IGEM
March 18-20, 2019
Taipei, Taiwan

On the use of a physically-based baseflow time constant in ORCHIDEE land surface model

Anne Jost, Ana Schneider, Ludovic Oudin & Agnès Ducharne

SCIENCES SORBONNE UNIVERSITÉ

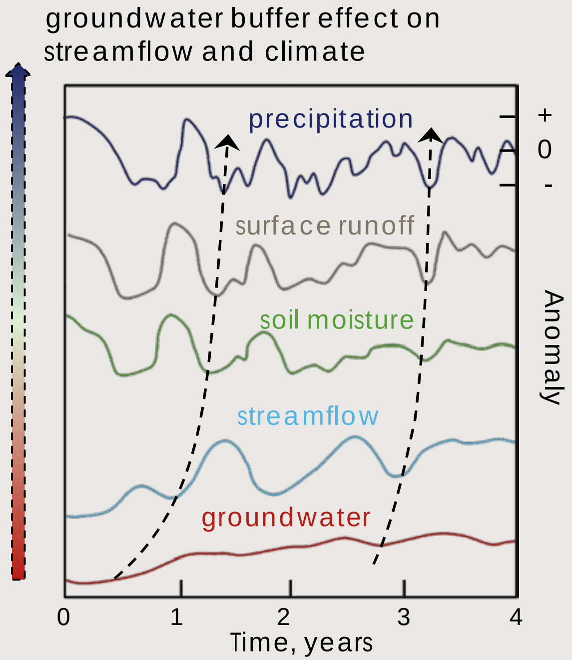
This work was supported by the I-GEM ANR.

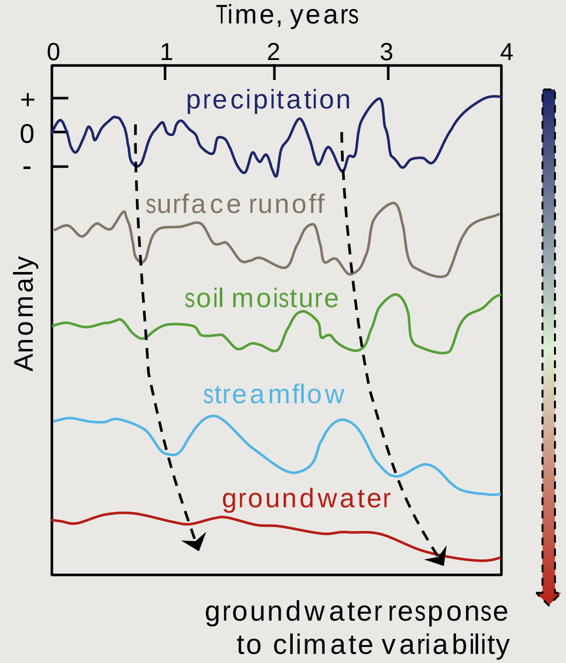
Motivation

Response time of groundwater to fluctuations in recharge

Climate point of view
→ buffer effect on soil moisture, evapotranspiration and precipitation

Hydrology point of view
→ buffer effect on streamflow





BUFFERING EFFECTS OF GROUNDWATER
(adapted from Entekhabi *et al.* 1996 & Lo)

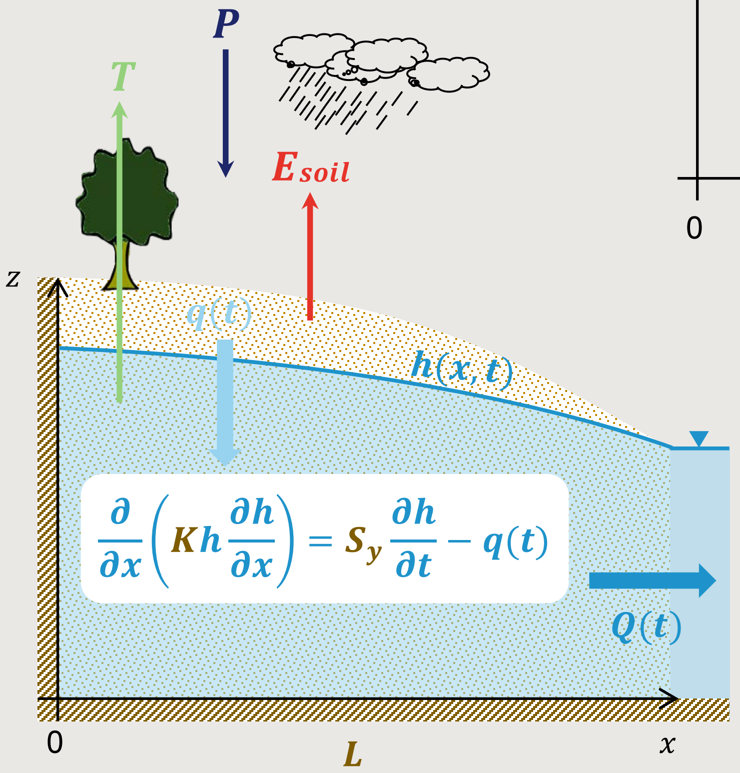
Motivation

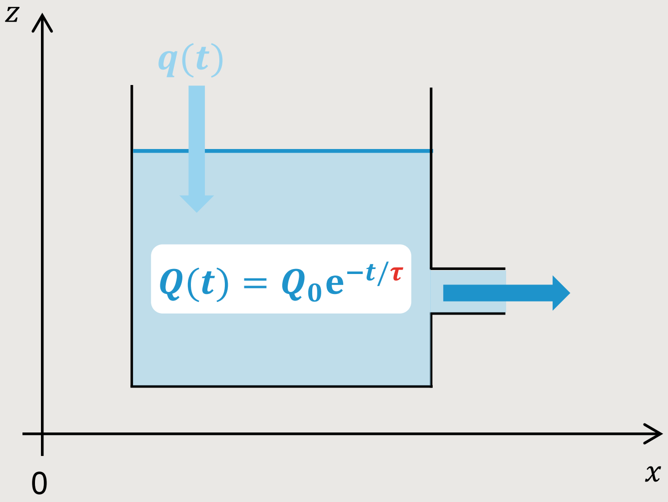
Baseflow modelling in land surface models

$$\frac{\mathrm{d}Q}{\mathrm{d}t} = -\alpha Q^b \quad \xrightarrow[b=1]{} \quad Q = Q_0 \mathrm{e}^{-t/\tau}$$

τ characteristic baseflow timescale

- calibration against discharge data
- recession flow analysis
- physically-based constant





$$\tau \propto \frac{L^2}{D}$$

$D = \bar{h}K/S_y$ hydraulic diffusivity ($m^2.s^{-1}$)

Research question

Can a physically-based baseflow time constant improve river discharge simulations in large scale land surface models?

Outline

1. ESTIMATION OF A PHYSICALLY-BASED BASEFLOW TIME CONSTANT

2. SIMULATING RIVER DISCHARGE WITH ORCHIDEE LAND SURFACE MODEL

3. DISCUSSION ON THE USE OF A PHYSICALLY-BASED BASEFLOW TIME CONSTANT IN LAND SURFACE HYDROLOGY MODELLING

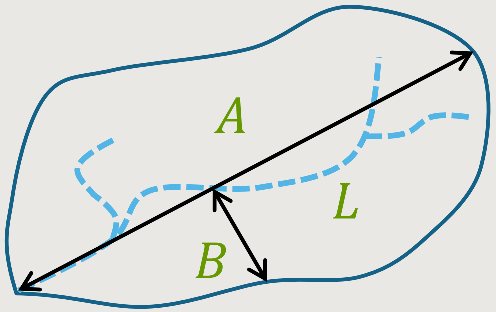
1

ESTIMATION OF A PHYSICALLY-BASED BASEFLOW TIMESCALE

Formulation

We use the long-time solution of the linearized Boussinesq equation to estimate τ as a function of catchment descriptors at global scale:

$$\tau_G = \frac{S_y}{\pi^2 T \delta^2 \cos^2\theta + \frac{\pi^2}{2} K \delta \sin\theta}$$

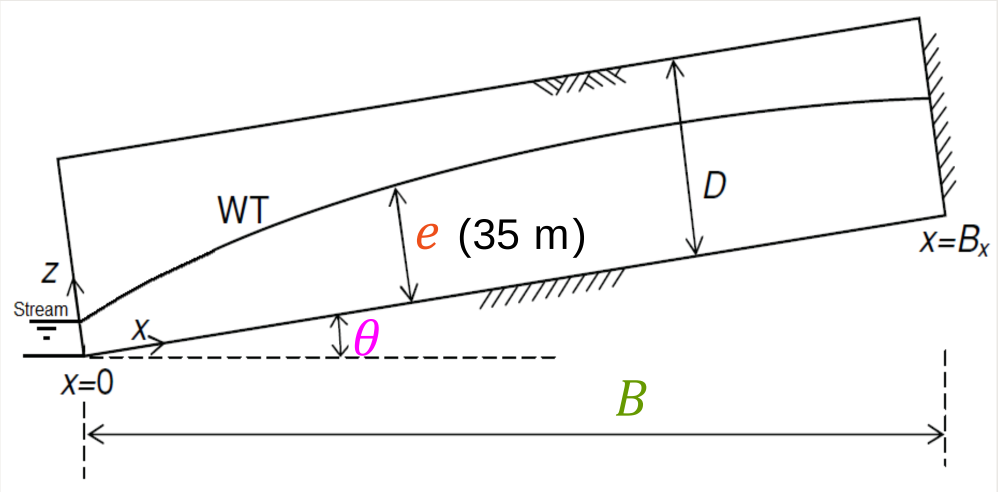


δ drainage density
$\delta = A/\sum L = 1/(2B)$ (m^{-1})

T transmissivity: $T = K \cdot e$ ($m^2.s^{-1}$)

S_y specific yield (-)

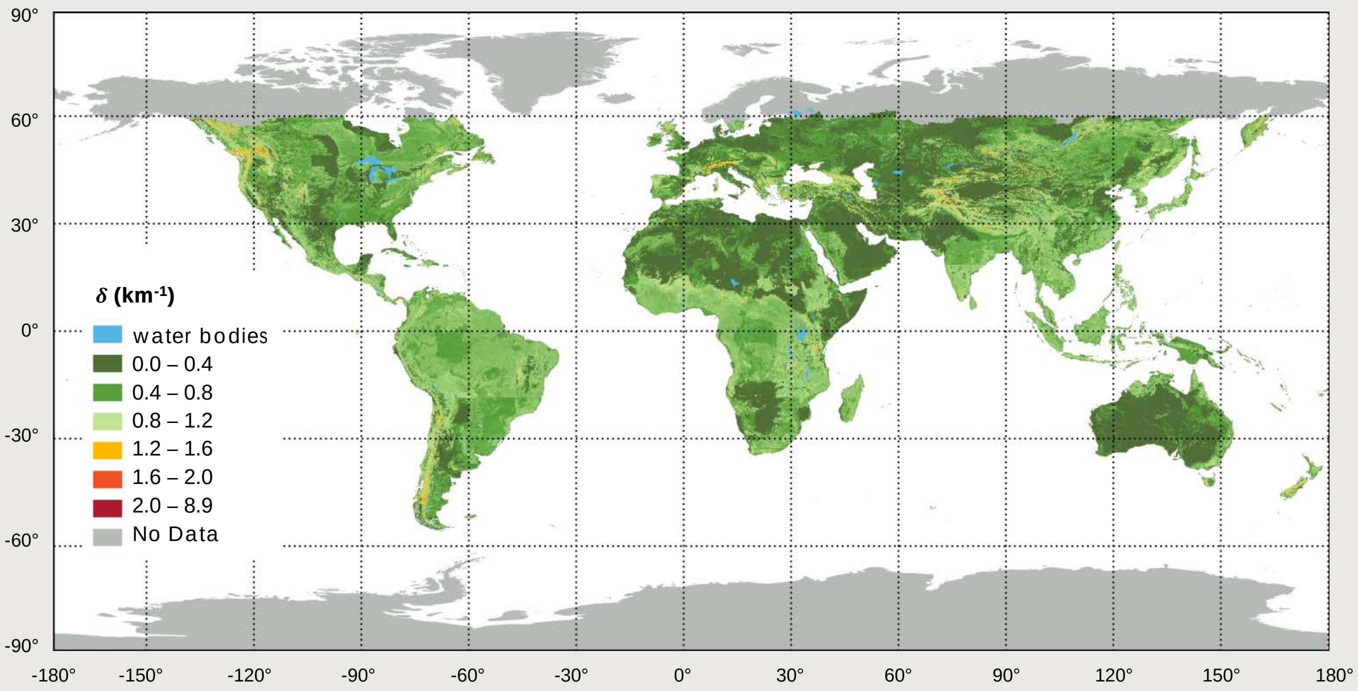
θ aquifer slope: ~water table slope (-) from Fan *et al.* (2013)



τ FORMULATION
(adapted from Brutsaert 2005)

Global scale datasets used in the estimation of τ

B derived from an estimation of δ using the GRIN global river network (Schneider *et al.* 2017)



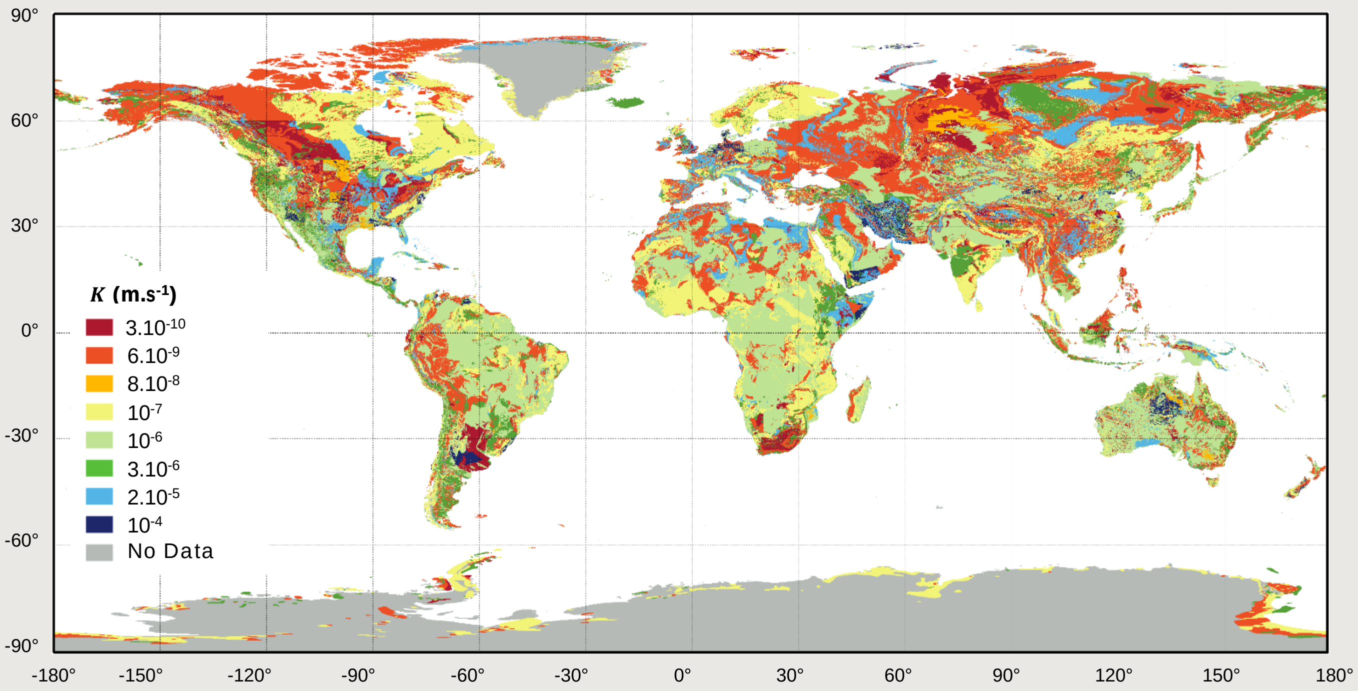
$$\delta_{mean} = 0.74\ \mathrm{km}^{-1}$$

GRIN HIGH-RESOLUTION DRAINAGE DENSITY
(Schneider *et al.* 2017)

Global scale datasets used in the estimation of τ

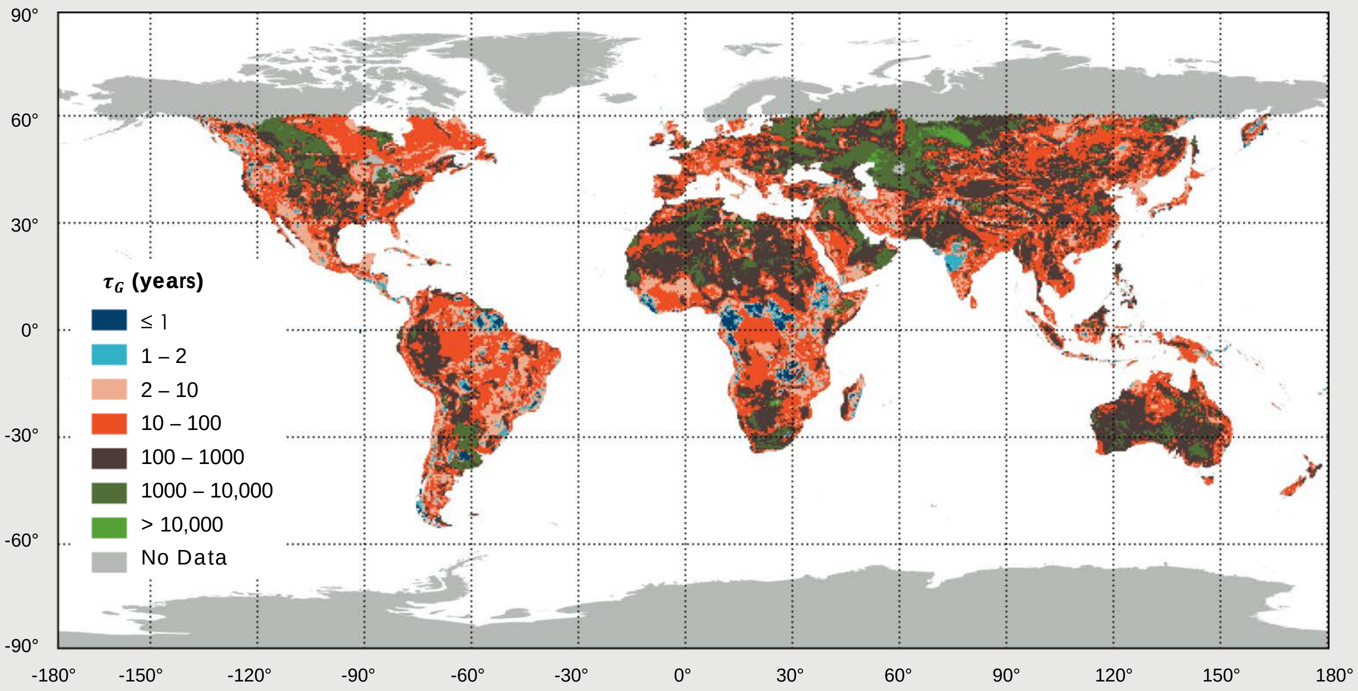
S_y from literature values (Morris & Johnson 1967)

T derived from GLHYMPS high-resolution dataset (Gleeson *et al.* 2014)



GLOBAL HIGH-RESOLUTION MAP OF NEAR-SURFACE PERMEABILITY
(Gleeson *et al.* 2014)

Estimation of the baseflow time constant τ at global scale



τ_{G_Q50} = 65 years

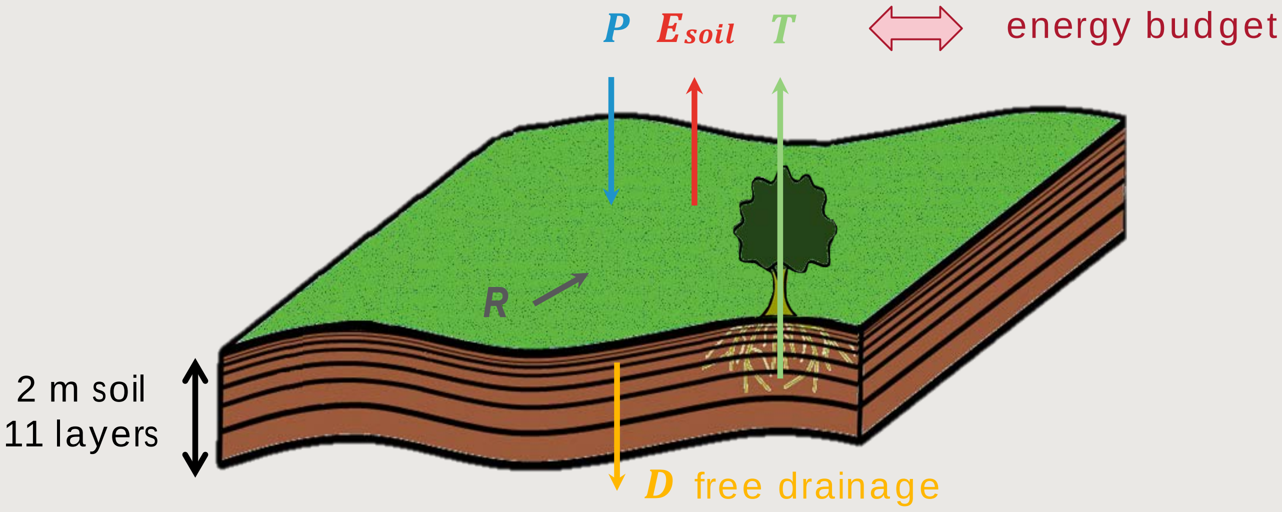
PHYSICALLY-BASED BASEFLOW TIME CONSTANT τ_G AT GLOBAL SCALE
(0.5° resolution)

2

SIMULATING RIVER DISCHARGE WITH ORCHIDEE LAND SURFACE MODEL

Soil hydrology in ORCHIDEE land surface model

- Physically-based description of soil water fluxes using Richards equation
- 2-m soil and 11-layers
- Hydraulic properties based on van Genuchten-Mualem formulation for 3 textures (fine, medium & coarse)
- Infiltration depends on precipitation rate
- Surface $Runoff = P - E_{soil} - Infiltration$
- Free Drainage at the bottom



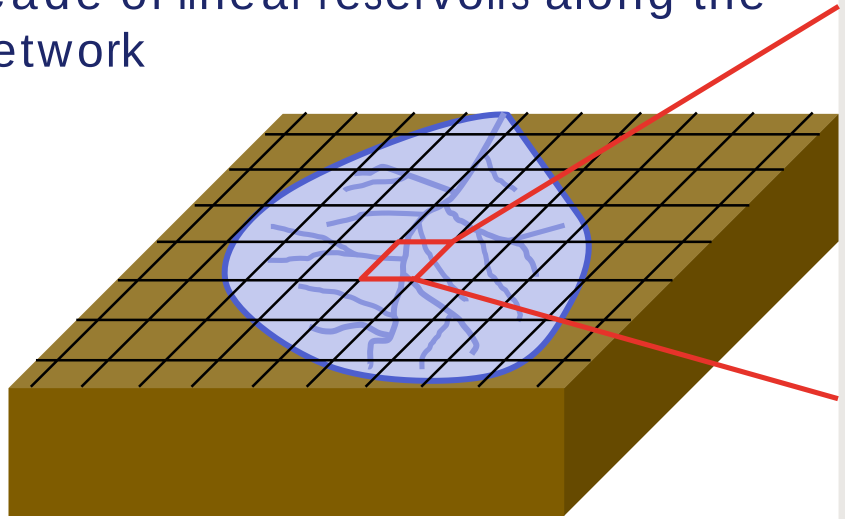
Δt = 30 min

water balance

$$R = P - E_{soil} - Infiltration$$

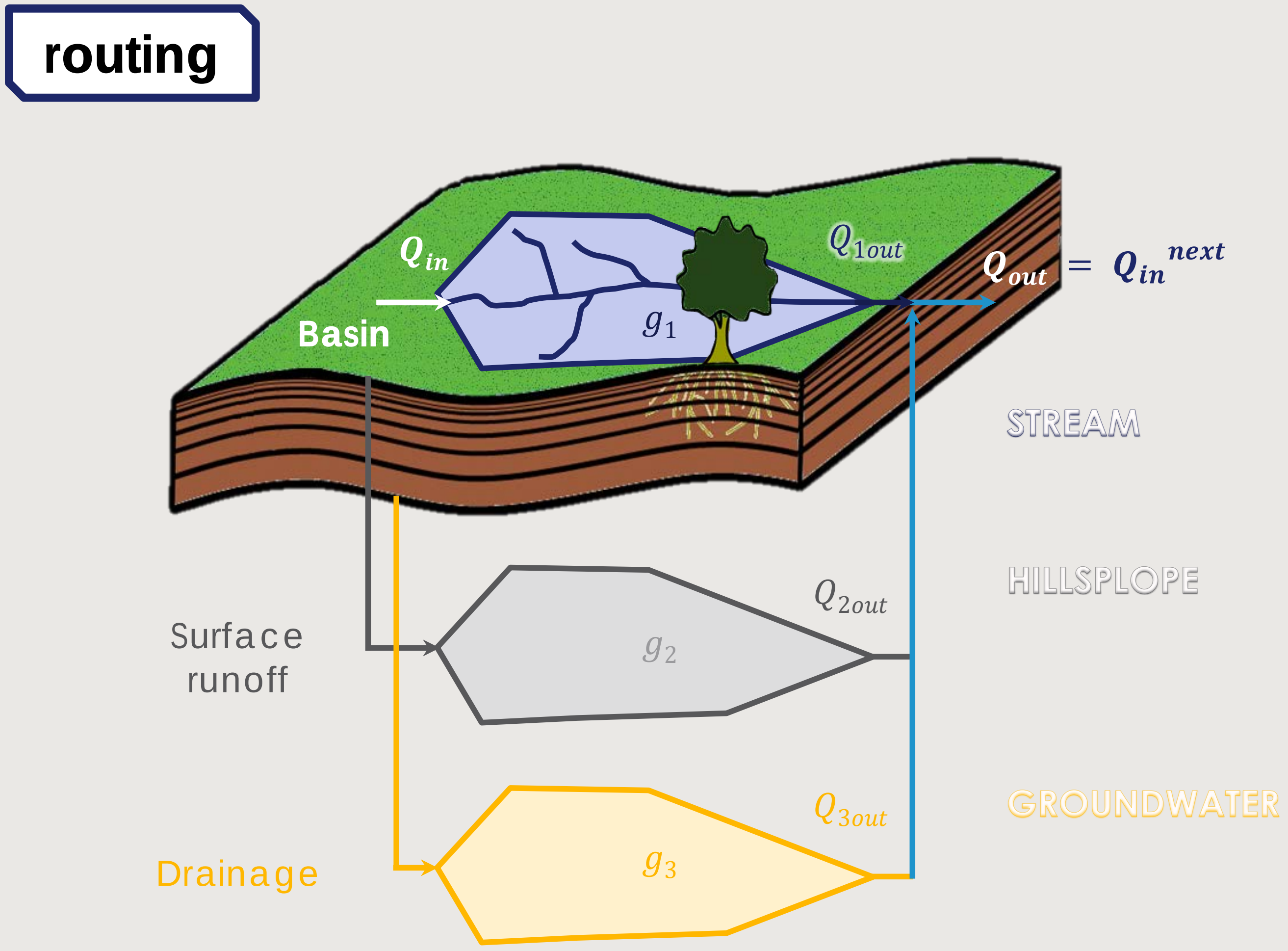
Routing scheme in ORCHIDEE land surface model

- Cascade of linear reservoirs along the river network



- Separate reservoirs for streams, hillslopes and groundwater

Δt = 1 day



ROUTING SCHEME IN ORCHIDEE
(Polcher 2003, Guimberteau *et al.* 2012)

Groundwater representation in ORCHIDEE land surface model

Q_i (kg.s-1) is the flux out of each reservoir

V_i (kg) is water amount in the reservoir i

τ_i (s) is the characteristic timescale of travel time within each reservoir i

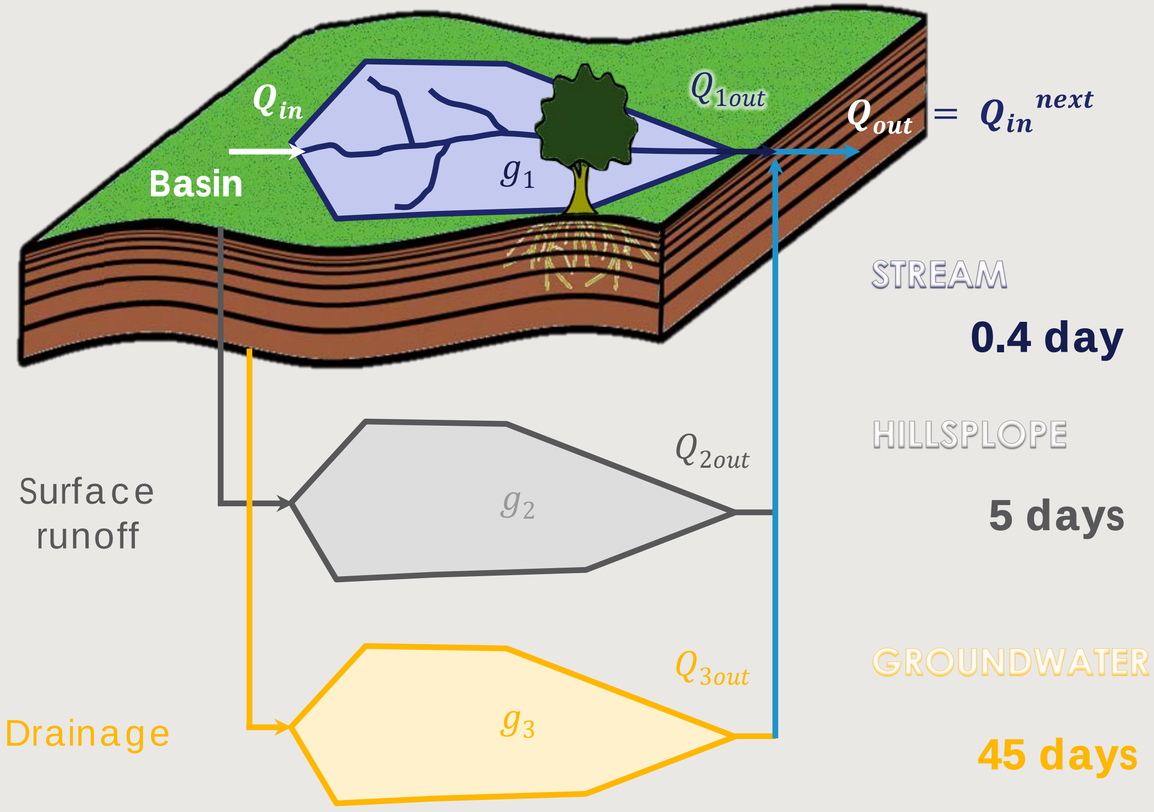
d (m) total river length inside the grid cell

θ river slope inside the grid cell

g_i (s.m-1) reservoir property obtained by calibration over the Senegal basin and used as a constant all over the globe

$$Q_{iout} = \frac{V_i}{\tau_i}$$

$$\boxed{\tau_i = g_i \frac{d}{\sqrt{\theta}}}$$

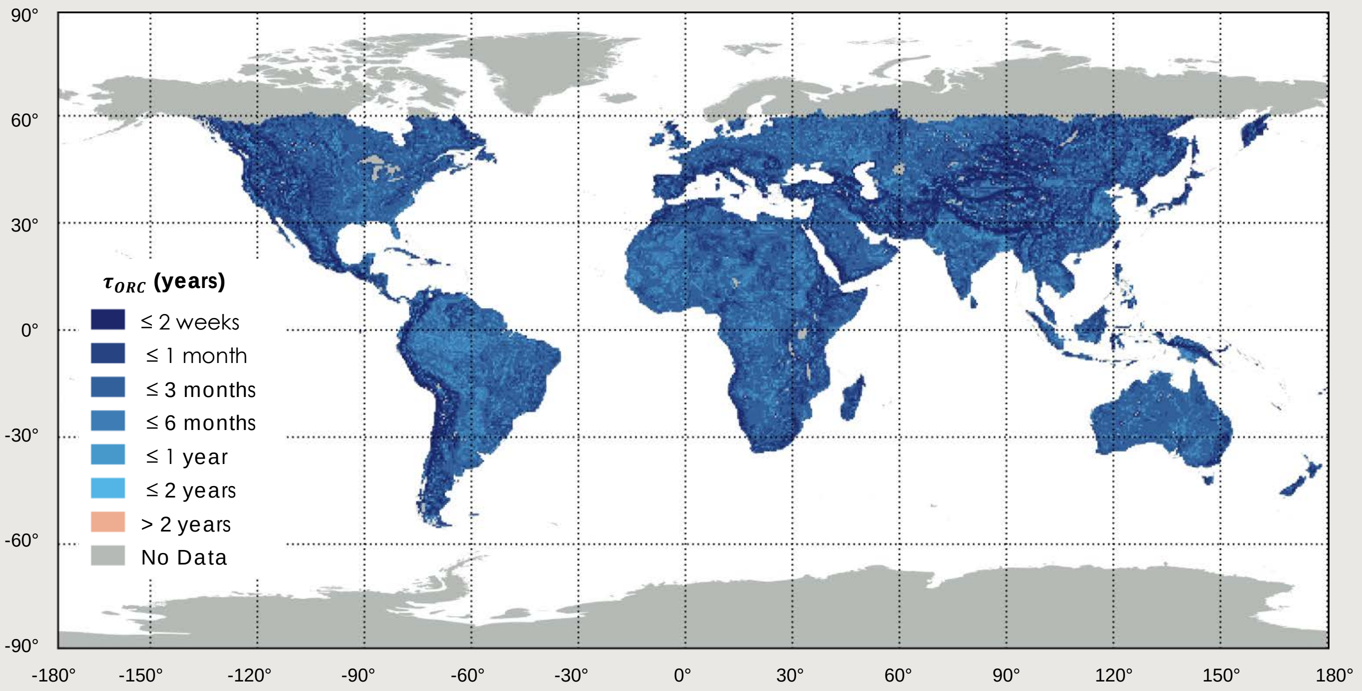


Median τ
in 0.5° x 0.5° cells

ROUTING SCHEME IN ORCHIDEE
(Polcher 2003, Ngo-Duc *et al.* 2007, Guimberteau *et al.* 2012)

Groundwater representation in ORCHIDEE land surface model

τ_{ORC} at global scale



τ_{ORC_Q50} = 45 days

ORCHIDEE BASEFLOW TIME CONSTANT τ_{ORC} AT GLOBAL SCALE
(0.5° resolution)

SCIENCES SORBONNE UNIVERSITÉ

metis UMR 7619

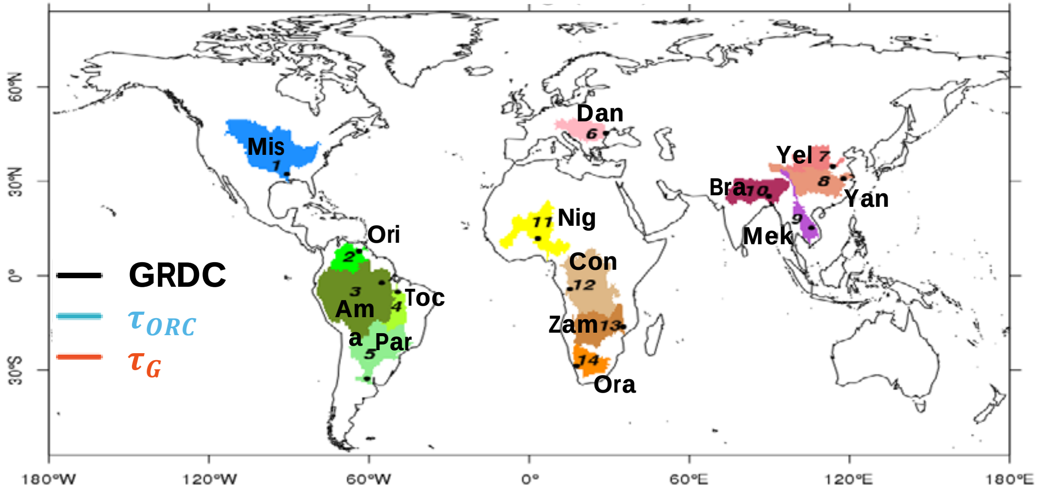
ORCHIDEE simulations

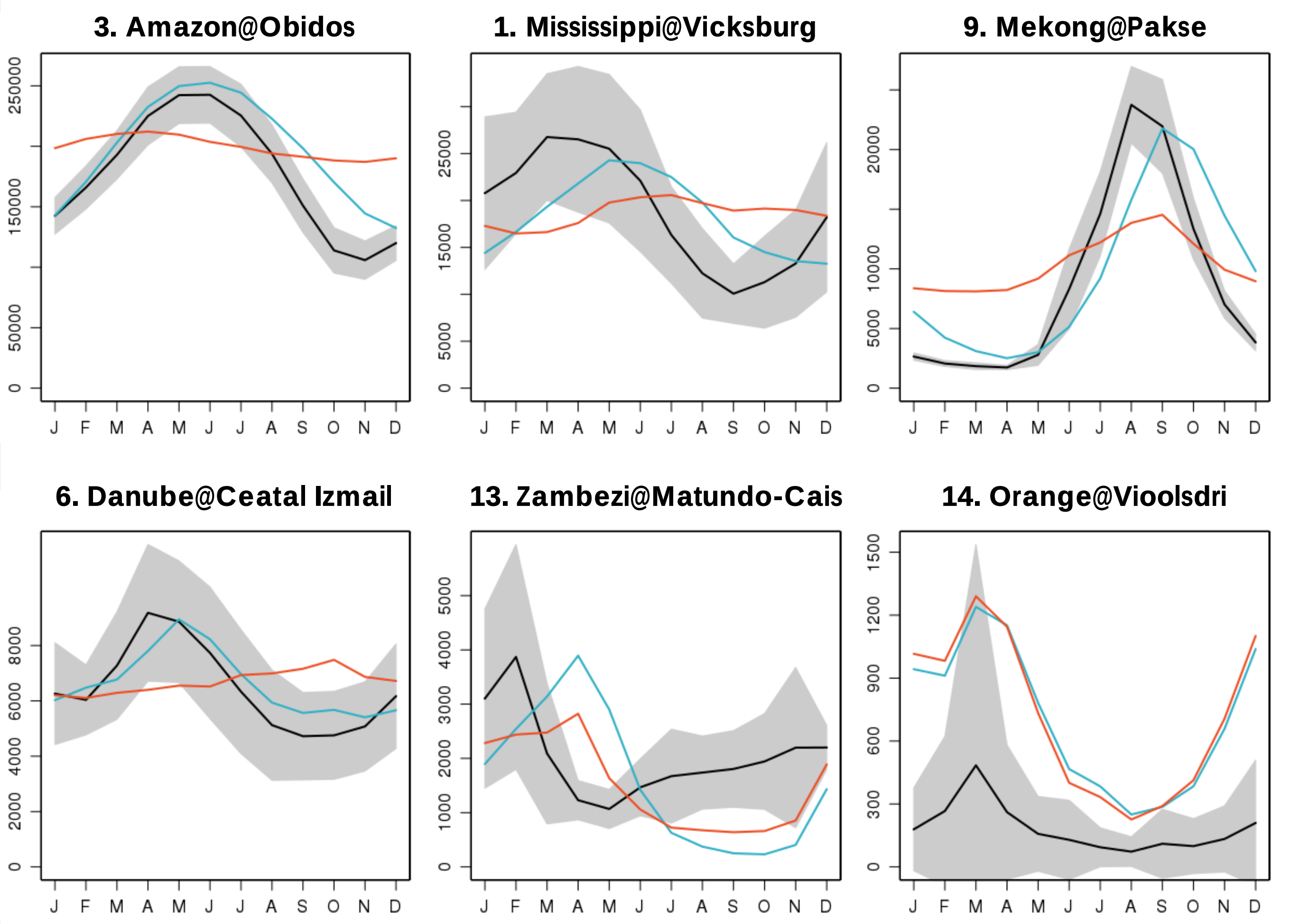
- ORCHIDEE run globally in offline mode
- All simulations performed at 0.5°
- WFDEI corrected by GPCC forcing (Weedon *et al.* 2014)
- Between 1979 to 2010 (six-year spin up)
- Groundwater reservoir initialization

Evaluation of τ in ORCHIDEE

Simulated river discharge using τ_G compared to the reference simulation using the initial τ_{ORC}

River discharge ($m^3.s^{-1}$)



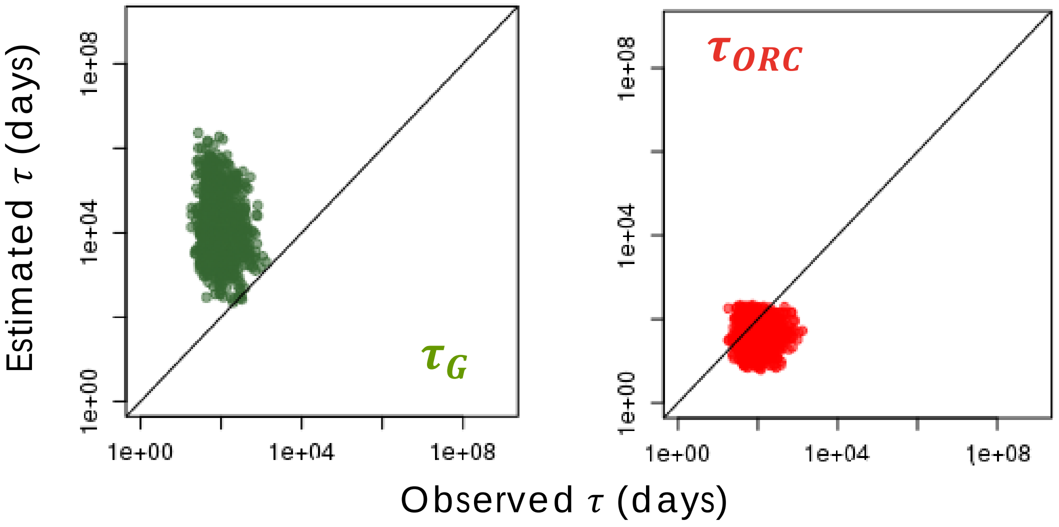


Increased buffering of river discharge variability

∝ drainage

EVALUATION OF THE SIMULATED AGAINST OBSERVED RIVER DISCHARGE ($M^3.S^{-1}$) FROM GRDC BETWEEN 1985-2010

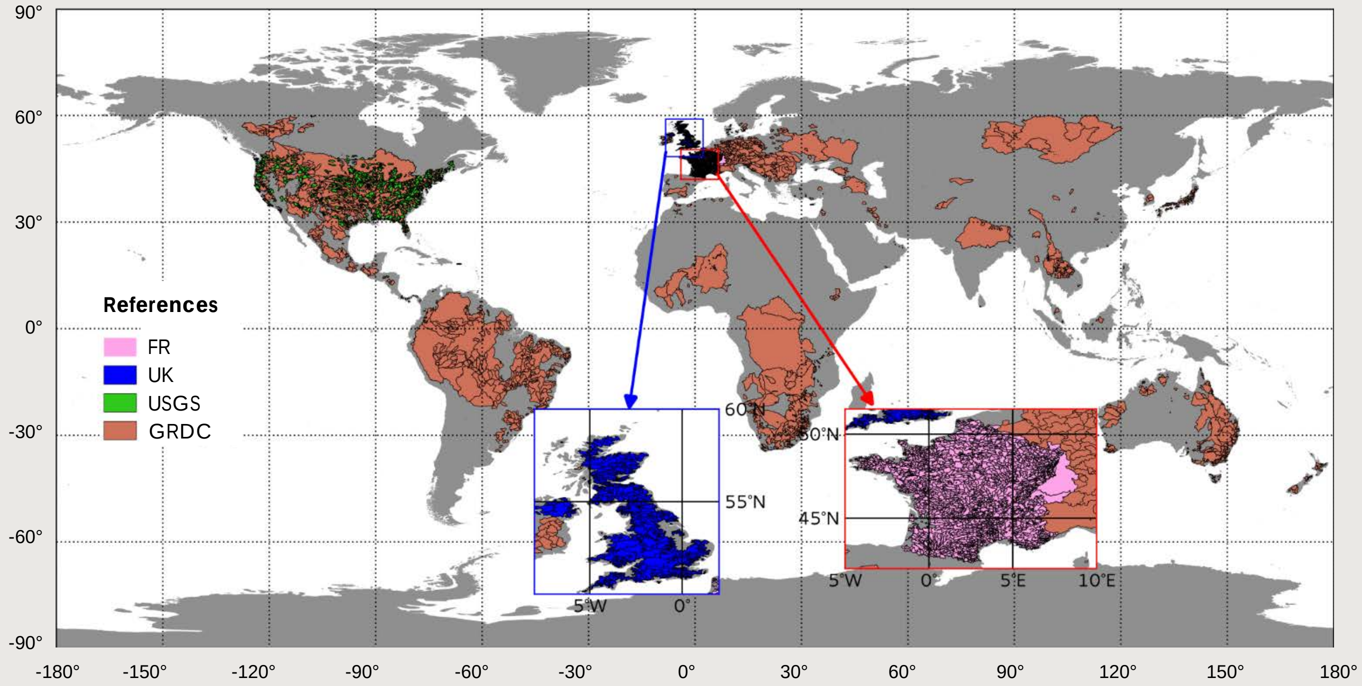
Evaluation of τ



τ_G is largely overestimated when compared to references at the basin scale and not suitable for parametrization of a shallow linear groundwater reservoir.

Validation data

τ issued from recession analysis using RECESS



τ_{obs} range from 18 days to 3.5 years

MAP OF ALL BASINS USED FOR τ VALIDATION.
(Data from France, United Kingdom, United States and global)

3

ON THE USE OF A PHYSICALLY-BASED BASEFLOW TIME CONSTANT IN LAND SURFACE HYDROLOGY MODELLING

3

1. Alternative scenarios for τ estimation
2. Underlying assumptions in the analytical method

Estimations of τ at global scale

$$\tau = \frac{S_y}{\pi^2 T \delta^2 \cos^2\theta + \frac{\pi^2}{2} K \delta \sin\theta}$$

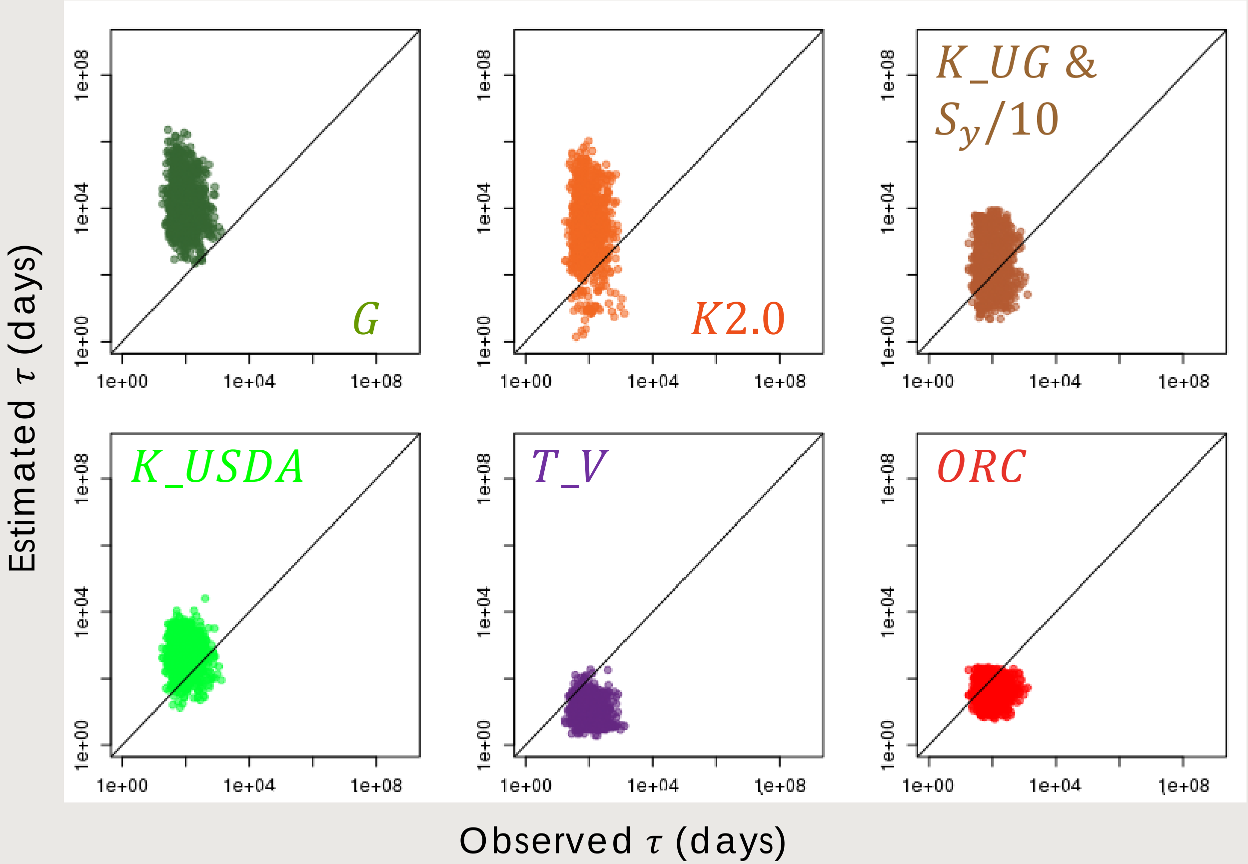
Alternative scenarios from available global scale datasets

δ	HydroSHEDS river network (Lehner *et al.* 2008)	LCS model of GRIN (Schneider *et al.* 2017)
S_y	total porosity of GHLYMPS (Gleeson *et al.* 2014)	specific yield (Johnson 1967)
θ	horizontal	calculated from water table depths (Fan *et al.* 2013)
K	GLHYMPS 2.0 (Hushcroft *et al.* 2018)	USDA soil database (Reynolds *et al.* 2012) & exponential decay
	combination of USDA & GLHYMPS	
T	model calibration (Vergnes & Decharme 2012)	

Evaluation of alternative scenarios

K	GLHYMPS 2.0	USDA & exponential decay
	combination of USDA & GLHYMPS	model calibration

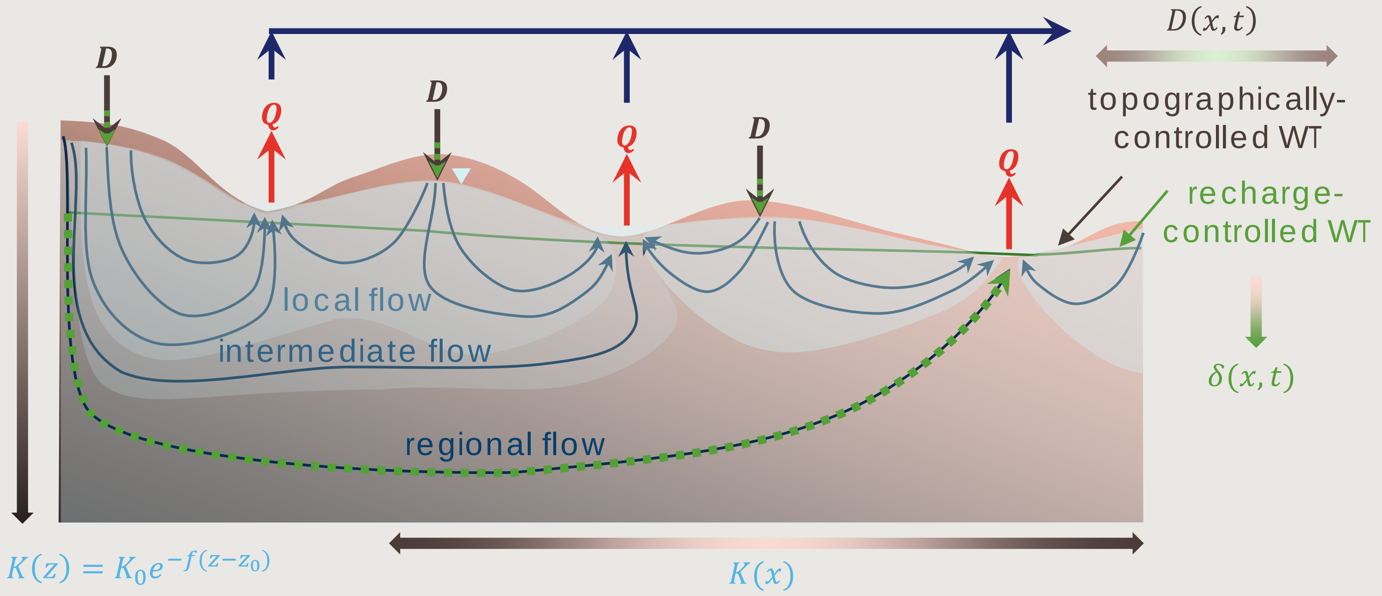
τ from model calibration and extrapolation result in the lowest bias but still with low correlation coefficients



COMPARISON OF OBSERVED τ
WITH PHYSICALLY-BASED ESTIMATIONS OF τ AND τ_{ORC}

Baseflow and catchment properties relationships

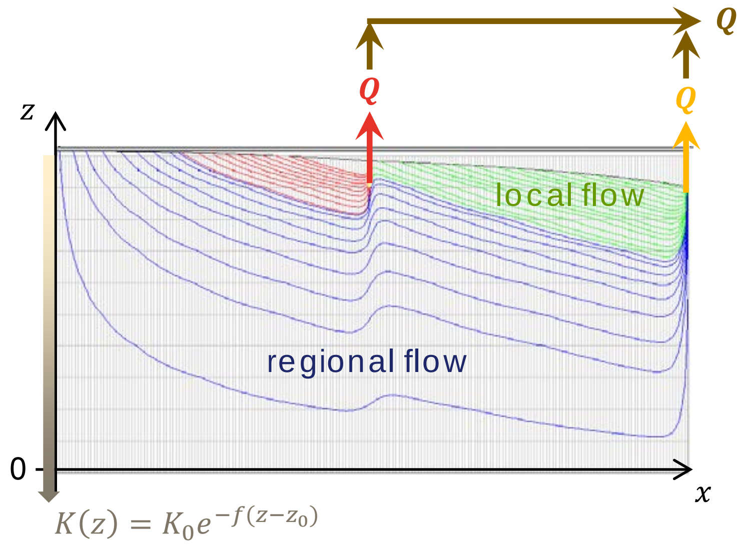
Preferential flow pathways due to natural heterogeneities in aquifers strongly influence groundwater recharge and discharge.



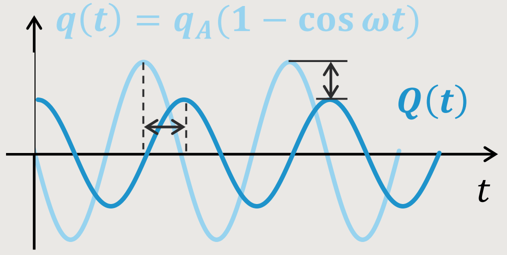
MULTISCALE GROUNDWATER FLOW
(adapted from Schaller & Fan 2009)

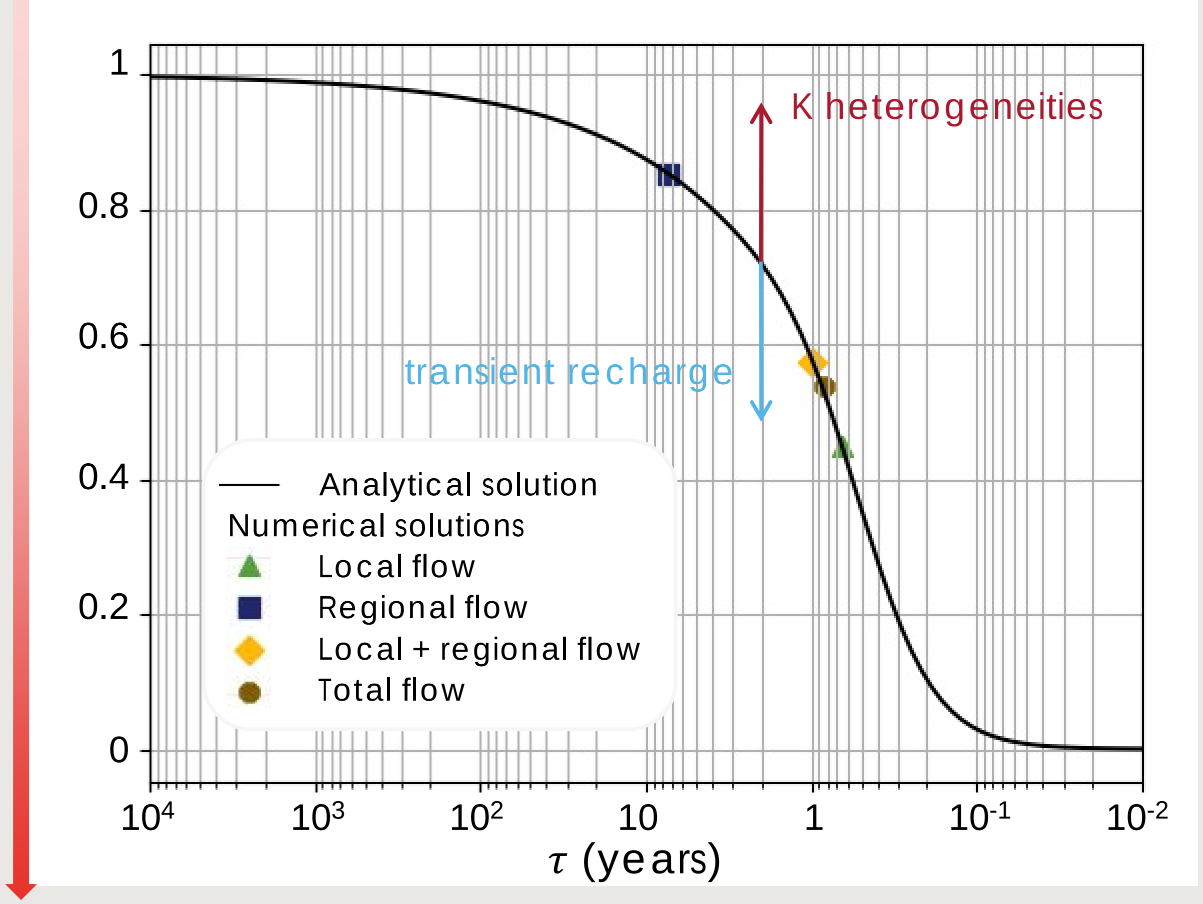
Baseflow and catchment properties relationships

Numerical modelling: idealised 1-D solutions using MODFLOW considering nested flow regimes



$$R_f = \frac{\bar{Q}_{min}}{\bar{Q}_{mean}}$$





$R_f - \tau$ **RELATIONSHIPS**
(adapted from Erskine & Papaiaonnou 1997)

Conclusion & perspectives

1. The use of a physically-based τ in ORCHIDEE deteriorates river discharge simulation due to a strong buffering effect.
2. A more appropriate description of the physical properties of near-surface aquifers (T & S_y) is required to provide better agreement with observations.
3. Future research may investigate (i) physical factors that control τ (ii) how to take into account spatial heterogeneity in τ formulation (iii) the implementation of a nonlinear storage groundwater reservoir in ORCHIDEE.

Thank you for your attention

SCIENCES SORBONNE UNIVERSITÉ