Trends in floods in small Norwegian catchments – instantaneous *vs* daily peaks

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Abstract This study compares trends in both the magnitude and frequency of high flow events in small catchments in Norway, using both daily and instantaneous data. Datasets of 31 annual maxima and 24 peak over-threshold series were analysed to detect spatial and temporal changes, addressing the question of whether floods have increased and/or become more frequent in Norway, and for improving flood estimates for climate change adaptation. All series were assessed for temporal autocorrelation prior to analysis. The Mann-Kendall trend test was applied to study changes, with trends evaluated for field significance. Results suggest that trends in the frequency of high flow events are stronger than the trend in the magnitude of annual maxima flood events. Similar spatial patterns are obtained when using daily and instantaneous flood peak data, but the number of stations showing a trend in both annual maxima and peak over threshold series is less pronounced when comparing daily with instantaneous data.

Key words flood; streamflow trends; annual maxima; peak-over-threshold; small catchments; Norway

INTRODUCTION

Climate change is expected to cause increased precipitation in Northern Europe, resulting in increased flood magnitudes in many areas. Although an increase in both the frequency and intensity of precipitation events has been observed across most of Norway over the long-term (Dyrrdal *et al*., 2012), no systematic spatial trends in flood magnitude have been identified (Wilson *et al*., 2010). If the increase in precipitation were most pronounced for local short-term extreme events, a larger increase in instantaneous flood peaks in small catchments compared to daily average floods would be expected. This has implications for flood risk assessments in Norway since mean daily annual maximum values are traditionally used for flood studies in the absence of sufficient periods of good quality instantaneous peak flow data. For many stations, discharge data with sub-daily resolution only span a period of 10–20 years.

In this study, data from small Norwegian catchments are analysed to investigate spatial and temporal trends in the magnitude of high flow events in small catchments within Norway, using both daily and instantaneous data. A comparison of the trends obtained using both daily and instantaneous data is of importance, given the lack of sufficient good quality high resolution flow data. Daily data are typically used in flood frequency analyses, with the ratio between daily and instantaneous values used to scale design flood magnitudes for analyses where an estimate of the instantaneous peak is required. The results of this study will provide a basis for improving such flood estimates for use in climate change adaptation. This research is being undertaken as part of a project jointly funded by three government agencies in Norway responsible for managing water resources, roads and railways.

DATA

Data from pristine small Norwegian catchments (<60 km^2) for the period 1980–2011 were compiled to investigate spatial and temporal changes in daily and instantaneous values of: (a) the magnitude of the annual maxima (AM), (b) the frequency of peak-over-threshold (POT) flood peaks, and (c) the ratio between daily and instantaneous values for the AM and POT series. AM series were investigated for 31 catchments, while the POT series were investigated for 24 catchments. Stations were selected based on the following criteria:

(a) that both instantaneous and daily data are available for the period 1980–2011;
(b) that the period of missing instantaneous and daily data for a station affects a maximum of eight separate years (i.e. 8/32 years). In assessing this criterion all series were carefully

reviewed and a year was included in analyses if there was evidence based on the available daily/instantaneous data that a flood peak (annual maxima or peak over threshold, as defined below) did not occur during a period of missing data.

(c) that the catchment is largely unaffected by human-induced changes, assessed based on the review by Fleig *et al.* (2013).

The AM and the frequency of events exceeding a threshold (peak over threshold) were investigated. The threshold was selected such that there was an average of two events per year as assessed over the entire period of record. Frequency was then assessed based on the number of events per year over this threshold. A threshold based on an average of two events per year was selected to restrict the study to the evaluation of high flow events, and is a compromise between obtaining a sufficient number of events and events of large enough size. An inter-event time of two days was used to identify independent peak flow events based on Engeland *et al*. (2004). In Norway the dominant high flow mechanisms are snowmelt and precipitation, in this paper no attempt was made to distinguish between these two types of events, but this will be undertaken in further more-detailed analysis. The ratio between instantaneous and daily flood peaks for the AM and POT series is defined in equation (1):

$$Ratio = Q_I / Q_D \quad (1)$$

where Q_I is the instantaneous flood peak and Q_D is the daily flood peak.

Since the aim of this paper is compare trends identified using daily and instantaneous flood peaks, years with missing values in the daily or instantaneous series were removed from both series. This ensures that the daily and instantaneous trend analyses are based on data from the same years, thus making the results obtained from both sets of analyses comparable. For the AM series, missing annual values were replaced with the median value of the AM series prior to trend analysis. For the POT series, a missing frequency for a year was replaced with the median frequency of the POT series. In this paper, the use of series that are as complete as possible for the detection of trends is less of a concern than ensuring that the daily and instantaneous analyses are performed for the same years since long-term (1920–2005) trends in the magnitude of annual maxima flood peaks were analysed previously by Wilson *et al*. (2010).

METHODS

Temporal autocorrelation within a time series and cross-correlation between sites in a dataset can both affect the ability of a trend test to assess trend significance (Yue & Wang, 2002). Ignoring either temporal or spatial correlation in a dataset can result in a null hypothesis of no trend being rejected more frequently than it should be when considering overall trends across a region (Renard *et al*., 2008). All series were tested for temporal autocorrelation, and the level of autocorrelation was found to be insignificant. Trend test and field significance procedures were then applied in this work and are detailed in the following sub-sections.

Trend test and significance testing

The Mann-Kendall test was applied to investigate trends in: (a) the magnitude and ratio of daily and instantaneous AM, and (b) the frequency and ratio of daily and instantaneous POT values. The Mann-Kendall test has been found to be appropriate for this purpose (e.g. Hisdal *et al*., 2001), and a description of the test can be found in Salas (1993). In the present study, trends are discussed in terms of their trend magnitude and direction. Significance testing of the results is not considered, since the long-term persistence of many hydroclimatic time series can cause trend test significance to be highly sensitive to the trend test used (Cohn & Lins, 2005). Critical values of the Mann-Kendall S statistic (S_{max}; Table 1) are used to identify strong and weak trends. The S_{max} values are defined using p-values (2-sided) of 0.05 and 0.3, which indicate the magnitude of the trend is likely to be in the upper or lower 2.5% and 15%, respectively, of the statistical distribution.

Table 1 Critical values of the Mann-Kendall Statistic for the identification of strong and weak trends.

Period of analysis	Number of annual data values in each station time series	Range of S	S_{max} (strong trends)	S_{max} (weak trends)
1980–2011	32	–496 to 496	≤–121 or ≥121	≤–64 or ≥64

Field significance testing

Field significance testing determines the percentage of stations expected to show a trend, for critical values of the Mann-Kendall S statistic, purely by chance, due to the effect of cross-correlation. Renard *et al.* (2008) compared several methods for assessing field significance using synthetic datasets and found a bootstrap method to be an adequate and robust tool. A bootstrap procedure described by Burn & Hag Elnur (2002) was used to determine the percentage of stations expected to show a trend due to the effect of cross-correlation. Where the number of observed trends is greater than the number of trends expected, the results can be considered field significant. In this paper, 2000 bootstrap samples were selected to establish the percentage of stations expected to show a trend.

RESULTS AND DISCUSSION

The results are discussed in terms of strong and weak trends, as defined in the previous section. In Figs 1–3 *Strong trends* are indicated in dark blue (strong positive trend) and red (strong negative trend). *Weak trends* are identified in light blue if positive, and orange if negative. Green indicates that *no trend* was found. All results are field significant, i.e. for both strong and weak trends the percentage of stations showing a trend is greater than that expected by chance.

A change in the magnitude and frequency of floods has implications for flood risk management and dam safety. Trends in daily and instantaneous AM are presented in Fig. 1. Results show the trend in AM is generally the same for daily and instantaneous flood peaks, with most stations showing no trend. Overall there are a greater number of positive (daily: 19%; instantaneous: 23%) than negative trends (daily: 10%; instantaneous: 13%) in flood magnitude, particularly at southern Norway stations. Only a few stations in central areas show a weak negative trend. These new results can be compared with the findings of Wilson *et al*., (2010) where no systematic trends were identified over the periods 1941–2005 and 1961–2000. Over the period 1920–2005 a trend towards decreasing peak flow dominated, particularly in southern Norway. Trends in annual maximum one-day precipitation over a similar period (1981–2010) show fairly high spatial variation (Dyrrdal *et al*., 2012). A comparison of the trends in precipitation and AM flood magnitudes reveals some spatial consistencies, but also differences, partly explained by some high flow events being thermally driven (i.e. snowmelt).

Trends in the frequency of daily and instantaneous POT values are presented in Fig. 2. Notably, no stations show a negative trend in the frequency of POT flood peaks. Results show the spatial patterns of trend in POT are similar for daily and instantaneous flood peaks, but the number of stations showing both strong and weak positive trends is greater when instantaneous (strong: 21%; weak: 25%) rather than daily (strong: 8%; weak: 21%) peaks are considered. Only a limited number of stations have been investigated, but these results indicate the frequency of POT events has increased at stations across Norway. An increase in the frequency of high flow events over the last 30 years, and particularly instantaneous flood peaks in small catchments as compared to daily average floods, is an important finding given that flood frequency analysis is frequently based solely on daily AM series. Trends in POT precipitation events are also stronger than trends in annual maximum values over a similar period (1981–2010; Dyrrdal *et al*., 2012). These results suggest a more pronounced change in the frequency than in the magnitude of moderate to large precipitation and high flow events over the last three decades.

Given the lack of sufficient periods with good quality instantaneous peak flow data in Norway, the ratio between daily and instantaneous flood peaks is frequently used to scale design flood estimates. Trends in the ratio of daily and instantaneous flood peaks for AM and POT data

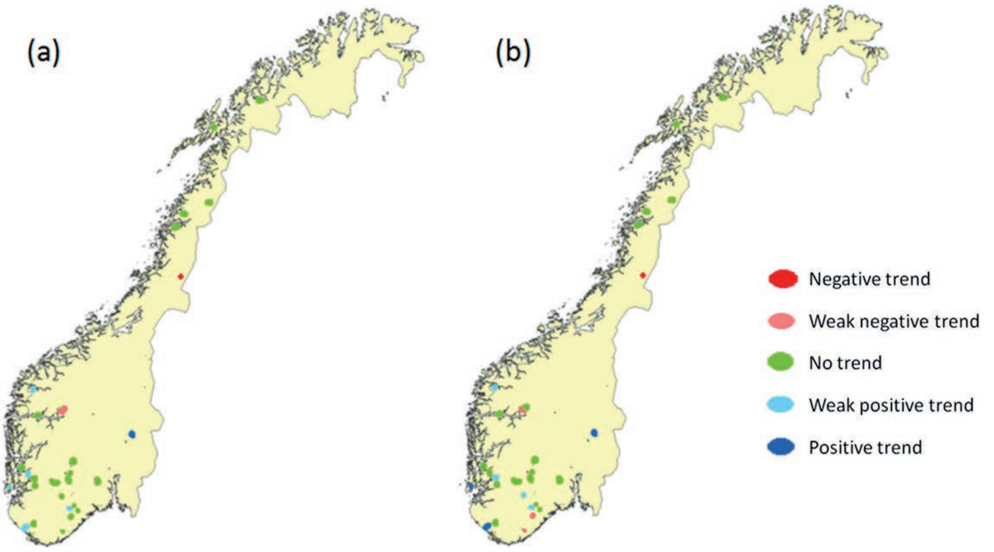

Fig. 1 Trends in: (a) daily annual maxima, and (b) instantaneous annual maxima for the period 1980–2011.

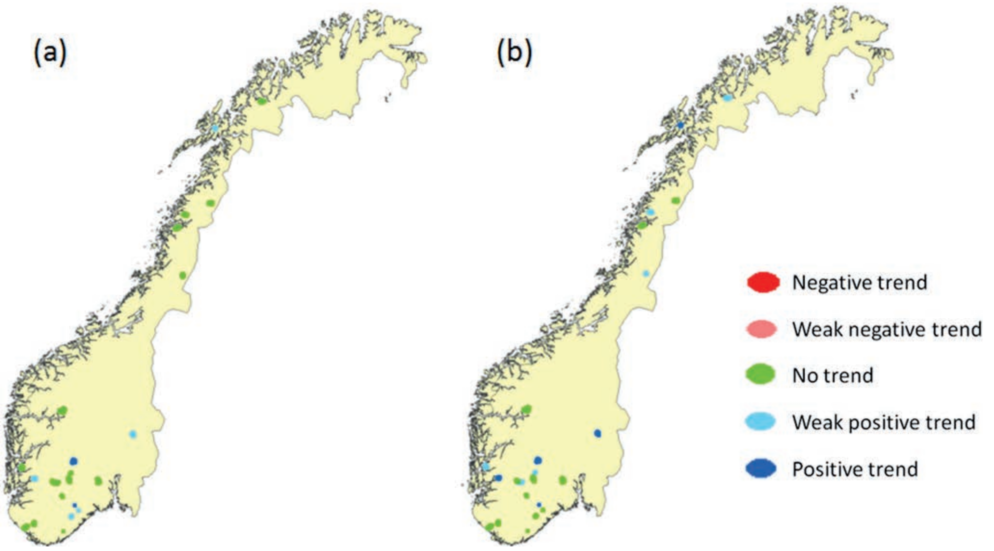

Fig. 2 Trends in: (a) daily POT, and (b) Instantaneous POT for the period 1980–2011.

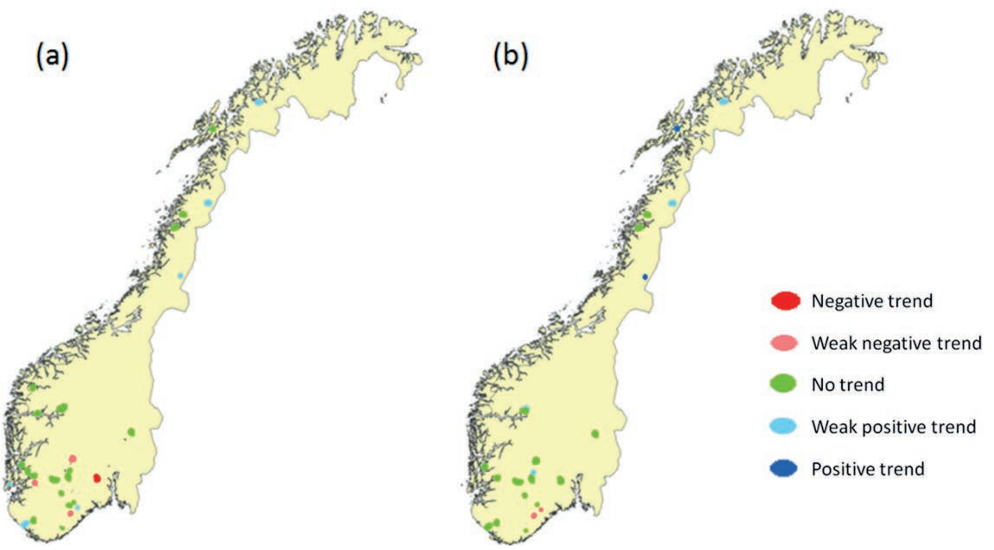

Fig. 3 Trends in the ratio of daily and instantaneous: (a) annual maxima, and (b) POT peaks for the period 1980–2011.

are presented in Fig. 3(a) and (b), respectively. Results show similar spatial patterns for the AM and POT series, with no trend in this ratio for the majority of catchments. However, positive trends in this ratio (for both AM and POT) are identified in northern Norway, with positive trends in the ratio of the AM series also identified at stations in southern Norway. An increase in the ratio is most critical for southern Norway, where a positive trend in flood magnitude has also been observed. Negative trends in the ratio of both the AM and POT series are identified in a fairly limited area of southern Norway.

CONCLUSIONS

An analysis of trends in floods in small Norwegian catchments is described over the period 1980–2011, based on daily and instantaneous annual maxima and peak-over-threshold series. Three sets of analyses are undertaken to investigate spatial and temporal changes in daily and instantaneous values of: (a) the magnitude of the AM, and (b) the frequency of POT high flow events, and (c) the ratio between daily and instantaneous AM and POT series. The purpose of this analysis is to investigate trends in floods in small catchments in Norway, possibly induced by climate change. The results will provide a basis for improving flood estimates for use in climate change adaptation.

Similar trends were observed for instantaneous and daily AM peaks, with no trend in their ratio for the majority of catchments. Out of the stations showing a trend, there are a greater number of positive than negative trends in flood magnitude, particularly at stations in southern Norway. A comparison of the trends in one day precipitation (Dyrrdal *et al*., 2012) and AM flood magnitudes reveal some spatial consistencies, but also differences, since snowmelt is also a dominant flood generating mechanism.

Results suggest that the frequency of POT high flow events has increased at stations across Norway over the last 30 years. Dyrrdal *et al*. (2012) found similar trends in the frequency of POT precipitation events. An increase in the frequency of flood events, and particularly instantaneous flood peaks in small catchments as compared to daily average floods, is of importance given that flood frequency analysis is frequently based solely on daily AM series.

The ratio between daily and instantaneous AM and POT series was investigated due to the lack of sufficient periods of good quality instantaneous peak flow data in Norway, which means the ratio between daily and instantaneous flood peaks is frequently used to scale design flood estimates. Results show similar spatial patterns identified for the AM and POT series, with no trend in this ratio for the majority of catchments. However, importantly for design flood estimation and climate change adaptation, positive trends in this ratio are identified in northern Norway with positive trends in the ratio of the AM series also identified at stations in southern Norway.

Further studies will include trend analysis of a larger dataset of daily average floods (Fleig *et al*., 2013), and an attempt to identify and analyse only rain dominated floods, and analysis of trends in the magnitude of POT flood events.

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