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


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
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

Precip

GW level
**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

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), interdecadal 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

Interannual variability
Low-freq precipitation and ground water level variations

MODWT filtering of low-freq components

Interdecadal variability
Low-frequency variations and the occurrence of droughts

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

HS2.4.6 Understanding the links between hydrological variability and internal/natural climate variability - EGU General Assembly 2020
Large-scale climate drivers of low-freq variability

SLP / z200 *interannual* patterns for hydrological variability

- Interannual SLP composite
- Interannual z200 composite

- SLP ~ meridional circulation instead of zonal, z200 ~ Rossby wave patterns
SLP / $z_{200}$ interdecadal patterns for hydrological variability

- SLP centers of action, $z_{200}$ 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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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

Precip

GW level

GW level (short TS)

zg
Low-freq precipitation and ground water level variations

Characteristics of spectral content and remarkable time-scales
Low-freq precipitation and ground water level variations

Characteristics of spectral content and remarkable time-scales
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