Trend analysis in Icelandic discharge, temperature and precipitation series by parametric methods

Jóna Finndís Jónsdóttir, Cintia B. Uvo and Robin T. Clarke

ABSTRACT

This paper presents results of analyses by parametric methods of annual means of temperature, precipitation and discharge, and of seasonal maximum precipitation at 17, 28 and 10 Icelandic stations, respectively, for the period 1961–2000. Trends in mean seasonal temperature and precipitation are in broad agreement with results found by other authors using other methods. A positive trend appears in both mean annual temperature and mean temperatures in most seasons. Annual mean precipitation trends are positive in most seasons except for negative trends in the September–November season in the south. Additionally, positive trends appear in maximum one-, three- and five-day precipitation, both during the spring and autumn, except at a group of stations in central Iceland. Some of the positive trends in mean annual and seasonal precipitation may, however, be attributed to the positive trend in temperature which may have influenced gauge catch. Trends in mean annual and seasonal discharge are small and statistically insignificant; the trends found in temperature and precipitation do not all relate directly to trends in discharge but suggest hypotheses for further study of the relationships between them.

Key words | discharge, Iceland, parametric methods, precipitation, temperature, trend

Jóna Finndís Jónsdóttir (corresponding author)
Hydrological Service,
National Energy Authority,
Grensásvegur 9 108 Reykyavik,
Iceland
Tel.: +354 569 6066
Fax: +354 568 8896
E-mail: *jonafinndis@gmail.com*

Jóna Finndís Jónsdóttir
Cintia B. Uvo
Department of Water Resources Engineering,
LTH, Box 118, 22100 Lund,
Sweden

Robin T. Clarke
Instituto De Pesquisas Hidráulicas -UFRGS,
Porto Alegre, RS
Brazil

INTRODUCTION

This paper presents results of analyses to detect trends in Icelandic records of precipitation, temperature and discharge. These results complement those reported earlier by Jónsdóttir *et al.* (2006) who looked for trends in seasonal and annual mean temperatures, in seasonal and annual precipitation totals, and in seasonal maximum discharges and their times of occurrence. The present paper differs from their work in that (a) the analyses for trends in the present paper use parametric methods, instead of the non-parametric tests used by Jónsdóttir *et al.* (2006) and (b) additional results are given for trends in annual and seasonal precipitation extremes of one-, three- and five-day durations. The period taken for analysis was the period 1961–2000, and the variables analysed were temperature, precipitation and discharges at both annual and seasonal timescales, using four three-month seasons. Times and magnitudes of seasonal flood occurrences were also analysed using two within-year periods: namely spring (1 March to 16 July) and autumn (17 July to 30 November). Additionally, trends in spring and autumn mean temperature and maximum precipitation were explored as part of an attempt to relate them to trends in spring and autumn floods, in terms of both the timing of maximum daily discharge and its magnitude.

The study by Jónsdóttir *et al.* (2006), which reviewed earlier studies of trends in Icelandic meteorological and discharge series, reported trends in temperature, precipitation and discharge for the periods 1941–2002 and 1961–2000, with a positive trend in mean annual temperature for the period 1961–2000 but a slightly negative trend during 1941–2002. They found trends in both annual and seasonal (three-monthly) precipitation for both periods but concluded that the trends in precipitation might be at least partially explained by precipitation gauge losses, which may

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have been reduced by installation of windshields and because of a positive trend in temperature for 1961–2000. They suggest that, at higher mean temperatures, more of the precipitation fell as rain so that gauge loss was smaller. The main conclusions from their study were that, despite a significant increase in measured precipitation, annual discharge in non-glacial rivers did not increase.

In addition, Crochet (2006) has evaluated precipitation trends for Iceland over the period 1961–2000 for both ECMWF Re-Analysis (ERA-40) precipitation and gauge-corrected precipitation. A trend of about 2.5% per decade was observed in annual area-averaged precipitation time series for the whole country.

DATA

The analyses used series of daily precipitation, temperature and discharge from 1 September 1960–31 August 2000. As described above, for analysis of meteorological variables the year was divided into four three-monthly seasons: September–November (SON), December–February (DJF), March–May (MAM) and June–August (JJA), following Jónsdóttir *et al.* (2006). For analysis of discharge, two seasons were used: (a) spring, defined as the period from 1 March to 16 July and (b) autumn, the period from 17 July to 30 November. Additionally, trends in meteorological variables were explored in the same seasons as discharge, i.e. spring and autumn, in an attempt to relate them to trends in spring and autumn floods. The same dataset was used as in Jónsdóttir *et al.* (2006) where all series were shown to be homogeneous according to a standard normal homogeneity test (Alexandersson 1986).

Most floods in Iceland, as in other cold regions, involve snow and ice. They are classified into three categories: floods due to the interplay of rain, snowmelt and ice, floods due to ice jamming and jam-breaking, and floods associated with glaciers (Snorrason *et al.* 2000). This study focuses on spring floods, caused by rain and snow melt, and autumn floods, caused by rain and in some cases melting of snow and ice. Although the separation of discharge means and maxima for spring and autumn seasons is intuitively reasonable, it does not account for all floods that appear in the rivers studied. Most of these rivers have substantial winter floods, caused by melting of snow during warm spells, and in some of the rivers winter floods appear to be larger than floods in spring and autumn.

Daily values of temperature and precipitation were taken from the database of the Icelandic Meteorological Office (IMO). The time series selected (17 for temperature; 28 for precipitation) have a fair geographical coverage but are restricted largely to coastal areas because of the difficult terrain and access in the interior. Figure 1(a, b) shows the location of the weather stations from which temperature and precipitation records were used and Table 1 shows station names, altitudes and mean annual precipitation and/or temperature. All stations are below 400 m a.m.s.l. and 26 of the 32 stations are below 100 m a.m.s.l. Observed precipitation was not corrected for wind loss; although clearly important for estimating precipitation depths, corrections might be expected to have a second-order effect on the time trends which are studied here. Records of daily precipitation were complete at 20 of the 28 stations, and for the eight stations where the daily records had gaps, special additional analyses were required, as set out below.

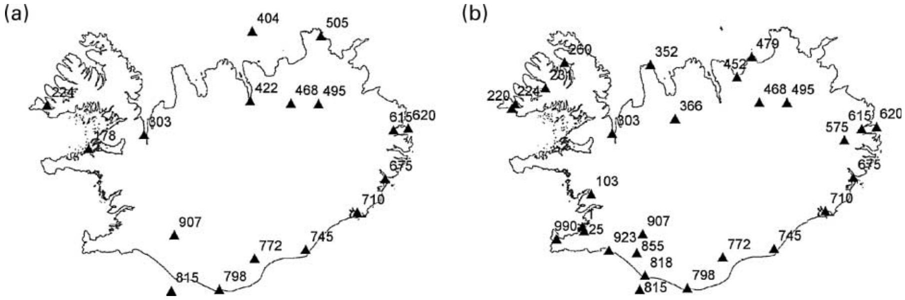


Figure 1 | Location of (a) temperature and (b) precipitation stations (triangles) used in the studies and their numbers. The stations numbered 404 and 815 lie on small off-shore islands.

Table 1 | Weather stations giving precipitation and temperature records: record lengths and height above mean sea level

Station number	Station name	Height (m a.s.l.)	Mean annual precipitation (mm/year)	Mean annual temperature (°C)
1	Reykjavík	52	806	
25	Rjúpnahæð	120	1001	
103	Andakílsárvirkjun	10	1477	
178	Stykkishólmur	15		3.4
220	Lambavatn	4	950	
224	Kvígindisdalur	49	1384	3.2
231	Mjólkárvirkjun	8	880	
260	Æðey	5	601	
303	Hlaðhamar	28	544	2.2
352	Hraun á Skaga	3	496	
366	Nautabú	115	468	
404	Grímsey	19		2.4
422	Akureyri	27		3.0
452	Sandur	3	565	
468	Reykjahlíð	285	439	1.2
479	Mánárbakki	17	565	
495	Grímsstaðir	384	348	0.1
505	Raufarhöfn	6		2.0
575	Grímsárvirkjun	95	784	
615	Seyðisfjörður	92	1552	3.6
620	Dalatangi	9	1434	3.6
675	Teigarhorn	23	1262	3.7
710	Hólar í Hornafirði	16	1483	4.3
745	Fagurhólsmýri	46	1812	4.4
772	Kirkjubæjarklaustur	32	1626	4.3
798	Vík í Mýrdal	15	2272	5.1
815	Stórhöfði	118	1561	4.7
818	Hólmar	10	1280	
855	Hella	20	1195	
907	Hæll	121	1117	3.3
923	Eyrarbakki	5	1404	
990	Keflavíkurflugvöllur	49	1083	

Daily discharge data series from 10 rivers were obtained from the Hydrological Service of the National Energy Authority in Iceland. These 10 stations all have records extending back to 1960. In most of the series gaps had been filled using the Service's routine methods; the station coded 32 in Table 2 had three years completely missing, but this presents no problem for the analysis of extremes, and is not a severe problem for the analysis of means (although the modelling of serial correlational structure becomes slightly more complicated). More serious than the absence of a few complete years was the fragmented record at the station coded 96, for which records were incomplete in 26 of the 40 years, so that the analysis of discharge for this site required special measures; we return to the reason for this

Table 2 | Discharge station names, origin of the river, size of watershed and mean annual discharge

Station number	Name of river	Origin of river	Size of watershed (km^2)	Mean annual discharge (m^3/s)
1	Elliðaár	L	272	4.5
10	Svartá, Skagafirði	DL	393	11
19	Dynjandisá	DL	43	3.0
32	Laxá, Aðaldal	LS	1547	41
43	Brúará, Biskupstungum	L	596	65
64	Ölfusá	LDJ	5678	374
66	Hvítá, Borgarfirði	DLJ	1669	80
81	Korpa	DL	44	1.5
96	Tungnaá	LJD	1131	82
197	Þingvallavatn	LS	1094	105

fragmentation in the discussion below. Icelandic rivers can be classified by the extent to which they are supplied by direct runoff (D), groundwater (L) or glaciers (J) and whether they flow through lakes (S). Following this classification by Rist (1990), Table 2 shows the origins of runoff together with watershed sizes and mean annual runoff. Where a combination of the letters D, L, J and S is shown, the first letter gives the primary source of runoff. Figure 2 shows the location of the discharge stations and corresponding watersheds. The fact that rivers in six of the eleven basins are supplied mainly from groundwater, compared with four from direct runoff, suggests that serial correlation in mean discharges may be important, and this was confirmed in analyses to be described.

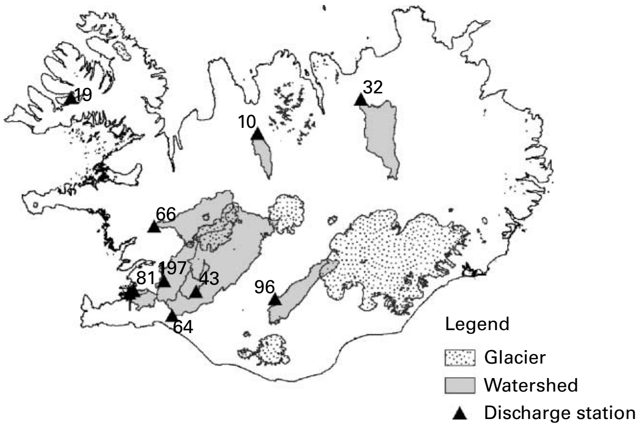


Figure 2 | Location of discharge stations used in this study and their corresponding watersheds.

METHODS

Trend analysis of extreme values by parametric methods

In the analysis of hydrological extreme values, whether of precipitation or discharge, the point of departure, as in the present study, is often the Gumbel distribution or, more generally, the Generalized Extreme Value (GEV: Coles 2001) distribution, of which the Gumbel distribution is a special case. In the research on trends reported here, the Gumbel distribution with superimposed trend in the position parameter was used (Clarke 2002), having probability distribution

$$
\begin{aligned}
f(x) &= f(x;\alpha,\beta,\sigma)\\
&= (1/\sigma)\exp[-(x-\alpha-\beta t)/\sigma - \exp\{-(x-\alpha-\beta t)/\sigma\}] \qquad (1)
\end{aligned}
$$

where α, β and σ are parameters for position, trend and scale, respectively. The Gumbel parameters α, β and σ were estimated by Maximum Likelihood (ML); given a sequence of extremes $x_1, x_2, \ldots, x_N$ from, say, N years of record, assumed serially independent, the log of the likelihood function is

$$
\ln L = \sum_{i=1}^{N} \ln f(x_i, \mu\sigma). \qquad (2)
$$

The more general GEV distribution, with an additional 'shape' parameter ξ, was also fitted, but estimates of ξ were small relative to their standard errors calculated from the information matrix of second derivatives of ln L obtained by Maximum Likelihood (ML) estimation, justifying the use of the Gumbel distribution. Thus the test for trend was given by comparing the maximum values of ln L assuming (a) the null hypothesis $\beta = 0$, that no trend existed; (b) the alternative hypothesis that trend was present, $\beta \neq 0$. Details of the test based on the ratio of the two maximized likelihoods are given in many standard texts (e.g. Coles 2001).

Although ML estimation of the trend parameter β, and its uncertainty as measured by its standard error, is relatively straightforward when records are complete, complications arise where, as in the present case, some precipitation and discharge records contain gaps. In the present study, one method used to deal with gaps was by means of 'censoring'; that is, to assume that, for an incomplete period, the maximum value of daily precipitation (or of mean daily discharge) that would have been observed if the record had been complete would be greater than or equal to the maximum observed in the incomplete period. Then, if records are incomplete in r of the N years, with the observed maxima in the r years being $x_j^*(j = 1, \ldots, r)$, then (2) becomes

$$\ln L = \sum_{i=1}^{N-r} \ln f(x_i, \alpha, \beta, \sigma) + \sum_{j=1}^{r} \ln \int_{x_j^*}^{\infty} f(u, \alpha, \beta, \sigma) \mathrm{d}x \qquad (3)$$

which again is to be maximized with respect to α, β and σ. The additional computational complexity is not a great problem, but the censoring approach has the disadvantage that it takes no account of the proportion(s) of the period(s) for which data are missing. Also where, as in the case of discharge station coded 96, data are missing in 26 of the 40 years of record, the ML estimate of trend is subject to great uncertainty (or, where a GEV distribution was fitted, could not be calculated at all). Methods are now available (Jones 1997; Clarke 2007; Svensson *et al.* 2007) which take account of the period of a year in which data are missing in a flood record, and in which the likelihood function ln L differs according to whether the missing period falls (a) in the flood season (so that the annual maximum discharge can be expected to be greater than that observed in the part of the year for which the record exists); or (b) in the part of the year when flows are lower, so that the observed maximum discharge is likely to be the highest for the year. The difficulty with using these methods in the present context is that each incomplete year must be considered individually, to determine which of the conditions (a) or (b) is appropriate, and the method becomes impracticable. For this reason, the simpler censoring approach was preferred in the present analysis.

Where, as in the case of discharge at station coded 32, special measures were required to deal with gaps in the record, the Gumbel analysis described above was supplemented by a weighted, distribution-free test, consisting of the following steps: (i) a weighted regression of the seasonal maxima on time (years) was calculated, using the proportion p of data present in each season as weights ($p = 1$ for a season with no missing data, $0 < p < 1$ otherwise); (ii) the years were permuted 999 times, and the weighted regression was re-calculated for each such permutation; (iii) the 1000 trend values (originating from the 999 permutations plus the observed trend value) were placed in ascending order and their 2.5% and 97.5% quantiles were calculated; (iv) the observed trend coefficient was compared with these quantiles, and if it lay between the two, it was concluded that there was no significant evidence of trend. Such a permutation test assumes that no serial correlation exists in the sequence of seasonal maxima, a not unreasonable assumption in the case of maxima (but inappropriate for any analysis of means: see below). Trends found significant using the Gumbel analysis described above were confirmed to be so by the weighted, distribution-free analysis, but the latter also identified a few trends as significant which the Gumbel analysis did not; however, results given in the figures below are the more conservative Gumbel results.

Trend analysis of seasonal and annual means, and of times of flood occurrence, by parametric methods

Whilst the method described in the preceding subsection is appropriate for analyses of extremes, a different approach was needed for the analysis of seasonal temperature means and precipitation totals. Where, in the analysis of means, it was necessary to allow for incomplete data in a period, the corresponding mean value was weighted according to the proportion of complete data in the period, as described in the preceding subsection: the weight p_i having the value 1 for a complete period, with $0 < p_i < 1$ otherwise. The test for trend was then effected by weighted linear regression on t, the year number, by minimizing the weighted sum of squared residuals

$$\sum_{t=1}^{N} p_i(y_t - \alpha - \beta t)^2. \tag{4}$$

Again, permutation tests were used to confirm the significance of trends found by F-tests of the null hypothesis that the trend coefficient $\beta = 0$ (Robson & Reed 1999).

Yet another approach was required when testing for trend in annual and seasonal mean discharges, because of serial correlation that reflects the contributions to river flow from groundwater and glacier melt-waters. Here, no satisfactory weighting procedure to allow for incomplete records could be found, so that of the ten stations analysed, the estimated trend for the one station where many data were missing (coded 96) must be open to question. For the remaining nine stations at which missing data were not a problem, trends in annual and seasonal means were estimated by means of the following model, which allows for serial correlation in the data sequences:

$$\begin{aligned} y_t &= \alpha + \beta t + \varepsilon_t \\ \varepsilon_t &= \rho \varepsilon_{t-1} + a_t \end{aligned} \tag{5}$$

where $\{a_t\}$ is a series of random (serially uncorrelated) variables and the additional parameter ρ represents the serial correlation in the $\{y_t\}$ data sequence. The four parameters in the model Equation (5)–namely α, β, ρ and the variance $\sigma_a^2$of the random variable a_t–were estimated by ML (a standard calculation in computer packages such as GenStat® (2007)). In the absence of any better alternative, the likelihood function ln L was constructed on the assumption that the $\{a_t\}$ were normally-distributed. The test for trend consisted of testing the null hypothesis $\beta = 0$. The series $\{\hat{a}_t\}$ calculated after the model was fitted showed serial correlations very close to zero, suggesting that the model in Equation (5) was satisfactory in explaining serial correlation in sequences of mean annual and seasonal discharge. Besides this regression model, the power spectra of annual mean discharges (taken without any allowance for missing data) were also calculated.

A similar approach to that in Equation (4) was used to test for trend in the timing of spring and autumn maximum discharges: that is, to test whether spring and autumn maximum discharges were occurring earlier or later in the season. In this case, the variable y_t in Equation (4) was the day-number within the period (from 1 to 138 for the spring period, 1 to 137 for autumn) on which the seasonal maximum discharge occurred: Day 1 was 1 March for the spring period and 17 July for the autumn period.

RESULTS

The following subsections describe the results of the analysis for each parameter and season. Results are shown in Figures 3–8, where the sign of trend is marked for each station: a positive trend is marked with a plus and a negative trend with a minus. Significant trends (where trend coefficients were larger in absolute magnitude than twice their standard errors) are shown with larger markers together with the estimated trend.

Results for temperature

Mean seasonal temperatures

For the 17 temperature records used, Figure 3 shows estimated trends in °C/decade where the trend is significant. The analysis of annual temperature shows positive trends at all except for two stations but only two of the trends are significant; as is to be expected, spatial correlation between the means is generally high. Trends in mean seasonal temperatures are small except during the season June–August and the autumn (17 July–30 November) season. Mean temperature in the autumn has increased by $0.2 - 0.4 \pm 0.1$°C/decade at seven stations and the trend is positive at all stations. Trends are generally not significant in other seasons but they are consistently positive except for a negative trend in the southern part of the country during March–May and the corresponding spring (1 March–16 July) season. The trends found here

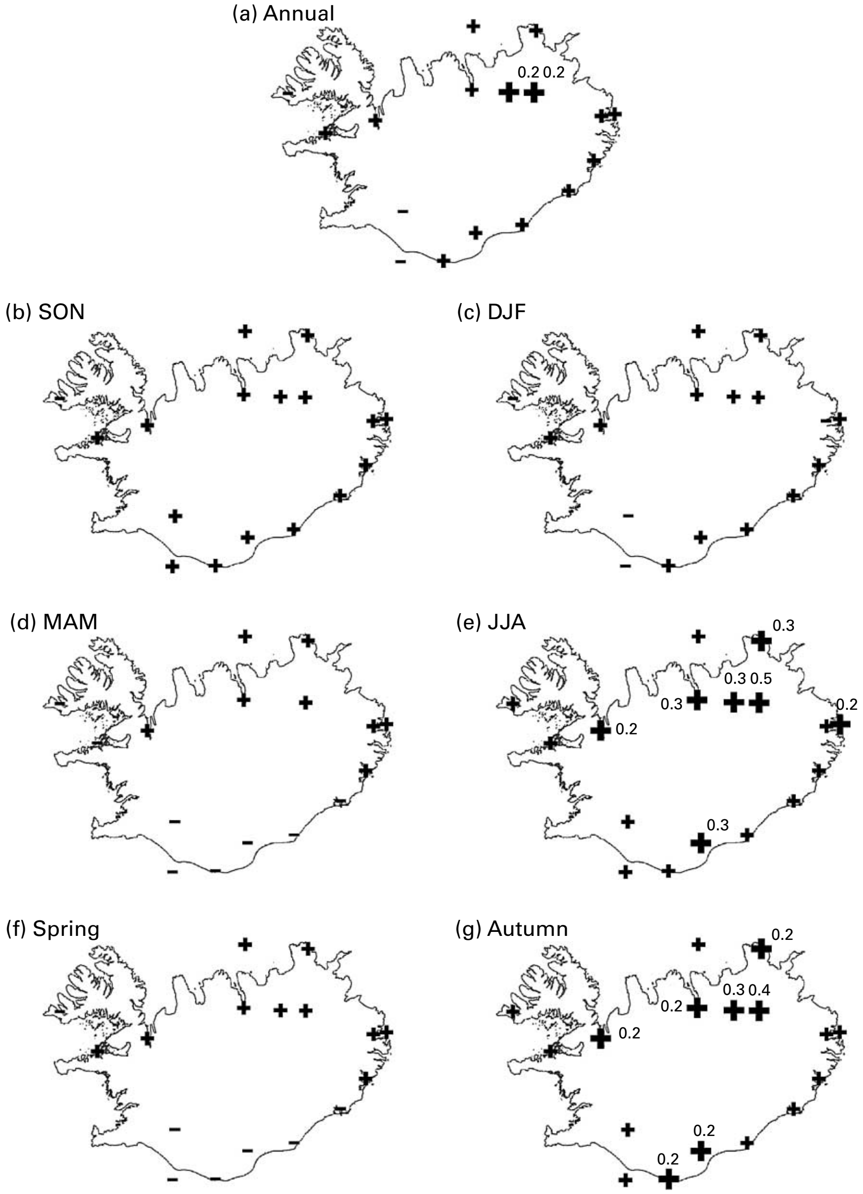


Figure 3 | Trends in mean temperatures are shown with a plus (positive trend) or a minus (negative trend). Stations with significant trends are shown with larger markers together with the estimated trend in °C/decade. (a) Annual, (b) Sep–Nov, (c) Dec–Feb, (d) Mar–May, (e) June–Aug, (f) spring (1 March–16 July) and (g) autumn (17 July–30 November).

are in good agreement with the trends found by Jónsdóttir *et al.* (2006).

Results for precipitation

Mean daily precipitation in spring and autumn periods

Figure 4 shows results from the trend analysis of spring and autumn precipitation totals. The percentages are calculated by dividing the trend by the 40-year average. The analysis of annual precipitation shows positive trends at most stations and a significant increase of $5 - 6 \pm 2\%$ decade^{-1} at six of the stations. In seasonal precipitation, trends are most clear in the September–November and December–February seasons in the north-eastern part of the country. There, the seasonal precipitation has increased by $8 - 13 \pm 4\%$ decade^{-1} at some of the stations. Meanwhile, most seasonal trends in other parts

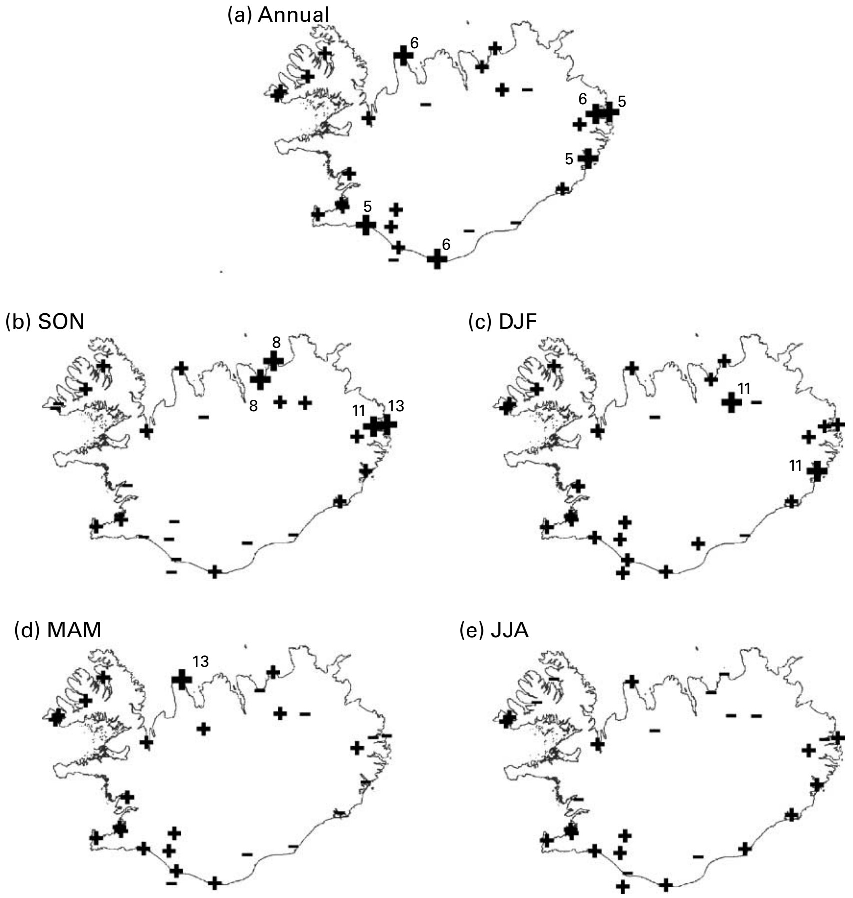


Figure 4 | Trends in mean precipitation are shown with a plus (positive trend) or a minus (negative trend). Stations with significant trends are shown with larger markers together with the estimated trend in % decade^{-1}. (a) Annual, (b) Sep–Nov, (c) Dec–Feb, (d) Mar–May, (e) June–Aug.

of the country are insignificant but positive, except for negative trends in the September–November season in the south. The trends found here are in good agreement with the trends found by Jónsdóttir *et al.* (2006).

Seasonal precipitation maxima

Figure 5 shows significant trend coefficients in spring and autumn one-, three- and five-day maximum precipitations, expressed as % decade^{-1}; the percentages are calculated by dividing the trend by the 40-year average. In spring (1 March–16 July), statistically significant trends were found at two sites, where the one-day maximum precipitation increased by $10 - 11 \pm 4\%$ decade^{-1}. Trends are positive in the western half of the country while no clear pattern is seen in the eastern half. In autumn (17 July–30 November), statistically significant trends were found at two sites in the Eastfjords, where the one-day maximum precipitation increased by $13 - 14 \pm 6\%$ decade^{-1}; otherwise most stations have a positive trend except for several stations in central Iceland where trends are slightly negative.

Results for discharge

Mean annual and seasonal discharges

Figure 6 shows the results of analyses of trend in mean daily discharge annually and during spring (1 March–16 July) and autumn (17 July–30 November) periods. As seen in Table 2, drainage basin areas varied from just over 40 to well over 5,000 km^2, so to facilitate comparisons trends were converted to % decade^{-1} by dividing the trend by the 40-year average. As mentioned above, some of the rivers

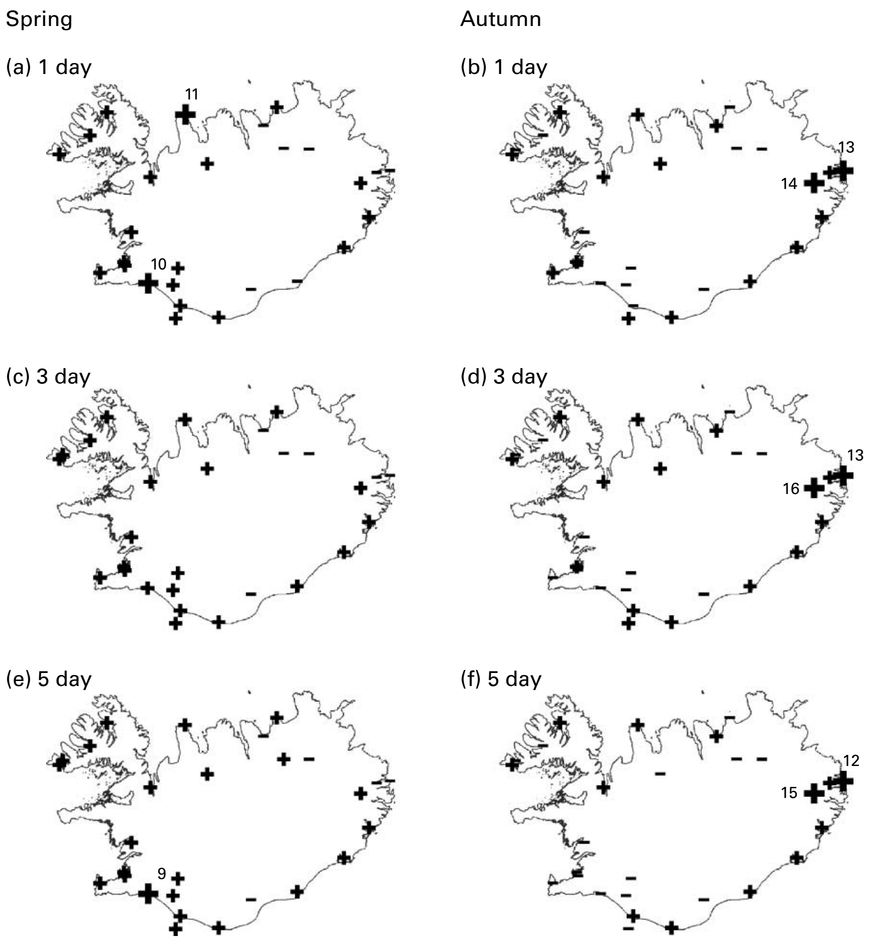
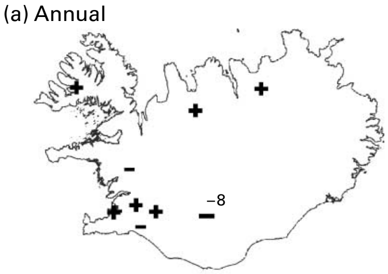


Figure 5 | Trends in maximum one-, three- and five-day precipitation in the spring (1 March–16 July) and autumn (17 July–30 November). Stations are shown with a plus (positive trend) or a minus (negative trend). Stations with significant trends are shown with larger markers along with the evaluated trend in % decade^{-1}. (a) One-day spring, (b) one-day autumn, (c) three-day spring, (d) three-day autumn, (e) five-day spring, (f) five-day autumn.

have high groundwater components which smooth out variations in the discharge between seasons and years.

The analysis of annual and seasonal discharge shows no clear trends. The trends are generally insignificant and more than half are slightly positive, corresponding to the positive trends found in precipitation. The only station (coded 96 in Table 2) showing a significant annual and spring decrease is a series in the highland where gaps in the discharge record are frequent, particularly in periods of low temperatures when streams may be ice-covered. The gauge there was moved a few hundred meters in 1988 and the water level at the new gauge gets less interrupted by ice than at the former site. There were, therefore, long gaps in the series during the first 28 years of the time period analysed and, on average, 5.5 months are missing, but for the last 10 years of the record, gaps were shorter and were filled using the routine procedures developed by the Hydrological Service. Therefore, mean discharge during the last few years, where winter discharge has been measured or estimated, is lower than the average during the first 28 years when winter discharge is not accounted for.

As mentioned earlier, the power spectra of mean annual discharges were calculated without any adjustment for missing data; when plotted, the spectra were reasonably well behaved except for the station coded 96 in Table 2 which, as mentioned earlier, had a very high proportion of missing records. Of the remaining nine station, all except one showed a marked peak at frequency 0.05, corresponding to a fluctuation with period $1/0.05 = 20\,\text{yr}$. This agrees with (and in the case of the River Brúará, coded


(a) Annual

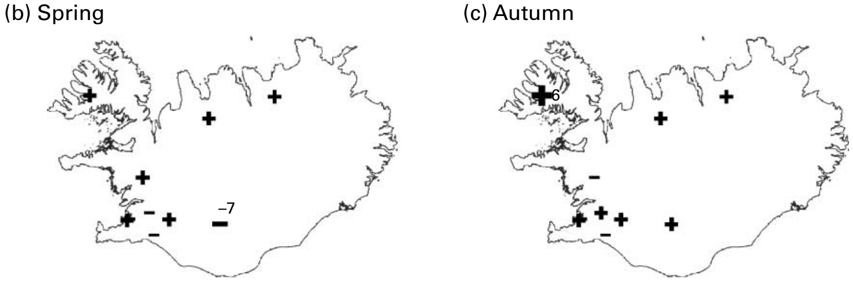

(b) Spring (c) Autumn

Figure 6 | Trends in (a) mean annual, (b) mean spring (1 March–16 July) and (c) mean autumn (17 July–30 November) runoff. Stations are shown with a plus (positive trend) or a minus (negative trend). Stations with significant trends are shown with larger markers together with the estimated trend in % decade^{-1}.

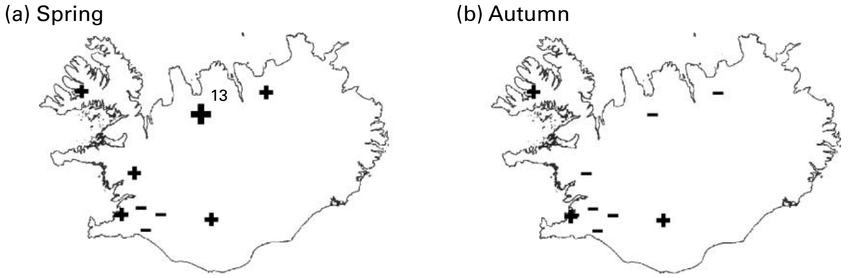

(a) Spring (b) Autumn

Figure 7 | Trends in seasonal maximum daily runoff (a) in spring (1 March–16 July) and (b) in autumn (17 July–30 November). Stations are marked with a plus (positive trend) or a minus (negative trend). Stations with significant trends are shown with larger markers along with the evaluated trend in % decade^{-1}.

43 in Table 2, confirms) the finding reported by Snorrason *et al.* (2003), whose analysis revealed a periodicity of 20 years in two Icelandic rivers: the Brúará and the River Sog, both with similar characteristics and both lying in the south of Iceland. Snorrason (1999) noticed this long-term fluctuation in the discharge series of the River Sog and Snorrason *et al.* (2003) related them to variation in the North Atlantic Oscillation; from the spectral analysis of records from the

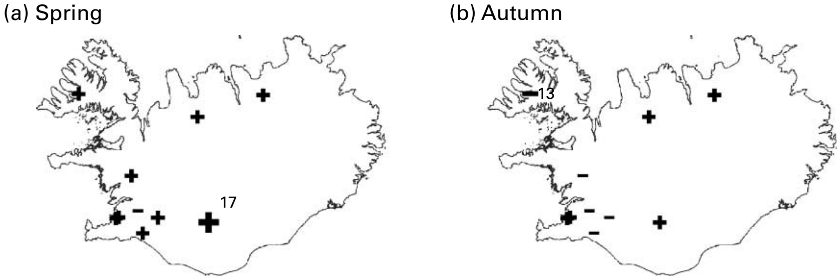

(a) Spring (b) Autumn

Figure 8 | Trends in timing of (a) spring (1 March–16 July) and (b) autumn (17 July–30 November) maximum daily runoff. Spring times are counted from 1 March; autumn times from 17 July. Stations are shown with a plus (positive trend) or a minus (negative trend). Stations with significant trends are shown with larger markers along with the estimated trend.

drainage basins in Table 2, it appears that the 20-year periodicity is also a characteristic of other Icelandic rivers.

Spring and autumn floods

Both spring and autumn floods (i.e. maximum mean daily discharges in the period 1 March–16 July for spring periods and maximum mean daily discharges in the period 17 July–30 November for autumn periods) were fitted by Gumbel and GEV distributions; the results are similar but only the Gumbel results are reported. As in the above, trends were converted to % decade^{-1}; the percentages are calculated by dividing the trend by the 40-year average maximum mean daily discharge, during spring and autumn, respectively. Figure 7 shows the sign and significance of estimated trends in the spring and autumn. A significant positive trend was found at only one station in the spring but during the spring most of the trends are positive while in the autumn most of the trends are negative.

Times of occurrence in spring and autumn floods

As explained above, the days on which spring and autumn floods occurred were determined, counting 1 March as day 1 for spring floods, and 17 July as day 1 for autumn floods. Weighted regression analyses (see Equation (4) above) gave the results shown in Figure 8. Although only one station shows a significant trend in the timing of spring flood, all except one show a positive trend, which signifies a trend towards a later spring flood. No clear trends show up in the timing of autumn floods, some being slightly positive and others negative.

DISCUSSION AND CONCLUSIONS

The results presented here may be compared with those reported earlier by Jónsdóttir *et al.* (2006), bearing in mind that results of the present paper were obtained by parametric methods to evaluate trends and trend significance, while Jónsdóttir *et al.* (2006) used a non-parametric Mann–Kendall test. As is to be expected, the trends evaluated here compare well with the trends reported earlier both with regards to the sign of trends as well as the magnitude of significant trends.

This analysis shows a positive trend in temperature for the period 1961–2000, both for annual temperature and for most seasons. The positive trend is highest during the June–August season and the partially overlapping autumn season (17 July–30 November). Trends are generally not significant in other seasons but they are consistently positive except for a negative trend in the southern part of the country during March–May and the corresponding spring season (1 March–16 July).

Annual mean precipitation trends are positive for the period 1961–2000, and for most seasons except for negative trends in the September–November season in the south. The positive trends are most clear in the September–November and December–February seasons in the north-eastern part of the country. Additionally, positive trends appear in maximum one-, three- and five-day precipitation, both during the spring and autumn, except at a group of stations in central Iceland. Some of the positive trends in mean annual and seasonal precipitation may, however, be attributed to the positive trend in temperature, since during November–March the mean monthly temperature stays below or around 0°C in most areas (Bjornsson *et al.* 2007) and precipitation is generally underestimated by precipitation gauges when precipitation falls as snow (Haraldsdóttir *et al.* 2001). A positive trend in temperature can, therefore, resolve in a slightly positive trend in measured precipitation even though actual precipitation does not increase.

Regarding trends in spring and autumn flood discharges, and in mean spring and autumn discharges, the slight trends over the period 1961–2000 are not statistically significant except at one station (not always the same one). The trends found in temperature and precipitation do not relate directly to trends in discharge, but the slight trends that are observed suggest hypotheses for further study. For example, trends in mean annual and seasonal discharge at over half the ten stations are positive, agreeing with the positive trend in precipitation. Spring floods appear to occur later in the spring and tend to be larger; these are generally snowmelt floods.

An additional topic for further study is the 20-year periodicity reported by Snorrason *et al.* (2003) which, from the analyses reported in this paper, appears to extend more widely than to the two rivers Sog and Brúará reported in their presentation.

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