What drives high flow events in the Swiss Alps?

Wavelet spectral analysis for the analysis of observed and simulated extreme events

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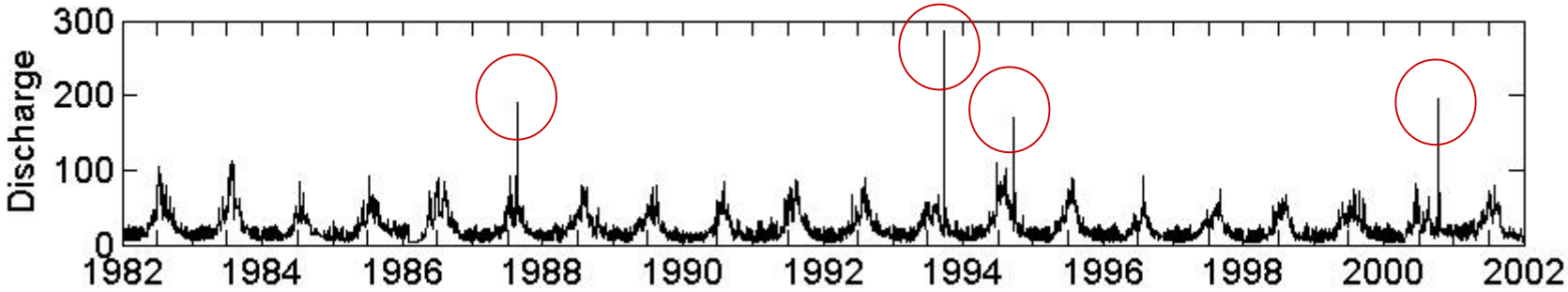
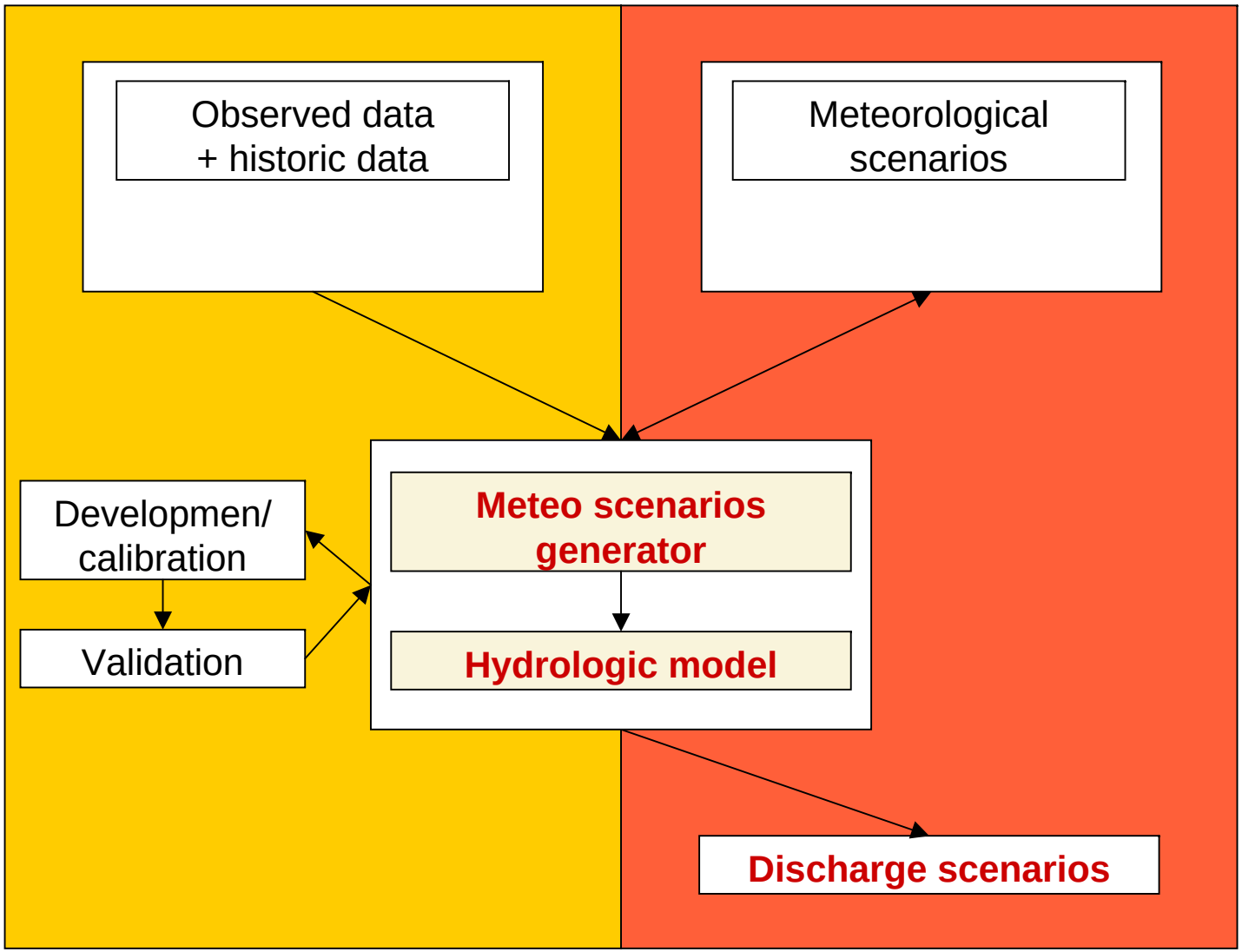
Motivation

- **Design flood estimation for the Swiss Rhone catchment**
  - ⇨ **4 observed high flow events**
  - ⇨ **all in autumn**



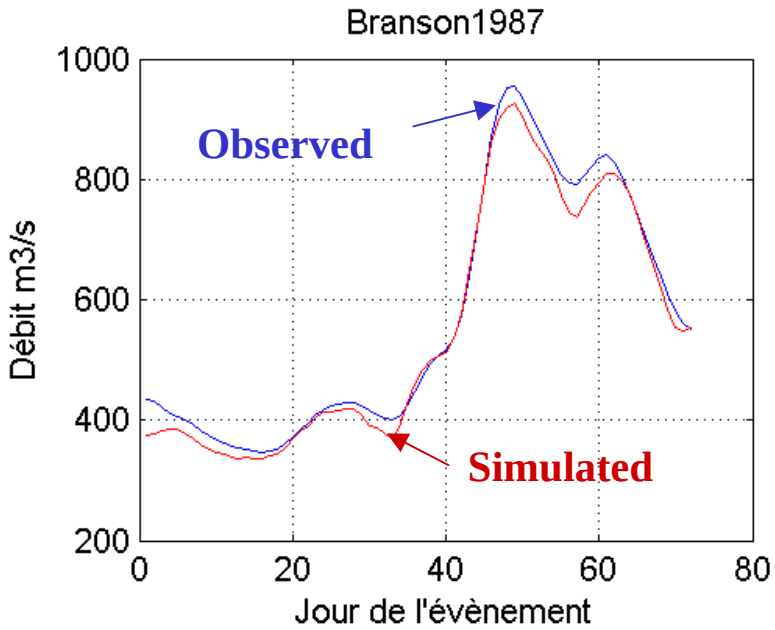
Estimation of design floods

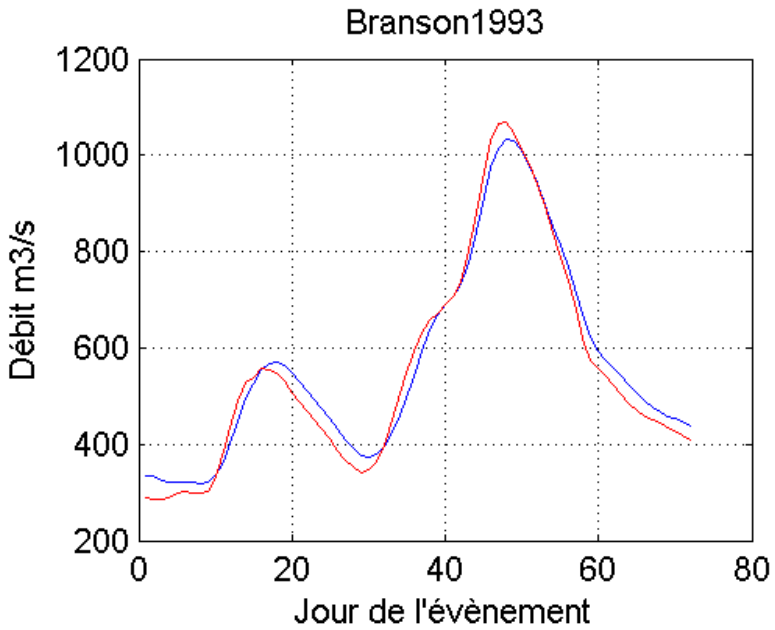


Motivation

- **Conceptual hydrologic model**

  ⇨ **good performance, reproduces observed high flows**





Motivation

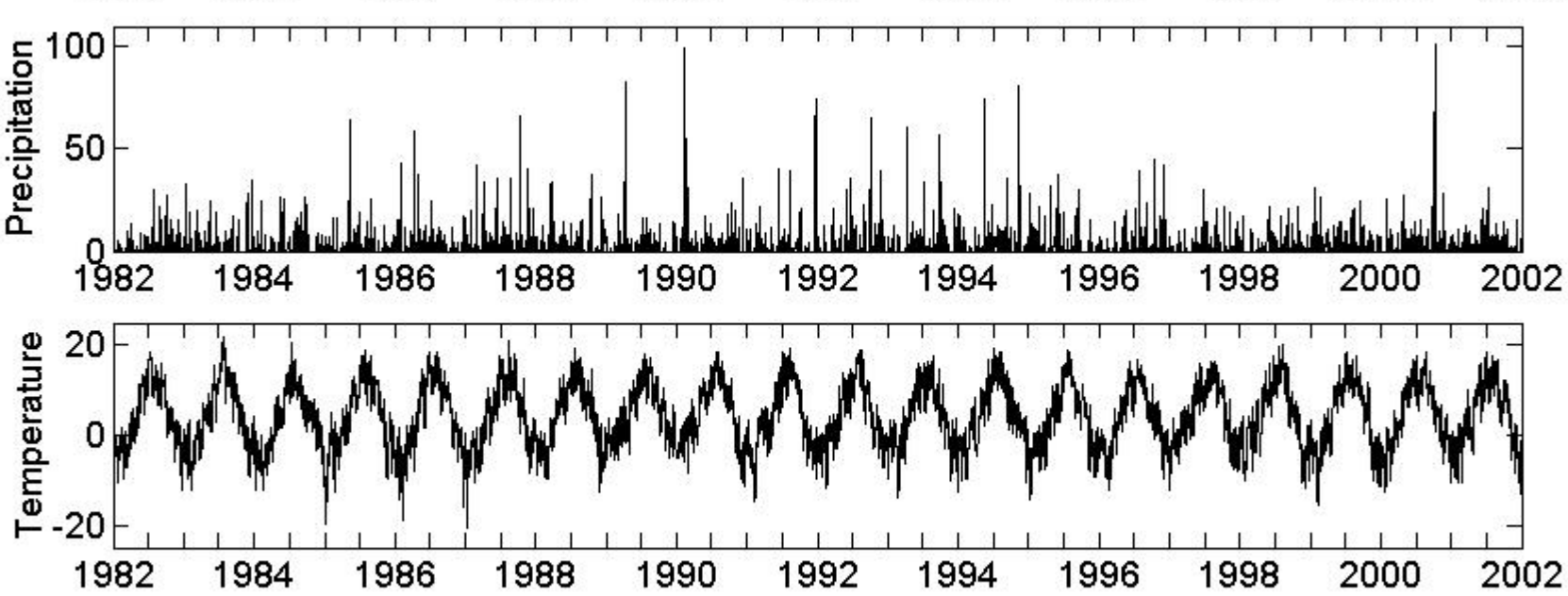
- **Discharge scenarios**
  - ⇨ **Surprise…. floods during spring**
  - ⇨ **Realistic or something wrong?**

- **New question:**
  - ⇨ **How good is the model for *potentially* flood producing situations?**
  - ⇨ **How to identify these situations?**

Motivation - Assumption

- **Extreme climate situations in the Alps**

= Unusual co-oscillation of temperature and precipitation



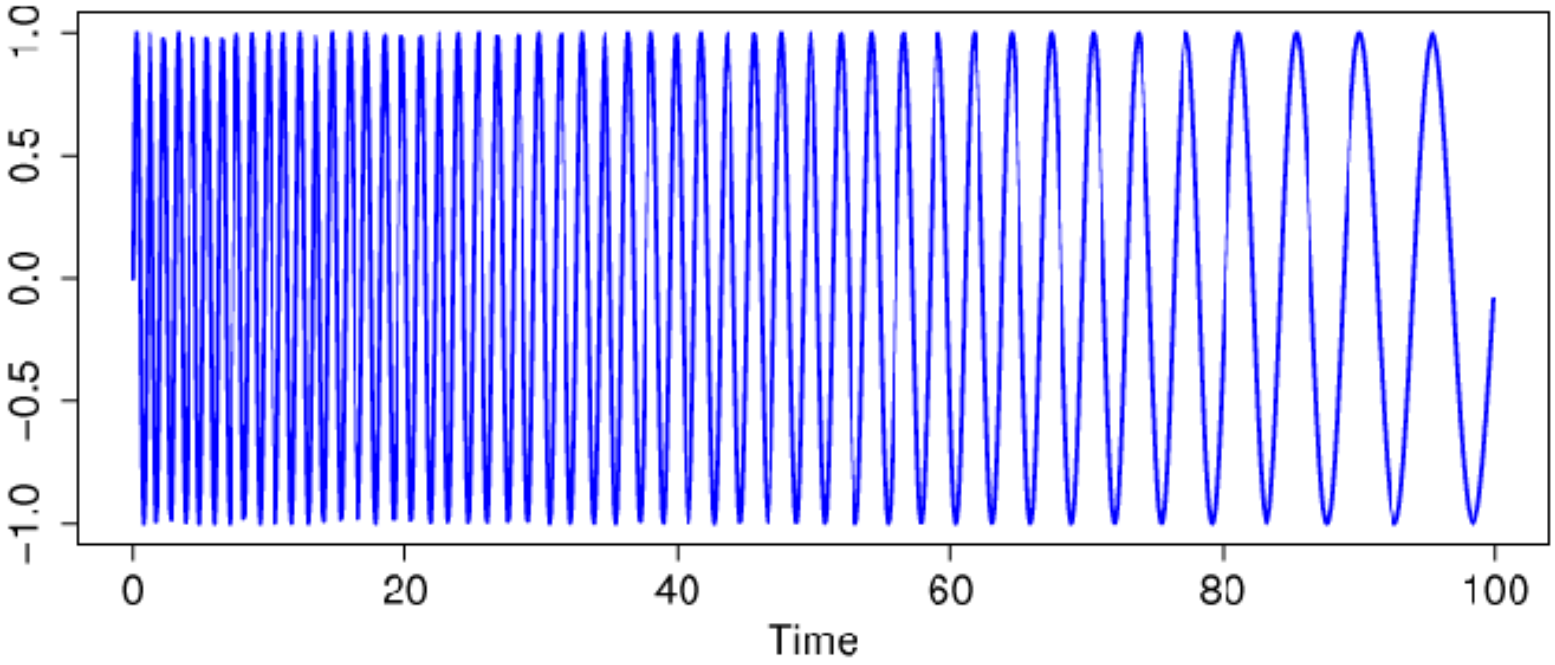
Motivation - Assumption

- **Extreme climate situations in the Alps**

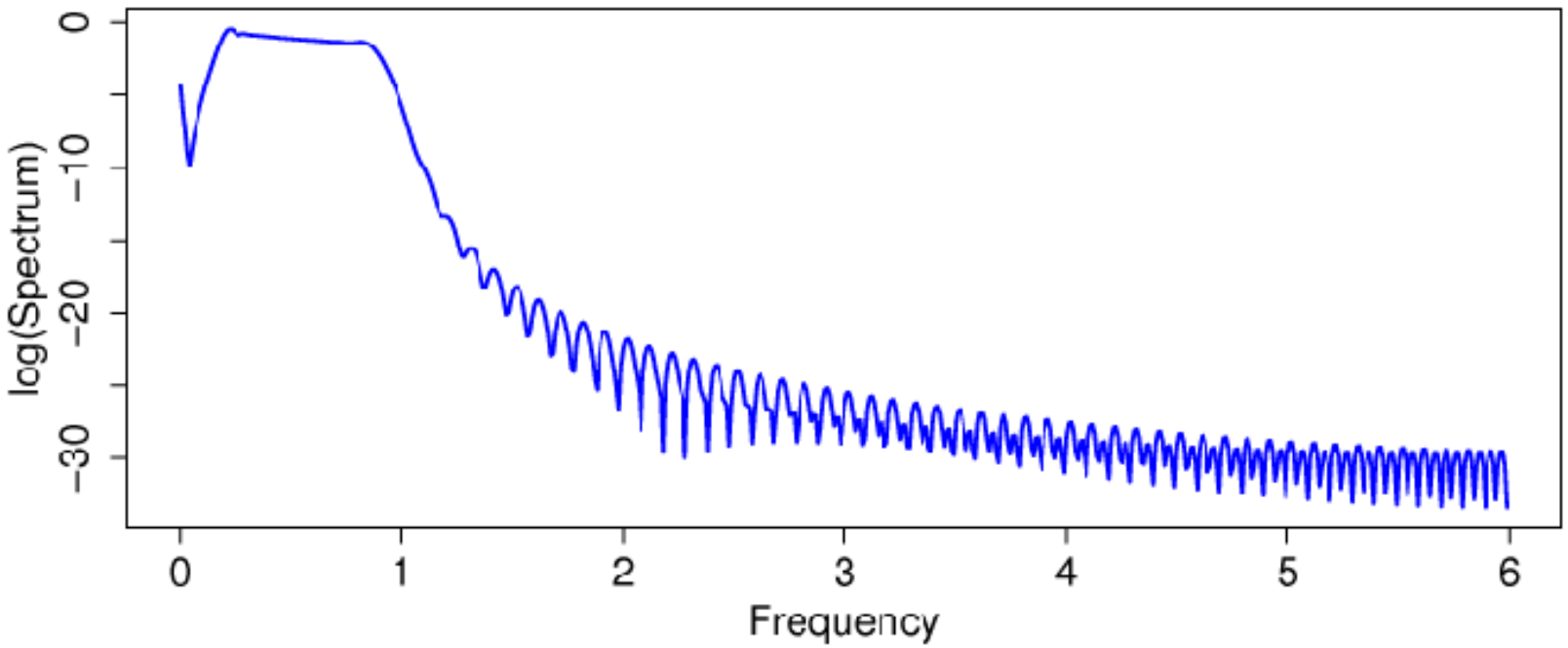
= Unusual co-oscillation of temperature and precipitation

- **Detection?**
  - ⇨ **Time and scale resolved analysis**
    - Scale ~ 1/frequency
  - ⇨ **Wavelet spectral analysis (continuous wavelet transform)**

Illustrative example: deterministic chirp



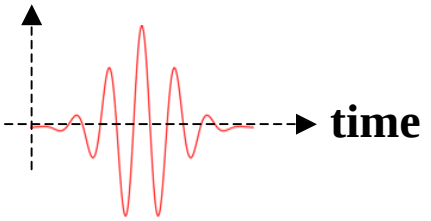
.. and its Fourier transform



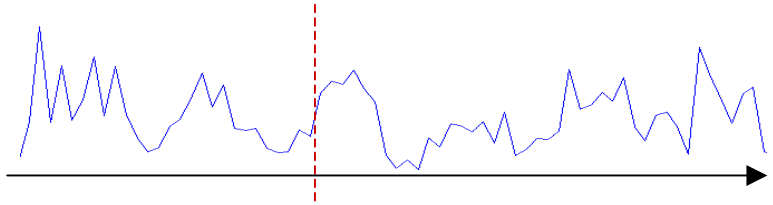
Time reference ?

Continuous wavelet transform

⇨ **Take a wavelet g** (fast decaying oscillating function of finite length)



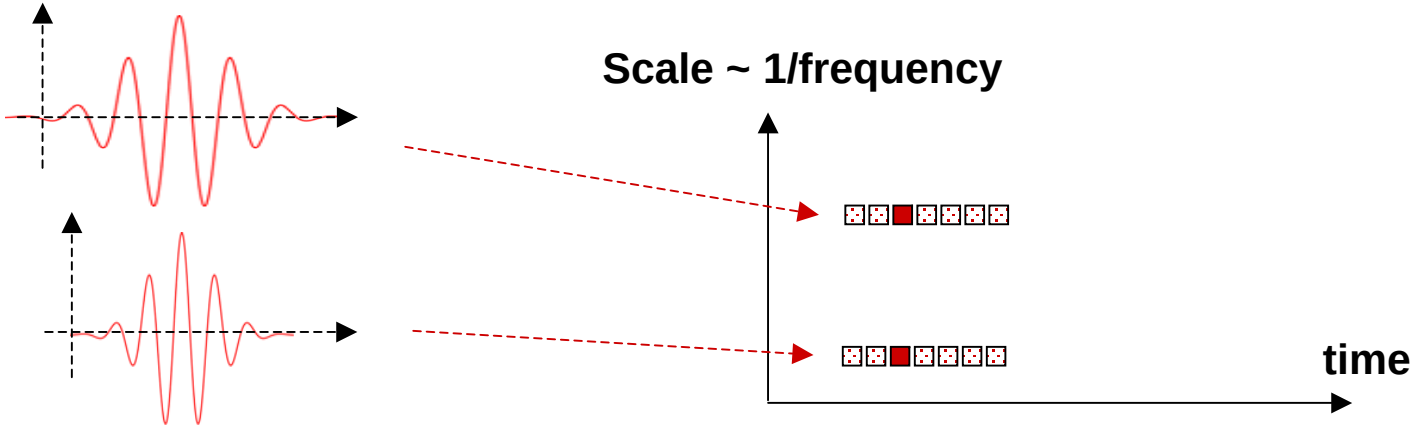
⇨ **Chose a location of time series s**



Convolute

$$W_g(b,a) = \int \frac{1}{\sqrt{a}} g^* \left(\frac{t-b}{a} \right) s(t) dt$$

⇨ **Repeat for all locations and all scaled versions of wavelet scales**



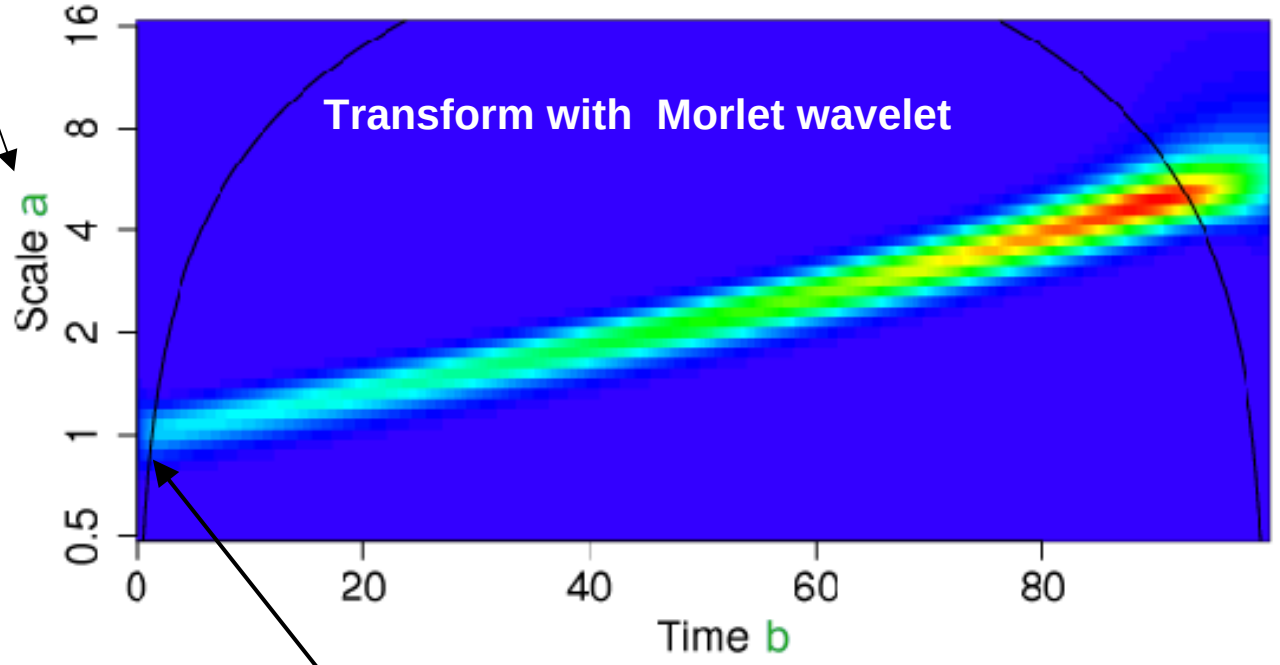
Wavelet power spectrum of the chirp

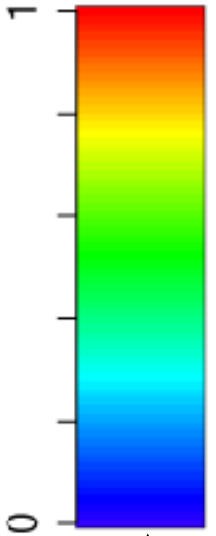
$$WPS(a,b) = E[W_g(a,b)W_g^*(a,b)]$$

Complex conjugate

Expectation

Scale
(≈ 1/ freq)





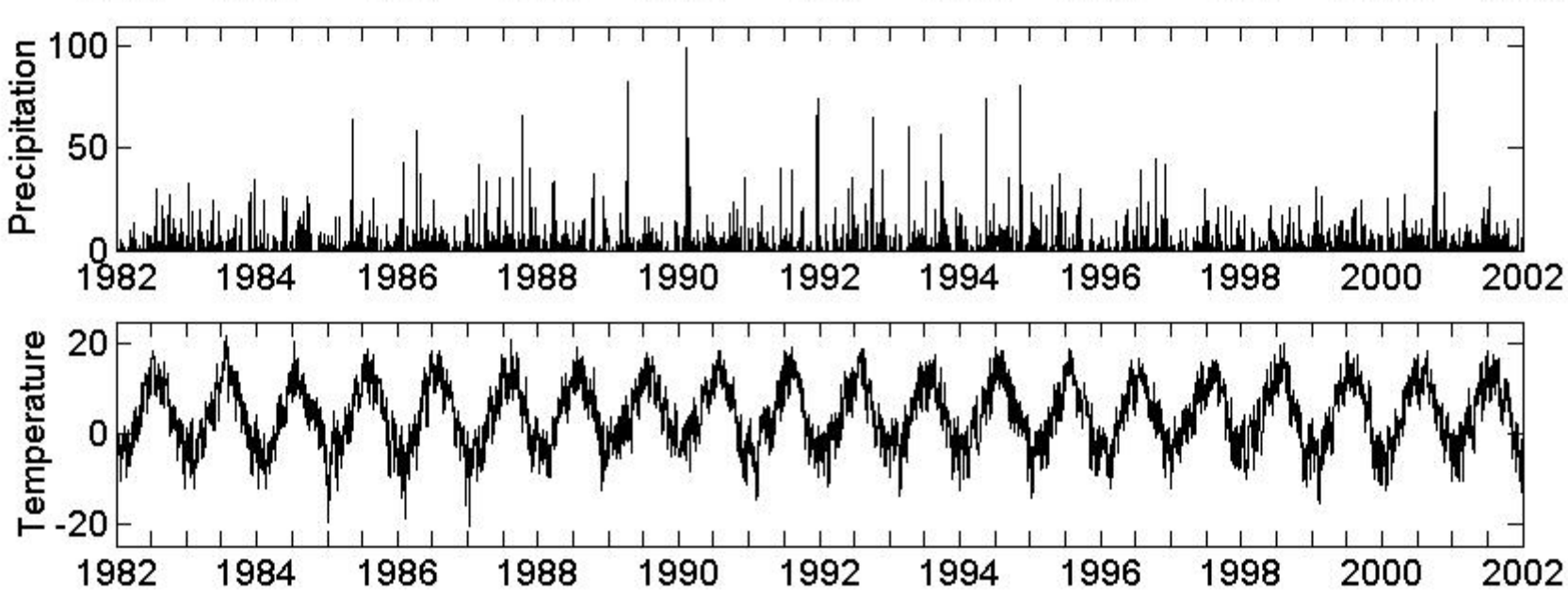
Cone of influence:

values above influenced by edge effects

Power scale
(normalized)

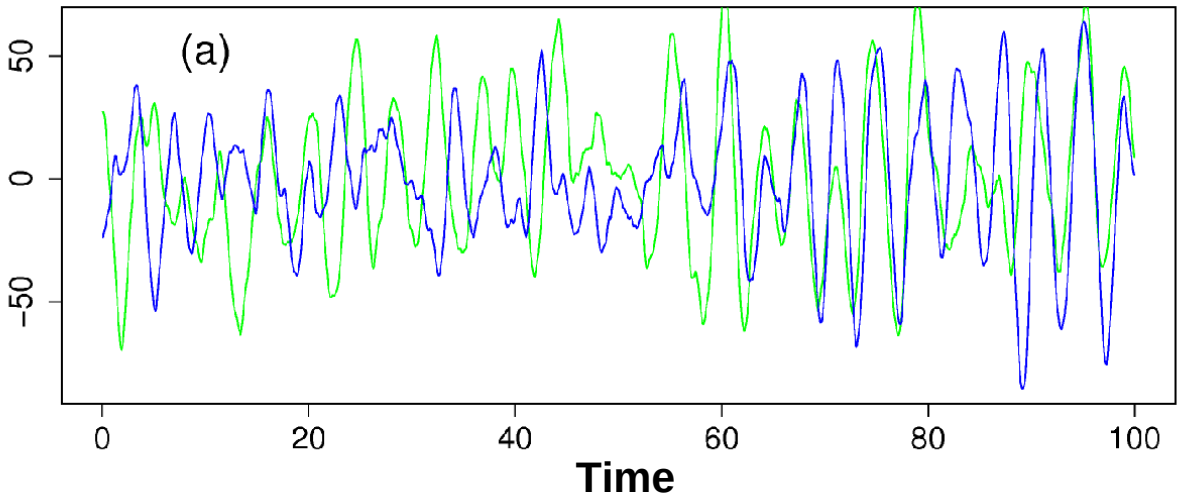
Detect co-osciallations

- **Detect coherency between two processes**



Co-oscillation example

Example: two co-oscillating processes



Method

- **Detect co-oscillation between processes**

- **Wavelet coherence**

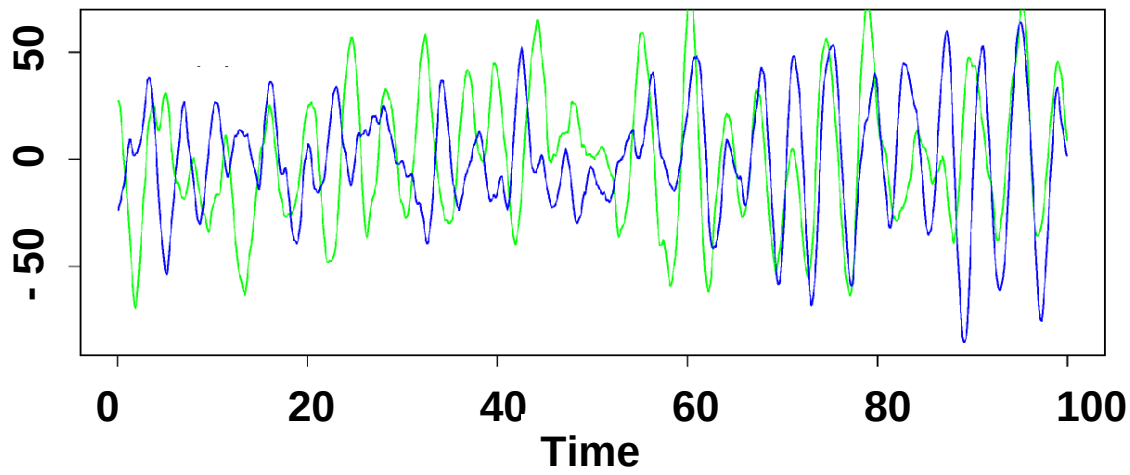
  ⇨ **Estimated wavelet cross spectrum of signal 1 and signal 2**

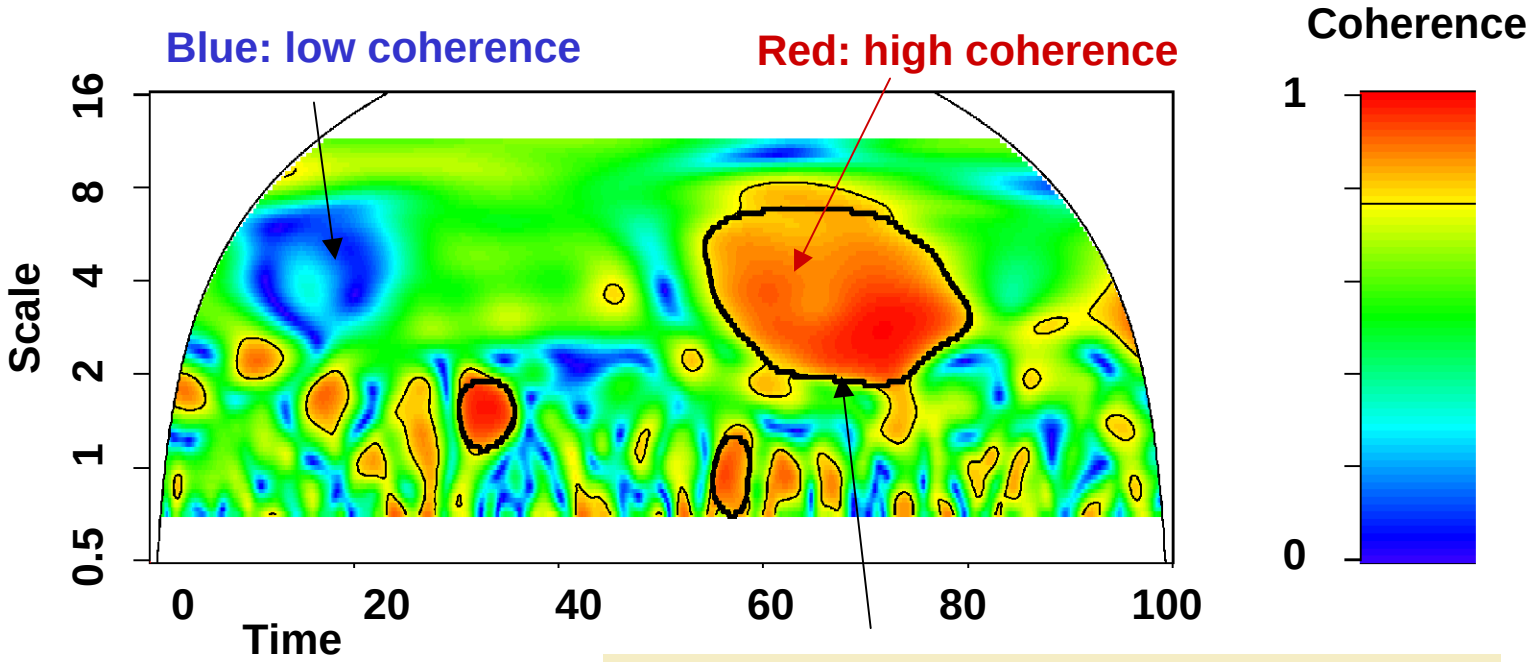
$$WCS_g(a,b) = E[\, W_g^{s_1}(a,b) W_g^{s_2 *}(a,b)]$$

  ⇨ **Wavelet coherency between $s_1(t)$ and $s_2(t)$**

$$WCO_g(a,b) = \frac{Estimated\ \ cross\ \ spectrum}{(Spectrum\ \ signal\ 1 \cdot Spectrum\ \ signal\ \ 2)^{0.5}}$$

Wavelet coherence





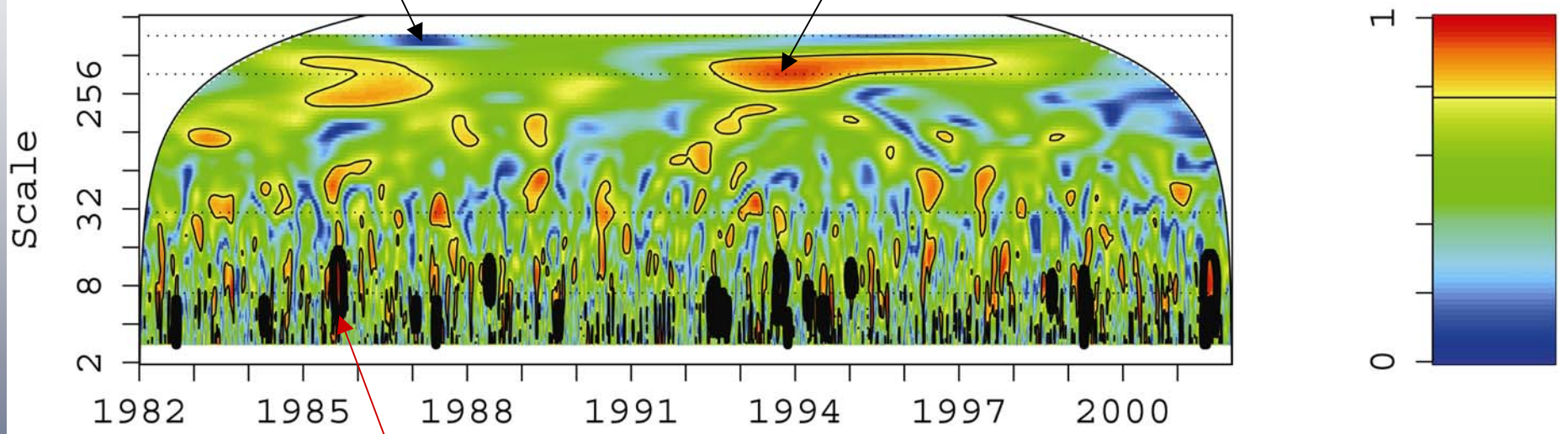
Black contour lines: significant coherence

Co-oscillation of meteo series

Coherence between temperature and precipitation

Blue: low coherence

Red: high coherence



Daily time step

Black contour lines: significant coherence

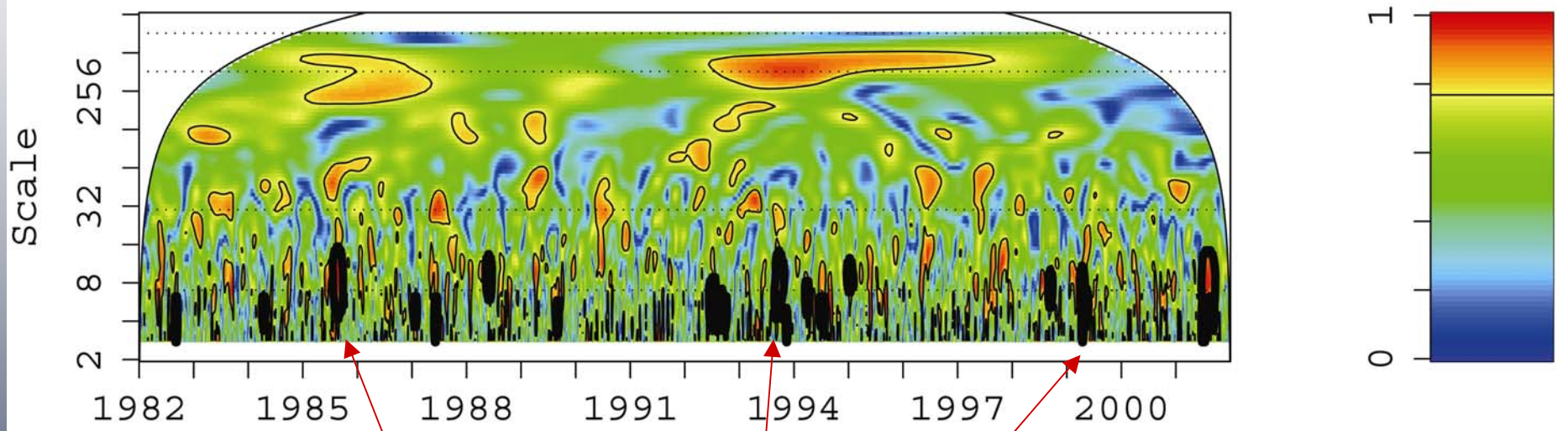
Remember: assumption

- **Extreme climate situations in the Alps**

  = Unusual co-oscillation of temperature and precipitation

Potentially flood producing situations

- **Coherence between temperature and precipitation**



Daily time step

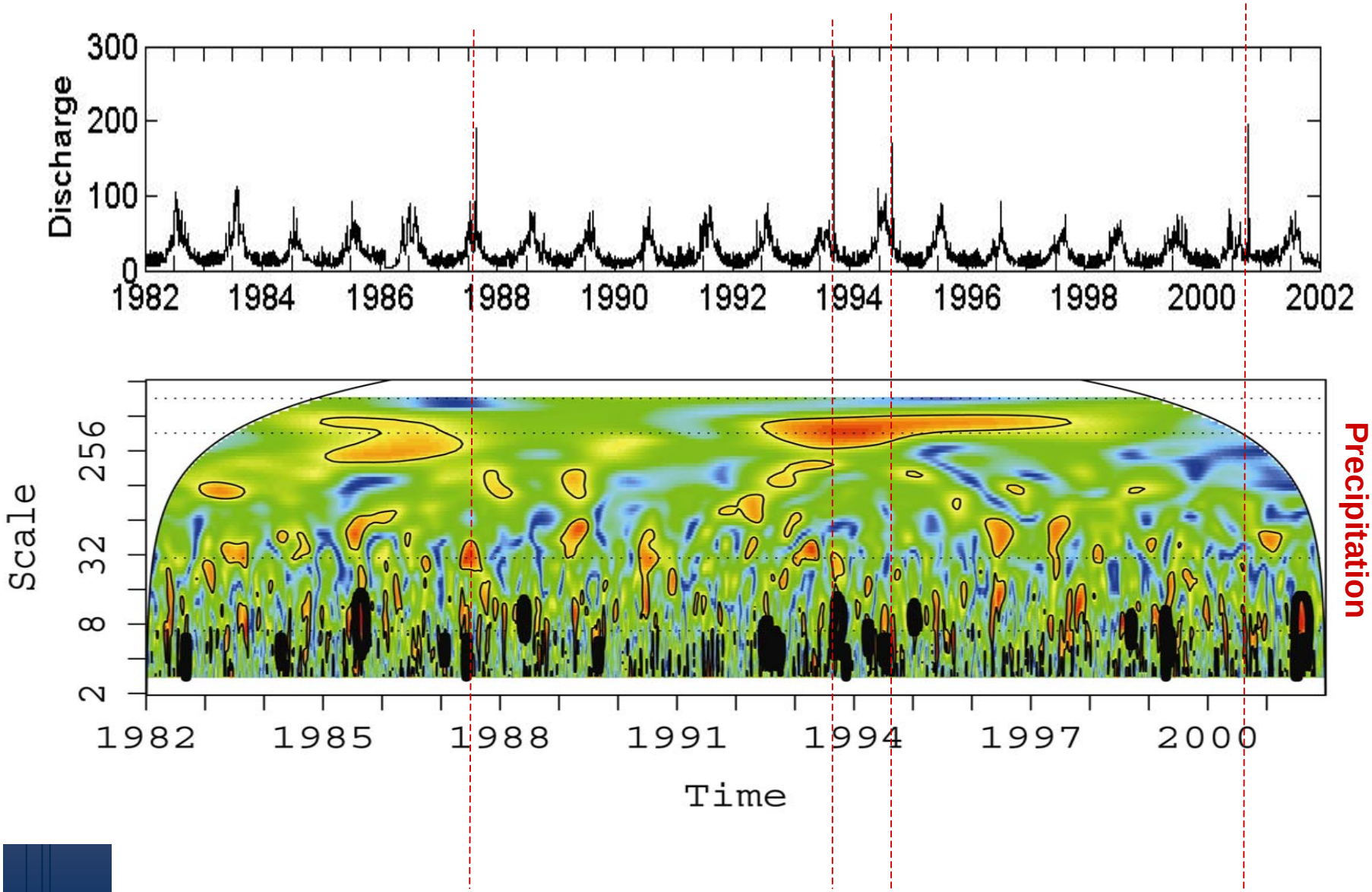
……

Potentially flood producing situations

… in spring and autumn!

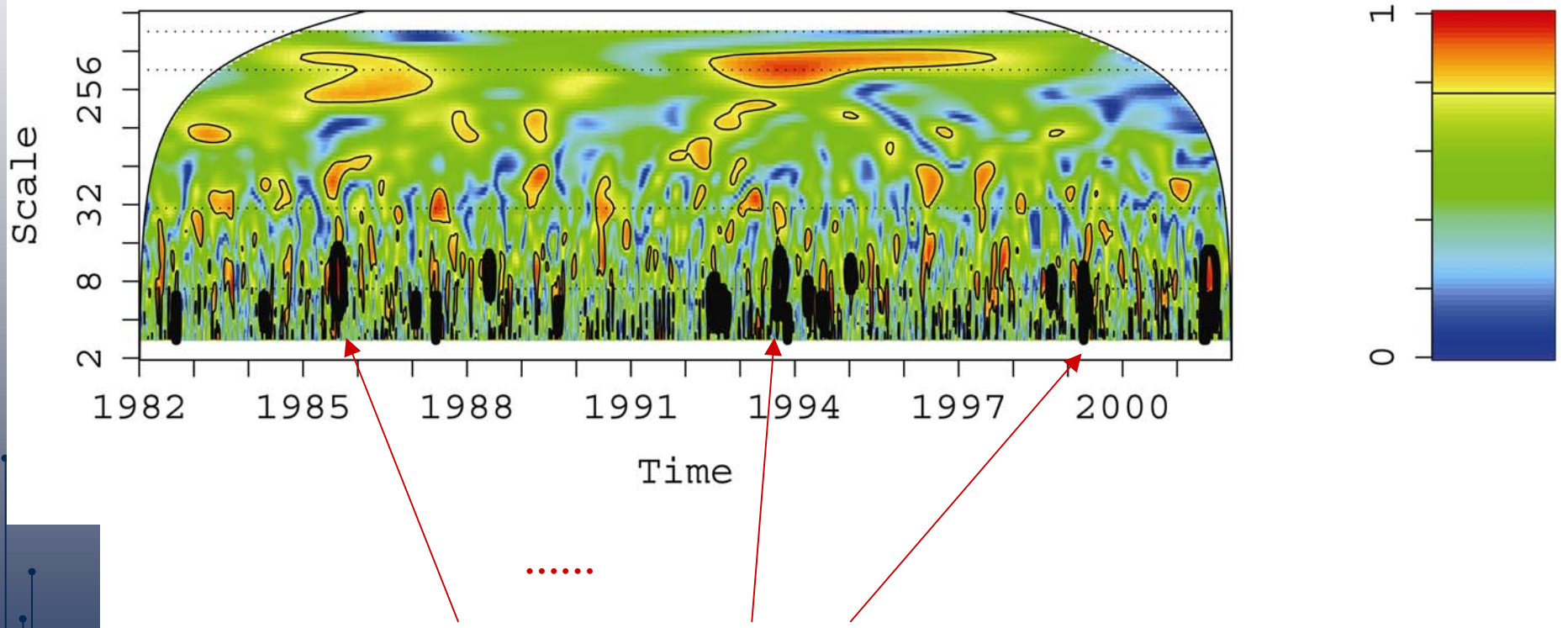
Connection to high flows

4 major high flow events



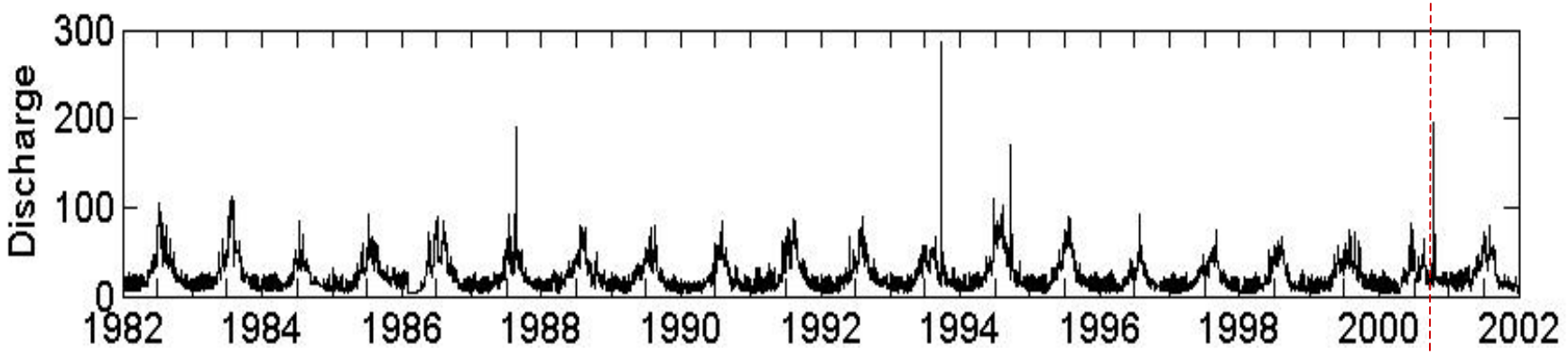
Results

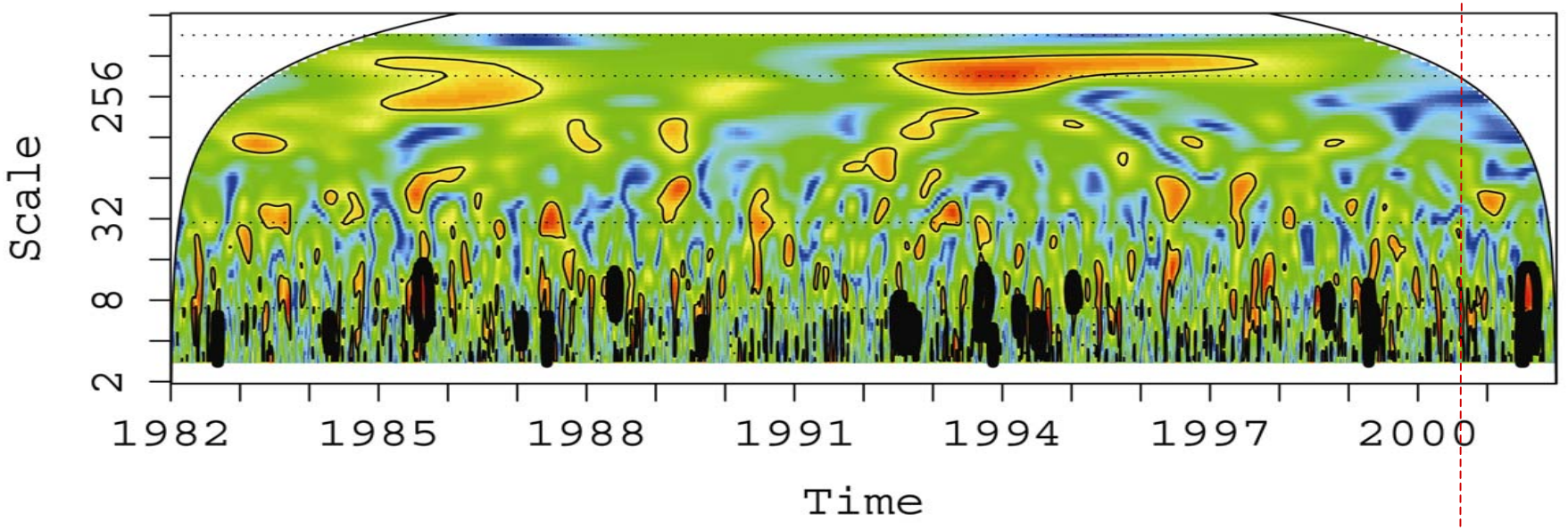
- **Model performance for all potentially flood producing situations? ⇨ ~ 15 events**



Results

Extreme flood 2000 ?

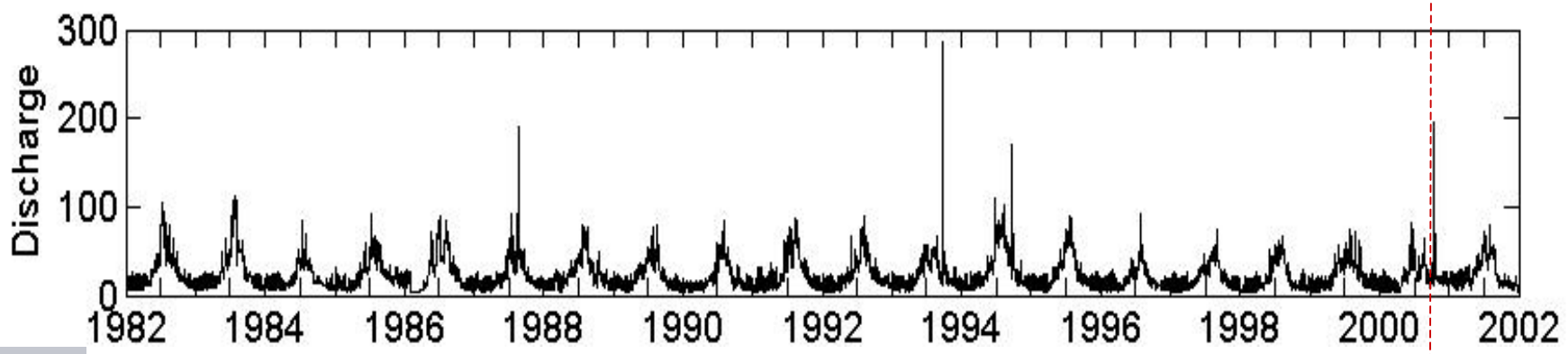


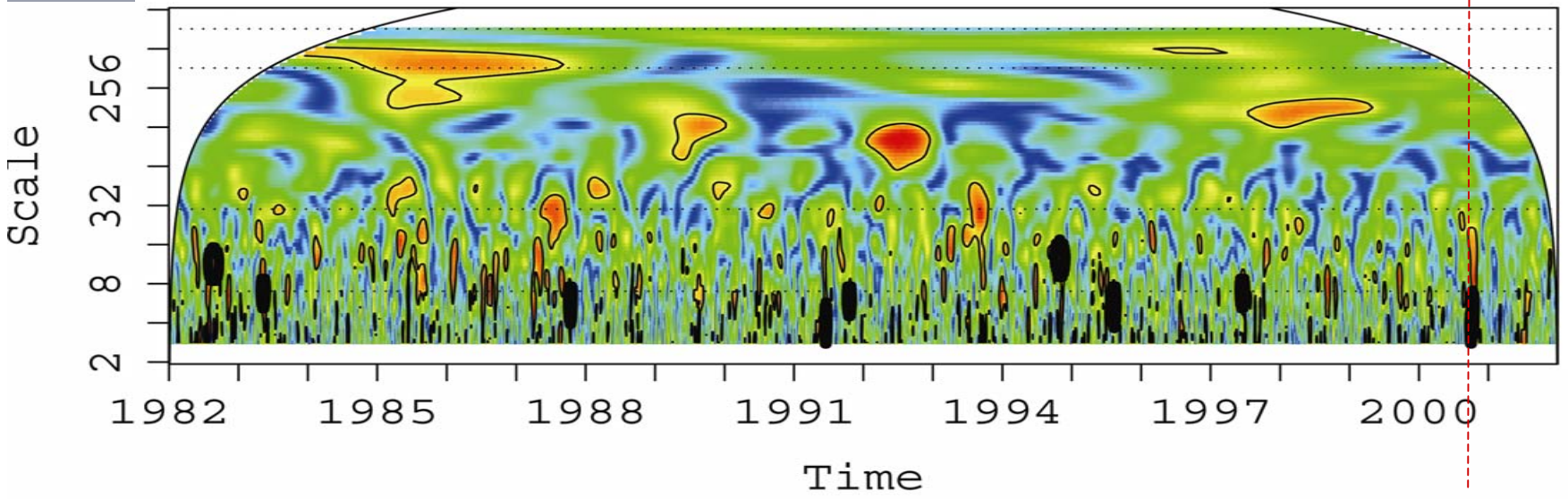


Temperature - Precipitation

Results

Extreme flood 2000 ?





Discharge - precipitation

Results

- **Coherence between precipitation & temperature**
  - ⇨ **Strong power on small scales (spring and autumn)**
  - ⇨ **Signature of climate in this region**

- **Situations with significant coherence of precip. & temperature**
  - ⇨ **high flows (not necessarily exceptional)**

- **Model development**
  - ⇨ **Concentrate on these situations**
  - ⇨ **Does meteo generator yield reasonable co-oscillation?**

Conclusion & Outlook

- **Analysis and simulation of extreme events**
  - ⇨ **Look at *potentially* flood producing meteorological situations**
  - ⇨ **Assess model performance for these situations**
- **Wavelet spectral analysis ….**
  - ⇨ **Time and scale resolved analysis**
  - ⇨ **But: due to correlations difficult to interpret**

Conclusion & Outlook

- **Drawn conclusions**

  = knowledge about physical processes

  x

  statistically rigorous wavelet analysis

- Reference: Schaefli, Holschneider, Maraun, 2007: What drives high flow events in the Swiss Alps? A review of wavelet spectral analysis with an application to hydrology

  ⇨ Submitted to Adv. in Water Resources