FR CNRS 3730

Large-scale ocean-atmosphere driving of decadal-scale precipitation and groundwater level variations with implication for groundwater drought occurrence

N. Massei, M. Fournier, B. Dieppois, K. P. Chun, Q. He, M. Fossa, C. Lattelais and J. P. Dupont

The authors thank the Seine-Normandy Water Agency for financial support

Background and objectives

Rationale

- Understanding the climatic determinism of water resources variability on long time-scales is crucial under climate change
- Hydrological processes oscillate over a range of short- to long-term scales according to ocean-atmosphere system variability
- Many studies in the past decade investigated low-frequency hydrological variability (e.g. inter-annual to decadal) and used circulation indices to identify climate drivers of hydrology
- More consistent climate drivers can be derived directly from hydrological variables using either correlation or composite maps of selected large-scale climate fields
- However the climate drivers of hydrology may not be similar across time-scales, i.e. interannual hydrological variability can be linked to some different large-scale pattern than decadal variability, for instance

Background and objectives

Aims

- Using long-term (> 100 years) time series to characterize the low-frequency (i.e. interannual to decadal) variability of precipitation and ground water level variations

- Getting further insights into the climate determinism of low-frequency hydrological variations: analysing and discussing potential large-scale relationships and forcings on hydrological systems including extremes and more particularly hydrological droughts

Data

Hydrological data

- Precipitation: obtained from the gridded Climatic Research Unit (CRU) Time-series (TS) data version 4.02 (CRU TS V4.02), over 2.0E-3.5E / 49.5N-50.5N

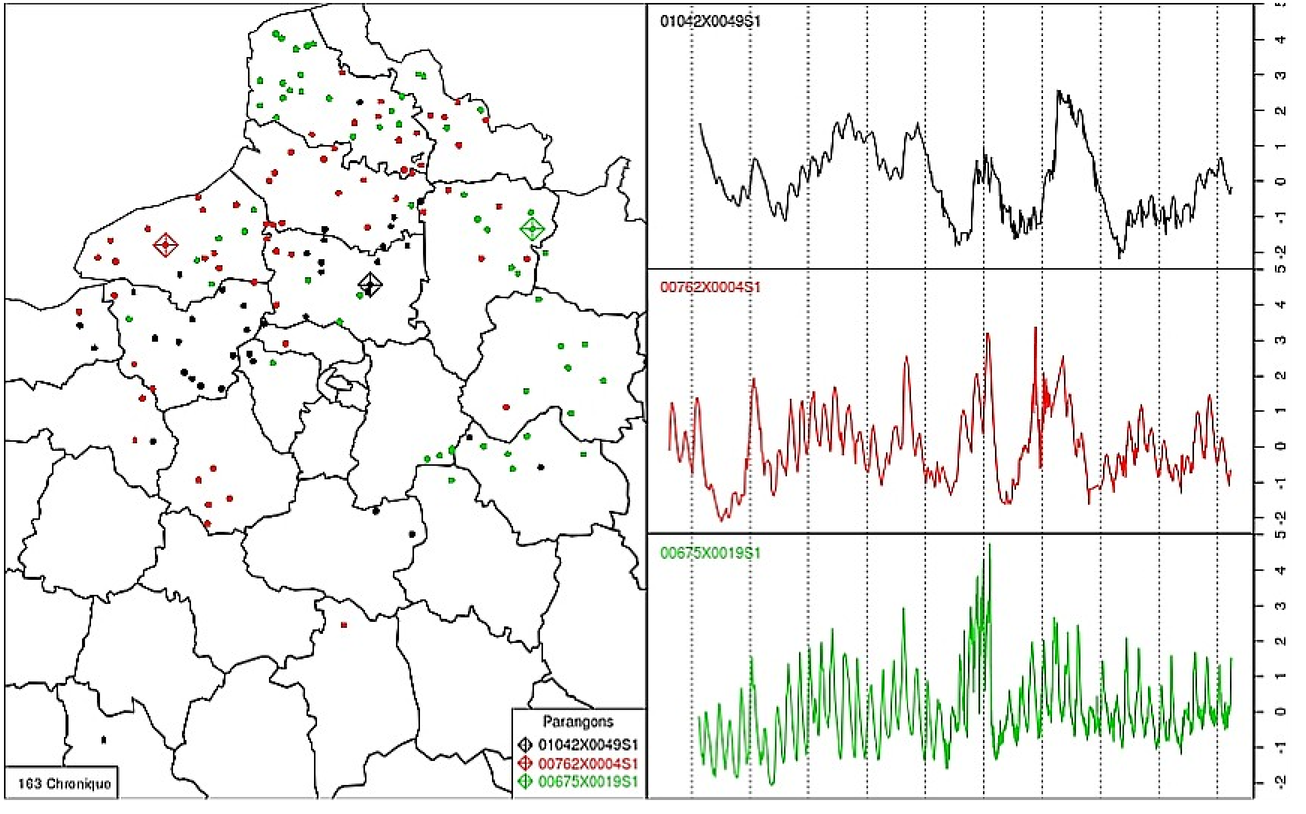
- Chalk aquifer ground water level in the Paris Basin: obtained from the National Groundwater Database (ADES), available at https://ades.eaufrance.fr/

- Time period: Jan 1, 1901 to Dec 31, 2012

- Monthly time-step

Data

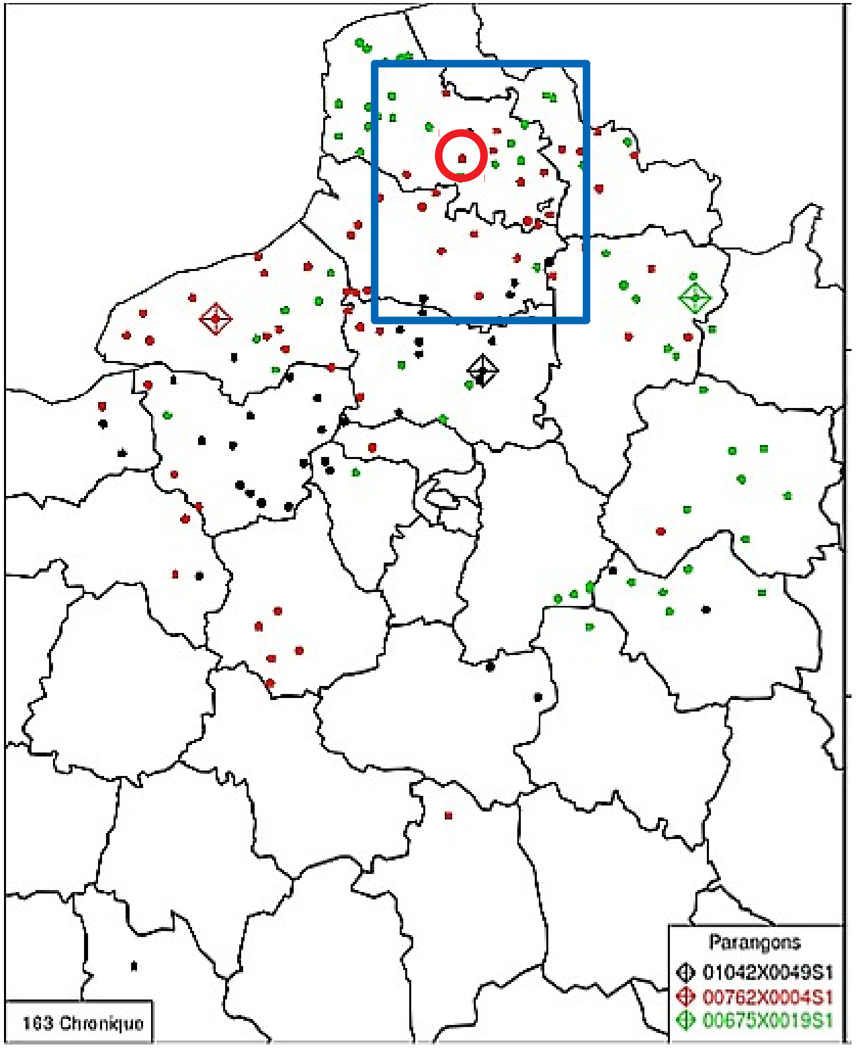
Hydrological data: regional context



163 GW level time series: low-frequency variability detectable in all time series (spatial differences owing to modulation by basin properties)

Data

Hydrological data: selected long-term time series

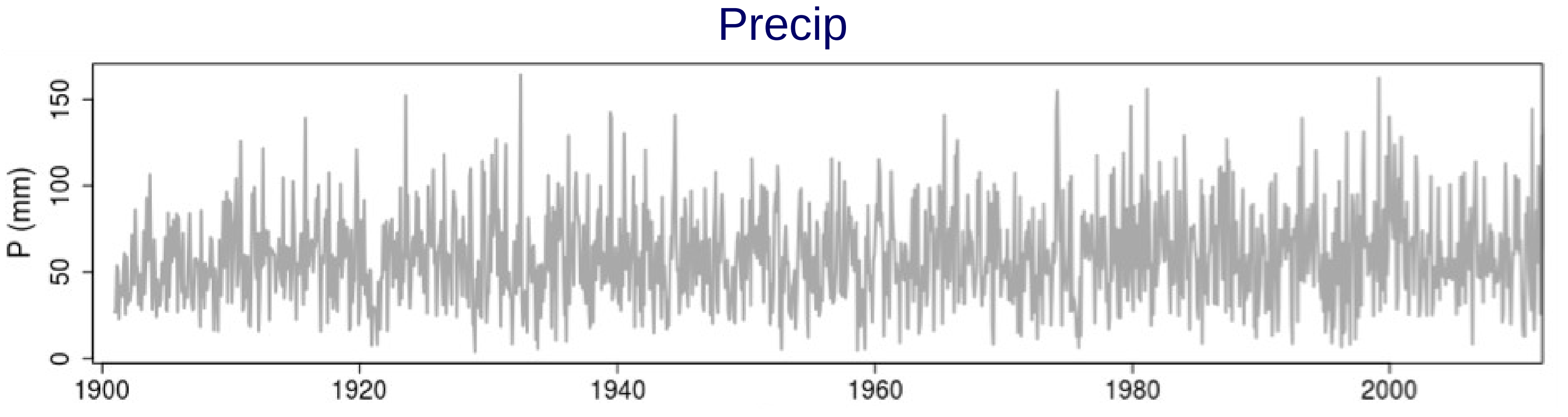


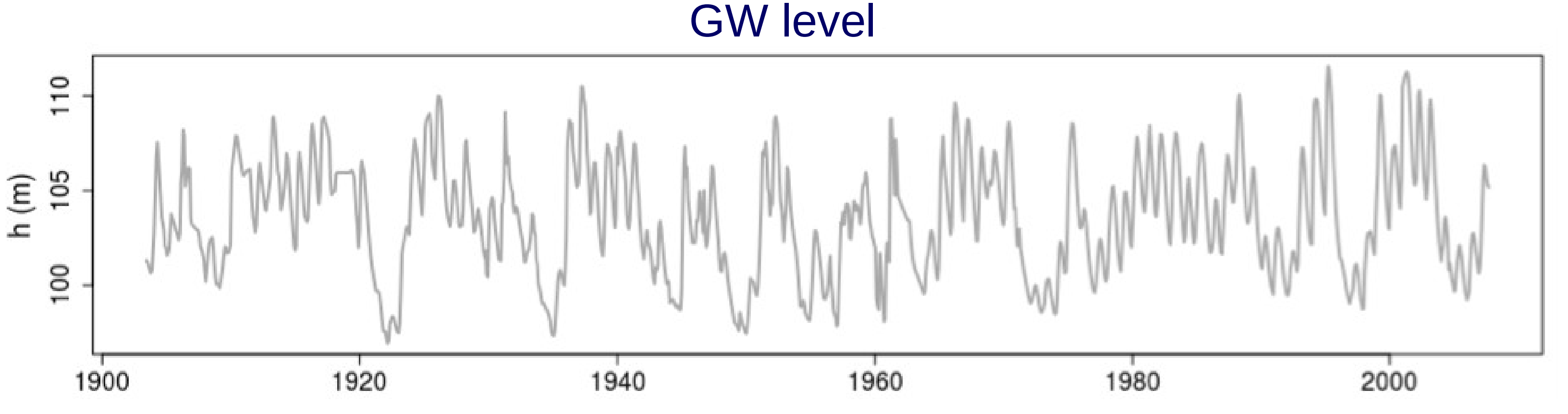
: Precip area

: GW level

Data

Hydrological data: selected long-term time series





Data

Large-scale climate data

- SLP and z200 fields: NOAA 20CR reanalysis over -110E - 60E / 15N – 90N

  SLP → near-surface atmospheric circulation

  200 mb geopotential height field z200 → jet-stream circulation near tropopause

- AMO index: multidecadal oceanic variability, NOAA/NCDC based on ERSSTv5
- Time period: Jan 1, 1901 to Dec 31, 2012
- Monthly time-step

Methodological approach

Time series analysis in the spectral/wavelet domain

- Continuous wavelet transform (CWT): identification of time-dependent spectral content

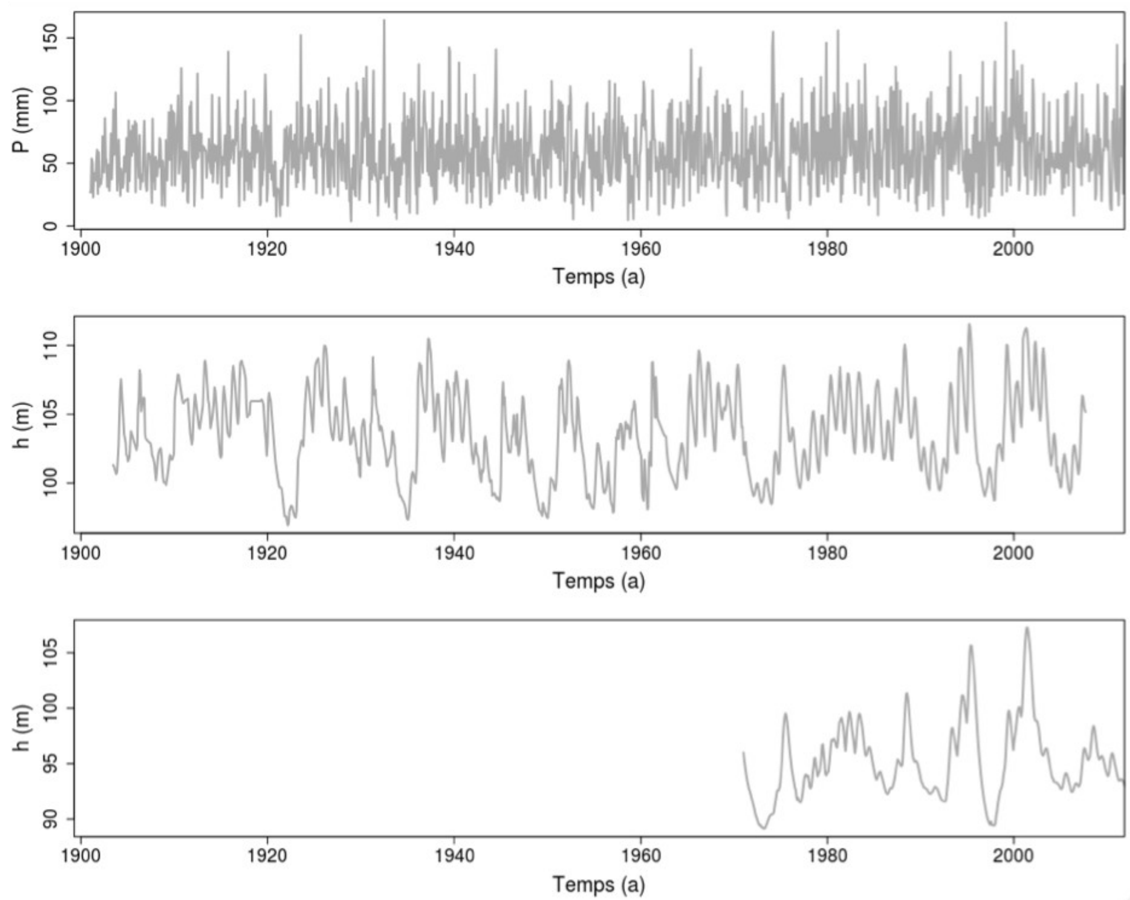
- Multiresolution analysis and synthesis by maximum overlap discrete wavelet transform (MODWT): extraction of the spectral components (wavelet details) of hydrological and large-scale field time series.

  - !! Max Overlap DWT ensures more physically meaningful wavelet details (as phase alignment is preserved between DWT coefficients for a given scale and variance of this time-scale in the time series)

- Oscillating components extracted by MODWT in both hydrological data and large-scale fields: SLP or z200 composite maps are generated from precipitation data for all identified time-scales of interest

Low-freq precipitation and ground water level variations

Characteristics of spectral content and remarkable time-scales



Precip

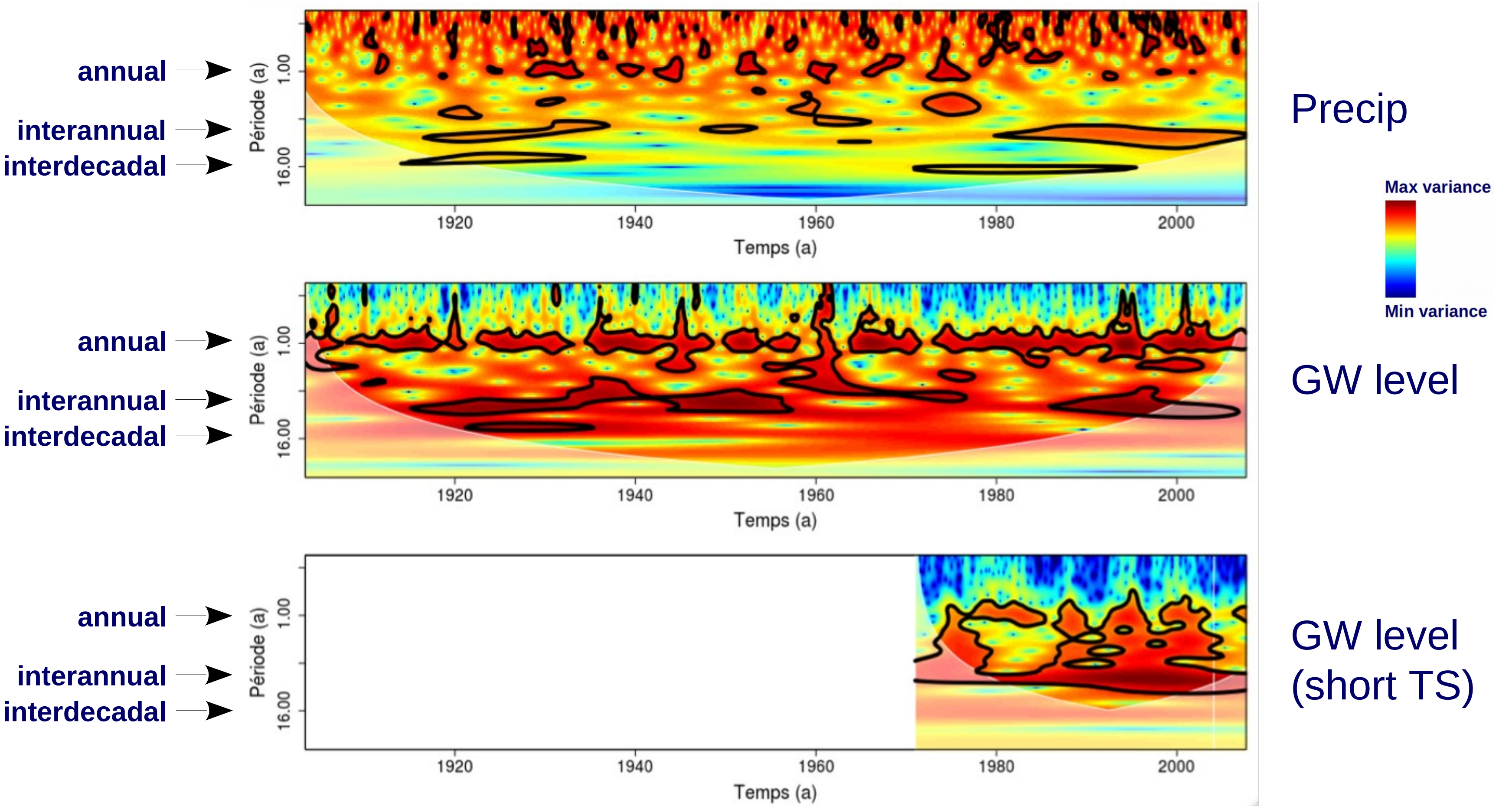
GW level

GW level (short TS)

- Hydrological time series

Low-freq precipitation and ground water level variations

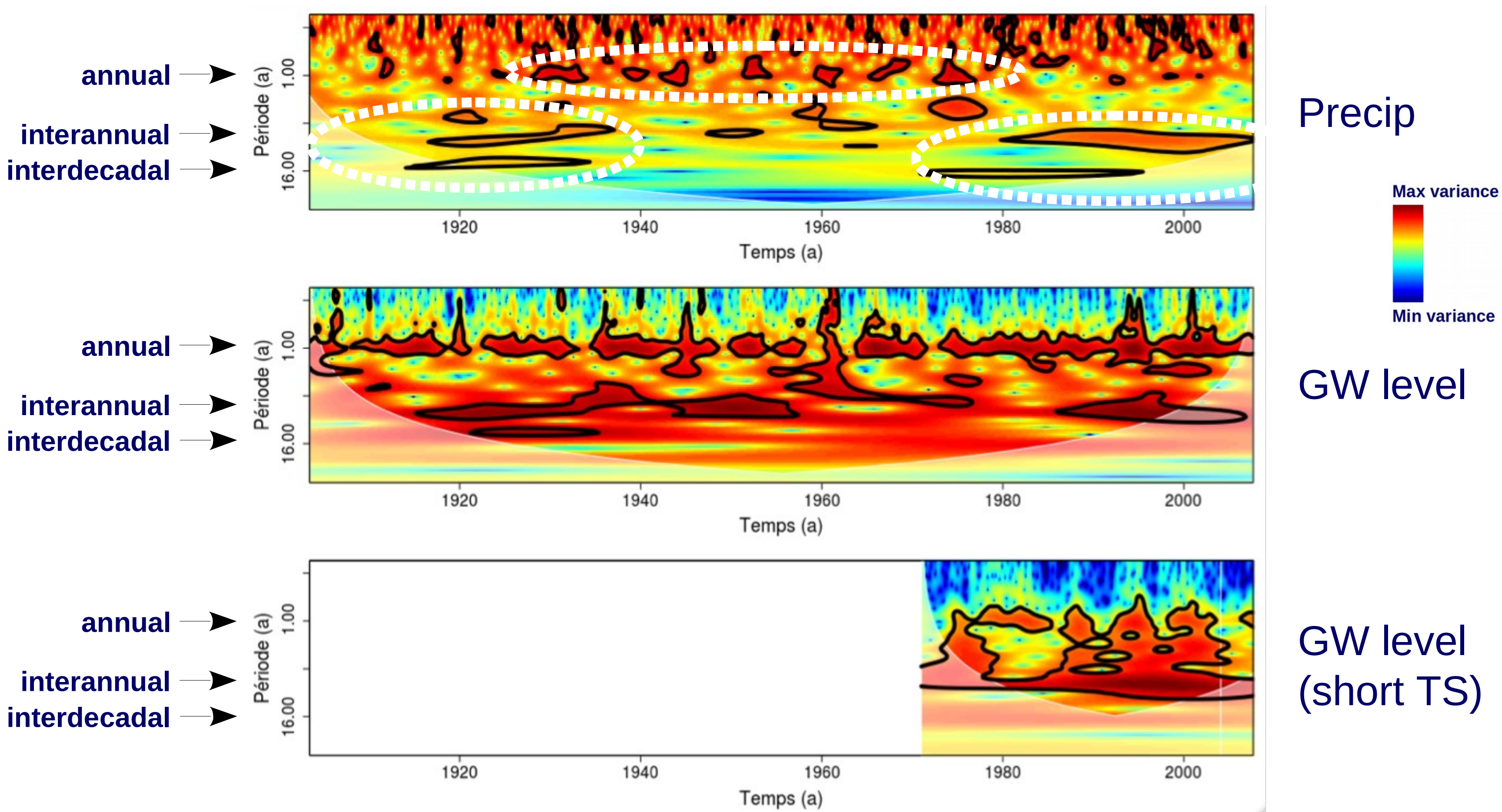
Characteristics of spectral content and remarkable time-scales



- Detection of annual and low-freq (interannual 4-12yr), interdecal 12-23yr) variability on CWT spectra

Low-freq precipitation and ground water level variations

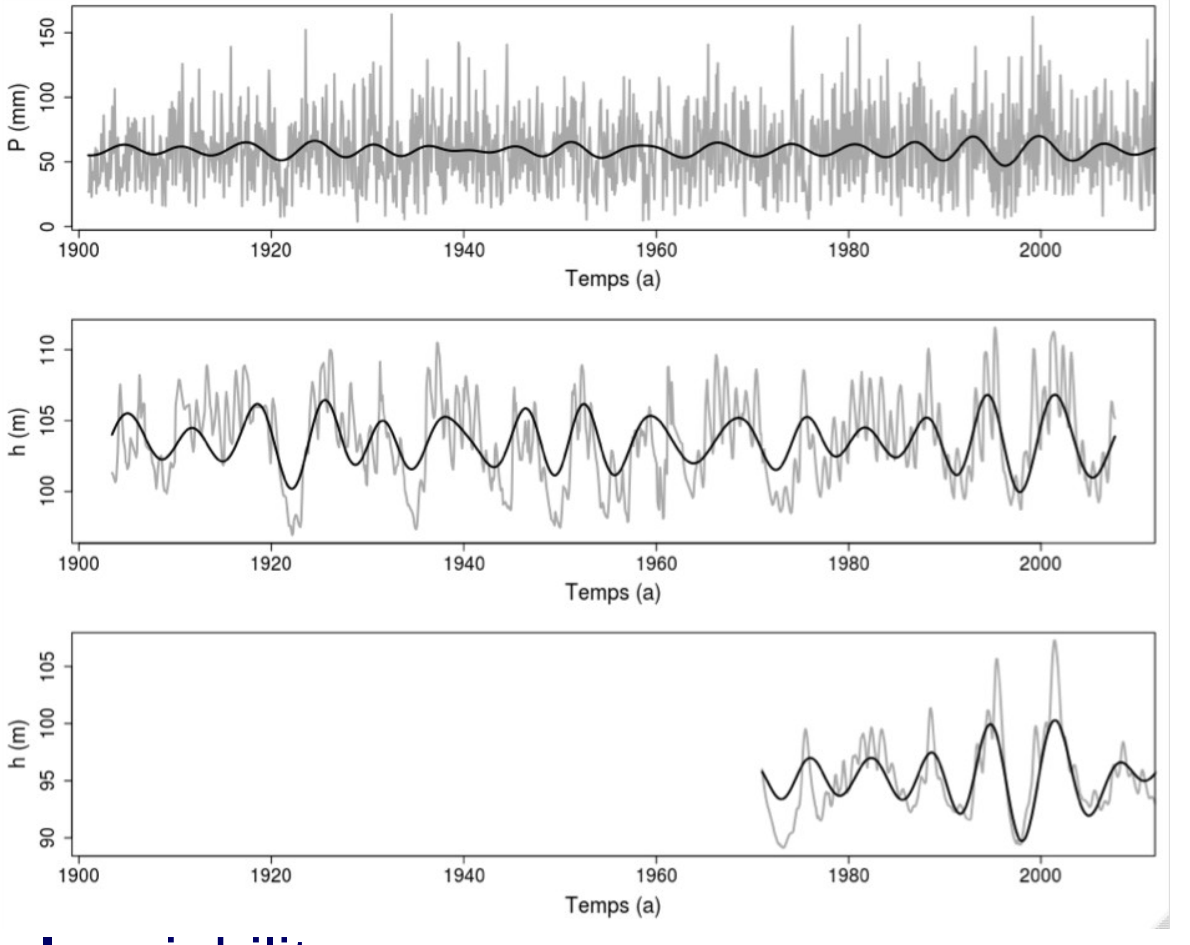
Characteristics of spectral content and remarkable time-scales



- Remark: in precip particularly, higher variance of annual component when variance of low-freq component is low

Low-freq precipitation and ground water level variations

MODWT filtering of low-freq components



Precip

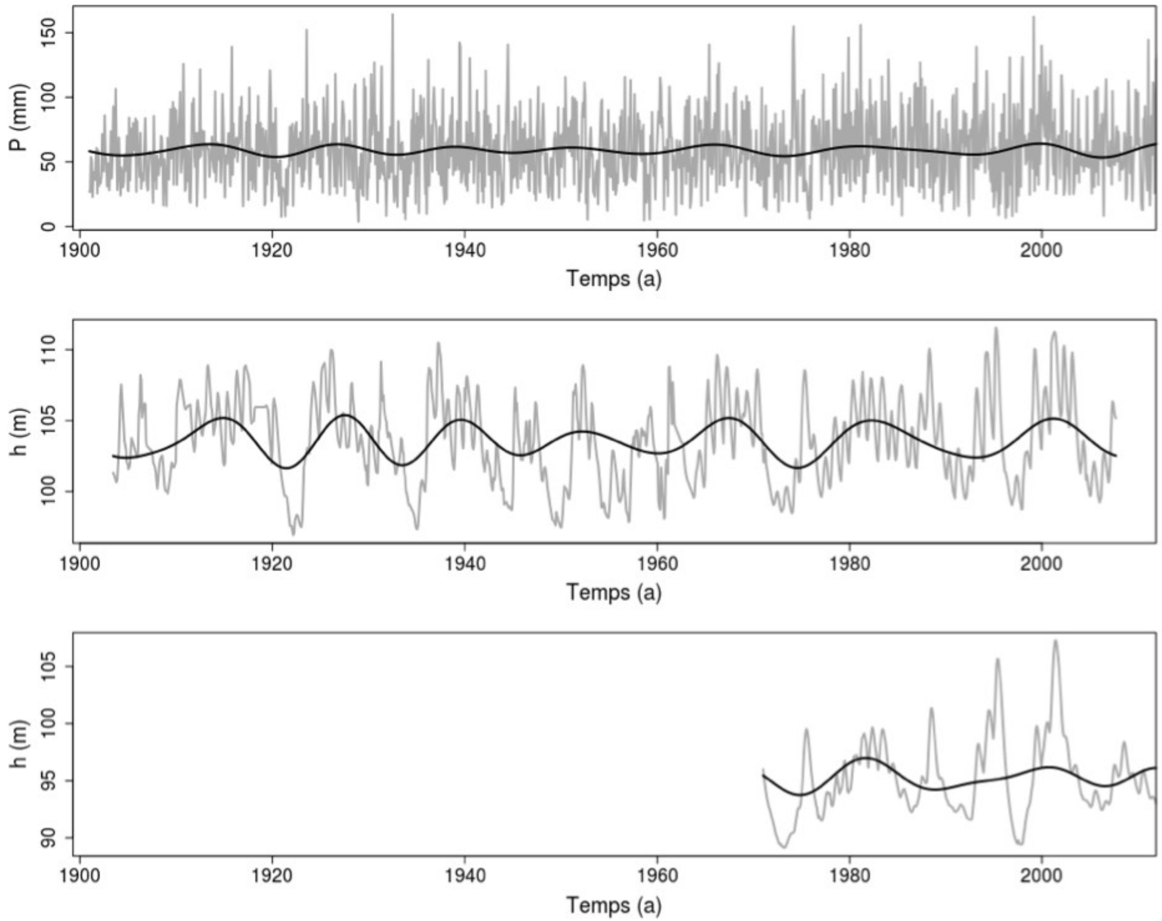
GW level

GW level (short TS)

- **Interannual** variability

Low-freq precipitation and ground water level variations

MODWT filtering of low-freq components



Precip

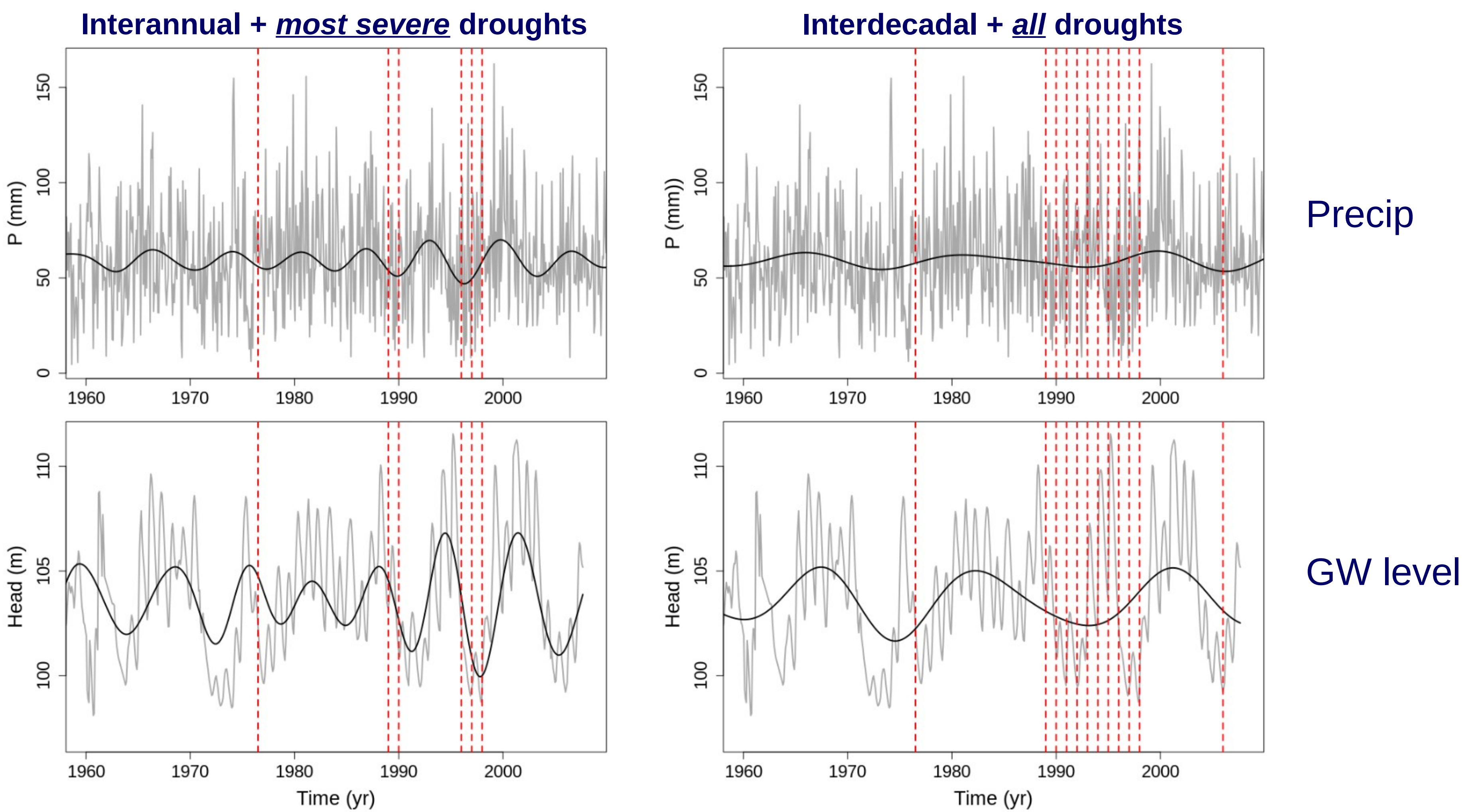
GW level

GW level
(short TS)

- **Interdecadal** variability

Low-freq precipitation and ground water level variations

Low-frequency variations and the occurrence of droughts

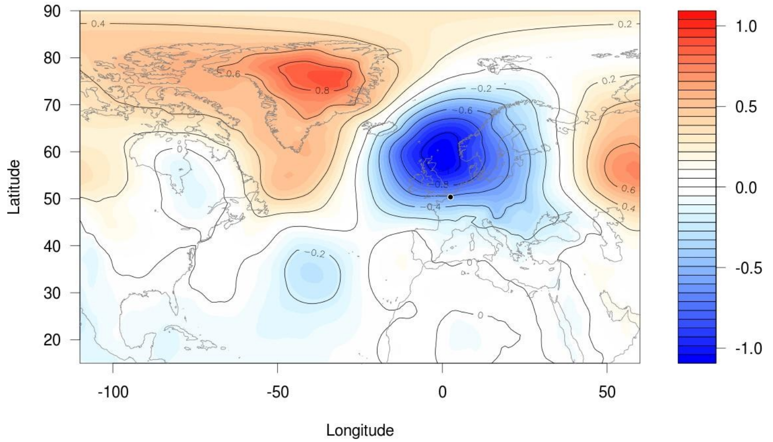


- Droughts (French natural disaster "CatNat" database) controlled by low-freq

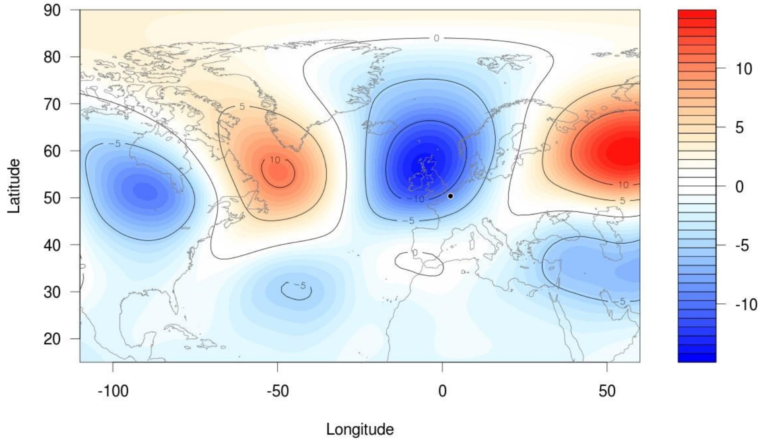
Large-scale climate drivers of low-freq variability

SLP / z200 *interannual* patterns for hydrological variability

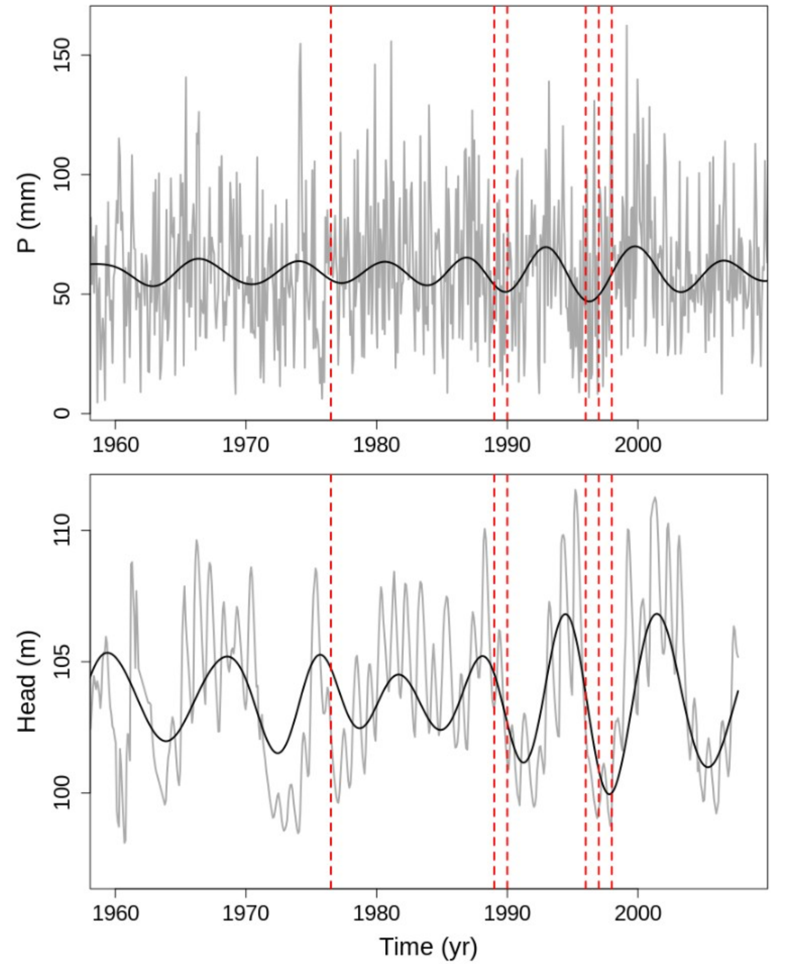
Interannual SLP composite



Interannual z200 composite



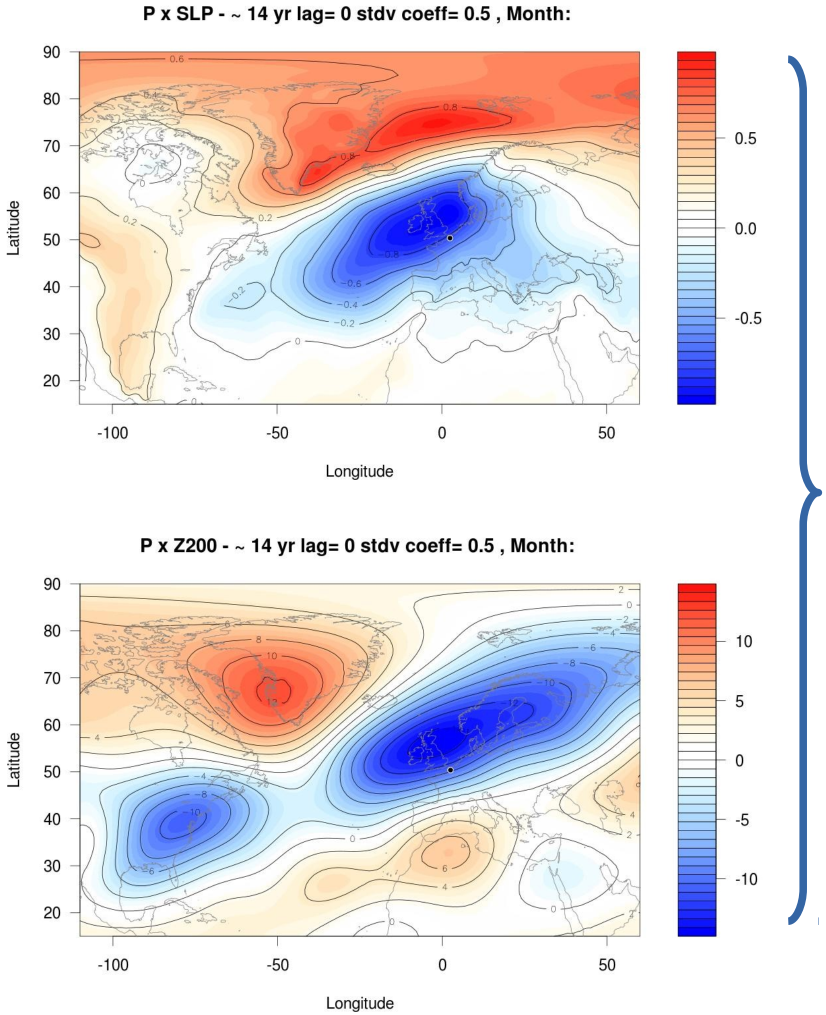
Interannual + *most severe* droughts



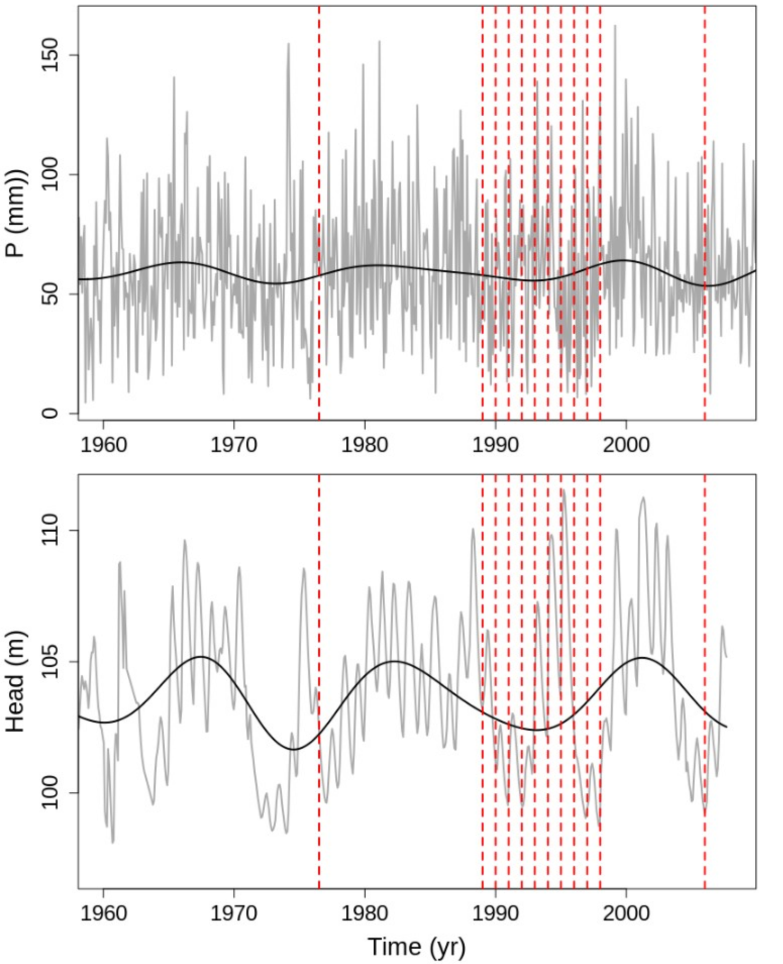
- SLP ~ meridional circulation instead of zonal, z200 ~ Rossby wave patterns

Large-scale climate drivers of low-freq variability

SLP / z200 *interdecadal* patterns for hydrological variability



Interdecadal + *all* droughts



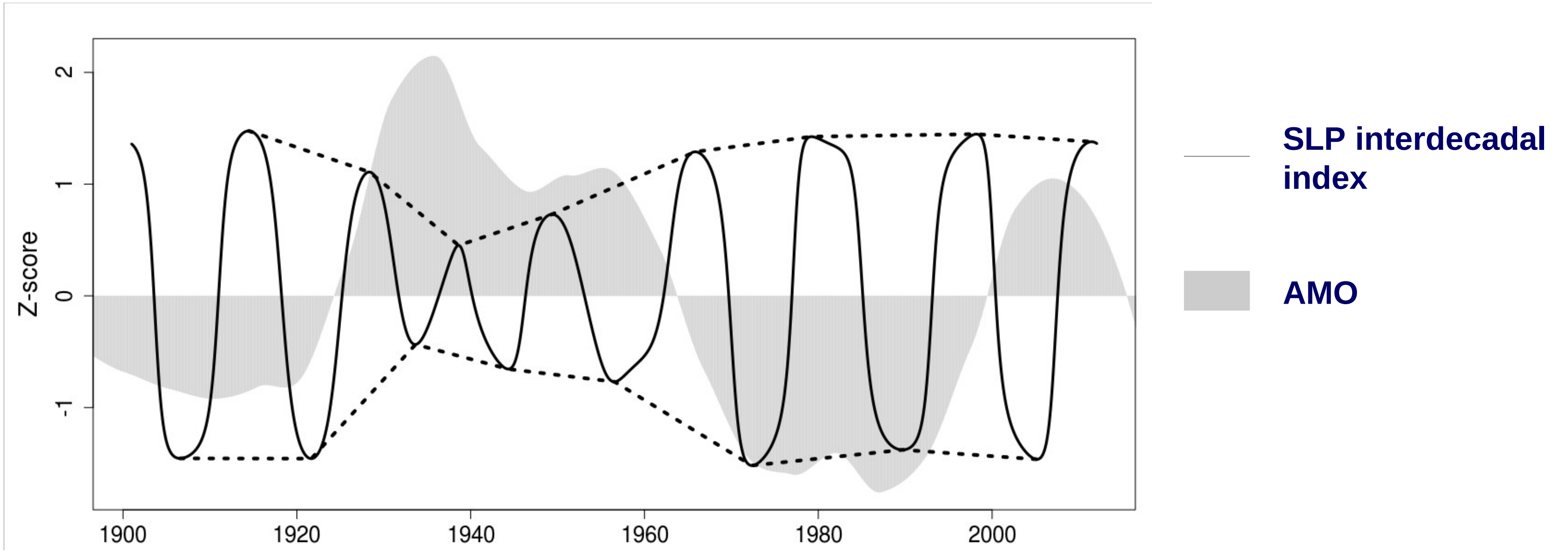
- SLP centers of action, z200 extending across the Atlantic ~ zonal circulation

Large-scale climate drivers of low-freq variability

A possible role of AMO on modulating interdecadal hydrological variability?

- Interdecadal SLP composite extending across the North-Atlantic

- An index was derived from the interdecadal SLP pattern and compared to AMO



- AMO might be involved into modulation of the interdecadal variability of precipitation and ground water level: **positive (resp. negative) AMO seems associated to low (resp. high) interdecadal variability**

In a nutshell

- Long-term behavior of ground water / hydrological droughts controlled by large-scale climate variability

- Improvement of drought prediction possible thanks to identification of climate drivers **but not** from hydrological signals alone: low-freq variations not periodic

- Results raise hypotheses about physical mechanisms to be tested:

  1. High-amplitude jet-stream oscillations responsible for the most severe droughts linked to interannual variability (cf. quasi-resonant amplification mechanism, e.g. Mann et al, 2018?)?

  2. More direct impact of Atlantic dynamics on occurrence of less severe droughts?

  3. Would AMO phases involve temporal changes in decadal-scale hydrological variability? What mechanism involved?

  4. What would be the impact of a possible AMOC slow-down (Rahmstorf et al, 2015): → on interannual/decadal variability of the Gulf Stream front, which controls atmospheric circulation on these time-scales (Feliks et al, 2010), and then hydrological variability?

Many thanks!

Large-scale oceanic/atmospheric forcing of decadal-scale precipitation and groundwater level variations, with implication for groundwater drought occurrence

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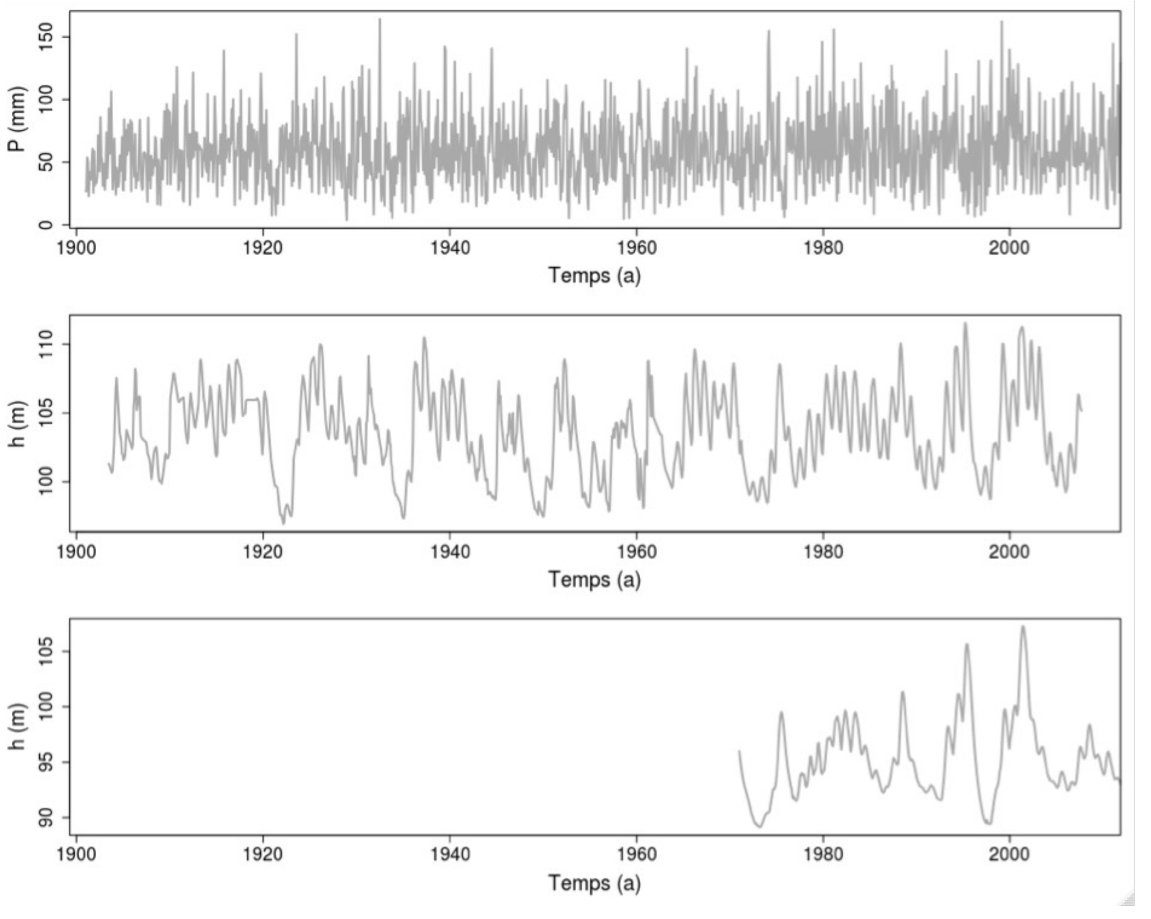
Hydrological data



Precip

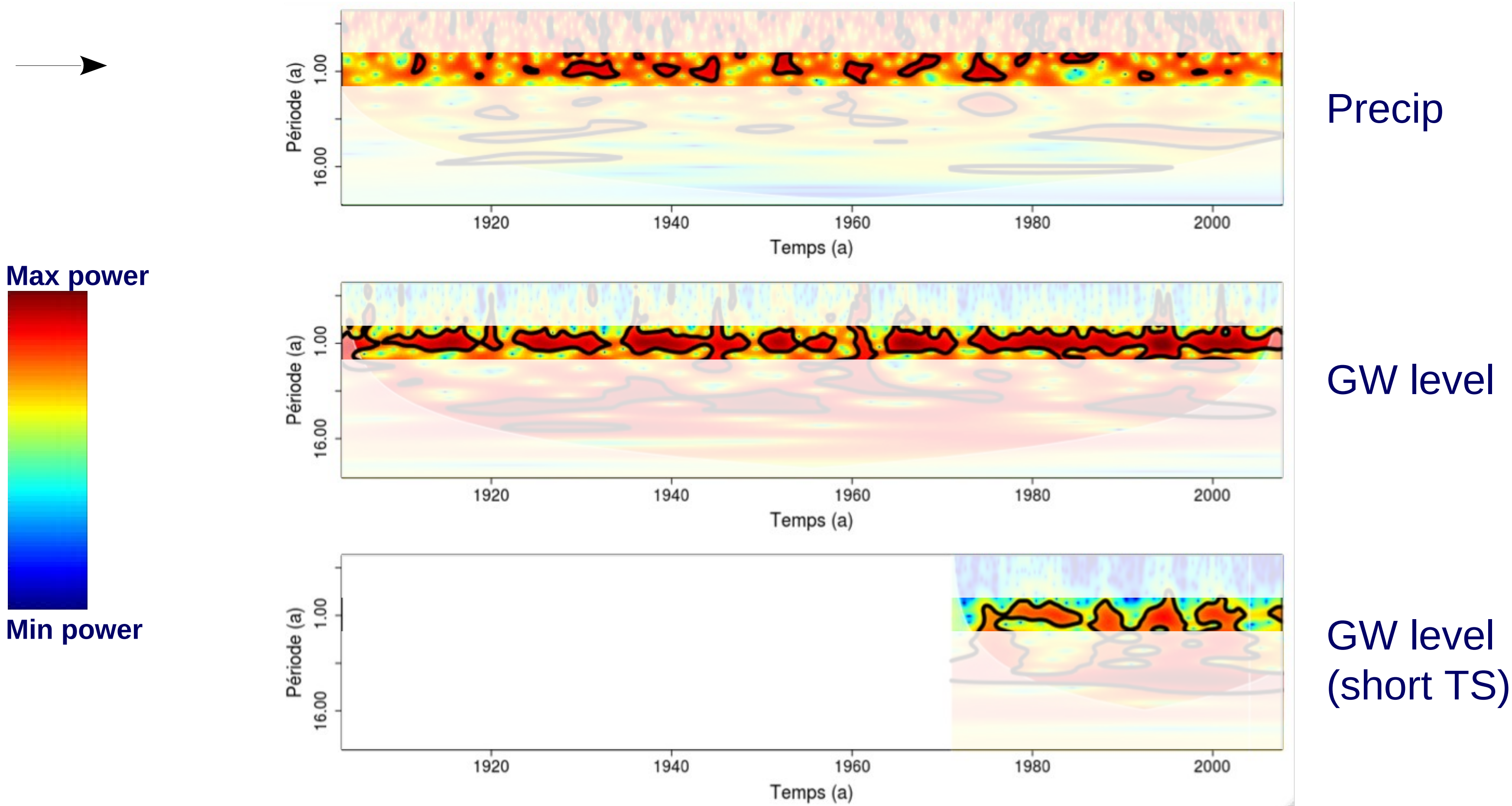
GW level

GW level (short TS)

The long-term time series are suitable for investigating low-frequency behavior

Low-freq precipitation and ground water level variations

Characteristics of spectral content and remarkable time-scales

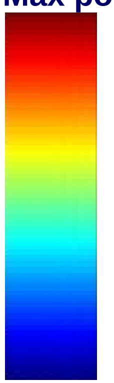


- zg

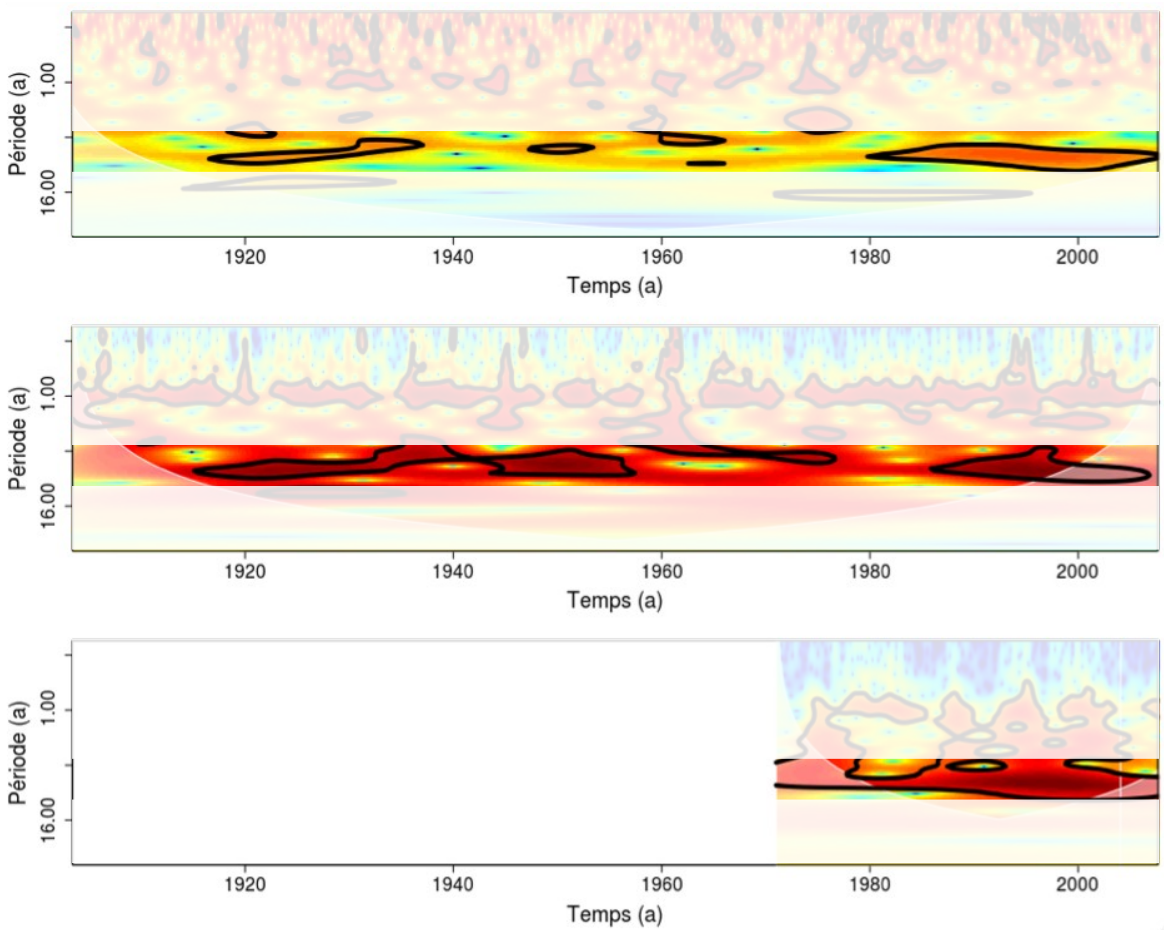
Low-freq precipitation and ground water level variations

Characteristics of spectral content and remarkable time-scales

Max power



Min power



Precip

GW level

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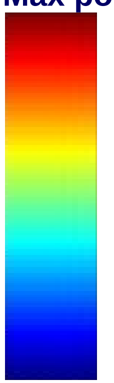
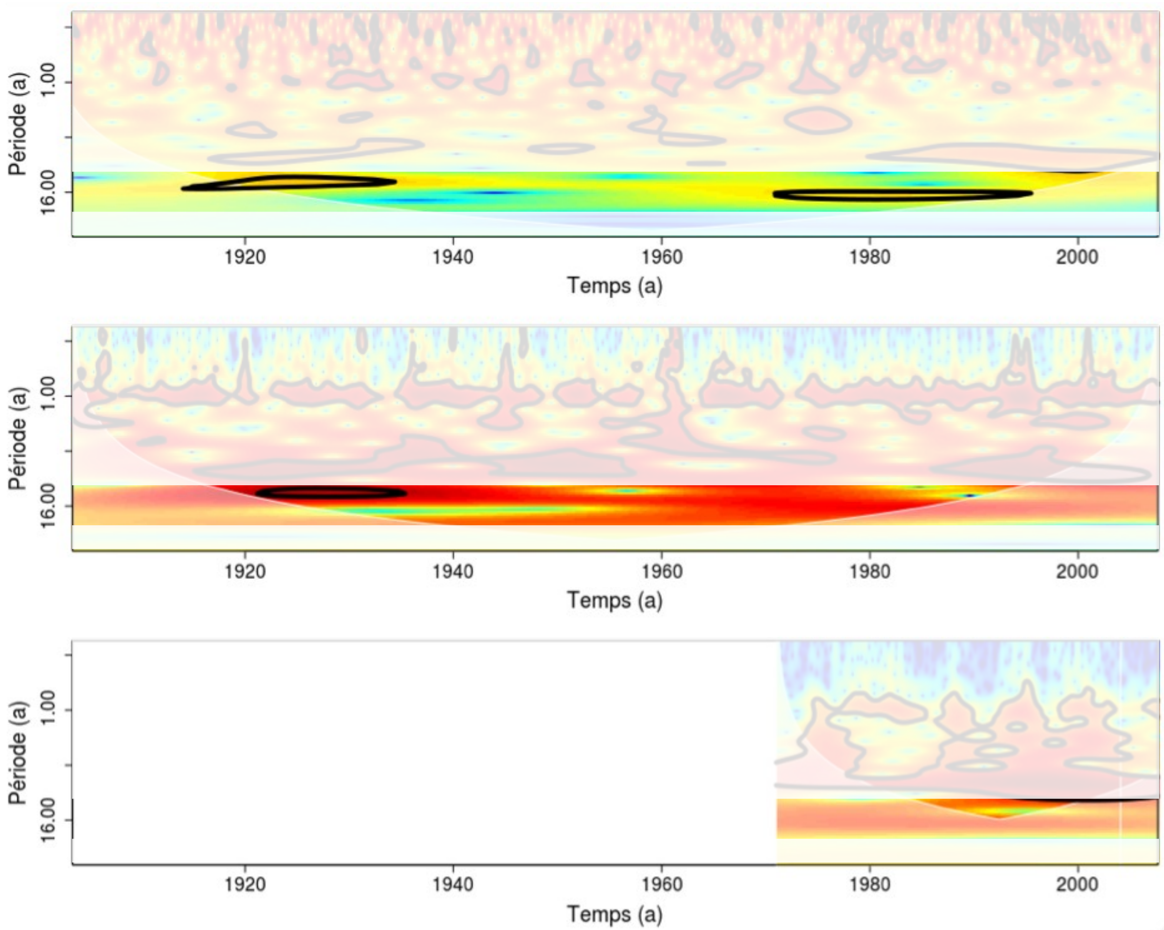
- zg

Low-freq precipitation and ground water level variations

Characteristics of spectral content and remarkable time-scales





Precip

GW level

GW level (short TS)

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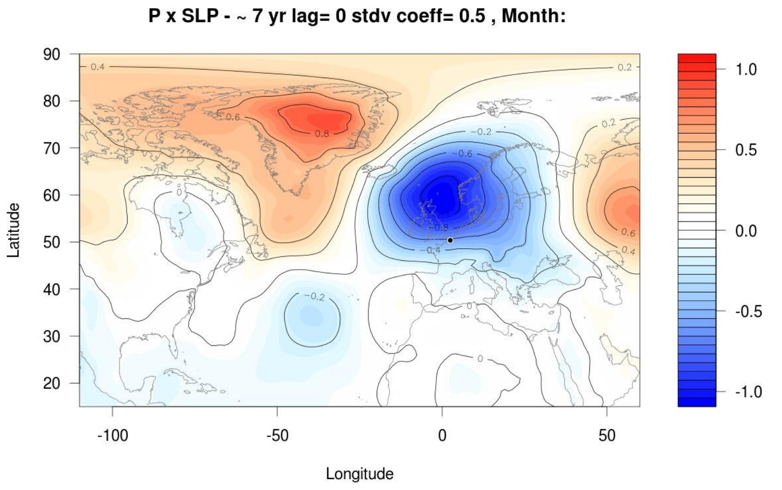
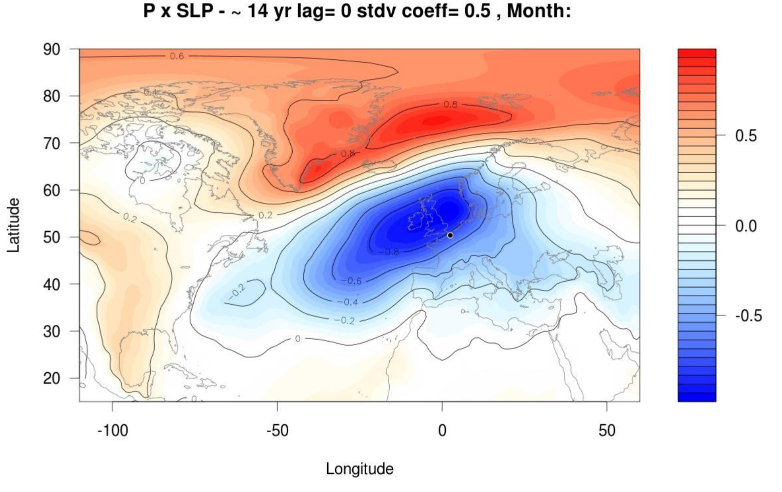
Large-scale climate drivers of low-freq variability

Low-freq SLP composites based on low-freq precip



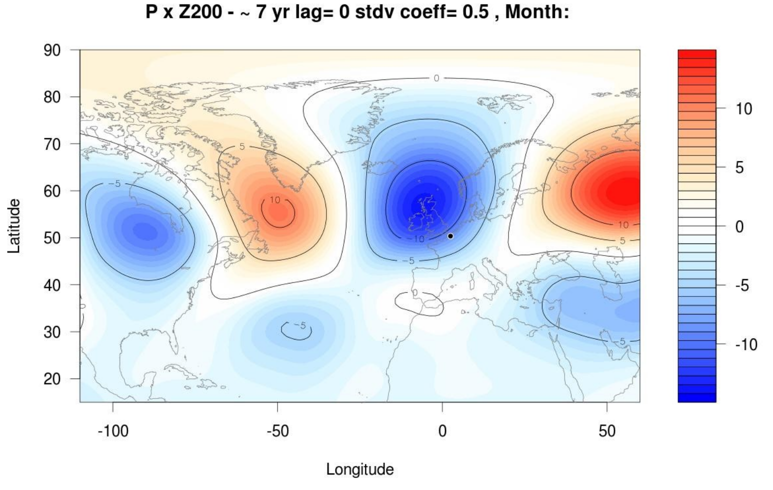
Interannual scale:
Location of SLP centers of action seem to favor meridional circulation instead of zonal



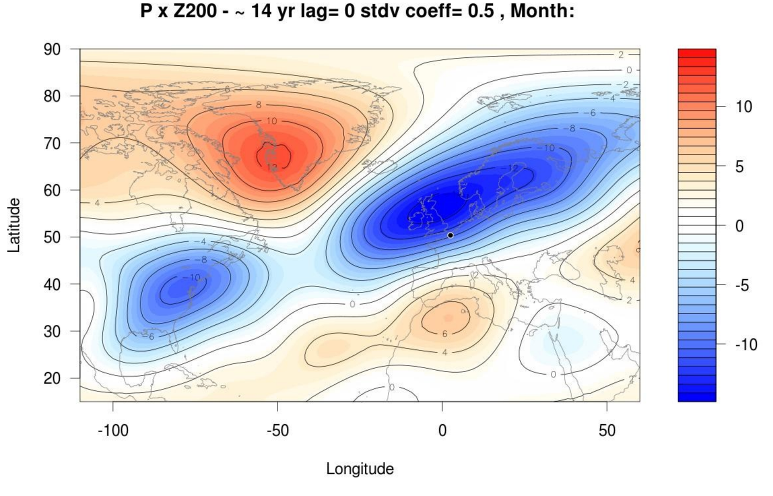
Interdecadal scale:
Centers of action extending across the Atlantic indicate preferentially zonal circulation

Large-scale climate drivers of low-freq variability

Low-freq z200 composites based on low-freq precip



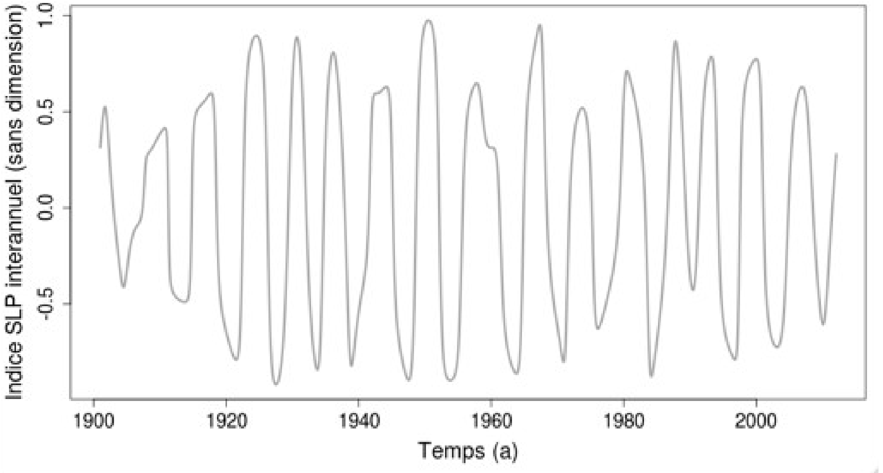
Interannual scale:
z200 field clearly indicates well-developed Rossby wave patterns

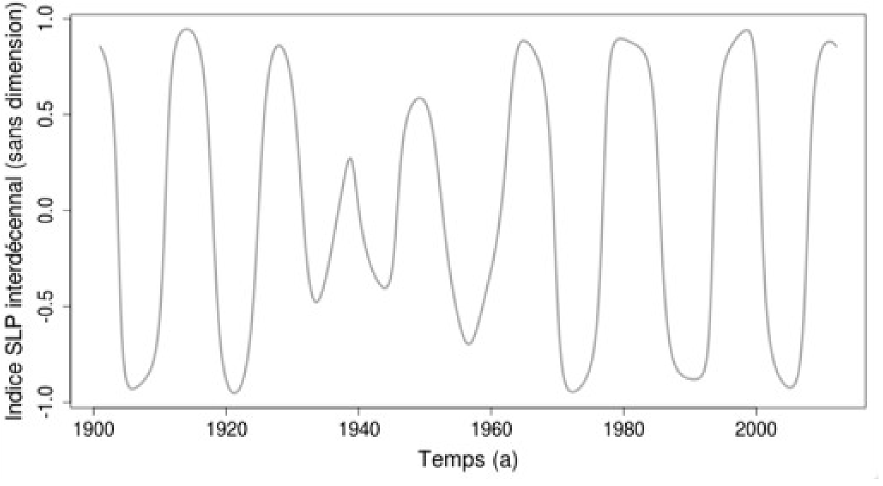


Interdecadal scale:
z200 field extents across the Atlantic and indicates preferentially zonal circulation

Large-/local-scale relationships across time-scales

z200 composites from low-freq precip variability





- Droughts (French natural disaster database) controlled by low-freq variations