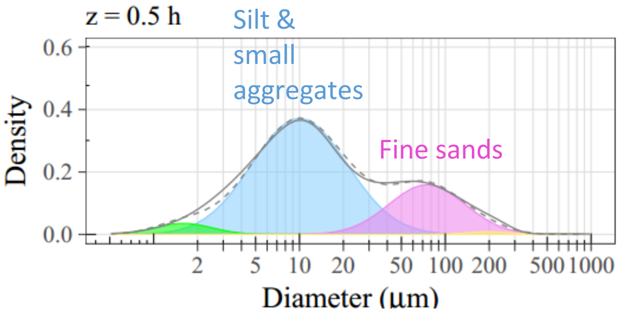
Sediment dynamics in the Ucayali basin, assessed by integrating field network, semi-distributed modelling and remote sensing




William.santini@ird.fr

Strategy: 2 classes of sediments

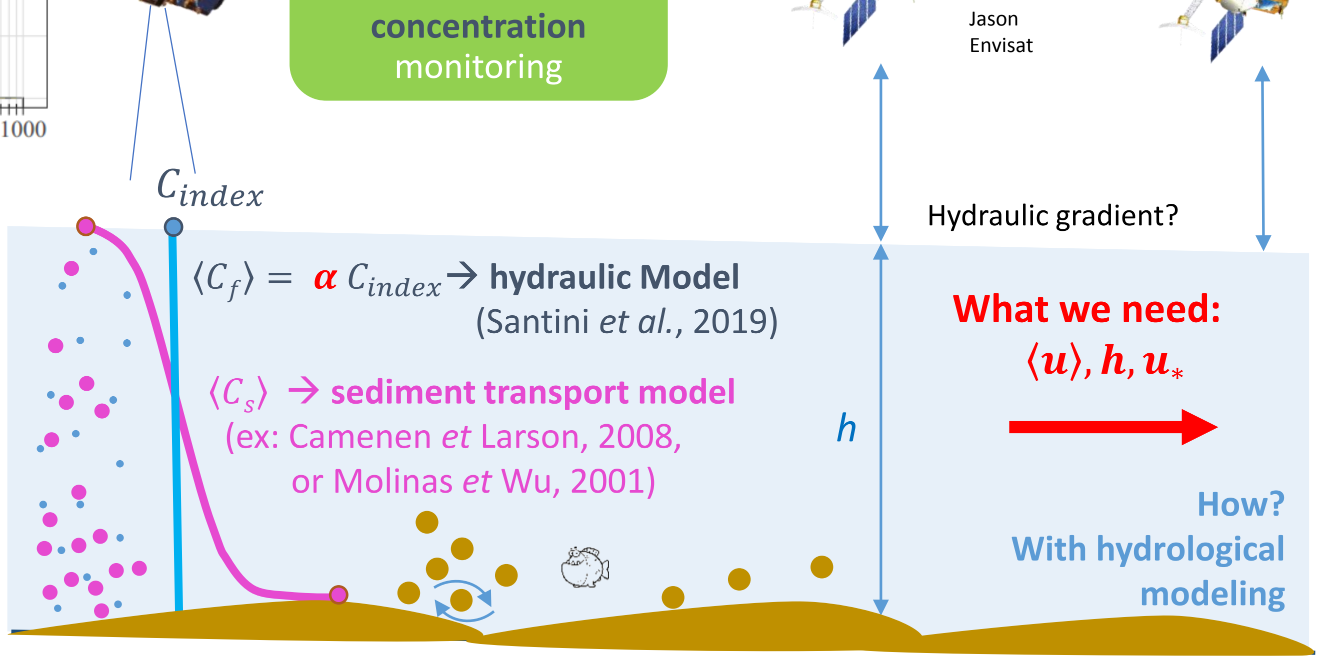
Satellite altimetry measurements to force the hydrological model



Ex: SENTINEL mission
Modis
LANDSAT

Reflectance measurements for the **fine sediments concentration** monitoring

Ex: SWOT mission
Altika
Jason
Envisat



Hydraulic parameters are required for:

- The estimation of the sand mean concentration

- The ratio α of mean concentration to index concentration for the fine fraction

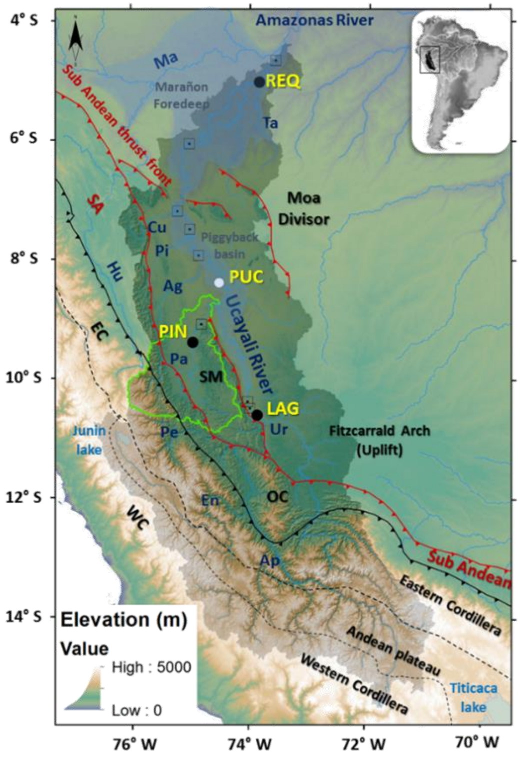
What we need:

$\langle \boldsymbol{u} \rangle, \boldsymbol{h}, \boldsymbol{u_*}$

How?

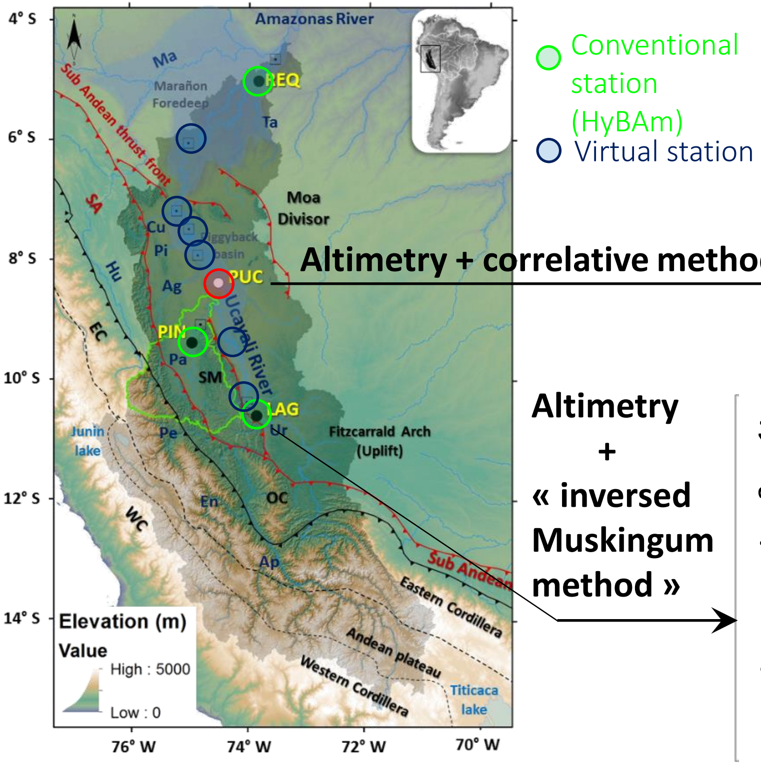
With hydrological modeling

Case study: the Ucayali basin (Peru)

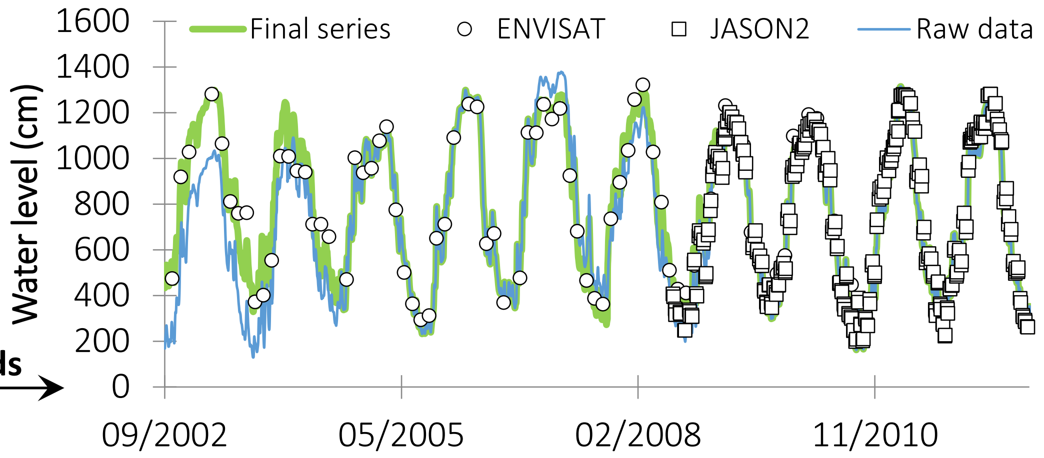


- Ucayali River
  - Longest branch of the Amazon River
  - 350 000 km², 2700 km
  - 12 100 $m^3\ s^{-1}$, 31 $l\ s^{-1}\ km^{-2}$
  - 305 10^6 $t\ yr^{-1}$
  - ~ 27 – 30 % of the Amazon Qs
- Pachitea River
  - 22 000 km²
  - 2100 $m^3\ s^{-1}$, 107 $l\ s^{-1}\ km^{-2}$
  - 60 10^6 $t\ yr^{-1}$

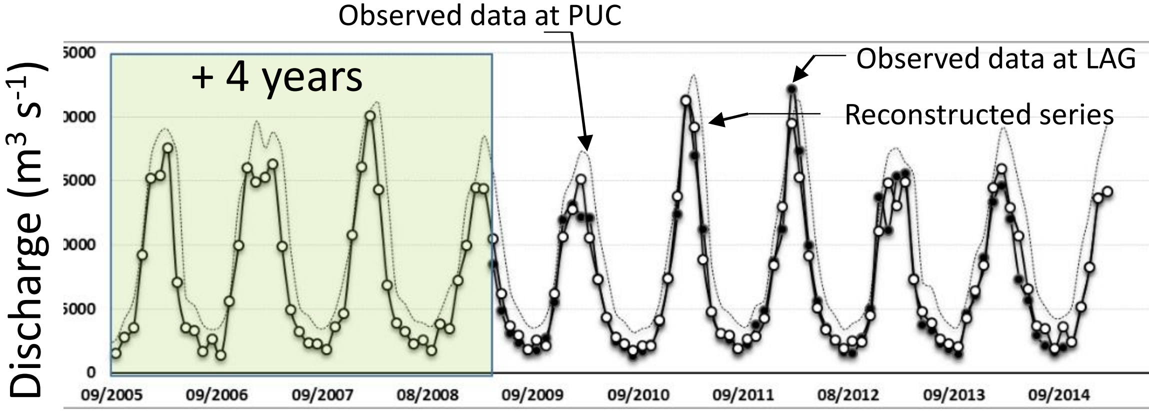
Dataset building: a mix of remote-sensing with conventional data



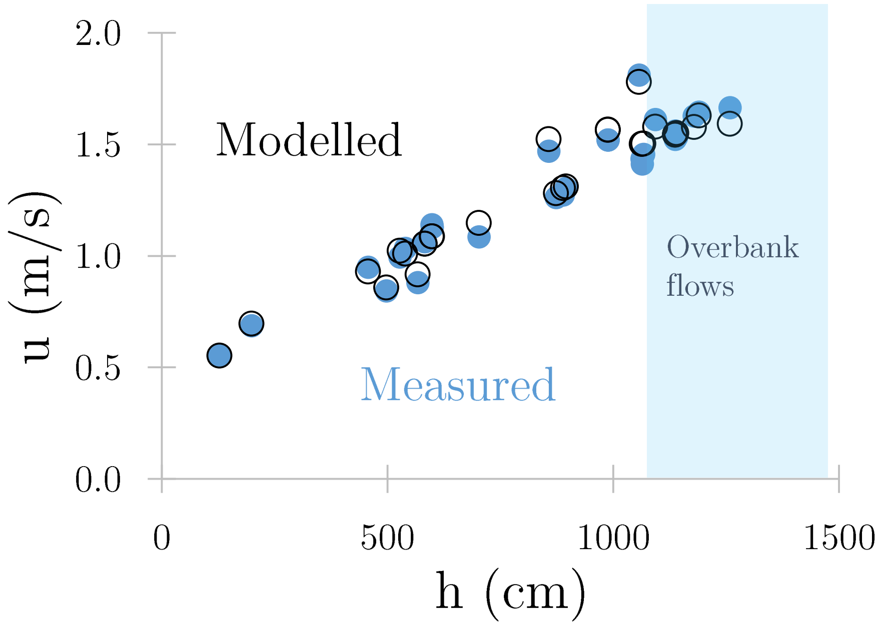
Altimetry + correlative methods



Altimetry + « inversed Muskingum method »



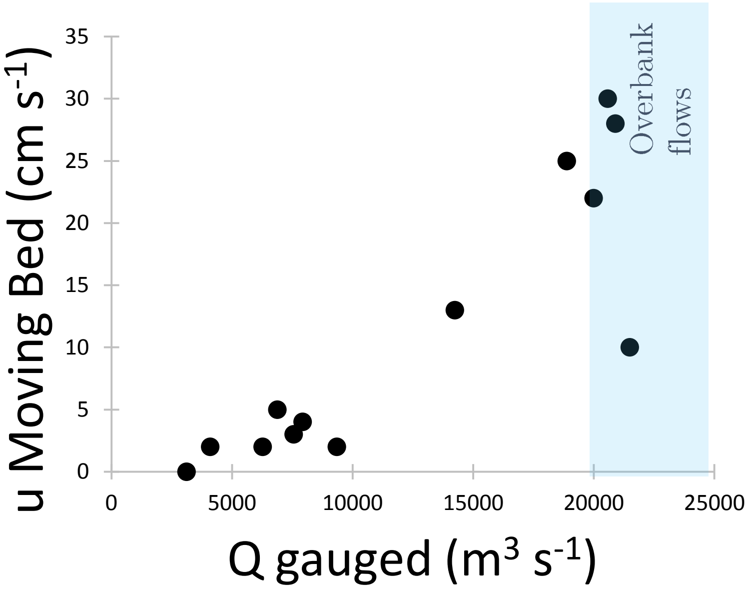
Dataset building: The calculation of water discharge is not so easy in the Amazonian Rivers…



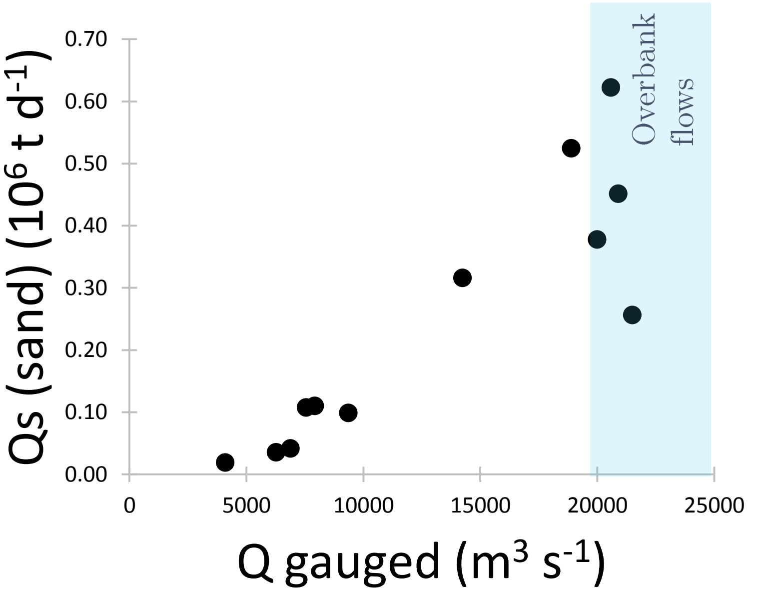
- Backwater effects
- Velocity in the main channel is reduced during floods:
  - Shear layer interface (composite bed) – momentum exchange
  - Energy drop induced by water flowing through floodplain channels or by diffusive incursion into the floodplain
  - Water Surface slope → mean valley slope

Impact on the sediment transport (sands)

~Proxy of bedload



Suspended sands



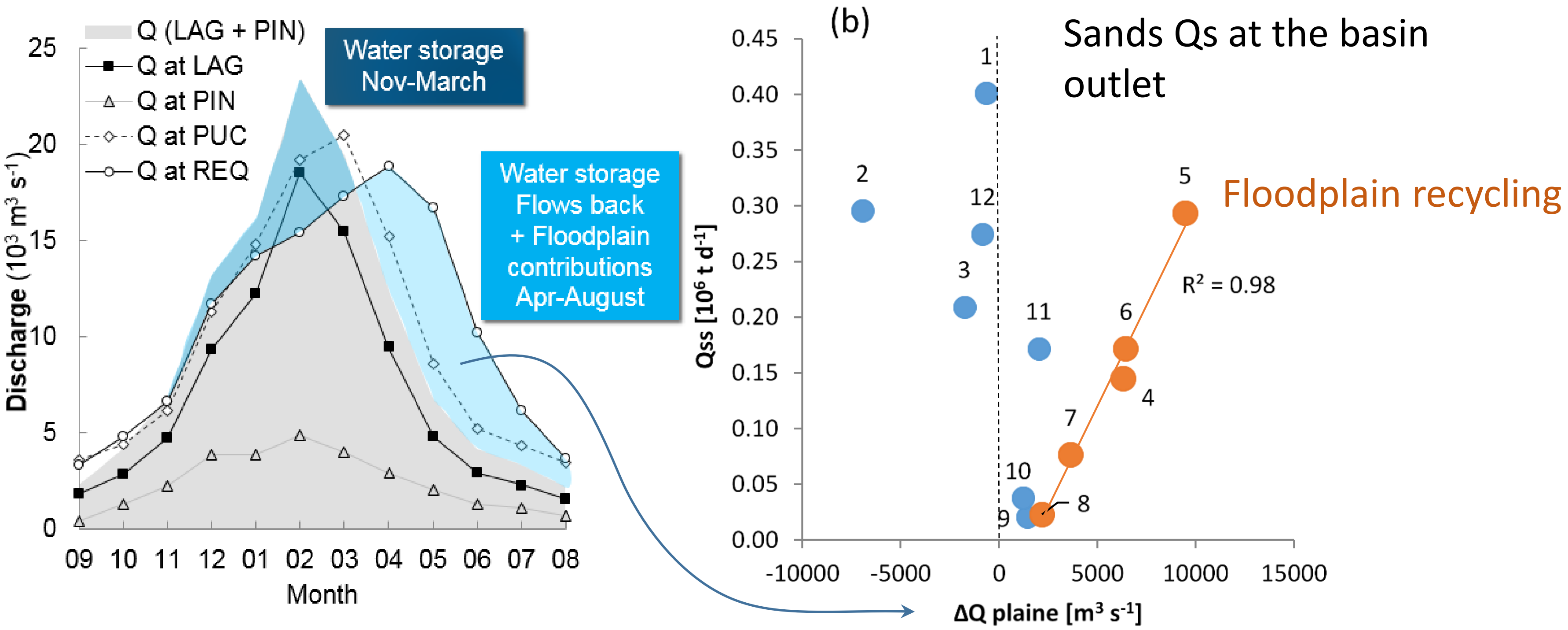
Additional resistance term (1d flow modeling)

- Main resistance sources for large Amazonian rivers:
  - Skin friction – small scale energy dissipation (f or n) → Fluids Mechanics (Re) / Impulse momentum viewpoint → Velocity and Concentration profiles
  - Geomorphological resistance scale:
    - Meanders (Constant sinuosity assumed)
    - Bed macro-forms (Dunes...) -> bed breathing according to u* cycle
    - **Floodplain drag!**

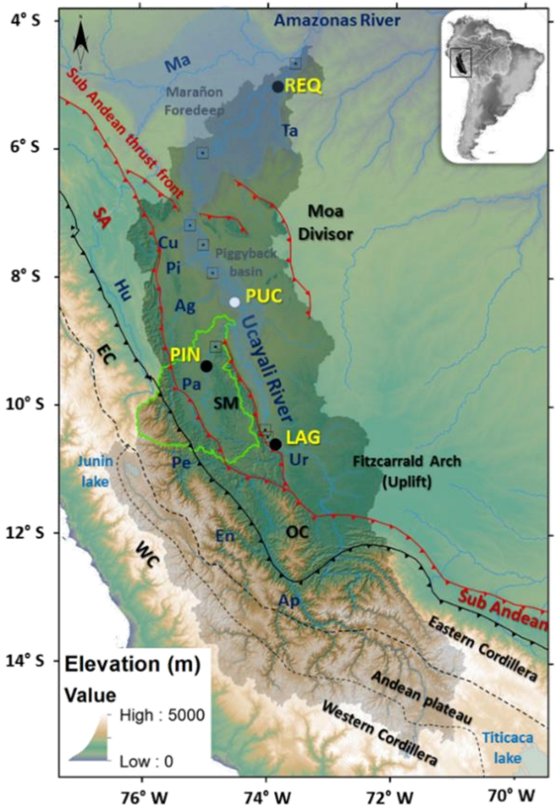
Energy concept:

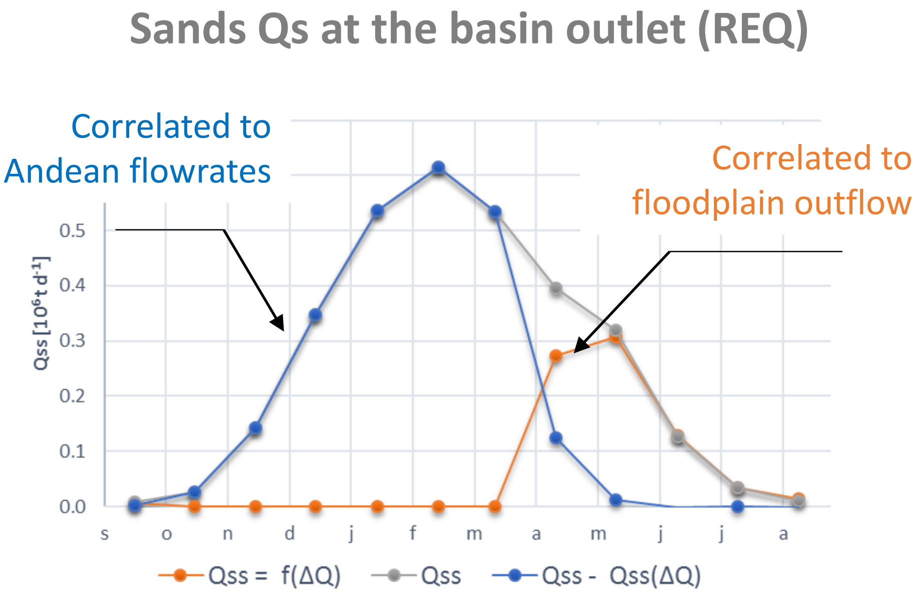
$$\theta = \sum_{i=1}^{n} \theta_i \rightarrow f = \sum_{i=1}^{n} f_i \rightarrow n^2 = \sum_{i=1}^{n} {n_i}^2$$

Field network results: what we know

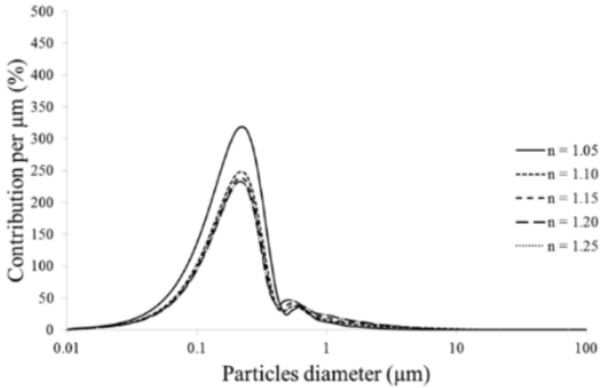


Field network results: what we know





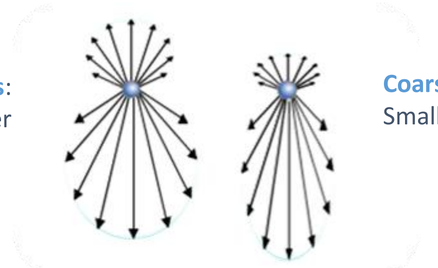
Use of reflectance data for the fine SPM concentration monitoring



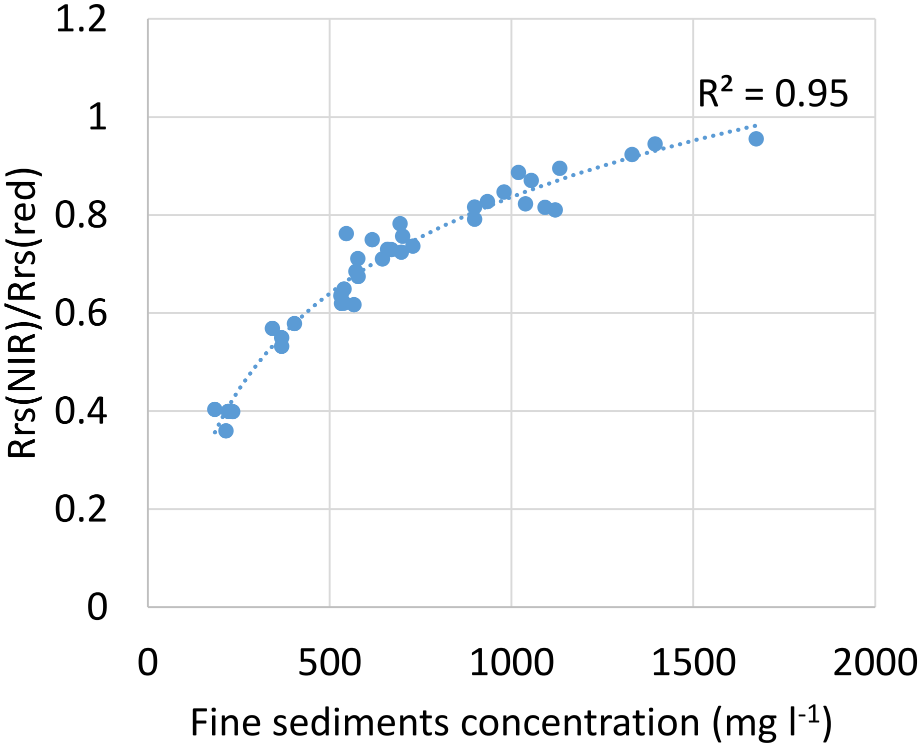
Pinet,PhD, 2017

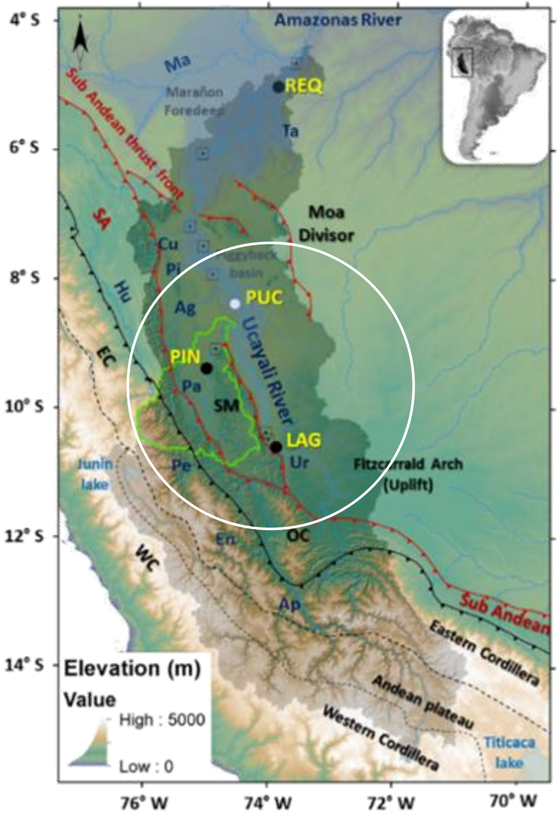
Most part of the reflectance signal is coming from clays particles; silts & fine sand particles signal are in the backscatter noise…

Mie theory

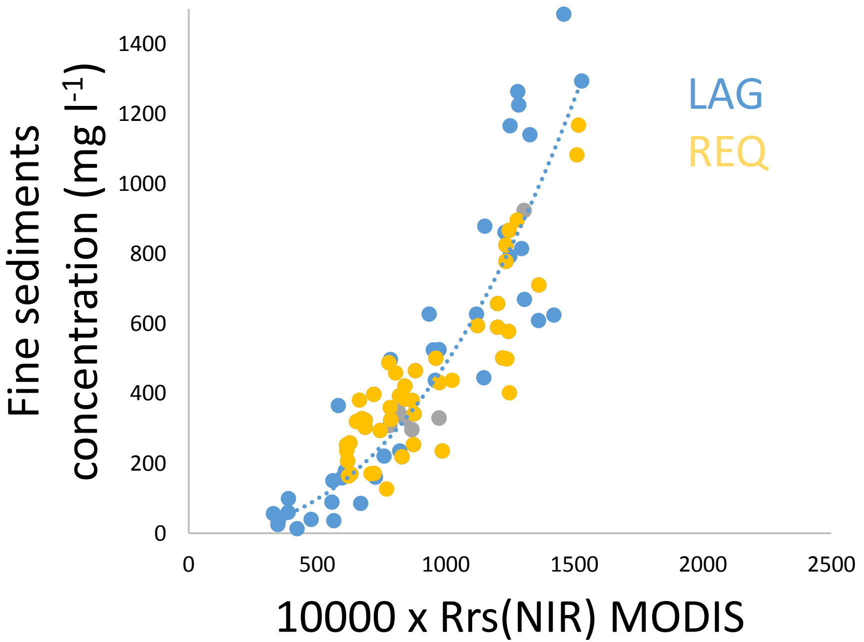


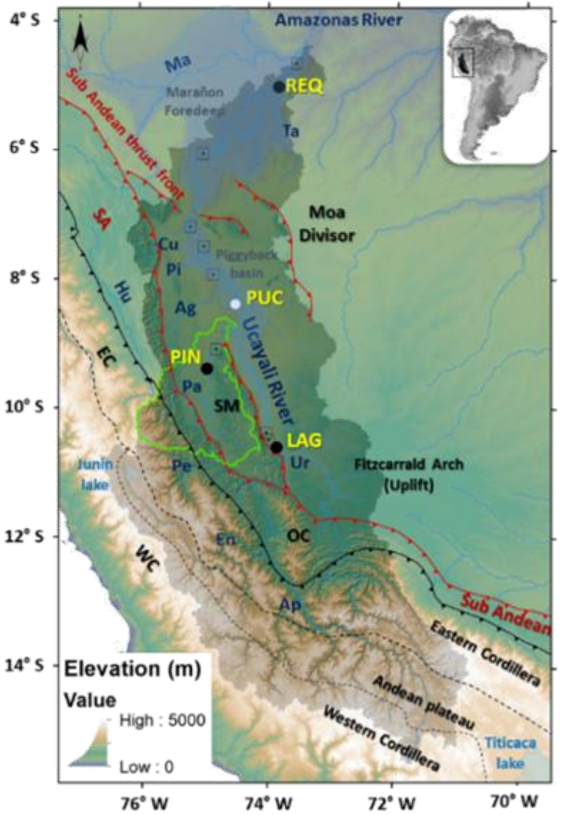
Cal/val measurements (Feb 2017)





A single law for the entire Ucayali River (plain)



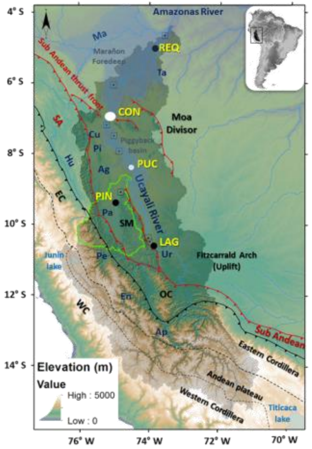


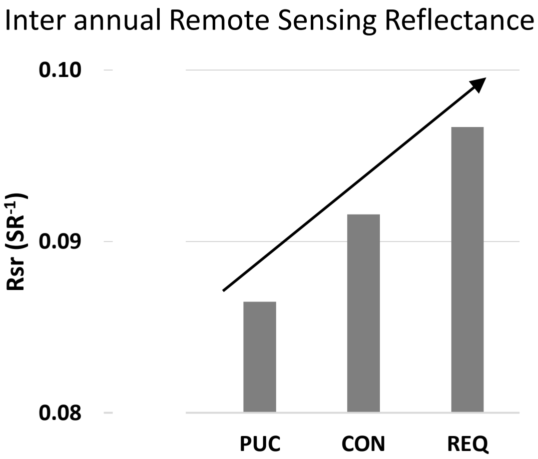
Particle absorption (a): weight of coarse particles?

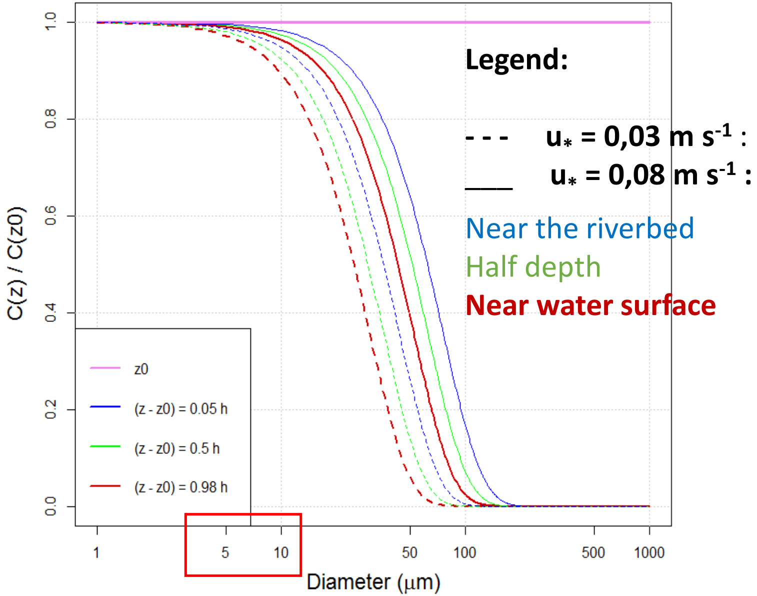
Reflectance (NIR) increases from upstream to downstream while sediment flow and concentration decrease

$$Reflectance = f' \frac{b}{b + a}$$

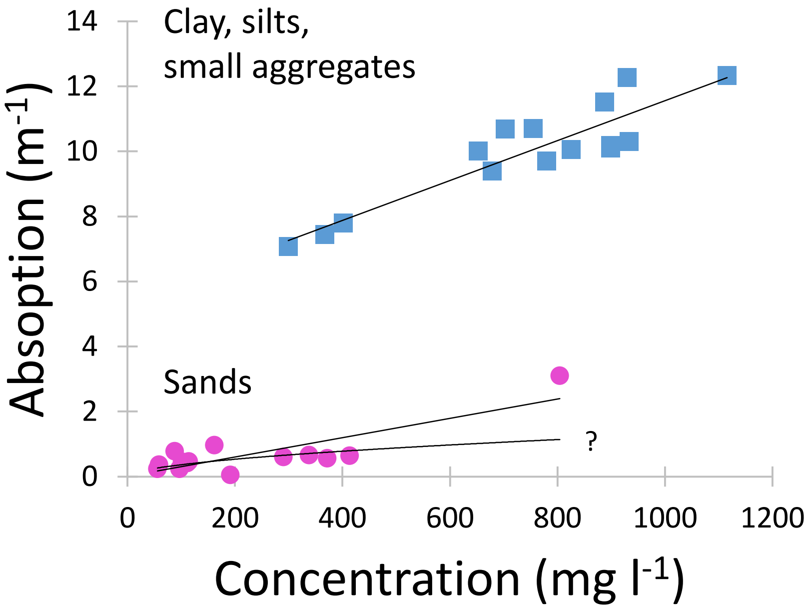
Coarse silts are also hydraulically sensitive

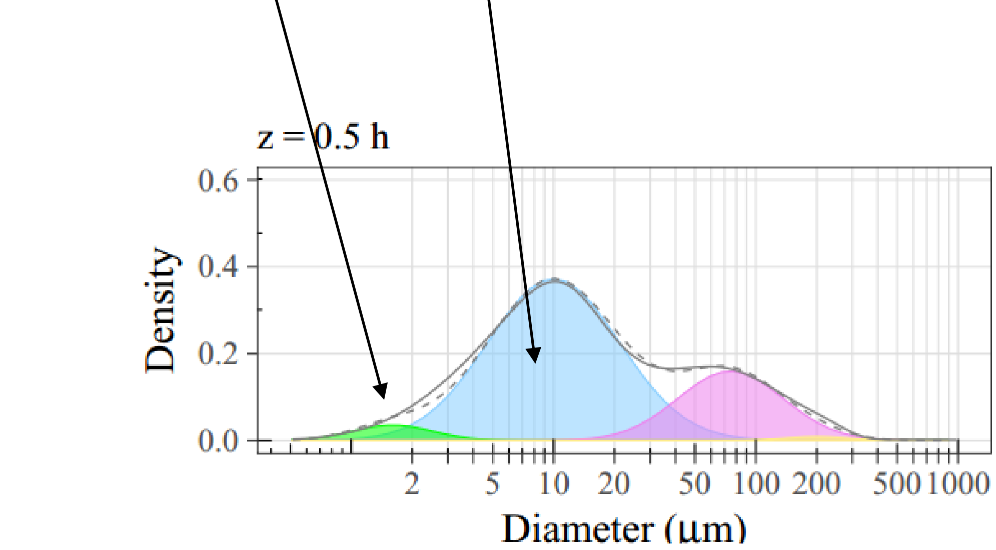






Coarse particles influence on remotely sensed reflectance values?



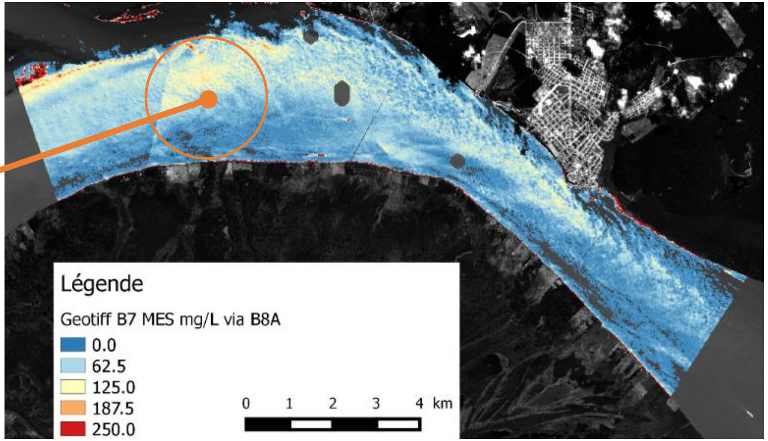


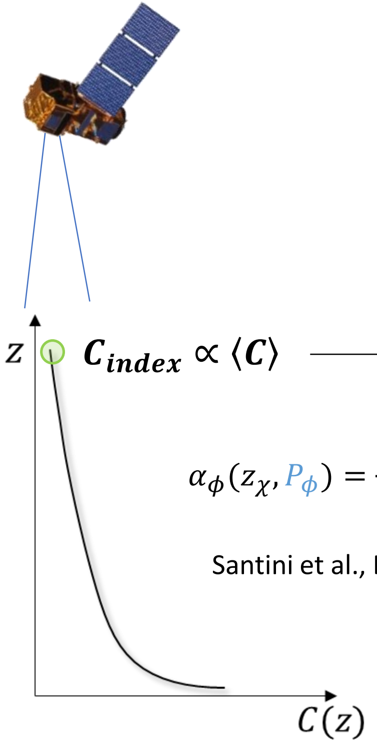
To link the concentrations derived from remote sensing data with the mean concentration transported by the river

- Model + hydraulic parameters

Index concentration

$C(z_\chi = h)$

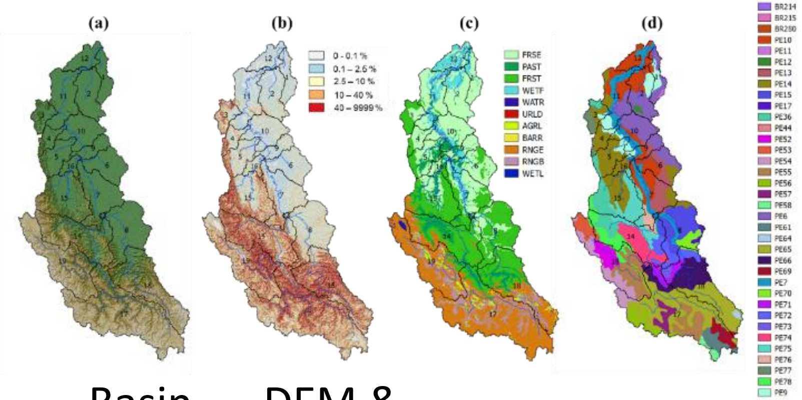




$$\alpha_\phi(z_\chi, P_\phi) = \frac{\exp(3\,P_\phi)\,(1-\exp(-6\,P_\phi))}{6\,P_\phi \exp\left(0.93\,P_\phi\left(\Phi(\frac{h}{2})-\Phi(z_\chi)\right)\right)}$$

Santini et al., Esurf, 2019

Hydraulic parameters → Semi-distributed modelling with SWAT



Basin HRU | DEM & Slopes | Land Use | Soils

+ Rainfall data: TRMM

+ ETP (Reanalisis)

Robust

Open code

Widely used

Well documented

Water quality modules

SWAT results – Water discharge

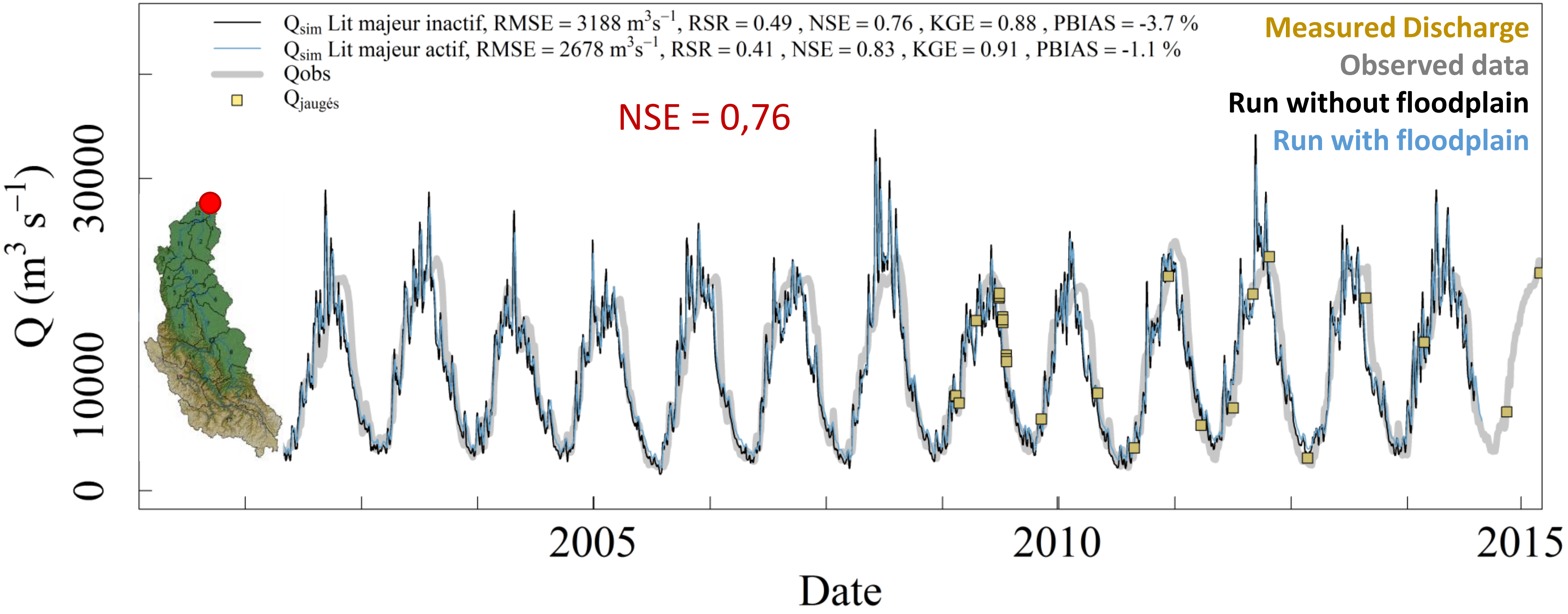
(Routing with the “SWAT” Muskingum method)

Water cycle simulation: ~Ok

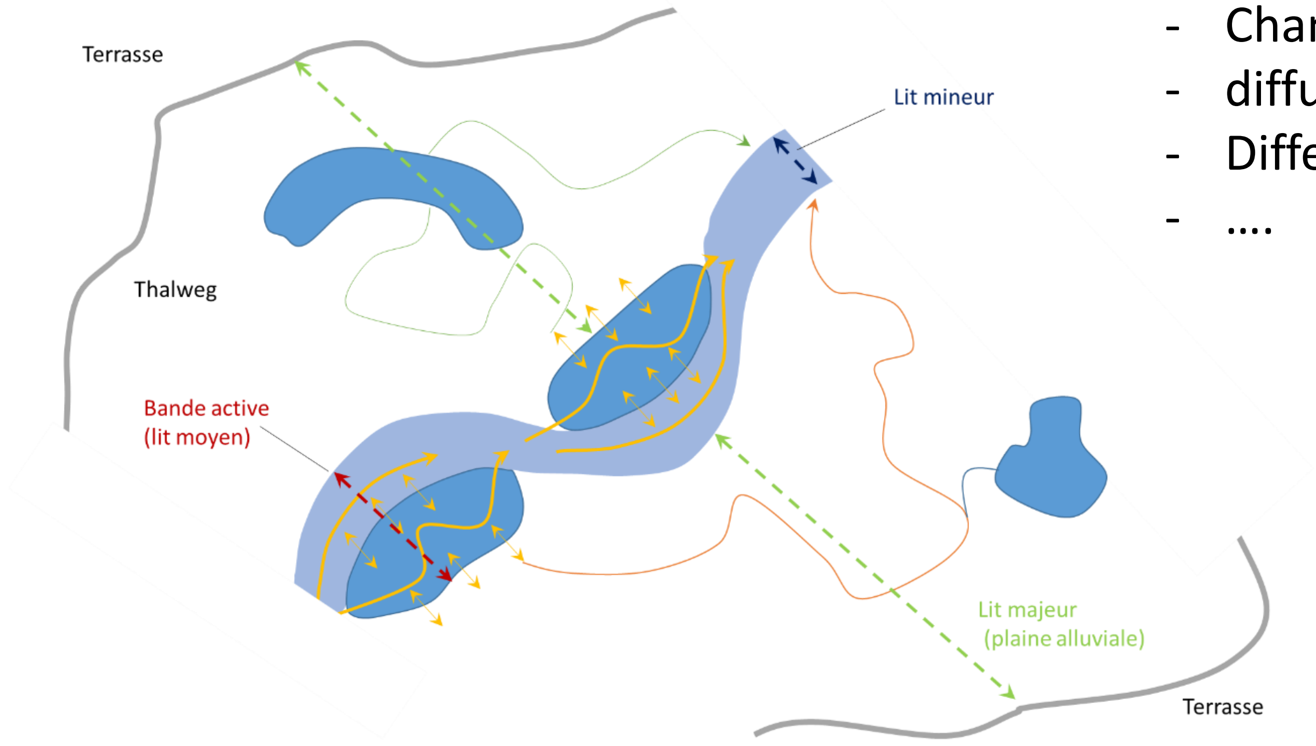
But the flood is not attenuated

The model is not able to simulate h and u

(a)

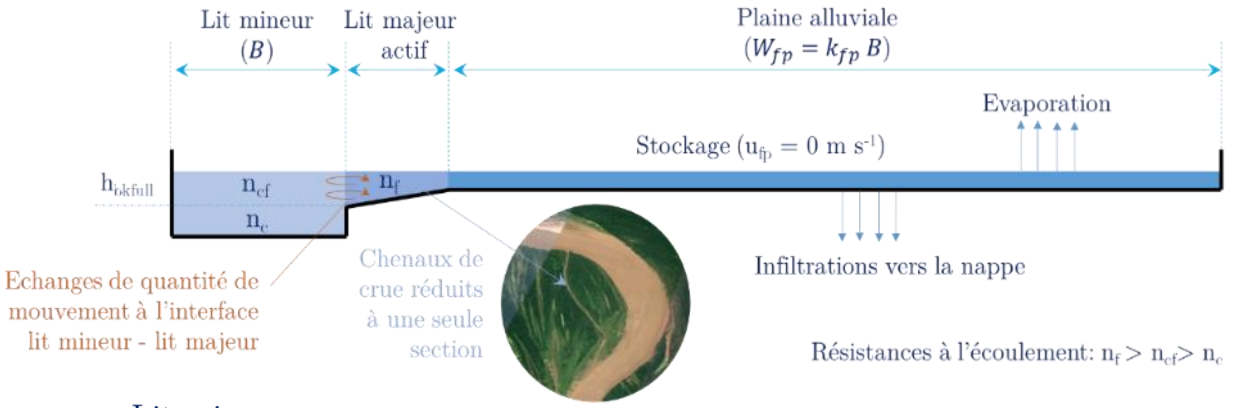


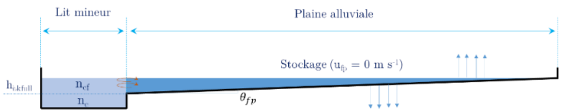
Water routing: the extraordinary complexity of the floodplain

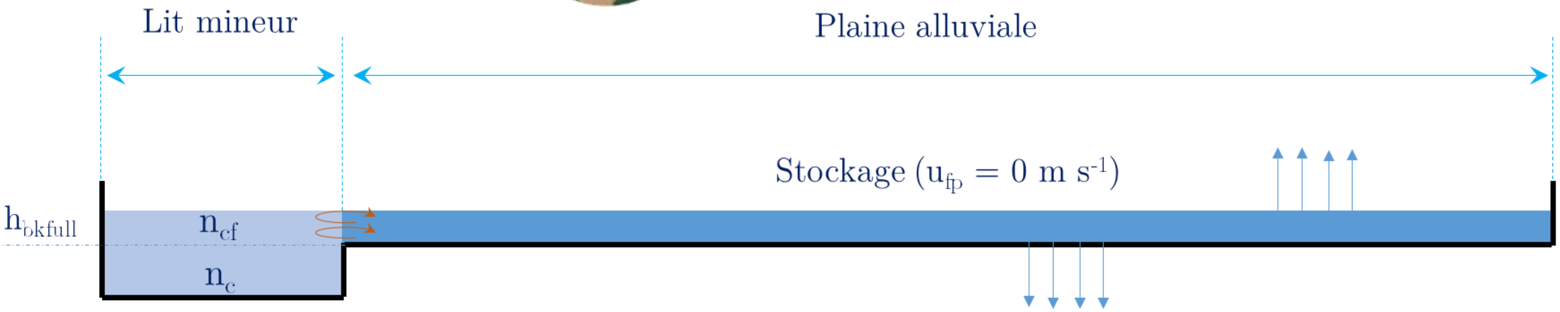


- Channelized flows and
- diffuse processes
- Different residence times
- ….

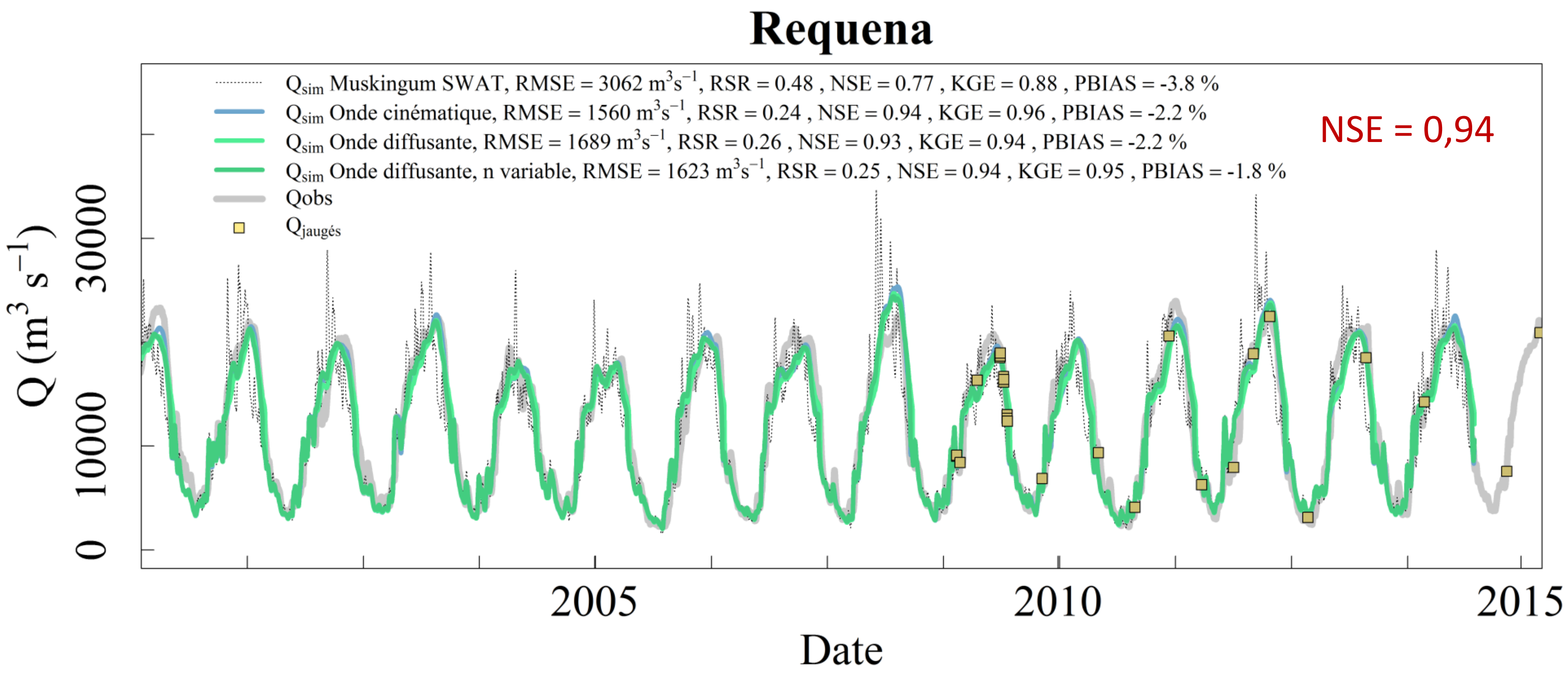
A simple approach: 1d flow simulation in the main channel, and a reservoir for modeling the floodplain storage







Results – Water discharge

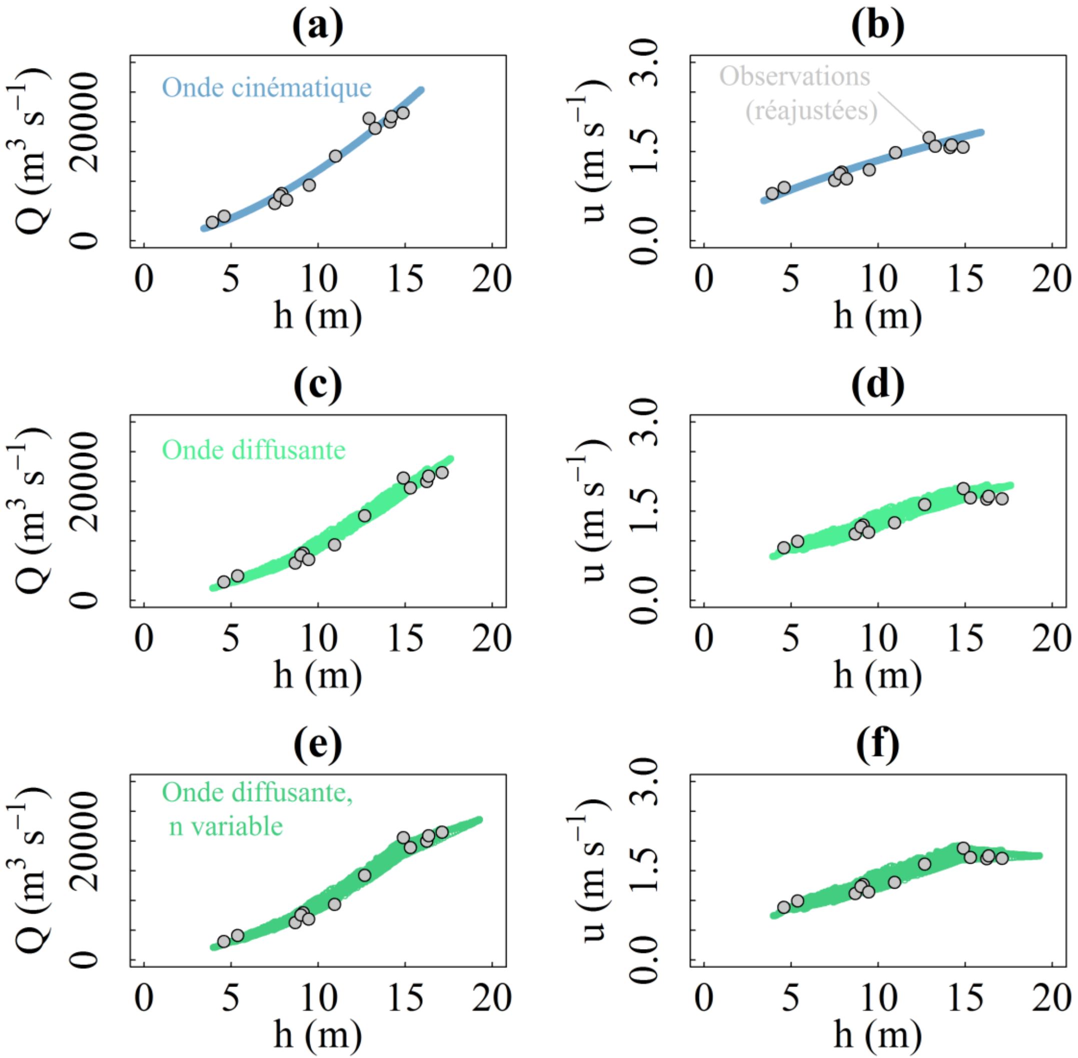


Results (basin outlet)

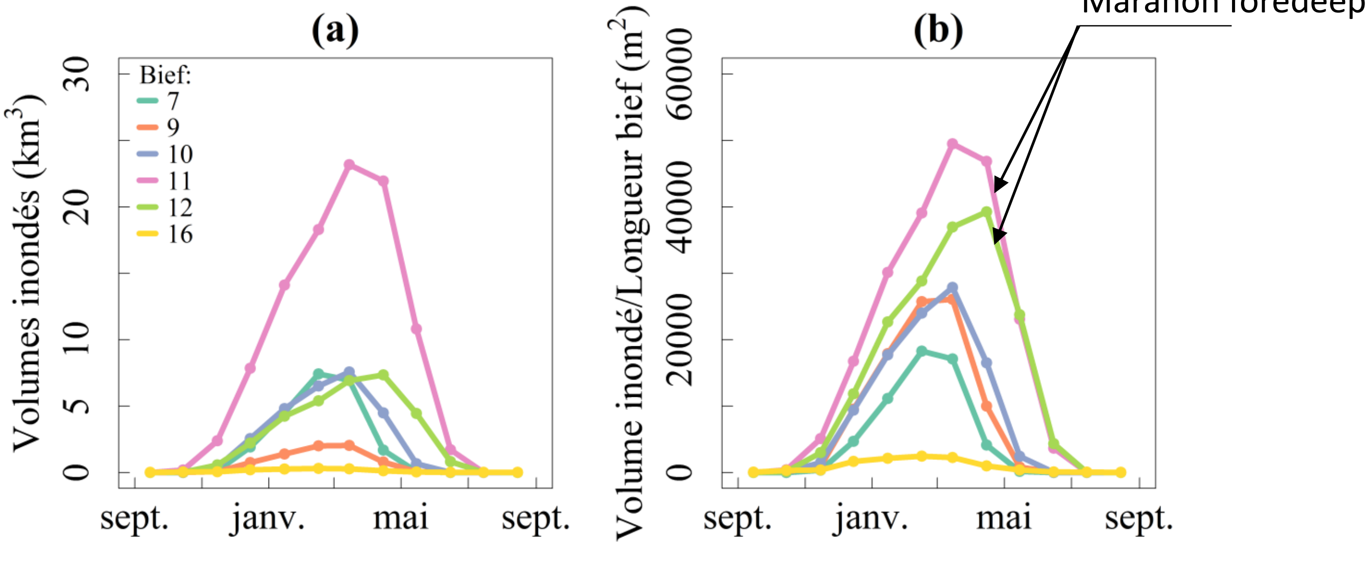
Cinematic wave
(no backwater effects)

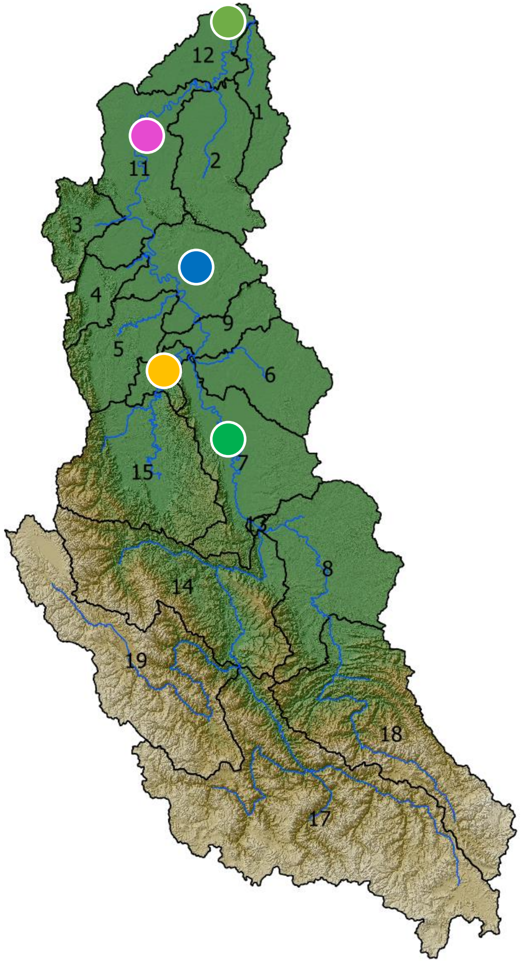
Diffusive wave
(backwater effects)

Diffusive wave
Resistance coeficient n change with the relative depth above the bankfull depth



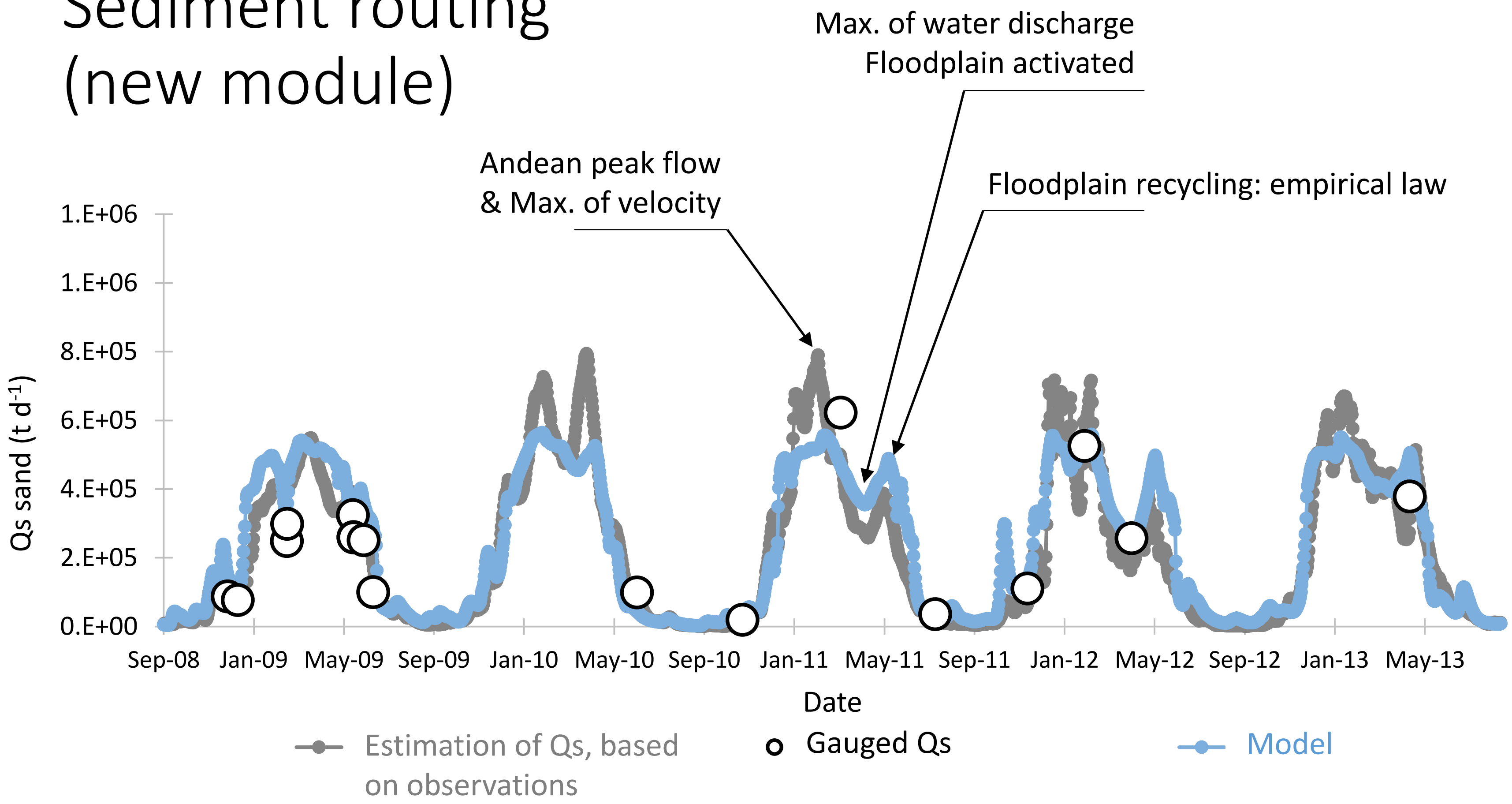
Huge volumes of water stored in the floodplain: ~50 km^3



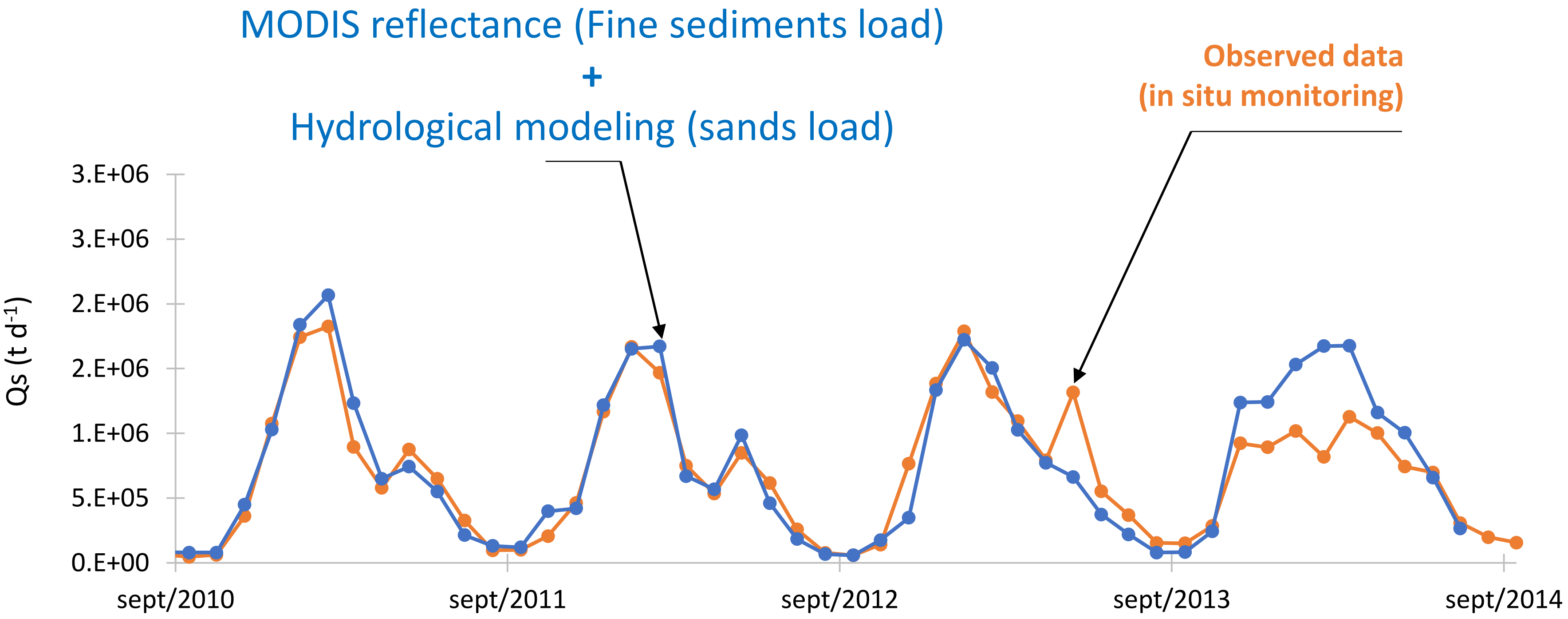


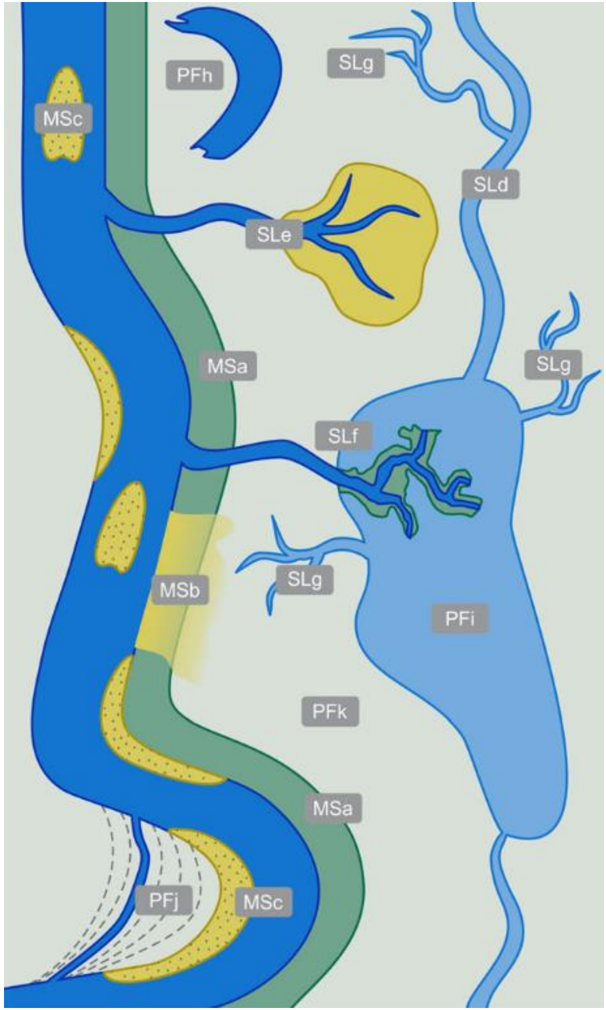
Leman Lake : 90 km^3

Sediment routing (new module)



Results: sediment load assessed by integrating field network, semi-distributed modelling and remote sensing





1d → 2d modeling?

We used empiral laws
Extapolation to the entire basin?
Data in the floodplain?
2d = other issues

« Spillage sedimentation »

"During floods, coarser sediment deposition occurs preferentially on developing spillage forms (e.g. levees of main channel and accessory channels, crevasse splays) and diffuse overbank layers, while intervening topographic depressions convey fine sediment-laden riverine water for longer distance"

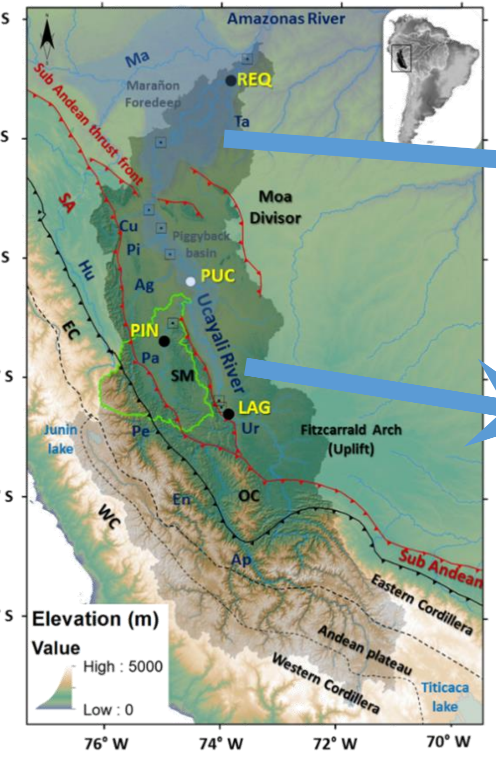
Lewin *et al.*, ESPL, 2017

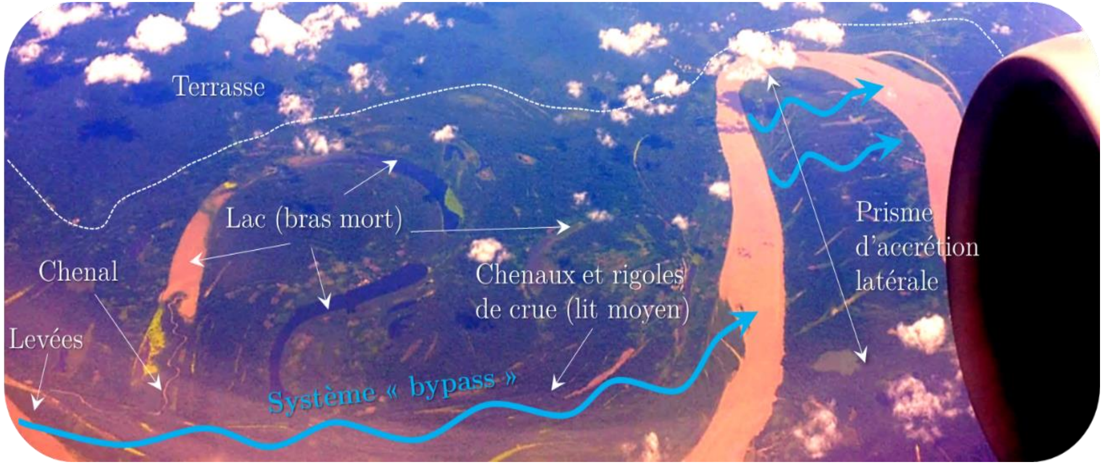
MS Mainstream sediments
MSa Levee
MSb Bank-top splays
MSc Channel bars & islands

SL Secondary linear systems
SLd Accessory channel
SLe Crevasse splays
SLf Crevasse with delta
SLg Internal drainages

PF Prior-form following
PFh Cutoff & palaeochannel fills
PFi Ponded lake filling
PFj Point bar swales & chutes
PFk Diffuse overbank spreads

Different floodplains, different processes…





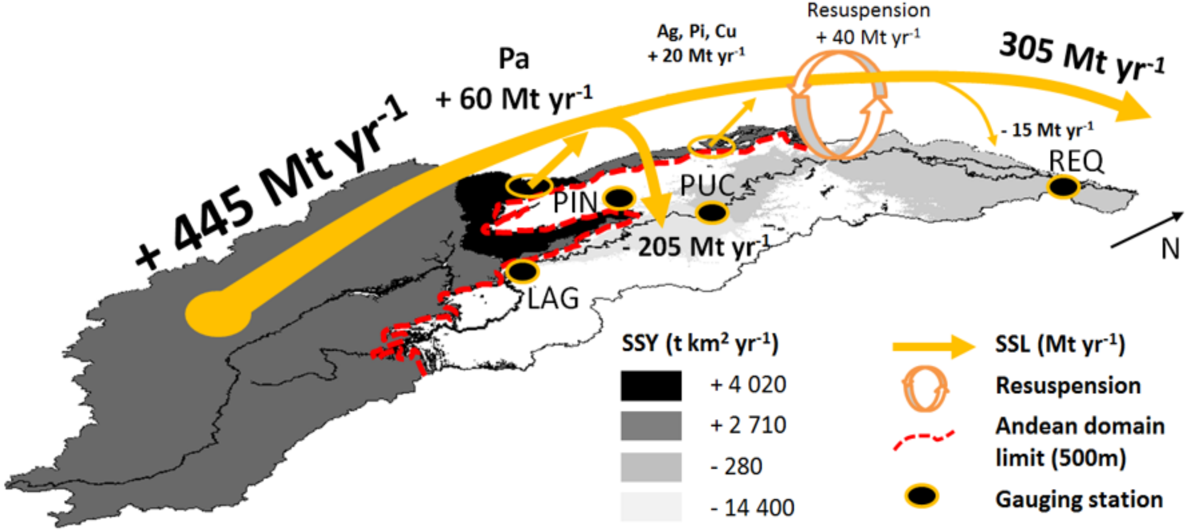
Complex water and sediments exchanges between the main channel and the floodplain

Strong tectonic control

Some conclusions

- This is not the end of the field measurements!
- Key gauging station + cal/val measurements + Gauging stations into the floodplain
- Robust floodplain data are crucial but not available
- 1d → 2d or pseudo-2d modeling of the floodplain?
- More insight into the SPM – reflectance concentration is required (works in progress: Morin et al., Martinez et al.,…)

Sediment budget in the Ucayali River basin



Santini *et al.*, 2014, AISH

To Resume:

525 Mt/yr exported from the Andes

High SSY in Pachitea River basin:
Hotspots + Tectonic activity + Vegetation decline

Resuspension is estimated at 13%

220 Mt/yr are deposited in the subsidence, mainly along the Shira Mountain thrust system

Ucayali River load represents **36% of Amazon River load**

Thanks, Obrigado, Gracias, Grazie
Merci!

www.ore-hybam.org

Um observatório para compreender a dinâmica da produção e transferência de água e materiais continentais, estudar forcings tectônicas e climáticas biogeoquímico e avaliar os impactos da variabilidade hidro-climática e antrópica sobre grandes bacias tropicais.