20th century trends of extreme precipitation conditions in the Swiss Alps

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Introduction

In central Europe an increasing trend of mean wintertime precipitation has been observed during the 20th century (Schönwiese et al., 1994). Regionally, in the Alpine mountain range the increase amounts to 15–30% and is statistically significant, but no significant trend has been found for other seasons of the year (Widmann and Schär, 1997; Schmidli et al., 2002). Furthermore, in accordance with the trend in the mean, Frei and Schär (2001) found a statistically significant increase in the frequency of intense precipitation events (return period: 30 days) in winter and autumn for a high number of Swiss rain-gauge stations. This frequency increase was in the order of 20–80%.

GCM simulations with an increased level of greenhouse gases suggest that global warming could affect mean seasonal precipitation through complex shifts in the distribution function of precipitation events (e.g. McGuffie et al., 1999; Kharin and Zwiers, 2000). Again, changes in the frequency distribution were found even in cases and for regions where mean precipitation was essentially unchanged (e.g. Semenov and Bengtsson, 2002; Voss et al., 2002). An increase in the frequency of heavy precipitation was also found in simulations with regional climate models for several European regions including the Alps (e.g. Frei et al., 1998; Räisänen and Joelsson, 2001; Durman et al., 2001).

The objective of the present study is to analyze the observed 20th century trends in the probability distribution function (pdf) of daily precipitation and a number of summary statistics characteristic of extreme conditions. Has there been a shift towards higher values for the entire pdf, or has the shape of the pdf changed with a stronger change of the tails of the distribution? Have the number of rain days changed? And what can be said about multi-day totals?

Data and method

The dataset for this study is composed of daily precipitation series at 104 rain-gauge stations in Switzerland (see Fig. 1). The data have been provided by MeteoSwiss Zürich and embrace all Swiss rain gauges for which a continuous and complete daily record is available throughout the 100-yr period 1901–2000. The station sample is similar to that used for a trend analysis of mean precipitation by Widmann and Schär (1997) and for a trend analysis of heavy precipitation by Frei and Schär (2001). With a typical interstation distance of 20 km it constitutes a long-term observation system with exceptional density. All data have been quality checked.

All precipitation related STARDEX Diagnostic Extreme Indices are evaluated (see Table 1). For a definition of the indicies refer to the user information provided with the STARDEX extreme indices software. Seasonal and annual indices were calculated for every year in the period 1901–2000 for all rain-gauge stations. The base period for the calculation of the long-term 90th percentile was 1961–1990. Trends are calculated for the period 1901–2000 and for 1958–2000. Trend magnitudes are expressed as percentage change over 100 years and statistical significance is assessed following the non-parametric Kendall-τ statistics (see Kendall, 1970).

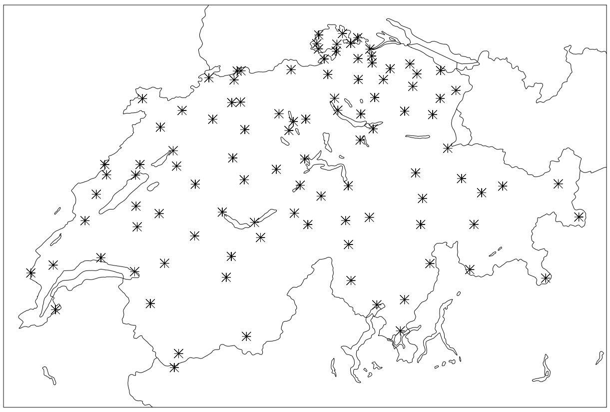

Figure 1: Geographic outline of Switzerland and the distribution of the 104 long-term rain-gauge stations used in the present analysis.

Table 1: STARDEX Diagnostic Extreme Indices related to precipitation.

name	STARDEX name	description
mea	601R	mean climatological precipitation
int	646SDII	simple daily intensity
fre		precipitation frequency
qNN	precNNp	NNth percentile of rainday amounts
fNN	fracNNp	fraction of total precipitation above annual NNth percentile
n10mm	606R10	No. of events $>=$ 10 mm
nl90	691R90T	No. of events $>$ long-term 90th percentile
fl90	692R90N	fraction of total precipitation above long-term 90th percentile
mx3d	643R3d	greatest 3-day total rainfall
mx5d	643R5d	greatest 5-day total rainfall
mx10d	643R10d	greatest 10-day total rainfall
pww	pww	mean wet-day persistence
pdd	persist_dd	mean dry-day persistence
pcr	persist_corr	correlation for spell lengths
mxncwd	642CWD	Max no. consecutive wet days
mxncdd	641CDD	Max no. consecutive dry days
wsp$*$	wet_spell_$*$	wet-spell statistics
dsp$*$	dry_spell_$*$	dry-spell statistics

Results

The results of the trend analysis for all indices are reproduced in the appendix. The annual and seasonal maps depcit the magnitude and statistical significance of the trend estimates (circles: increasing, triangles: decreasing, trend magnitude: $<$ 10%, 10–30%, $>$ 30%, filled symbols: $p <$ 5%) for each of the 104 long-term rain-gauge series. Results for selected indices are summarized in Table 2 and 3.

All indices, for which significant trends are found, reveal a seasonally distinct trend signal. This confirms the necessity of a seasonally stratified trend analysis.

Indices related to extreme precipitation

In spring and summer the trend results in the station sample are roughly balanced between increasing and decreasing estimates for most indices related to heavy precipitation. There is only a small number of stations for which the trends are statistically significant. (Note that using a

Table 2: Number of Swiss long-term rain-gauge series with positive/negative (in parantheses) and significant ($p < 5\%$, no parantheses) trends for 1901–2000. Total number of stations is 104.

	winter		spring		summer		autumn	
index	+	-	+	-	+	-	+	-
mea	47 (93)	0 (11)	6 (77)	0 (27)	6 (44)	3 (60)	6 (94)	0 (10)
int	46 (93)	0 (11)	11 (77)	3 (27)	11 (69)	3 (35)	28 (95)	0 (9)
q90	47 (96)	1 (8)	8 (78)	1 (26)	11 (67)	5 (37)	34 (95)	0 (9)
n10mm	53 (95)	0 (9)	8 (73)	1 (31)	2 (41)	3 (63)	8 (90)	1 (14)
nl90	50 (91)	1 (13)	10 (67)	2 (37)	11 (61)	4 (43)	35 (97)	0 (7)
fl90	27 (88)	1 (16)	7 (67)	1 (37)	13 (75)	1 (29)	30 (95)	0 (9)
mx5d	45 (98)	0 (6)	6 (77)	1 (27)	11 (77)	2 (27)	15 (89)	1 (15)

p-value of 5% even for a sample of random time series one would expect to find on average five stations with significant trends). However, for the indices related to stronger precipitation events such as q80. . .q95, f95, and nl90 the number of significant increases is noticeably larger than the number of significant decreases. In contrast, for winter and autumn, the station charts suggest an increasing trend signal with a clear prominence of positive trend estimates, and a high number of sites with significant test results (see Table 2). In winter, the spatial pattern of the trend signal is remarkably coherent for the different indices, whereas, in autumn, the spatial pattern is more variable.

In winter, the clearest trend signals are obtained for the two indices n10mm and nl90. These indices exhibit a particularly high density of significant increases over western and northern Switzerland. Basically the same pattern is also found for the indices mea, int, q40, . . . , q95, fl90, mx3d, mx5d, and mx10d and less clearly also for fre. It can be seen that the increase of the precipitation intensity is accompanied by an even stronger increase of moderate and strong precipitation events, as is revealed in the larger percentage increase of high compared to low quantiles. Also the positive trend for mean precipitation is even stronger than for the precipitation intensity, due to the slight increase in the number of rain days.

In autumn, the largest trend signals are observed for the indices nl90 and fl90. In contrast to the winter season, the trend pattern is more uniform over all of Switzerland, that is there are also a signifcant number of increases in southern Switzerland. A similar pattern is also obtained for the indices int, q80, q90, q95. A more irregular pattern, but also with many increases, is found for n10mm, mx3d, mx5d, and mx10d. In contrast to winter, the positive trends in autumn are restricted to the indices related to stronger precipitation events. Furthermore, few significant increases are found for mean precipitation. This is not only due to the weaker trend in precipitation intensity and the higher precipitation variability in autumn, but also due to the decrease in the number of rain days.

Careful inspection of the trend diagrams in the Appendix reveals that the trends for one station in north-eastern Switzerland are often inconsistent with the rest of the sample. See, for example, a statistically signficant decrease in annual nl90. This station is located on mount Säntis (2500 mMSL) and its record is known to be affected from several displacements and new constructions around the site (Patrich Hächler, MeteoSwiss, personal communication).

Indices related to drought conditions

For the indices related to drought conditions (pdd, dry spells) no significant changes are observed.

Table 3: Number of Swiss long-term rain-gauge series with positive/negative (in parantheses) and significant ($p < 5\%$, no parantheses) trends for 1958–2000. Total number of stations is 104.

	winter		spring		summer		autumn	
index	+	-	+	-	+	-	+	-
mea	3 (87)	0 (17)	0 (87)	0 (17)	1 (51)	0 (53)	15 (99)	0 (5)
int	43 (102)	0 (2)	8 (83)	0 (21)	9 (67)	1 (37)	8 (73)	0 (31)
q90	27 (101)	0 (3)	5 (80)	0 (24)	10 (70)	2 (34)	11 (83)	0 (21)
n10mm	8 (88)	0 (16)	2 (65)	1 (39)	0 (45)	1 (59)	10 (91)	0 (13)
nl90	11 (85)	0 (19)	6 (66)	0 (38)	10 (61)	2 (43)	25 (95)	0 (9)
fl90	20 (97)	0 (7)	4 (69)	1 (35)	11 (66)	2 (38)	14 (92)	0 (12)
mx5d	38 (97)	0 (7)	17 (93)	0 (11)	10 (63)	2 (41)	18 (101)	0 (3)

Trend results for 1958–2000

The overall picture for the shorter period 1958–2000 is similar to that for the longer period 1901–2000. The most interesting seasons, in terms of statistically signficant trends, are again winter and autumn. The most eminent differences with regard to the longer period are: In spring, a signficant increase of mx5d. In winter, a decrease of the precipitation frequency resulting in a weaker increase of mea, and n10mm, but a stronger signal for int, q90, fl90, mx3d, and mx5d. In autumn, there is now an increase of the precipitation frequency leading to a stronger trend signal for mea, nl90, mxncwd, and also dspmed (which shows a significanc decrease).

Summary

For winter and autumn, there is a clear positive trend signal with a high number of sites with signficant test results. The clearest and most coherent trend signal is obtained for the winter season, where, for many sites and for most indices related to heavy precipitation events, trends of 20–30% per 100 yr and more are found. For autumn the situation is more complex. For the period 1901–2000, the trend signal is most pronounced for the indices related to precipitation intensity such as int, q90, q95, fl90. For the period 1958–2000, the trend in the precipitation intensity is weaker. There is, however, a stronger trend in the precipitation frequency, leading to a stronger signal for mea, nl90, mxncwd, and dspmed. For spring and summer, there is a weak positive trend signal for the indices related to the most extreme events.

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