Past and future changes in flood and drought in the Nordic countries

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Abstract Based on a data set of 46 daily streamflow records from the Nordic region for the period 1920–2002 the natural variability in trends and estimated return levels of flood and drought has been studied. In addition, for a subset of series, return level estimates based on historical records were compared to extreme estimates for a control period, 1961–1990, and a scenario period, 2071–2100. It was shown that detected trends and return levels strongly depend on the time period studied because the natural variability in the extremes is large. The scenarios indicated reduced annual floods in eastern Norway, increased annual floods in the western part and varying results for the basins in central and northern Norway. Droughts in general tended to become more severe in the scenarios. The expected changes in floods in the scenarios were only larger than the differences found due to natural variability for one AOGCM-Regional climate model combination.

Key words Scandinavia, flood, drought, trend, climate variability and change, scenarios

INTRODUCTION

The projected global temperature increase is expected to cause an intensification of the hydrologic cycle leading to changes in streamflow, including flood and drought. Major hydrological extremes in Europe are often interpreted as a result of human induced climate change. Recent Nordic examples are the flood in central Norway in January 2006 with estimated return levels of more than 200 years, and the drought in 2002/2003 covering the whole Nordic region, with estimated damage in Finland alone of more than 100 million € (Silander, 2004).

Climate change studies traditionally include identification of natural climate variability, attempts to detect a climate change signal in historical data and elaboration of possible scenarios for the future. It has previously (Hisdal *et al.*, 2006) been shown that in general for the Nordic countries, no clear spatiotemporal trend patterns can be found in flood peak, neither for the autumn nor the spring season. However, there is a clear tendency towards an earlier spring flood. There is also a tendency towards more severe summer droughts in southern and eastern Norway. In Roald *et al.* (2006) studies of the impacts of climate change on streamflow for catchments representing different runoff regimes in Norway were carried out based on the combined use of two global atmosphere–ocean general circulation models (AOGCMs), two regional climate models and a hydrological model. It is concluded that we can expect a reduction in the annual flood in basins with dominating snowmelt floods and an increase in basins with a dominating coastal climate. There will be more winter floods and the snowmelt flood will occur earlier.

This paper addresses: (a) the influence of time period on trends and estimated return levels of hydrological extremes, and (b) the comparison of historical extremes with extreme estimates based on a control period (1961–1990) and scenarios (2071–2100). In the next sections the data and methods are described, the results are presented and discussed and conclusions are given.

DATA AND METHODS

A total of 46 daily series from Denmark, Finland, Norway and Sweden covering the period 1920–2002 were collected (Fig. 1). This enables a regional study of changes in extremes. A quality control has ensured that the data, as far as possible, are uninfluenced by human activity in the basin.

All records were used in the study of how trends might vary depending on the time period and when evaluating the variability in estimated return levels. A selection of eight Norwegian records was studied when comparing historical and scenario extremes.

The annual maximum flood discharge was analysed. The streamflow was considered to be in a drought situation when the flow is below a specific threshold, the threshold level method

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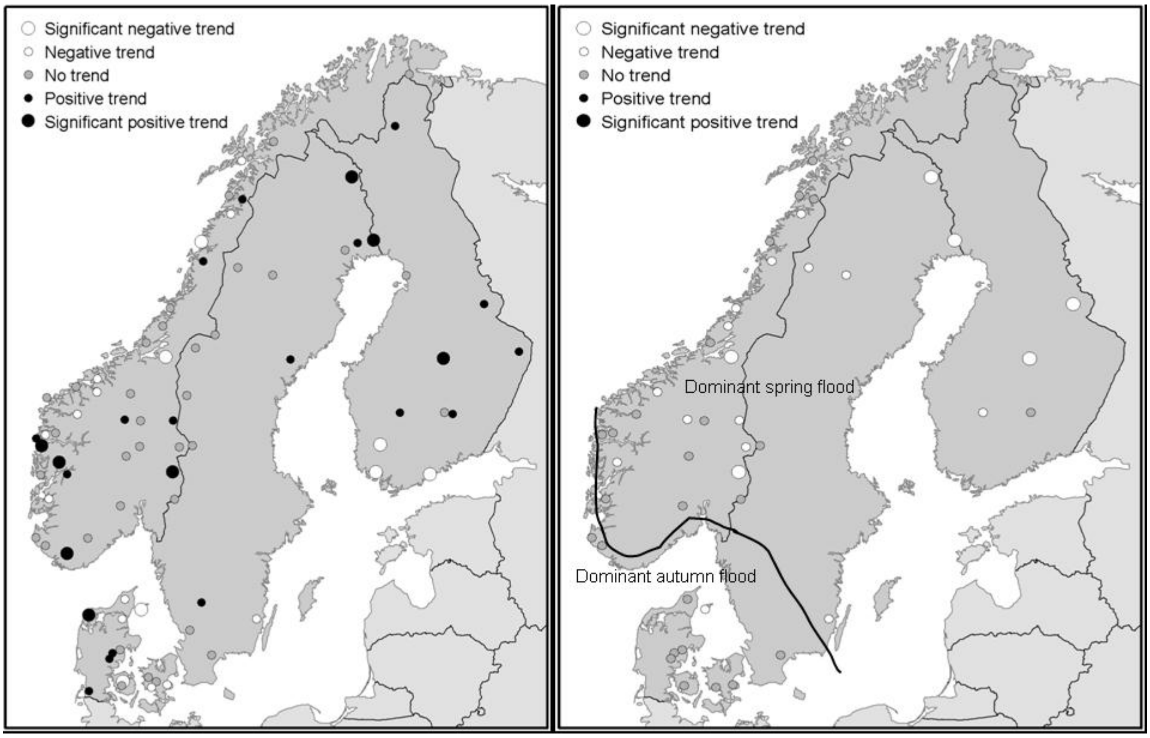

Fig. 1 Trend in annual maximum flood peak value (left) and timing (right) for the period 1920–2002.

(Hisdal *et al.*, 2004). The flow exceeded 70% of the time (70-percentile) was used as the threshold. This means that the drought duration and deficit volume can be identified. As these two drought characteristics are highly correlated, only the results for drought duration are presented here. To perform a consistent analysis of droughts it is necessary to distinguish between droughts caused by lack of precipitation and high evapotranspiration losses (summer droughts) and droughts caused by precipitation being stored as snow (winter droughts). Only summer drought was considered.

Trends in successive 30-year periods using the non-parametric Mann-Kendall test with a 5% significance level were estimated. It was then possible to study how potential trends change based on the time period studied.

According to extreme value theory, the block maxima of a sequence of identically, independently distributed (*iid*) random variables in the limit follows a Generalized Extreme Value (GEV) distribution (e.g. Coles, 2001). Assuming that annual maximum series of flood and drought are *iid*, the GEV distribution was fitted to the annual maximum flood peak and drought duration. The distribution parameters were estimated by Probability Weighted Moments (PWM). By estimating floods and droughts of specific return periods (5-, 10-, 20- and 50-year event) based on successive 30-year periods, the variability in floods and droughts was studied.

For a detailed description of the estimation of the streamflow scenarios see Roald *et al.* (2006). Results from two AOGCMs were used as boundary conditions for the regional climate model simulations: the ECHAM4/OPYC3 and the HadAm3H model. These models were run with assumptions according to the A2 and B2 greenhouse gas emission scenarios. The two regional models were the Regional Climate Development under Global Warming (RegClim) model and the Rossby Centre Regional Atmosphere–Ocean (RCAO) model. All of the hydrological simulations used the time slice approach whereby model simulations representing a slice of time (1961–1990) in present climate (control) and in a future (2071–2100) climate (scenarios) were performed. Daily precipitation and temperature from the regional climate models were further downscaled to meteorological stations using two different approaches. The RegClim approach was a statistical adjustment technique which preserves the frequency of precipitation and temperature as predicted by the climate models, aiming at reproducing observed monthly means and standard deviations for the control period (Engen-Skaugen *et al.*, 2005). Changes in meteorological variables between the control and the scenario simulations from the RCAO model were processed in a model interface before being transferred to an observed climate database, the delta change approach. The downscaled regional climate model results were subsequently used for driving a spatially distributed version of the hydrological HBV-model (Beldring *et al.*, 2003), yielding an ensemble of streamflow simulations for present and future conditions.

RESULTS AND DISCUSSION

Trends and variability in floods and droughts

In Hisdal *et al.* (2006) it was concluded that no systematic pattern in autumn and spring flood peak values could be identified for the period 1920–2002. Trends in the *annual* flood peaks are shown in Fig. 1. As expected no regional pattern can be observed (Fig. 1, left). Seven of the 46 stations do have a significant trend at the 5% level, two towards more severe floods and five towards less severe floods. There is neither a tendency of positive trends (more severe floods) for stations with dominating autumn rain floods nor negative trends (less severe floods) for stations with dominating snowmelt floods during the spring. However, regarding the timing of the annual flood (Fig. 1, right) there are only trends towards an earlier timing, especially in regions with a dominating spring snowmelt flood. Regarding trends in drought duration for the period 1920–2002, around 60% of the stations (7 of 11) in Southeast Norway showed a tendency towards longer summer droughts. For this period the stations that tend to get shorter summer droughts were found in Denmark.

The dependency of the trend on the period analysed was found by calculating the trend for successive 30-year periods, starting in 1920–1949 and ending in 1973–2002. Figure 2 illustrates the changing Mann-Kendall test statistics for both flood and drought for the Knappom station in eastern Norway. For test statistics values larger than |1.96| (the 0.975 quantile of the standard normal distribution) a trend is significant with a 5% level of significance. It can be seen that significant negative and positive trends are found both for flood and drought depending on the underlying 30-year time period. The spatial pattern of the fluctuating Mann-Kendall test statistics varies. Regarding drought, all stations in Denmark have the same behaviour. There is some greater variability between the stations in Sweden and Finland whereas the spatial variability in Norway is largest with positive and negative trends for the same time period, reflecting the various climatic influences and hydrological regimes. As drought is a more persistent phenomenon than flood and also covers larger regions. The variability in trends between stations is therefore larger for floods than droughts.

Floods and droughts of various return periods (5, 10, 20 and 50 years) were also calculated for successive 30-year periods. For drought the 70 percentile for the period 1920–2002 was used to extract the drought events. The estimates may vary considerably depending on the underlying

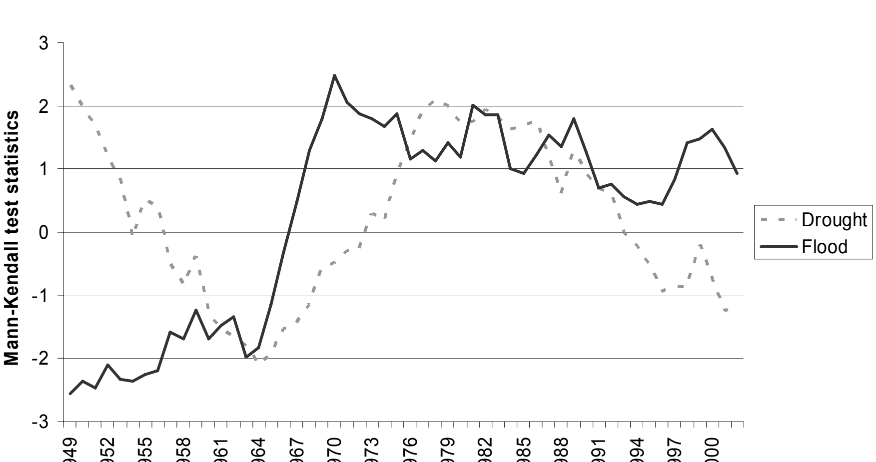

Fig. 2 Mann-Kendall trend test statistics for the annual maximum flood peak and drought duration for the Knappom basin calculated for consecutive 30-year periods.

30-year period, reflecting that the uncertainty in estimated return levels is large. The deviation (in percent) from the average estimated 50-year annual maximum flood and summer drought based on different 30-year periods of observation is illustrated in Fig. 3. For floods, on average the 50-year event estimates varied by 34% (min. deviation 13%, max. 80%). For drought the average deviation was 38% (min. deviation 15%, max. 79%). Normally, the percentage deviation was lower for the shorter return periods, but even for the mean annual flood and drought, the percentage deviation could be quite large.

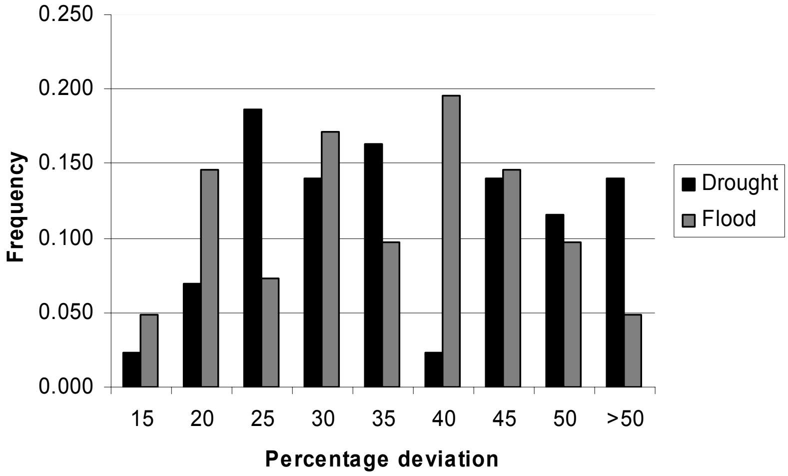

Fig. 3 The deviation (in percent) from the mean estimated 50-year event and the difference between the maximum and minimum estimated 50-year flood and drought.

Comparison to scenarios

The mean and standard deviation of the annual maximum floods based on observations (1961–1990), the control run (1961–1990) and the 2071–2100 scenarios were compared for eight stations in Norway (Table 1). For four of the stations seven scenarios exist; for the other four stations only three scenarios exist. When studying climate change effects on hydrological extremes it is important that the mean values and standard deviation observed in the historical data are reproduced in the control runs. It can be seen (Table 1) that the mean annual flood (MAF) is underestimated in all control runs. The largest underestimation is found for the Rossby control runs. These also underestimate the standard deviation. In the RegClim case the standard deviation is both over- and underestimated. The misfit observed for the MAF is mainly caused by the fact that the hydrological model in general simulates too small annual maximum discharge values. It might also be that the precipitation and temperature data are not representative. The unclear results regarding the standard deviation in the RegClim case could have been caused by the precipitation and temperature estimation procedures. The misfit between the moments in the observations and control runs complicates the interpretation of the expected changes in annual floods peaks and even more for floods of higher return periods.

Expected changes in the future were found by comparing the control-runs with the corresponding scenarios. The MAF was reduced by between 1% and 25% (seven scenarios) in the two inland and mountainous basins in eastern Norway with snowmelt dominated spring floods. All scenarios indicated an increase in MAF in basins in western Norway, where the floods are mostly caused by rainfall combined with some snowmelt. The RegClim and HadAm3H-Rossby scenarios indicate increases of up to 40%, and the ECHAM4-Rossby combination 51–99%. In central and northern Norway only Rossby scenarios exist and they diverged from slightly decreasing (2–9%) MAFs when based on the HadAm3H scenario to increases (35–69%) based on the ECHAM4 scenario. The order of magnitude of change for the 50-year flood was similar to annual flood changes. An exception was the ECHAM4-Rossby combination that increased the 50-year flood by more than

Table 1 MAF and standard deviation for the observed series, control runs and scenarios.

	Nybergs. E-Norway		Knappom E-Norway		Stordalsv. SW-Norw.		Bulken W-Norway		Viksvatn NW-Norw.		Høggås Central Norway		Øyungen Central Norway		Skarsvatn N-Norway	
	Mean (m^3s^{-1})	Std	Mean (m^3s^{-1})	Std	Mean (m^3s^{-1})	Std	Mean (m^3s^{-1})	Std	Mean (m^3s^{-1})	Std	Mean (m^3s^{-1})	Std	Mean (m^3s^{-1})	Std	mean (m^3s^{-1})	Std
Observed 1961–1990	326	121	181	58	76	21	346	83	181	32	148	36	117	42	47	16
RegClim Control, 61-90 HadAm3H	308	131	179	62	59	12			179	50						
RegClim HadAm3H-A2	279	113	140	53	67	18			211	50						
RegClim HadAm3H-B2	291	117	178	67	74	13			234	52						
RegClim Control, 61-90 ECHAM4	303	74	178	75	56	14			180	52						
RegClim ECHAM4-B2	231	97	135	57	76	14			232	49						
RCAO Control, 61-90	288	94	172	55	56	12	325	62	169	30	117	24	112	27	41	11
RCAO HadAm3H-A2	238	93	142	45	72	16	452	116	208	58	114	24	109	39	38	12
RCAO HadAm3H-B2	250	93	141	46	72	18	435	115	208	51	108	19	102	36	38	12
RCAO ECHAM4-A2	215	81	166	58	92	22	649	156	314	79	191	46	188	49	65	20
RCAO ECHAM4-B2	218	82	153	50	85	20	571	117	282	62	166	36	164	46	55	17

100% for the western coast basins. The topography of Norway causes strong dependency of the regional distribution of precipitation and floods on the atmospheric circulation. The two AOGMs produce differences in the projected pressure fields, which explain some of the differences in the regional distribution of the floods in the north.

Except for the ECHAM4-Rossby combination, the estimated human induced climate changes were less or equal to the differences found based on different historical 30-year periods. The exception was the western coast basins Bulken and Viksvatn that only had 18% difference in the different historical 30-year MAFs, but between 12% and 49% increases in the scenarios.

As drought duration was defined as the summer season maximum number of days below the 70 percentile, the mean drought duration and standard deviation remains unchanged. The change in drought duration therefore had to be evaluated by comparing the 70 percentile and the maximum drought duration in the control run and the scenarios. If the 70 percentile decreases in the scenario, the total number of days with low flow can be expected to increase. Coherent with the findings of Roald *et al.* (2006), where the scenarios indicate a reduction in summer flow in most of Norway, the 70 percentile generally decreased. The only significant increase was found for the two basins in central Norway with the ECHAM4-Rossby combination. Regarding the maximum drought duration, it increased for 56% of the scenarios and decreased for 36%. The increase was most pronounced for the two basins in eastern Norway (up to 17 days) and the decrease was largest for the northernmost basin (up to 25 days).

It is important to note that a preservation of the variability in the control period compared to the observations would probably either increase or decrease the variability in the scenarios. Large uncertainties are therefore related to the quantification of expected changes in floods and droughts.

The results show that the scenario summer drought duration is influenced by the increasing temperature that both increases evapotranspiration and causes an earlier snowmelt that again increases the probability of having a long summer low flow period. Even if a temperature increase reduces the snow cover and to some extent the snowmelt floods, generally changes in floods are more influenced by changes in precipitation.

CONCLUSIONS

This study has focused on changes in floods and summer droughts in the Nordic region, both in historical data and scenarios. Past data are useful in clarifying the background of natural variability, and it was shown that the variability in estimated design events for flood and drought is large. In some cases this variability was even larger than the expected increase or decrease in flood peak or drought duration in the scenarios, reflecting the fact that the uncertainty in the design event estimates may outweigh the uncertainty in the estimated changes in hydrological extremes based on scenarios.

An improved estimation of the variability in the extremes is needed before we can conclude much about the expected quantitative changes in the extremes due to human induced climate change. However, it is possible to indicate a direction of change. In the eastern inland catchments in Norway the flood peaks can be expected to decrease. In the western part of the country the scenarios are uniform too, indicating increased flood peaks; when based on the ECHAM4-Rossby model, the increase is quite substantial. In central and northern Norway the picture is unclear with decreasing flood peaks based on the HadAm3H-Rossby model and increasing flood peaks based on the ECHAM4-Rossby model, reflecting differences in the pressure fields projected in the two AOGMs. Also, more severe droughts can be expected especially in southeast Norway. For the period 1920–2002, the trends in extremes show similar directions to the scenarios regarding the timing of the snowmelt flood and summer droughts in southeastern Norway, but not with respect to the flood peaks.

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