Downscaling climate models for Hydrology: Pitfalls and Needs ?

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Downscaling climate models for Hydrology: Pitfalls and Needs ?

Stating the obvious…

Climate models are devoted to reproduce climate
Impact models are devoted to reproduce a given impact, most often, already partly solved by the climate models, but, with more details/accuracy

Studying climate change with an impact model means to deals with:

- The bias/errors associated with the impact models

- The bias/errors associated with the climate projection

- The possible inconsistency between the climate & impact model hypotheses or results (for instance, in terms of water and energy balance, in a region were the impact model is energy limited, should water limited climate models should be avoided ?)

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Stating the obvious…

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Studying climate change with an impact model means to deals with:

- The bias/errors associated with the impact models

Such errors also depend on the present day atmospheric forcing used by the impact model…
Such errors are not always well-known, due to the density of the observed network…

- The bias/errors associated with the climate projection

Downscaling methods are used to erase/reduce such bias

- The possible inconsistency between the climate & impact model hypotheses or results (for instance, in terms of water and energy balance, in a region were the impact model is energy limited, should water limited climate models should be avoided ?)

What about the consistency with the downscaled climate models?

Downscaling climate models for Hydrology: Pitfalls and Needs ?

1. Characteristics of the hydrological studies
2. A bit of history
3. How to improve the downscale climate restitution
4. Examples of limitation with hydrogeological impact models

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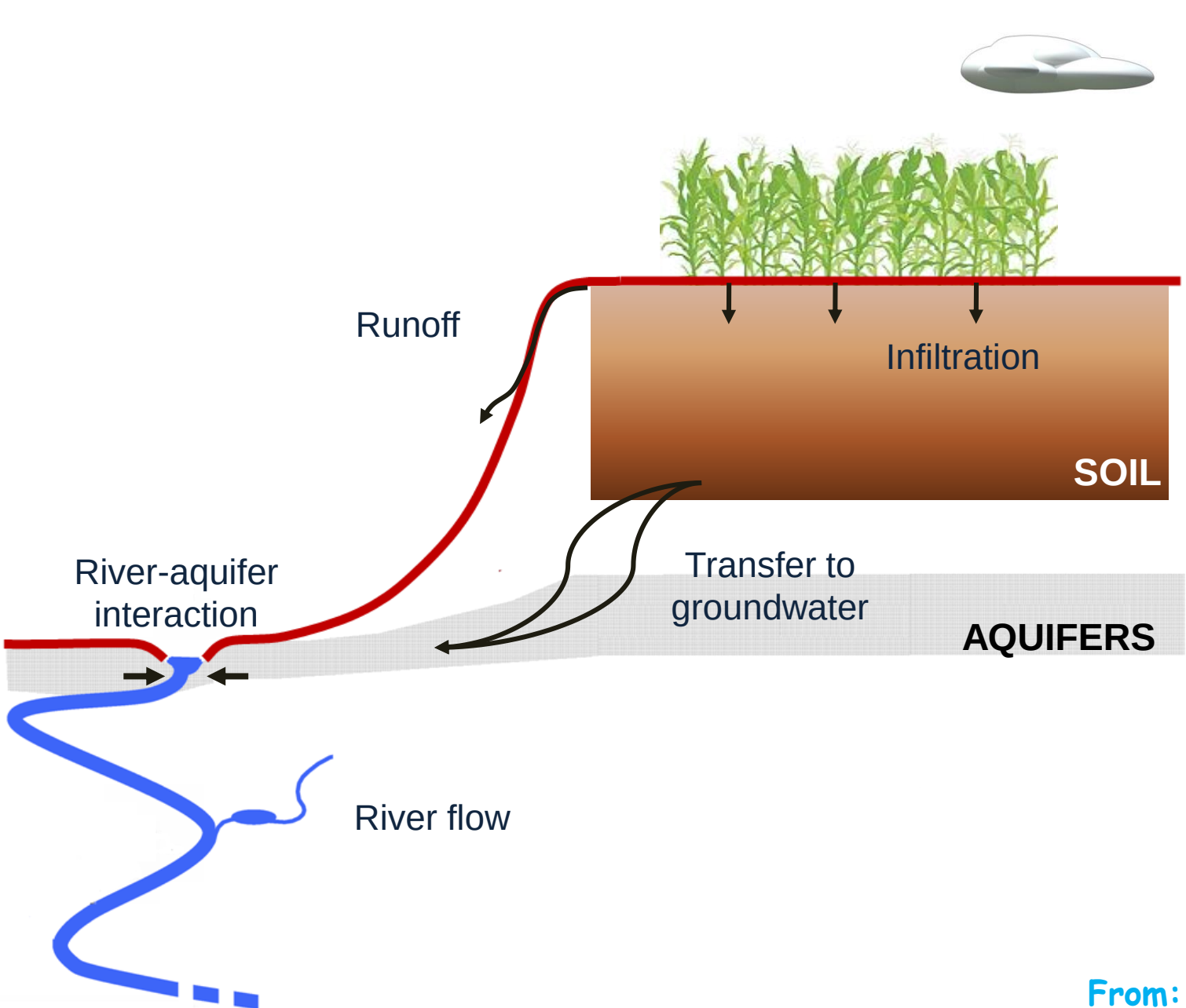
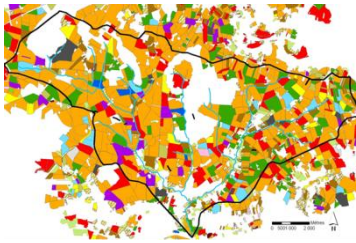
1. Characteristics of the hydrological studies



From: Gallois 2017

1. Characteristics of the hydrological studies

Fertilizers/
pesticides



Land Use

Volatilisation

Runoff

Infiltration

SOIL

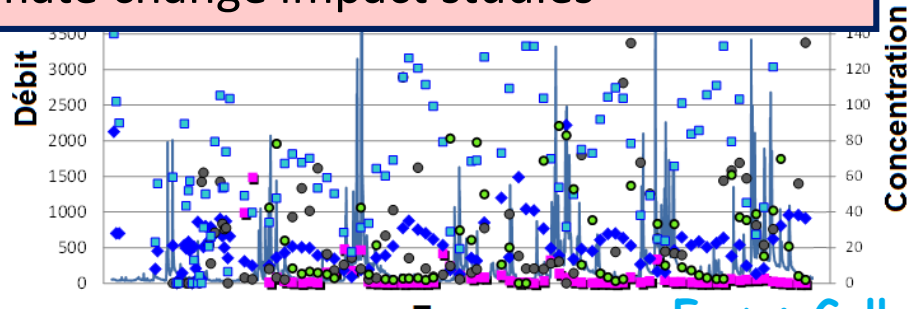
River-aquifer
interaction

Applications:

- ➔Riverflow & Aquifer monitoring & forecast
- ➔ Pollution monitoring & forecast
- ➔Climate change impact studies

River flow

River stream
/Aquifer
pollution



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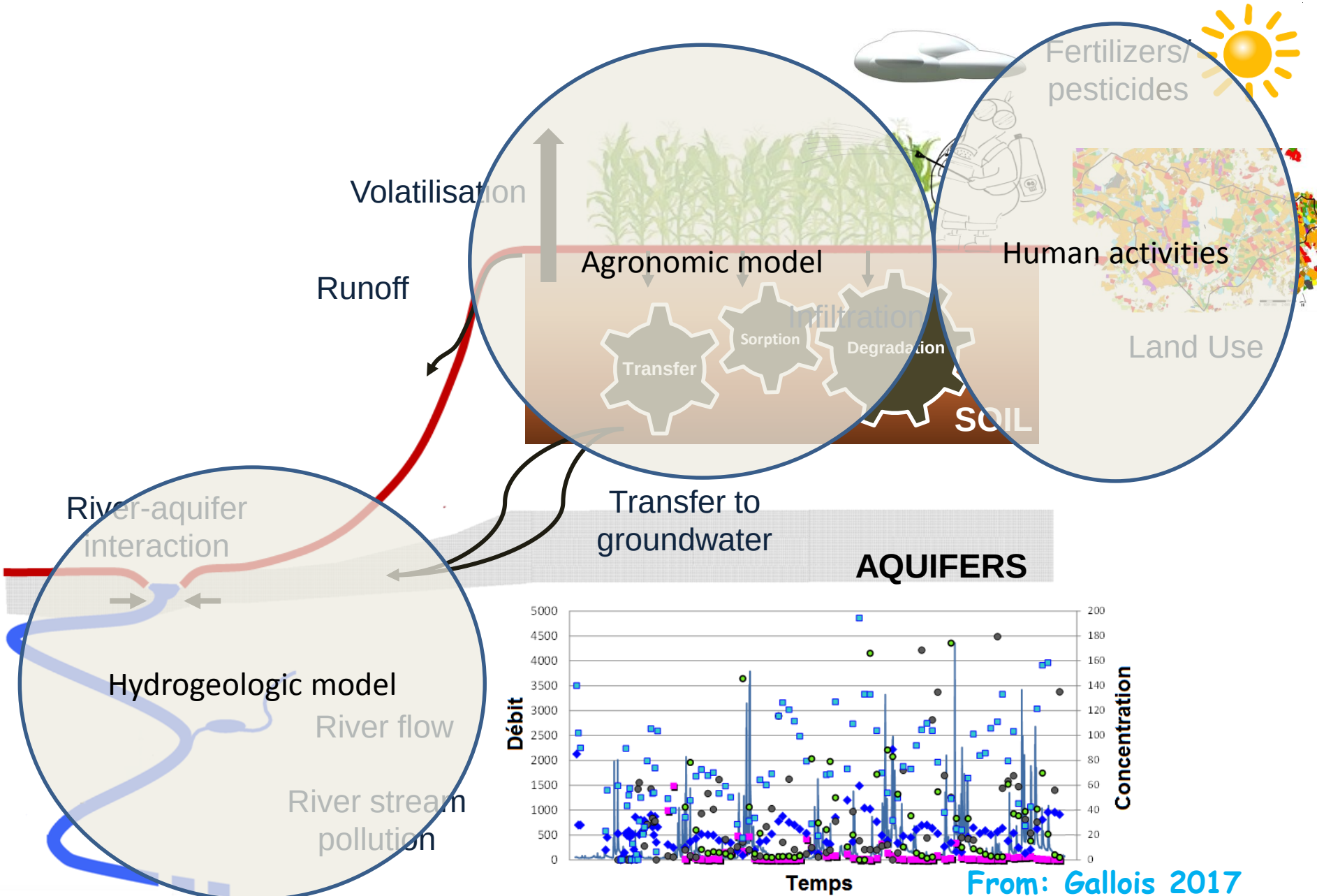


From: Gallois 2017

1. Characteristics of the hydrological studies

Hourly/Daily
Precipitation,
PET
Tx,Tn
Solar Radiation

Scenarios

Agronomic model

Transfer

Sorption

Degradation

SOIL

Human activities

Land Use

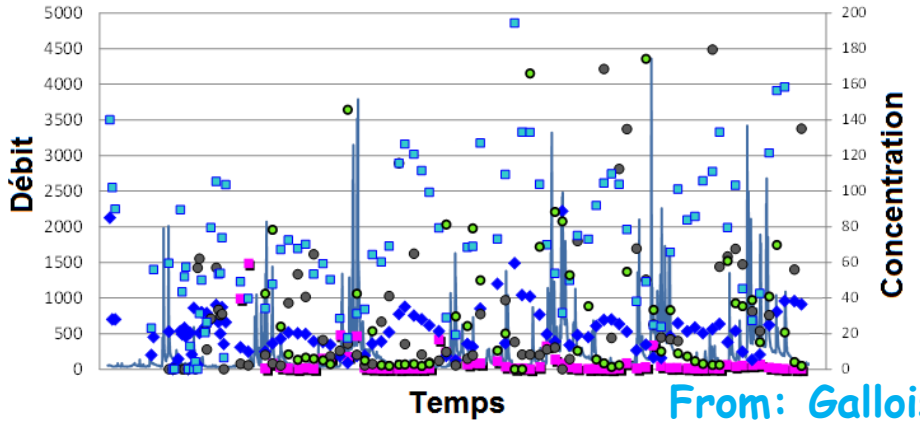
Hourly/Daily
Precipitation,
PET,
Temperature

Transfer to
groundwater

AQUIFERS

Hydrogeologic model

River stream
pollution



From: Gallois 2017

1. Characteristics of the hydrological studies

PET depends on temperature, radiation, wind, humidity

Hourly/Daily Precipitation, PET Tx,Tn Solar Radiation

Scenarios

Agronomic model

Transfer

Sorption

Degradation

Human activities

Land Use

Hourly/Daily Precipitation, PET, Temperature

Transfer to groundwate

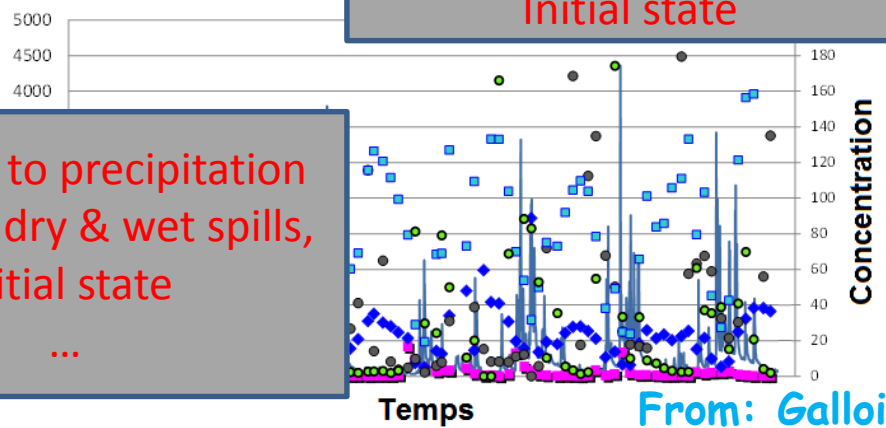
Sensitive to temperature stress (daily), Water stress (daily to monthly), Initial state

Hydrogeologic mod

River poll

Sensitive to precipitation intensity, dry & wet spills, Initial state

...



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1. Characteristics of the hydrological studies

PET depends on temperature, radiation, wind, humidity

Hourly/Daily
Precipitation,
PET
Tx,Tn
Solar Radiation

Agronomic model

Scenarios

Human activities

Hour
Precip
Temp

Hydrogeologic mod

River
poll

Needs for:

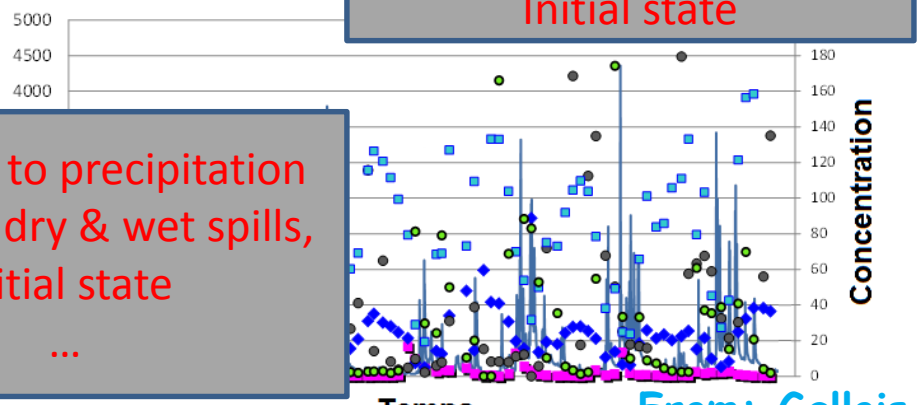
➔Consistency between atmospheric variables (especially Radiation/precipitation)

➔ Good short term variabilities & intensities

➔ Good long term variabilities (for initial state)

Initial state

Sensitive to precipitation intensity, dry & wet spills, Initial state
…



From: Gallois 2017

2. A bit of history

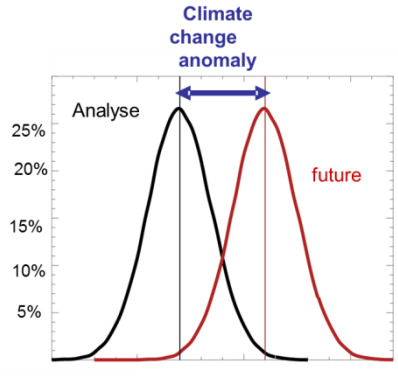
It was simpler before….

In the 90's, climate projections for the impact models were mostly available on slice periods

The delta (or anomaly) method was used to correct the projection:
main hypothesis: the error is constant in time:

ΔClimate_Model = Climate_Model_future – Climate_Model_present

→ **Downscaled_Future** = **Observation** + **ΔClimate_Model**



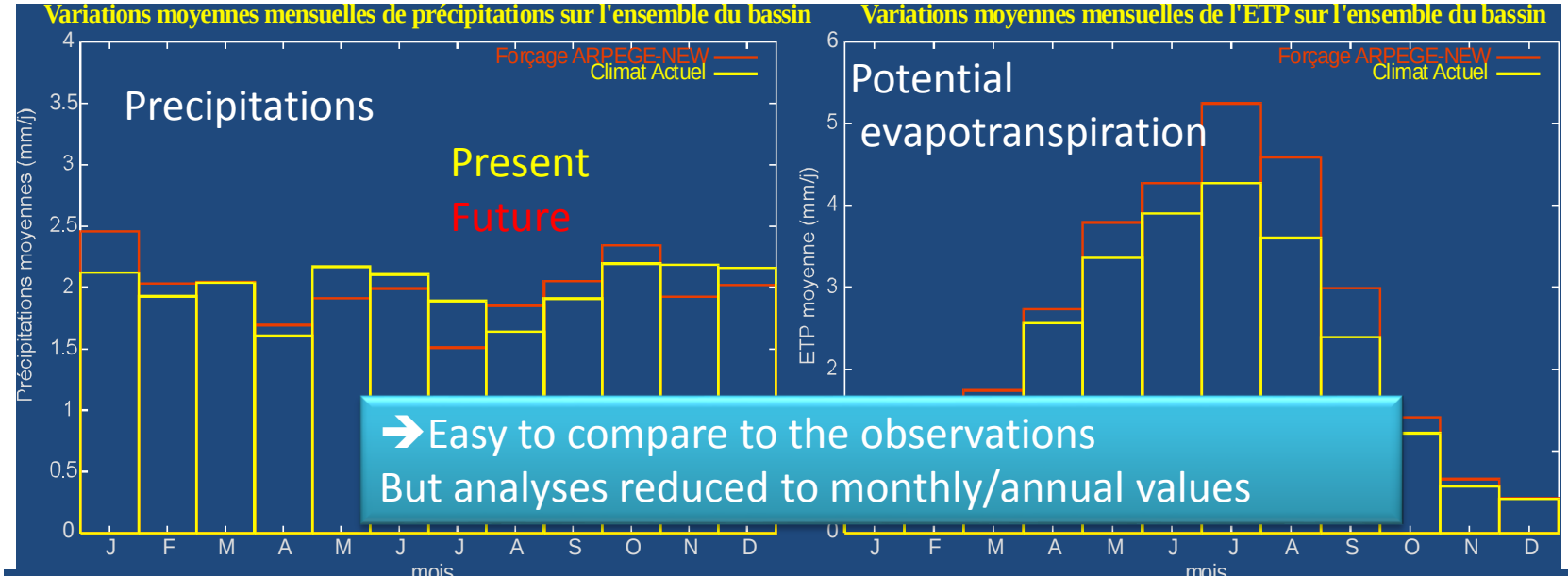
Good points for the impact models were :

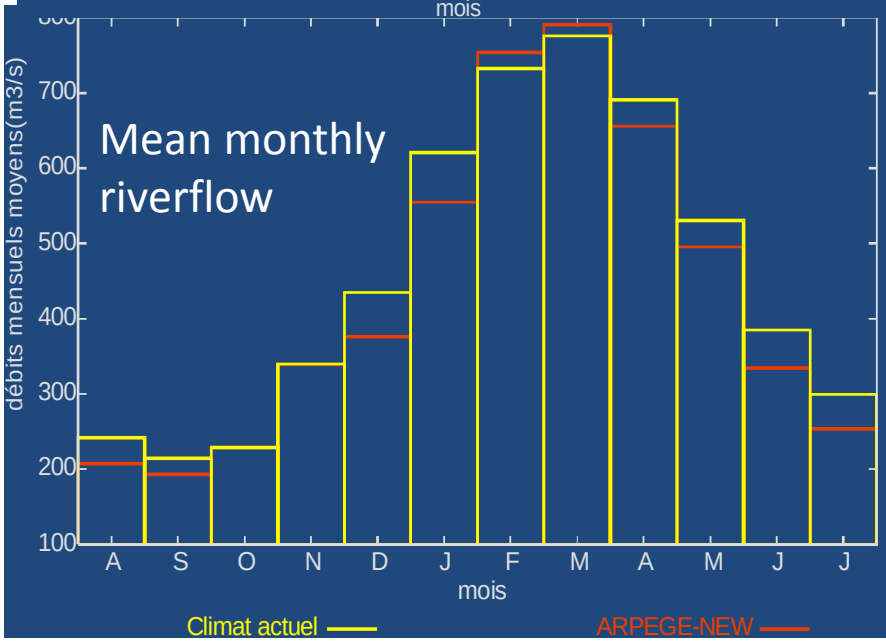
- Deterministic future : one future for one climate model and one anomaly method (although, some variabilities on the delta method)
- References of the impact model is based on the present day observation ➔ expected rather good agreement with the observations….

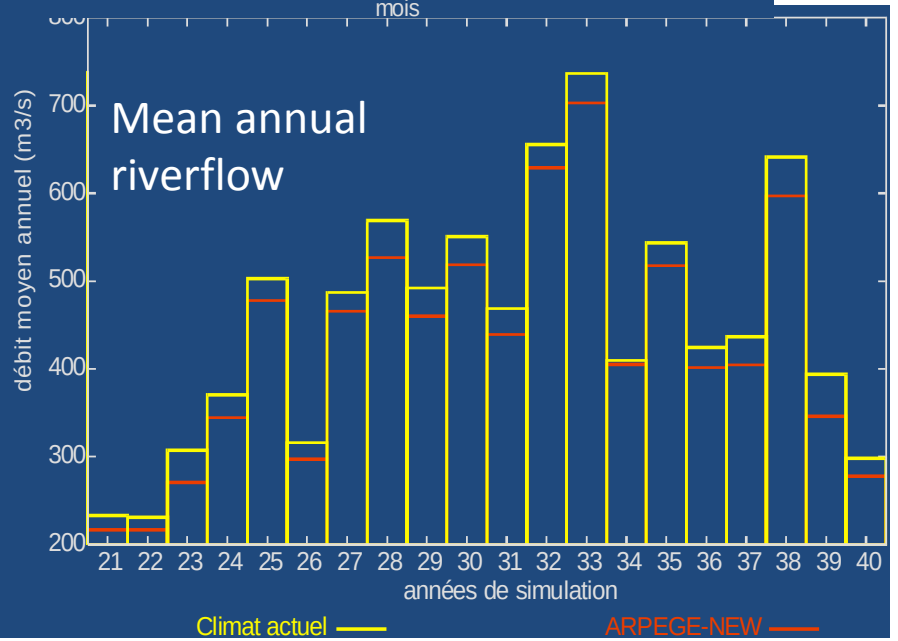
2. A bit of history

Example from the Seine basin, study from AR3

Viennot et al., 2009, Ducharne et al., 2007



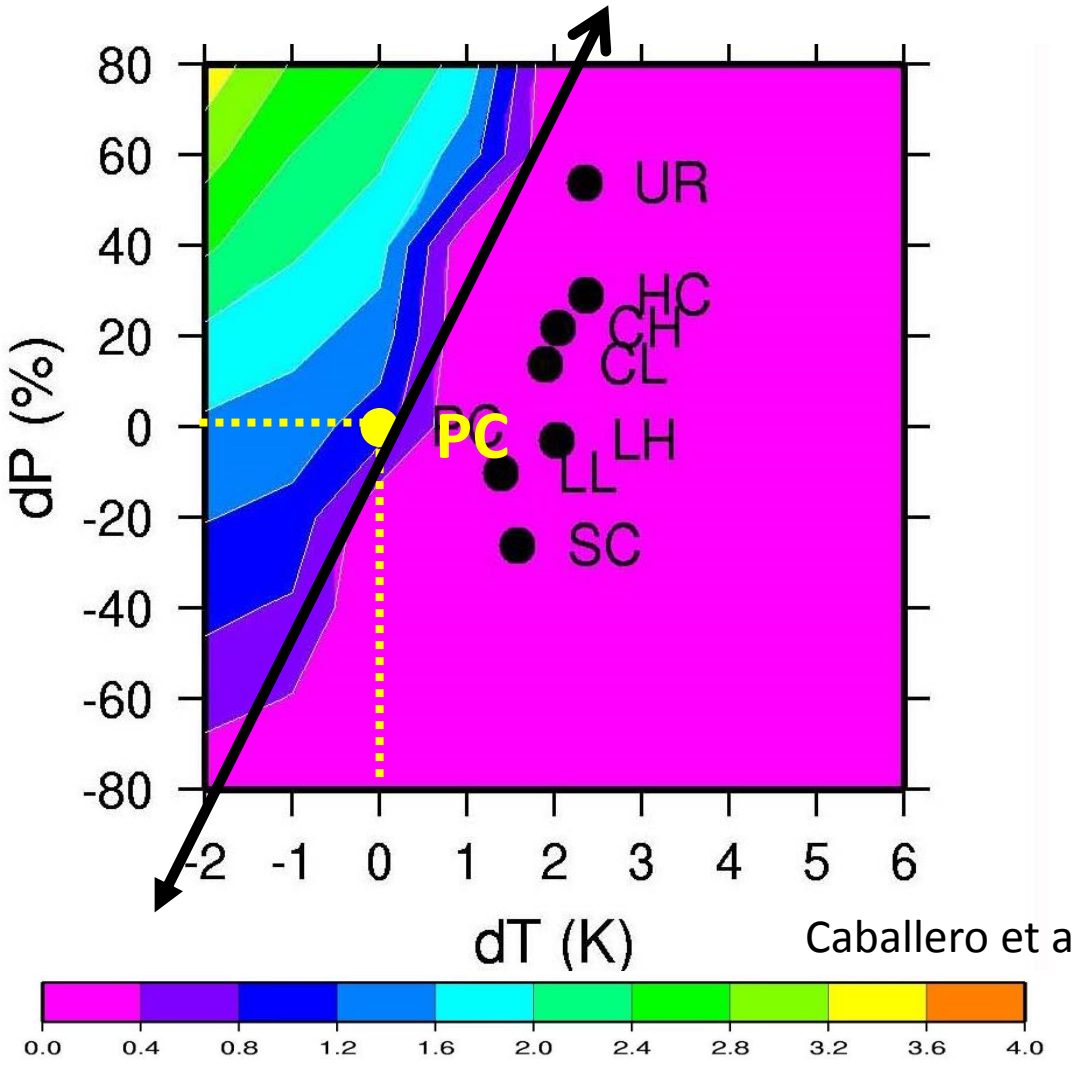




2. A bit of history

Sensitivity tests are easy to do with delta method

Example with the snow pack: which conditions for its complete disapearance?

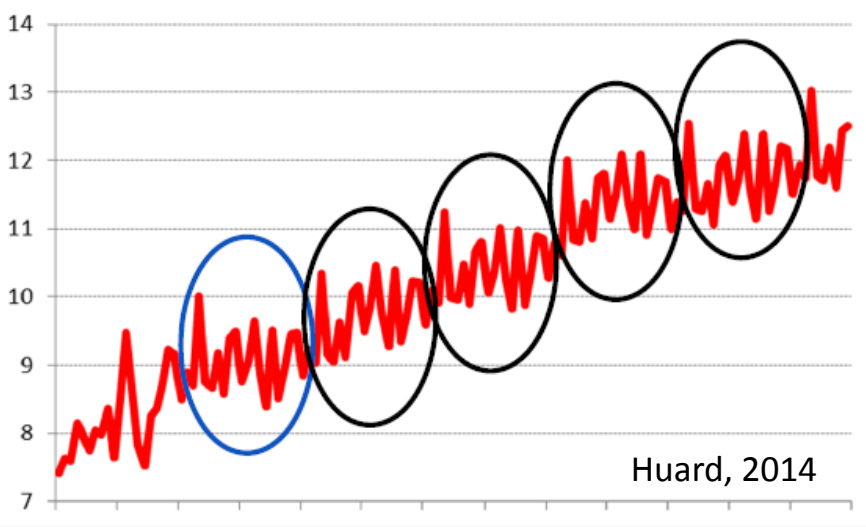


Caballero et al., 2013

2. A bit of history

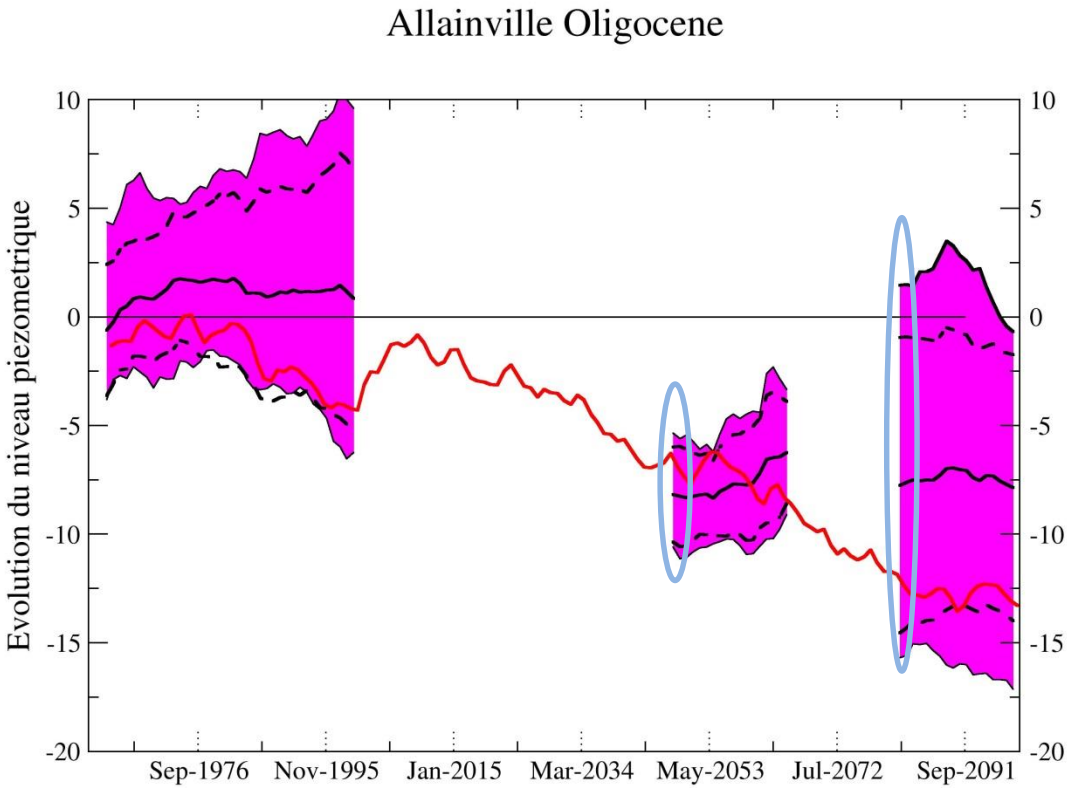
It was simpler before….

The delta method is also used for continuous projections, using short observed period (a decade) with the same limitations



2. A bit of history

Continuous projections are necessary for slow varying/long memory variables simulated by impact models like groundwater level



Habets et al., 2013

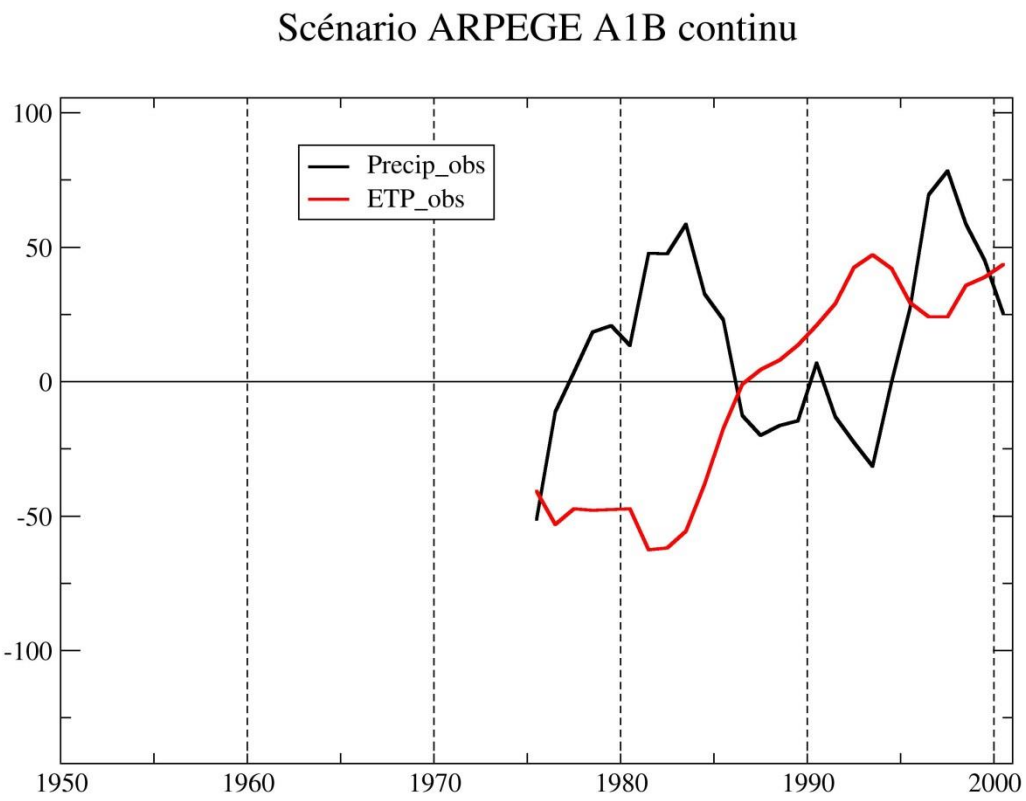
Initial state of the groundwater for slice projections are based on a method built based on a continuous projection(s)

2. A bit of history

Downscaled climate projection in present days:

Example from the Seine basin

Atmospheric forcing



2. A bit of history

From the delta method to improved downscaling technics

Statistical Downscaling Method (SDM):

Weather typing

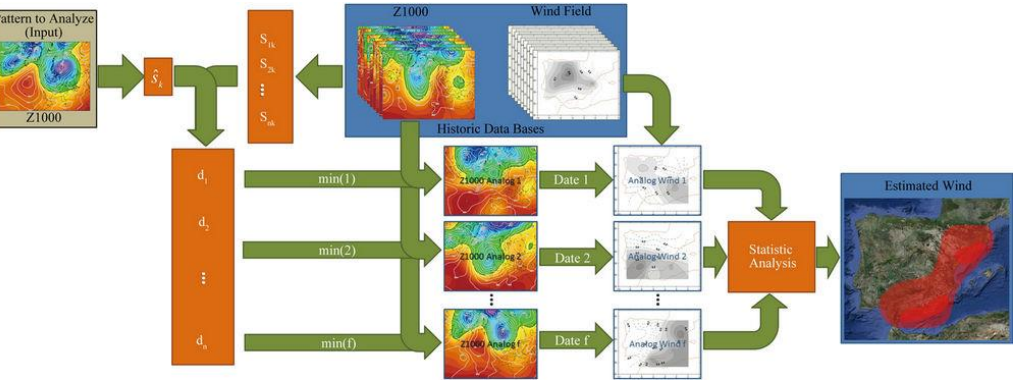
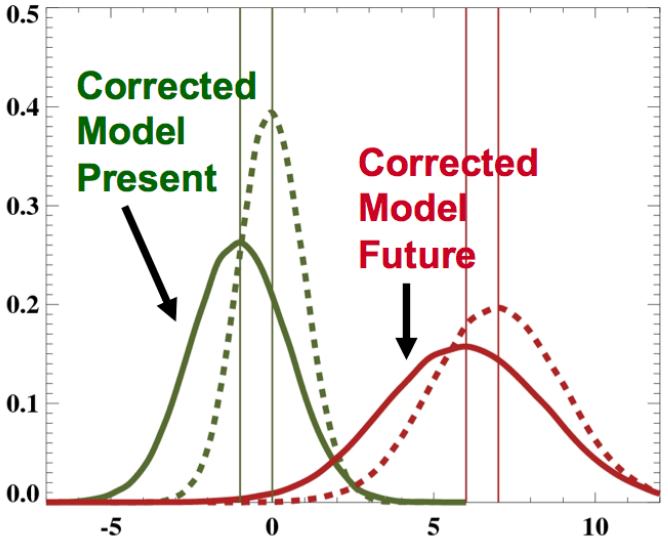


Fig: Pascual, 2013, AJCC

Quantile mapping



Probability Density Functions

Allows to treat extremes

Implies to compare future climate projections to present climate projections

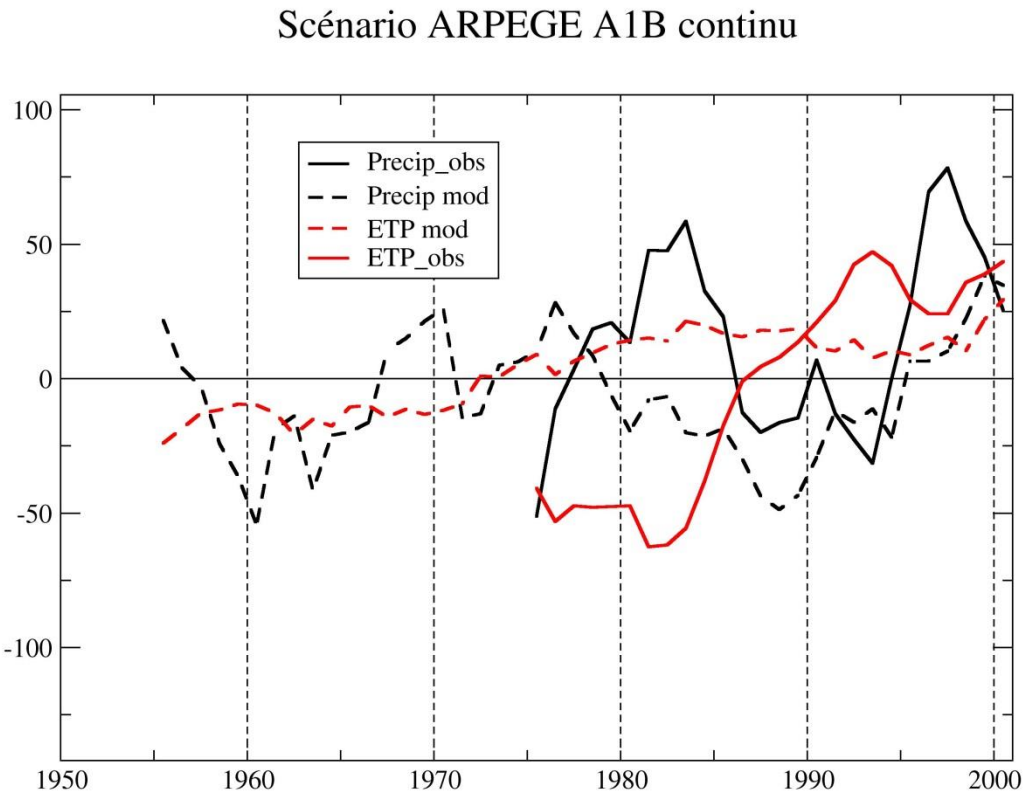
➔Several present day climates….

2. A bit of history

Downscaled climate projection in present days:

Example from the Seine basin

Atmospheric forcing



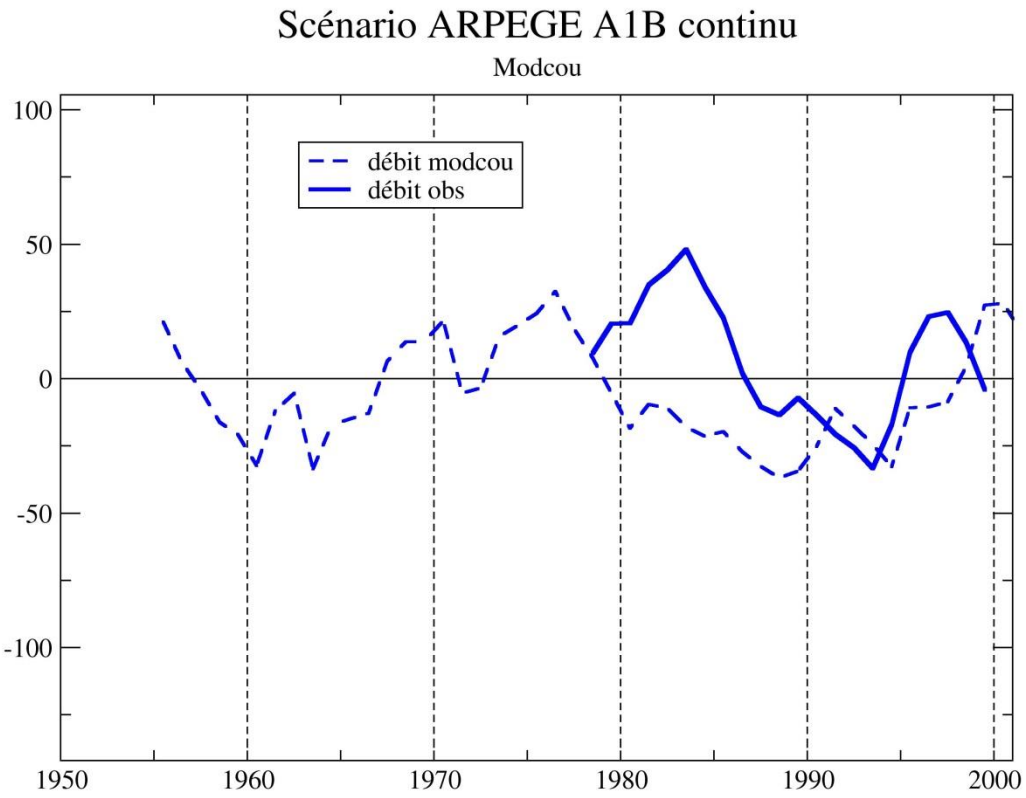
not the same dynamic between the obs and the downscaled climate model

From Habets et al., 2013

2. A bit of history

Downscaled climate projection in present days:

Example from the Seine basin River flow



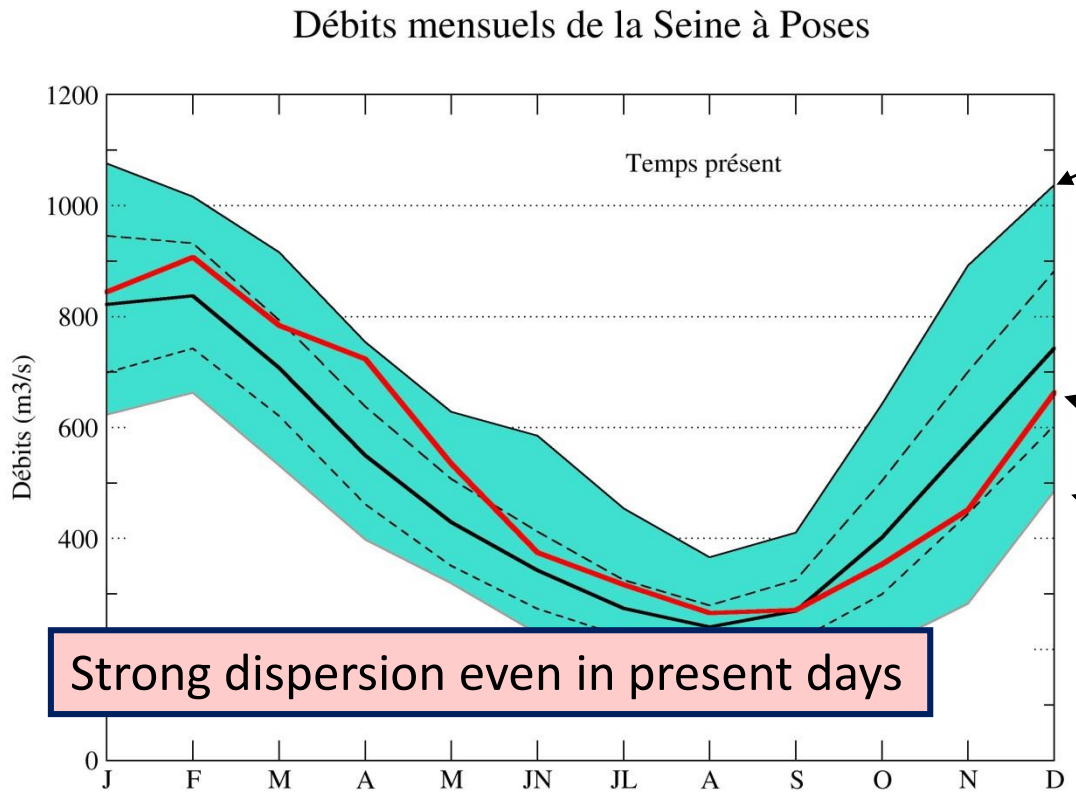
➔ not the same dynamic between the obs and the impact model

From Habets et al., 2013

2. A bit of history

Downscaled climate projection in present days:

Example from the Seine basin River flow



Max

Mean +/- standard deviation

Impact model mean

Observed mean

Min

Strong dispersion even in present days

44 cases (impact model x climate projection x SDM)

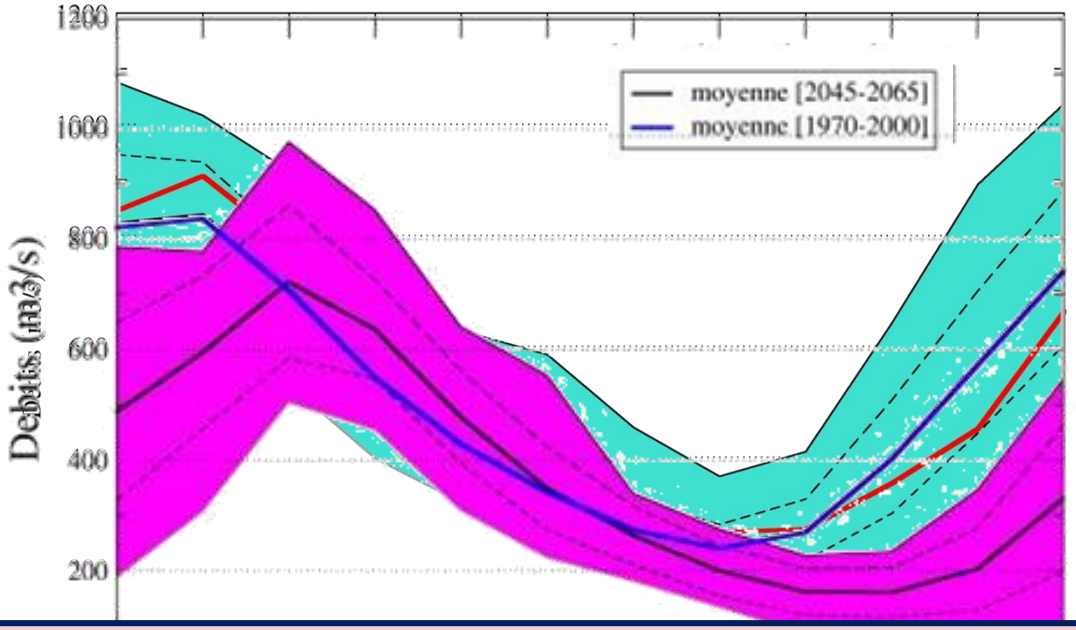
Mean simulated riverflows: 515 +/- 65 m^3/s ⇔ -30 m3/s compare to the obs

From Habets et al., 2013

2. A bit of history

Downscaled climate projection in present days:

Evolution of riverflow at the Seine Outlet [2045-2065]



- ➔ For this basin, low flow signal is clear, but high flow signal is uncertain, and may vary from a CMIP to another….
- ➔ it's not always that easy to disentangle the uncertainty and the climate change signal
- ➔ Uncertainty is associated to several drivers, including SDM

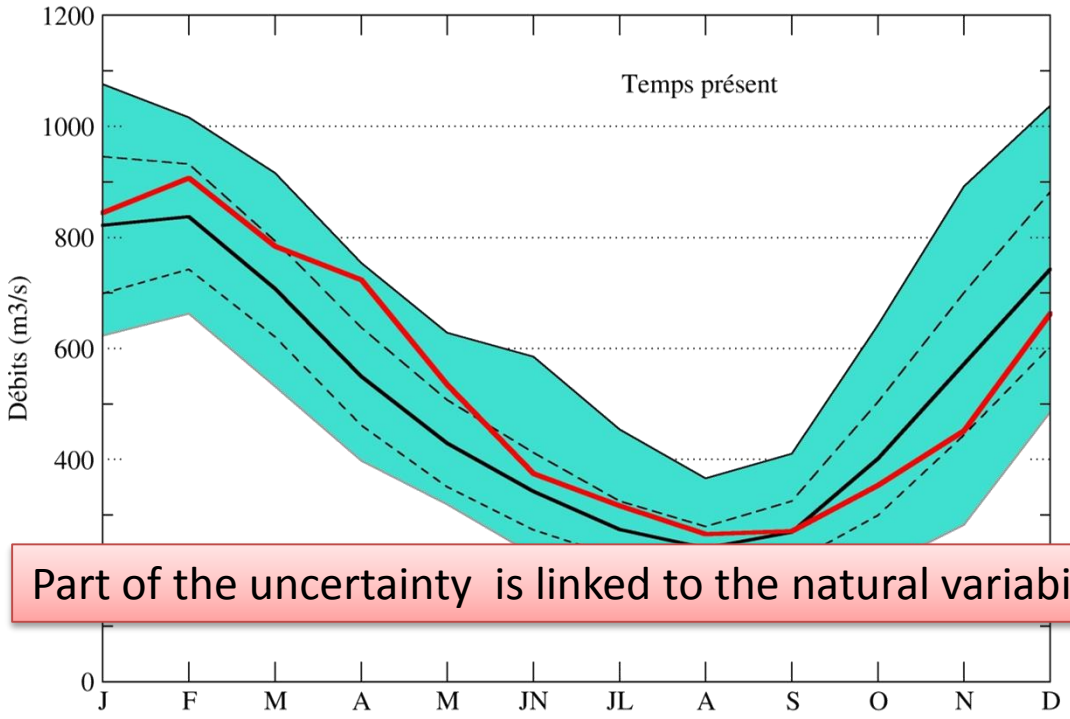
From

3. How to improve the downscale climate restitution?

3.1 Using present day history

➔ Which part is linked to the natural variability

Evolution of riverflow at the Seine Outlet [2045-2065]



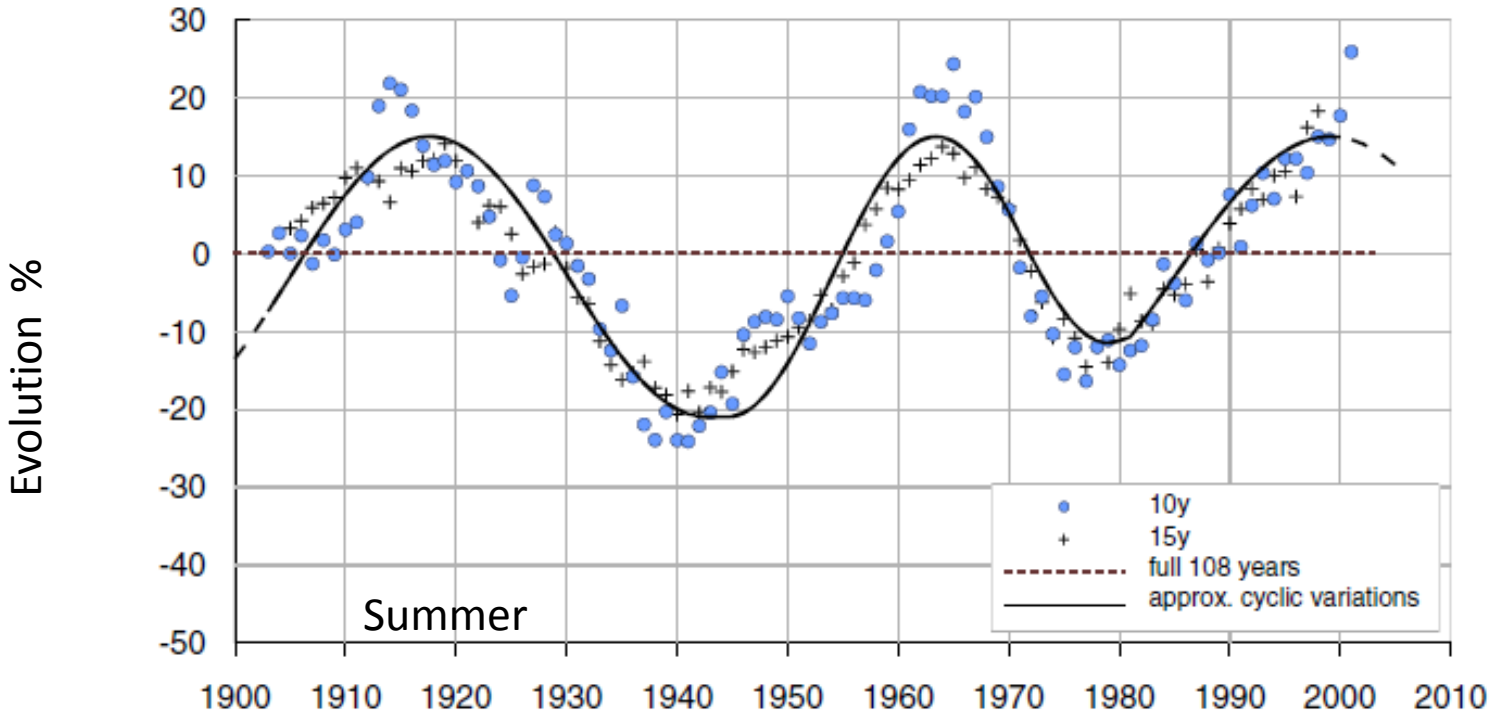
Part of the uncertainty is linked to the natural variability

Present day : -30 m3/s +/- 65 m^3/s compared to the obs

3. How to improve the downscale climate restitution?

3.1 Using present day history

Evolution of **extreme precipitations** from a 10min sample available from **1898** at Uccle, Belgium



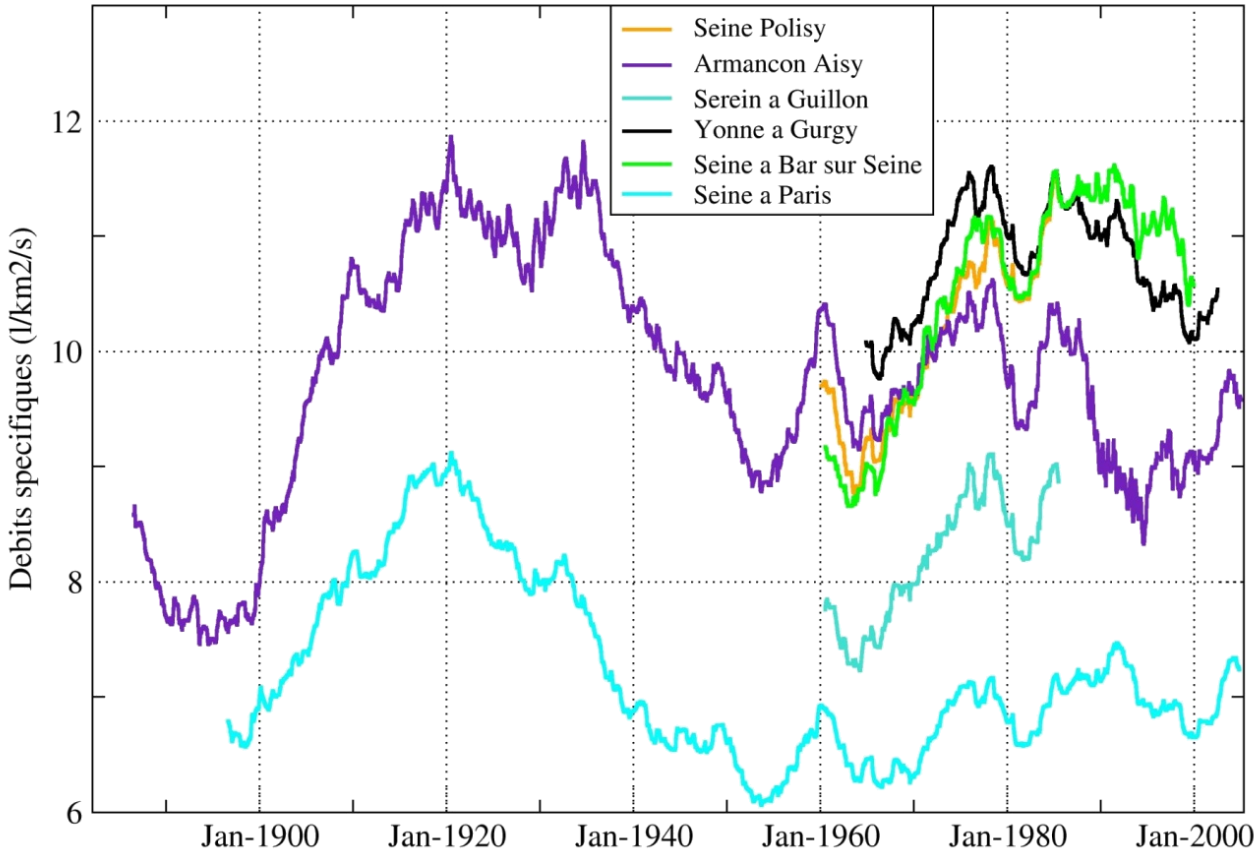
Evidence of strong natural variability in summer

Willems, Climatic Change, 2013

3. How to improve the downscale climate restitution?

3.1 Using present day history

Evolution of **observed discharge in the Seine basin from 1870**



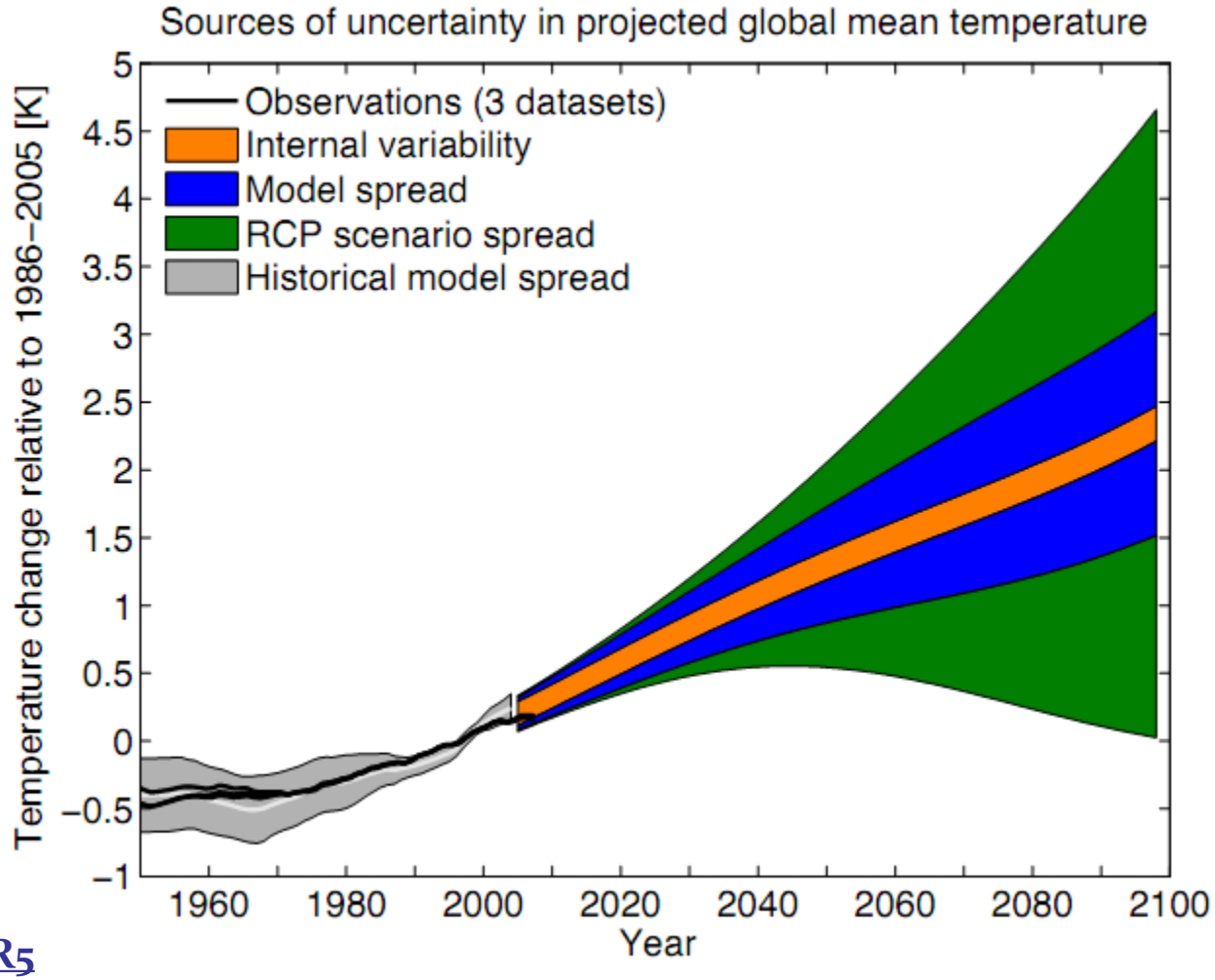
Evidence of strong natural variability in annual discharges

Boé et Habets, HESS 2014

3. How to improve the downscale climate restitution?

3.1 Using present day history

➔ Internal variability is clearly identified as an important uncertainty source

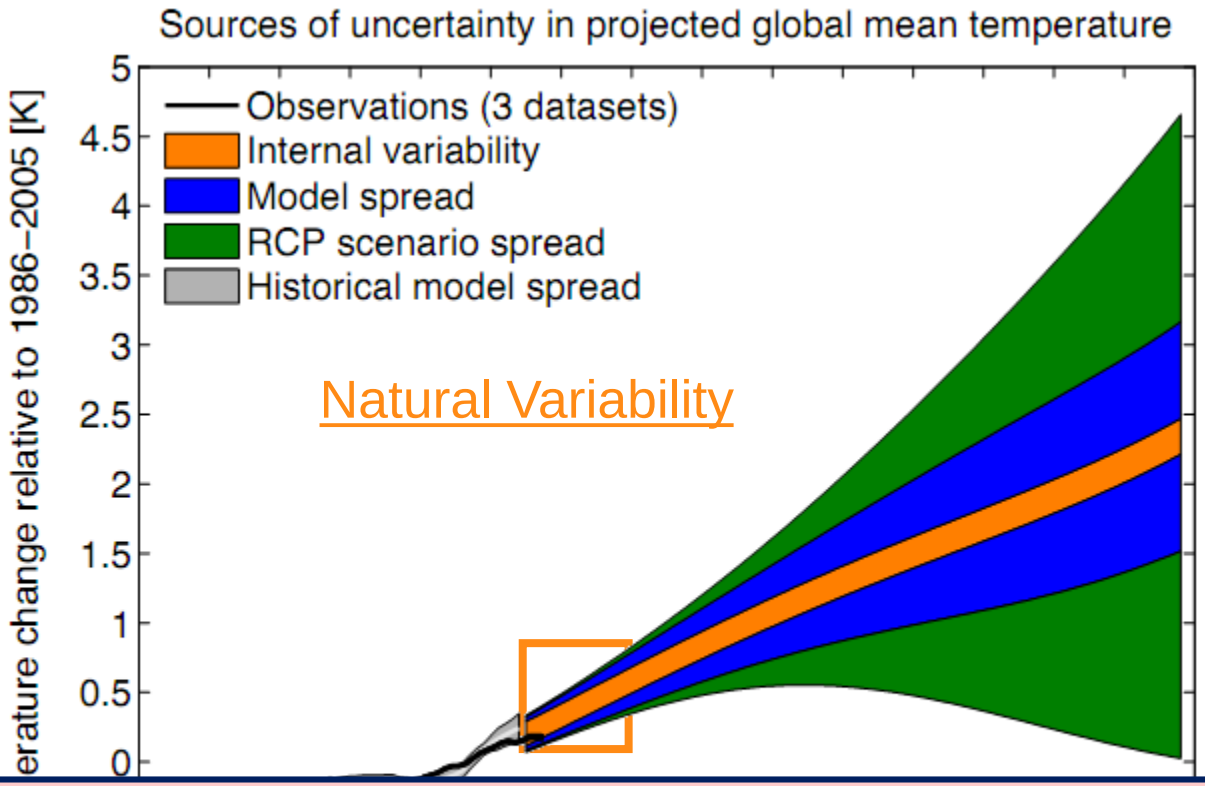


Source IPCC AR5

3. How to improve the downscale climate restitution?

3.1 Using present day history

➔ Internal variability is clearly identified as an important uncertainty source



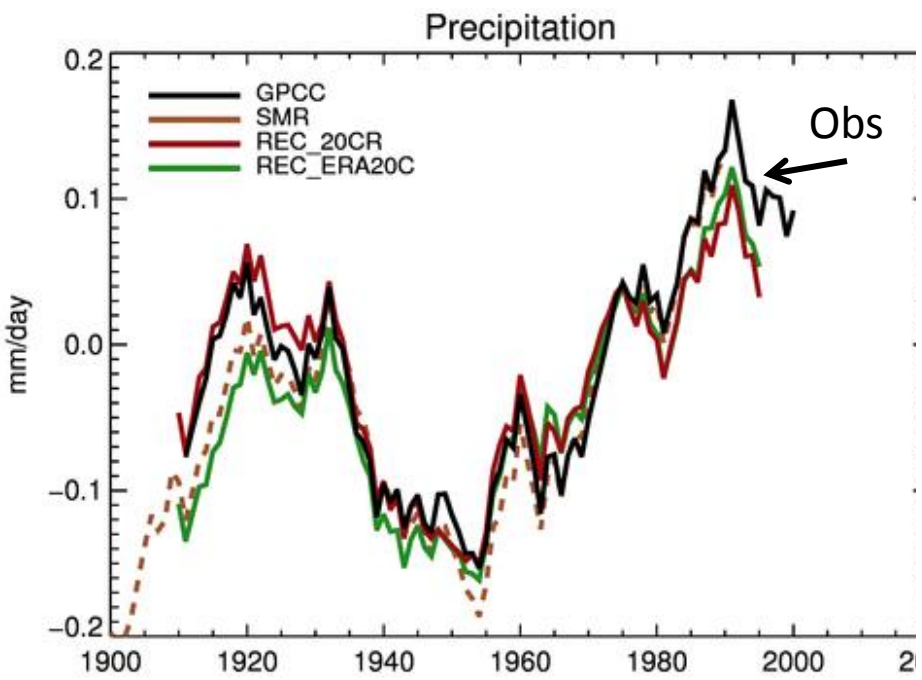
Can long term re-analyses be used to learn about how to handle natural variabilities?

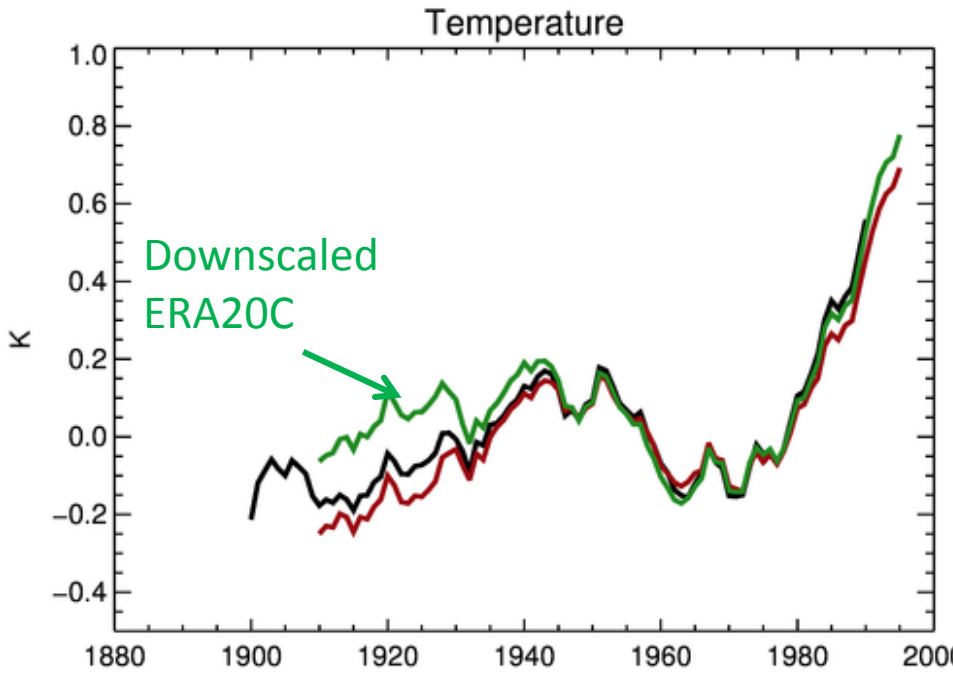
Source IPCC AR5

3. How to improve the downscale climate restitution?

3.1 Using present day history

Reconstitution of the XX century atmospheric forcing over the Seine basin





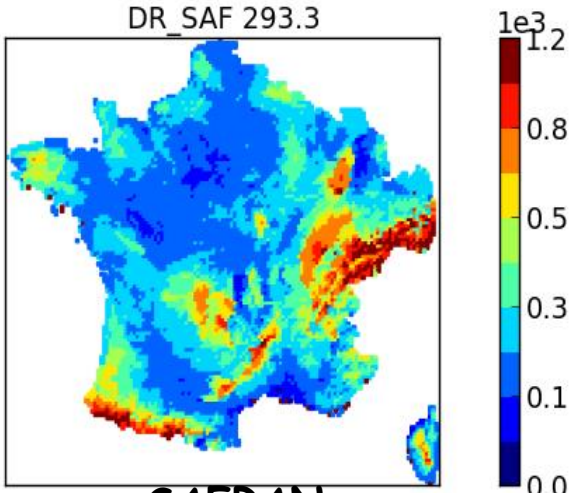
Rather good downscaling of the atmospheric forcing ERAC20C / 20CR compare to the variability of the available obs

From Boé et al., 2017

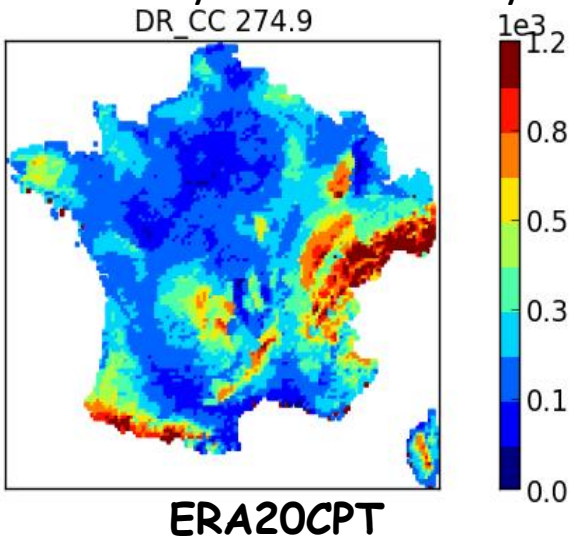
3. How to improve the downscale climate restitution?

3.1 Using present day history

Comparison on the period 2958-2004 on the period cover by reference analysis

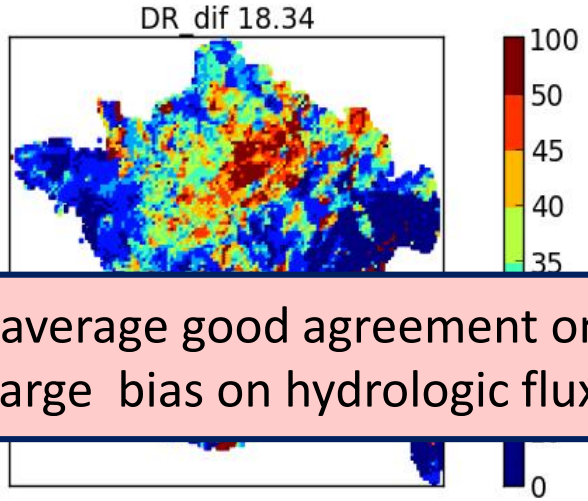


SAFRAN



ERA20CPT

Drainage



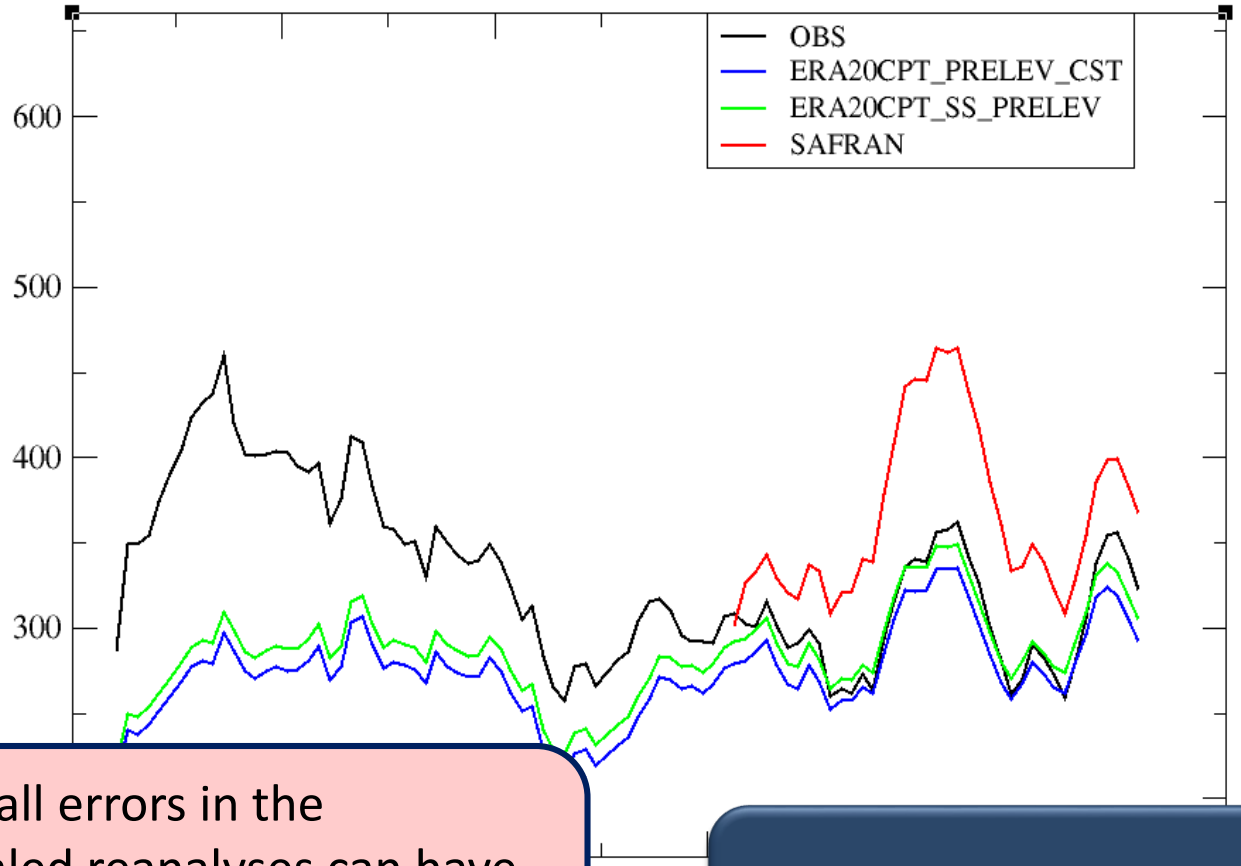
DIFFERENCE
SAFRAN-ERA20CPT (%)

Although there were an average good agreement on the precipitation there are large bias on hydrologic flux

3. How to improve the downscale climate restitution?

3.1 Using present day history

Reconstitution of the XX century ➔ Comparison with piezometric head since 1902



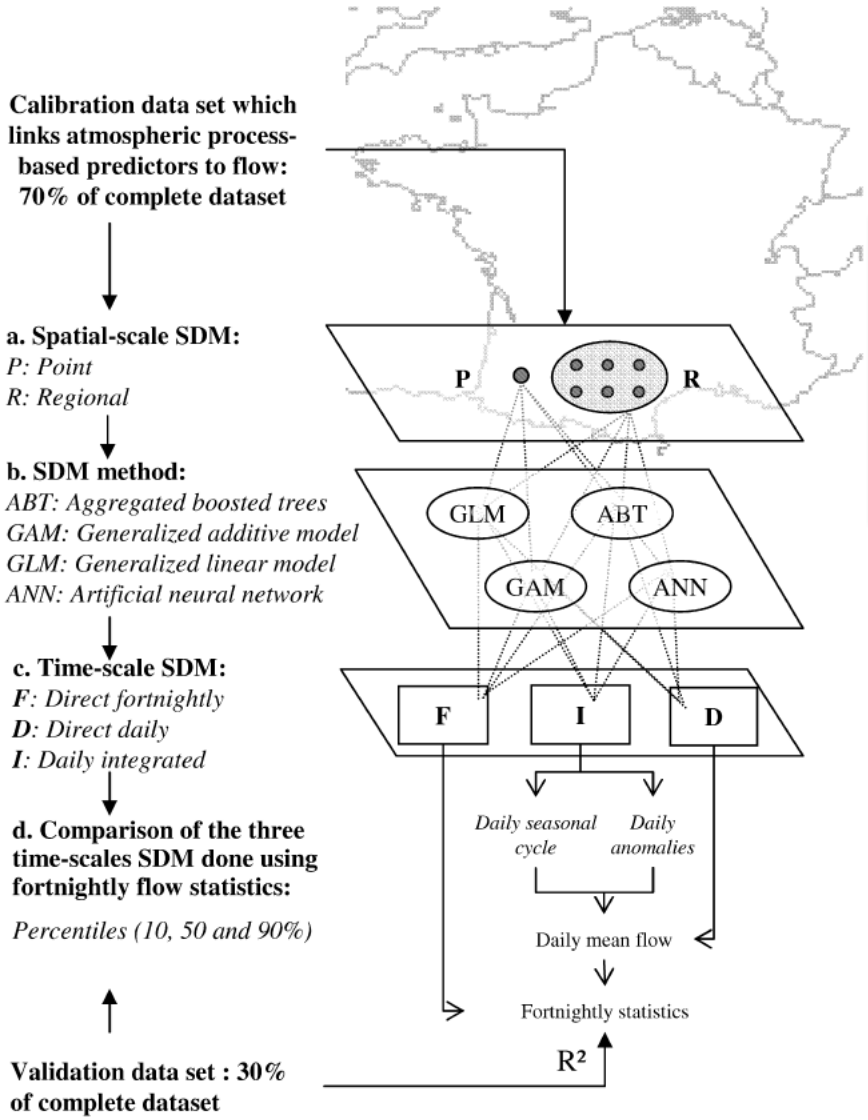
Even small errors in the downscaled reanalyses can have large consequences within the impact model

Using long observed time series can help improving donwscaling methods

Fro

3. How to improve the downscale climate restitution?

3.2 Methods using observed targeted variables



Direct connection between atmospheric variables and river flows

➔ Avoid the impact model

➔ Reduction of the uncertainty in present day

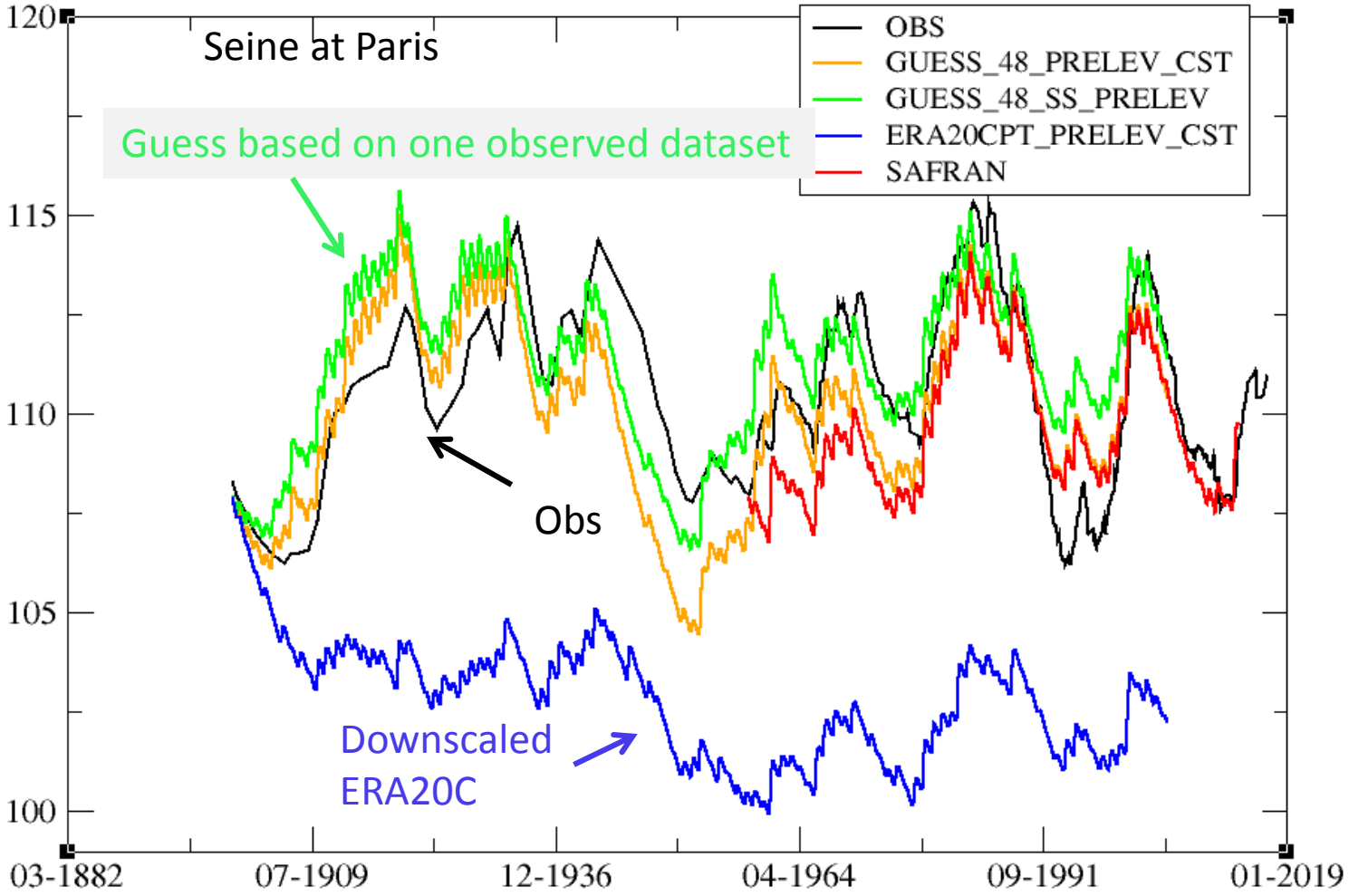
What about the accuracy of the future projection

Tisseuil et al., J. Hydrol, 2010

3. How to improve the downscale climate restitution?

3.2 Methods using observed targeted variables

Reconstitution of the XX century ➔ Comparison with piezometric head since 1902

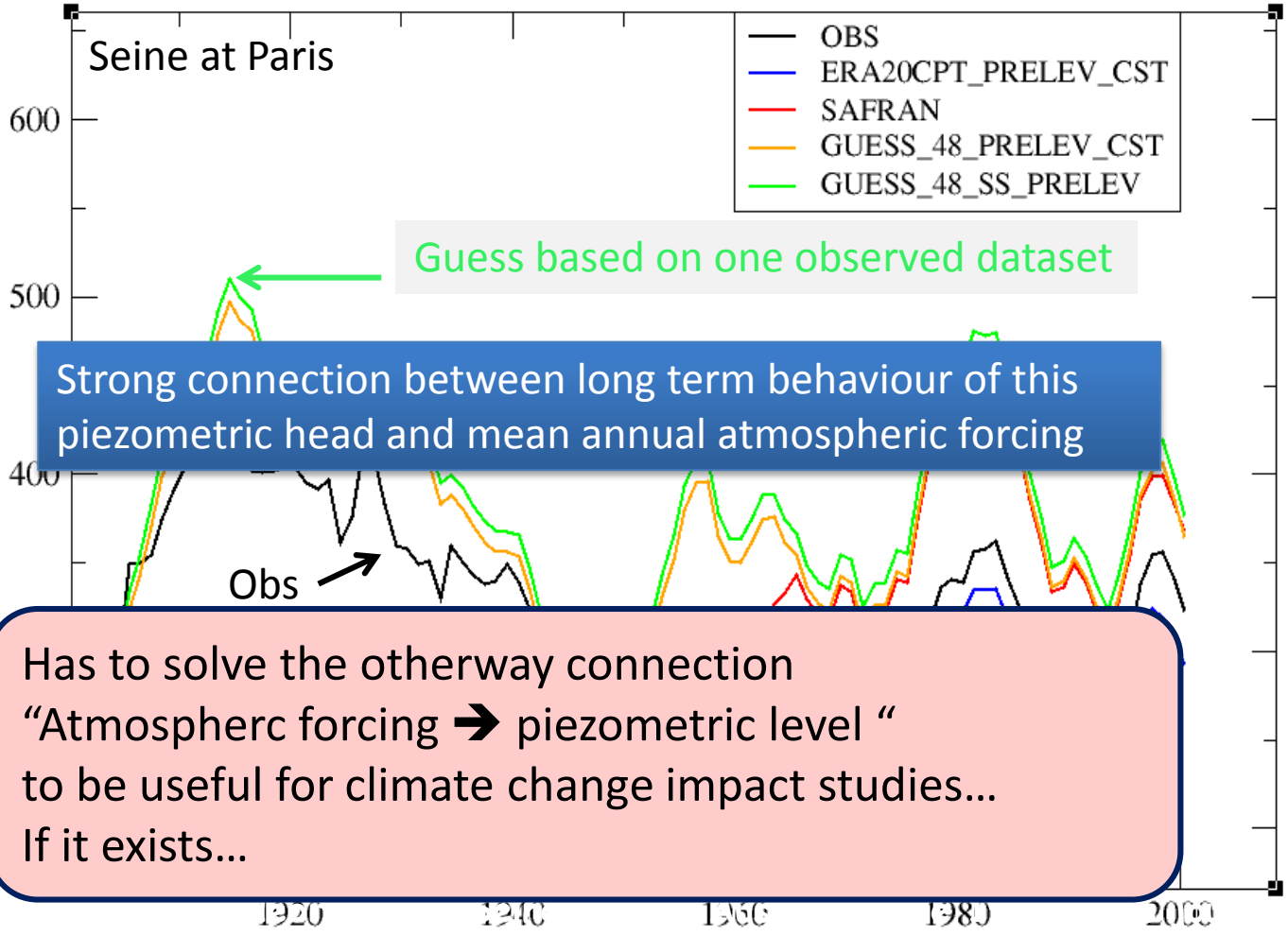


From Boé et al., 2017

3. How to improve the downscale climate restitution?

3.2 Methods using observed targeted variables

Reconstitution of the XX century ➔ assessment with riverflows since 1900



Has to solve the otherway connection
"Atmospherc forcing ➔ piezometric level "
to be useful for climate change impact studies…
If it exists…

From Boé et al., 2017

3. How to improve the downscale climate restitution?

3.3 Assessment of downscaling methods

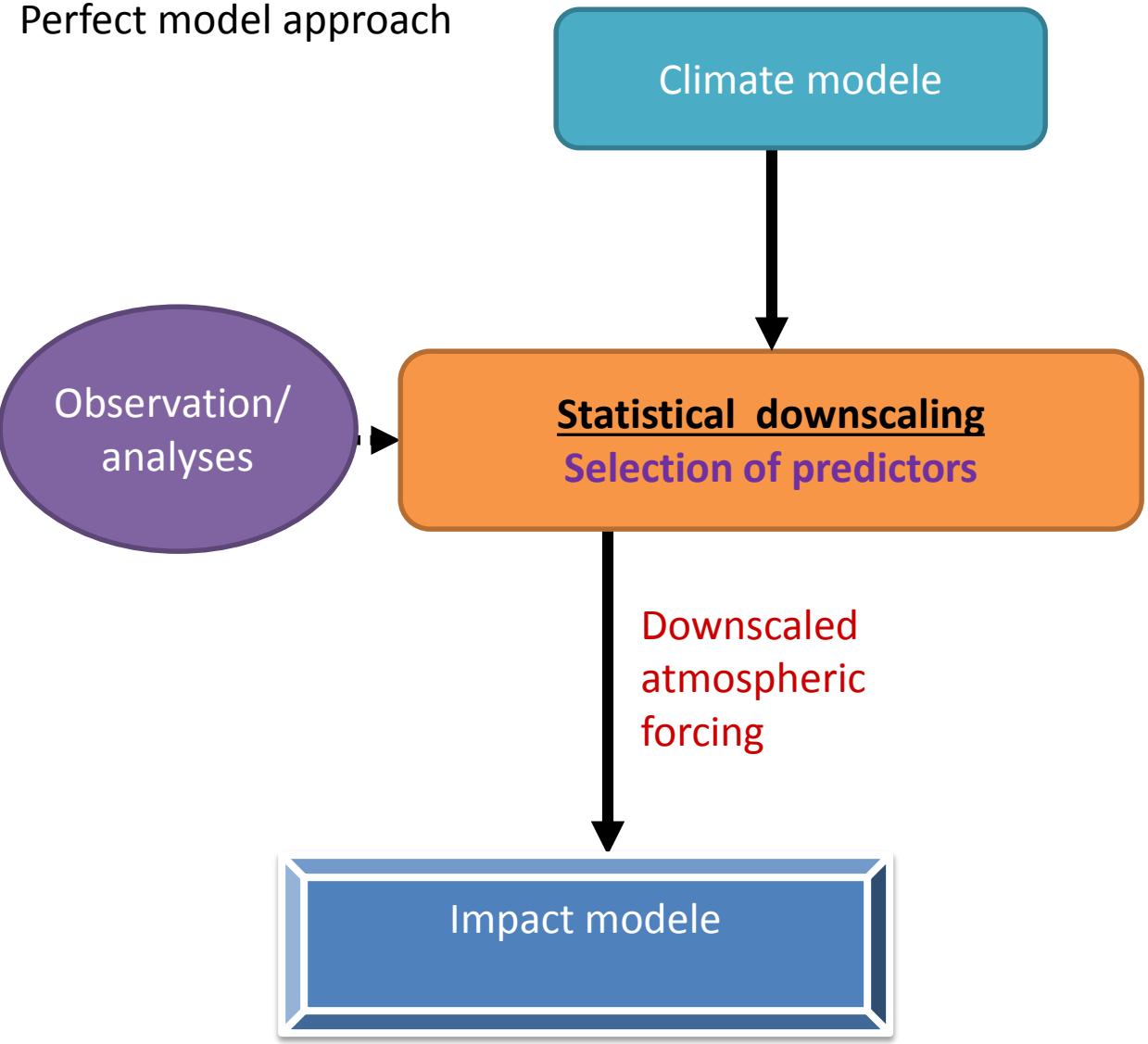
How to be sure that the SDM efficient in present day would be efficient in the future ?

➔ Focus on past selected periods : pb limited time periods, limited change
➔ Perfect model approach

3. How to improve the downscale climate restitution?

3.3 Assessment of downscaling methods

Perfect model approach

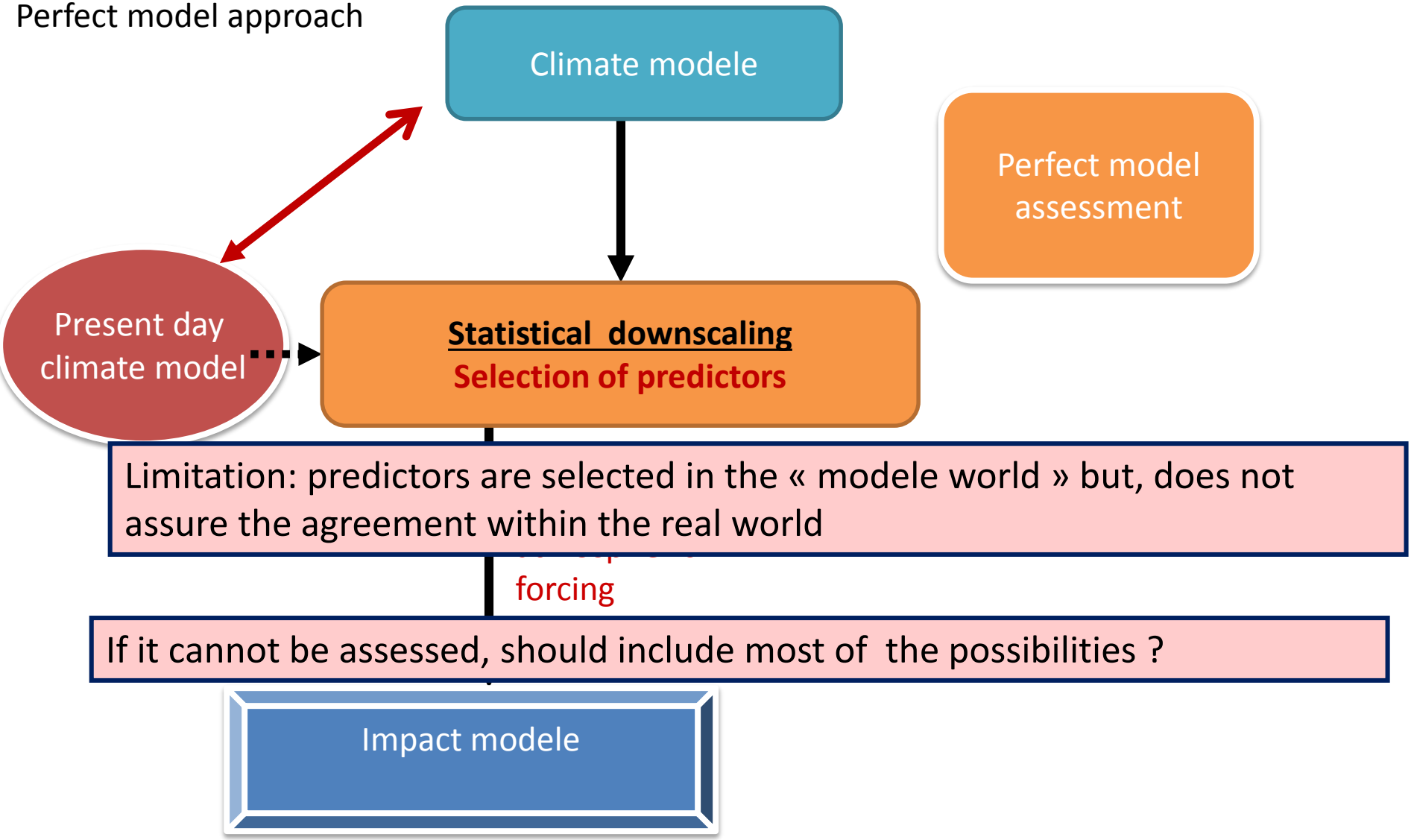


Dayon et al., JGR A, 2016

3. How to improve the downscale climate restitution?

3.3 Assessment of downscaling methods

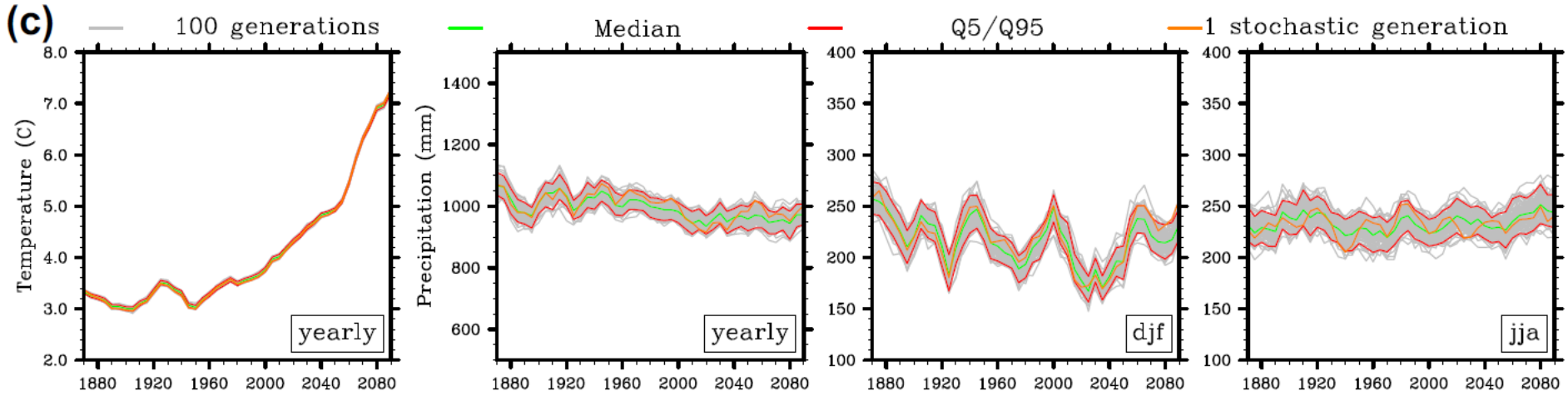
Perfect model approach



Dayon et al., JGR A, 2016

3. How to improve the downscale climate restitution?

3.4 Stochastic approach



For each downscaling method, for each climate model x GHG scenario

➔ Several series are provided

Limitation: costly, large spread, not sure to have only « good uncertainty »

Lafaysse et al., WRR, 2014, Vidal et al, HESS 2016

4. Questions to be adressed by hydrological studies

From impact to adaptation

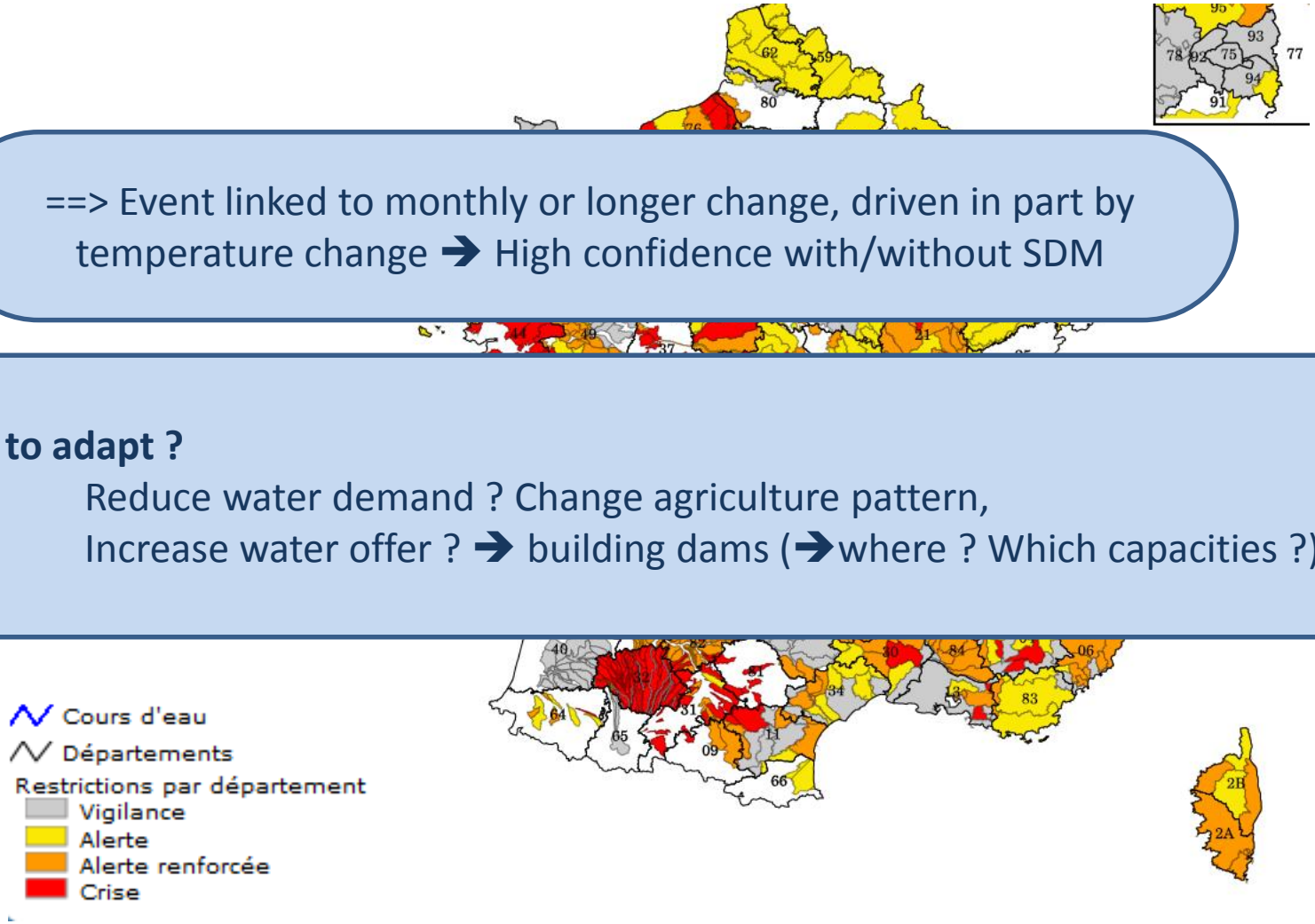
Previous studies mainly focused on estimated the impact
No we have to go to adaptation

« No Regret » strategies is not enough, as there are a lot of pressure by numerous parties that claim some changes are needed by mixing economic and climate change issues….

4. Questions to be adressed by hydrological studies

From impact to adaptation

Drought occurrence & intensity are expected to increase



==> Event linked to monthly or longer change, driven in part by temperature change ➔ High confidence with/without SDM

How to adapt ?

Reduce water demand ? Change agriculture pattern,

Increase water offer ? ➔ building dams (➔where ? Which capacities ?)

Drought alert 18 septembre 2017

4. Questions to be adressed by hydrological studies

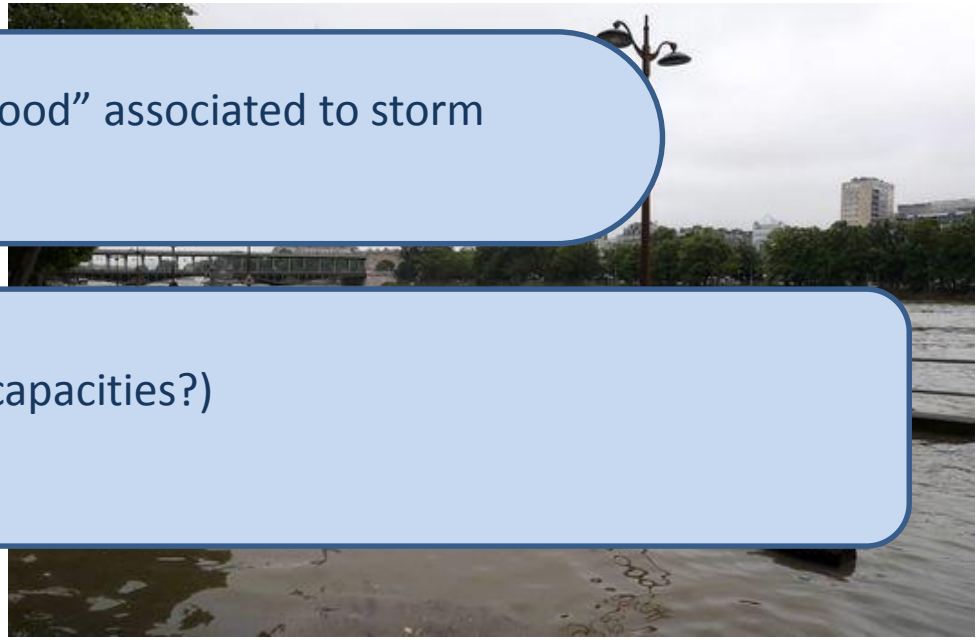
From impact to adaptation

➔ There may be some difficulty to fill up the dams

4. Examples of limitation with hydrogeological impact models

From impact to adaptation

Flood occurrence & intensity may increase



➔ Rather high confidence for “flash flood” associated to storm
➔ Low confidence for “slow flood”

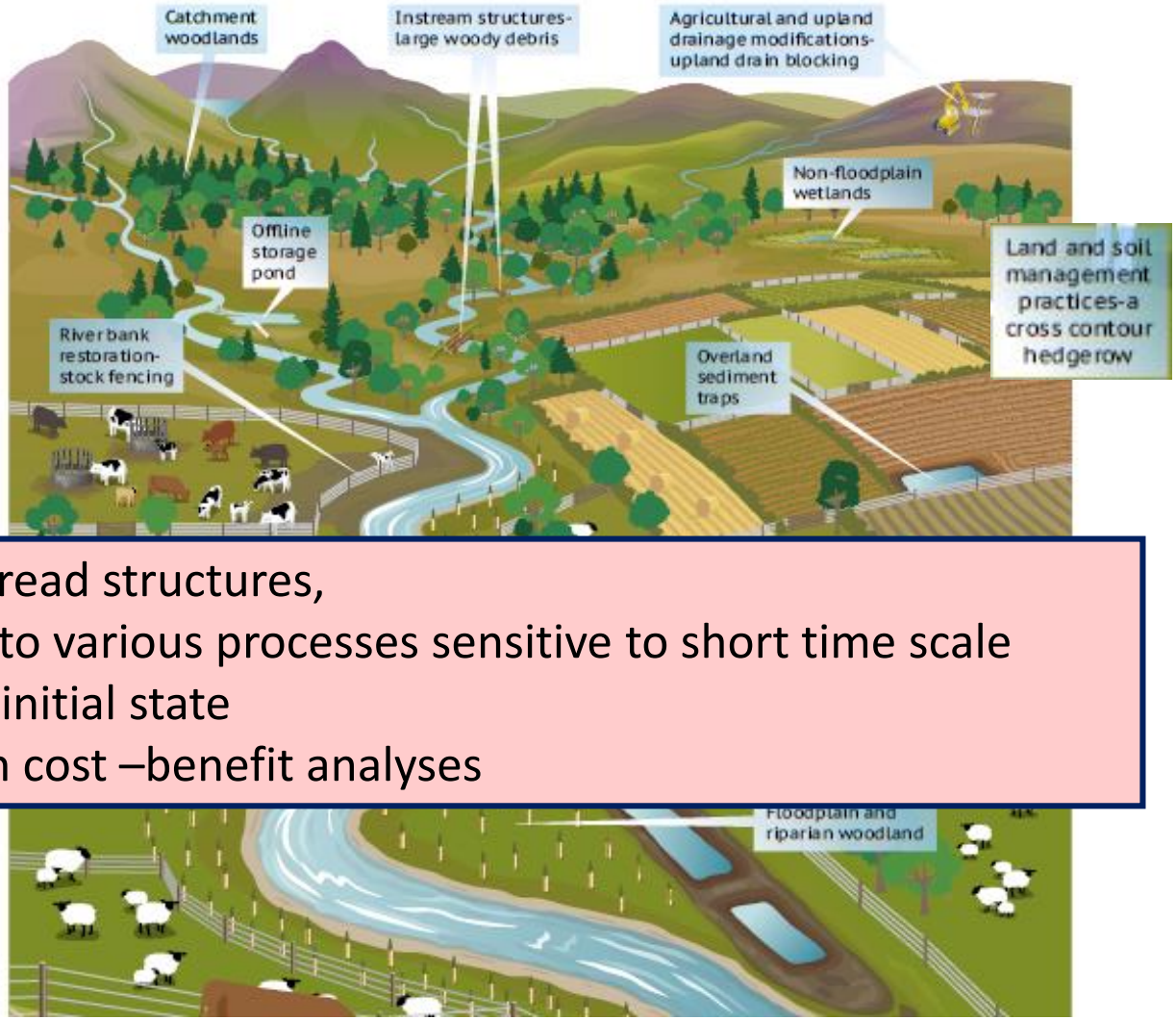
How to adapt ?

Build dams ? (➔where ? Which capacities?)
Increase Exclusion zone ?
Invest in Nature Based Solution ?

4. Examples of limitation with hydrogeological impact models

From impact to adaptation

In the watershed: summary of the nature based solution



Spatially spread structures,
Associated to various processes sensitive to short time scale events and initial state
Depends on cost –benefit analyses

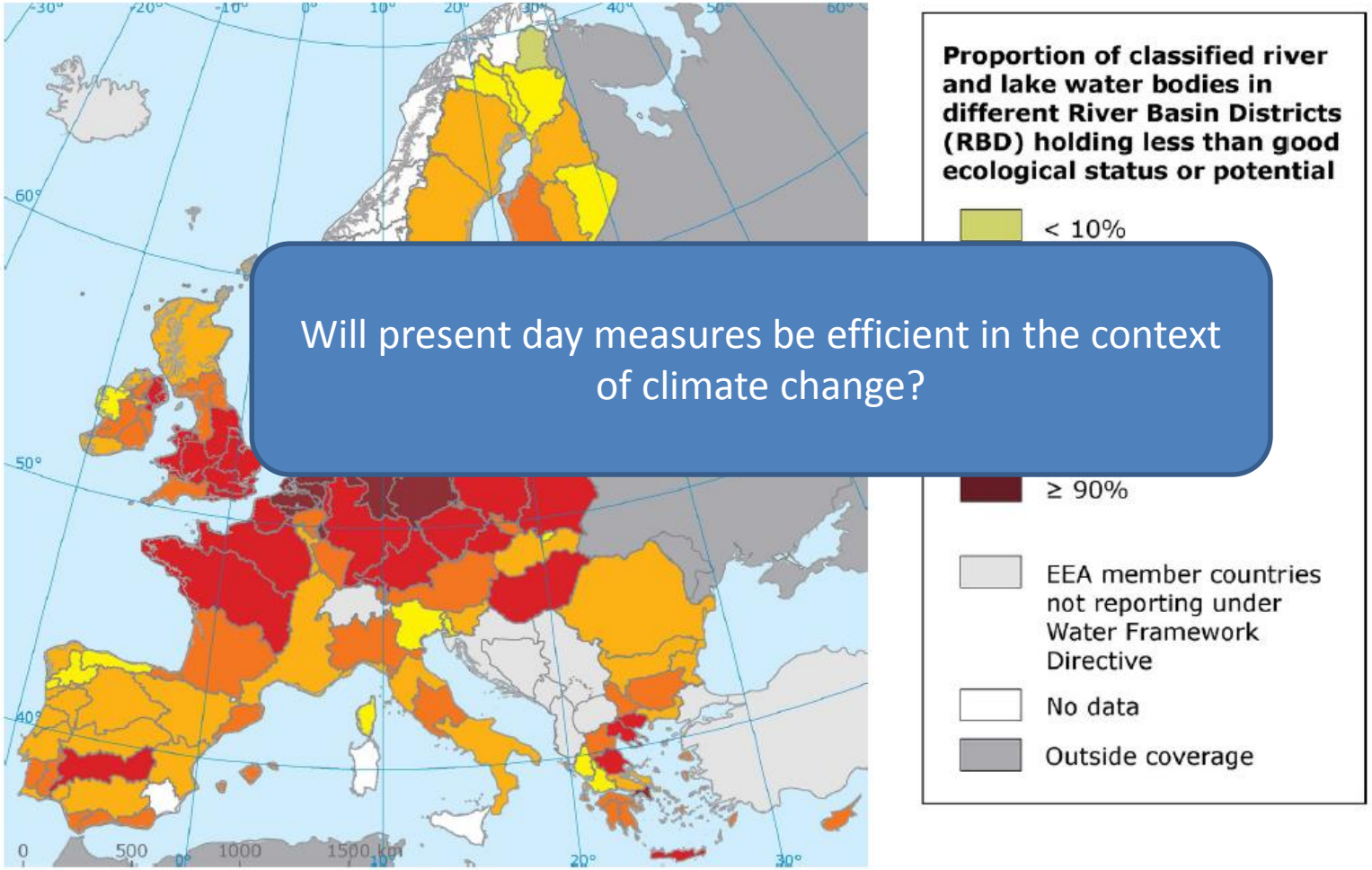
SEPA, Forbes et al., Natural Flood Managment hanbook2015

4. Examples of limitation with hydrogeological impact models

From impact to adaptation

Water Quality

Percentage of « water bodies » that fail to access a good quality according to the European Water Framework Directive



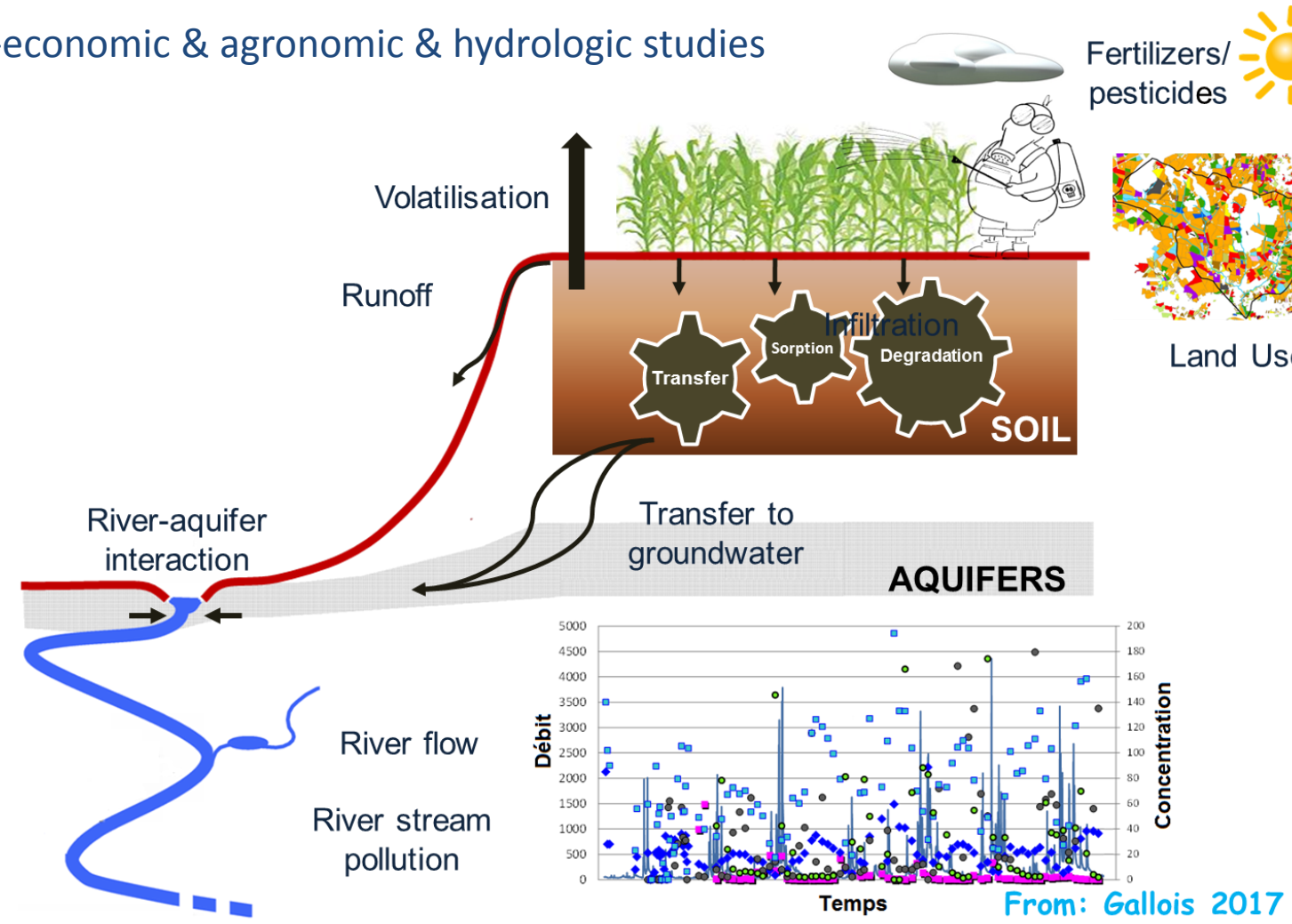
Will present day measures be efficient in the context of climate change?

4. Examples of limitation with hydrogeological impact models

From impact to adaptation

Water Quality

➔ Coupled socio-economic & agronomic & hydrologic studies

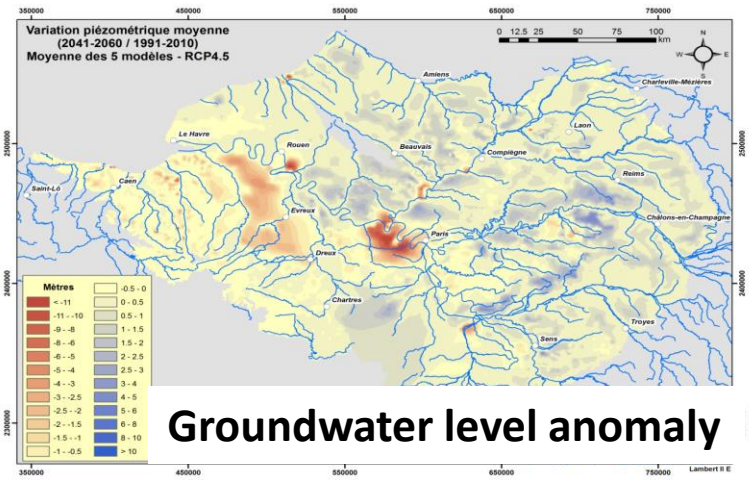


4. Examples of limitation with hydrogeological impact models

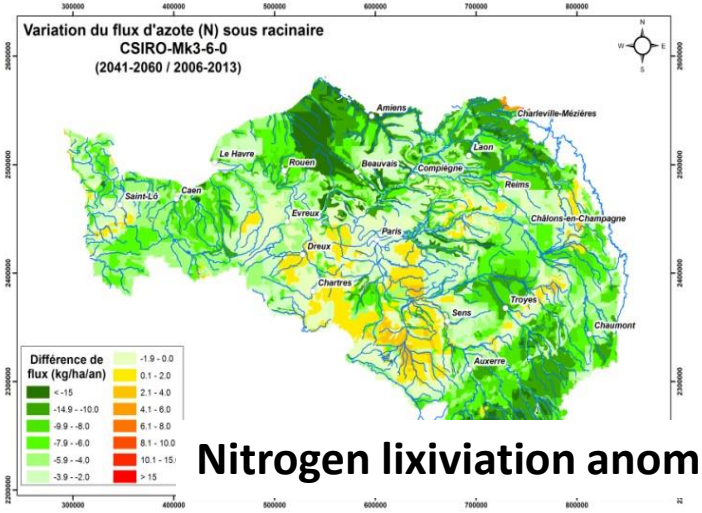
From impact to adaptation

Water Quality

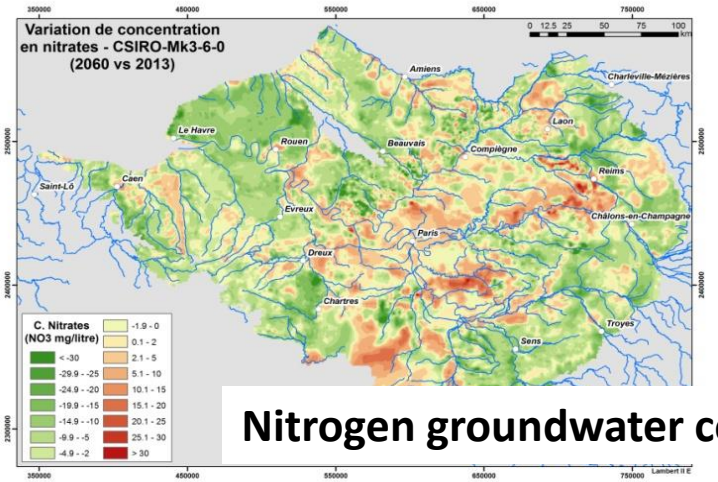
Difficulty to address such issue in term of anomalies



Groundwater level anomaly



Nitrogen lixiviation anomaly



Nitrogen groundwater concentration anomaly

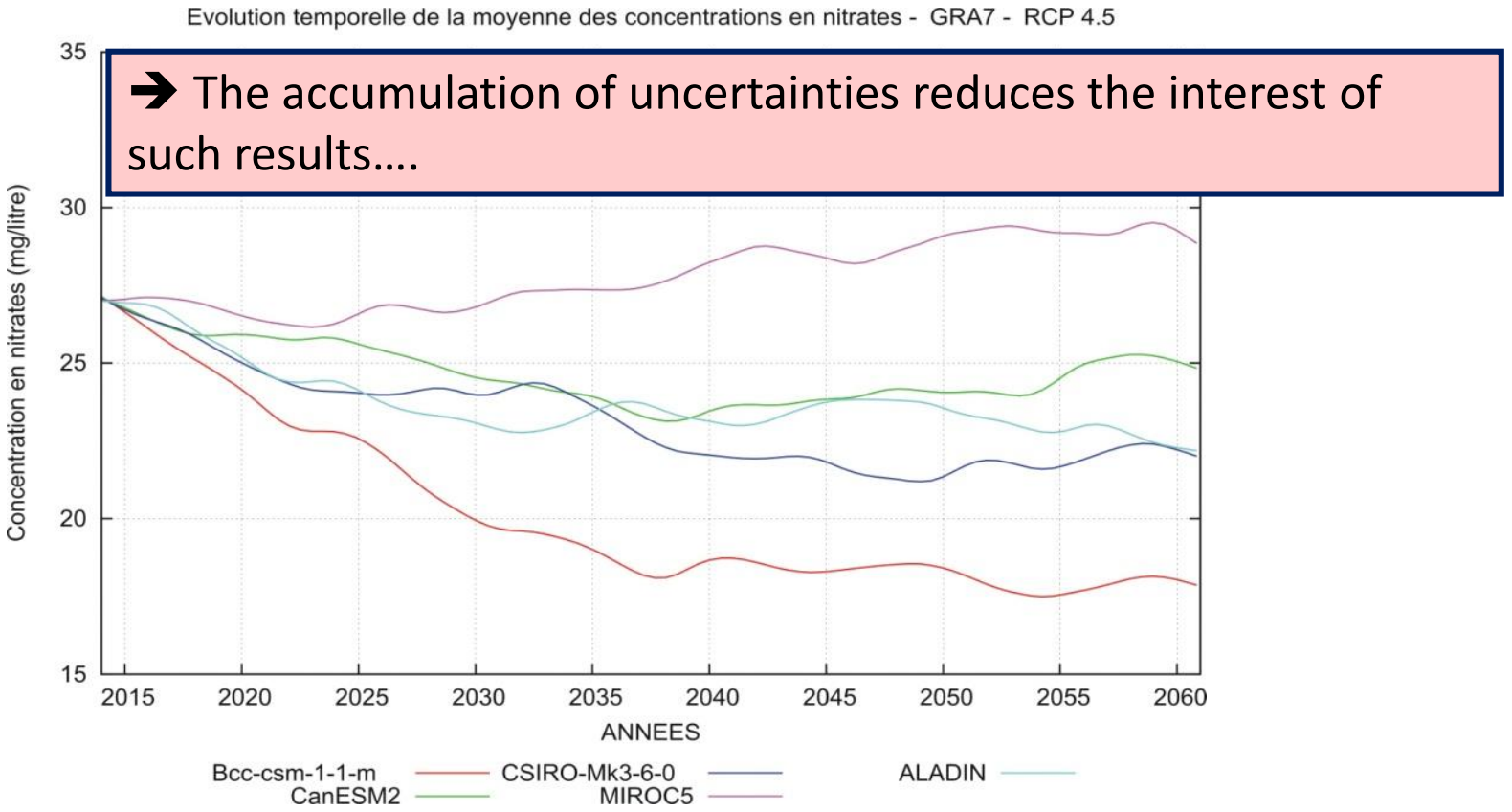
Viennot & Gallois 2017

4. Examples of limitation with hydrogeological impact models

From impact to adaptation

Water Quality

Difficulty to address such issue in term of anomalies
But time evolution of the groundwater nitrogen concentration implies hypotheses on present day condition



➔ The accumulation of uncertainties reduces the interest of such results….

Conclusion

There is a need to help stakeholders with adaptation to climate change
however, such studies are still challenging for hydrological impact studies

Costly, a lot of uncertainties ➔ **Is it worthwile?**

- Hydrological model can be simpler (less costly, less sensitive?)

➔ however, it is known some processes are complex, will this reduce the uncertainty ?

- Impact could be directly estimated by « earth system model », thus limiting the cascade of uncertainty (Climate model ->SDM –> Impact model)

➔ Still difficult to be confident so far… some kind of SDM will be still needed

- Reducing the spread by selecting the downscale projections 

➔ Yes, but is it really possible according to the large impact of natural variability ?

- Won't it be better to have less accurate & more easy to interpret results, as the one derived from delta method, or some downscaling based on the targeted variables…
- As long term observations are often not available, should we use reconstructed past model reconstruction instead of obs ?
- Should Weather Generator system will solve part of the problem ?