Routing development since October 2020

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discussions with Agnès, Philippe, ...

- Current situation of the development
- The equations implemented in ORCHIDEE
- Numerical properties of the scheme :
  - Sensitivity to reservoir constant
  - Sensitivity to number of HTU per grid.
- Floodplains development
- Diagnostic tools

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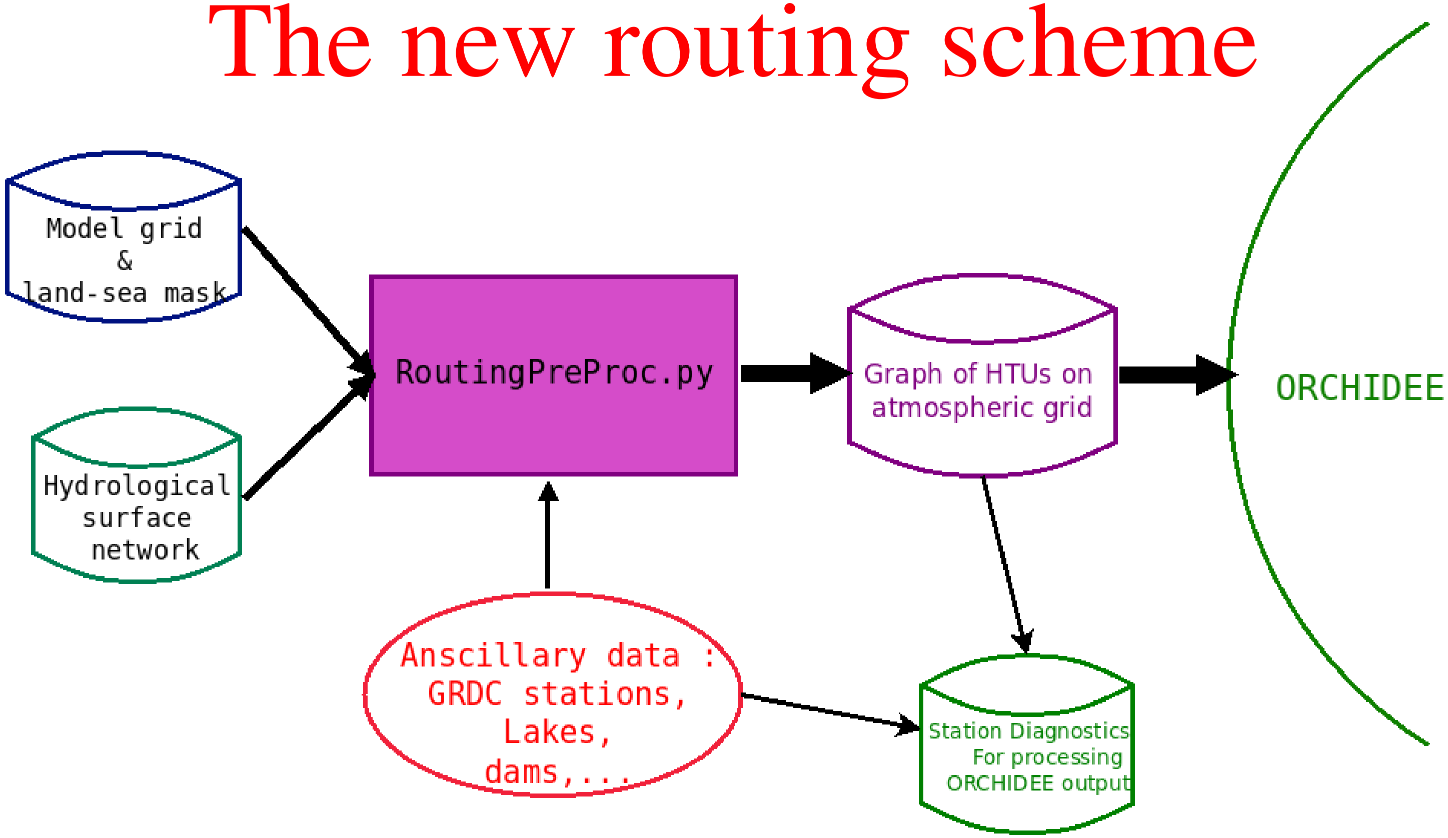
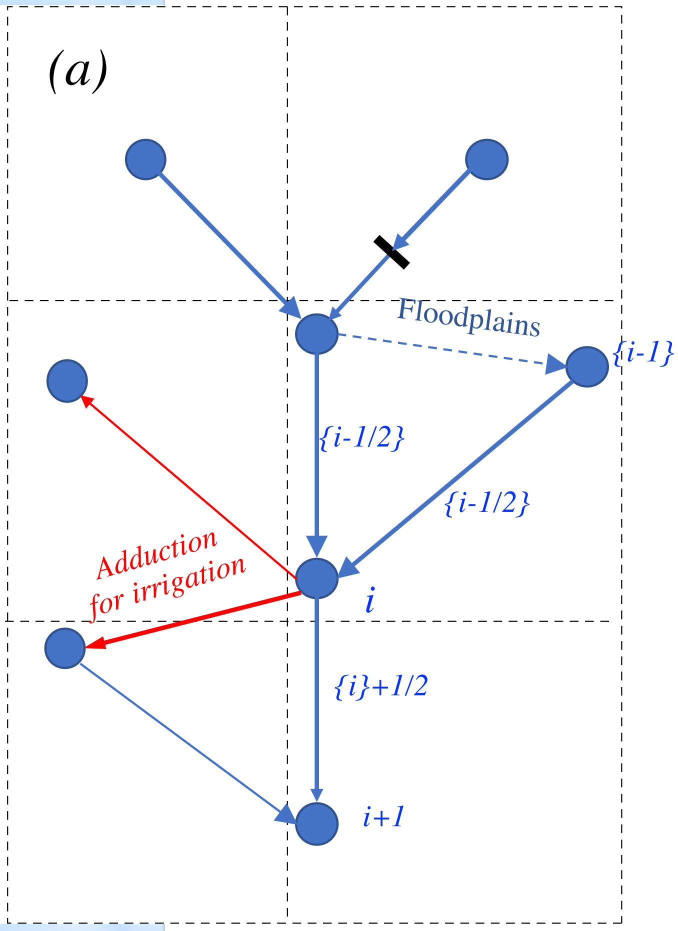
The new routing scheme



- The new structure was explained in October 2020.
- Questions were asked about the numerical stability of the scheme.
- Today we will discuss the numerical conditions which ensure a stable scheme on the atmospheric grids we use.
- Since October diagnostic tools were developed for the new routing.
- The database of river gauge observations was expanded.



Equation for water flow

$$\frac{\partial W_{stream,i}}{\partial t} = \sum_{j \in \{i-1\}} \left(Q_{stream,j} + Q_{fast,j} + Q_{slow,j}\right) - Q_{stream,i}$$

$$Q_{stream,i} = \frac{W_{stream,i}}{\tau_i} \quad \text{with} \quad \tau_i = \lambda g_{stream}$$

λ : geometrical characteristic (topoindex) of HTU in km.

g_{stream} : "time constant" of the reservoir in s/km

$$W^{t+1}_{stream,i} = \left(1 - \frac{\Delta t}{\lambda g_{stream}}\right) W^{t}_{stream,i} + \Delta t \sum_{j \in \{i-1\}} \left(Q^{t}_{stream,j} + Q^{t}_{fast,j} + Q^{t}_{slow,j}\right)$$

This yields a condition on the time step : $\Delta t < \lambda g_{stream}$

The equation can also be implemented with an implicit outflow of the stream store.

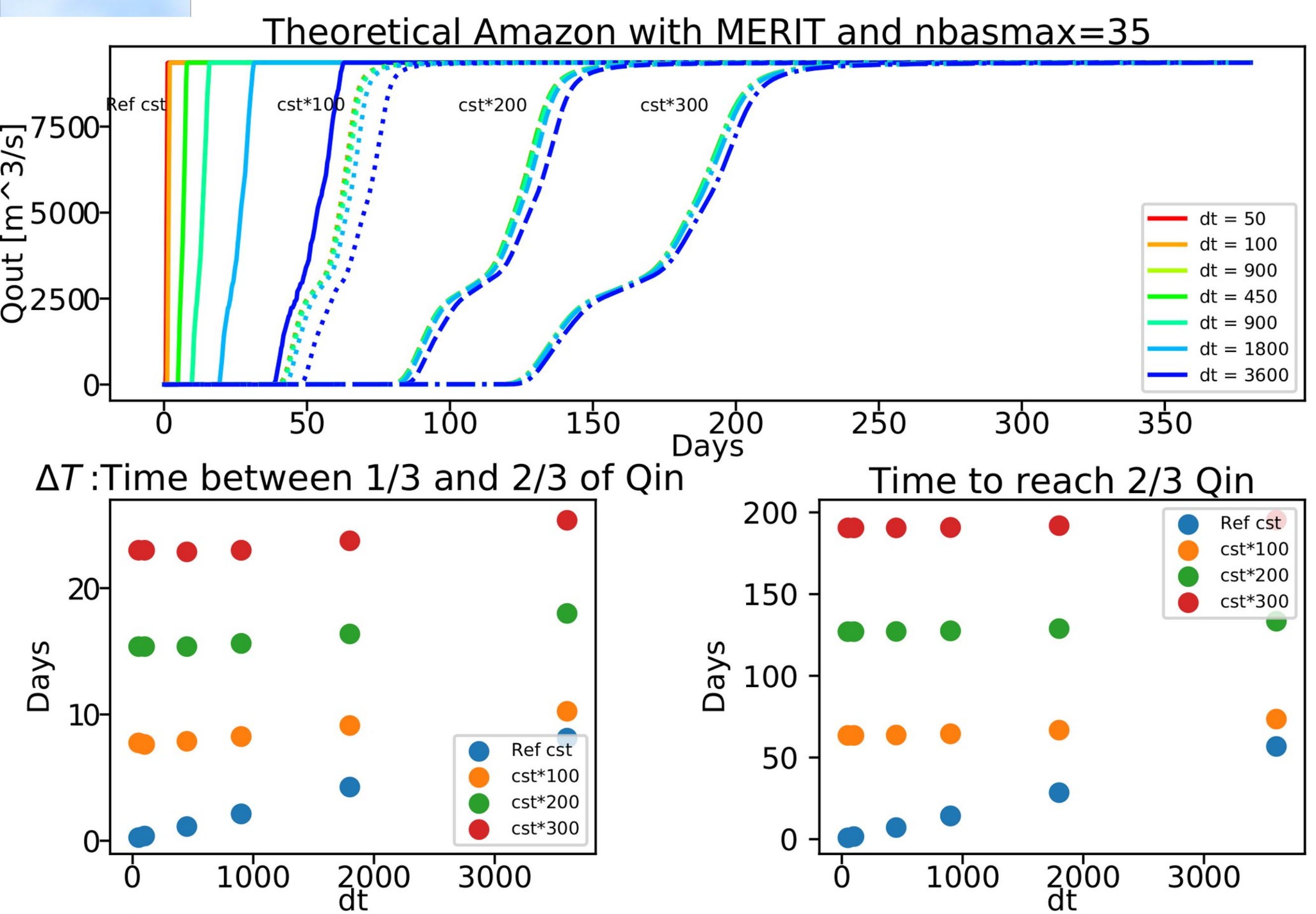
Stream temperature advection

$$\frac{\partial T_{stream,i} W_{stream,i}}{\partial t} = \sum_{j \in \{i-1\}} \left(T_{stream,j} Q_{stream,j} + T_{fast,j} Q_{fast,j} + T_{slow,j} Q_{slow,j} \right) - T_{stream,i} Q_{stream,i}$$

- This equation can be implemented with an explicit or implicit method.
- The same option as the water flow will be used.
- The fast and slow reservoir temperatures are taken from the ground temperature :
  - *T_{slow} = Temperature of the deepest soil moisture.*
  - *T_{fast} = Temperature of the top 10cm of soil moisture.*
- It will be useful to be able to test the river temperature with the “testrouting” code.

Testing the equations

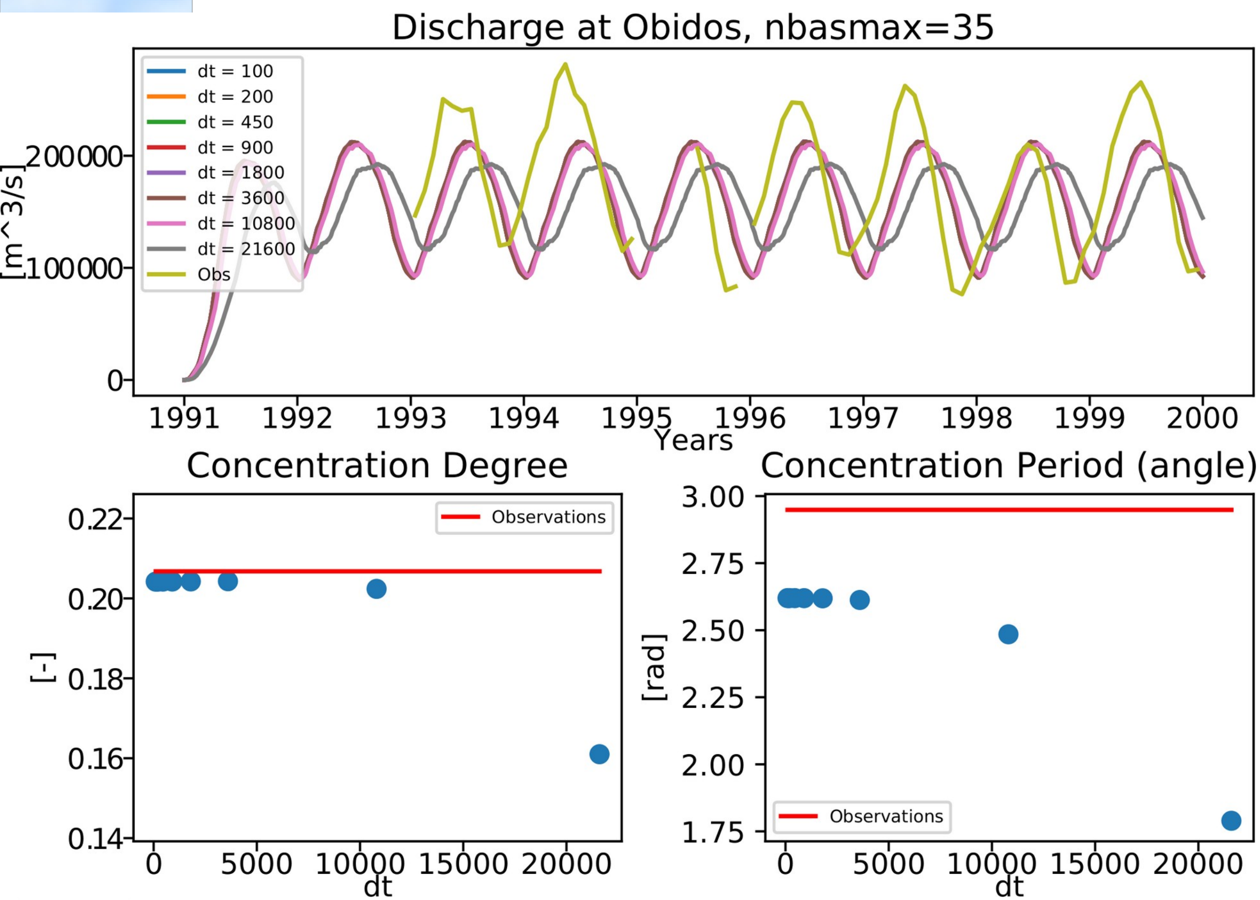
- A simple model was coded in a Jupyter Notebook : A constant flux at the top of a 6500km slope and 4000m elevation change.
- A similar test was implemented with ORCHIDE's routing network to test the time step condition :



- *South American continent at 0.5°*
- *A constant runoff and drainage on all elevations above 1500m*
- *The discharge at the estuary of the Amazon is analysed*
- *Sensitivity to time step and τ is tested.*

A more realistic test

- The same South-American domain is used.
- A climatology of runoff and drainage are applied over 9 years.
- The flow at the Obidos station is decomposed in terms of phase (Cp) and amplitude (Ca).



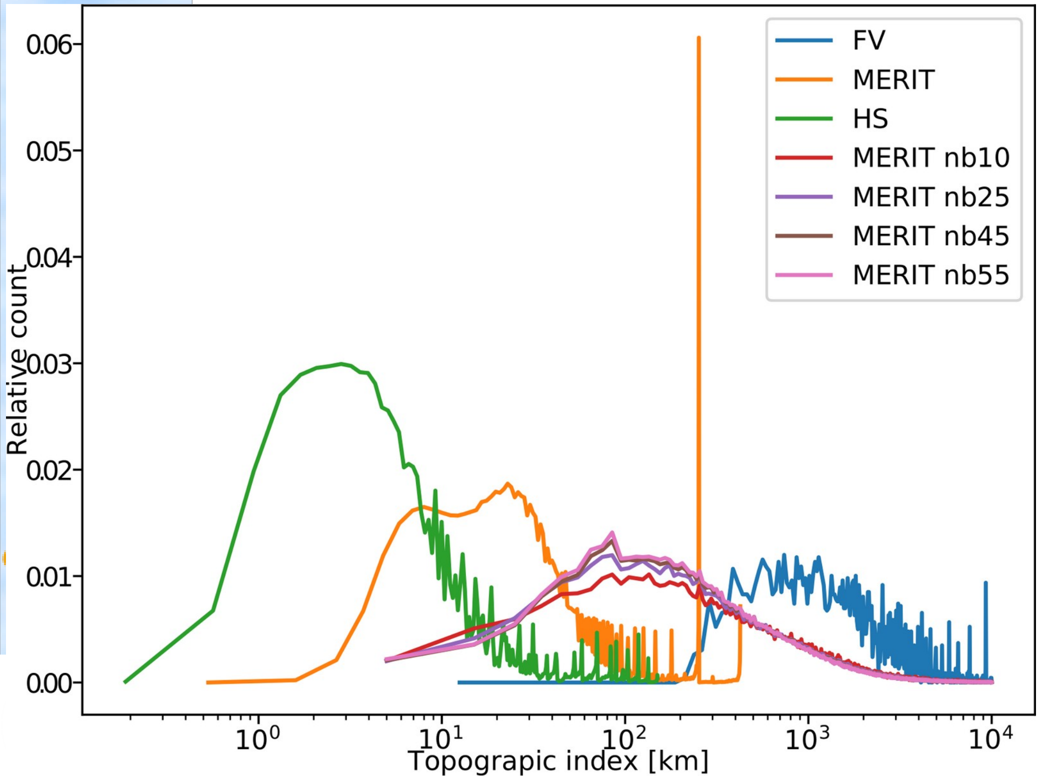
The ref*300 “time constant” set of the previous test is used. For the stream reservoir the constant is : 30 s/km

The critical parameters for stability are :

- Distribution of λ and
- The value of g_{stream}

The topoindex (λ) distribution

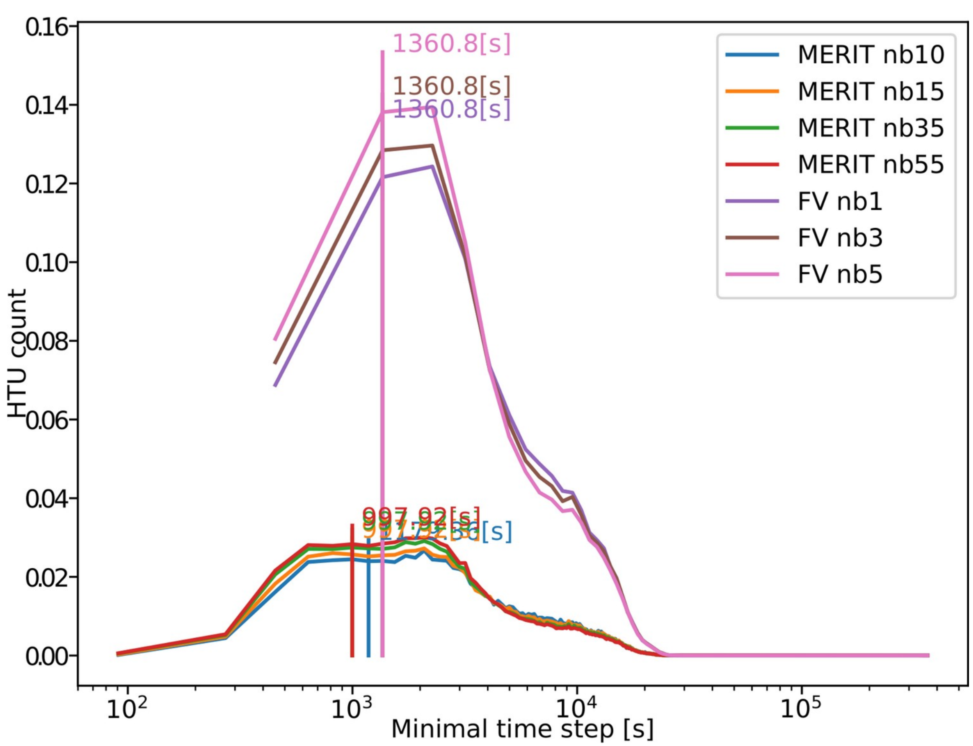
- The distribution of topoindex depends on the resolution of the topography and the course of the river.
- With the nbasmax parameter some of the higher resolution information can be preserved.
- λ computed can be compared to the original data (Fekete & Vörösmarti, MERIT or HydroSHEDS).



- The aggregation method proposed by Agnès is used :
  - Along a river λ is summed.
  - For converging rivers the λ are averaged.
- Some verifications and refinements are still needed.
- Should an area weighting be applied ?

Predicting the maximum timestep

- Based on the distribution of τ ($\lambda . g_{stream}$) we can choose the quantile of HTUs for which we accept to be below the stability criteria.
- This gives a maximum time step for the routing scheme.
- The code for computing average τ per HTU needs to be verified.

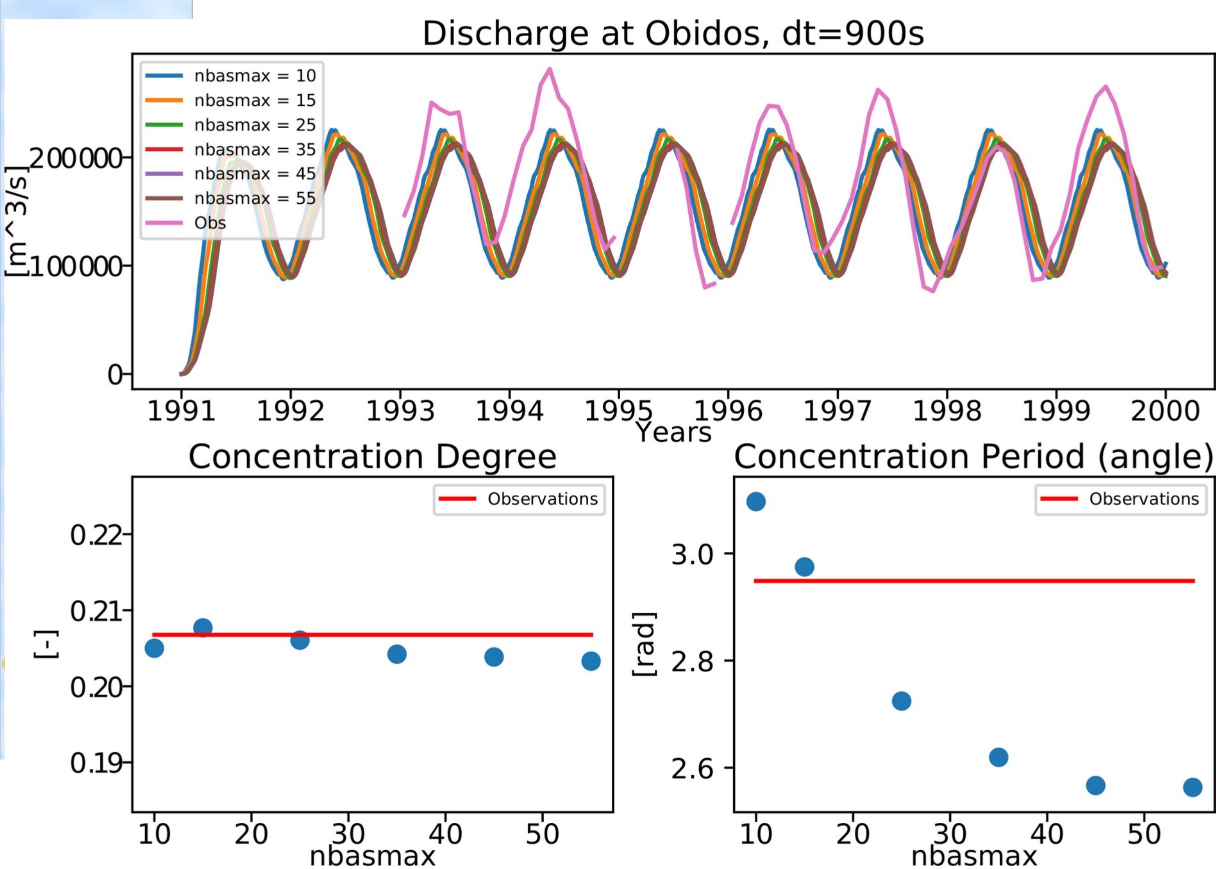


With the correct distribution we re-run the climatological flux test to :

- Choose the correct HTU constants (gstream).
- Determine the stable time step.
- Find the corresponding quantile of the distribution.

Impact of nbasmax on discharge

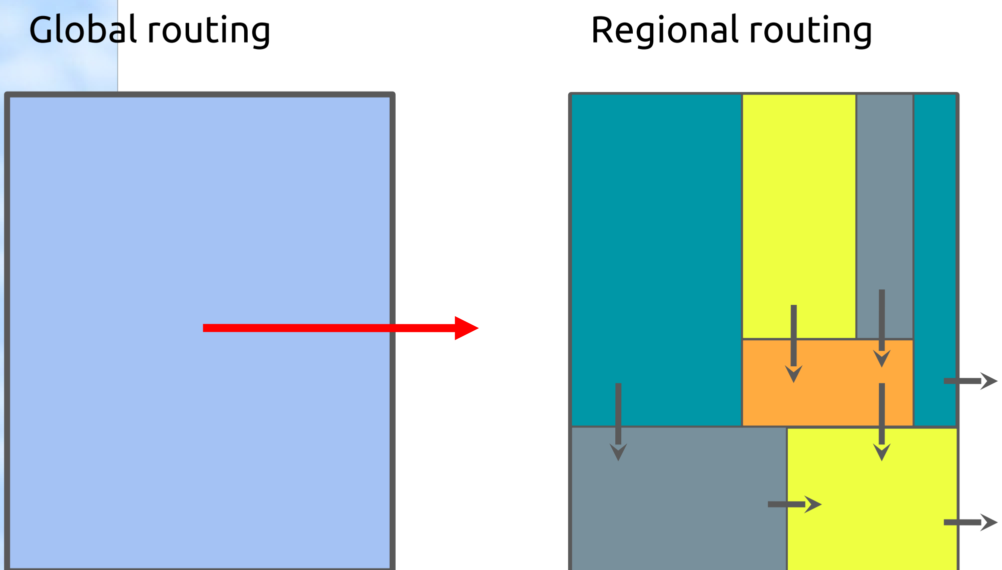
- The choice of the aggregation method for λ (topoindex) will also depend the sensitivity of the scheme to the truncation.
- A first test was carried out with the climatological forcing.



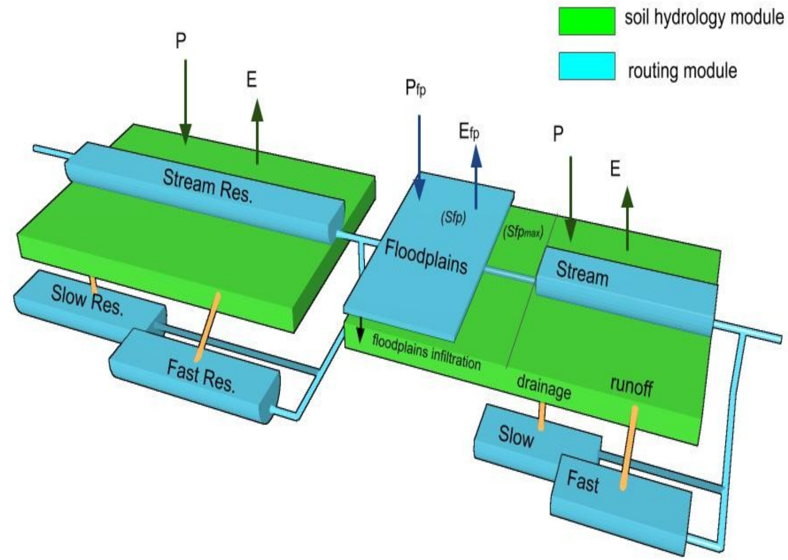
- With increasing complexity of the river network (increasing nbasmax) the phasing of the dischage changes.
- The impact on amplitude is small.

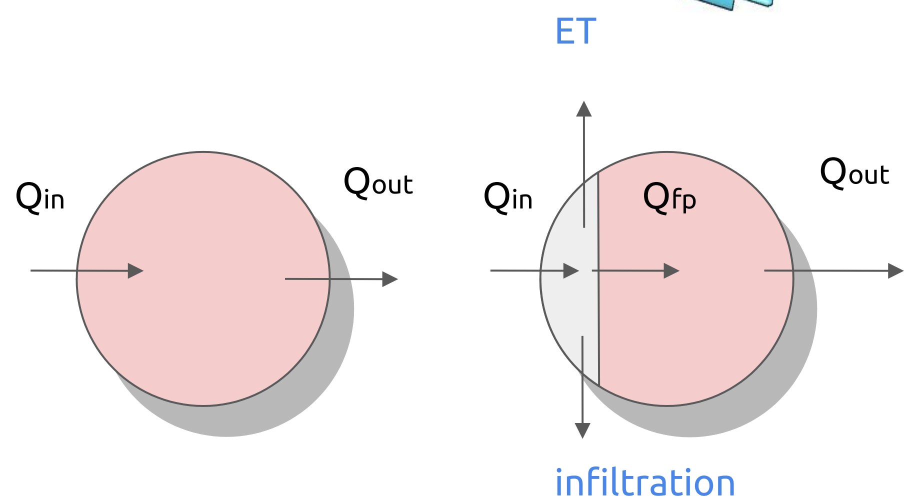
Needs to be refined with the new λ aggregation method.

Moving the floodplain scheme to high resolution



At higher resolution we have to adapt the processes and explicitly represents sub-grid processes.
Main issue here is to allow the HTUs to flood their neighbours in floodplains regions.

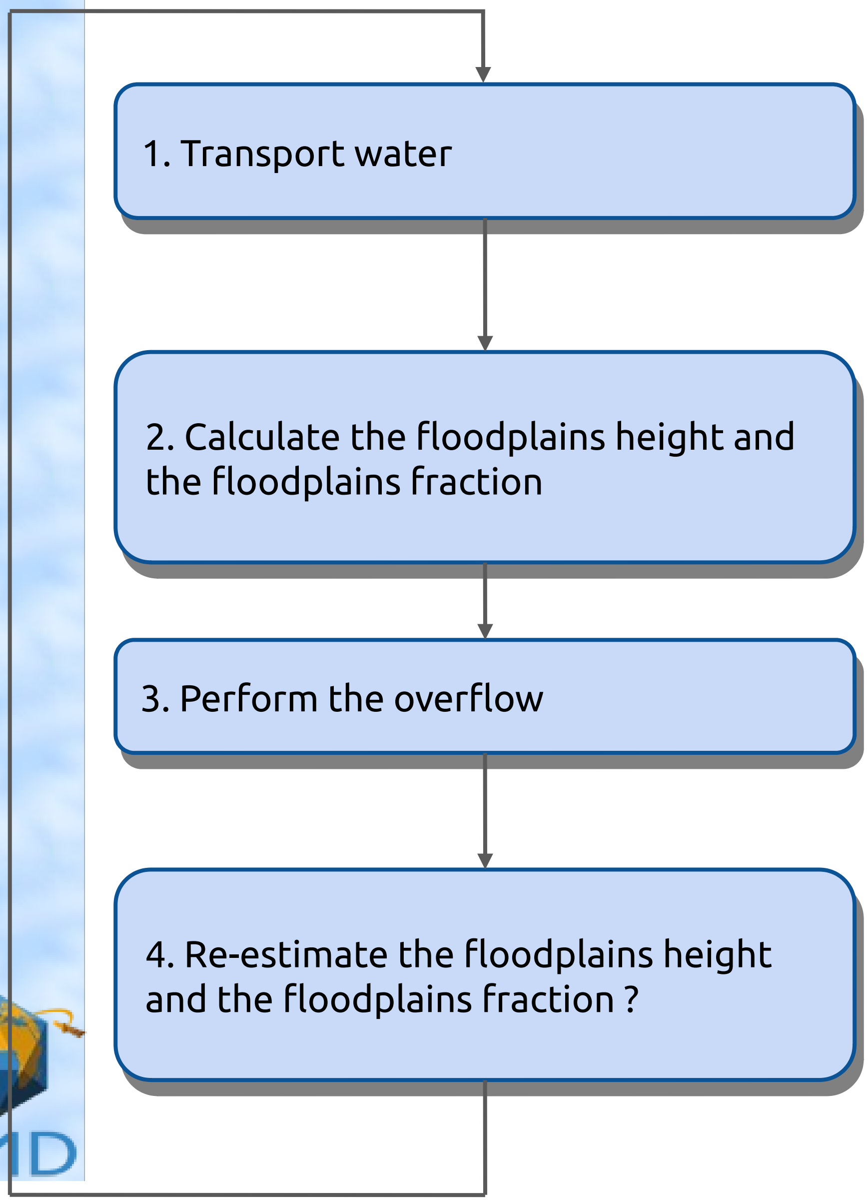




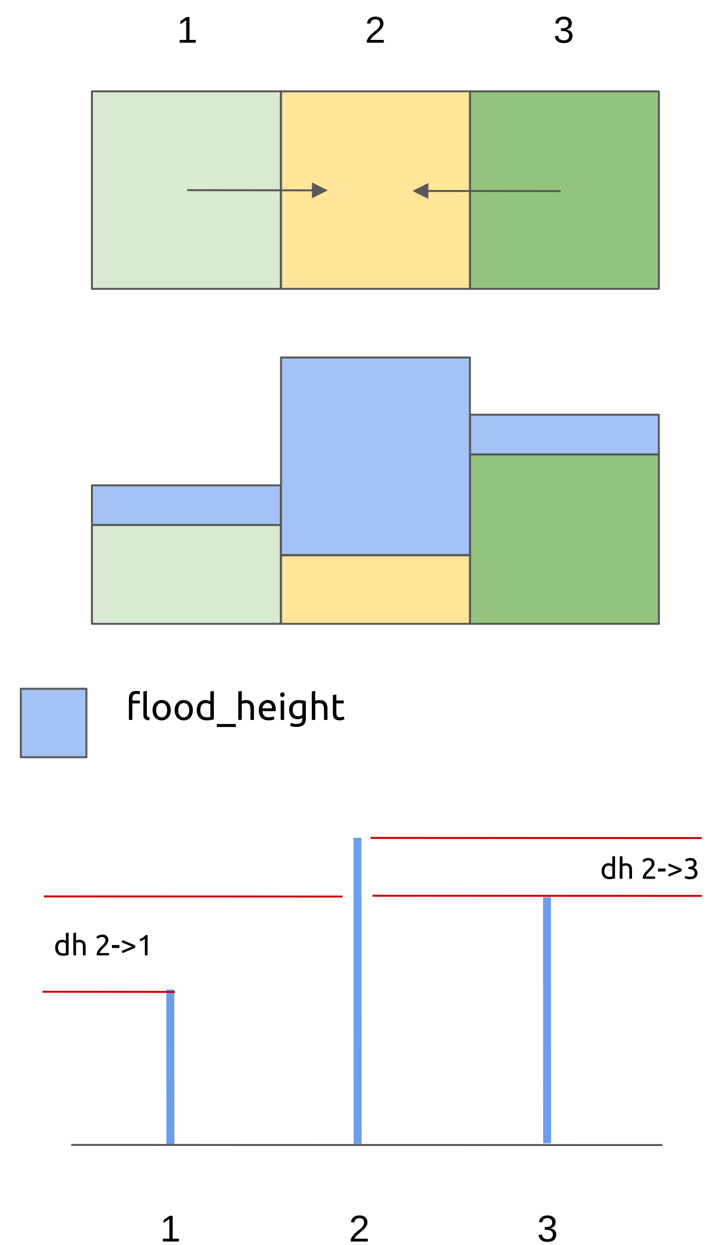
No Floodplains

Floodplains

Floodplain scheme



Overflow

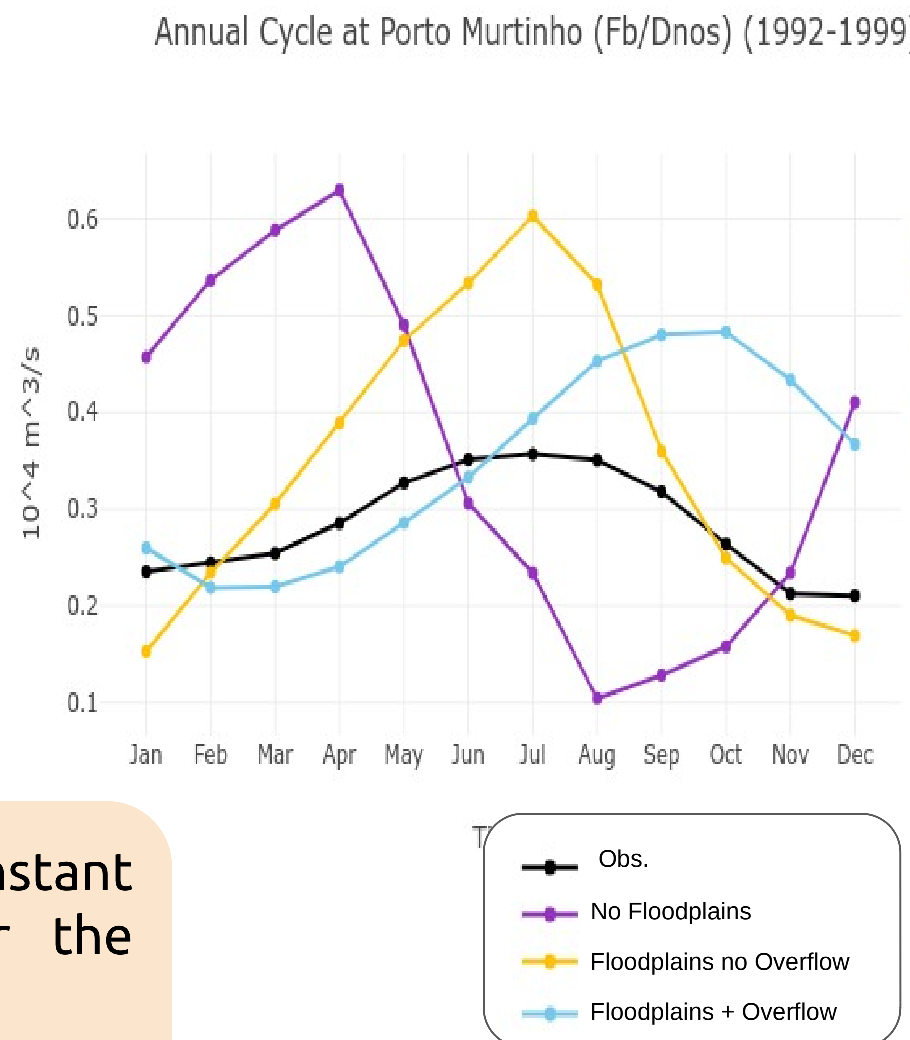


Preliminary results

The overflow has already been implemented and tested with *testrouting* with different forcings:

- WFDEI (0.5°)
- AmSud-I forcing (from the RegIPSL run at 20km)

(on the right the results from the WFDEI simulations)



These are preliminary results, the time constant used in the floodplains module and for the overflow must be adjusted rigorously.
This will be done when the stream / fast / slow time constant will be well defined.

Validation

11356 fluviometric stations are now collected !

Recent version of GRDC has been merged with dataset of stations from :

- SPAIN (from Observatorio del Ebro)
- HyBAM (Amazonia)
- Brazil (from Agência Nacional das Aguas - ANA)
- Argentina (Red Hidrológica Nacional)
- Working on HydroFrance

On the left : Stations localized for the WFDEI forcing over the South American domain.

Tools are being developed to select the stations to be diagnosed for model monitoring and data assimilation.

Conclusion

- The numerical properties are now better understood.
- Clearly the time step of routing needs to be below 1h, even with Fekete & Vörösmarty.
- More variables will be exchanged spatially as the model develops.
- This poses a challenge to the efficiency of the parallelisation.
- This new version of the routing will facilitate the validation of the water cycle in our Earth system models (global and regional).
- It will make ORCHIDEE more suitable for climate service applications.