Land surface processes for km-scale Earth system models

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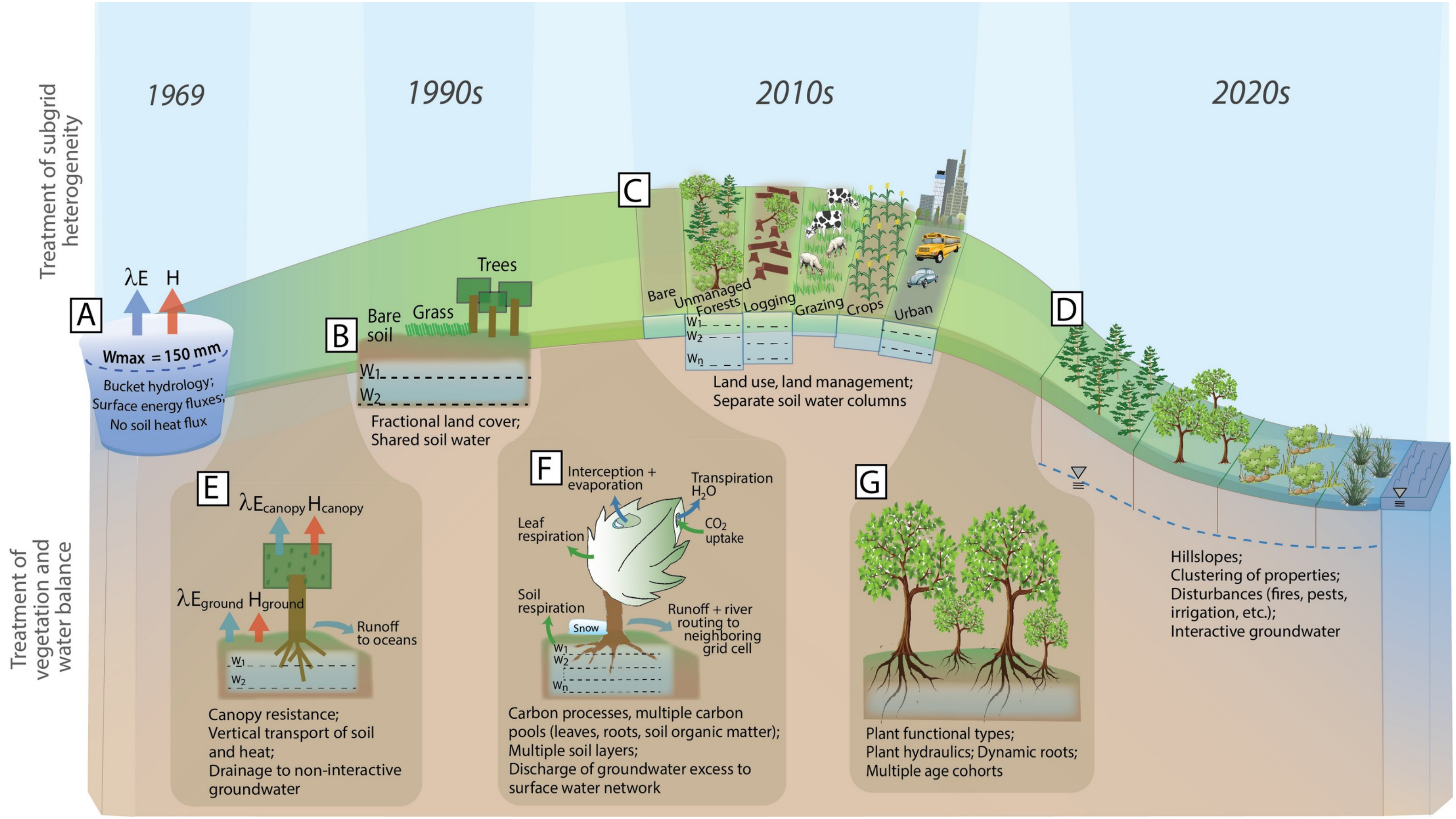
- The hydrological problem of km-scale modelling.
- How does the land surface coupling change with resolution ?
- How can km-scale models better represent the continental water cycle ?

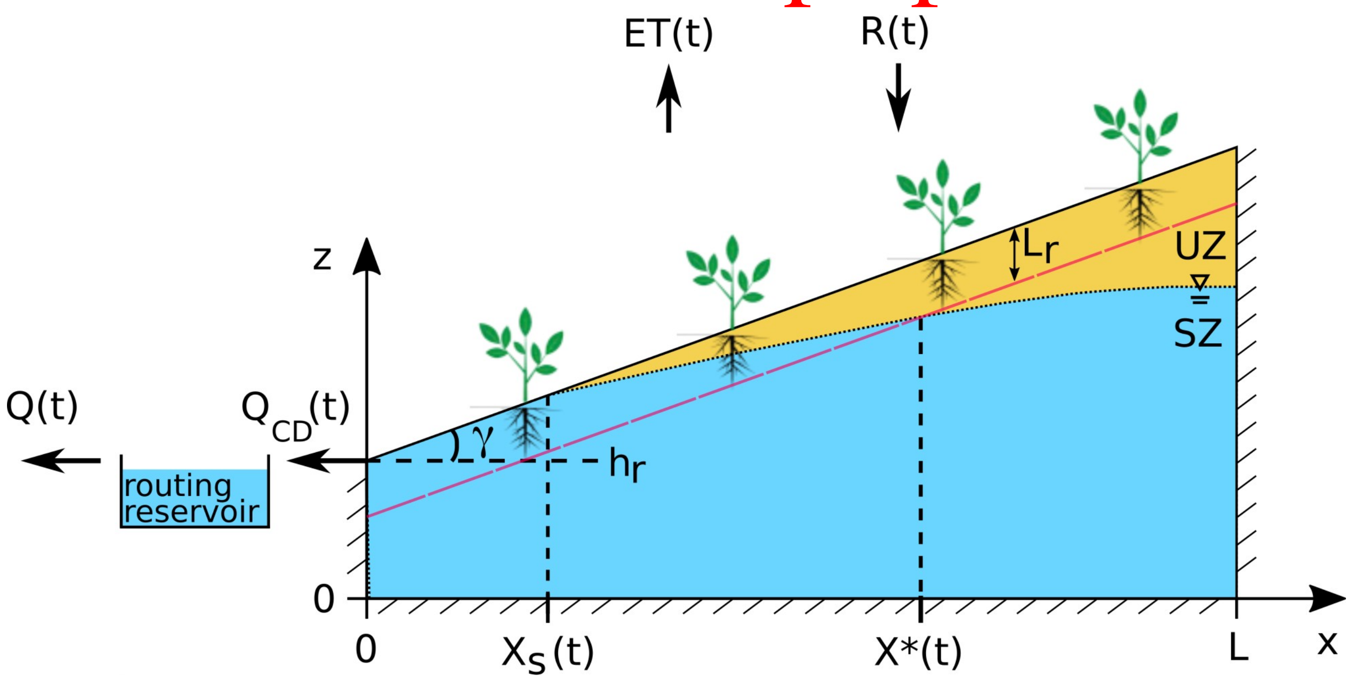
Evolution of land surface models



In the last 40 years land surface models have seen a tremendous evolution.
A number of complex surface processes are now represented.
In most cases these are solved using sub-gridding approaches :

- Surface heterogeneity is large,
- Atmospheric models or forcing data are/were coarse.

Hill-slope processes



Picourlat et al. 2022

The canonical view of atmosphere & hydrology interactions :

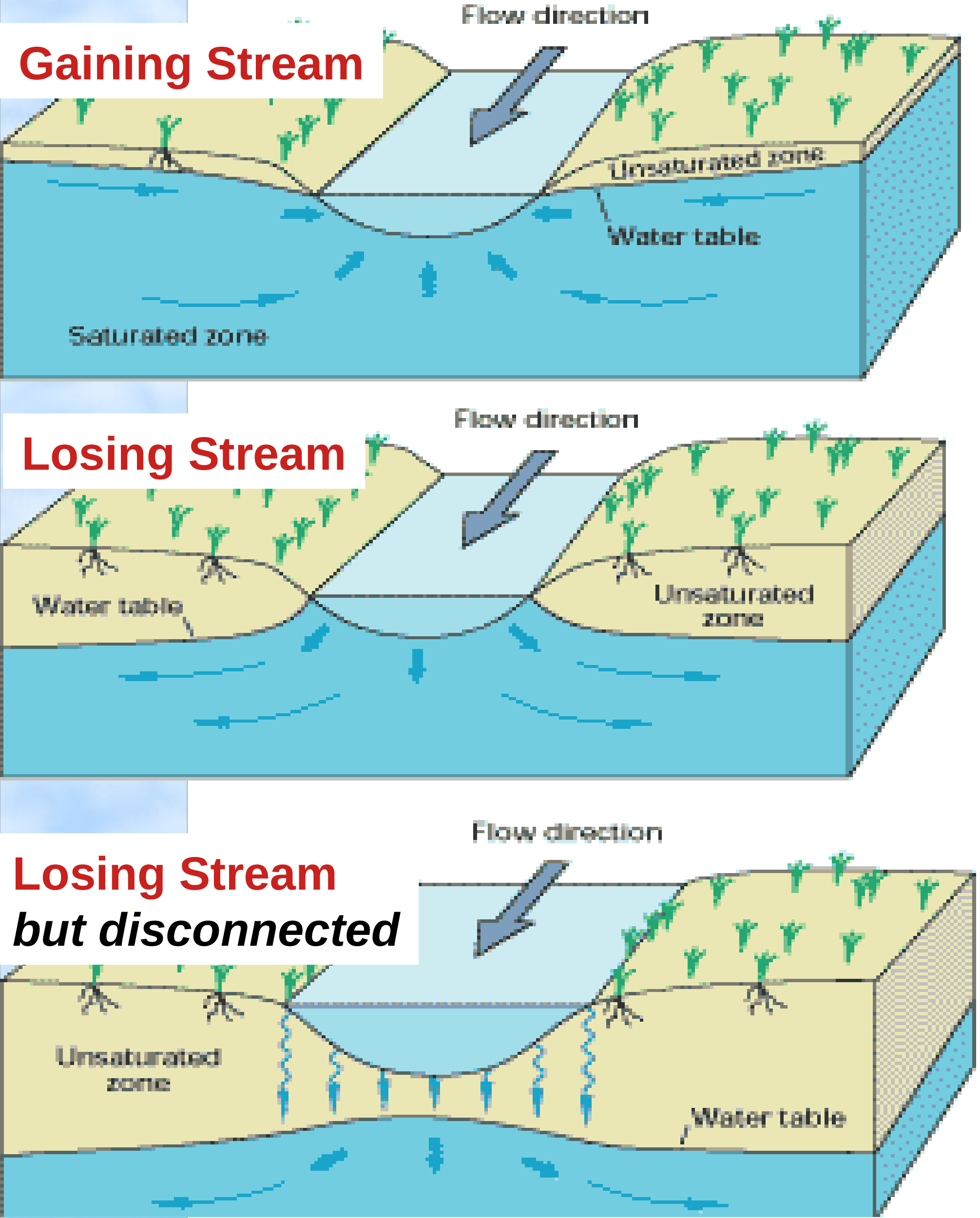
- It exists over a wide spectrum of spatial scales.
- It is responsible for the spatial structure of soil moisture stress
- It introduces inertia in the water cycle and delays of weeks to years.

This vision can be parametrized :

- The impact on moisture stress and plants is well in hand.
- The delayed propagation of P-E anomalies is more challenging.

These processes will always need to be parametrized at the sub-grid level, but with increasing resolution the need to represent it explicitly increases !

Surface aquifer interactions are complex



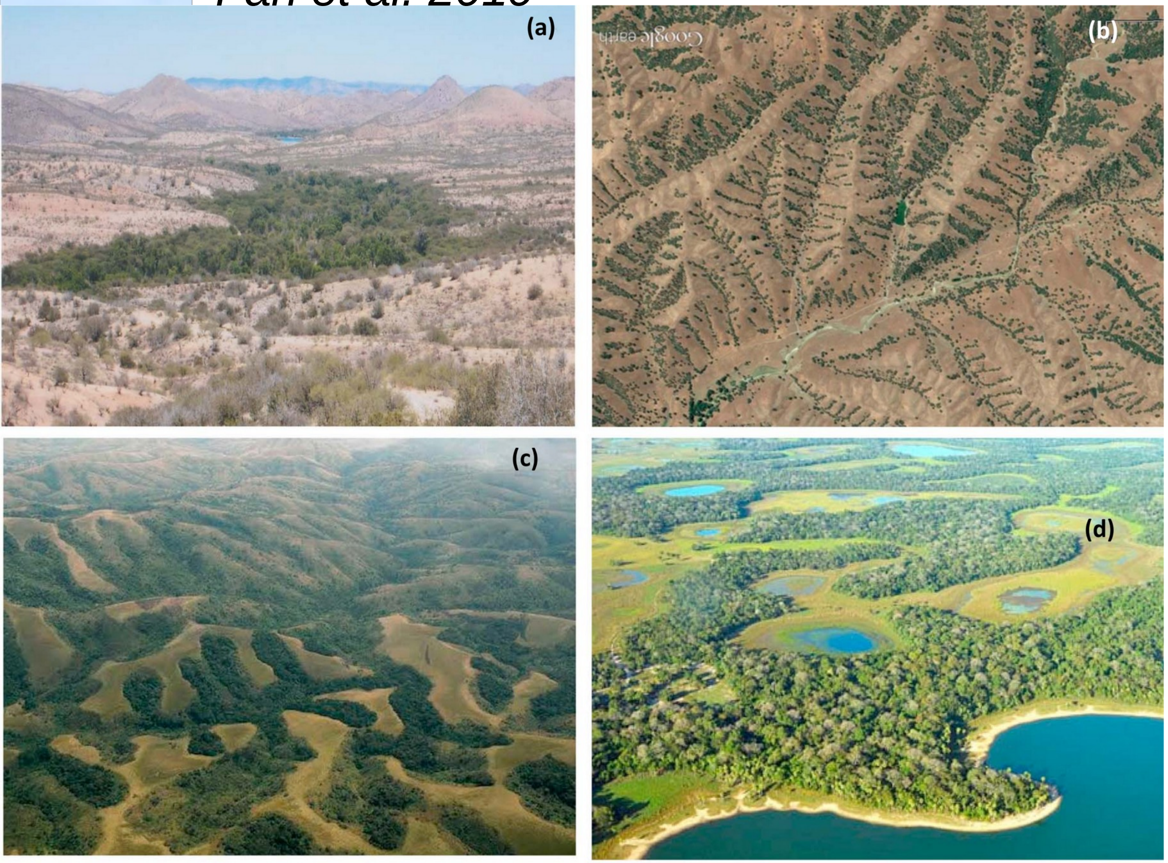
The interactions of streams with the surface processes has been neglected or seen in a uni-directional way.

They are more complex and cannot be treated as sub-grid as they require the large scale transport of water.

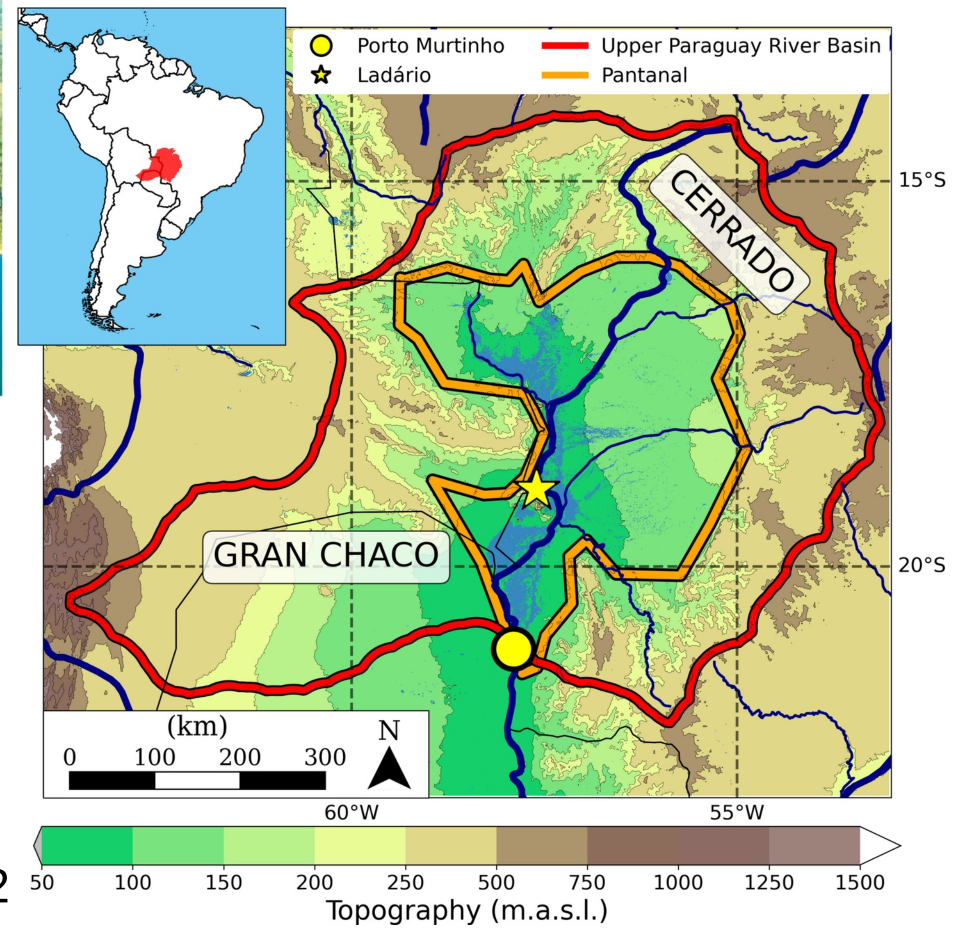
If hill-slope processes are treated explicitly then rivers feeding surface moisture need to be covered as well.

Water flows organize landscapes at all scales

Fan et al. 2019



For climate scales these interactions need to be treated.
In principle the LSMs should have them included if the hydrology would be correct.



The vegetation structures shows that the hill-slope hydrology impacts surface/atmosphere interactions.

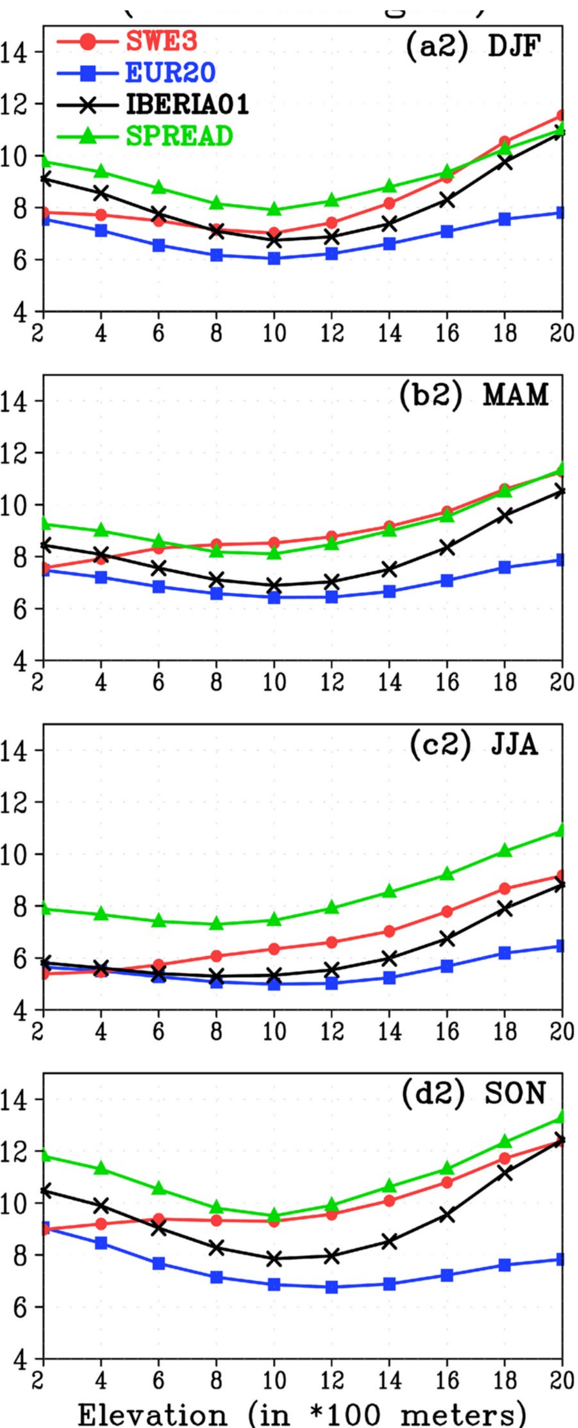
Schrapffer et al. 2022

The impact of km-scale grids at the surface

- At higher resolution topography is better represented → The role of flowing water becomes more important for the interactions with the atmosphere
- Fewer processes can be treated with sub-grid methods.
- Surface gradients will become more important and need to be explicitly represented for km-scale atmosphere models.
- The land scape organisation needs to be explicitly represented to predict its evolution.

The grid-to-grid transfers of water subsurface and above ground requires an explicit treatment now.

Precipitation intensity (mm/d)



The atmosphere also becomes more contrasted

Rainfall intensity is critical for hydrology as it determines how much water infiltrates given a surface state.

At km-scale (SWE3) the rainfall representation improves relative to 20km (EUR20) compared to observations.

For higher altitude classes the improvement is most notable.

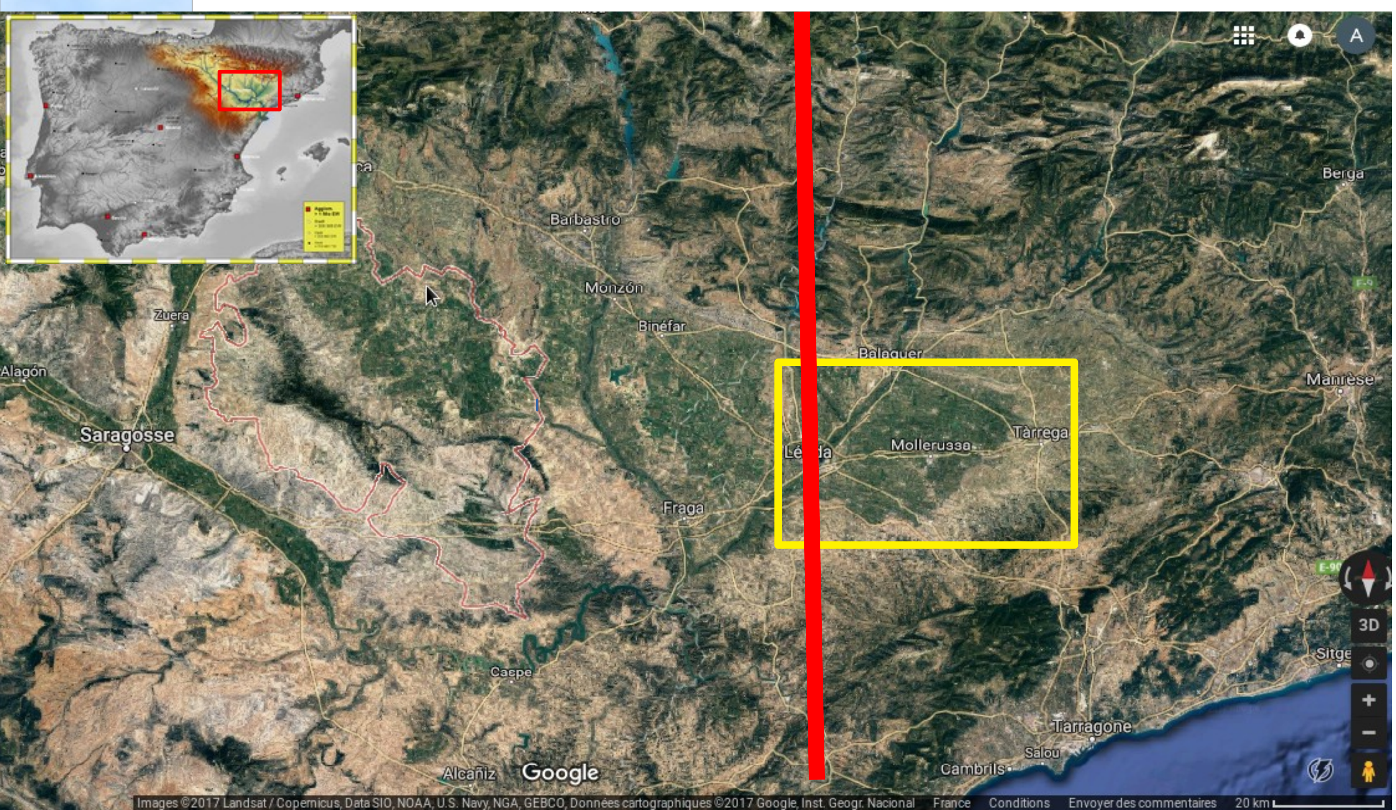
Topographic rain is improved in general and brings more moisture to higher elevations.

Sahahi et al. 2022

How will evaporation demand change ?

To explore the dependence of evaporative demand to resolution we can used an idealized model : The FAO reference evaporation.

- Penman-Monteith equation applied at daily scale.
- Idealized crop without soil moisture stress.
- Fixed surface albedo, emissivity and roughness.



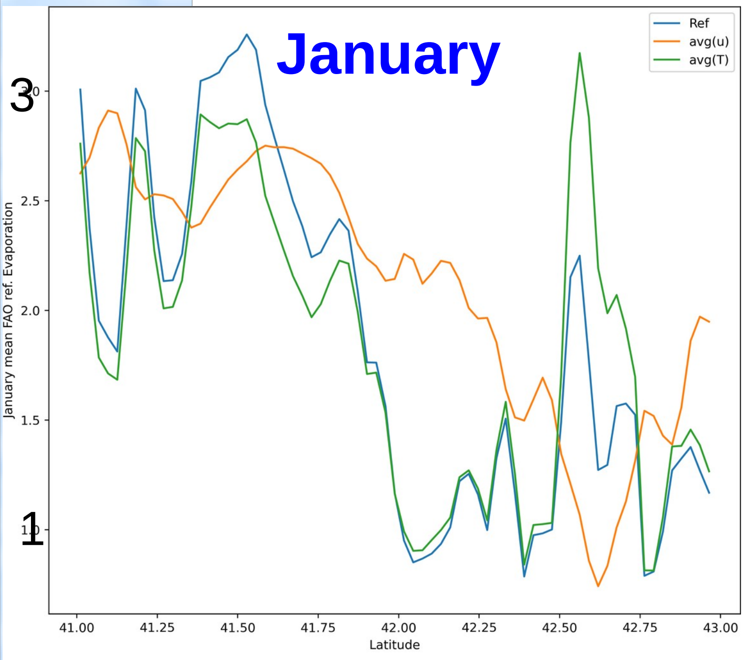
The approach is tested on a transect through the area of the LIAISE field campaign.

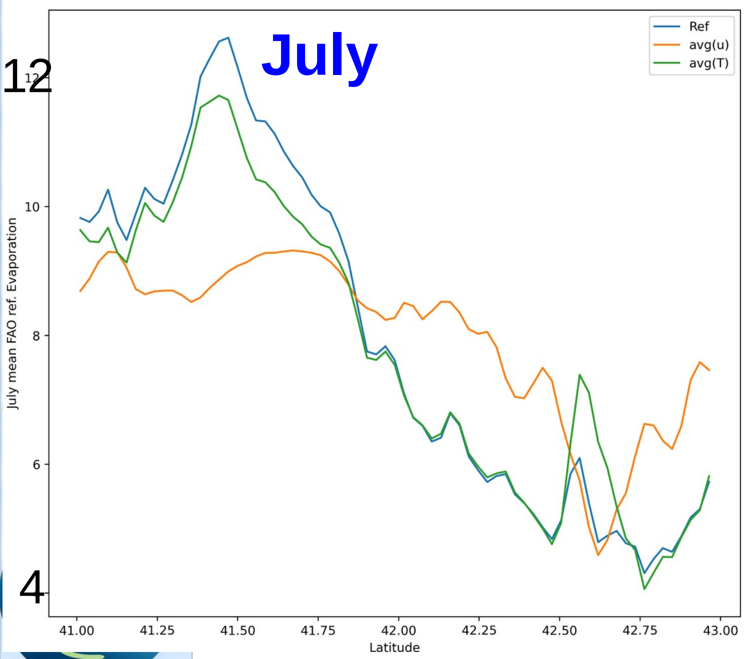
Simulations used :

- 3km
- 20km

Topographic dependence of E_{ref}

Reference evaporation [mm/d]





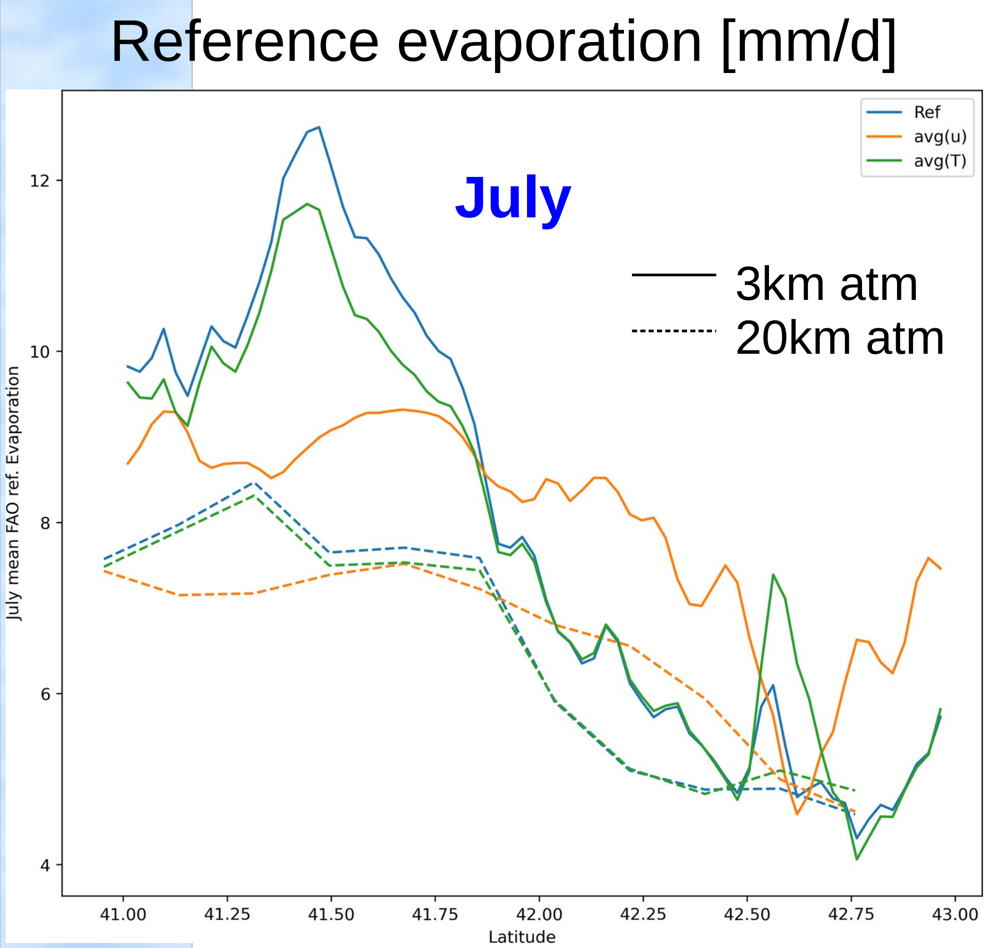
The altitudinal variations of evaporation demand is larger in July than January.

That is independent of water availability at the surface !

All dependences of E_{ref} to atmospheric forcing were tested by replacing them by the transect mean.

- Air temperature, VPD or radiation play little role (Thus possible model biases are of little consequence here.)
- Wind speed explains most of the altitudinal variations in July.

Resolution dependence of E_{ref}



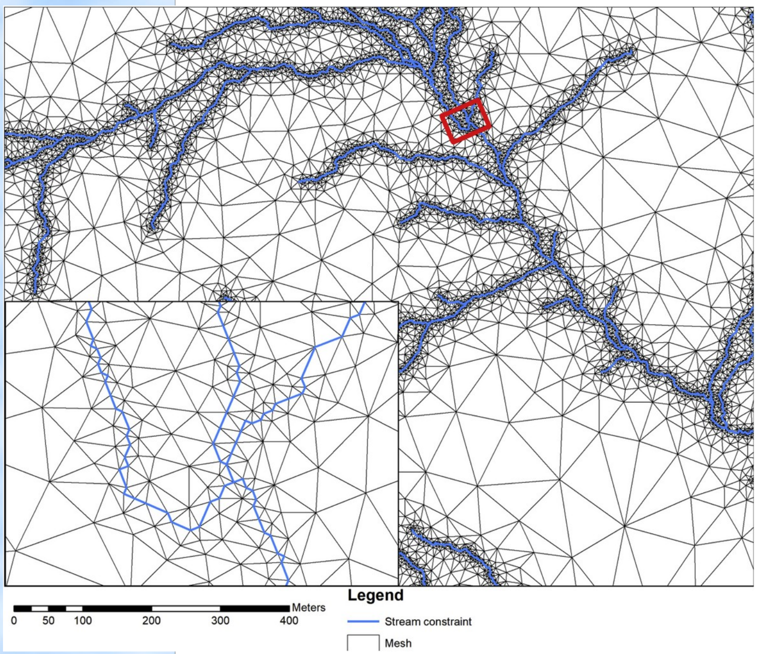
Obviously at 20km resolution the atmospheric data does not contain the information to produce a strong altitudinal contrast in E_{ref}.

The sensitivity to the atmospheric parameters is also modified.

The enhanced turbulent mixing generated at higher resolution seems to be important in order to reproduce the evaporation contrasts.

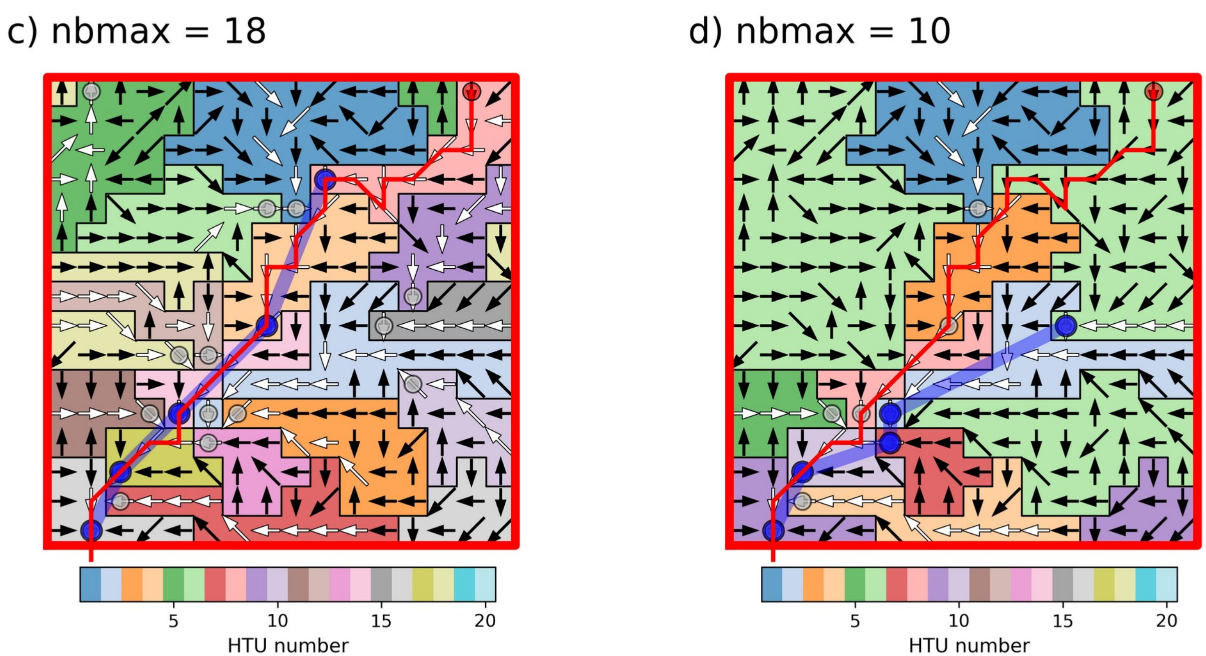
This leads to a much larger moisture convergence over topography as resolution increases. How will this water flow downhill to satisfy the atmospheric demand there ?

How to use hydrological expertise for water transfers in atmospheric models ?



Marsh et al. 2018

- The hydrological community has a large experience with km-scale modelling.
- Their discretization are driven by topography.
- Regular grids are ill-suited for hydrological processes.



Is catchment level sub-gridding the solution ?

Polcher et al. 2022

Conclusion

- Going to km-scale will require to rethink the coupling of the water cycle between the surface and atmosphere.
- The hydrological community has expertise to contribute at these resolutions and a closer interaction is needed.
- Land surface models are excellent starting points. But their GCM heritage probably gives them a “smooth vision” of the surface.
- Stronger gradients between moisture convergence and moisture divergence regions are to be expected.
- To simulate that water transports at the surface will be key.

Including proper hydrology (and other land processes) will make km-scale models more suitable for climate services.