Modeling aquifers and floodplains in global climate simulations : evaluation and impact

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IGEM Workshop, Paris, October 5th 2016

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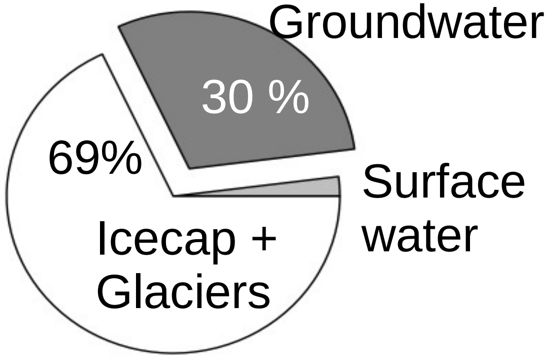
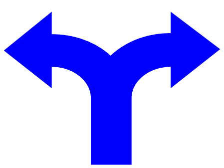
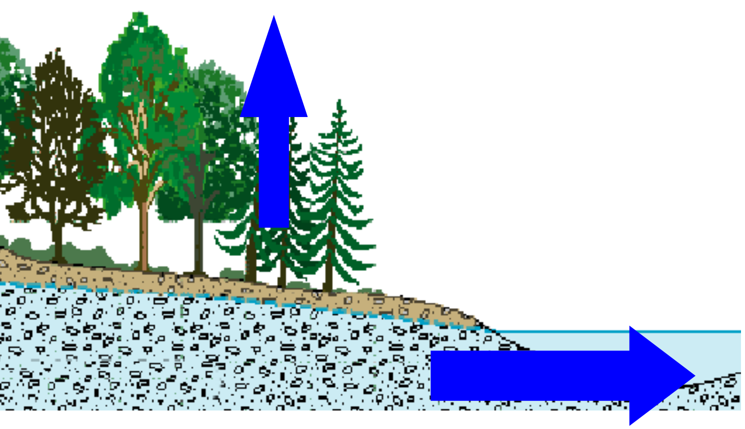
Motivations

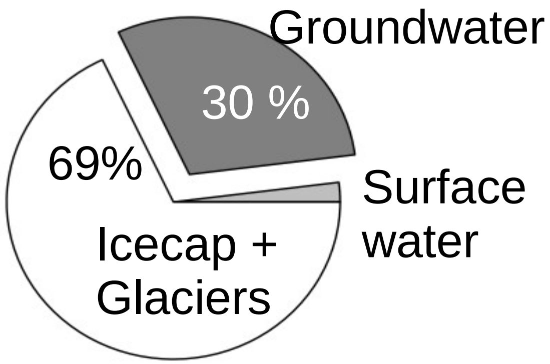


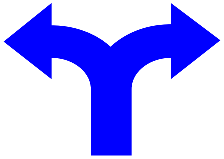


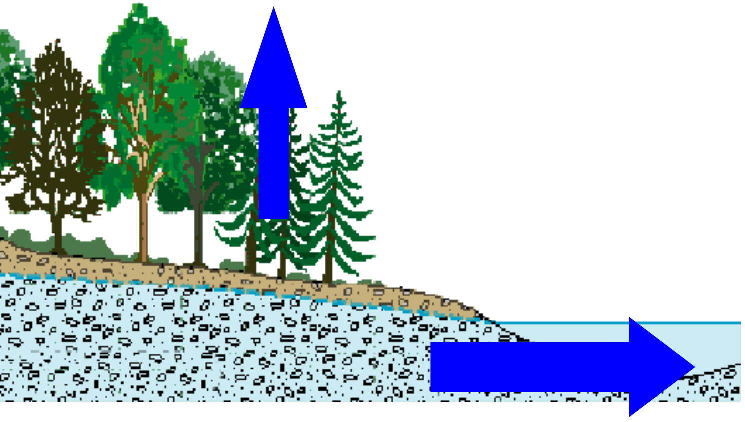


- **Why modeling groundwater in a climate model ?**
  - To simulate its evolution in a changing climate
  - To take into account the possible impact on the simulated atmosphere and/or ocean
- **How accurately do we simulate aquifers and floodplains ?**
- **Does it improve the rest of our hydrology?**
- **What is the impact on the simulated (present-day) climate ?**

Motivations







- **Why modeling groundwater in a climate model ?**
  - To simulate its evolution in a changing climate
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  Same perspective for the modeling of floodplains

- **How accurately do we simulate aquifers and floodplains ?**

- **Does it improve the rest of our hydrology?**

- **What is the impact on the simulated (present-day) climate ?**

Outline

1. Presentation of the model

- CNRM-CM6 climate model
- Aquifer scheme
- Flood model
- Simulations

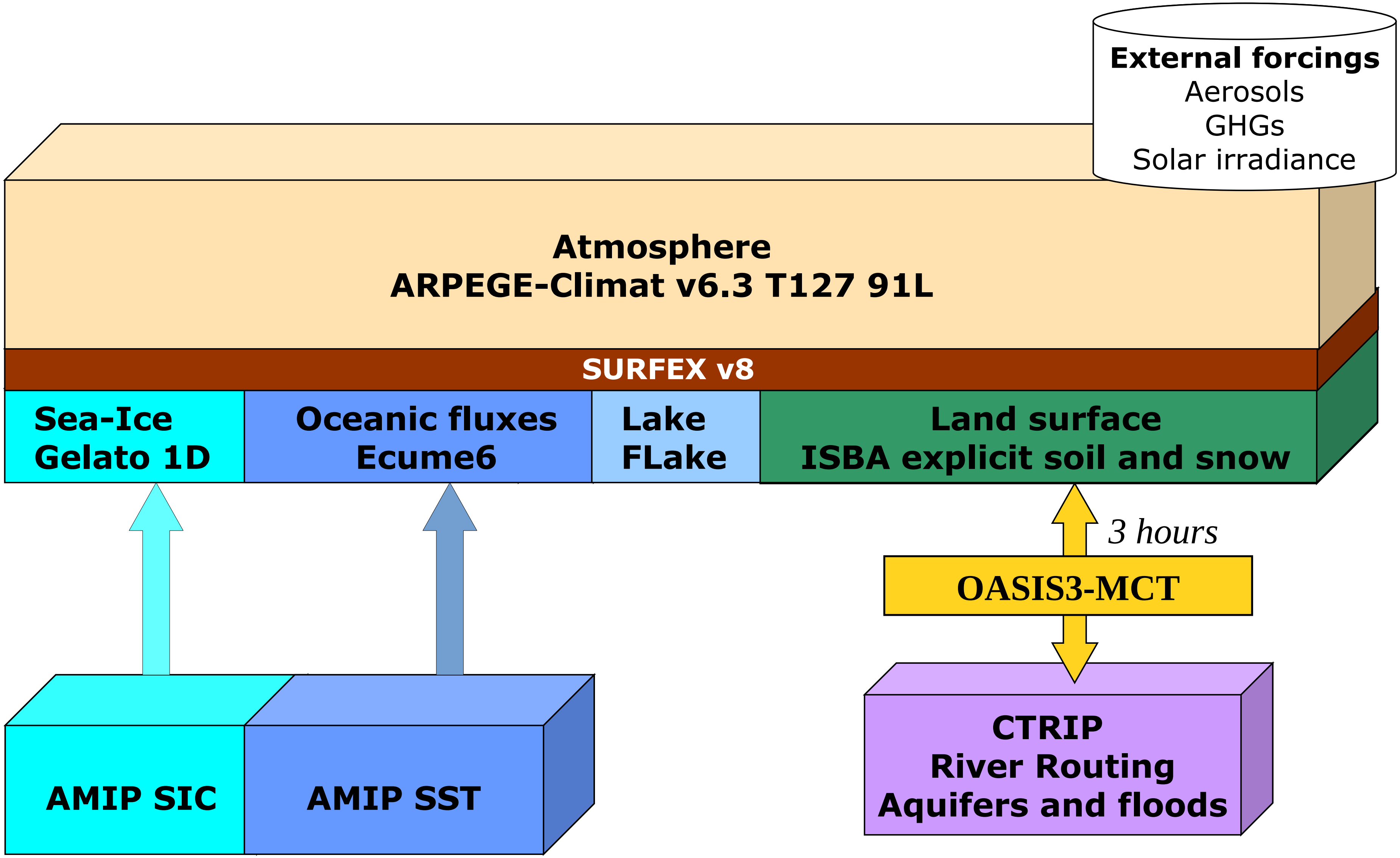
2. Validation/evaluation

- Validation in offline mode (land/river only)
- Evaluation in inline mode (coupled to the atmosphere)

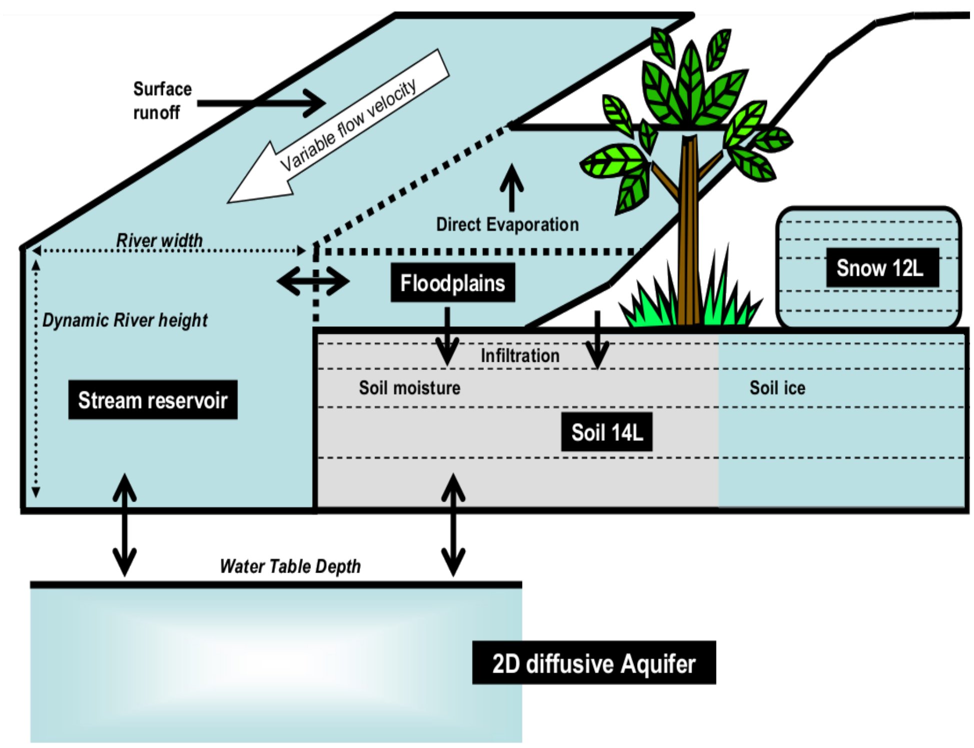
3. Impact on the simulated climate

Summary and outlook

The CNRM-CM 6 (CMIP6) climate model

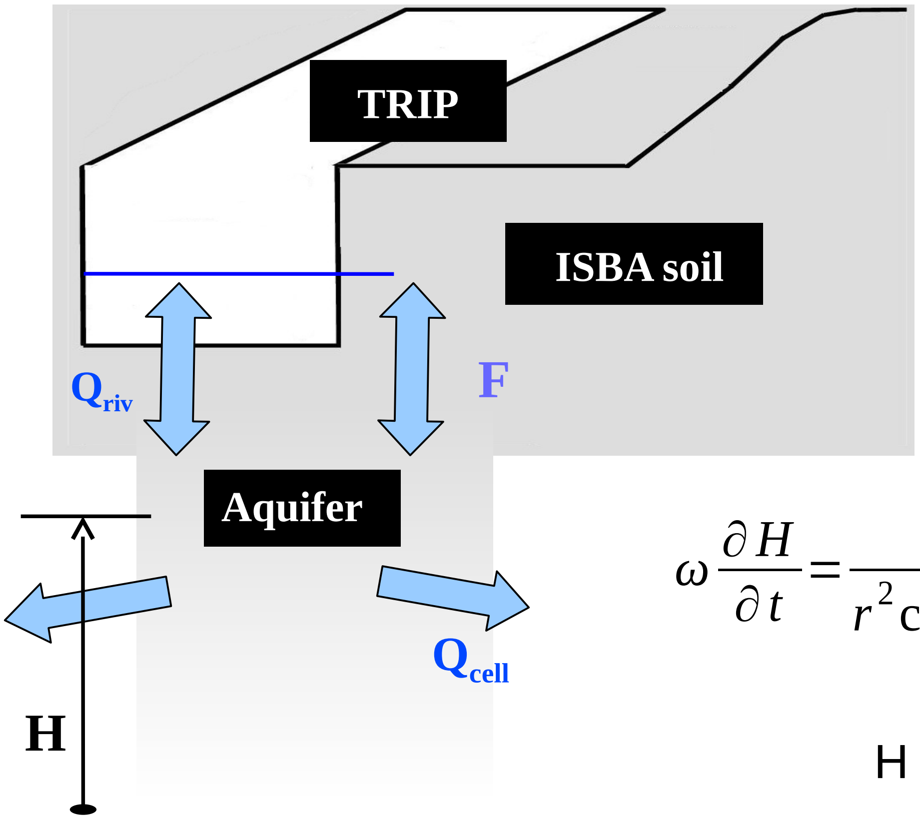


Hydrology in ISBA-CTRIP
New version (CNRM-CM6)



- 14-Layers explicit soil scheme
  Boone et al., 2000
  Decharme et al., 2011 & 2013
- 12-Layers explicit snow scheme (mass and heat) & Soil Organic Carbon effects on soil properties
  Boone and Etchevers, 2001
  Decharme et al., 2016
- Variable flow velocity and river network at 0.5°
  Decharme et al., 2011
- Two-dimensional diffusive aquifer allowing upward capillarity fluxes to the subsoil
  Vergnes et al., 2012a,b & 2014
- Floodplains dynamics with direct re-evaporation, precipitation interception and soil re-infiltration
  Decharme et al., 2008 & 2012

Aquifer scheme



(Vergnes et al. 2012, 2014)

Unconfined aquifers

One layer

Groundwater-river exchanges Q_{riv}

Lateral fluxes Q_{cell}

Coupling with ISBA Flux F

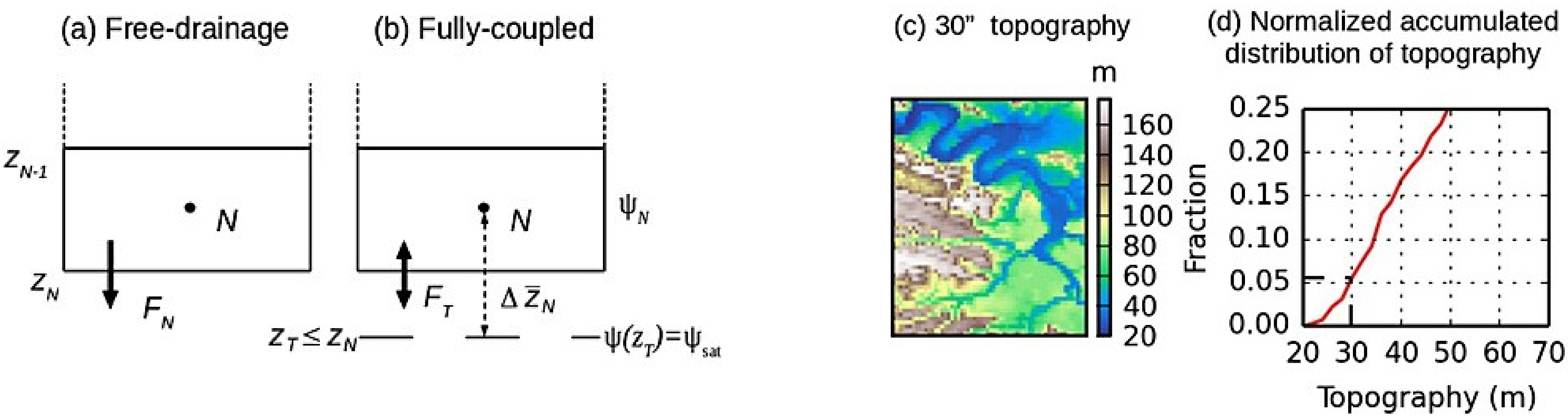
$$\omega \frac{\partial H}{\partial t} = \frac{1}{r^2 \cos(\phi)} \left[\frac{\partial}{\partial \theta} \left(\frac{T_\theta}{\cos(\phi)} \frac{\partial H}{\partial \theta} \right) + \frac{\partial}{\partial \phi} \left(T_\phi \cos(\phi) \frac{\partial H}{\partial t} \right) \right] + Q_{sb} - Q_{riv}$$

H : water table head (m)

ω : effective porosity

T : transmissivity (m²/s)

Aquifer scheme : coupling with the soil column



$$F_N = k_N$$

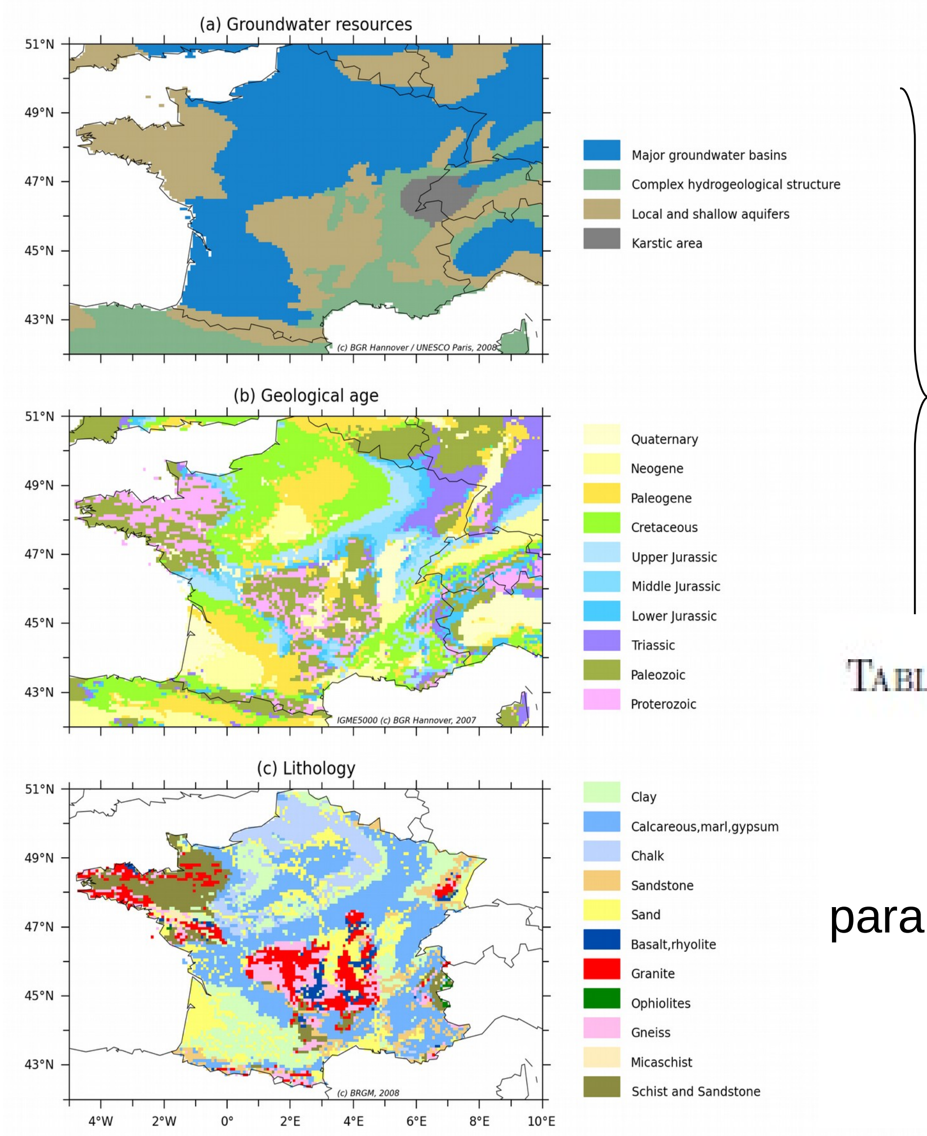
$$F_T = k_N\left[\frac{(\psi_N - \psi_{sat})}{\Delta\bar{z}_N} + 1\right]$$

f_{wtd} : fraction of the grid-cell affected by capillary rise.

$$\boxed{F = f_{wtd}F_T + (1 - f_{wtd})F_N}$$

(Vergnes et al. 2012, 2014)

Aquifer basins and parameters
development at a regional scale



Aquifer basins

TABLE 1. Mean values of transmissivity and effective porosity taken from the

parameters

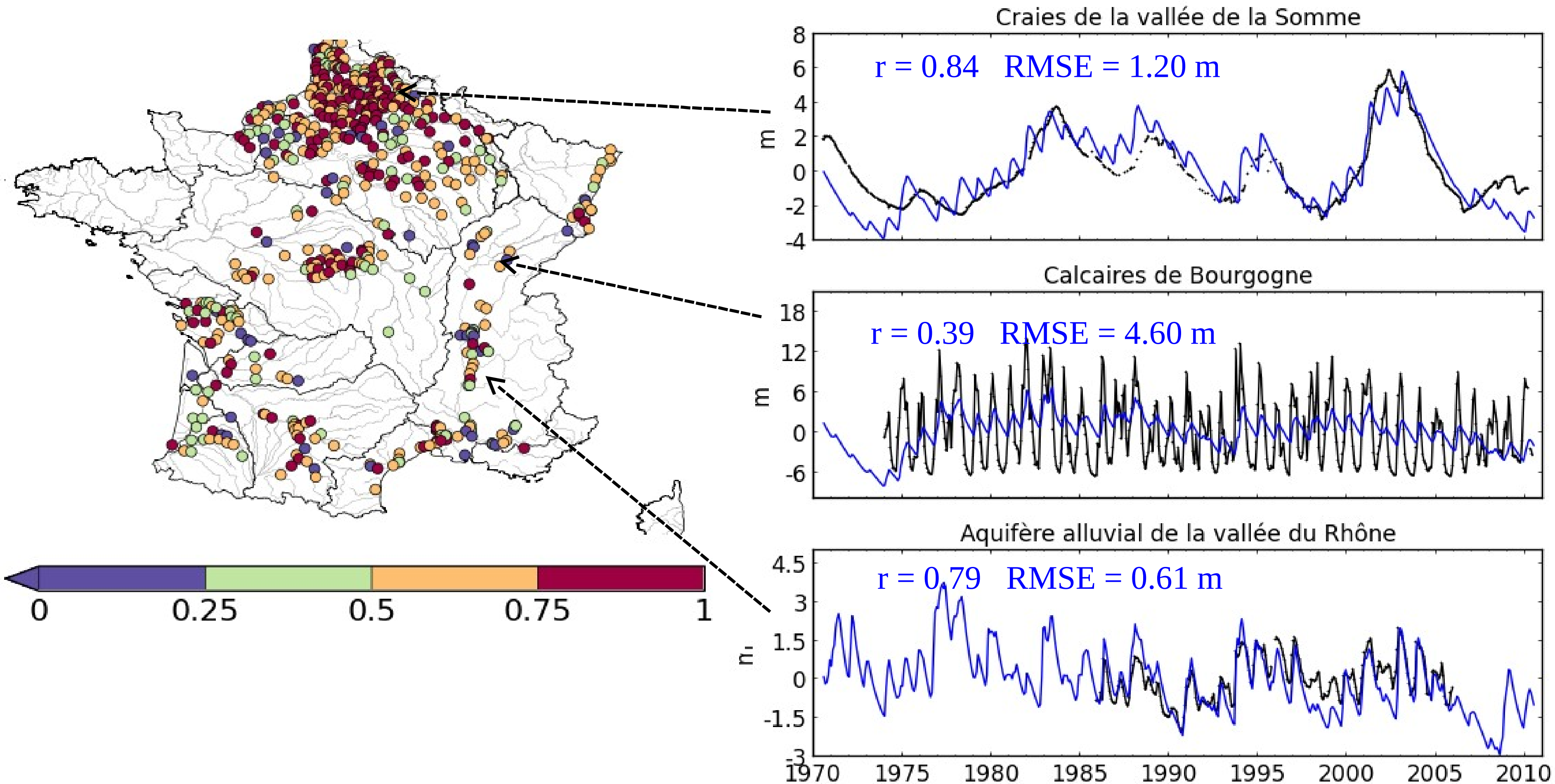
Lithology	Transmissivity ($m^2\ s^{-1}$)	Effective porosity
Clay	5.10^{-4}	0.01
Limestone	5.10^{-3}	0.03
Chalk	1.10^{-2}	0.05
Sandstone	2.10^{-2}	0.07
Sand	5.10^{-2}	0.1

Vergnes et al., 2012a

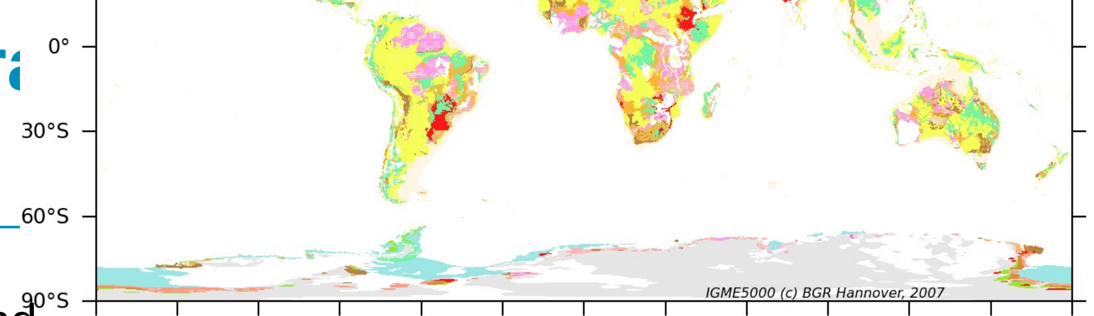
Aquifer scheme validation at a regional scale

GW12 correlation

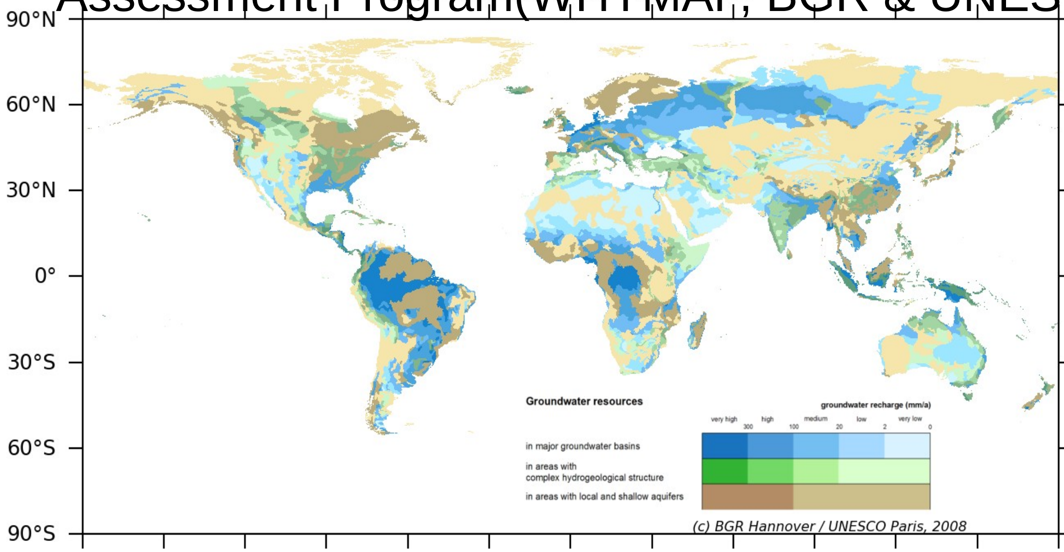
Vergnes et al., 2012a



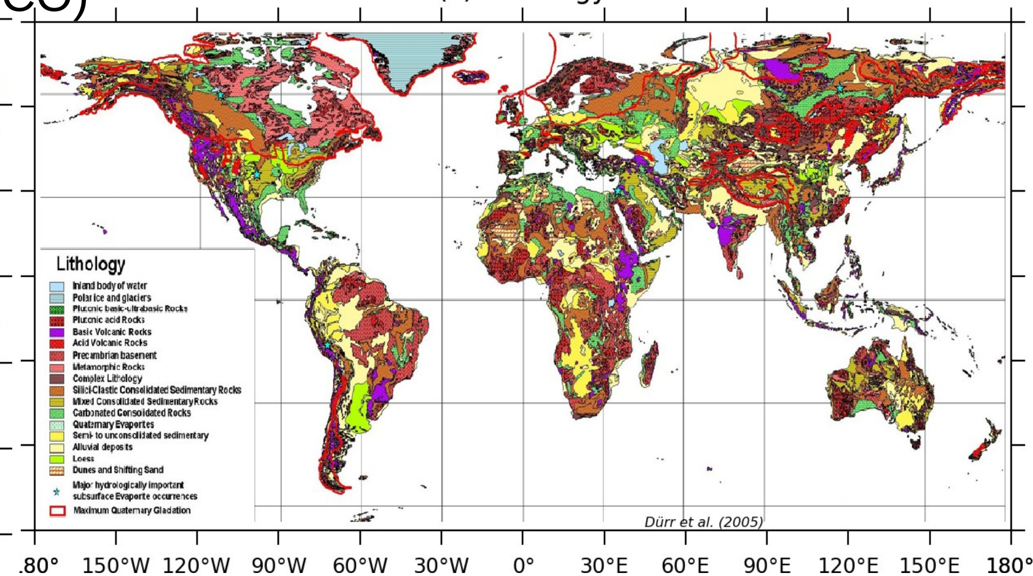
Aquifer basins and par
extension at global scale

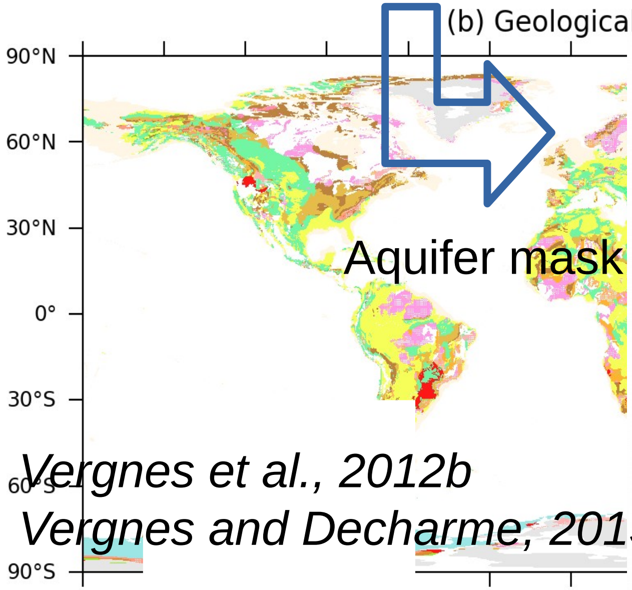


The World-wide Hydrogeological Mapping and Assessment Program(WHYMAP; BGR & UNESCO)

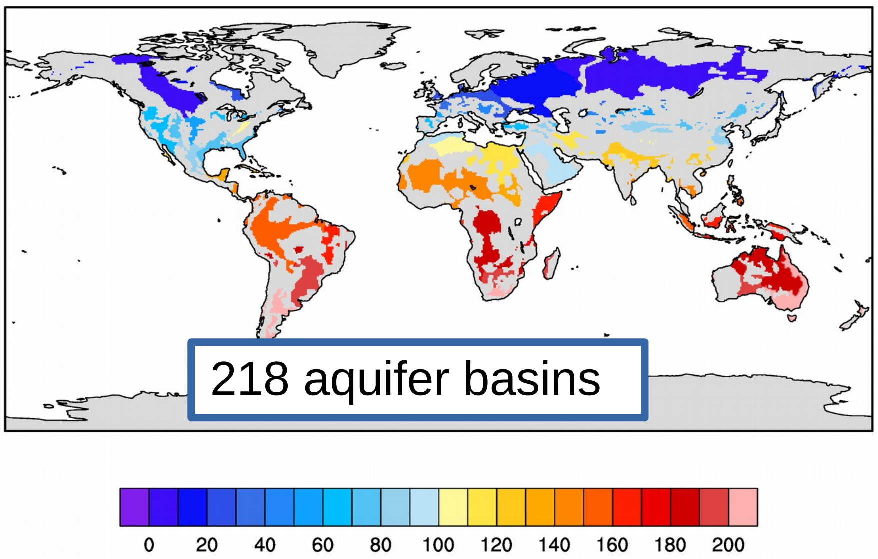


Lithology map (Dürr et al., 2005)





Aquifer mask

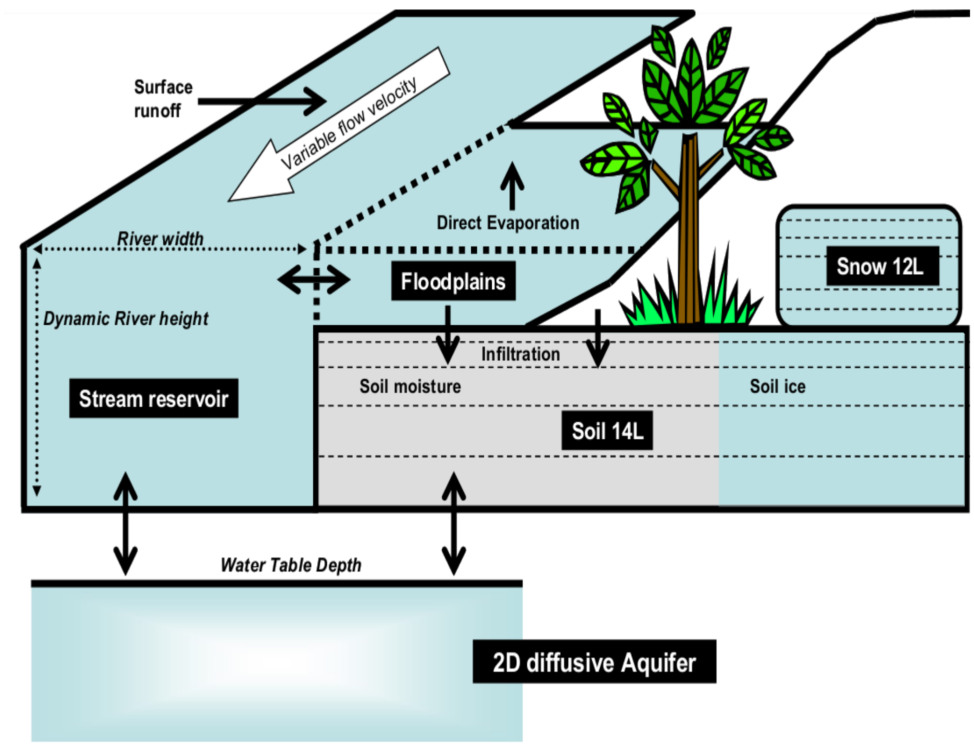


218 aquifer basins

Transimittivities and porosities

Vergnes et al., 2012b
Vergnes and Decharme, 2013

Flood model



- Addition of a flood reservoir in TRIP

$$\partial F / \partial t = Qin - Qout + (Pf - If - Ef)$$

Qin (kg/m²) : Inflow from the river

Qout (kg/m²) : Outflow into the river

Pf (kg/m²) : Precipitation intercepted by the floodplain

If (kg/m²) : Infiltration of the flooded fraction of the ISBA grid cell

Ef (kg/m²) : Direct Evaporation

(Decharme et al., 2008 & 2012)

Simulations

Offline (SURFEX-TRIP stand-alone)

TRIP 0.5°
SURFEX 1°

1979-2010

Forcing : PGF

CTL : River routing, variable stream velocity (Manning)

GW : Vvar + Aquifer

GW+FLD : Vvar + Aquifer + Flood

Inline *(coupling with the atmosphere)*

TRIP 0.5°
SURFEX
ARPEGE-Climat

$\left.\begin{matrix}\text{SURFEX}\\ \text{ARPEGE-Climat}\end{matrix}\right\}$ T127 – 150 km

1979-2010 (5-year spin-up)

Coupling with ARPEGE-Climate

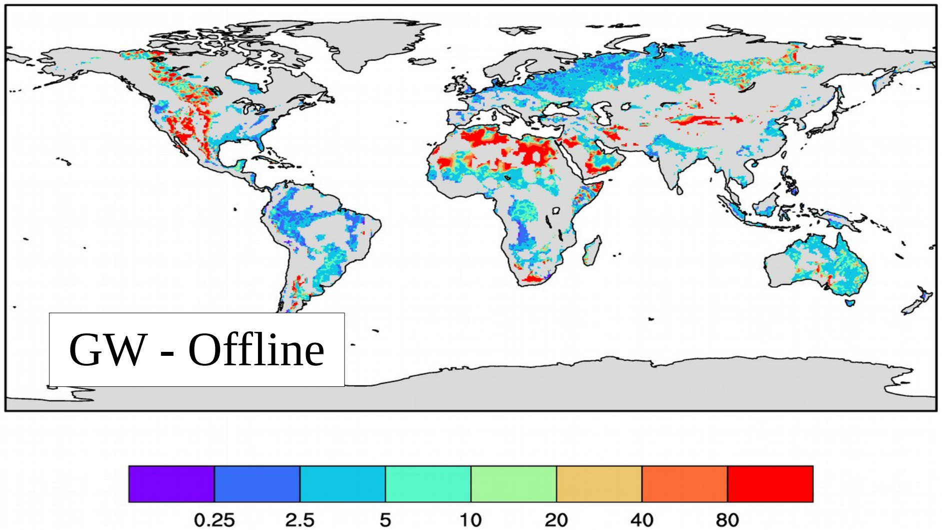
CTL

GW

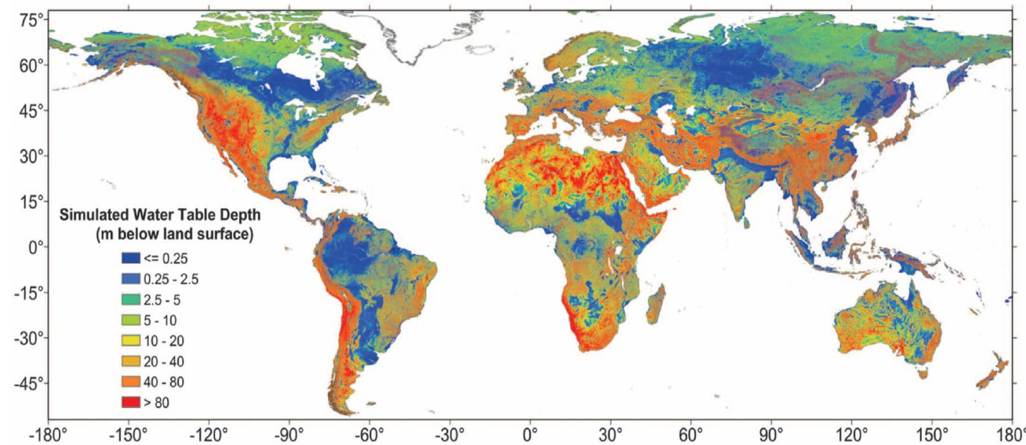
GW+FLD

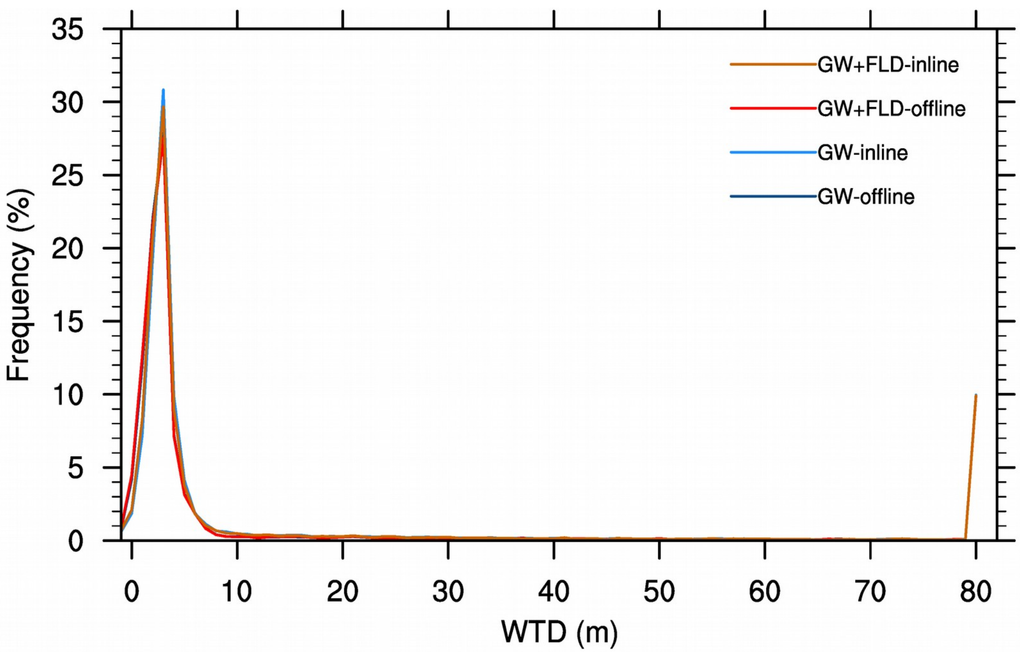
2. Validation and evaluation
Water Table Depths (WTD)

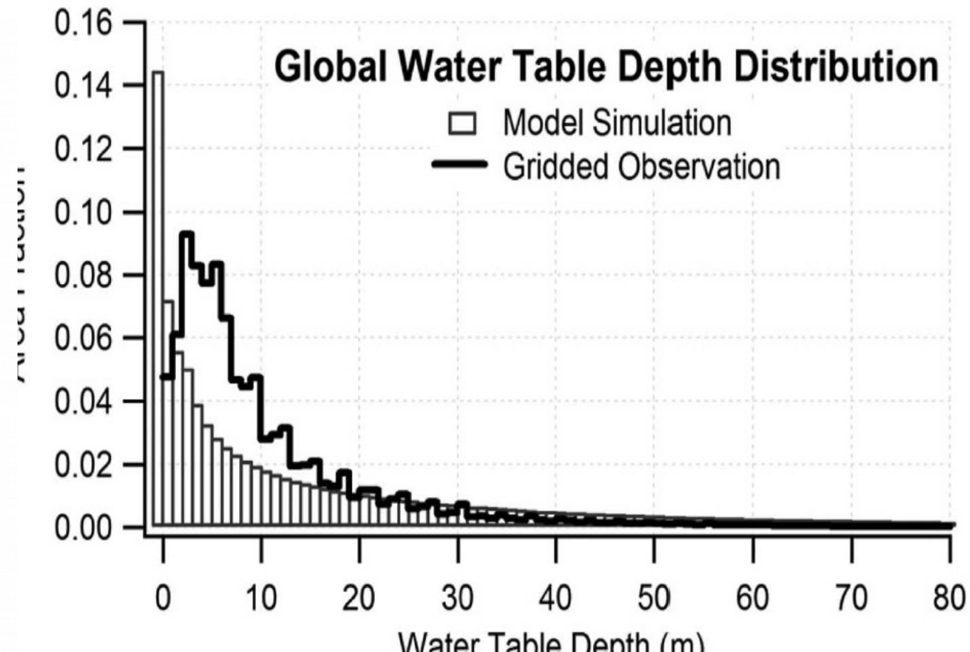
GW simulations



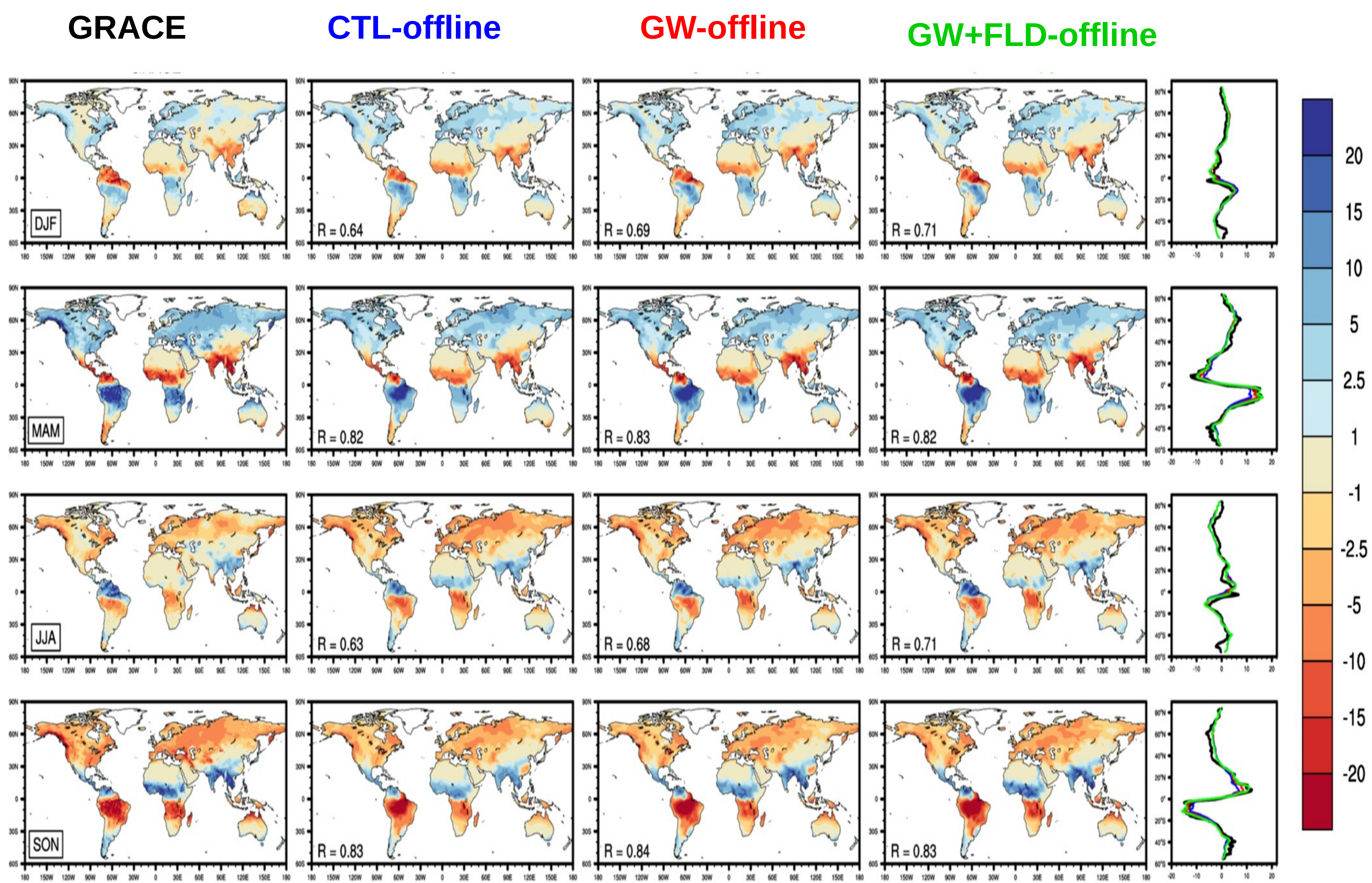
Model and data from Fan et al., 2013



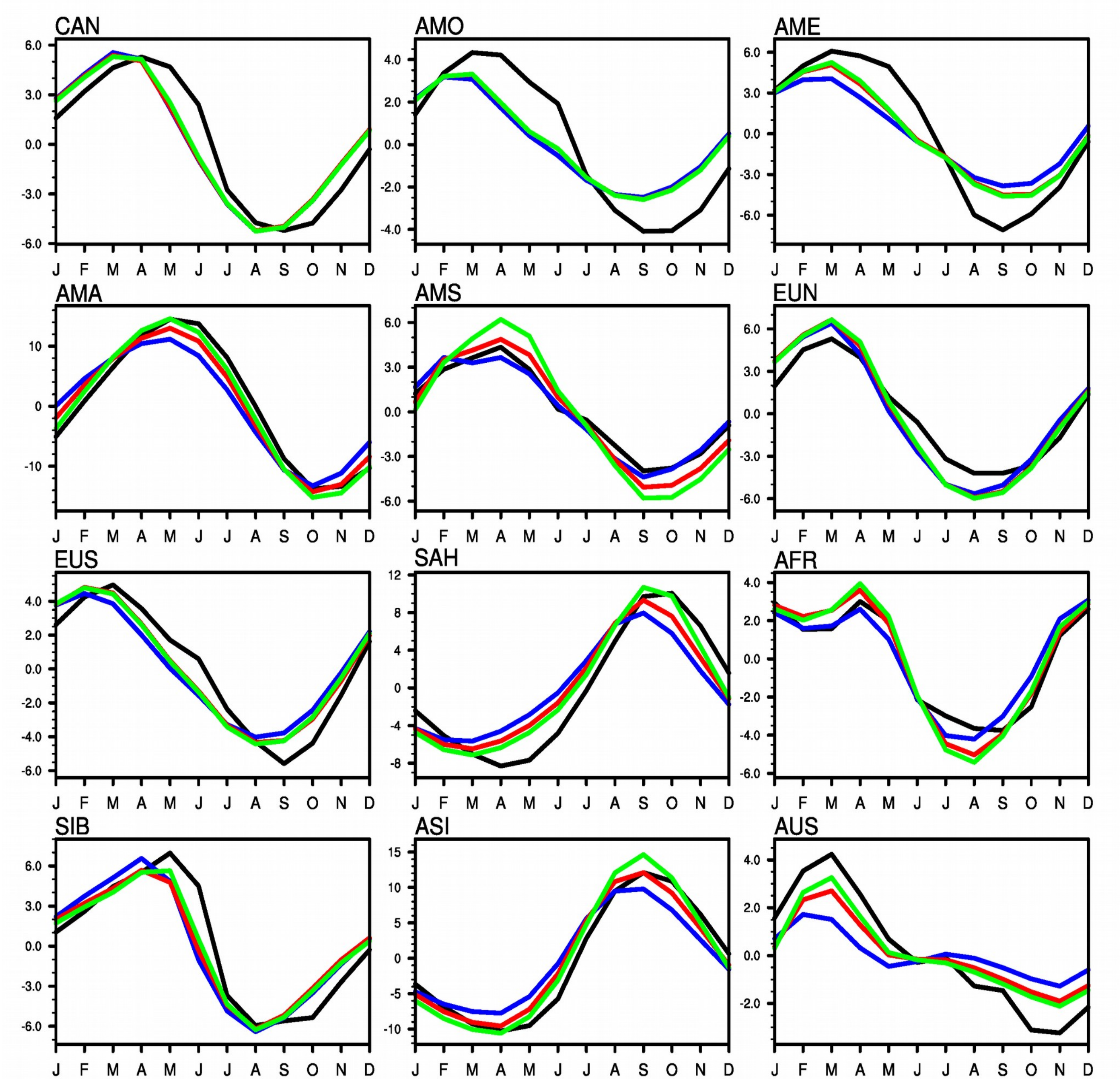


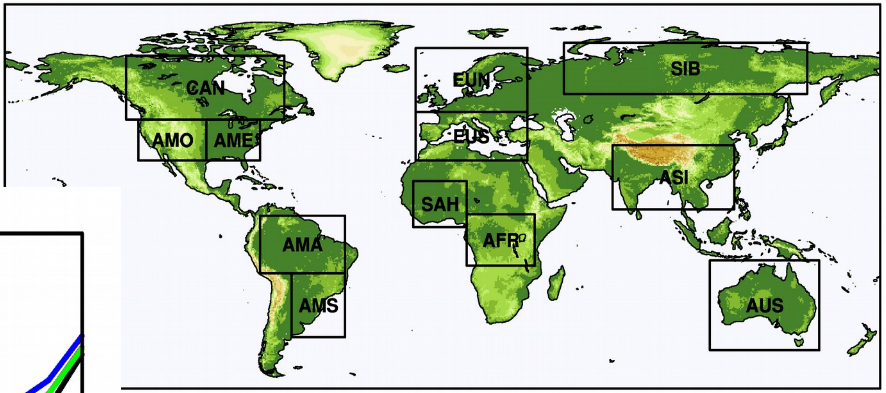


Terrestrial Water Storage (TWS)
Seasonal means



TWS
Seasonal cycle

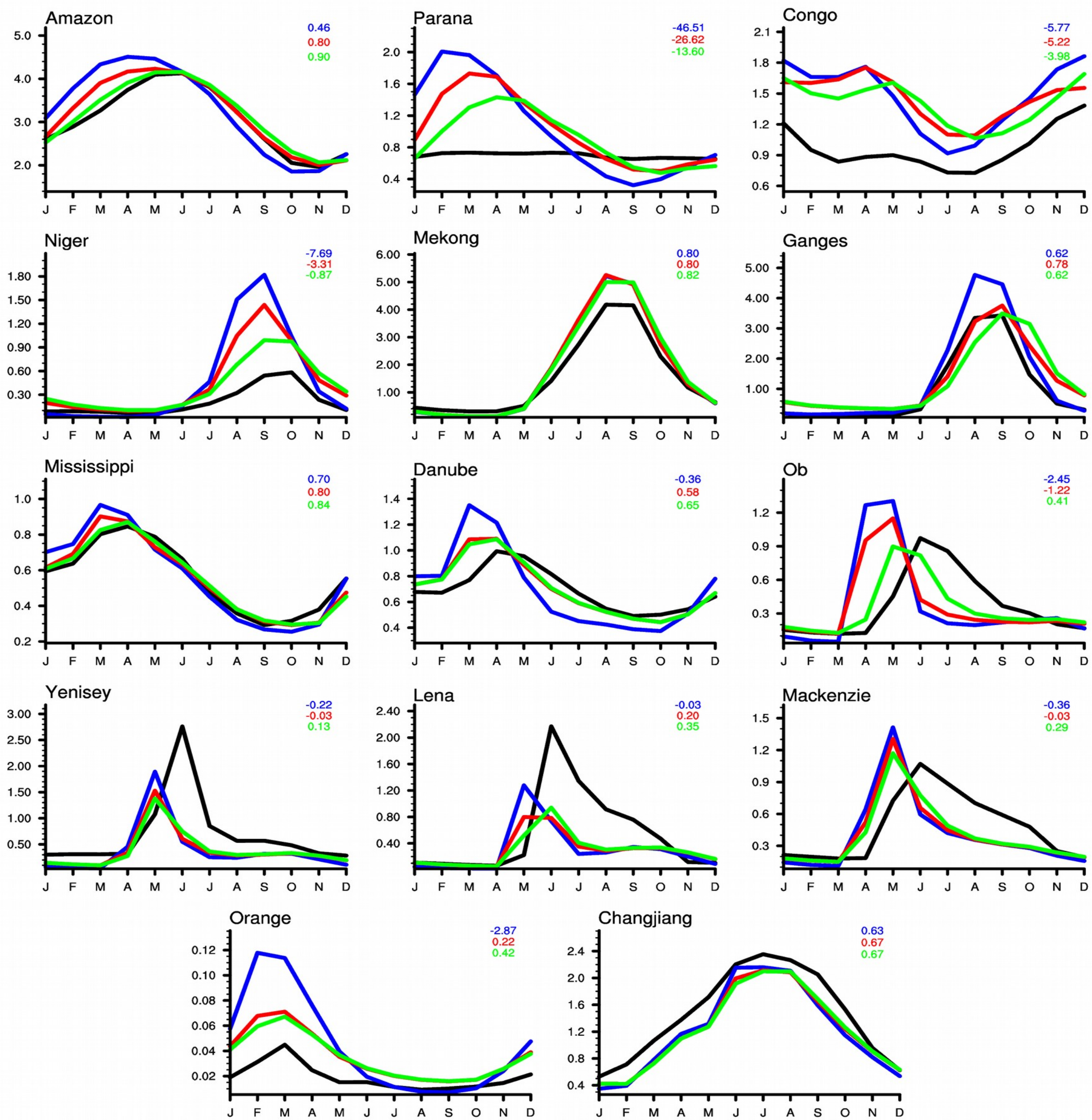


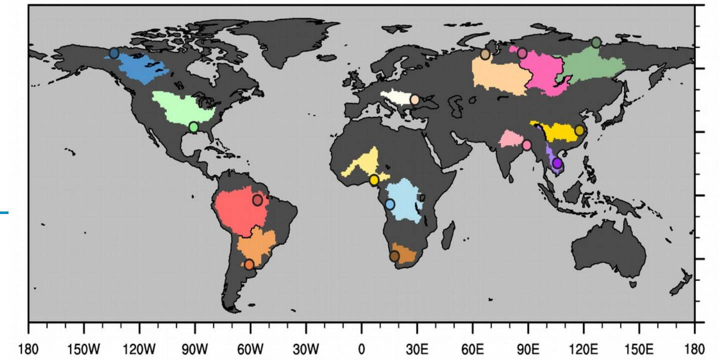


GRACE
CTL-Offline
GW-Offline
GW+FLD-Offline

GW improves results
The effect of floodplains depends on the region

River discharge
Seasonal cycle





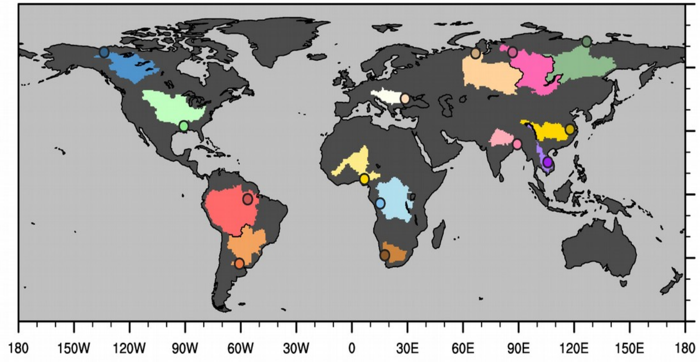
Observation
CTRL-Offline
GW-Offline
GW+FLD-Offline

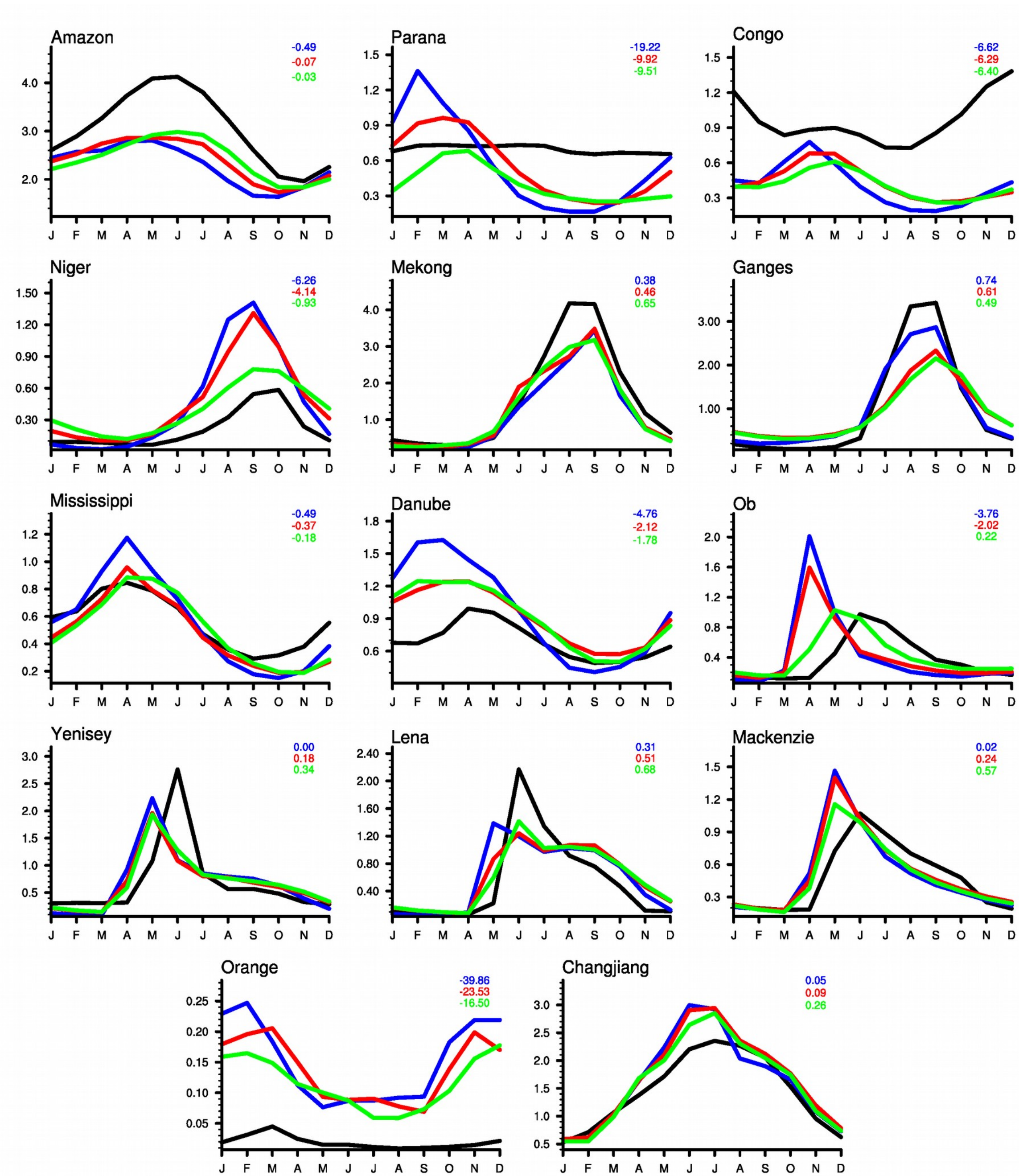
GW : generally improves the cycle

GW + FLD : even better

Inline simulations

River discharge





Obs
CTL-Inline
GW-Inline
GW+FLD-Inline

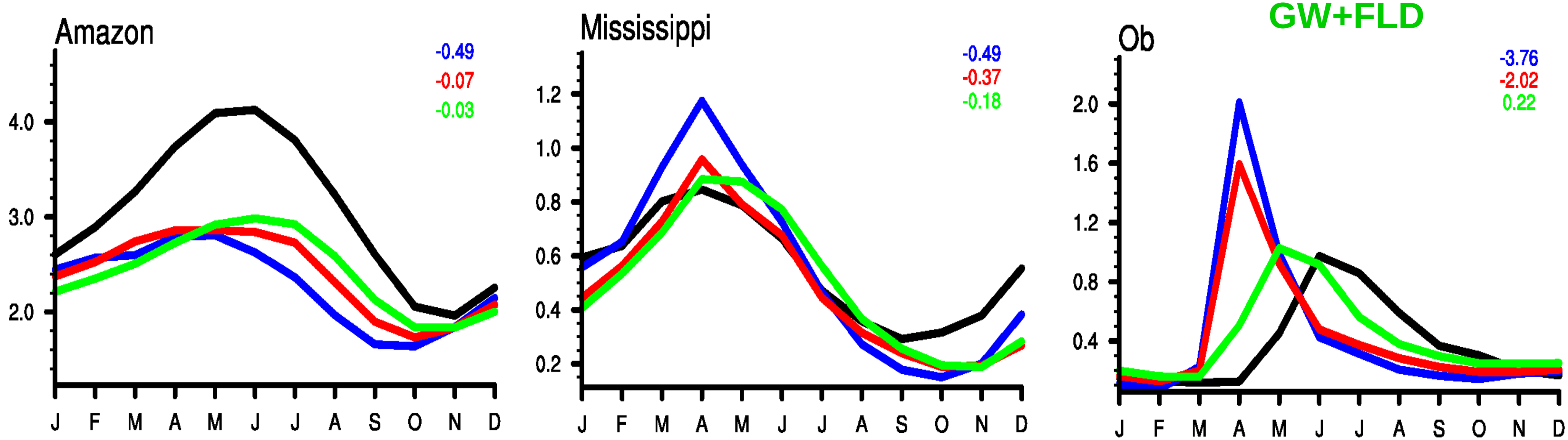
Inline discharge integrates error on the simulated precipitation

Improvement in almost every basin with GW,
and sometimes even more so with GW+FLD.

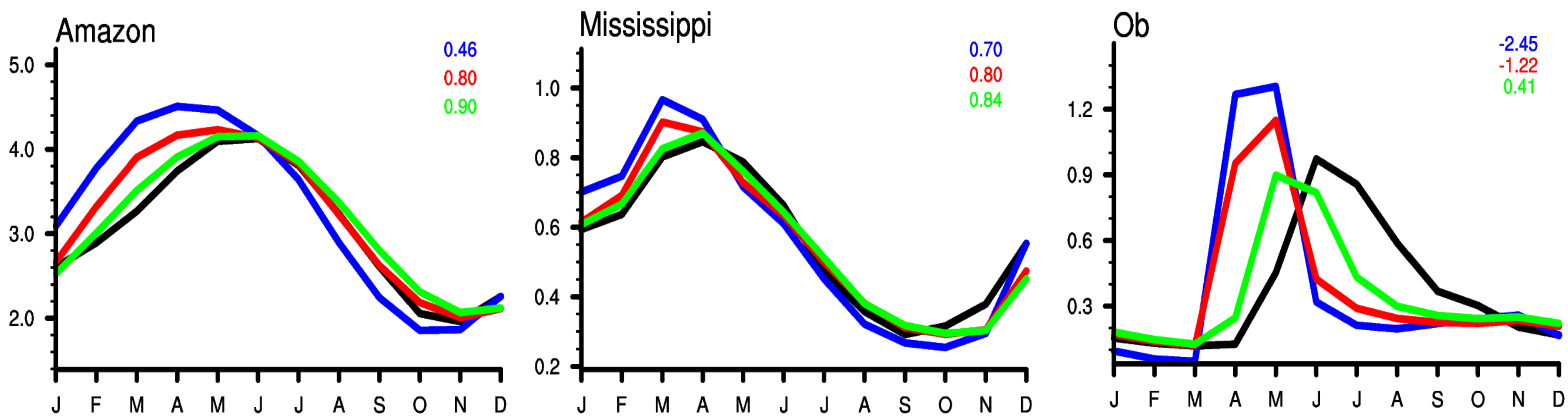
River discharge

Obs
CTL
GW
GW+FLD

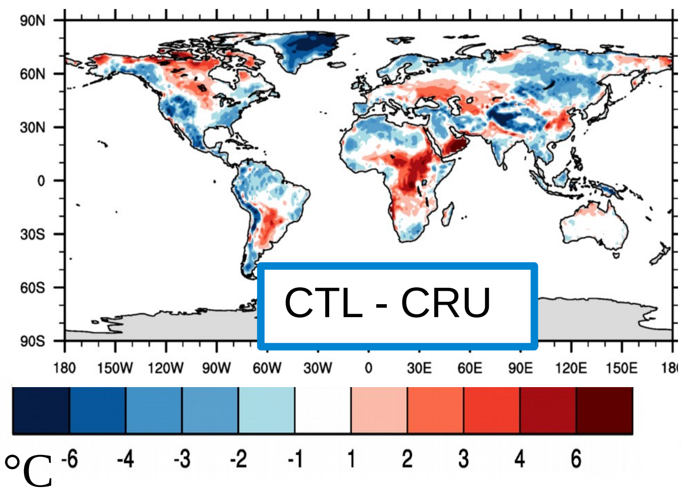
Inline simulations

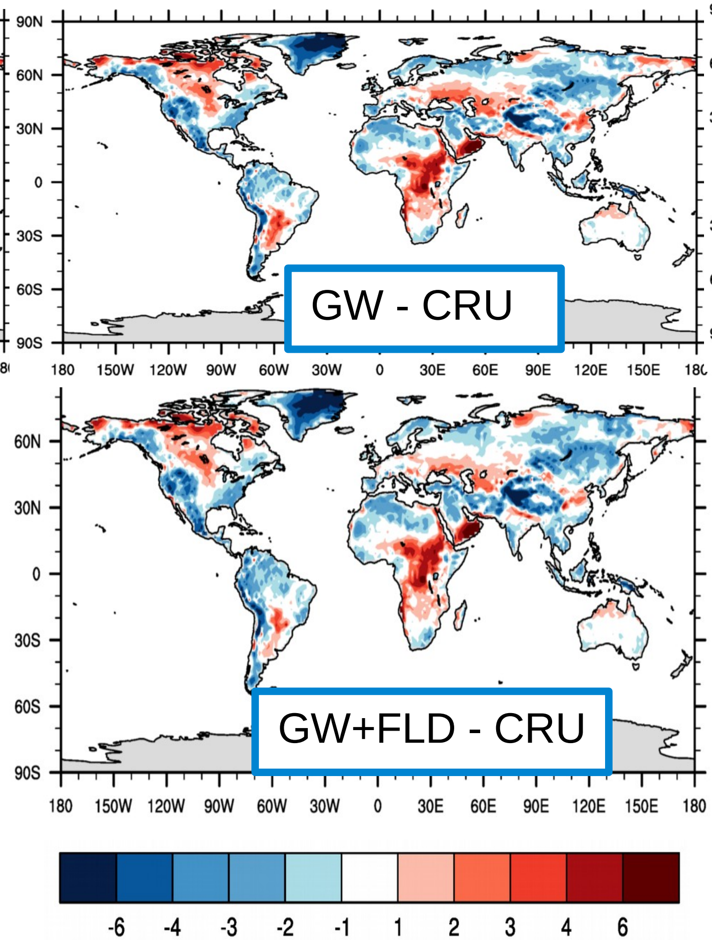


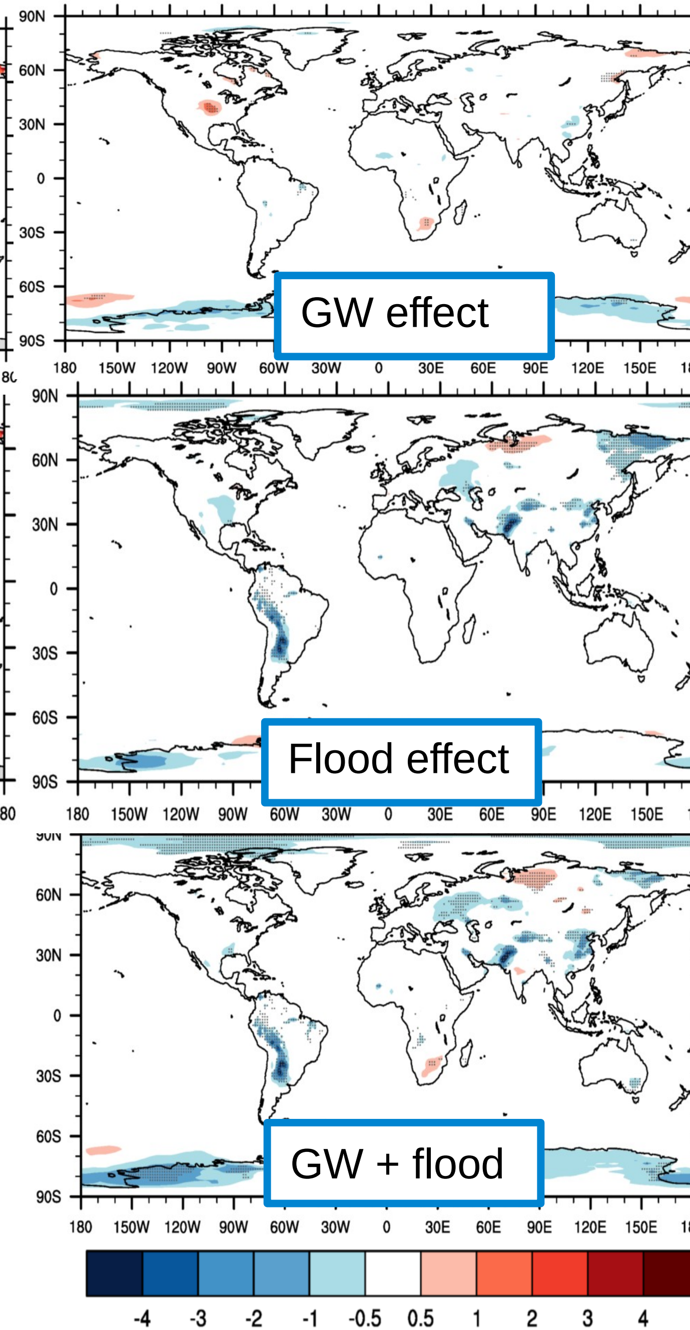
Offline simulations



3. Impact on the simulated climate
2-meter daily max. temperature (JJA)

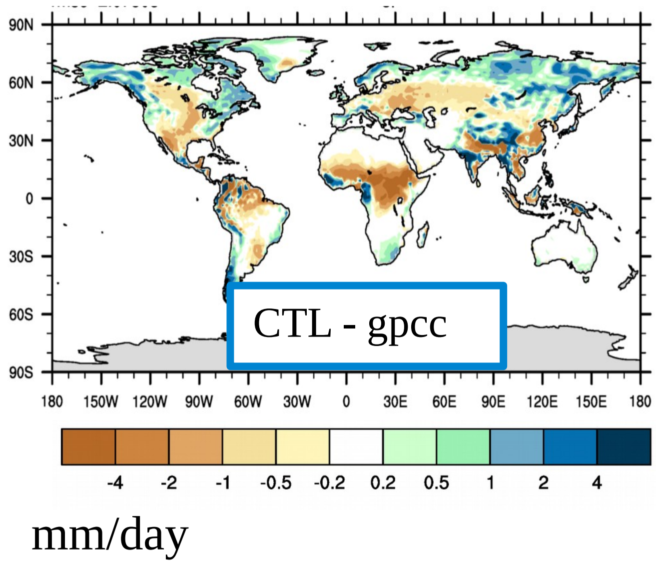


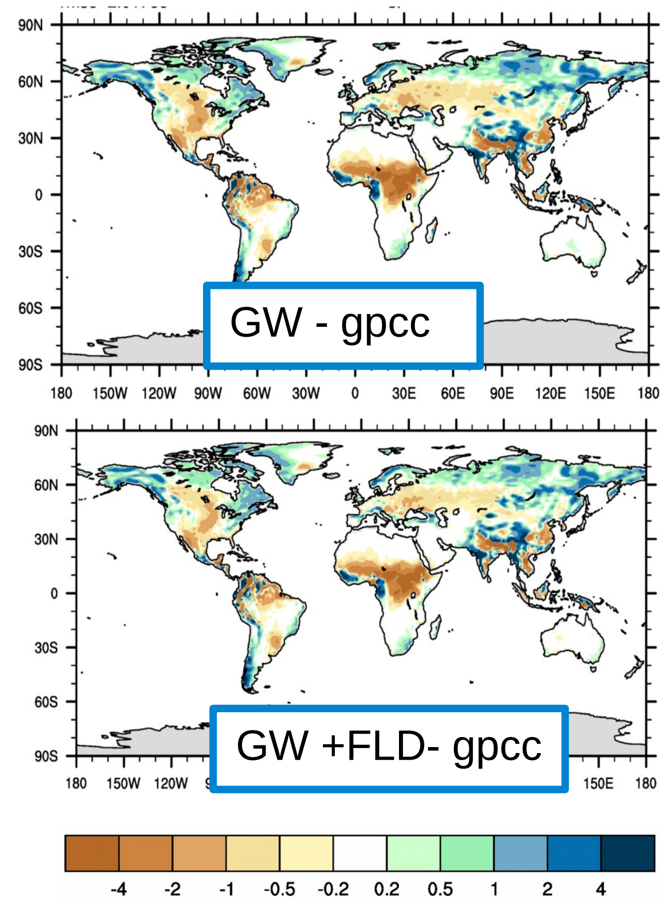


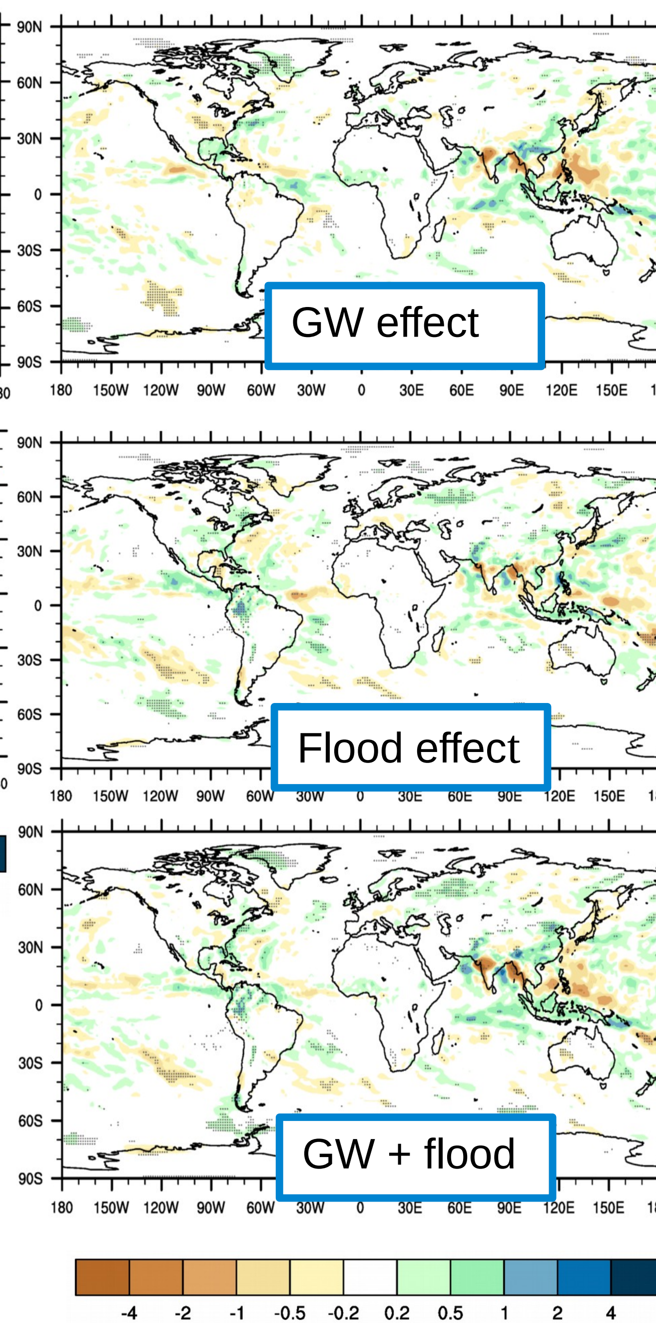


- No impact of the aquifers
- Floodplains lead to a cooling

Precipitation (JJA)

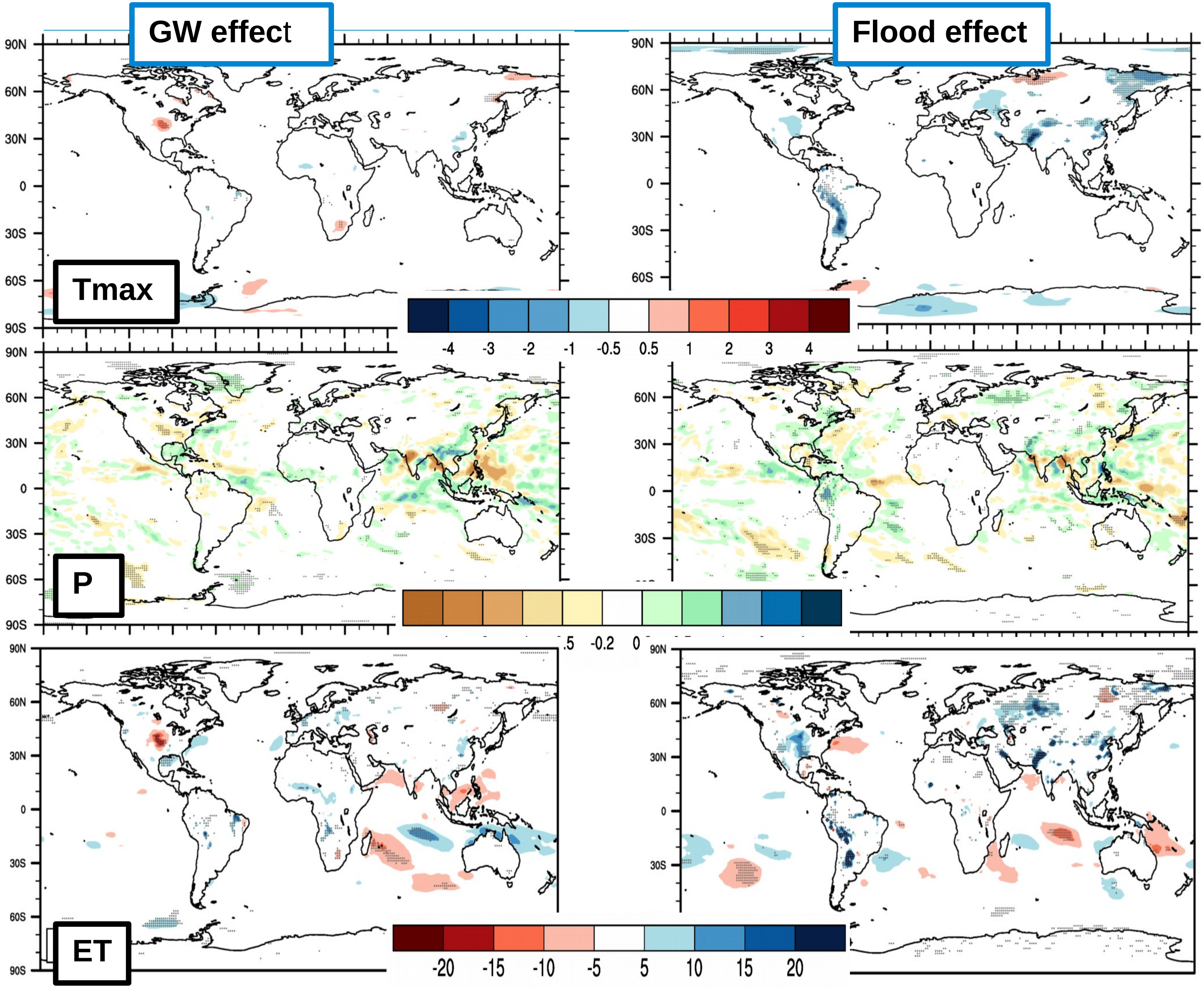






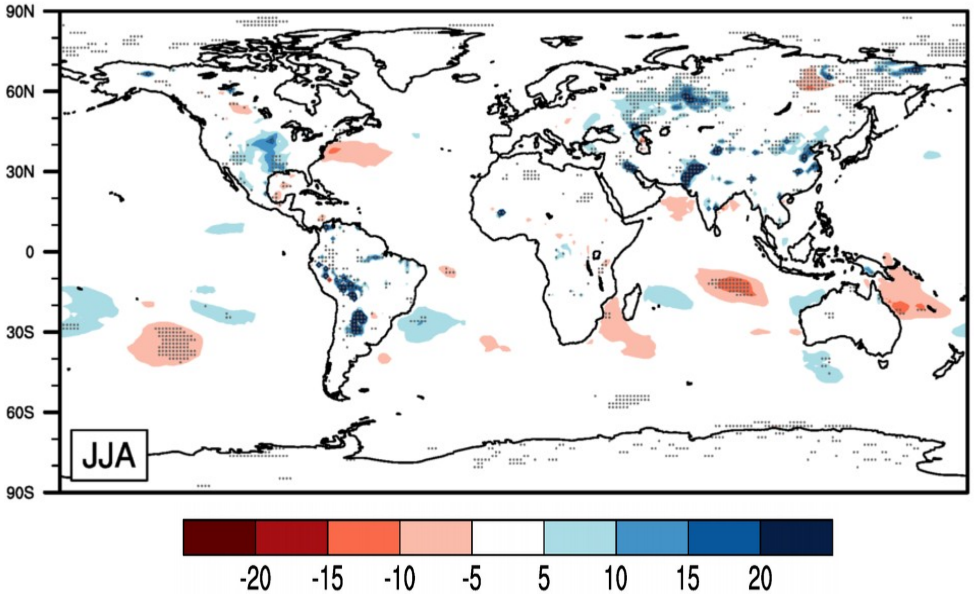
- No impact of the aquifers
- Floodplains enhances the precipitation

Evapotranspiration changes

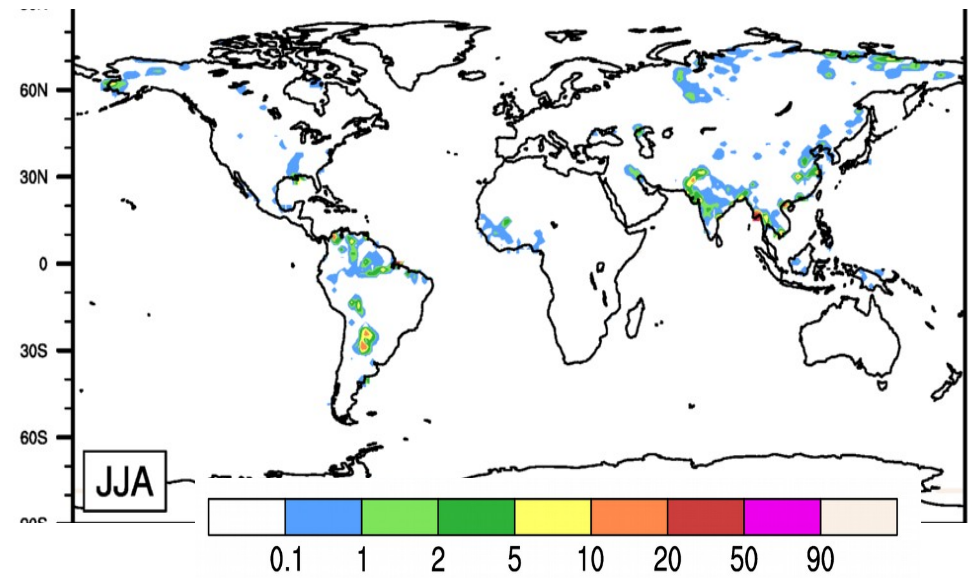


Floodplains effect
Infiltration or open water evaporation ?

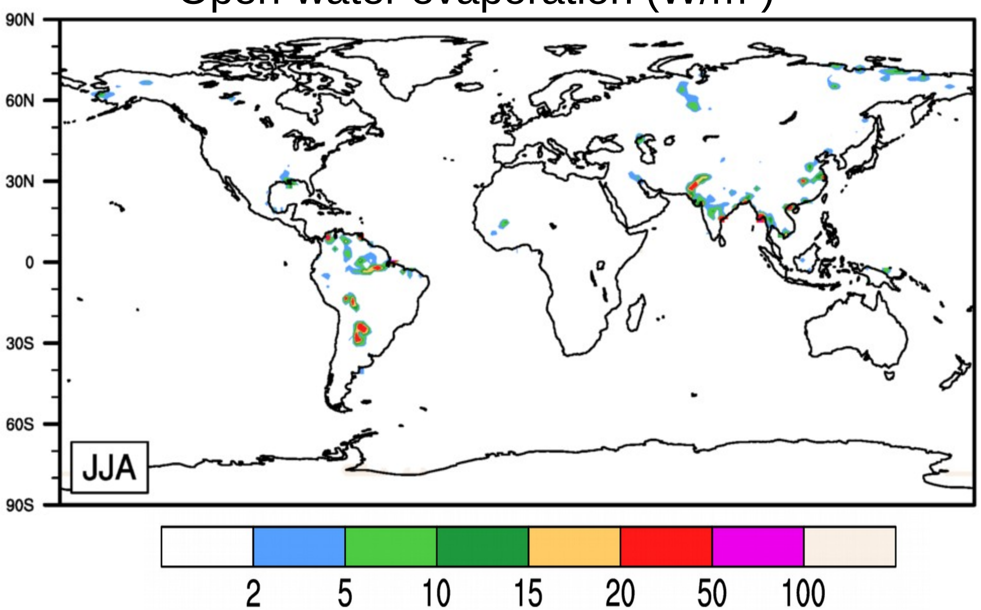
ET differences (W/m^2)



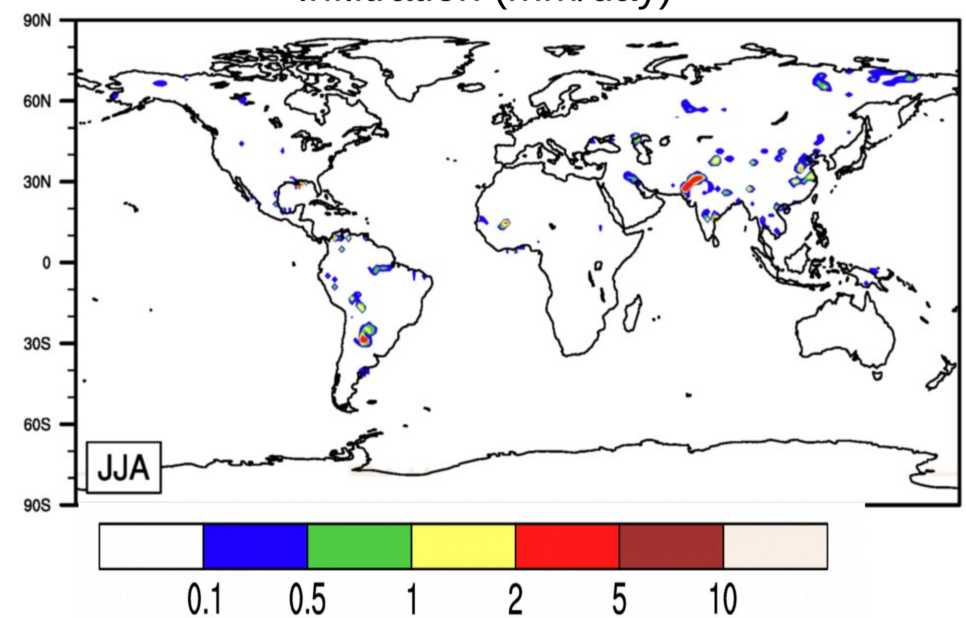
Floodplains grid cell fraction (%)



Open-water evaporation (W/m^2)



Inflitration (mm/day)



Summary

- An 2D-diffusive aquifer model and a floodplain scheme were added to the new version of the Land Surface Model ISBA-CTRIP.
- A first set of global climate simulations were performed with it.
- The simulated water table depths seem reasonnable.
- Offline (Land ony) evaluation show a moderate effect of aquifers and floodplains on Terrestrial Water Storage, but they do lead to an improvement of river discharge (seasonal cycles, as well as variability)
- The impact of the simulated aquifers on the climate is virtually Nonexistant in the summer. There is however an impact in winter (DJF) over Eastern Europe (not shown). The processes involved need further investigation.
- The floodplains scheme leads to a cooling of maximum

Outlook

- Further analysis of the results

- Run ensembles ?

- Assess the impact of groundwater at higher resolution (either globally or regionally)