Simulating aquifers and floodplains in a global climate model : evaluation and impact

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Motivations

- **Why modeling aquifers and floodplains in a climate model ?**
  - Because it is more realistic...
  - To take into account their possible impact on the simulated climate
  - Evolution of groundwater ressources in the future ?

- **How accurately do we simulate aquifers and floodplains ?**
- **Does it improve the SURFEX-CTRIP hydrology (river discharges) ?**
- **What is the impact on the simulated (present-day) climate ?**

Outline

1. Presentation of the model

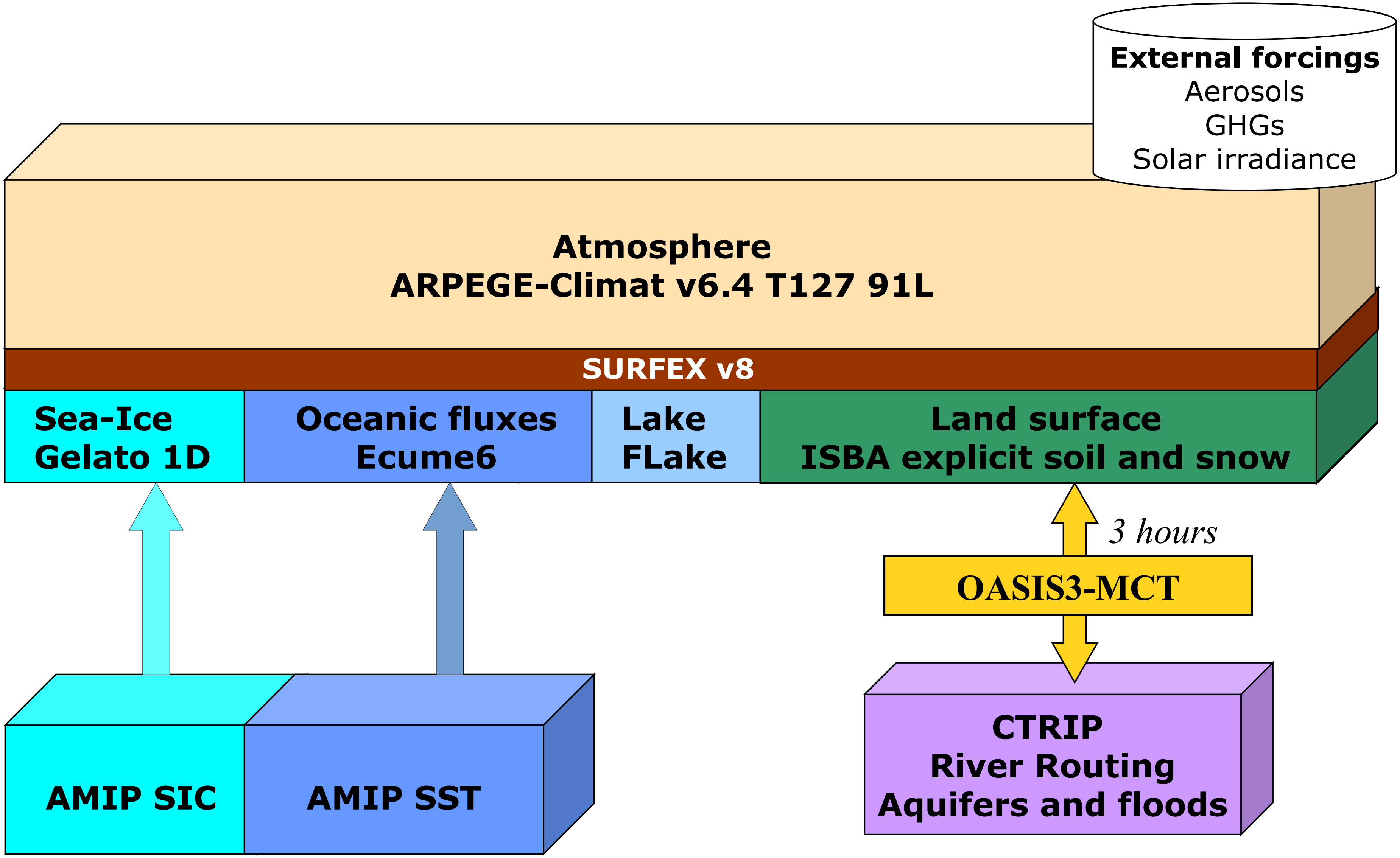
- CNRM-CM6 climate model
- Aquifer scheme and floodplains model
- Simulations

2. Evaluation

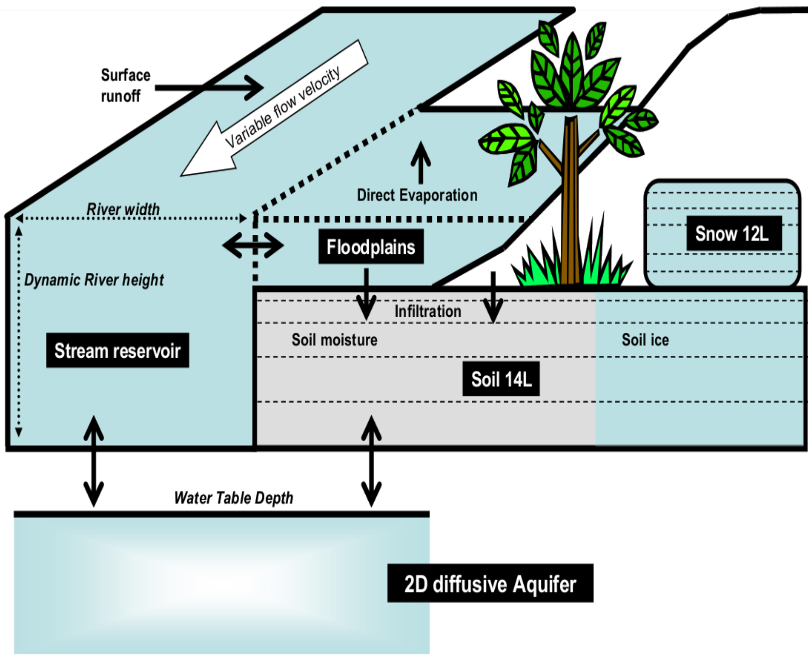
3. Impact on the simulated climate

Summary and outlook

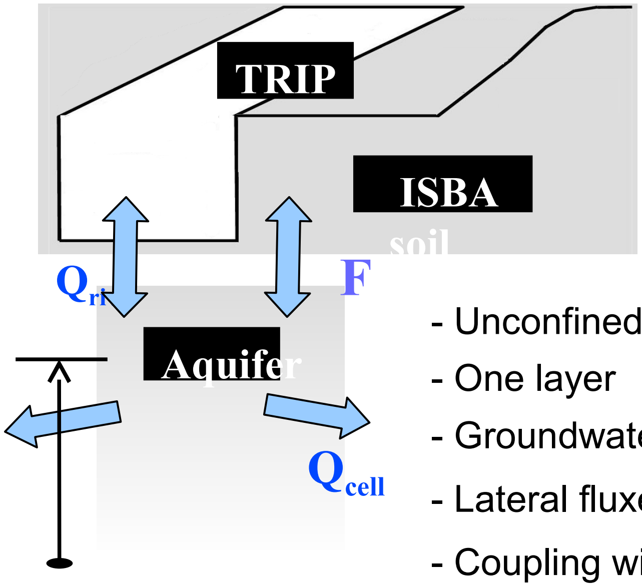
The CNRM-CM 6 (CMIP6) climate model



Hydrology in ISBA-CTRIP and aquifer scheme
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*



- Unconfined aquifers
- One layer
- Groundwater-river exchanges Q_{riv}
- Lateral fluxes Q_{cell}
- Coupling with ISBA Flux F

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

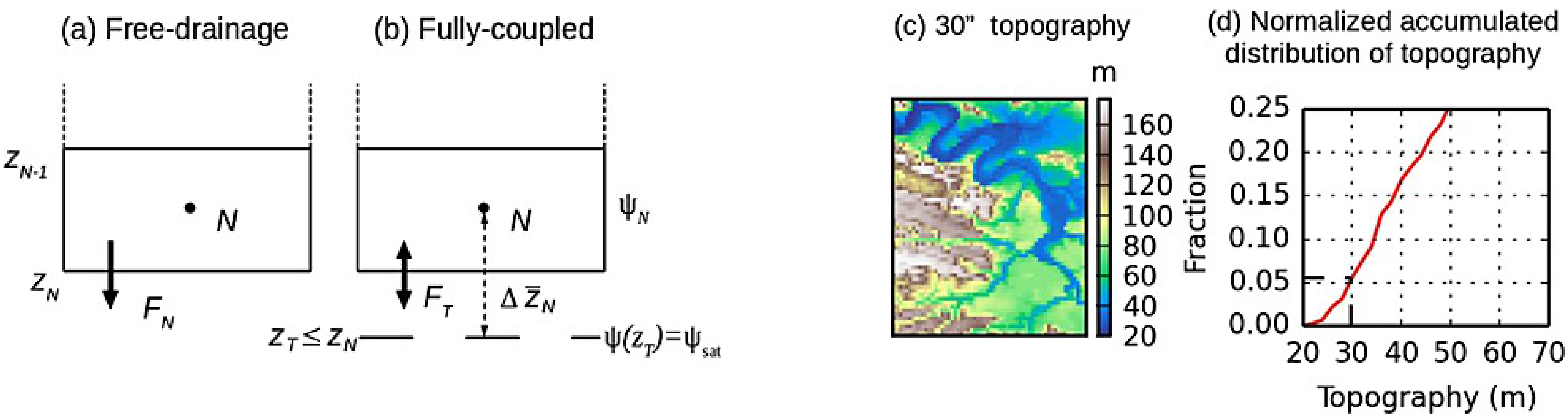
H : water table head (m)

ω : effective porosity

T : transmissivity (m²/s)

(Vergnes et al. 2012, 2014)

Aquifer scheme : coupling with the ISBA soil column



$$F_N = k_N$$

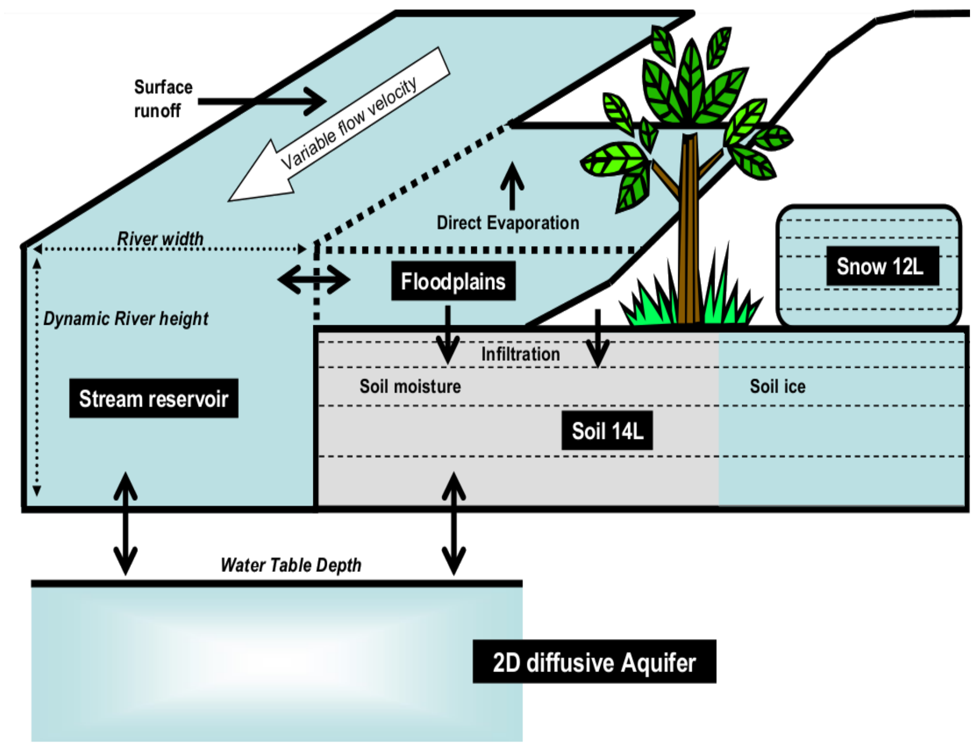
$$F_T = k_N \left[\frac{(\psi_N - \psi_{sat})}{\Delta \bar{z}_N} + 1 \right]$$

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

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

(Vergnes et al. 2012, 2014)

Floodplains model



- Addition of a flood reservoir in TRIP

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

Qin (kg.s^{-1}) : Inflow from the river

Qout (kg.s^{-1})) : Outflow into the river

Pf (kg.s^{-1}) : Precipitation intercepted by the floodplain

If (kg.s^{-1}) : Infiltration of the flooded fraction of the ISBA grid cell

Ef (kg.s^{-1})) : Direct (open-water) Evaporation

(Decharme et al., 2008 & 2012)

Simulations

Inline *(coupling with the atmosphere)*	***Offline*** (SURFEX-CTRIP stand-alone)
TRIP 0.5° SURFEX ARPEGE-Climat } T127 – 150 km	TRIP 0.5° SURFEX 1°
1979-2010 (5-year spin-up)	1979-2010
Coupling with ARPEGE-Climate	Forcing : PGF

CTL : Control

GW : Aquifers

GW+FLD : Aquifers + Flood

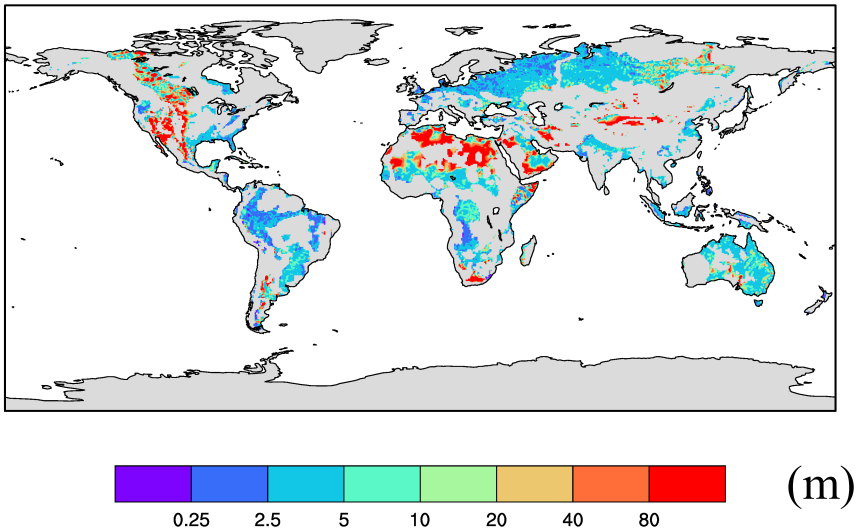
CTL

GW

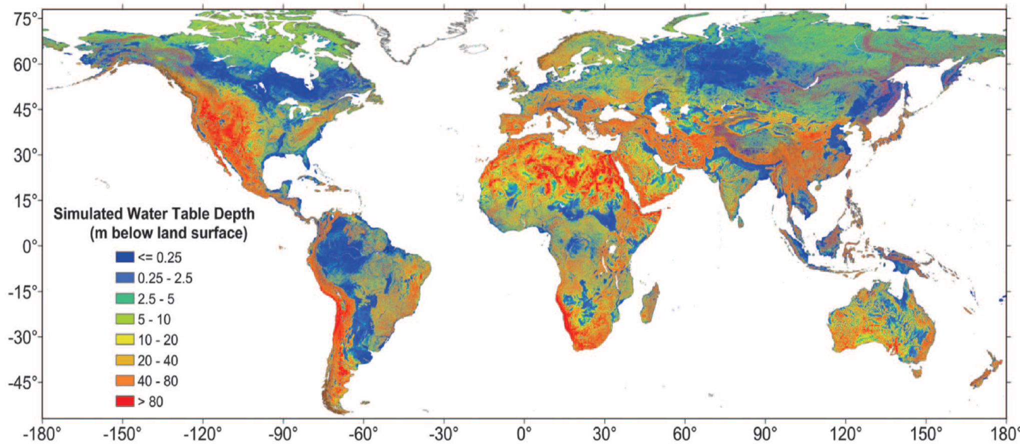
GW+FLD

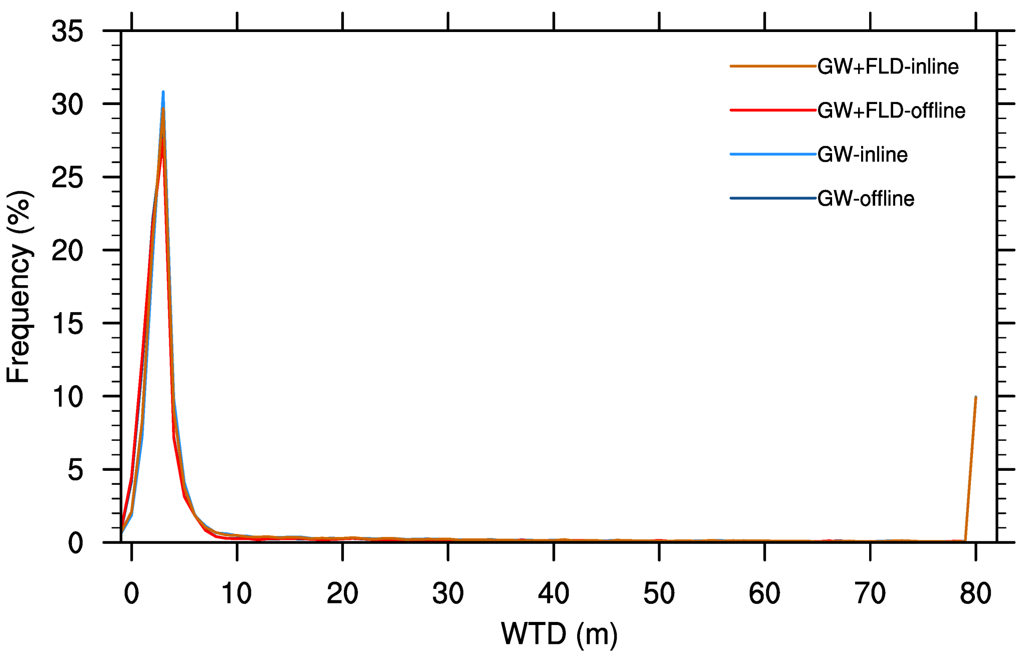
2. Validation and evaluation
Water Table Depths (WTD)

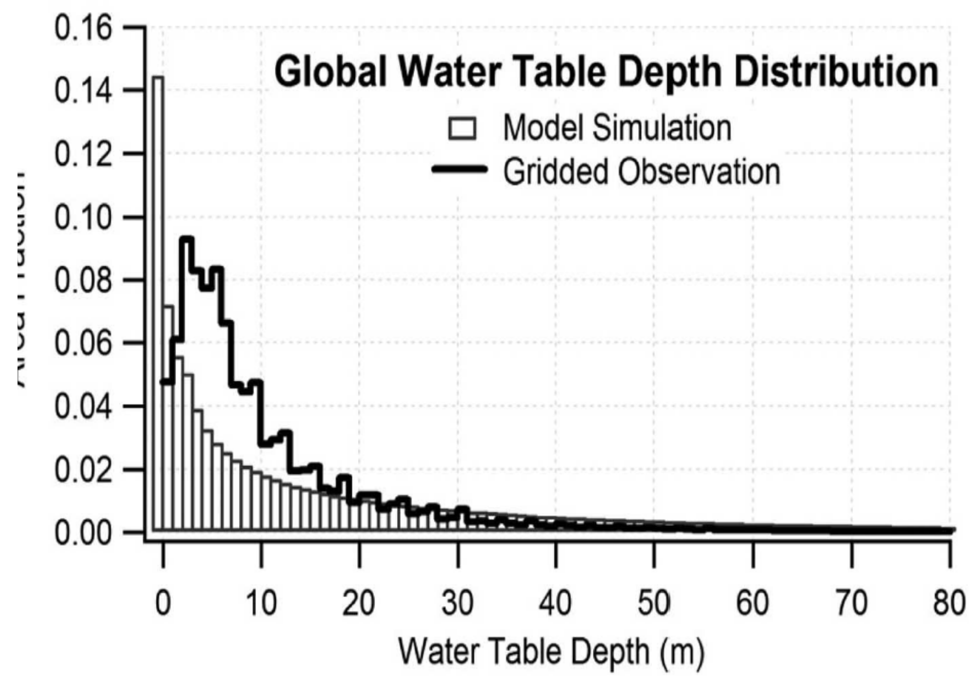
GW offline simulation



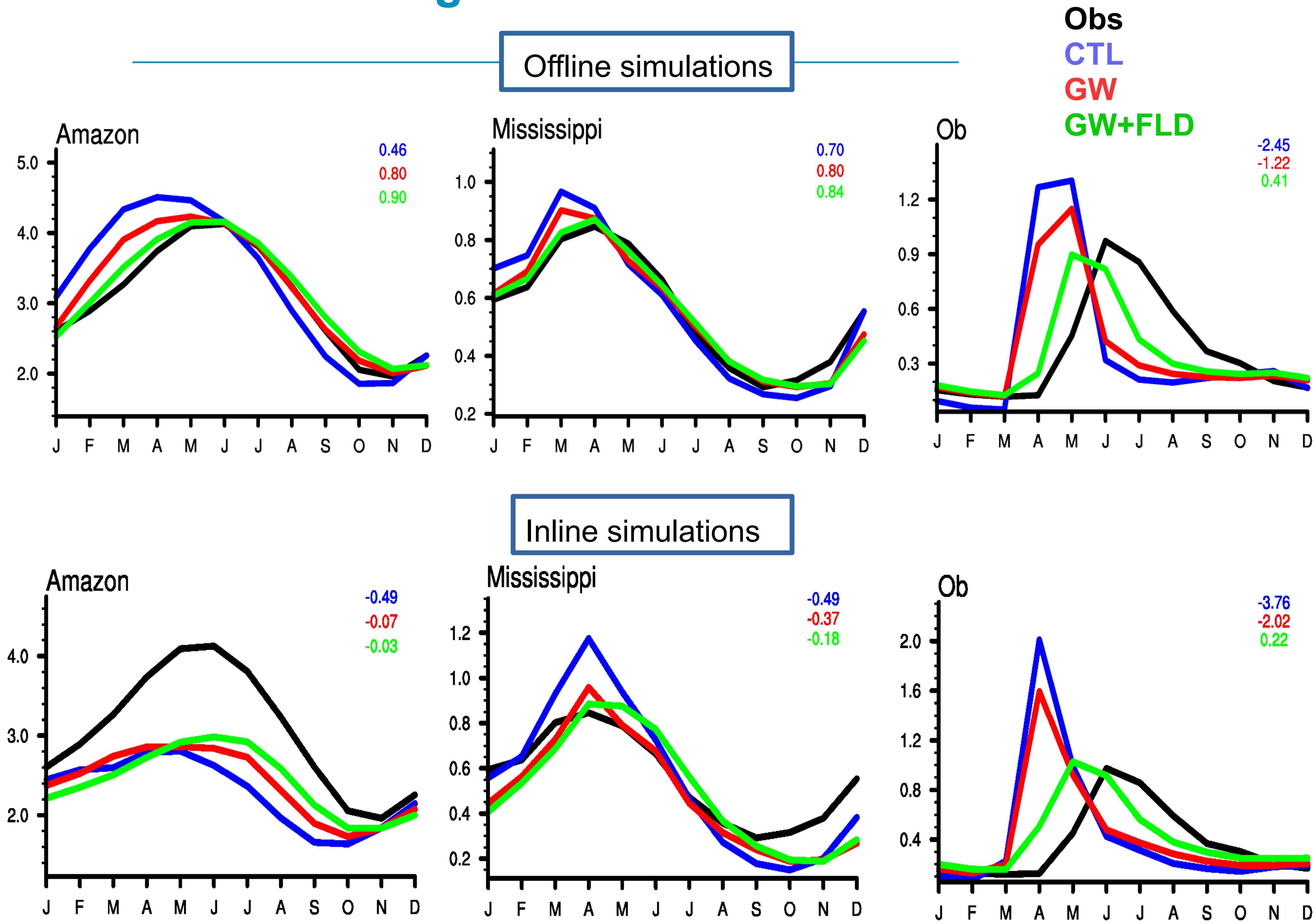
Model and data from Fan et al., 2013





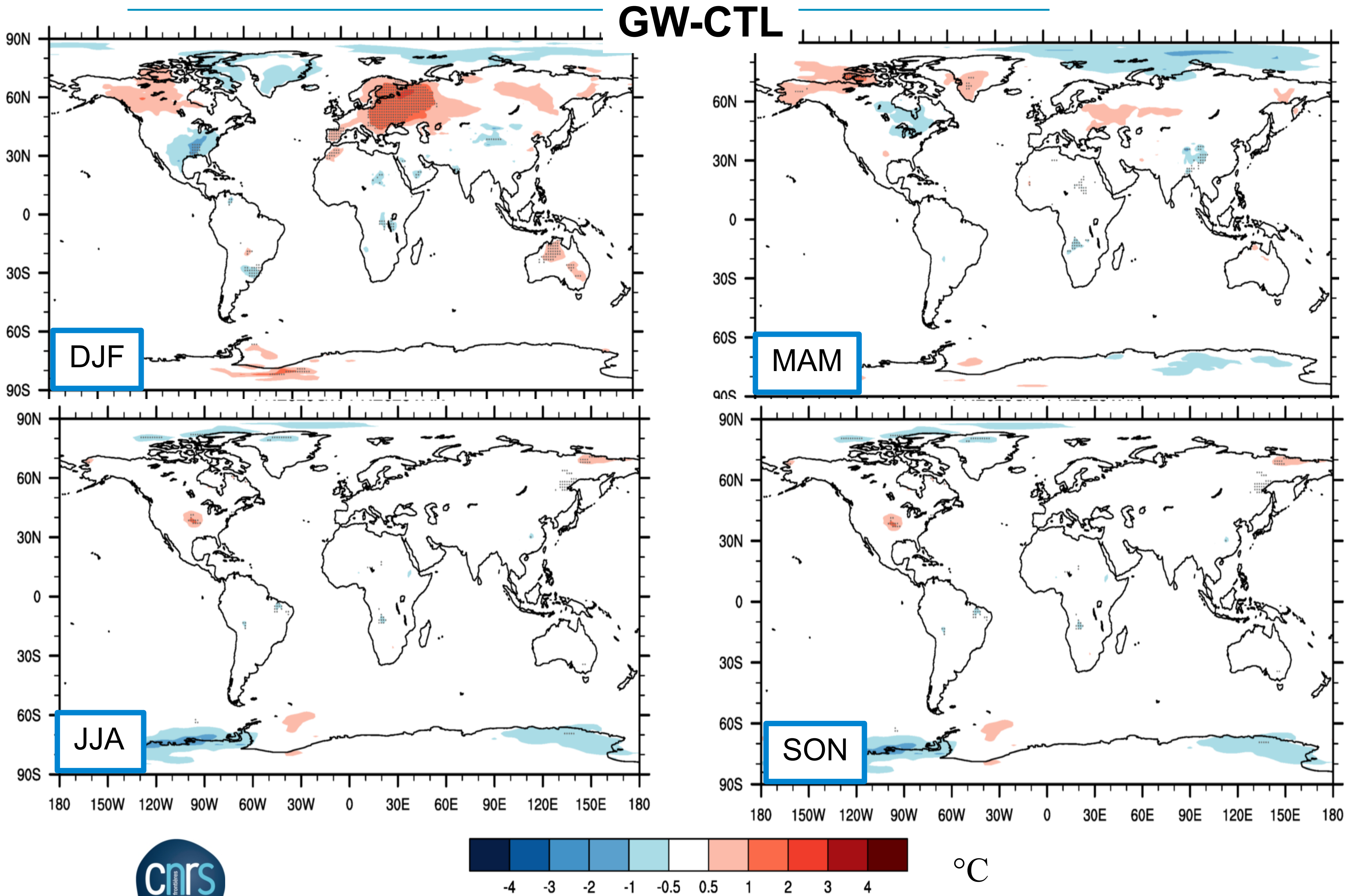


River discharges



3. Impact of aquifers on the simulated climate

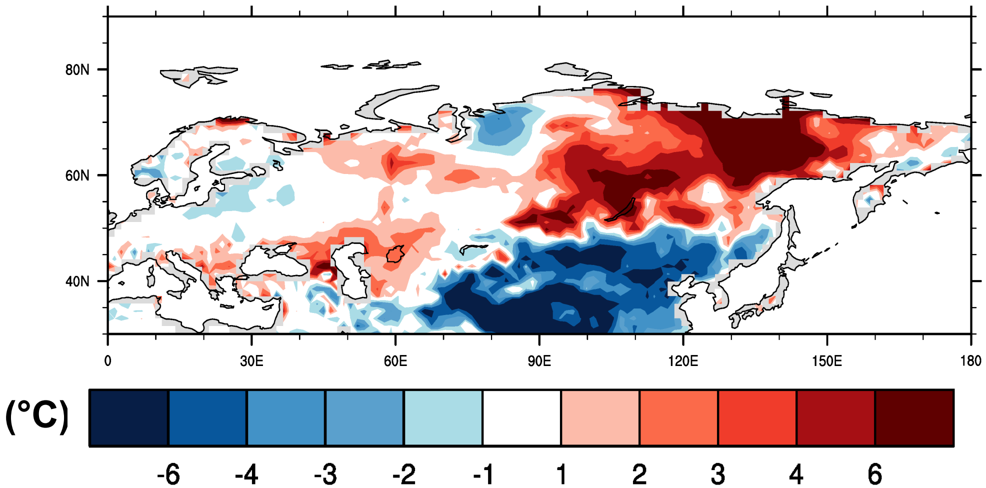
2-meter temperature



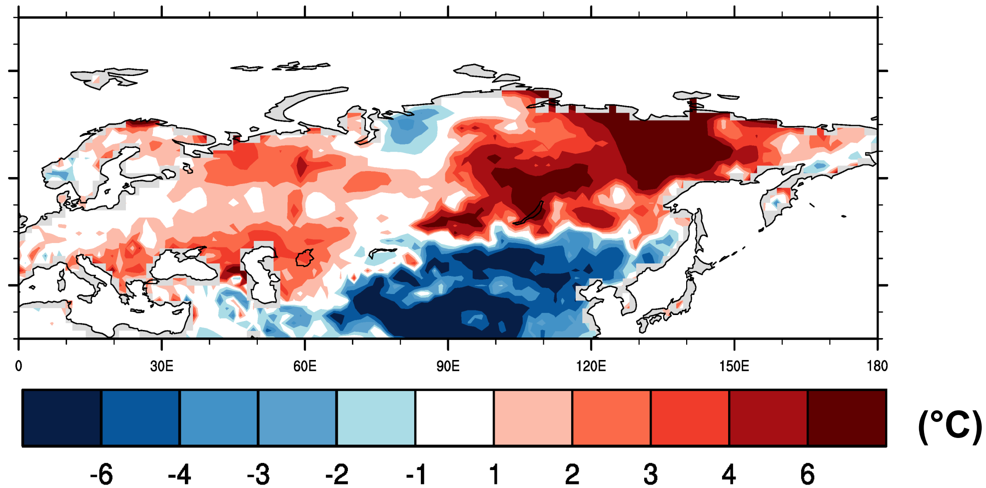
=> Impact in winter only

Warming in winter (DJF) – 2-meter temperature

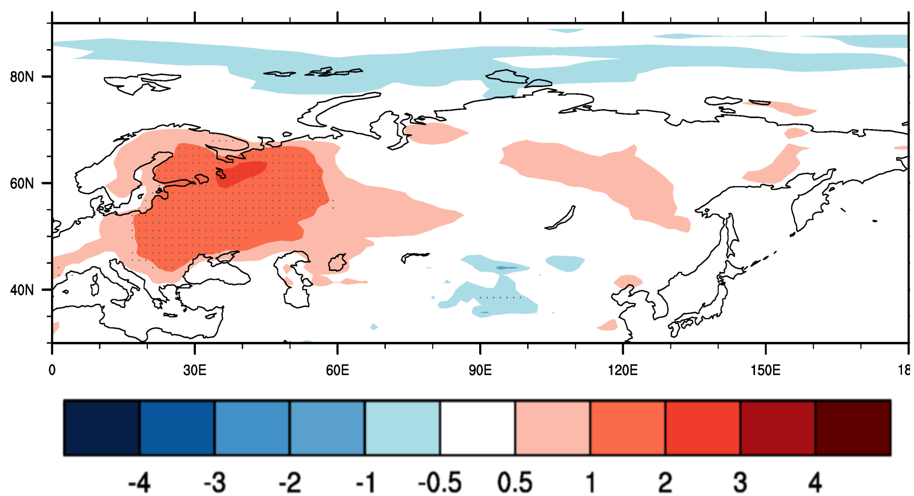
CTL – CRU (obs)



GW – CRU (obs)

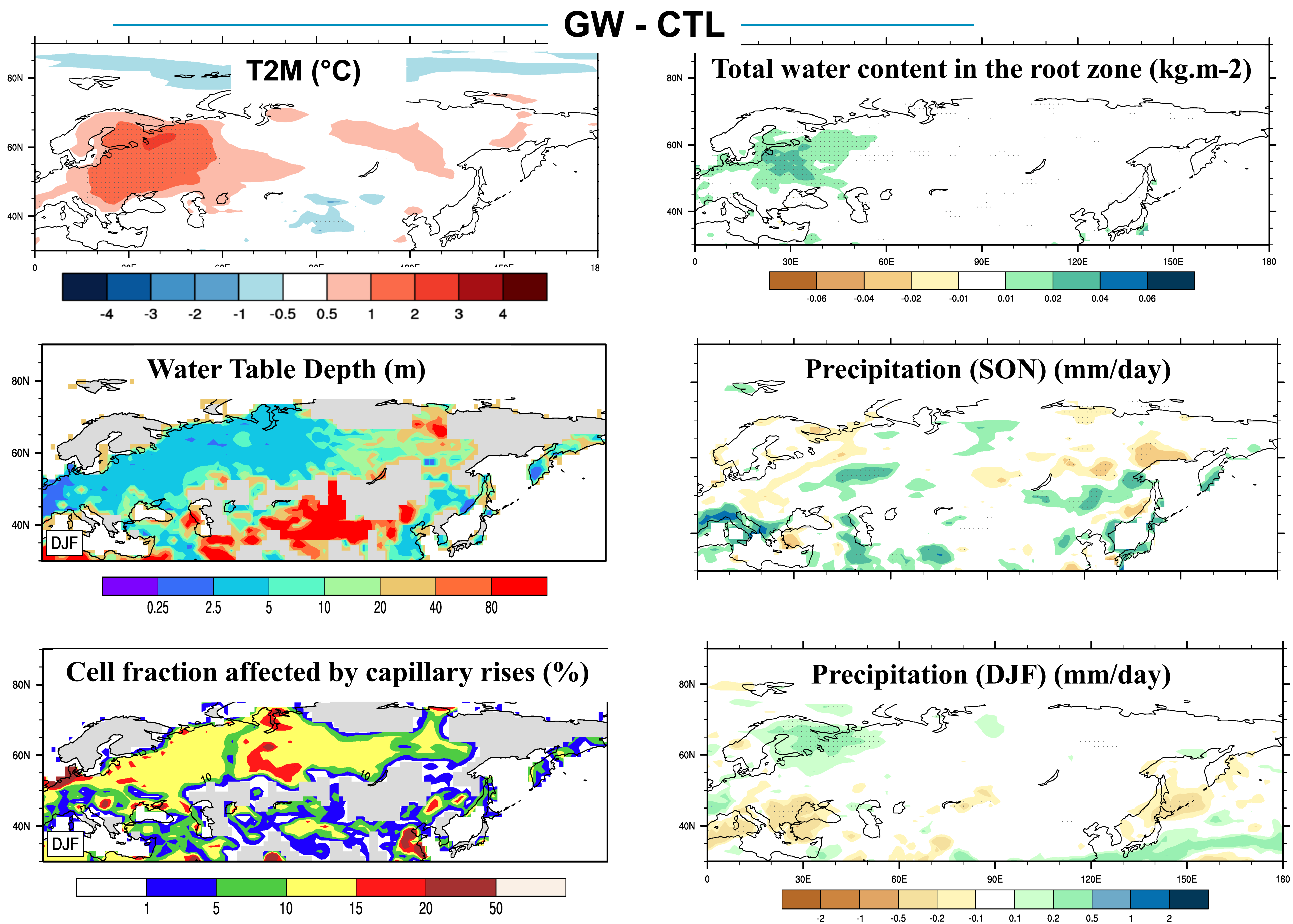


GW-CTL

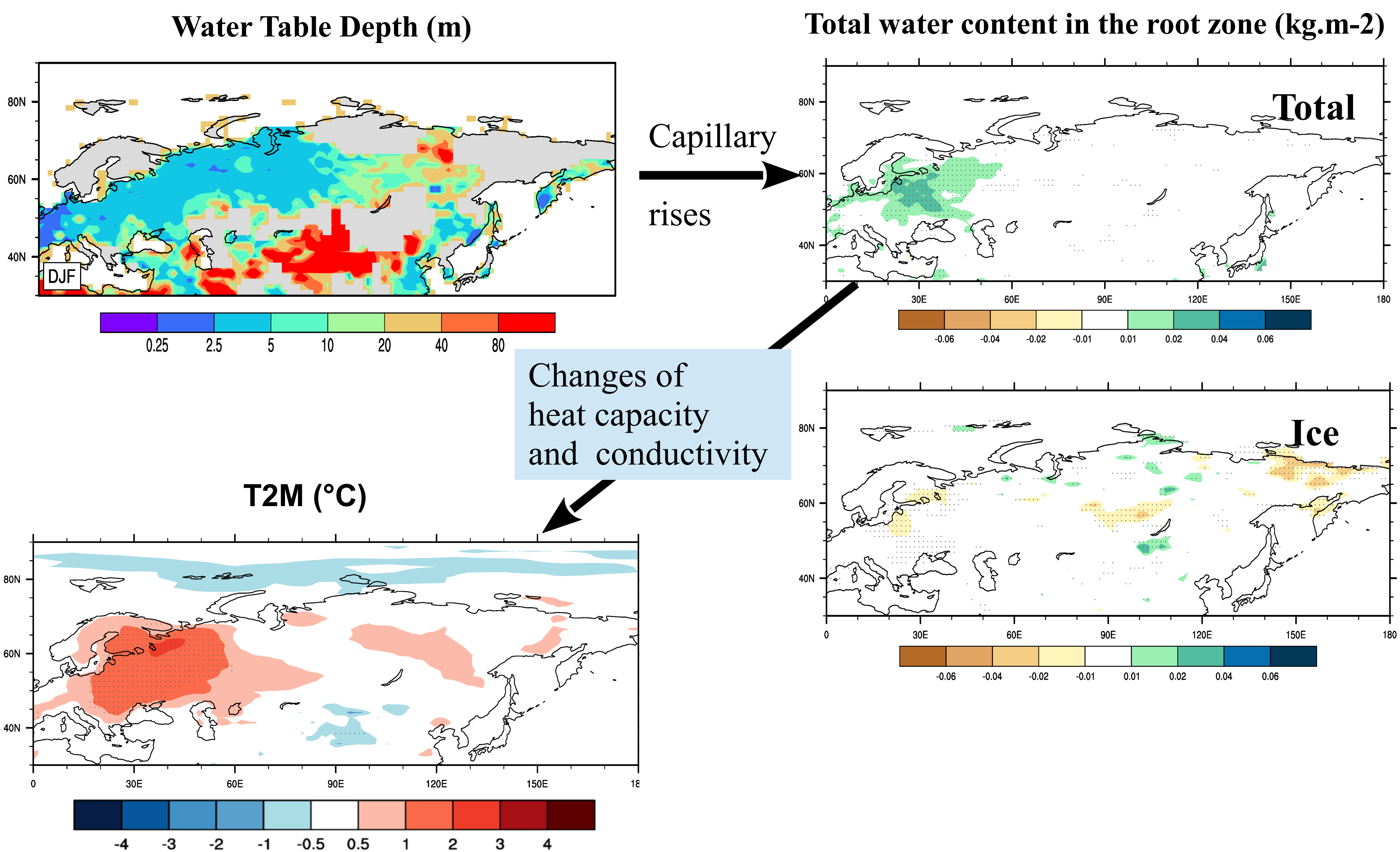


Not necessarily an improvement in this case…

Warming in DJF : processes involved ?

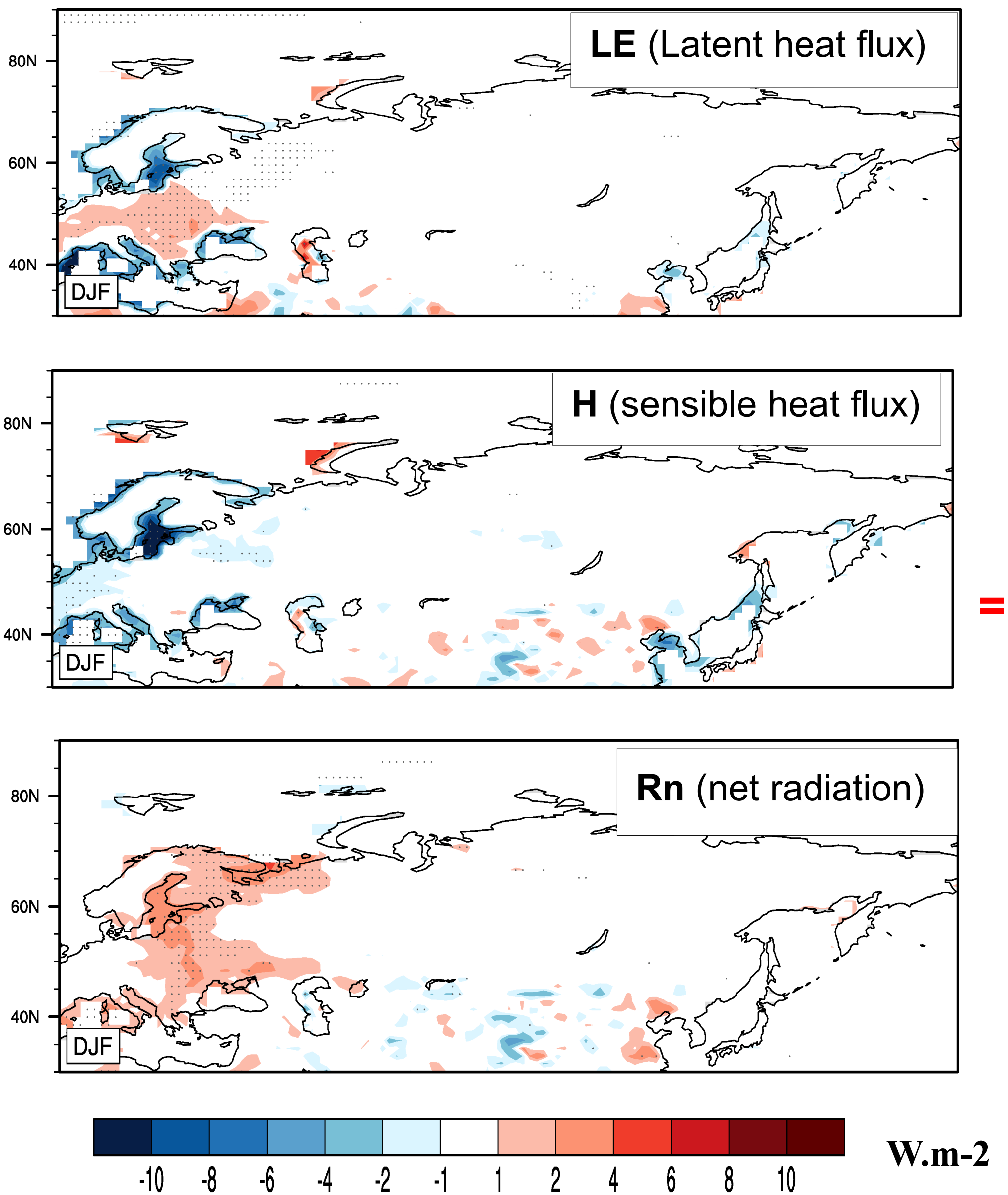


Warming in DJF : processes involved ?



Energy budget

GW-CTL (DJF)

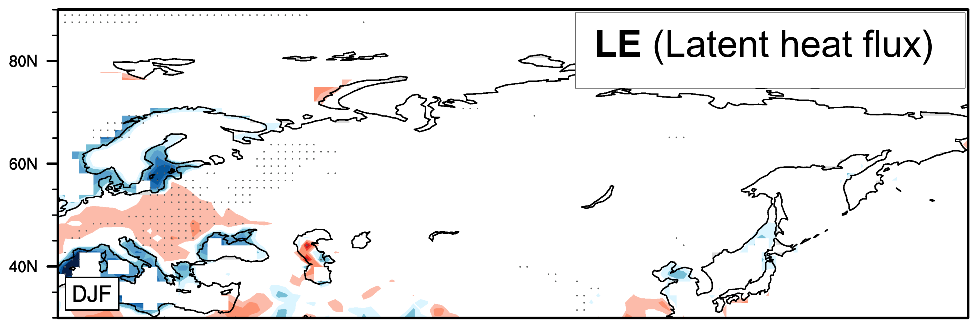


=> Cooling effect

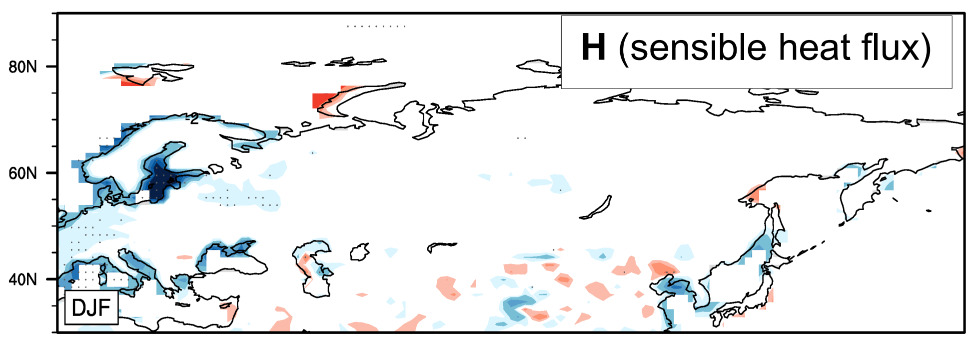
=> No change

Energy budget

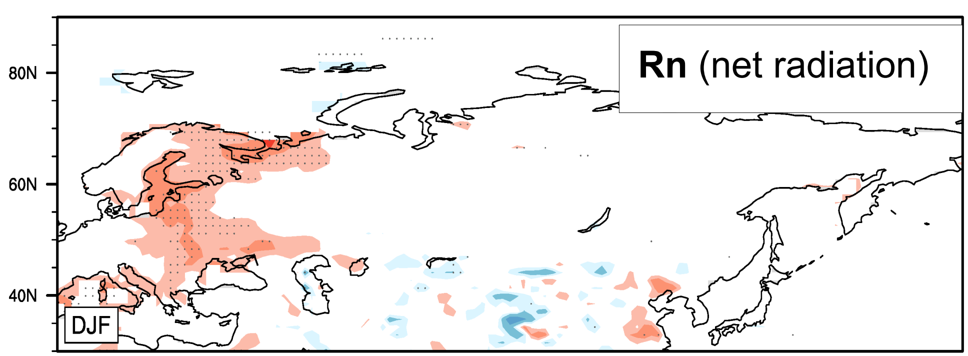
GW-CTL (DJF)

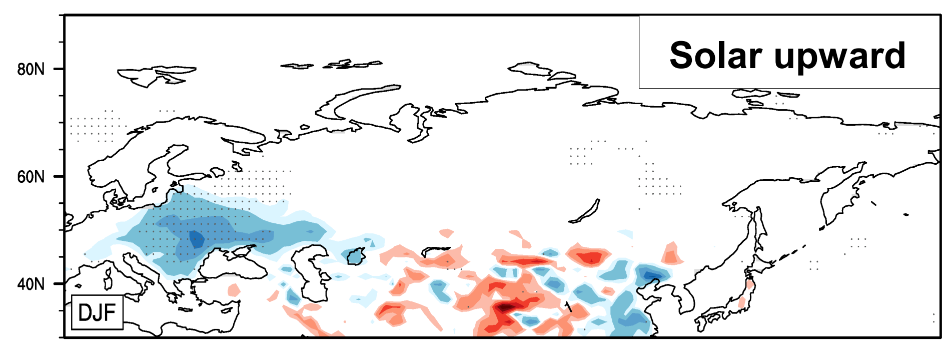


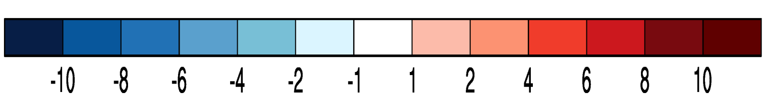
=> Cooling effect



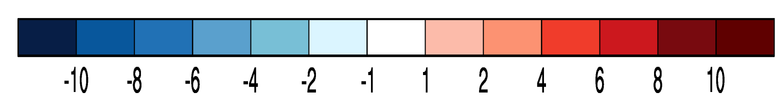
=> No change





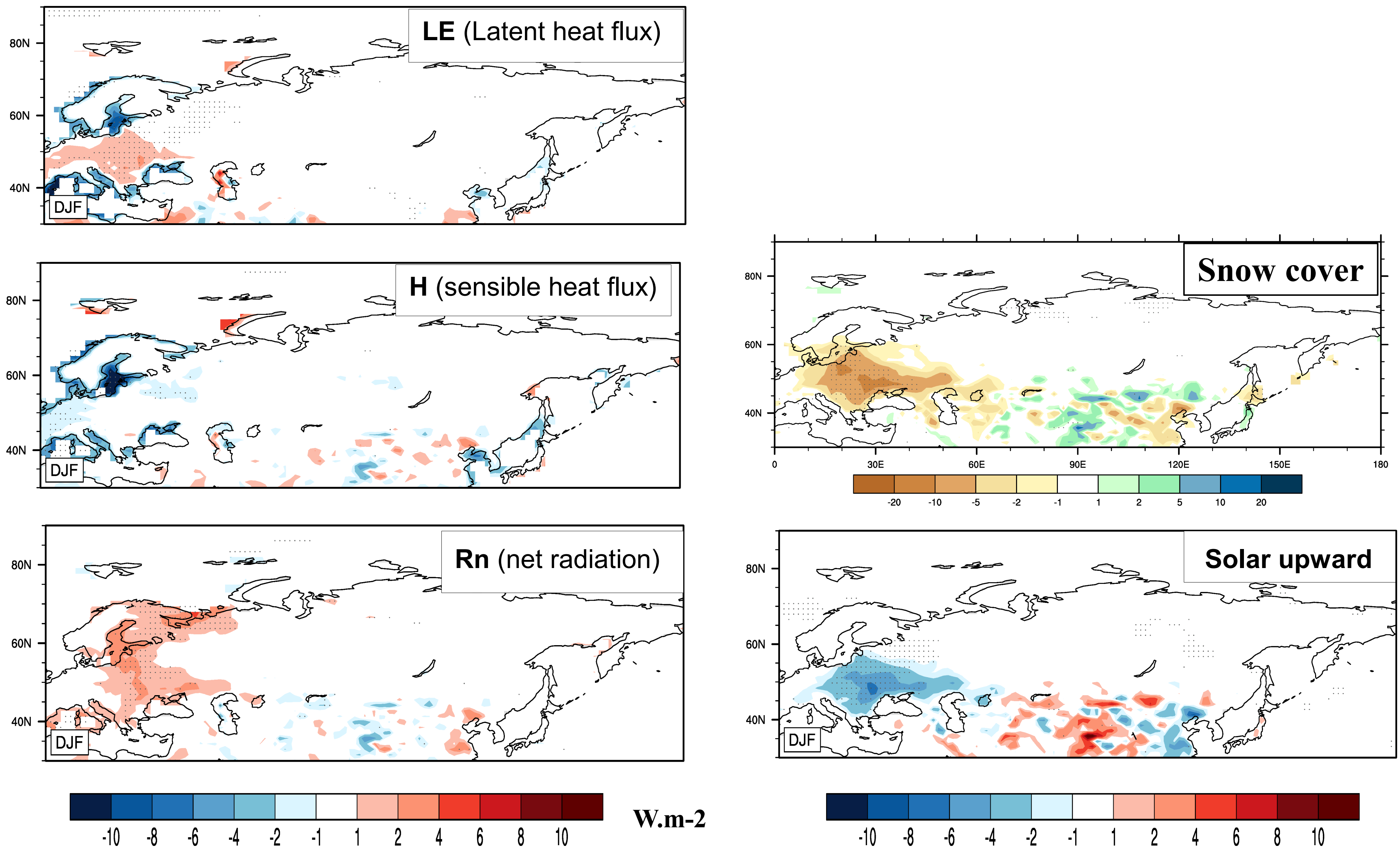


W.m-2

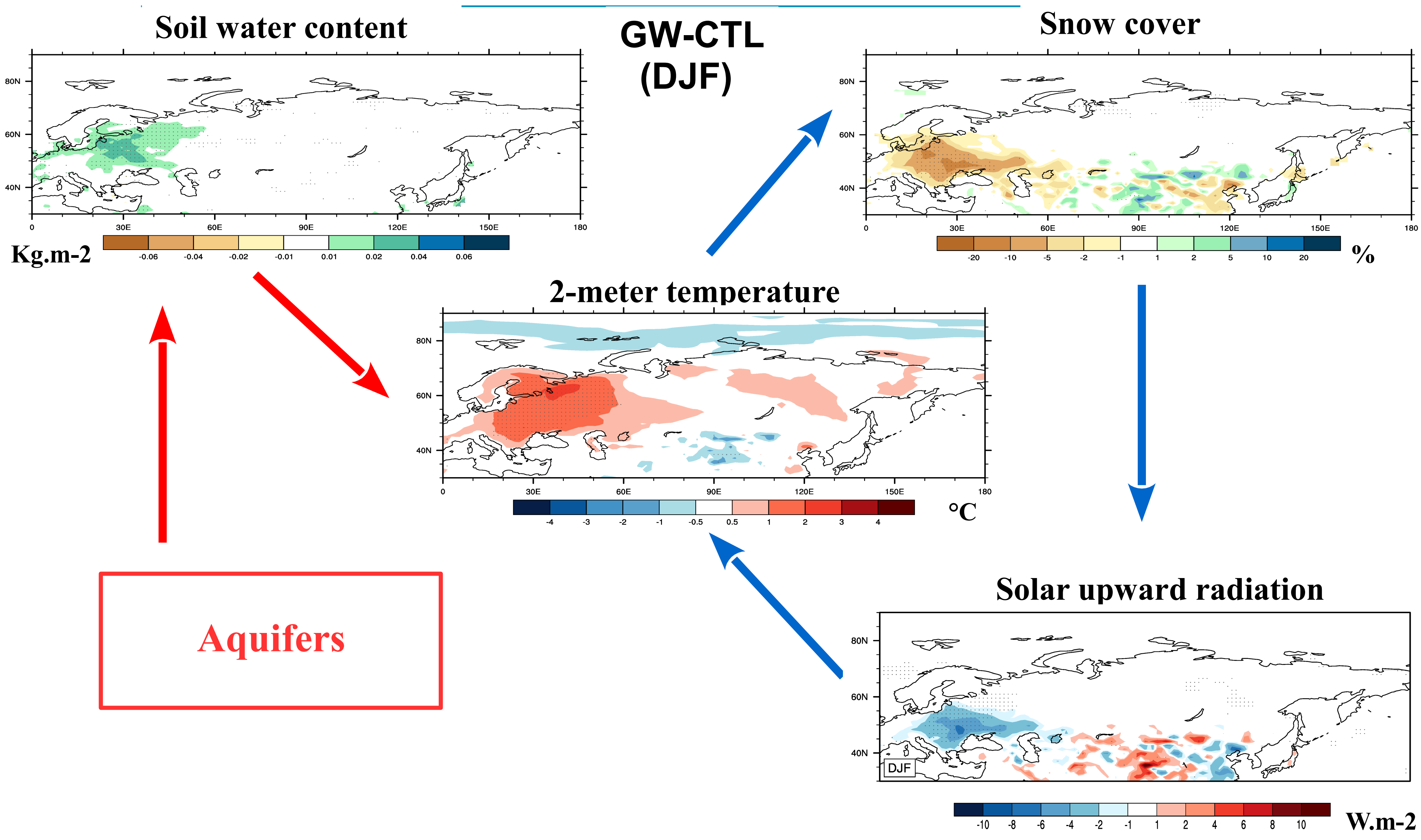


Energy budget

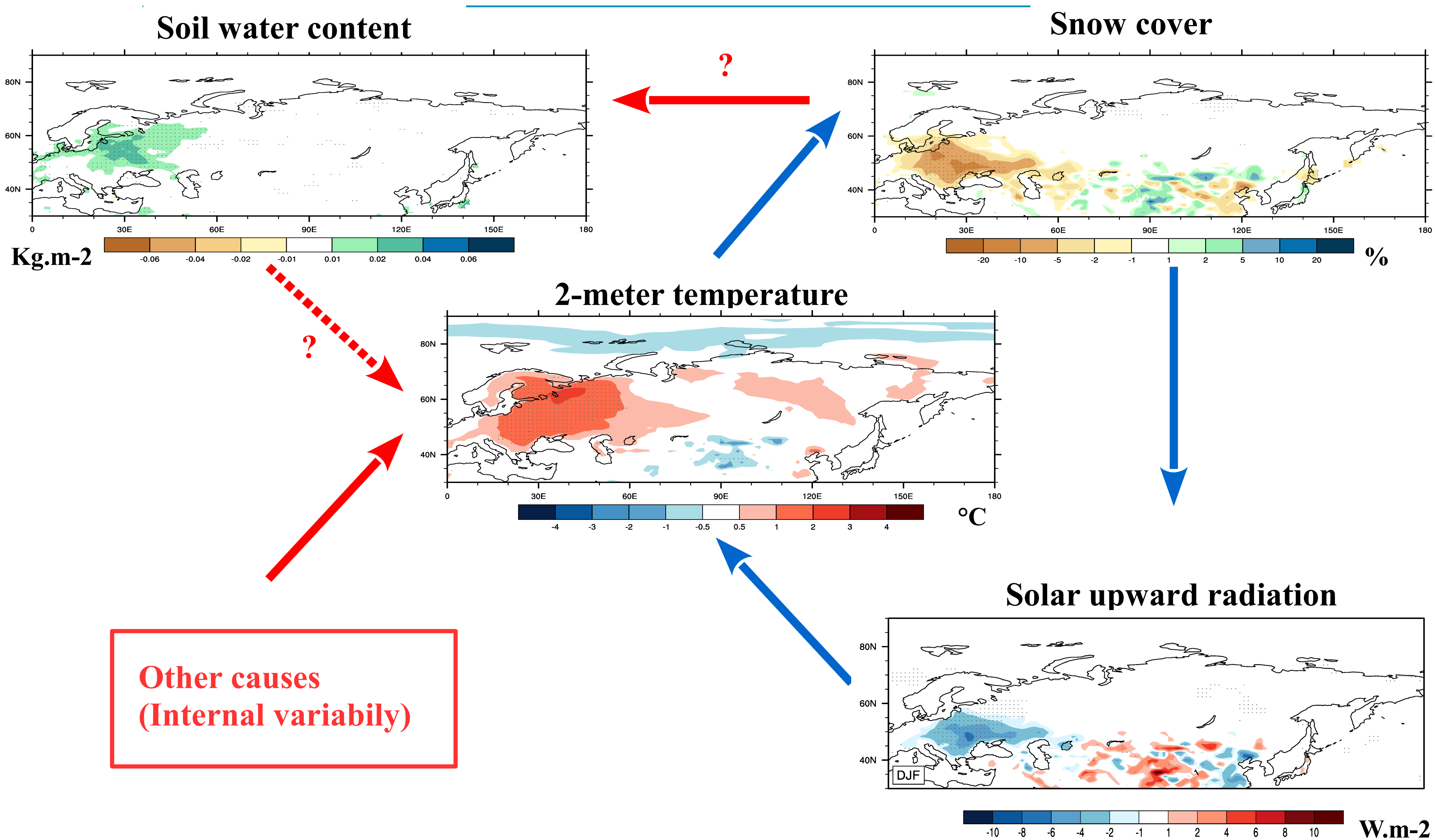
GW-CTL (DJF)



Feedback loop

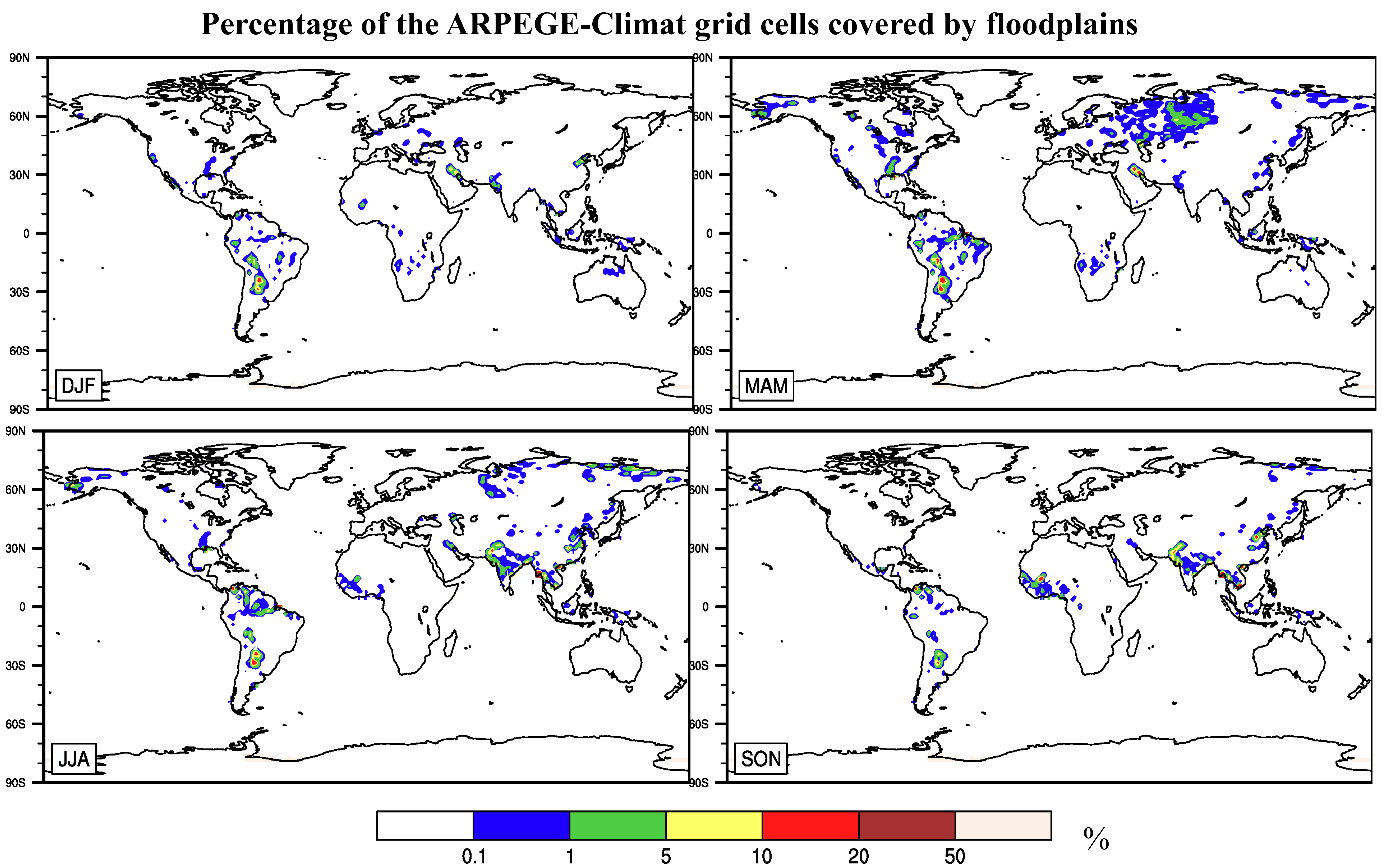


Feedback loop



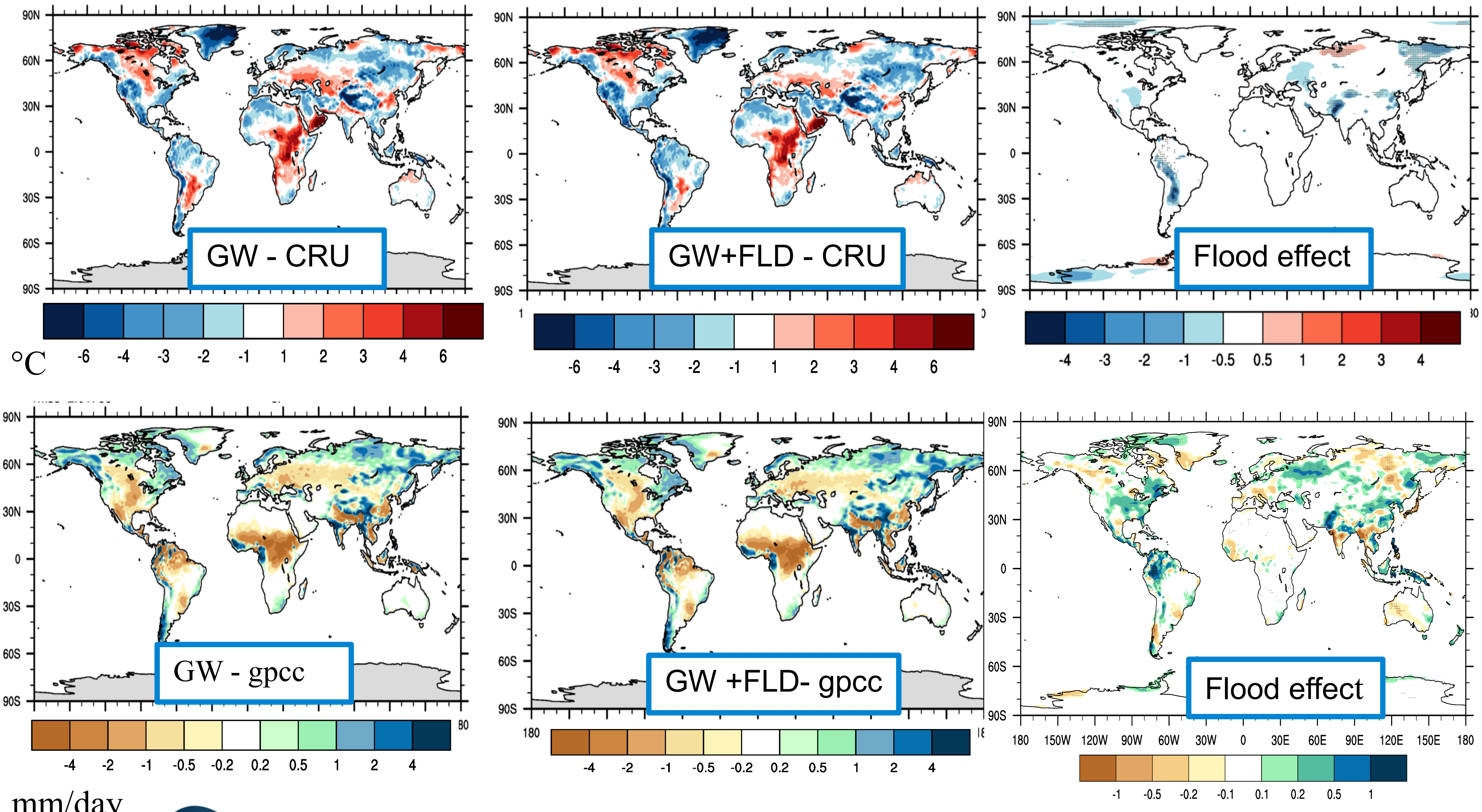
=> Run ensemble simulations

3. Impact of the floodplains on the simulated climate



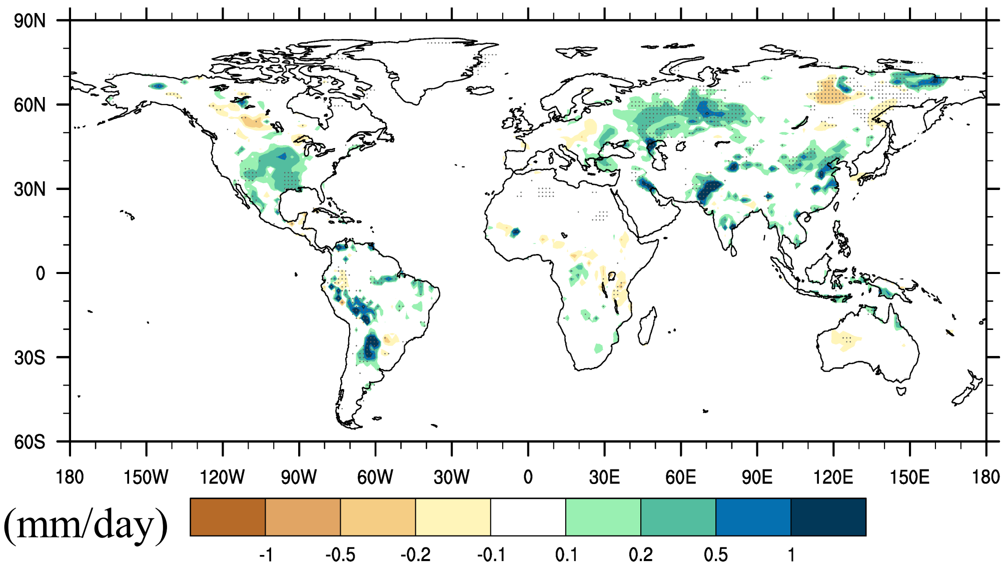
3. Impact of floodplains on the simulated climate

2-meter daily max. temperature and precipitation (JJA)

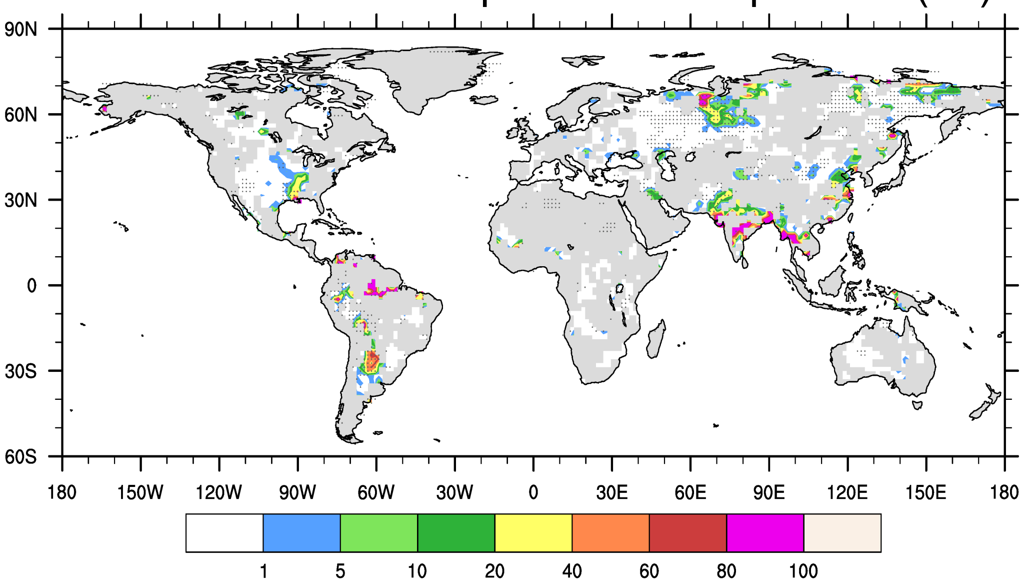


Floodplains effect in JJA
Infiltration or open water evaporation ?

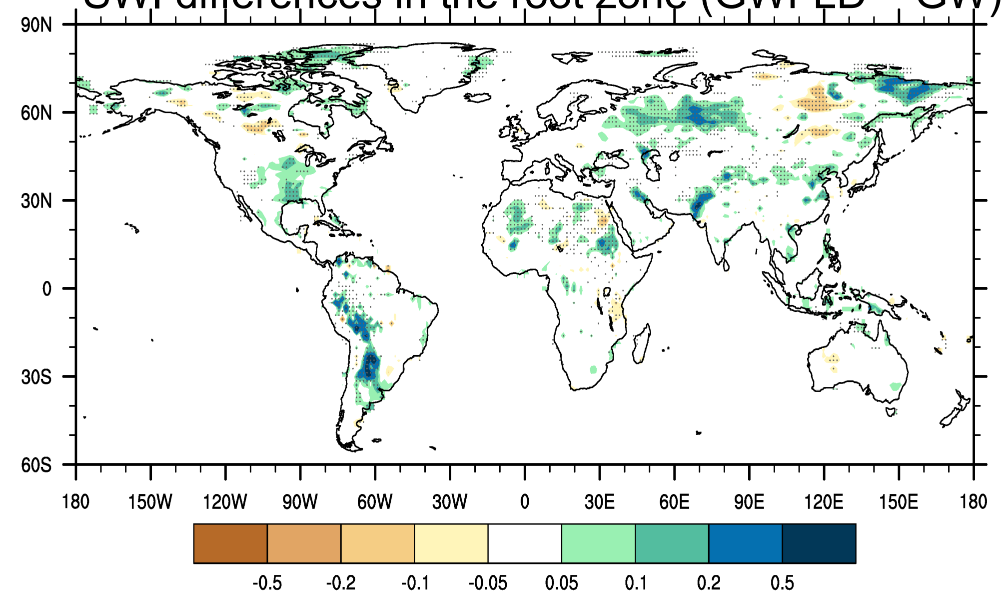
Evapotranspiration differences (GWFLD – GW)



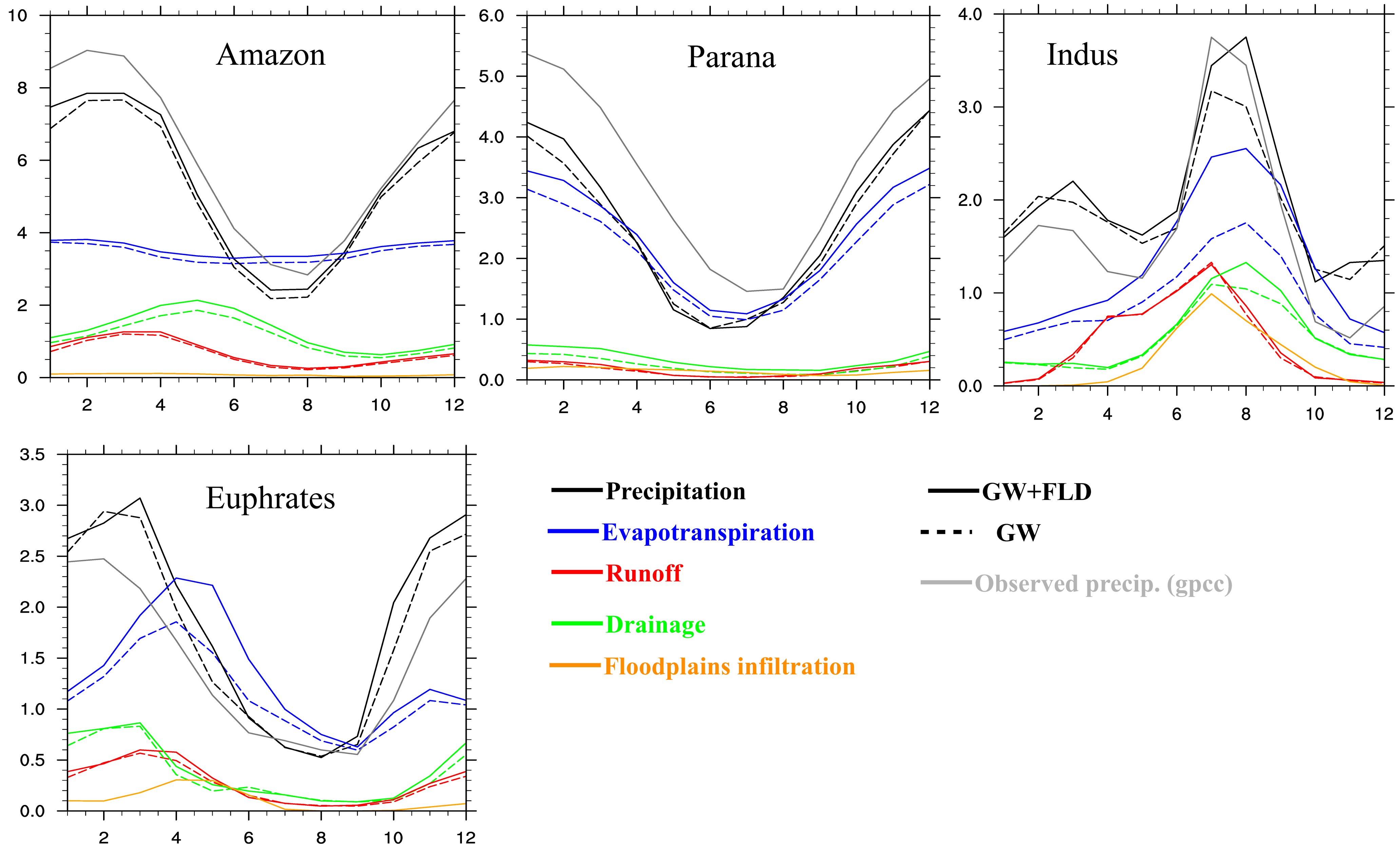
Contribution of the open-water evaporation (%)



SWI differences in the root zone (GWFLD – GW)



Mean annual water cycles in some basins



Summary

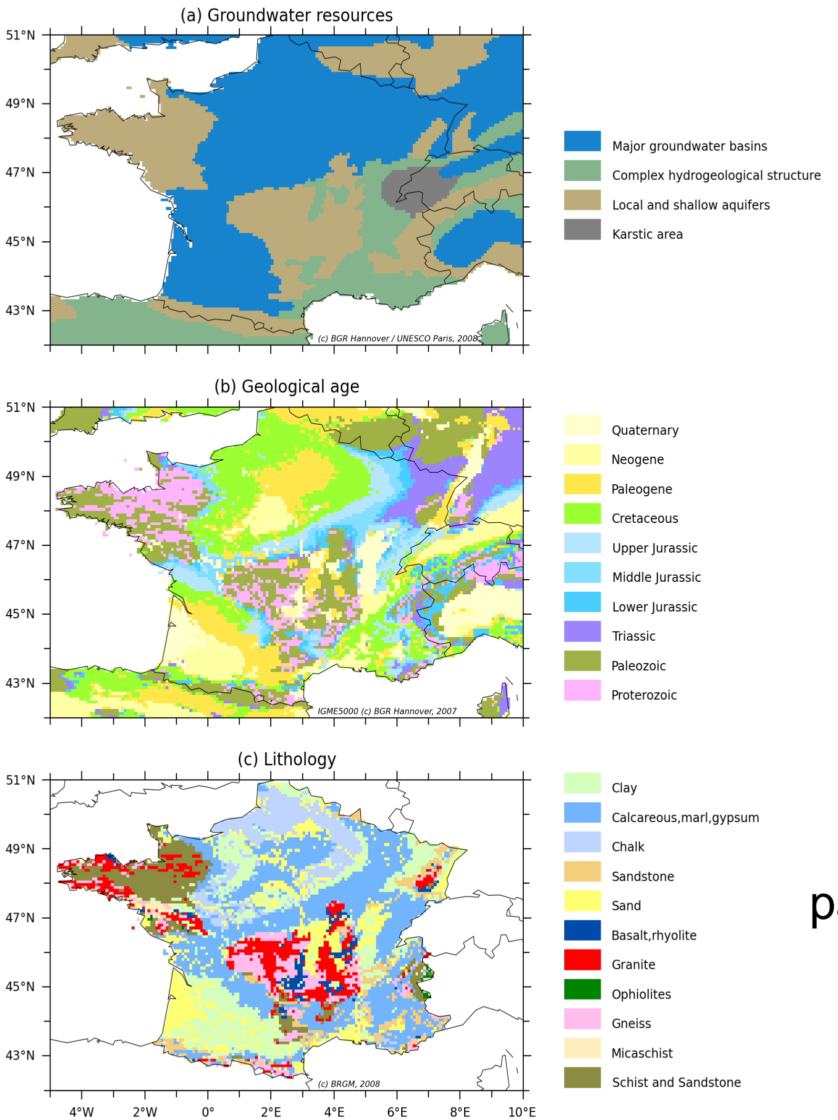
- An 2D-diffusive aquifer model and a floodplain scheme were added to the new version of the Land Surface Model ISBA-CTRIP.
- A first set of global climate simulations were performed with it.
- The simulated water table depths seem reasonnable.
- Offline (Land only) and inline evaluation show an improvement of river discharge with aquifers and floodplains.
- The aquifers lead to a warming of eastern Europe in winter (through an increase of liquid water in the soil column, leading to an warming of the soil temperature and a decrease of the snow cover in this region).
- The floodplains scheme leads to a cooling of maximum temperatures in summer (through an enhanced evapotranspiration)

Outlook

- Further analyse the results
- Run ensembles
- Assess the impact of aquifers and floodplains at higher resolutions (either globally or regionally)
- Assess the impact of aquifers and floodplains in scenarios of climate change

QUESTIONS ?

Aquifer basins and parameters
development at a regional scale



Aquifer basins

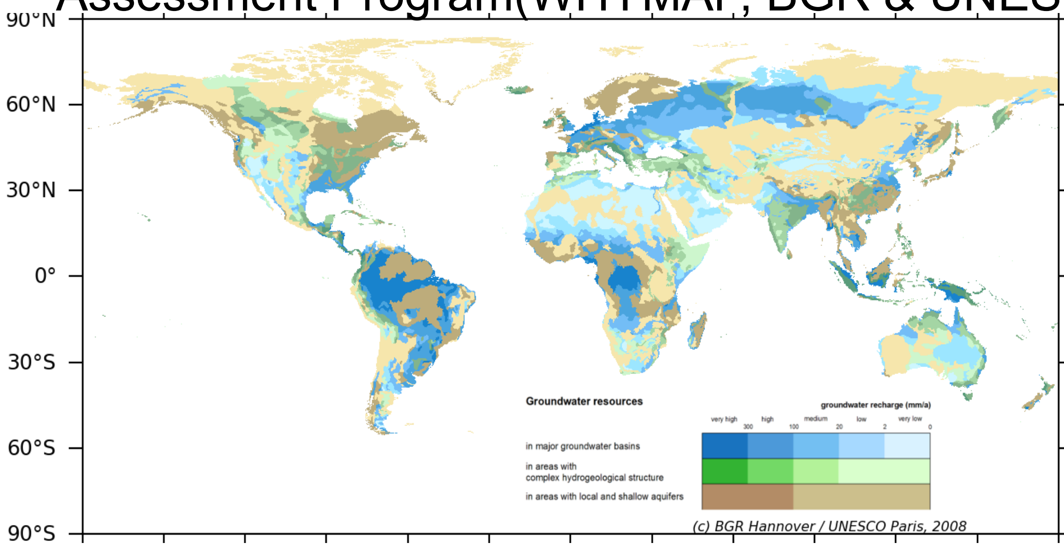
parameters

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

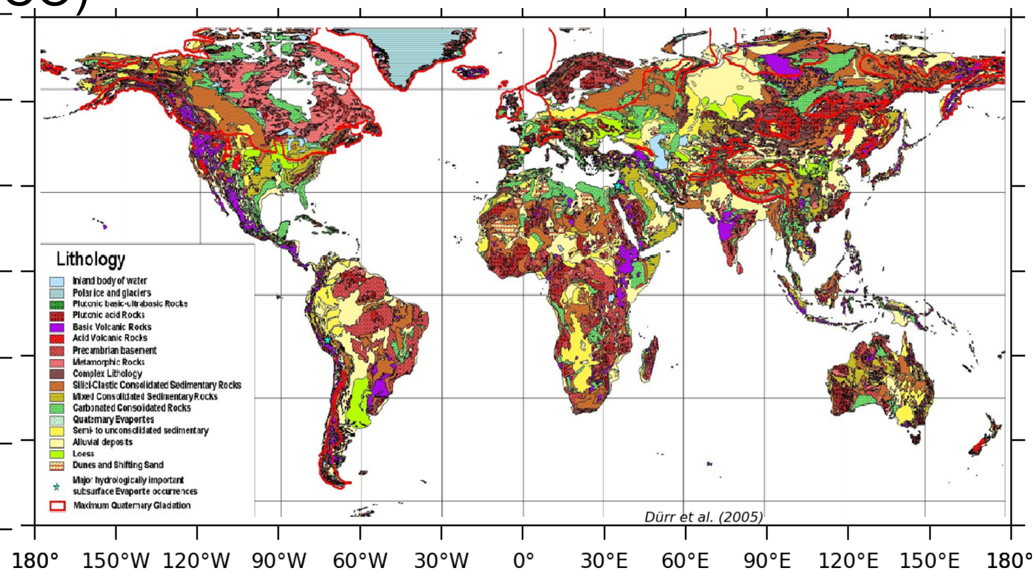
Vergnes et al., 2012a

Aquifer basins and parameters
extension at global scale

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

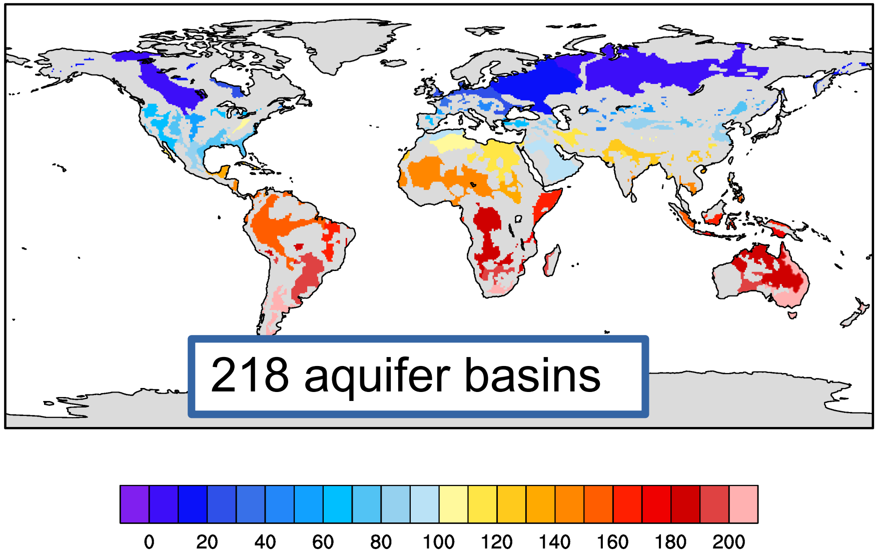


Lithology map (Dürr et al., 2005)



Aquifer mask

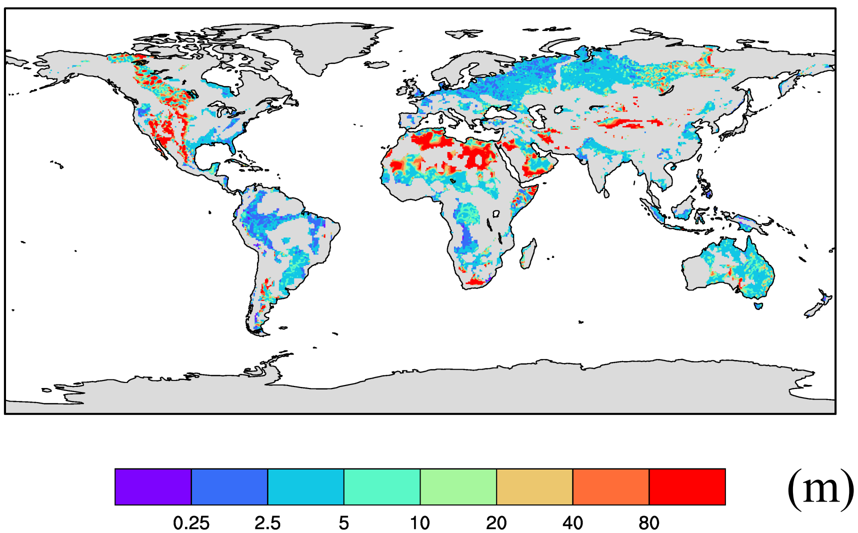
Transimittivities and porosities



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

2. Validation and evaluation
Water Table Depths (WTD)

GW offline simulation



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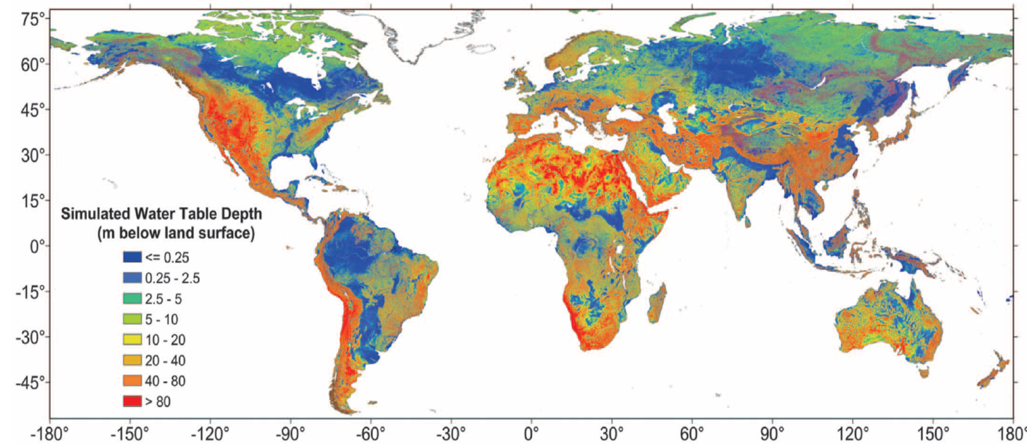
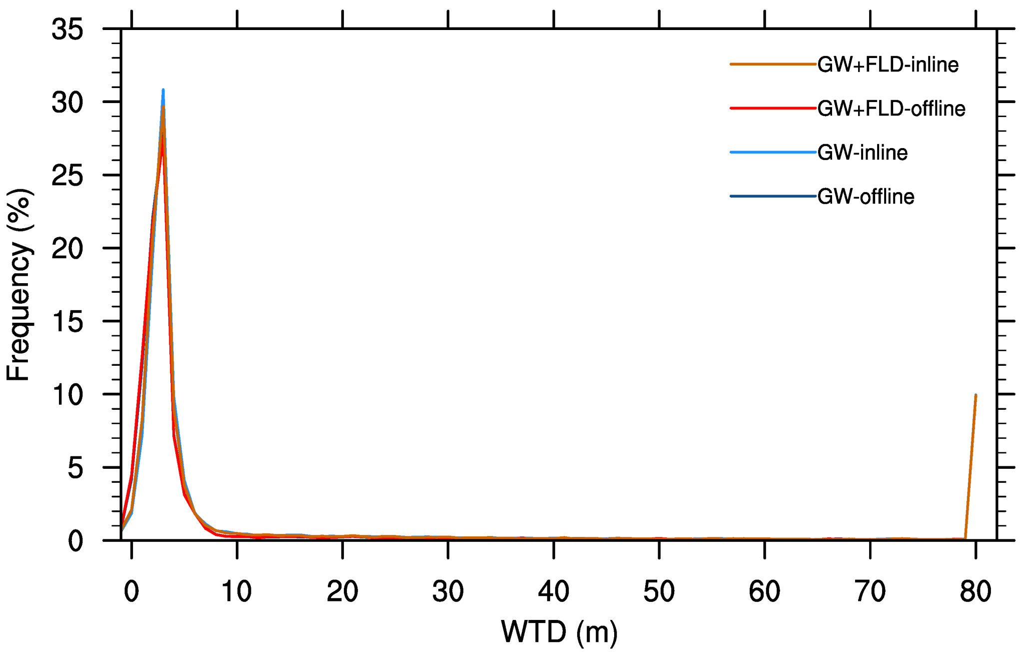
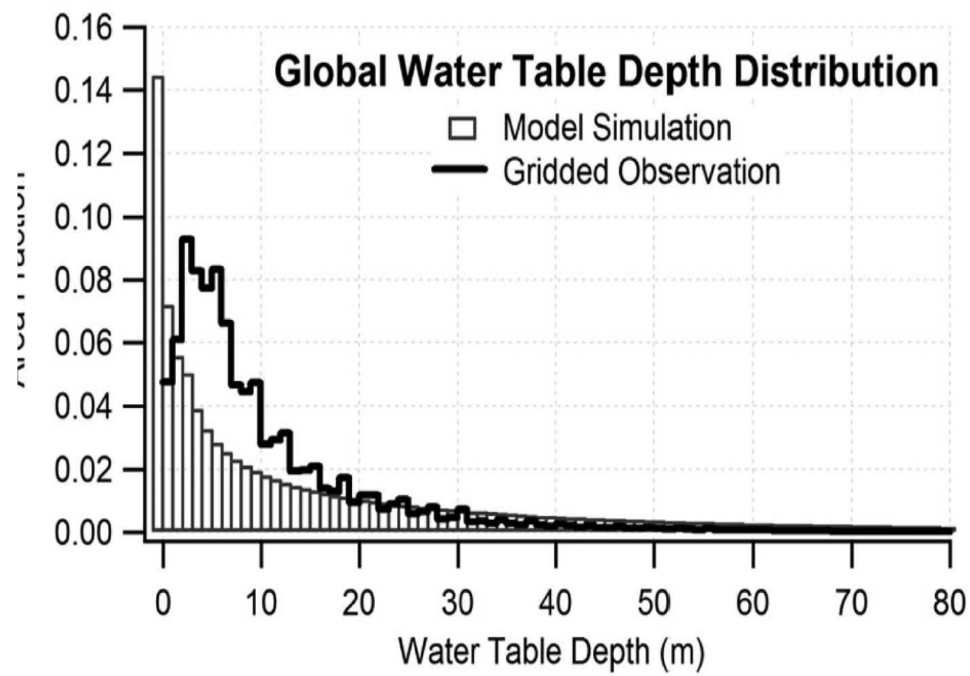
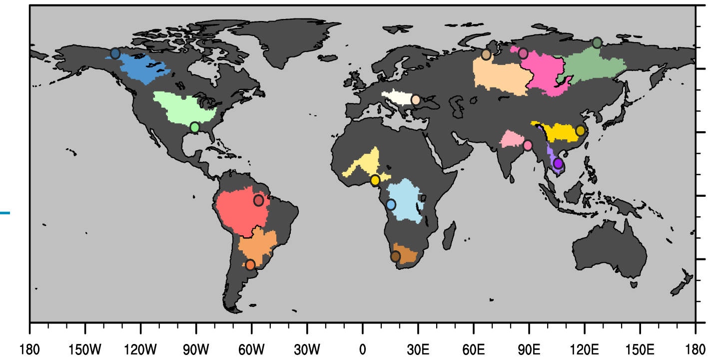
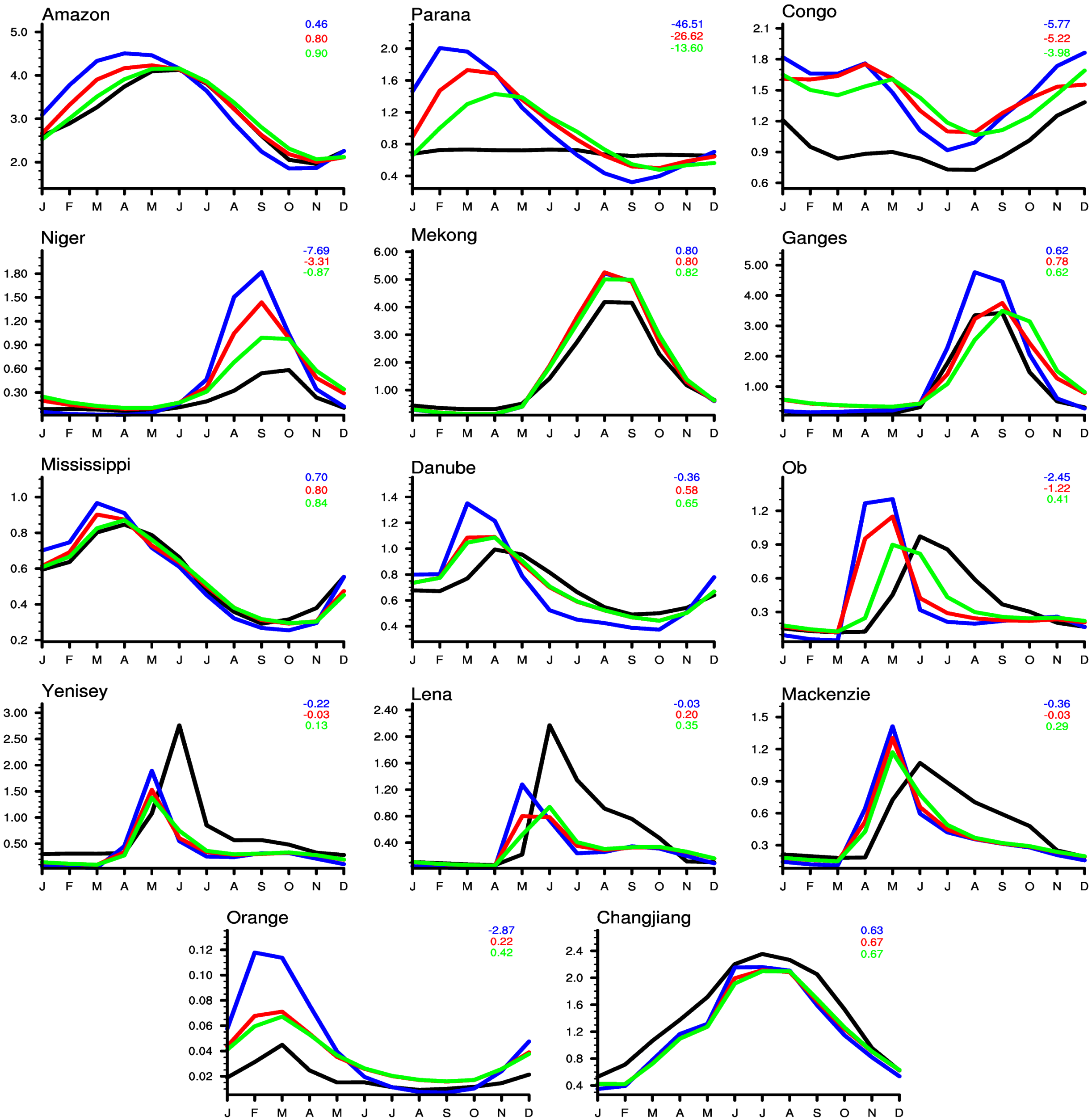






River discharge
Seasonal cycle





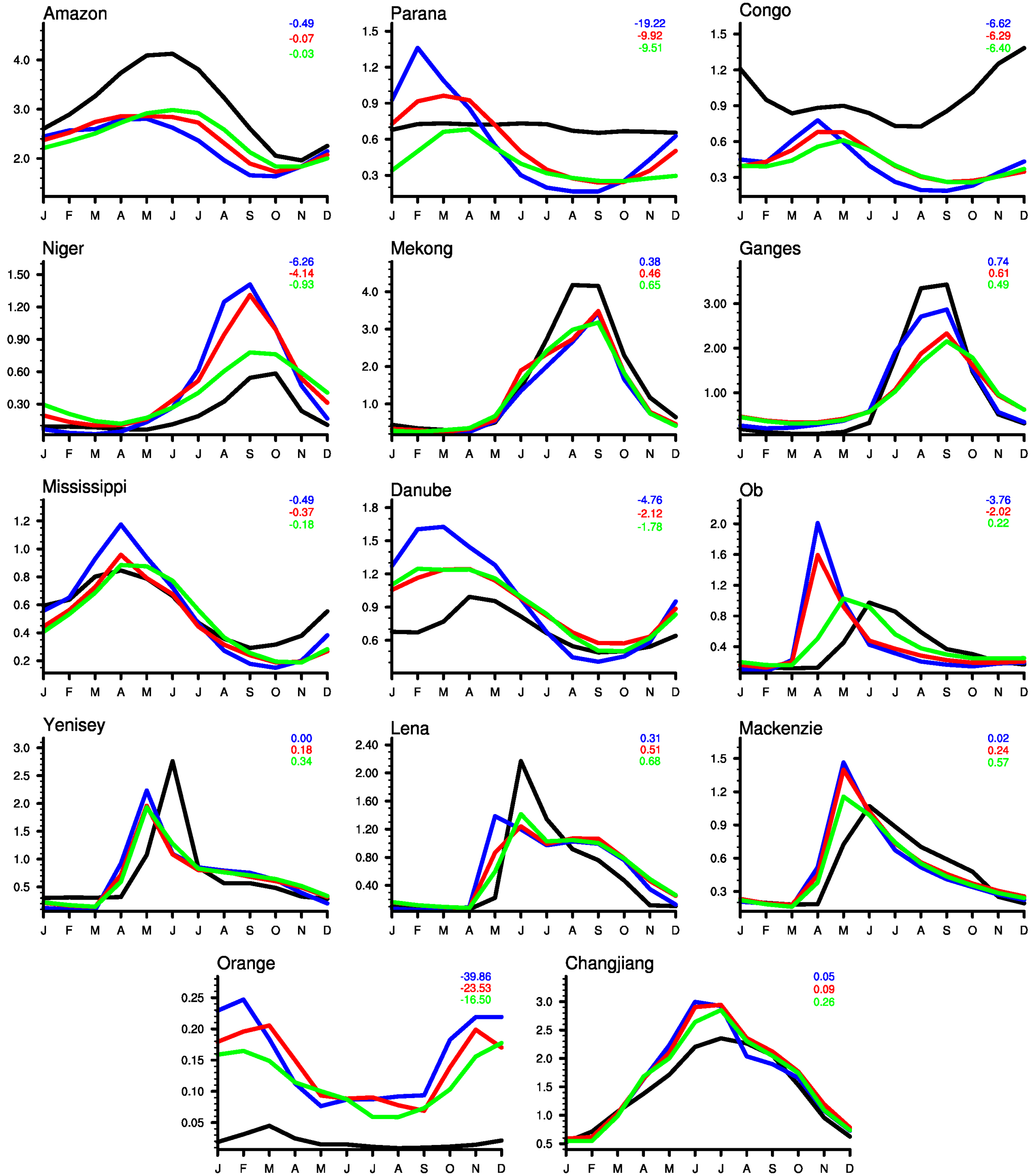
Observation
CTRL-Offline
GW-Offline
GW+FLD-Offline

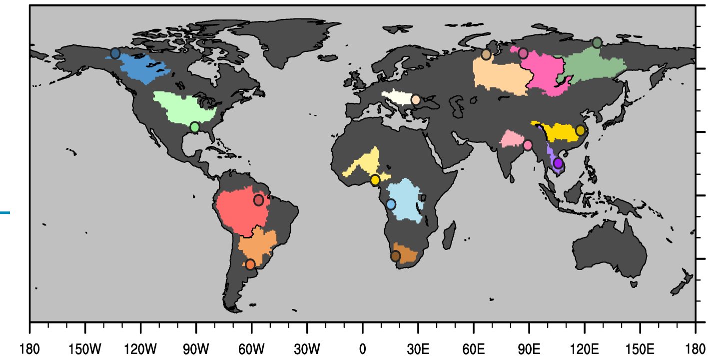
GW : generally improves the cycle

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.