Trends in annual maximum snow water equivalent in South-Norway (1914 - 2008)

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ABSTRACT: Since 1915, snow has been measured annually at expected snow maximum in Norway in relation to power production and flood forecasting. Analysis of annual maximum snow water equivalent shows no temporal trend when looking at a regional dataset. However, looking at each single station with more than 15 years of data within a meteorological normal period, many single stations shows significant trend (α=0,05) Most of the trends are positive for high altitude locations.

KEYWORDS: snow water equivalent, trends, climate change, South Norway

1 INTRODUCTION

Temperature and precipitation have showed positive trends in Norway for the past century. Annual temperature has increased by 0.5-1.5°C and annual precipitation has increased statistically significant in almost all of Norway and as much as 15-20% in the north-western areas (Hanssen-Bauer, 2005). Future scenarios (2071-2100) of temperature and precipitation for Norway indicate that the trends will continue to be positive. Temperature and precipitation will increase for all regions, but the increase in precipitation will be higher for the western part than for the inland (Beldring et al., 2008).

Snow cover has decreased in the northern hemisphere in the past 50 years (Lemke et al., 2007) and scenarios for 2071-2100 predict a decrease in maximum snow water equivalent (swe) for the entire country, but a more, topographically detailed hydrological study of the same scenario dataset suggest that for certain high elevation areas annual maximum swe might increase (Vikhamar-Schuler and Førland, 2006).

A possible interpretation of these studies concerning the future snow conditions is thus that the season of precipitation as snow, in general, becomes shorter in all areas, with the potential of more snow at some areas of high elevation, due to increased winter precipitation, (e.g. the western part of Norway) where the increase in temperature is not sufficient to compensate for the higher winter precipitation.

Many recent studies (especially in the US) on historical data on snow water equivalent (swe) have investigated possible trends in swe during the last 50-60 years. Howat and Tulaczyk (2005) found both increasing and decreasing trends in SWE for increased winter temperature for the period of 1950-2002. Increases in SWE are, of course, found for high elevations where winter precipitation had increased and decreasing trends were found where increased winter precipitation could not compensate for the temperature increase. This find is consistent with the work done by e.g. Mote (2003; 2006).

The aim of this study is to quantify and detect trends in Norwegian snowdata, especially at higher altitudes. More than 50 % of the snowstations in South Norway are located above 1000 masl and this gives us a unique opportunity to do analyses in areas that are poorly covered by meteorological stations.

In this study, we will analyse temporal trends of swe in South Norway. The temporal trend analysis includes trend analysis within different normal periods (1931 - 1960, 1961 -1990, 1991-2008) and analysis of temporal trend as a function of altitude.

This analysis is carried out in cooperation with the Norwegian meteorological office as a part of the NORCLIM-project.

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2 DATA

Since 1915, snow has been measured in South Norway in relation to power production and flood forecasting. The observations are mainly done by the power production companies once a year at expected snow maximum (middle of March – middle of April). Throughout this paper, the acronym, “swe”, is used for annual measurements of maximum snow water equivalent.

Figure 1 shows all snow measurements in Norway. The stations in South-Norway are located between 125 and 1713 masl. and more than 50 % of the stations are located above 1000 masl.

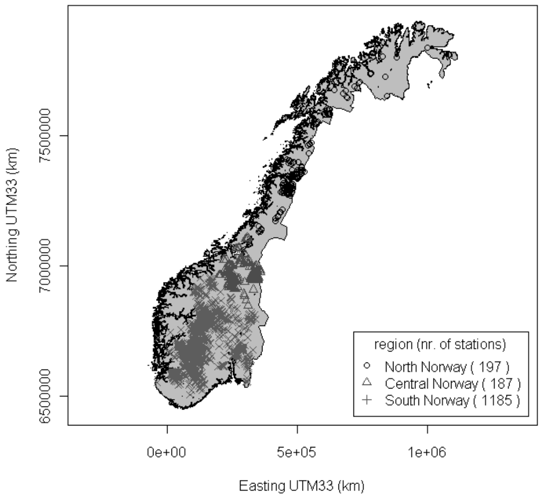

Figure 1. Location of the snowstations.

3 METHODS

With such an extensive data set at hand, it is important to carry out the study of detecting possible temporal trends in a manner in which possible trends are not lost in statistical noise due to choice of timeperiod, choice of climatic region or by not taking into account the dependence of swe on altitude. In order to be able to compare the changes in swe from station to station without the study being compromised by local climatic differences, a normalization procedure was carried out. For each station, the annual data point of swe is divided by the long-term mean of the station.

To investigate how the trends may vary with choice of timeperiod, the entire dataset is divided into the different meteorological normal periods (1931 - 1960 and 1961- 1990, and the years from 1991 - 2008). Before 1931, the number of stations with data is too small to be included.

Since both temperature and precipitation are found to be increasing (Hanssen-Bauer, 2005), the investigations of possible trends in swe can be made difficult by the fact that these two factors have the opposite effect on swe. If we assume that more precipitations could compensate for decreasing temperature at higher altitudes, we would expect to find a trend ranging from negative trend at lower altitudes and to more positive trend at higher altitudes. To examine the variation in trend with elevation, the trend, estimated for each station, is plotted against elevation and location (E-W). In this part of the study, we are using the measured swe instead of the normalized swe described earlier. Only stations with more than 15 years of data within each 30-years period are included in the analysis. From 1991 - 2008, stations with more than 8 years of data are included in the analysis.

To determine the significance of possible trends in time, linear trend analysis is performed. A linear regression model in the form; $y = a + bx$, is fitted to the measurements. When b equals zero, no trend is assumed to be present. A two-sided t-test is carried out to check the statistical significance at b. The hypothesis to be tested is if b is significantly different from zero at a level, α=0, 05.

4 RESULTS

4.1 Temporal trends

Temporal trend in swe in South Norway for each period is shown in Figure 2. Linear trend analysis on the mean annual value shows neither an increase nor a decrease, and the slope does not differ significantly from zero at a level α = 0, 05.

4.2 Temporal trend with altitude

In Figure 3, each station in South-Norway is represented with a triangle or a circle. The x-axis indicates the altitude whereas the y-axis indicates the location in west-east direction. For each station, trend and p-value is estimated, and illustrated with upward and downward triangles with varying sizes denoting significant

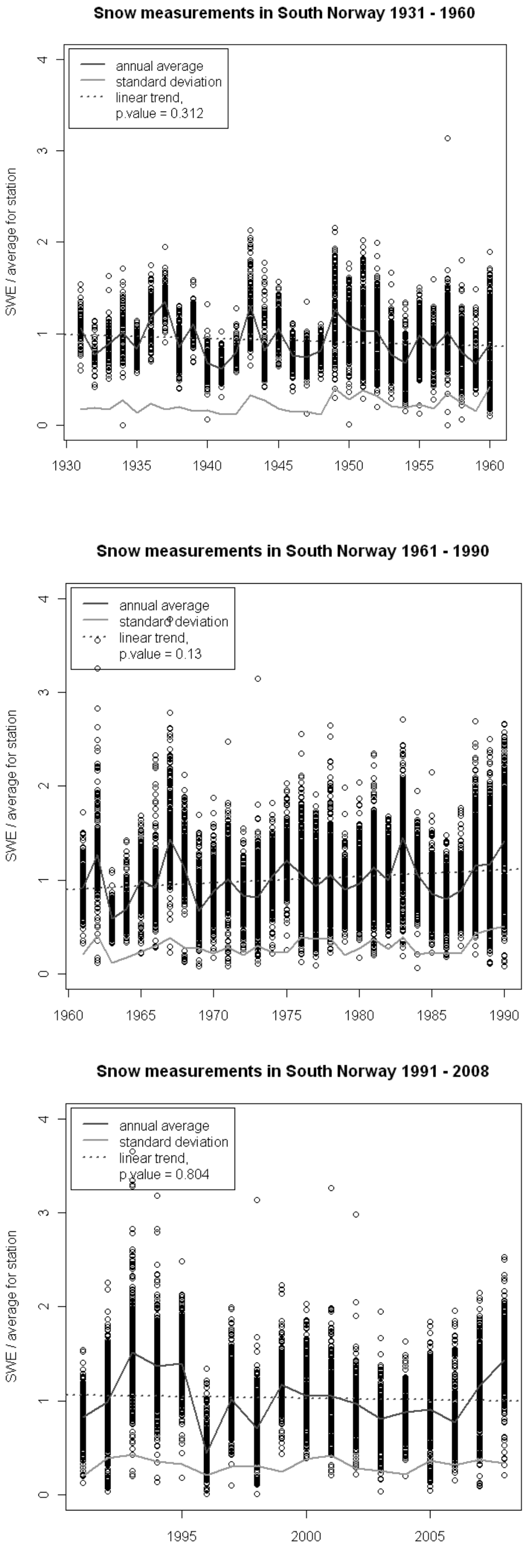

Figure 2. Temporal variations in swe from stations in South Norway for different periods (1931-1960, 1961-1990, 1991 - 2008). The upper line shows the annual average, while the lowest line shows the standard deviation. The linear trend in the average (dotted line) is not significant different from zero at level α = 0, 05.

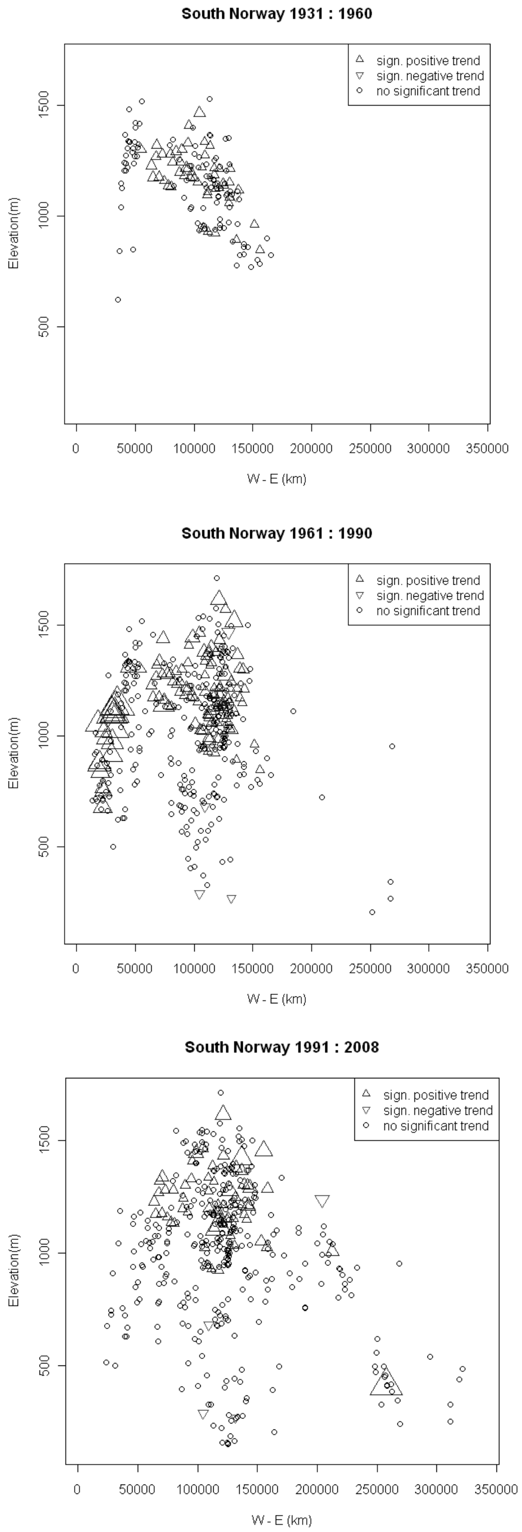

Figure 3. Each snowstation is positioned according to altitude and E-W coordinates. The “upward” triangles denote significant positive trend (at level $\alpha = 0, 05$), while the “downward” triangles denote significant negative trend. Circles are stations with no significant trend. The sizes of the triangles indicate how strong the trend is, related to the range of trend in each plot.

positive trend and significant negative trend, respectively. The larger the triangle, the stronger linear trend. Black circles denote no significant trend in swe.

During 1961-1990 positive trends at more westerly stations are more common than in 1931-1960 and 1991-2008, and for both 1961-1990 and 1991-2008 most of the stations with negative trends are located at lower altitudes (below 700 masl). Note the different scale in the range of the triangles: The strongest absolute trend in 1931-1960 is 0,006 m/yr, while the strongest absolute trend in 1961-1990 and 1991-2008 is 0,031 and 0,036 m/yr respectively.

5 DISCUSSION & CONCLUSION

The snow-conditions in the first and last years of the data period will influence the sensitivity of the linear trend, especially when the data points are few and there is a lot of noise in the dataset. This weakness by using linear trend is discussed in Mote (2008) and Hisdal et al. (2001).

5.1 Temporal trend

The lack of significant trend in the mean annual swe could be caused by the mixing of all stations, independent of elevation, local climatic differences and different timeperiods even though we are looking at normalized swe (annual swe divided by the long-term mean of each snowstation).

From studies in the US, we find that at lower altitudes, increasing temperature is likely to cause a decline in swe, whereas at higher altitudes; increasing precipitation is likely to cause an increase in swe (Howat and Tulaczyk, 2005; Mote 2003, 2006). Mixing stations with different altitudes disguise the pure impact of increasing temperature and increasing precipitation.

Different numbers of stations are present in each time period, and how the stations are distributed with altitude, may affect the results. Mote (2008) showed that diverging results among different periods are strongly correlated with the elevation-distribution of the stations. A very small number of stations in this study have continuous records of snow measurements. It is thus likely that the available number of stations within each timeperiod and their distribution with altitude is important when comparing trends among different time periods.

Even by looking at a semi-confined region, the dataset is influenced by climatic differences. Different meteorological processes dominate south Norway in an east-west direction. In figure 2, swe-stations in continental, inland climate are grouped together with stations located in maritime climate. According to Andreassen et al. (2005), the maritime glaciers in Southern Norway are increasing, whereas the glaciers located inland are decreasing. A similar behavior of swe is to be expected for this area. By normalizing the swe data by dividing the annual data point of swe by the long-term mean of the station, we try to reduce the impact of regional differences in mean annual swe. Still, we have not reduced the regional differences in trends in precipitation and temperature. An increase in temperature in maritime climate is likely to cause more precipitation as rain during the winter, whereas on the other hand, raising temperature in a cold inland areas is likely to results in more precipitation as snow, due to the enhanced capacity of air to contain more moisture (Howat and Tulaczyk,2005; Mote,2006).

5.2 Temporal trend with altitude

According to studies from the US (Howat and Tulaczyk, 2005; Mote 2003, 2006), we did expect to find trends ranging from negative (decreasing swe) at lower altitudes and to positive (increasing swe) at higher altitudes. Even though the number of stations and their distribution with altitude is limited, a pattern in the plots were found.

Many of the stations with positive trend in South-Norway are located in the western part of the mountains, especially when looking at the 1961-1990-plot. From 1931-1960 to 1961-1990 and further on to 1991-2008, there is a change in how the most westerly stations behave. This can be interpreted as a result of climate variability. During 1931-1960 no trend is present, whereas in 1961-1990, we may se the results of increasing precipitation. In 1991-2008, on the other hand, an increase in precipitation could be predominated by increasing temperature and no significant trend is present anymore. This is, off course, sensitive to the selection of stations present in each period.

The westerly location also corresponds to a nival area and a relationship between the size of the trend and the annual average swe is plausible. Analysis of correlation between annual average swe and calculated trend shows indications on relationships between the average swe and trend, and by limiting the analysis to stations with significant trend, a strengthen relationship is found .This could be interpreted as the average swe affecting the trend. Using a normalization/ standardization procedure on the calculated trend at each station does not, however, change the pattern in the plots or our conclusion.

5.3 Conclusion

There are no indications of significant trends in the mean annual swe in South Norway, not even by looking at different time periods. However, by looking at trend in time with altitude for each station, single stations seem to have significant trends. The stations with significant positive trend seem to be located in nival areas.

The temporal trends in swe are stronger in 1961-1990 for certain stations than in 1931-1960 and 1991-2008 and could be explained by climate variability: At 1961-1990 an increase in precipitation dominates, whereas in 1991-2008, swe is more sensitive to increasing temperature.

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