Workshop and Expert Meeting

on

Climatic Changes and their Effect on Hydrology and Water Management in the Rhine Basin

Ede, The Netherlands, 24-25 June 2003

Streamflow trends in Switzerland

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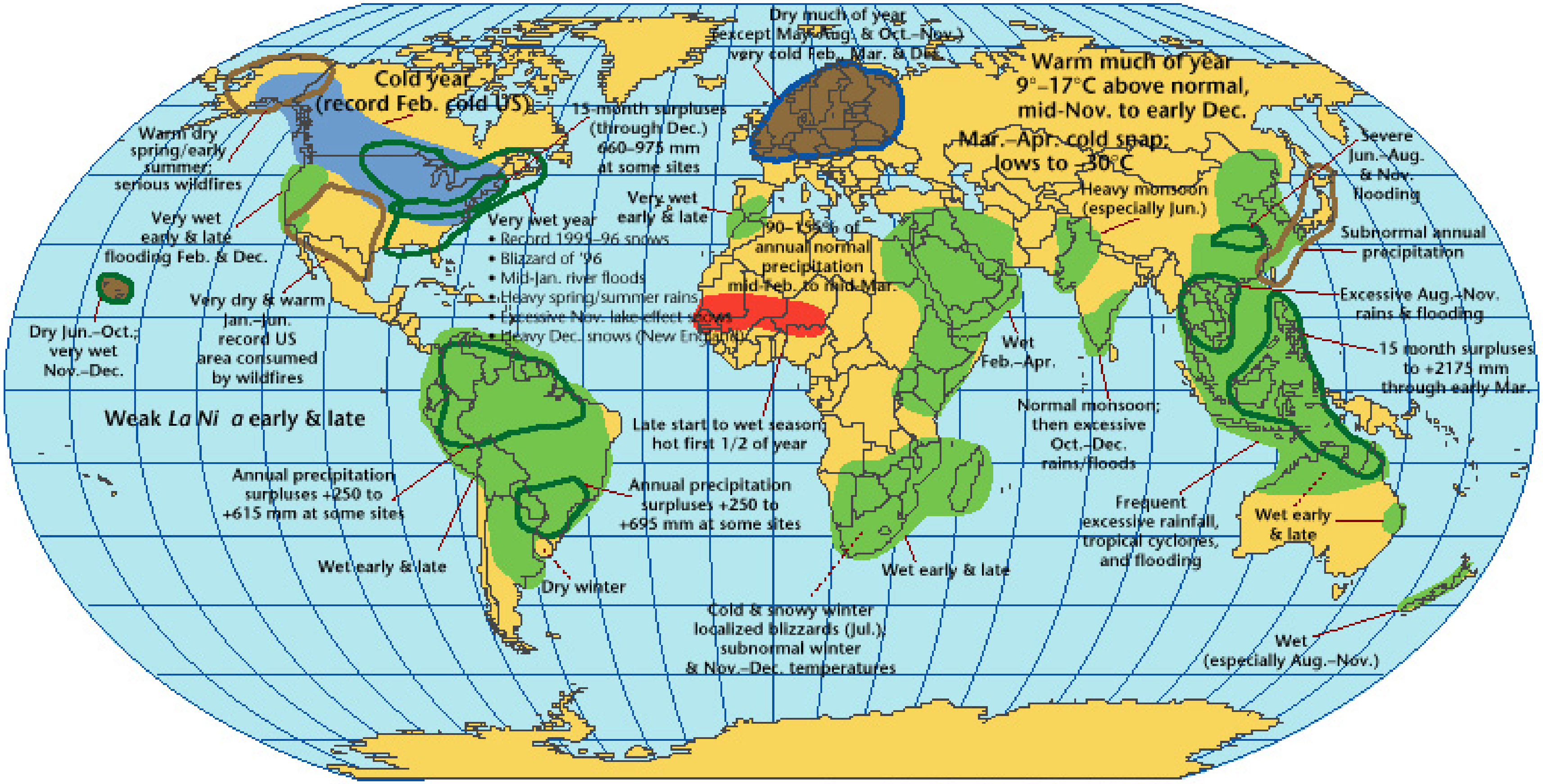
Evidence for climate change?

[Source: WMO Rep. n°858,
WMO statement on the status of the global climate in 1996]



Source: Climate Prediction Center, NOAA, USA

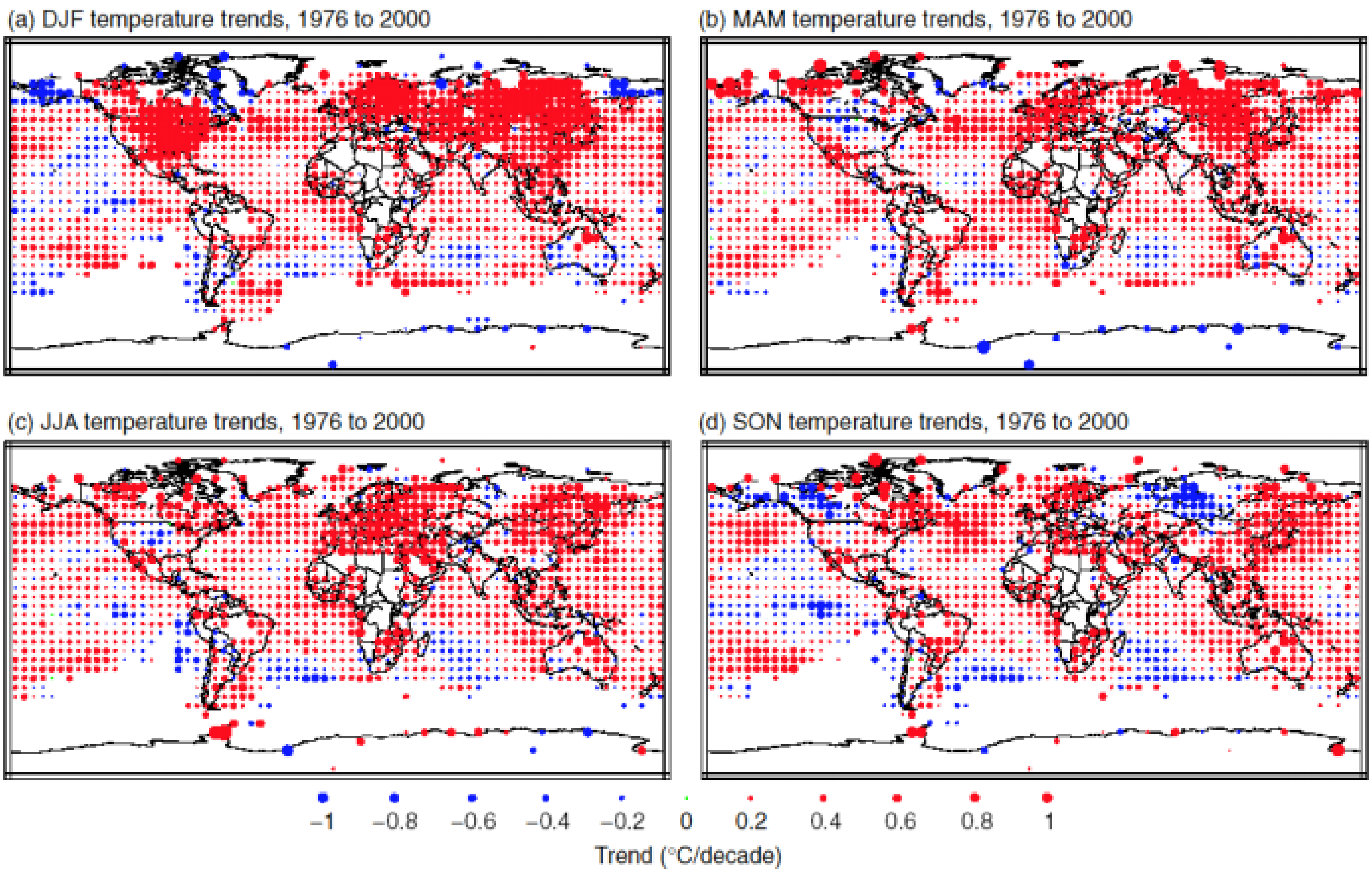
1996

… the global mean surface temperature anomaly *was, overall, the* eight highest *and the* eighteenth consecutive year *with positive values since records began in 1860.*

IPCC trend assessments

[source: IPCC Third Assessment Report, 2001]

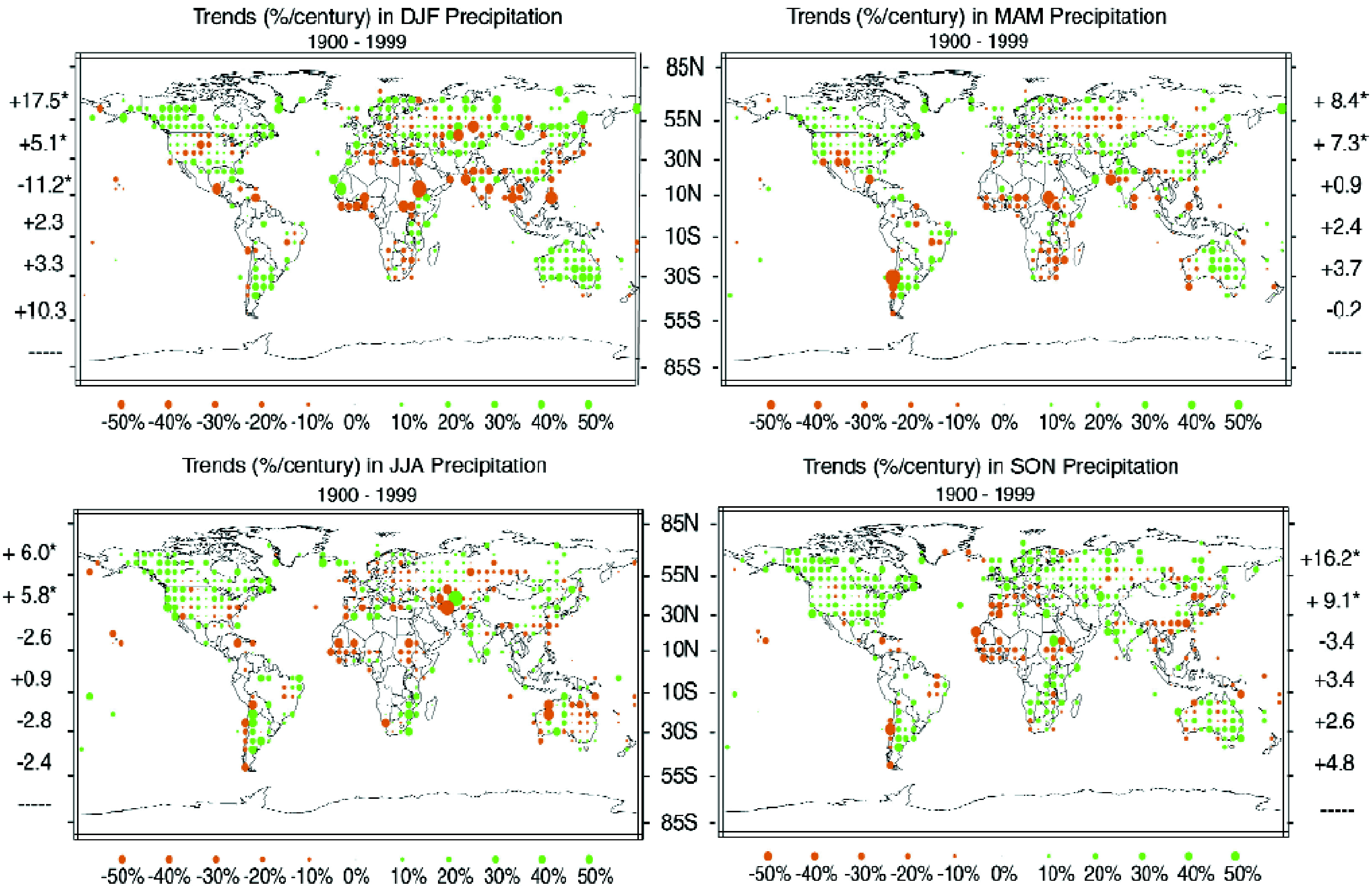
Temperature trends (seasonal)



IPCC trend assessments

[source: IPCC Third Assessment Report, 2001]

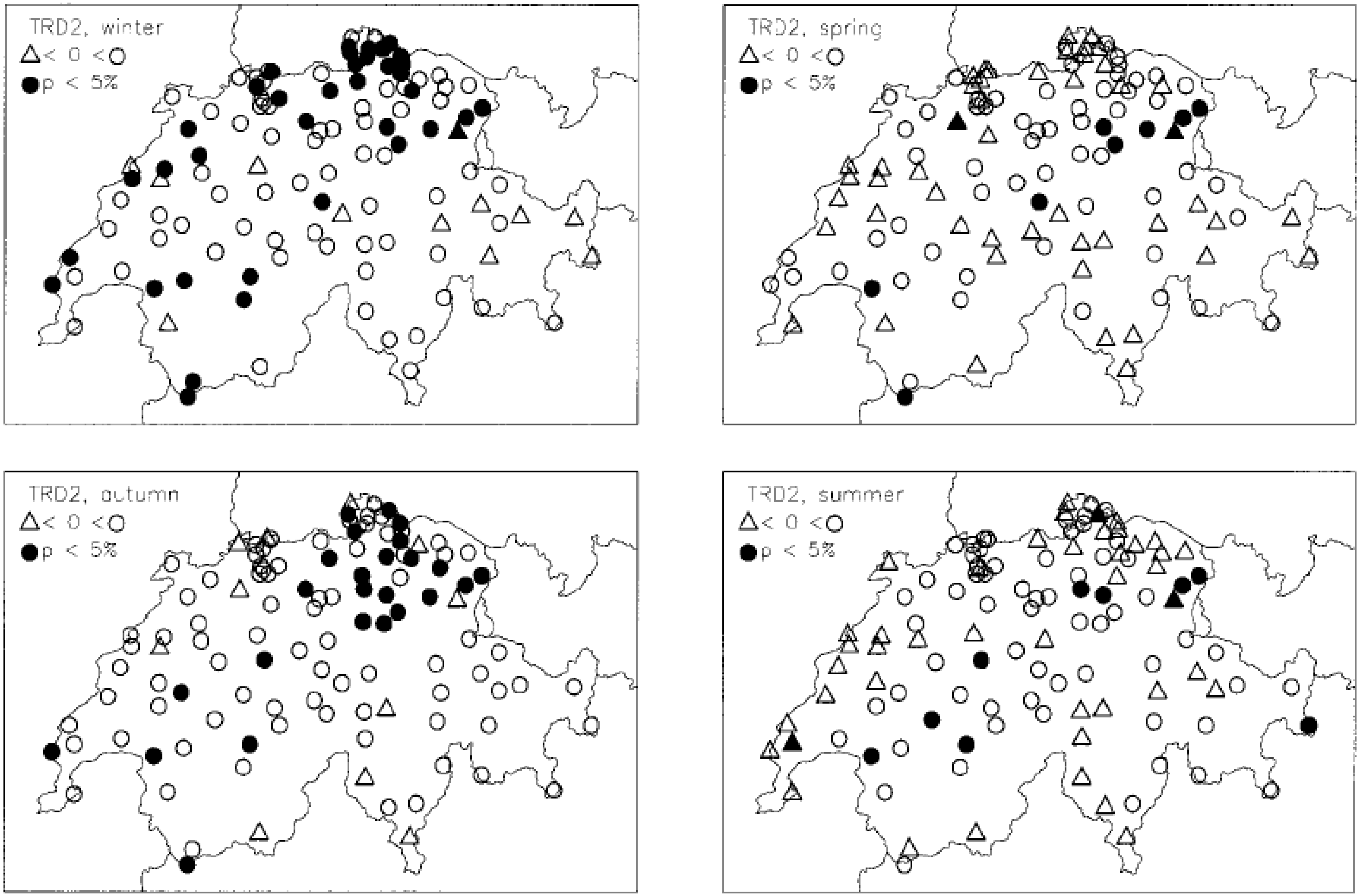
Precipitation trends (seasonal)



Trend assessments in Switzerland

Intense (=$\max_{30\ days}$) daily precipitation trends (seasonal)

Frei & Schär, 2001



● increasing ▲ decreasing

data record 1901-1994

Trend of mean seasonal precipitation (1901–1990)

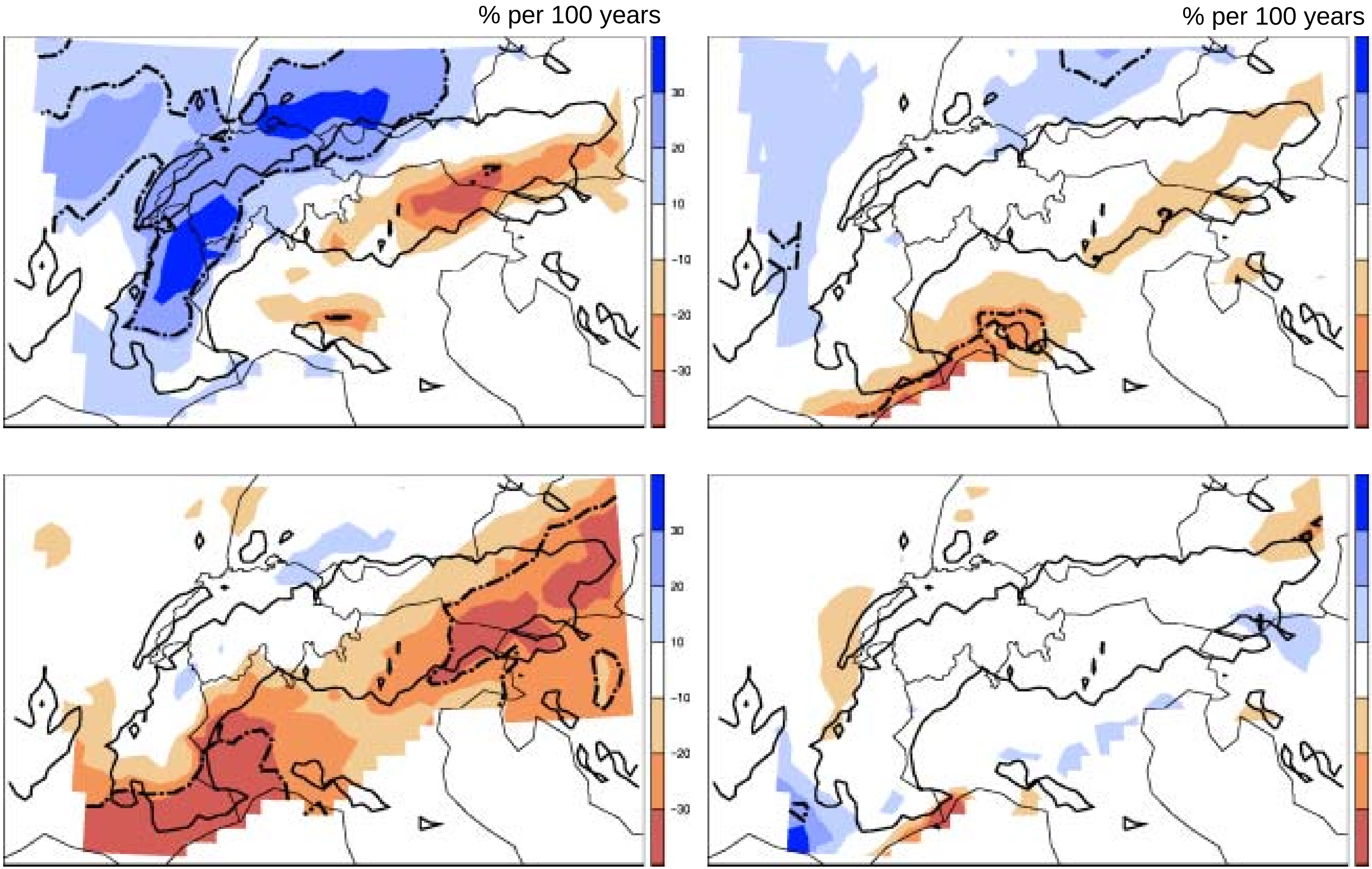


Figure 11. Linear trends of seasonal precipitation means for the period 1901–90. The trends are given as a percentage of mean seasonal precipitation (1971–90) at the corresponding grid point per 100 years. The bold dashed line is the 10% significance level. The contour interval is 10, except that the 0 and ±10 contours are excluded

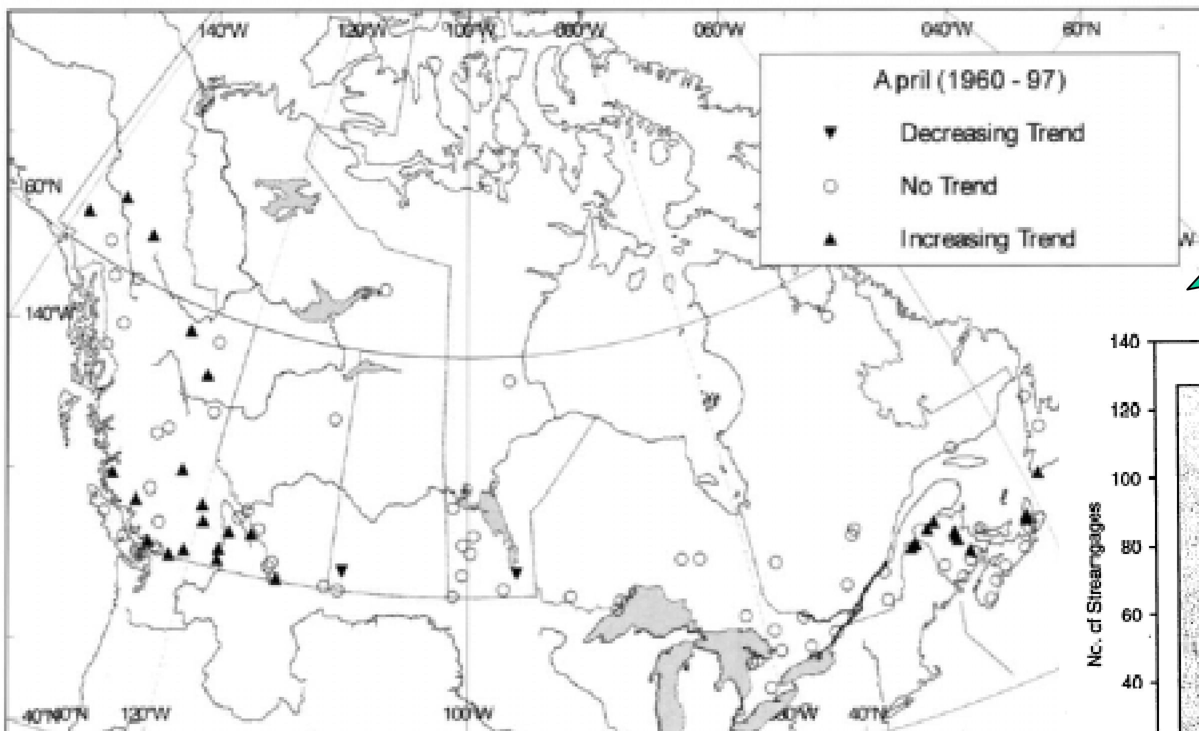
(courtesy of Ch. Schär [Schmidli, Schmutz, Frei, Wanner and Schär 2001])

Streamflow trend assessments

Streamflow integrates the influence of atmospheric variables over a watershed

↳ changes in P and T reflected at watershed scale
↳ spatially integrated ⇨ more appealing than point P and T

investigations mainly in Canada
e.g. Burn & Hag Elnur, *JH* 255 [2002]



and US
e.g. Lins and Slack, *GRL* 26 [1999]

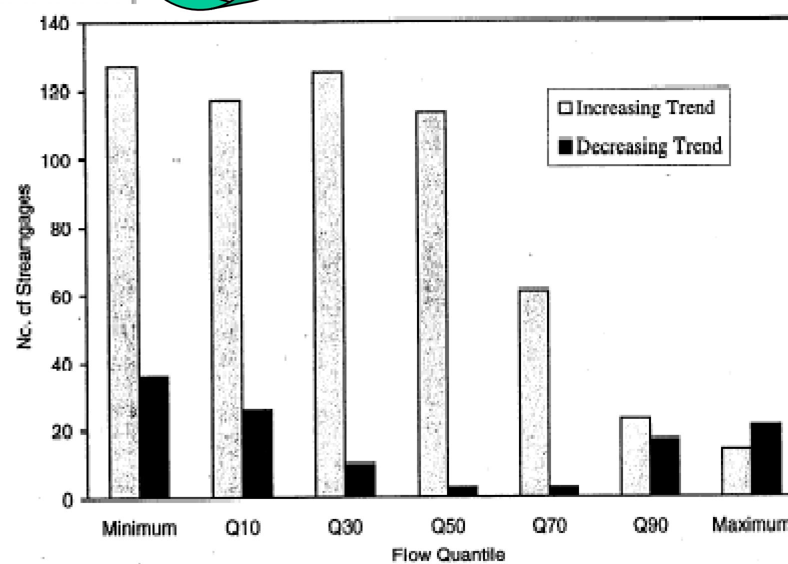


Figure 1. Number of streamgages, out of a total of 395, with statistically significant ($p \leq 0.05$) trends for the 50-year period 1944-1993.

Swiss streamflows - framework of the trend analysis

Objectives

- investigate the observational evidence of significant trends
- investigate connections between observed changes in Q, P and T
- investigate the correlation (if any) between streamflow trends and watershed properties (vulnerability of basins to changes)

Methods

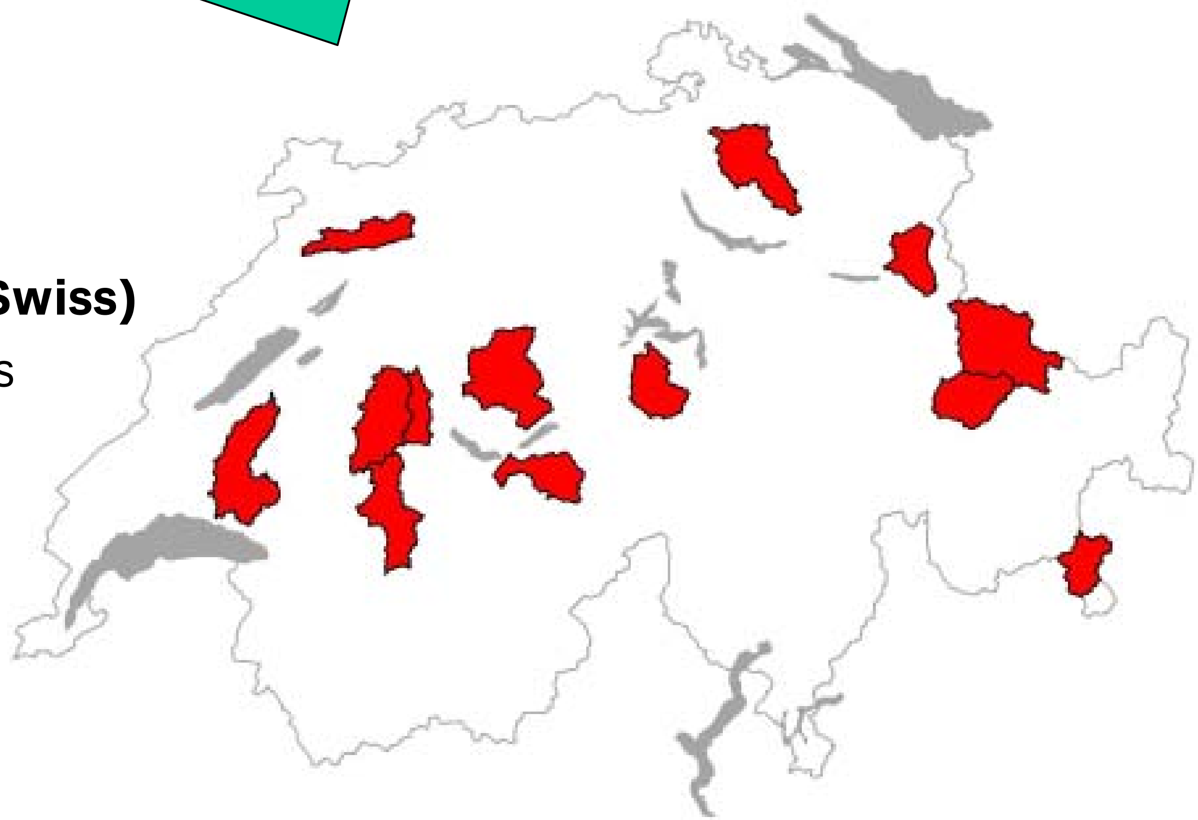
- undisturbed basins
- non parametric tests
- isolate trends from stochastic fluctuations and serial correlation
- annual and seasonal scale
- min, max and quantiles

Swiss streamflows - data

Selection criteria

- Hydrometric Network of the Swiss Federal Office for Water and Geology
- no substantial influence of the natural regime by water withdrawals
- basin independence in space
- continuous records

- 49 sites 1971-2000
- 31 sites 1961-2000
- 13 sites 1931-2000



Climatological data (MeteoSwiss)

- 109 P stations for all periods
- 16 T stations 1931-2000
- 26 T stations 1961-2000
- 42 T stations 1971-2000

Basin data

- DEM 25m
- Thematic maps (raw and elaborated)

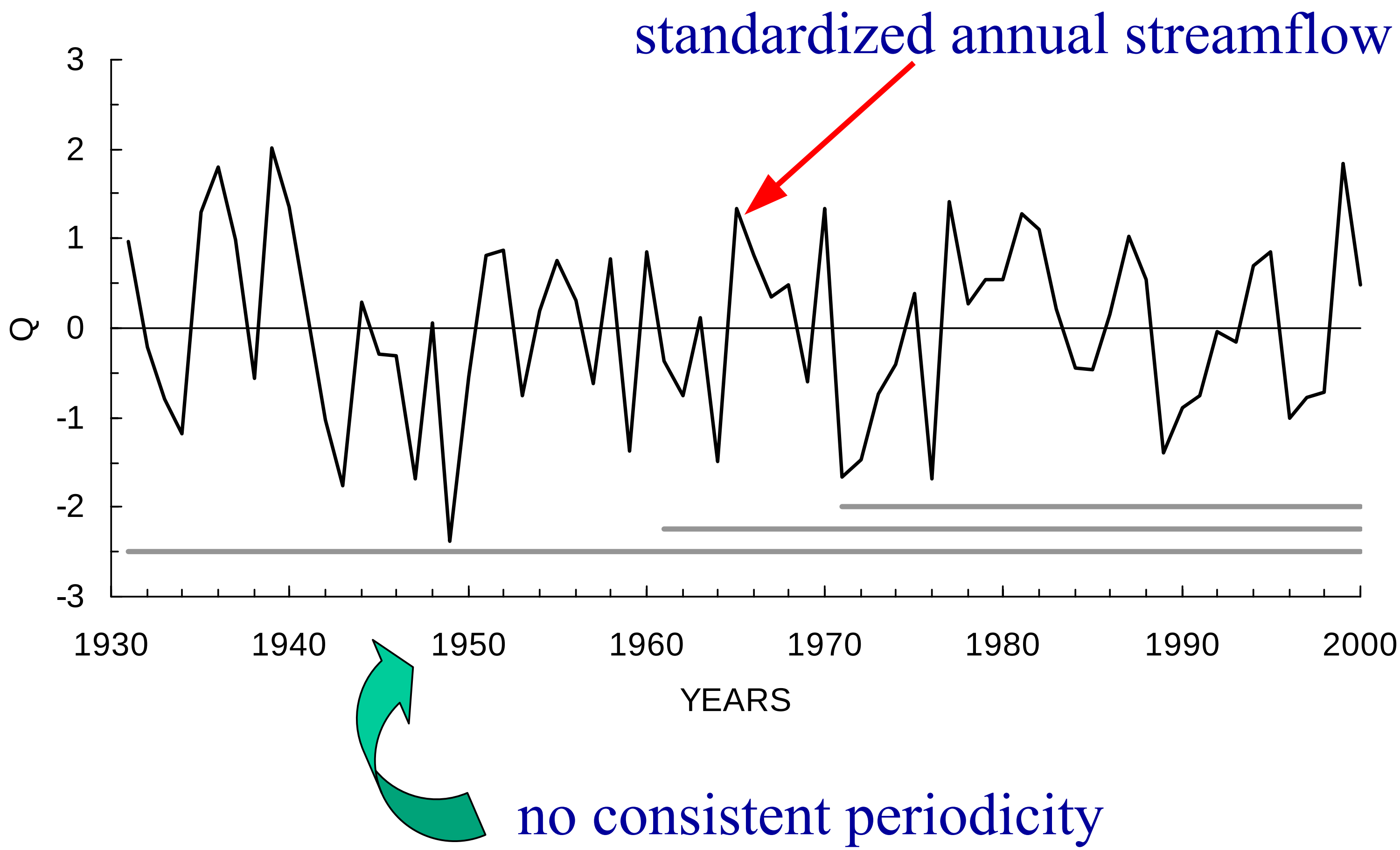
Swiss streamflows - data summary

	min - max (average)	*unit*	*data source*
Annual streamflow statistic :			
annual mean	0.55 - 42.2 (5.88)	m^3s^{-1}	FOWG
annual minimum	0.29 - 32.3 (3.91)	m^3s^{-1}	FOWG
annual maximum	0.81 - 55.7 (8.29)	m^3s^{-1}	FOWG
coefficient of variation	0.09 - 0.28 (0.18)	-	FOWG
skewness	-0.42 - 1.17 (0.17)	-	FOWG
lag-one serial correlation	-0.03 - 0.78 (0.17)	-	FOWG
Basin attributes :			
basin area	14.1 - 913 (161.3)	km^2	DEM
mean altitude	473 - 2710 (1618)	m	DEM
mean slope	2.6 - 34.2 (21.4)	°	DEM
basin shape index (Gravelius)	1.5 - 2.8 (2.0)	-	DEM
river density	523 - 4121 (1807)	$m\ km^{-2}$	Geostat
mean soil depth	10 - 98 (42)	cm	Geostat
surface rock coverage	0 - 57.6	%	Geostat
surface glacier coverage	0 - 45.7	%	Geostat
mean CN (SCS curve number)	64 - 84 (73)	-	Pfaundler (2001)
mean annual precipitation	816 - 2151 (1332)	mm	MeteoSwiss
mean daily max precipitation	45 - 124 (62)	mm	MeteoSwiss

Swiss streamflows - preliminary check

Check for large scale periodic behaviour

- trend analysis should be done on periods that include one or more full cycles



Swiss streamflows - method (1)

(e.g., Helsel and Hirsch, 1992)

Trend analysis were conducted by the **non-parametric Mann-Kendall test**

- widely used in hydrological studies
- distribution free
- robust against outliers
- higher power than other common tests

$$\mathrm{H}_0: \quad \mathrm{Prob}[x_j > x_i] = 0.5,\ j > i$$

$$\mathrm{H}_A: \quad \mathrm{Prob}[x_j > x_i] \neq 0.5,\ \text{(two-sided test)}$$

x_j and x_k data values in years j and k, $j > k$,

Mann-Kendall statistic S

$$\boxed{S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k)}$$

where

$$\mathrm{sgn}(x_j - x_k) = \begin{cases} 1, \text{ if } x_j - x_k > 0 \\ 0, \text{ if } x_j - x_k = 0 \\ -1, \text{ if } x_j - x_k < 0 \end{cases}$$

The distribution of S can be approximated well by a normal distribution for large n, with

$$\mu_S = 0$$

$$\sigma_S^2 = \left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5) \right] / 18$$

includes correction for ties (identical values)

the variable:

$$\boxed{Z = \begin{cases} \dfrac{S-1}{\sigma_S} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{\sigma_S} & \text{if } S < 0 \end{cases}}$$

is checked against the standard normal variate Z_q

if $|Z| > Z_q$, $q = \alpha/2$ ⇨ H_0 rejected

Swiss streamflows - method (2)

Investigated variables

- daily streamflows, precipitation, temperature
  - original series, x
  - prewhitened series, x^*: $x_i^* = x_i - r_1 x_{i-1}$ (applied only to series with $r_1 > 0$)
- quantiles of the empirical distribution (p=0.1, 0.2, ..., 0.9) of
  - annual streamflows
  - seasonal streamflows (4 climatological seasons: Winter=DJF, Spring=MAM, Summer=JJA, Autumn=SON)
- mean Q, P, T
- minimum Q, P, T
- maximum Q, P, T

Basin characteristics

basin area, mean altitude, mean slope, basin shape index, river network density, mean soil depth, percentage of rock and glacier coverage, maximum soil potential retention (SCS-CN), mean annual precipitation, mean daily may precipitation

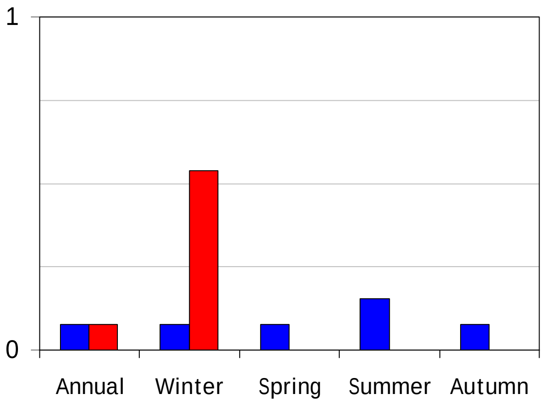
Swiss streamflows trends - results

Frequency of statistically significant trends - mean

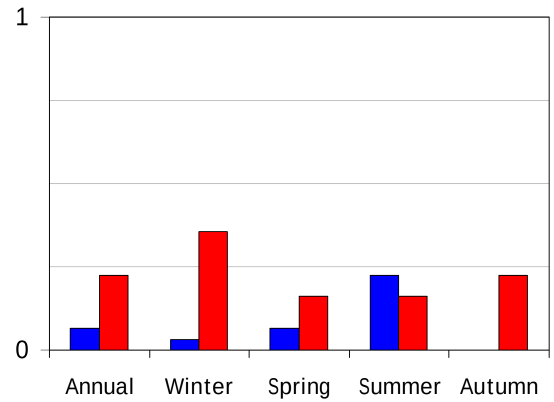
Downward

Upward

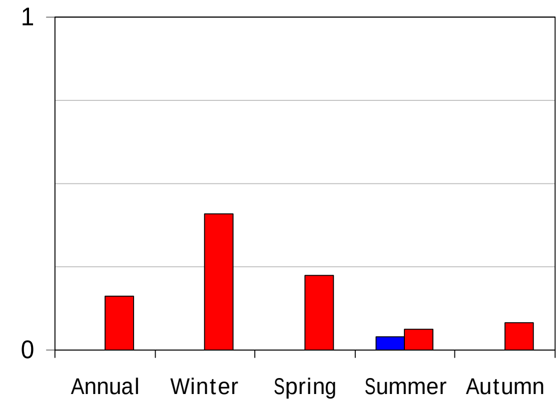
Original



1931-2000

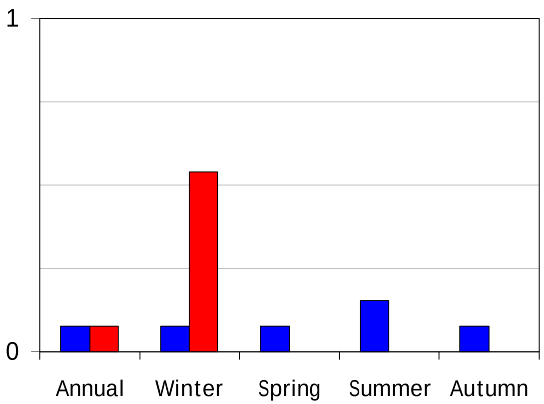


1961-2000

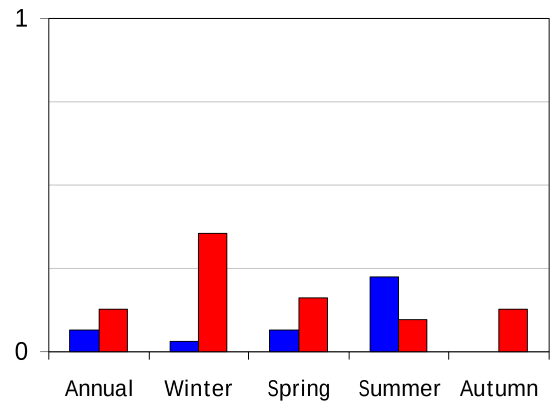


1971-2000

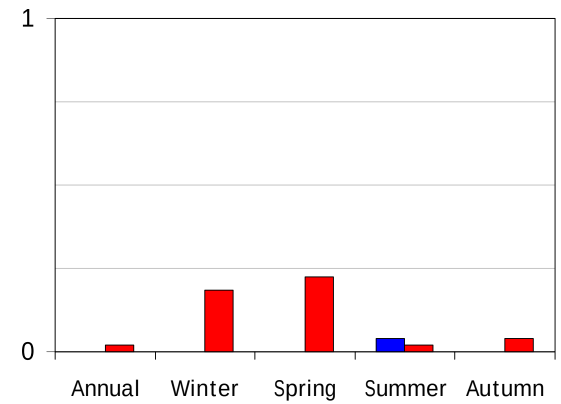
Prewhitened



1931-2000



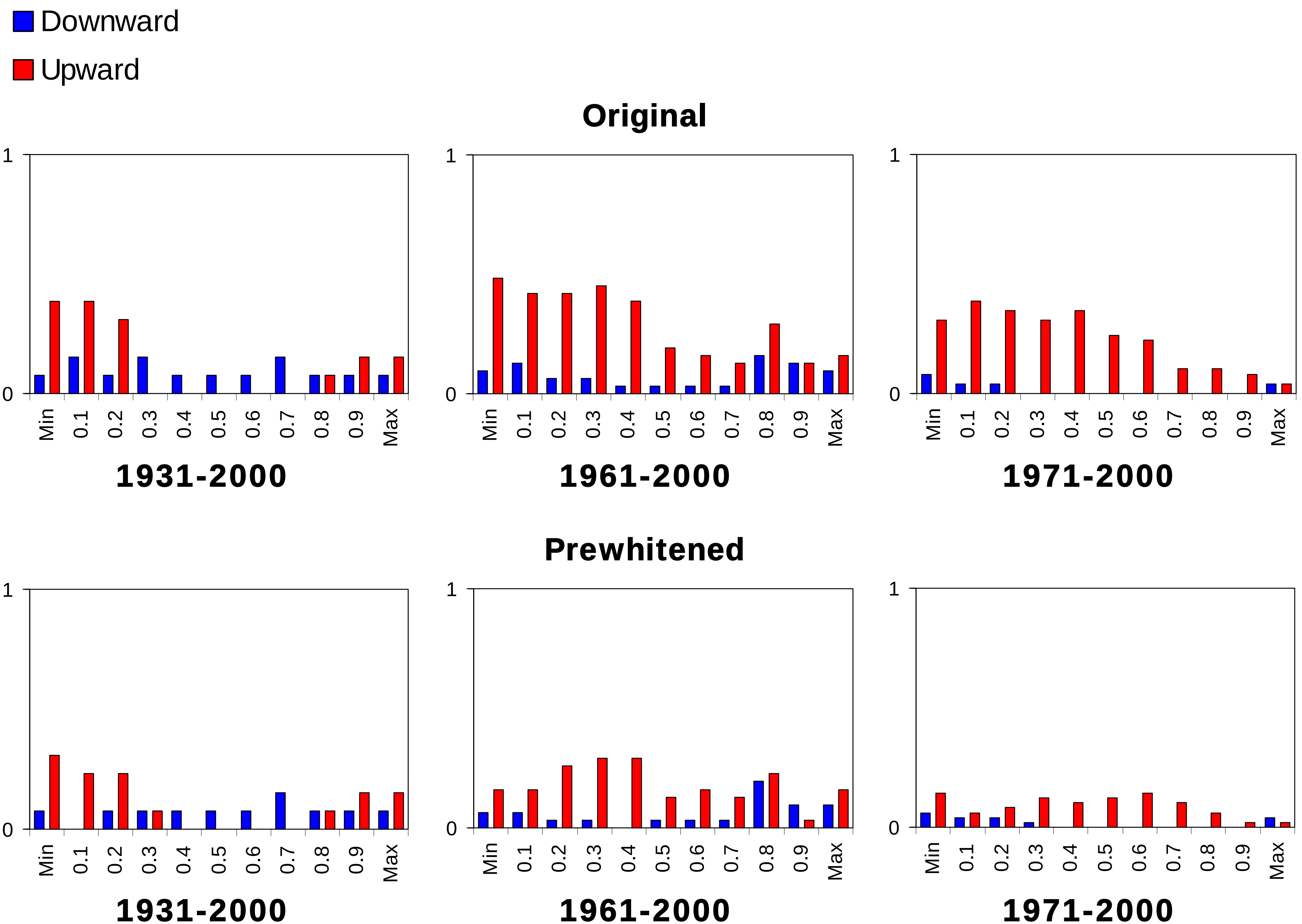
1961-2000



1971-2000

Swiss streamflows trends - results

Frequency of statistically significant trends - annual quantiles

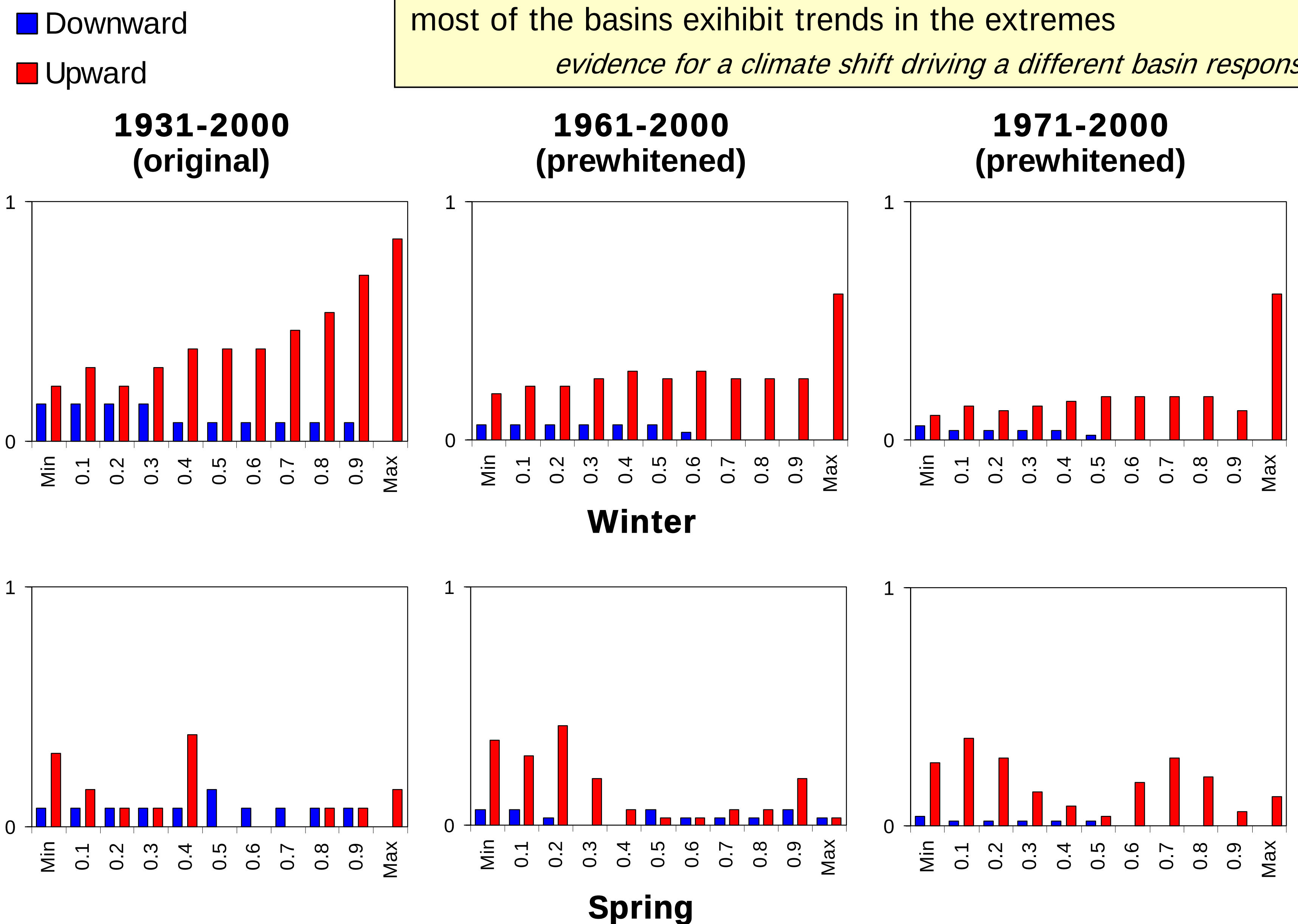


Swiss streamflows trends - results

Frequency of statistically significant trends - seasonal quantiles

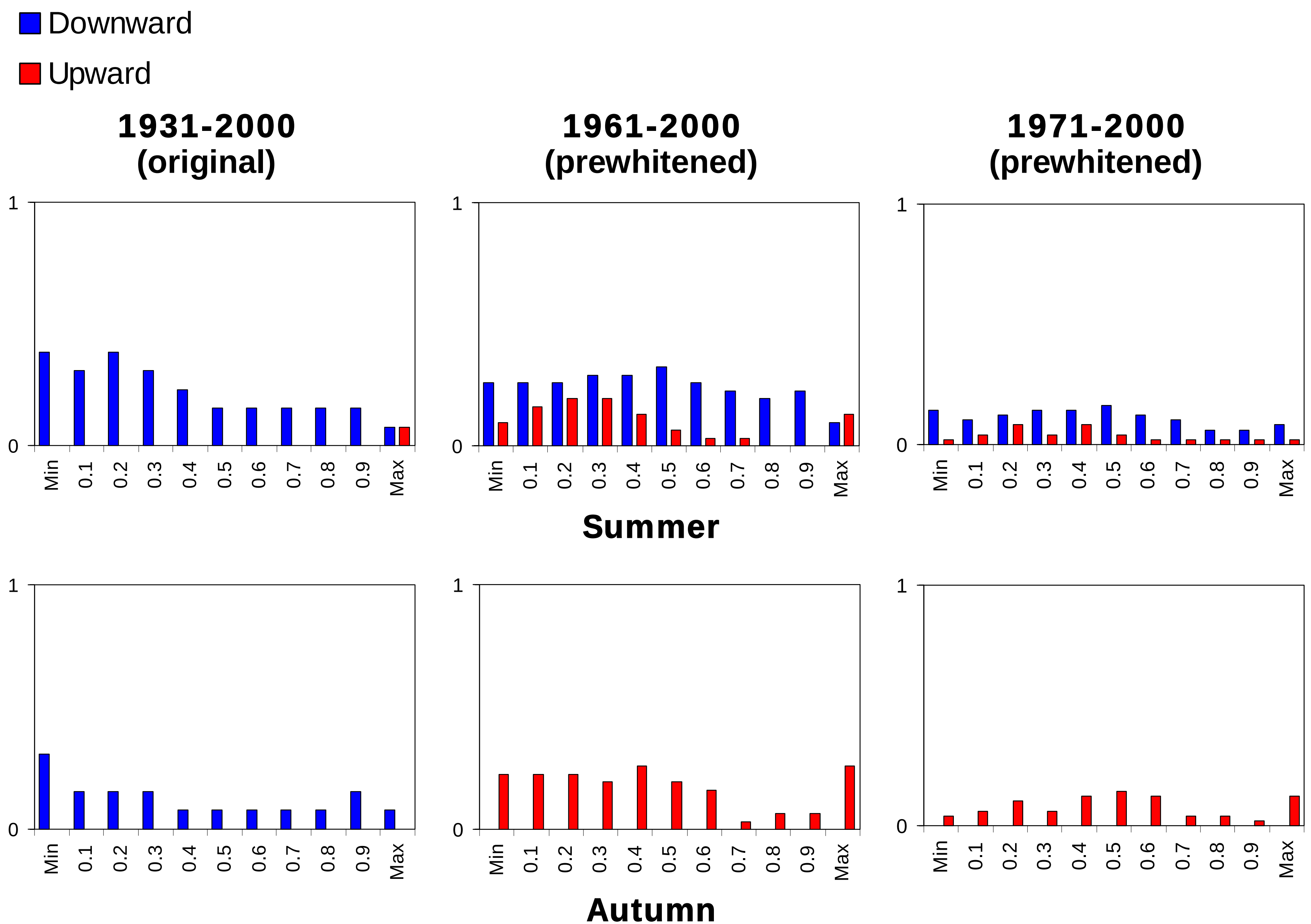
most of the basins exihibit trends in the extremes

evidence for a climate shift driving a different basin response?



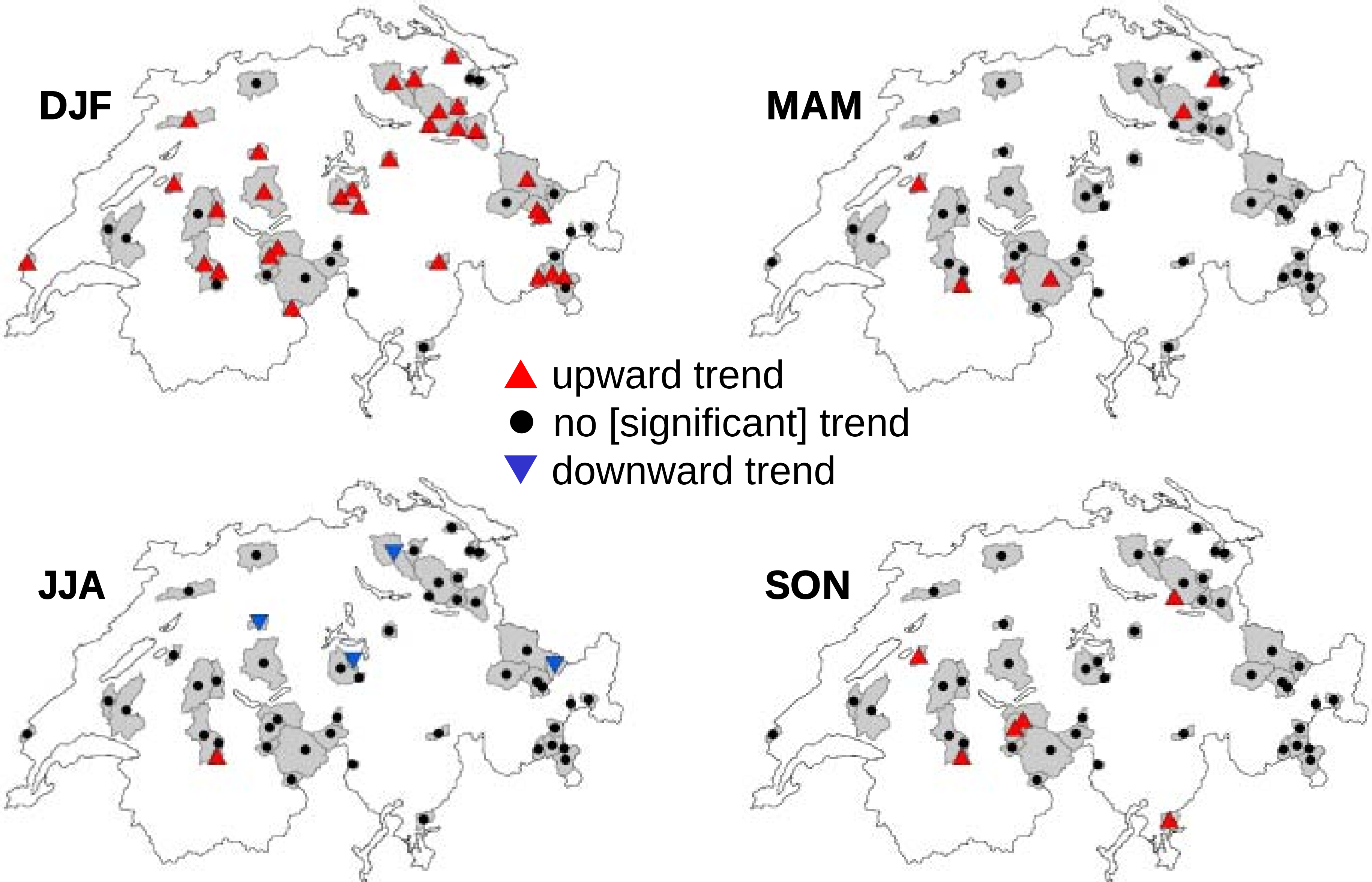
Swiss streamflows trends - results

Frequency of statistically significant trends - seasonal quantiles



Swiss streamflows trends - results

Spatial distribution of statistically significant trends



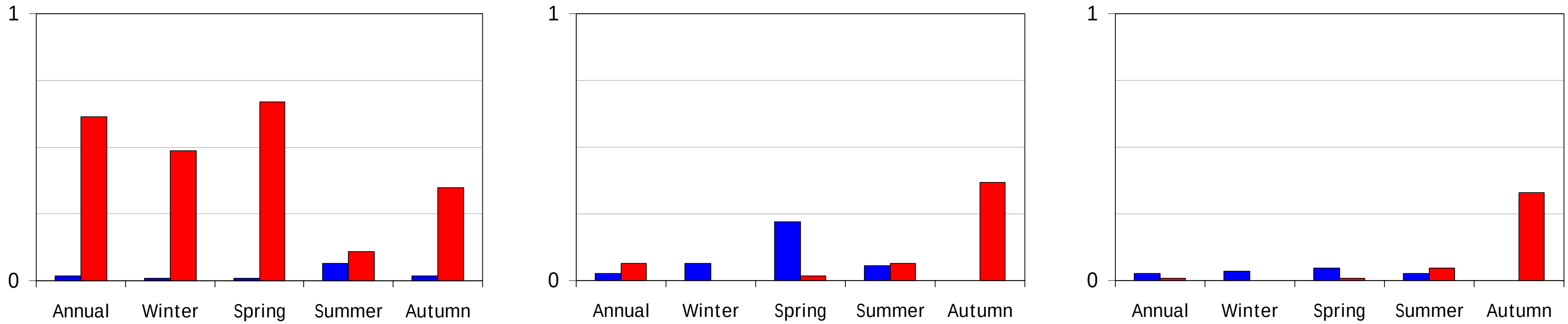
Swiss streamflows trends - results

Frequency of statistically significant trends - precipitation

Downward
Upward

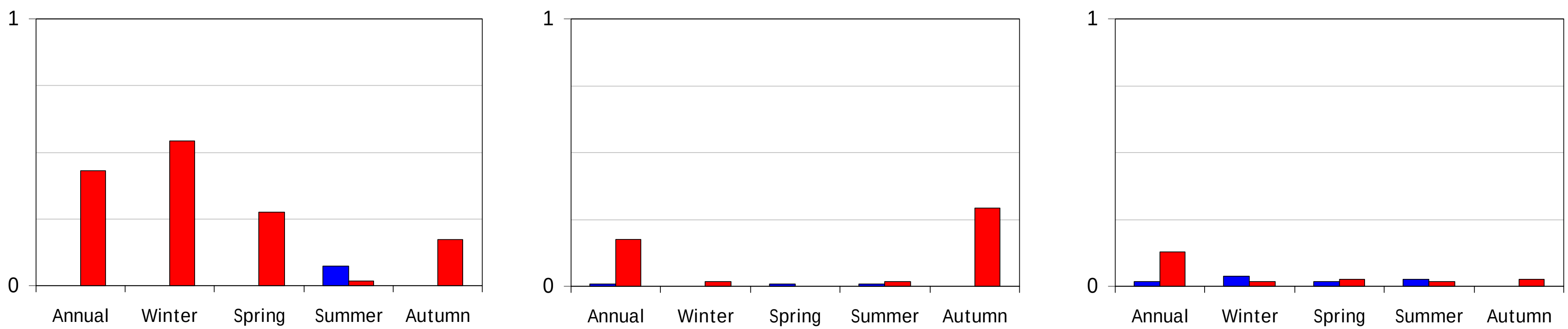
Results from other investigations are confirmed
(e.g. Widmann and Schär, 1997; Frei & Schär, 2001; Schmidli et al., 2002)

Number of days with precipitation



1931-2000 (original) 1961-2000 (prewhitened) 1971-2000 (prewhitened)

Precipitation amount



1931-2000 (original) 1961-2000 (prewhitened) 1971-2000 (prewhitened)

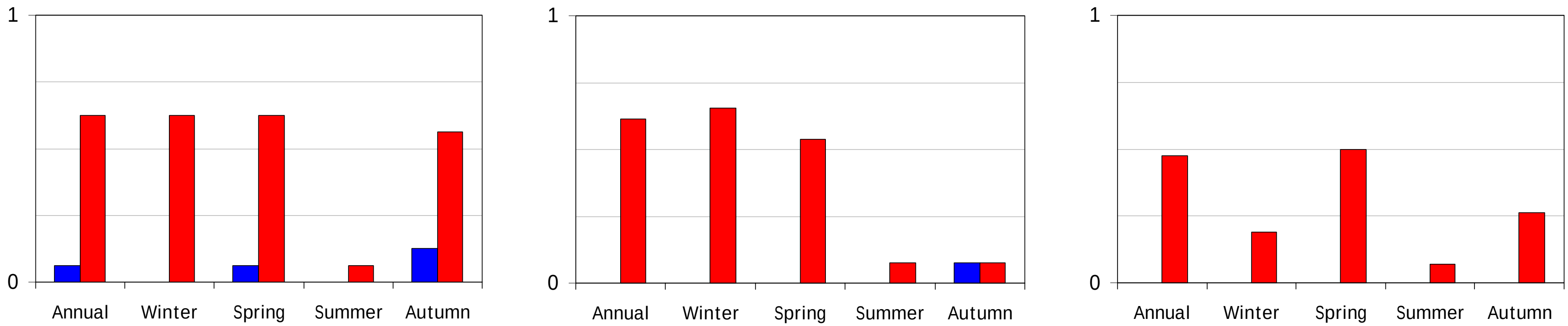
Swiss streamflows trends - results

Frequency of statistically significant trends - t_{min}>0 C

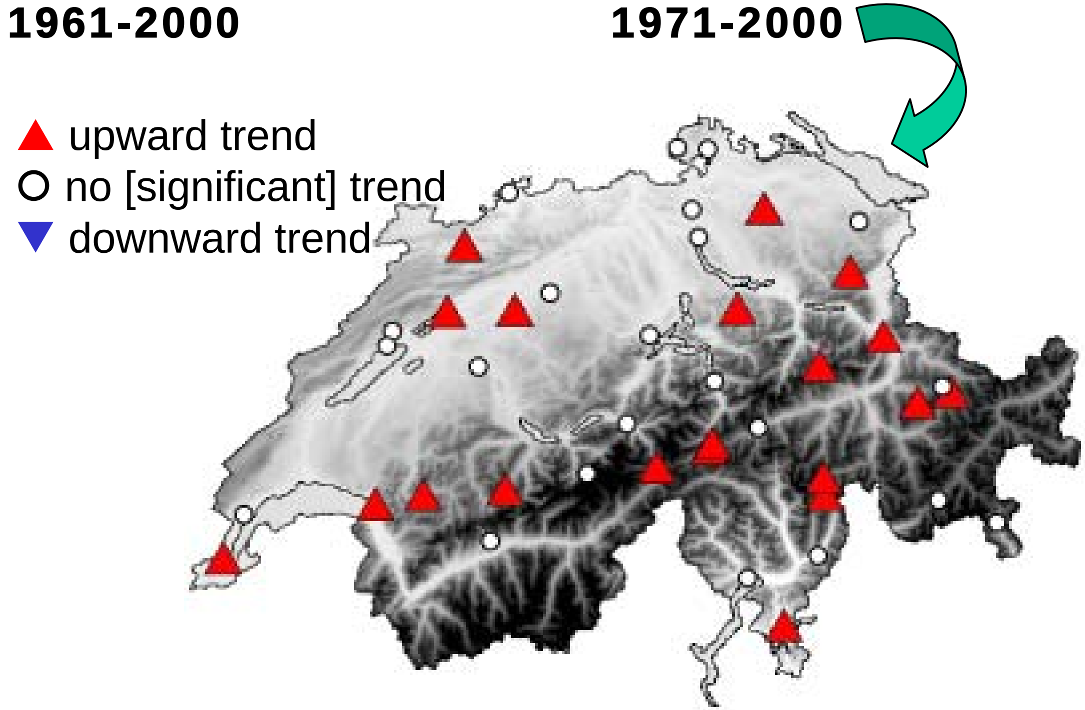
Downward

Upward

Number of days with t_{min}>0 C



1931-2000 **1961-2000** **1971-2000**



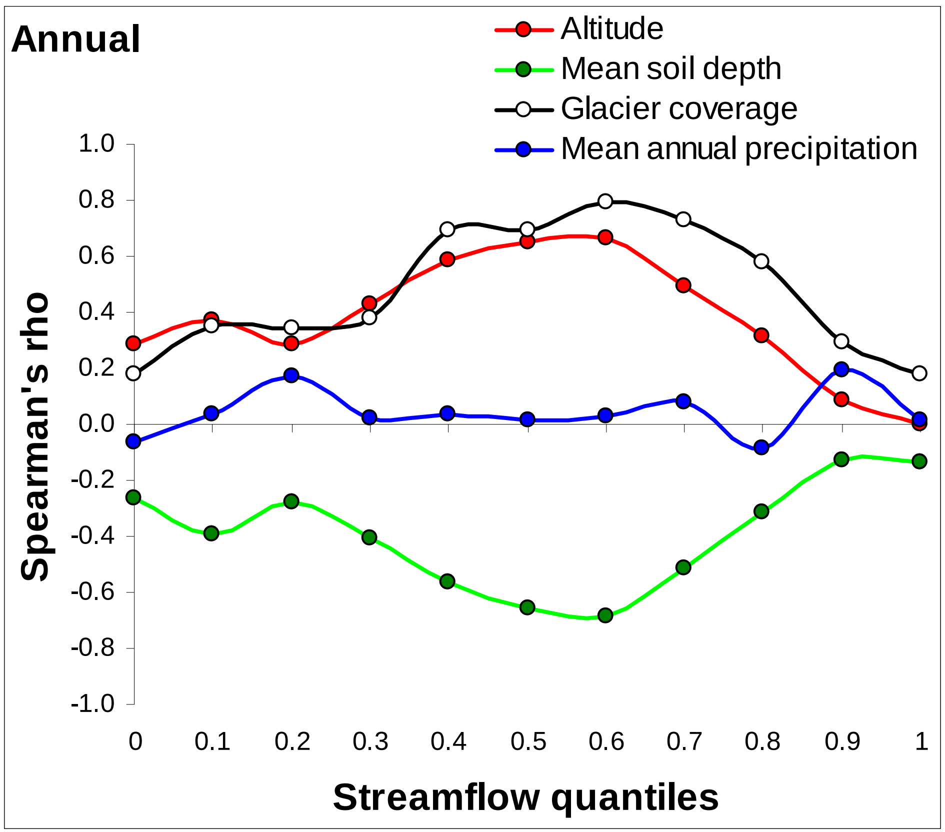
- 50% stations exihibit an increase of # days t_{min}>0
- increase of t_{min} in all seasons
- decrease of t_{max} in all seasons except winter
- homogeneous result over the three study periods

Swiss streamflows trends - results

correlation between trend results and basin characteristics (1)

Assumption: basin attributes substantially static

Computed: monotonic and linear correlation coefficients (regardless of α)



$$\rho_s = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n\left(n^2-1\right)} \;; \qquad d_i = r_{x_i} - r_{y_i}$$

- fairly good correlation for some attributes
- extremes are poorly correlated, moderate flows correlate at best
- (annual) precipitation poor indicator
- mountain basin attributes (elevation, rock, glacier coverage) shows high positive ρ ➯

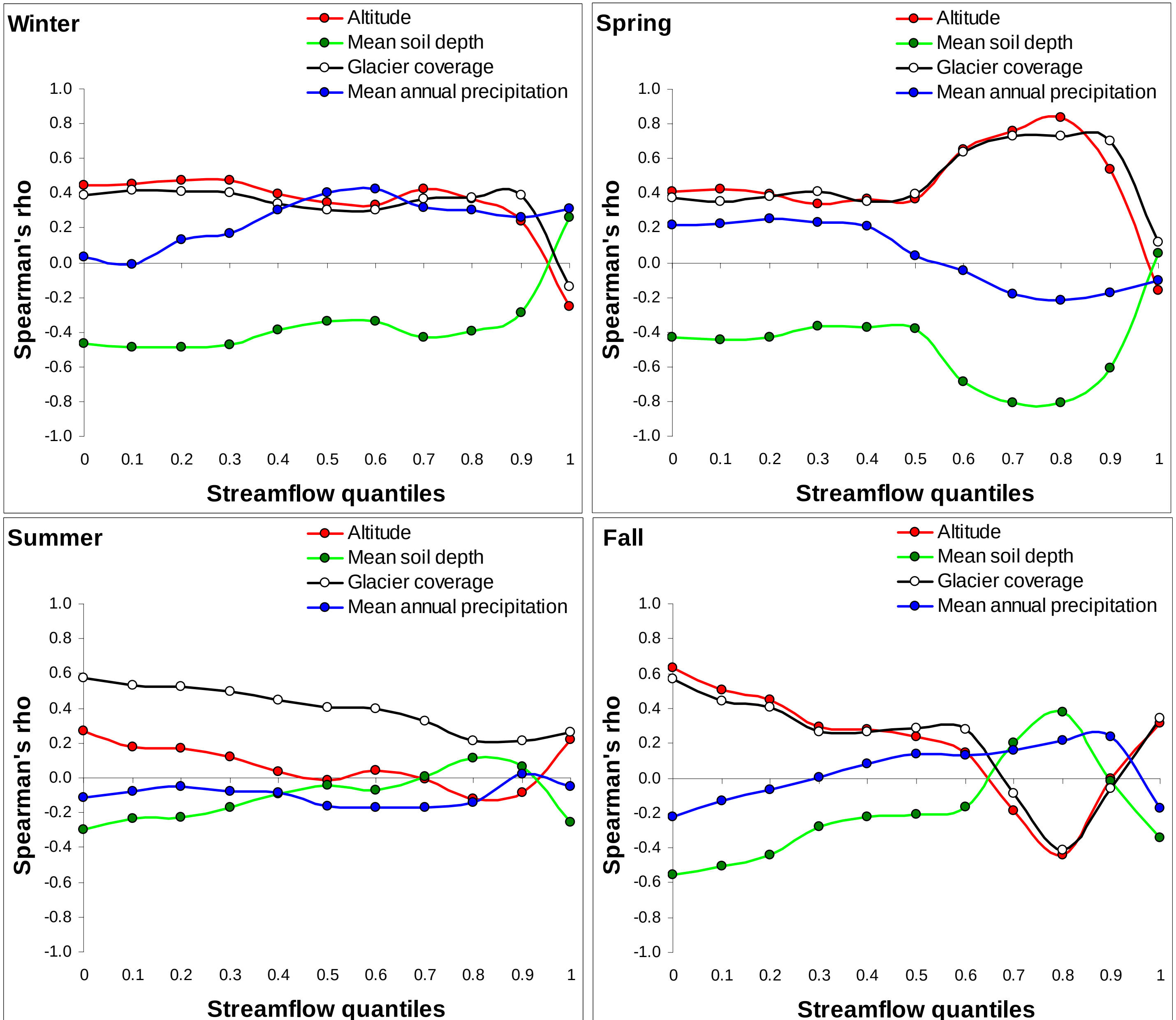
  the higher the coverage the higher the trend

- basin mean soil depth shows negative ρ ➯

  the higher the depth the lower the trend

Swiss streamflows trends - results

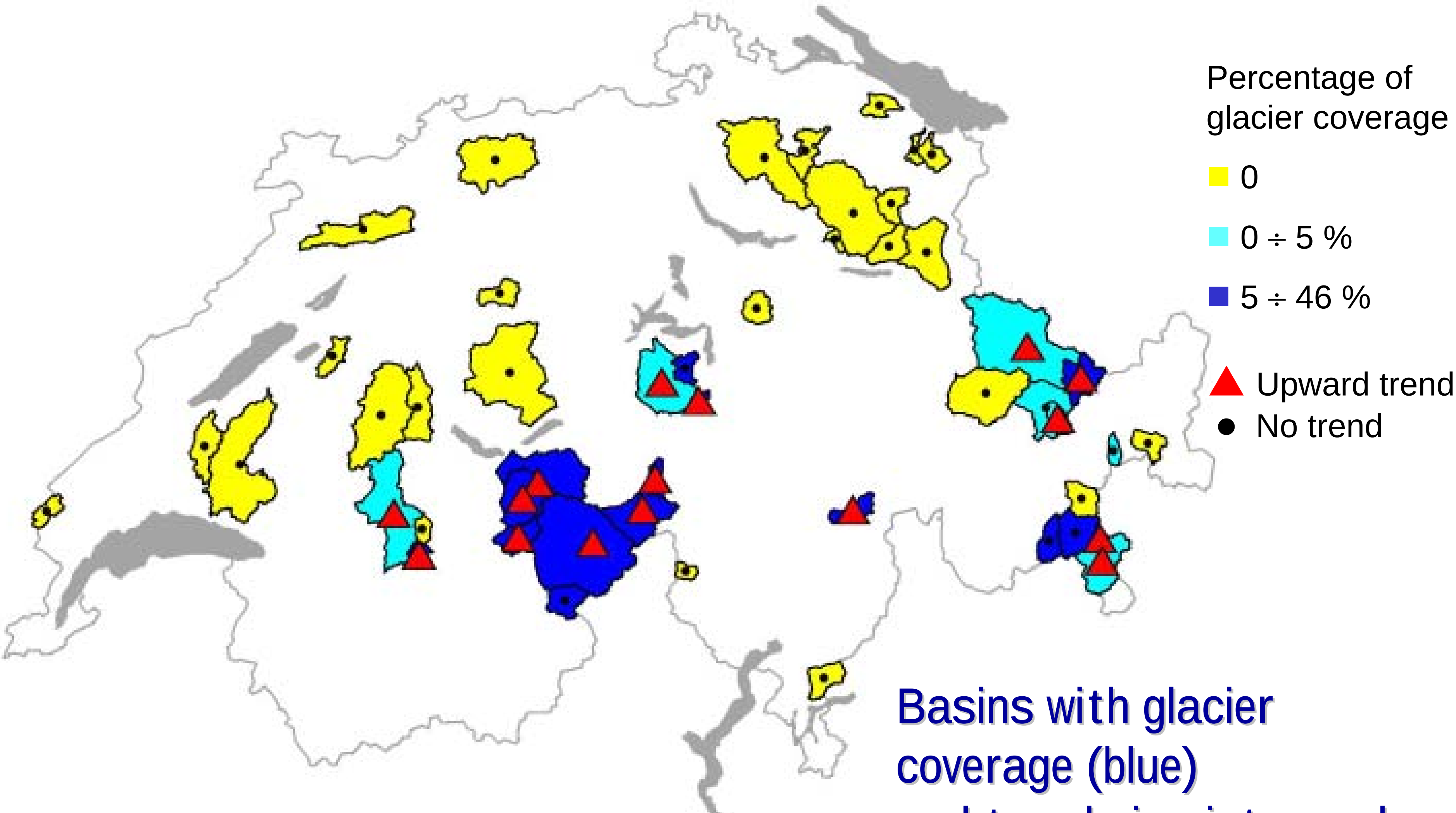
correlation between trend results and basin characteristics (2)



- basin coverage more effective in spring and summer
- mean soil depth more effective in winter and spring
- extremes poorly correlated in all seasons
- only winter precipitation exihibits accountable correlation

Swiss streamflows trends - results

correlation between trend results and basin characteristics (3)



Basins with glacier coverage (blue)
and trends in winter and spring mean streamflow

Swiss streamflows trends - discussion

Evidence of changes in the natural regime

- increase in
  - **winter streamflow, especially maxima**
  - **spring streamflow**
- lack of trend in summer streamflow
- no spatial coherence
- unaccountable noise due to uncontrolled (minor) anthropogenic influence (land-use, glacier retreat, ...)

e.g. Frei and Schär, 2001

Impact of climate and basin properties

- analysis confirms other trend studies on precipitation (winter trends)
- precipitation W trends coherent with W streamflow trends & # of days with t_{min}>0 steadily increasing in W ⇨
  - ***low and moderate flows steadily rising since 1961***
- rock and glacier coverage favour trends due to climate shifts, soil depth acts as a buffer ⇨ ***implications on water resources management***

Swiss streamflows trends - concluding summary

Evidence of changes in the natural regime

- The **natural streamflow regime has changed** since 1961:
  - increase in annual streamflow
  - mainly winter (60% of basins) and spring
  - mostly low and moderate flows
- **Winter** changes concern **maxima**, **spring** changes concern **low and moderate flows**
- **Changes in precipitation** amounts alone (**minor after 1961**) cannot explain changes in streamflow
- Changes in **temperature** (concentrated in winter, **decrease of diurnal range**) provide a key to explain trends in streamflow (**more rainfall and increased / earlier snowmelt**) ⇨ ***mountain basins particularly at risk***
- Correlation between trends and basin attributes
  - positive for mean elevation, and rock and glacier coverage (**enhance climate shifts**) ⇨ ***mountain basins particularly at risk***
  - negative for mean soil depth (**buffers climate shifts**?)
  - is **highest for low and moderate flows**
  - low correlation for extremes