates mean winter (DJF) temperature for the normal period 1961-90. Stations in white show very low correlation.

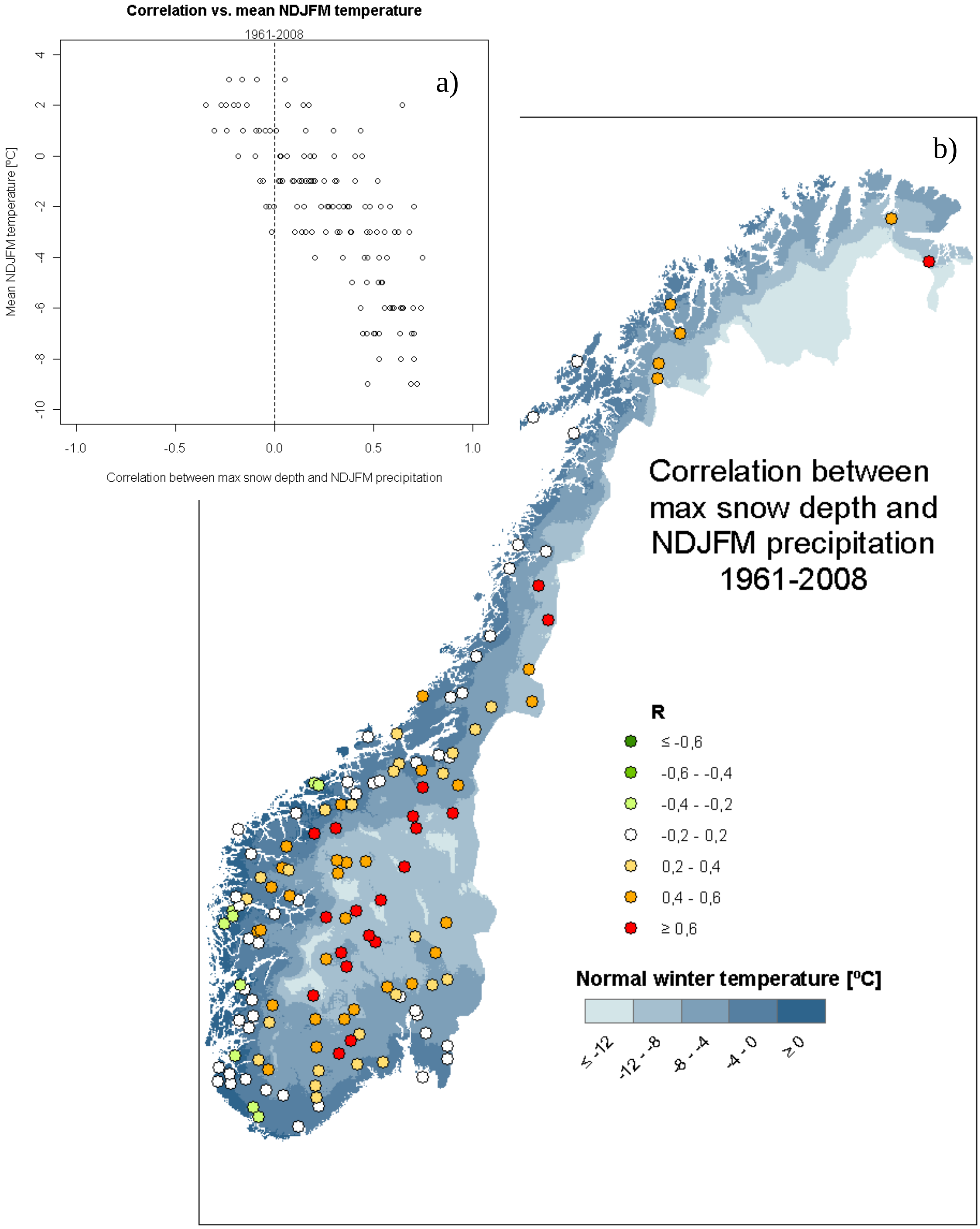

Fig.16: a) Correlation (R) between max snow depth and NDJFM precipitation versus mean NDJFM temperature in the period 1961-2008 (mutual stations).

b) Correlation (R) between max snow depth and NDJFM precipitation in the period 1961-2008 (mutual stations). Blue background indicates mean winter (DJF) temperature for the normal period 1961-90. Stations in white show very low correlation.

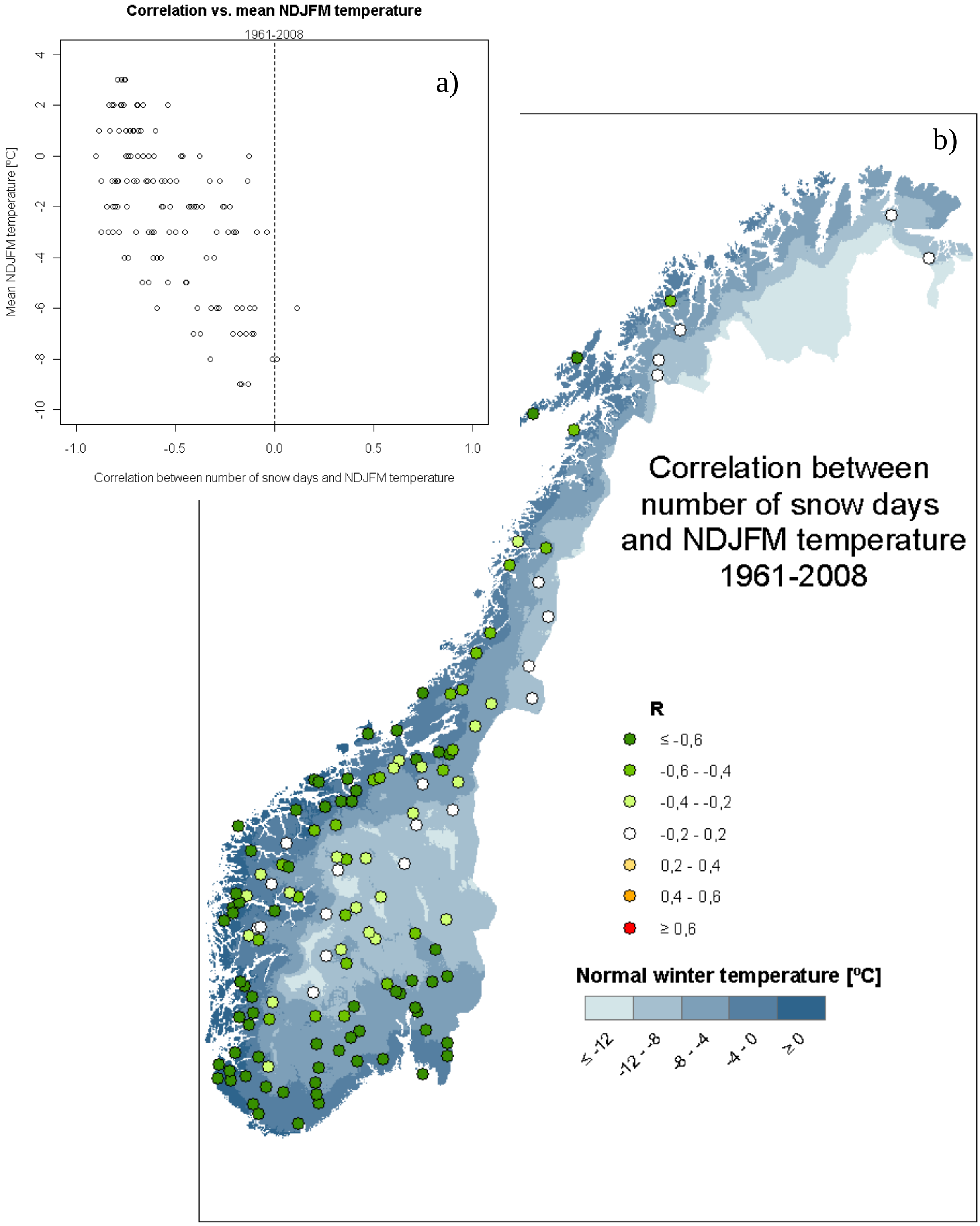

Fig.17: a) Correlation (R) between number of snow days and NDJFM temperature versus mean NDJFM temperature in the period 1961-2008 (mutual stations).
b) Correlation (R) between number of snow days and NDJFM temperature in the period 1961-2008 (mutual stations). Blue background indicates mean winter (DJF) temperature for the normal period 1961-90. Stations in white show very low correlation.

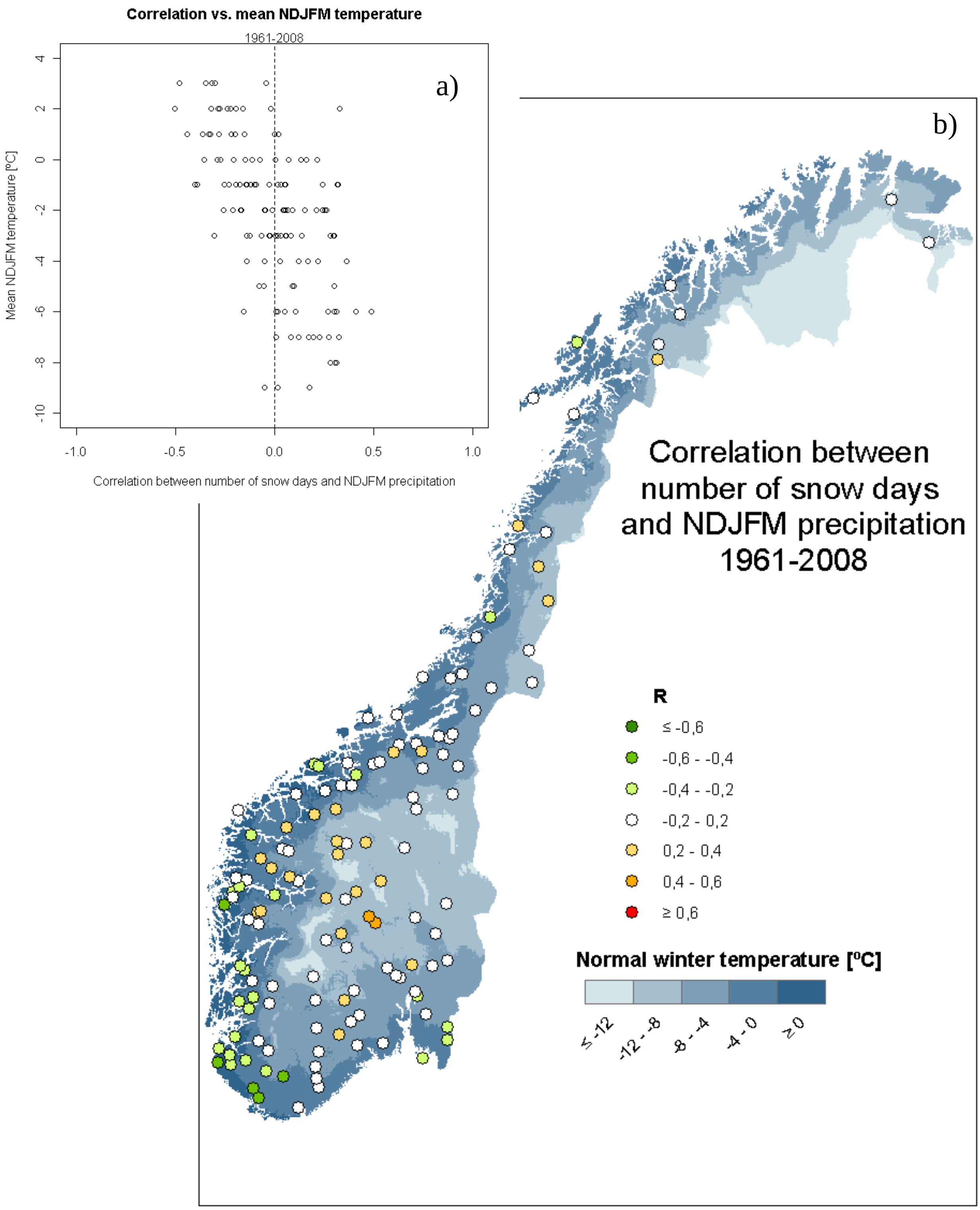

Fig.18: a) Correlation (R) between number of snow days and NDJFM precipitation versus mean NDJFM temperature in the period 1961-2008 (mutual stations).
b) Correlation (R) between number of snow days and NDJFM precipitation in the period 1961-2008 (mutual stations). Blue background indicates mean winter (DJF) temperature for the normal period 1961-90. Stations in white show very low correlation.

4. Summary and conclusions

Due to the limited number of stations in period I it is hard to reach a conclusion, but there is a tendency to positive trends along the southern coast. In period II and III, however, trends become more and more negative in the entire country. The strongest decrease is found for number of snow days in warmer areas over the last few decades. Trends in max snow depth, however, vary between colder and warmer regions. Positive trends in max snow depth occur mostly in colder regions. In these regions precipitation comes as snow at the height of winter, despite the recent warming, and there has been an intensification of snowfalls. Førland and Arntzen (1994) found a clear connection between higher winter temperatures and more snow accumulation in western Norway. The main reason for this is that high winter temperatures in this area are related to strong and humid winds from the west, enhancing orographic precipitation in this part of the country. In elevated areas most of this precipitation comes as snow during the winter months.

In warmer areas the recent climate development has caused less precipitation to fall as snow as well as more and stronger melting occurs. This is mostly due to a milder climate, but also since more precipitation comes as rain. Number of snow days has decreased in both warm and cold regions, as a result of higher temperatures causing a later start and earlier end of snow season. In warmer regions the higher occurrence of mid-winter rainfall and melting episodes is an additional factor. The same tendency was seen in Räisänen (2008), who found that snow water equivalent (SWE) at the height of winter increases in the coldest parts of the Northern Hemisphere, elsewhere, SWE decreases. In the same study it was concluded that even where SWE increases at the height of the winter, it decreases early in the fall and late in the spring, thus, shortening the snow season.

The correlation analysis indicates that number of show days is greatly sensitive to temperature changes in all parts of the country. The same dependency applies to max snow depth in warmer regions, while in colder regions max snow depth is also very sensitive to precipitation changes.

Results from this study are consistent with a warmer and wetter climate in Norway over the past 30-40 years. As more and more locations reach a certain temperature level, it is likely that the observed trend in snow parameters will continue into the future. Variations in cold-season temperature might become increasingly important to snow conditions, including max snow depth. Still, the relationship between snow parameters and winter climate is not linear, and snow depths are also affected by other factors such as changes in snow density and wind. Thus projecting future changes in snow season duration and snow depths is not a straight forward task.

A study on April 1st snow depth in collaboration with NVE started in 2010. We consider certain regions with a wide number of observations from low elevations (met.no stations) and high elevations (NVE stations) for different periods in the past. This allows us to obtain results from the entire elevation profile.

5. Acknowledgements

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