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Long-term variations in runoff and temperature in Sweden

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Abstract The objective of this paper is to study long-term variations in runoff and flood frequency in Sweden. Runoff over the 20th century increased by about 4% on average, but the trend was not statistically significant. The runoff during 1981–2000 was about 8% above the century average, but runoff in the 1920s was also as high. Records from the 19th century indicate that runoff was higher then, but temperatures were lower. The combination of high temperatures and high runoff in recent years is quite different from earlier records. The increase in the average level of annual floods in northern Sweden was larger, about +10%, but problems with the reliability of older data made it difficult to conclude that the change is in fact significant. The average increase at a selection of the most reliable stations was considerably smaller.

Key words floods; peaks; runoff; Sweden; temperature; trends

BACKGROUND

Sweden, as well as many other countries, has experienced a large number of floods in recent years. The precipitation record over all of Sweden was broken in the year 2000, with high floods in central Sweden in July, and in Arvika in the southwest in November and December. The water level in Lake Vänern, the largest lake in Sweden, rose to a record high level in January 2001. It was estimated that the water level would have been the highest ever recorded, with recordings dating back to 1807, if the lake had remained unregulated. Recent studies of variations in water resources and flood frequency in Sweden have been made by Jutman (1991) and Lindström (1999). Similar studies in nearby countries include those by Robson *et al.* (1998), Roald (1999), Førland *et al.* (2000) and Bering Ovesen *et al.* (2000), among others.

The objective of the present paper is to study long-term variations in runoff in Sweden, now that data from the whole of the 20th century are available.

METHODS AND DATA

Systematic runoff measurements of discharge began in Sweden at the outlet of Lake Vänern in 1807. In addition, there are two other discharge series of considerable length in the country: at the outlet of Lake Vättern, and in the River Dalälven, at Fäggeby. Today, most large rivers are affected by regulation. For the present study, stations were selected with the emphasis on length and quality of the observations. Series with gaps, and stations influenced by ice jamming and other uncertainties, were avoided. Two independent estimates of the total runoff from all of Sweden, during the period 1901–2000, were made. The first estimate was based on 20 small unregulated rivers, with a

basin area less than 3000 km^2. The second estimate was based on the largest basins possible. This estimate consisted of 15 series, covering a total basin area of 333 000 km^2, corresponding to 70% of the total national territory. To cover the whole period 1901–2000, some of the selected stations data had to be extended by use of other series.

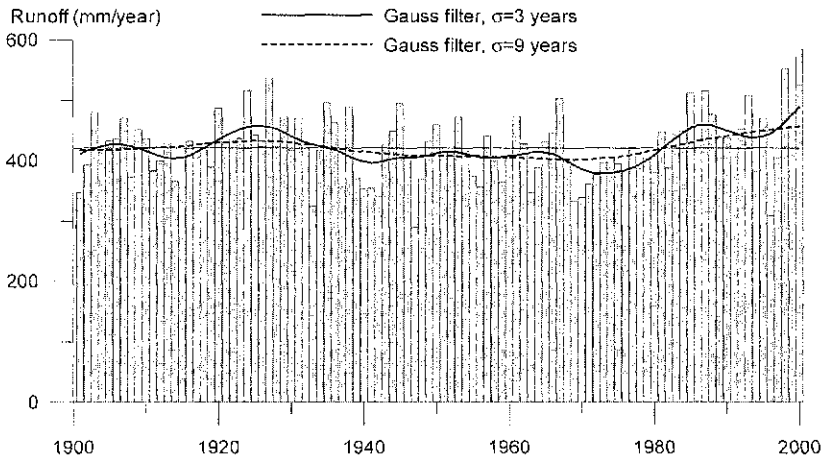

Fig. 1 Estimated runoff in Sweden during the 20th century, based on data from 15 large basins.

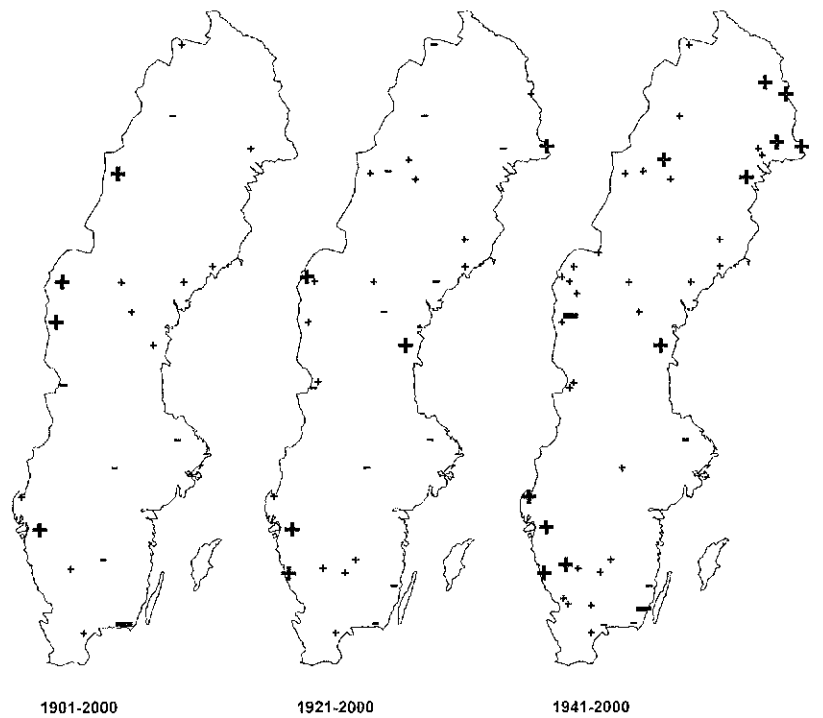

Fig. 2 Results from trend analysis for 45 unregulated basins, by linear regression. The sign gives the slope of the regression line, regardless of level of significance. The large symbols denote a significant trend at a confidence level of 95%.

ANNUAL RUNOFF VOLUMES

The two estimates of runoff during the 20th century matched very well. Figure 1 gives the average runoff for each year during the whole century, based on the 15 large basins. The runoff during the period 1981–2000 was about 8% higher than during the rest of the century. This wet period followed after the dry 1970s, which was the decade deviating the most from the rest of the century (–9%). The runoff in the 1920s was as high as in the last 20 years. A linear regression to the runoff during the whole century gives an increase of 4%, but the change was not statistically significant. A substantial part of the surplus in recent years occurred in the period January–June, due to heavy winter precipitation associated with westerly winds. If isolated, the period 1920–1980 could be interpreted as having a falling tendency, whereas an increasing tendency appears from about 1950 to 2000. The results from station-wise trend analysis depend considerably on the choice of time period (Fig. 2). The high runoff in recent years was most pronounced in the north and in the southwest. The longest records (Fig. 3) rather indicate a falling tendency and high runoff in the 19th century.

Figures 4 and 5 give a joint analysis of runoff and temperature. The national average temperature values were estimated by Alexandersson (2001). In the northern part of the country the last 10 years have been among the wettest in 100 years and very warm (Fig. 4). For southern Sweden, and in a longer time perspective, the high temperatures are more impressive than river runoff (Fig. 5). The 1970s stand out as extremely dry. It is clear that the high river flow in the 19th century was connected to cold weather. The combination of high temperatures and high runoff is what makes recent years remarkable.

FLOOD PEAKS

The average of all index floods (i.e. normalized by division with the average) in a set of 28 unregulated stations in northern Sweden is presented in Fig. 6. The spring flood in 1995 stands out in northern Sweden, with record high floods at many stations. The 1995 flood led to problems primarily in unregulated rivers, as much of the effect was masked by reservoir operation in regulated rivers. On the other hand, several of the recent summer and autumn floods caused considerable problems in regulated systems, e.g. 1993, 1998 and 2000. The highest average flood in the southern part of the country was the spring flood in 1951.

A linear regression to the set of annual floods during the period 1911–2000 indicates an increase of about 10%. This increase is almost significant at the 95% level. The analysis of flood peaks is, however, even more uncertain than the analysis of annual averages. Flood peaks in old data are probably underestimated, since readings were made less frequently than today. The clearest increase was, furthermore, found in basins with the less reliable observations (Fig. 7). A smaller increase was obtained for a subset of stations, which were considered to be the most reliable. No significant trend was found in that selection. Seen in a shorter perspective, the autumn floods increased considerably during the period 1970–2000. However, similar autumn floods were experienced in the 1920s. No increased frequency of very high floods, here defined as having a return period of at least 10 years, could be determined. Flood levels in

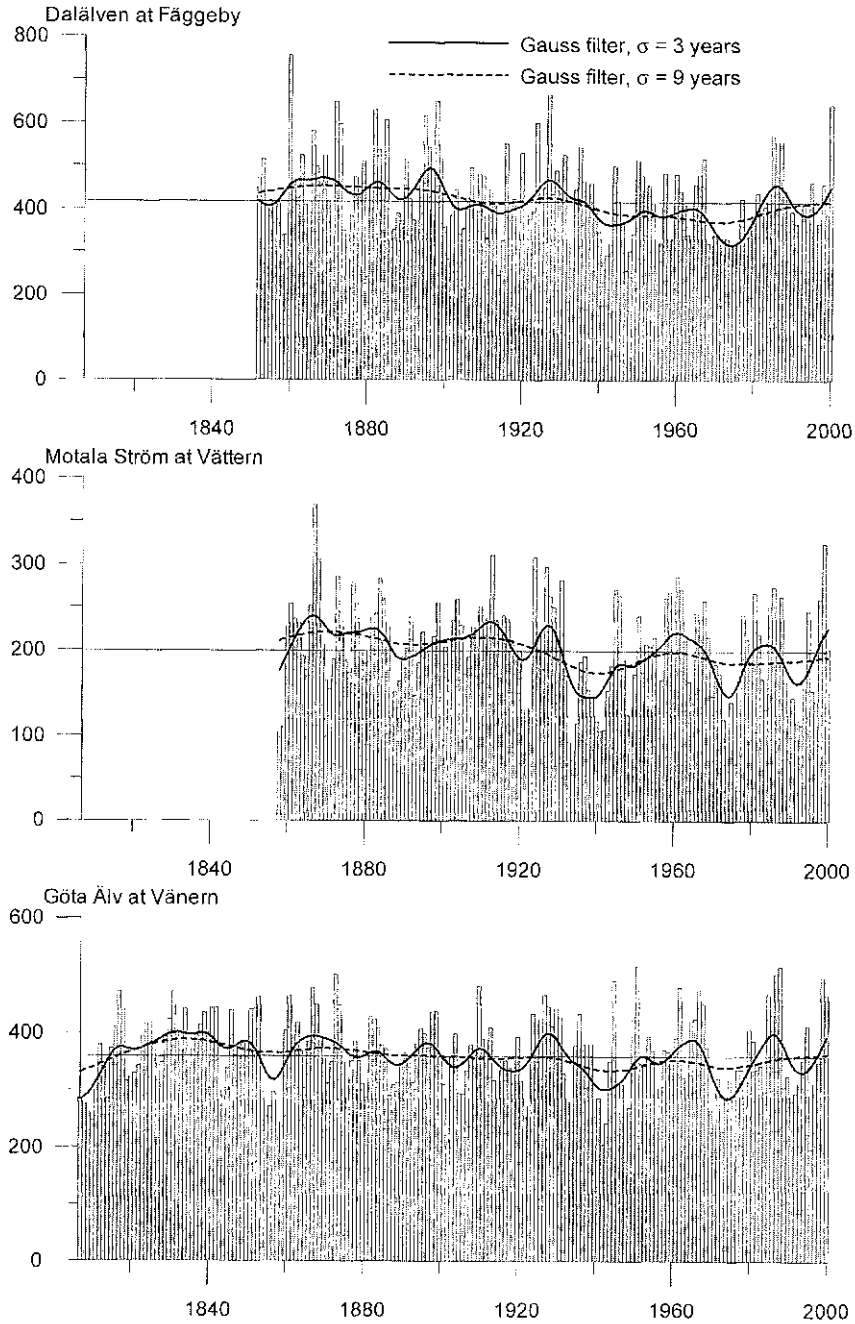

Fig. 3 Annual runoff (mm year^{-1}) according to the longest records in Sweden.

the southern part of the country generally decreased, but this tendency was very weak and not statistically significant.

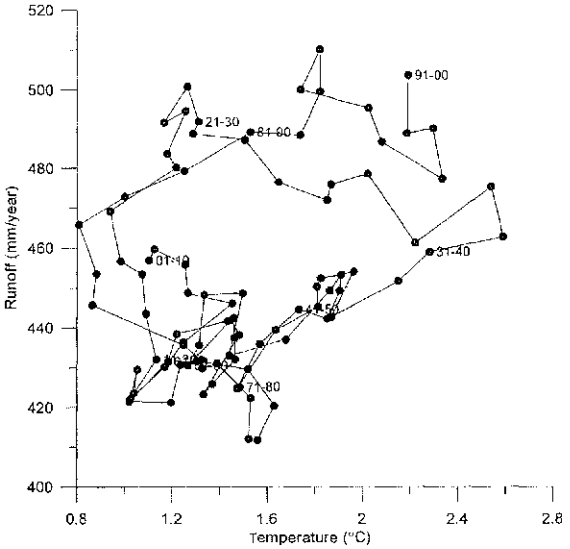

Fig. 4 Integrated analysis of air temperatures and river runoff for northern Sweden during the period 1901–2000. The dots show the average for 10 years.

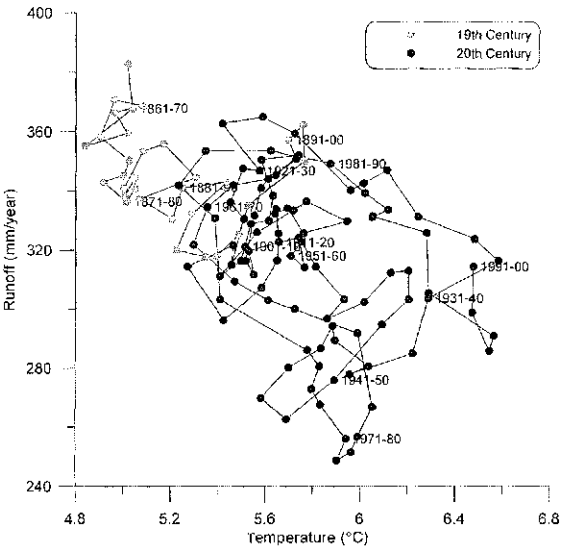

Fig. 5 Integrated analysis of air temperatures and river runoff for southern Sweden during the period 1860–2000. The dots show the average for 10 years.

CONCLUSIONS

Runoff increased by about 4% over the 20th century, seen as an average over the whole country, but the trend was not statistically significant. Records from the 19th century, however, indicate that runoff was higher then, but at lower temperatures. What makes recent years remarkable is the combination of high temperatures and

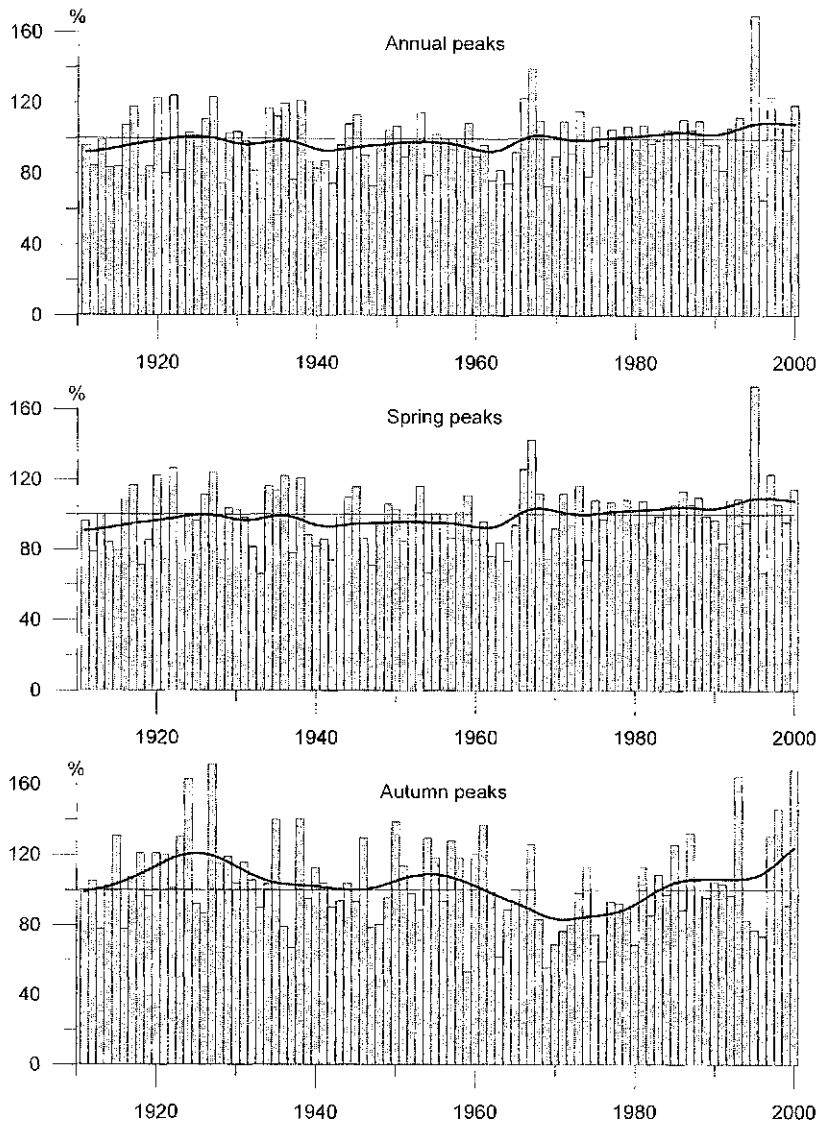

Fig. 6 Mean index floods for northern Sweden, according to 28 basins, with 1941–2000 as the reference period (100%), and Gauss-filtered values ($\sigma = 3$ years).

high runoff. The increase in average flood level in northern Sweden was larger, about +10%, but problems with the reliability of older data made it difficult to conclude that the change is in fact significant. The average increase in a selection of the most reliable stations was considerably smaller.

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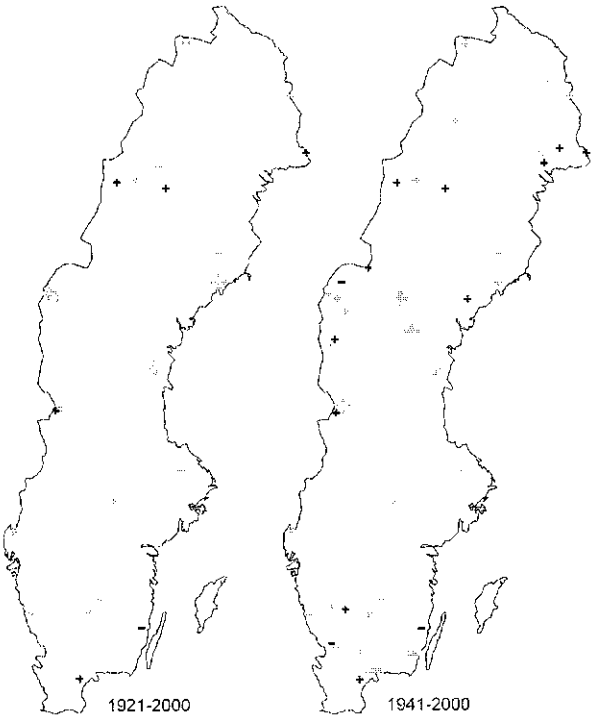

Fig. 7 Results from trend analysis for annual maximum floods, in 43 unregulated basins, by linear regression. The sign gives the slope of the regression line, regardless of the level of significance. The large symbols denote a significant trend at a confidence level of 95%. The 14 stations considered to be most reliable stations are marked with a black sign, others with a grey sign.

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REFERENCES

Alexandersson, H. (2001) Homogenisation of climate data, difficult but necessary. In: *Detecting and Modelling Regional Climate Change* (ed. by M. Brunet India & D. Lopez Bonillo), 3–12. Springer Verlag, Berlin, Germany.

Bering Ovesen, N., Legard Iversen, H., Larsen, S., Müller-Wohlfeil, D. I. & Svendsen, L. (2000) Afstrømningsforhold i danske vandløb (Runoff in Danish water courses, in Danish). DMU Report no. 340, Miljo-og Energiministeriet. Danmarks Miljoundersøgelser, Silkeborg, Denmark.

Førland, E., Roald, L. A., Tveito, O. E. & Hanssen-Bauer, I. (2000) Past and future variations in climate and runoff in Norway. Report no. 1900/00 KLIMA, DNMI, Oslo, Norway.

Jutman, T. (1991) Analys av avrinningens trender i Sverige. (Analysis of runoff trends in Sweden, in Swedish). Report Hydrology no. 30, SMHI, Norrköping, Sweden.

Lindström, G. (1999) Trends and variability in Swedish Floods. In: *Hydrological Extremes: Understanding, Predicting and Mitigating* (ed. by L. Gottschalk, J. C. Olivry, D. Reed & D. Rosbjerg) (Proc. Birmingham Symp., July 1999), 91–98. IAHS Publ. no. 255.

Roald, L. A. (1999) Analyse av lange flomserier (Analysis of long flood records, in Norwegian). HYDRA-rapport no. F01, NVE, Oslo, Norway.

Robson, A. J., Jones, T. K, Reed, D. W. & Bayliss, A. C. (1998) A study of national trends and variation in UK floods. *Int. J. Climatol.* **18**, 165–182.