Implementation of water table dynamics and river routing into WRF: the LEAFHYDRO model as a new LSM option (WRFHYDRO system)

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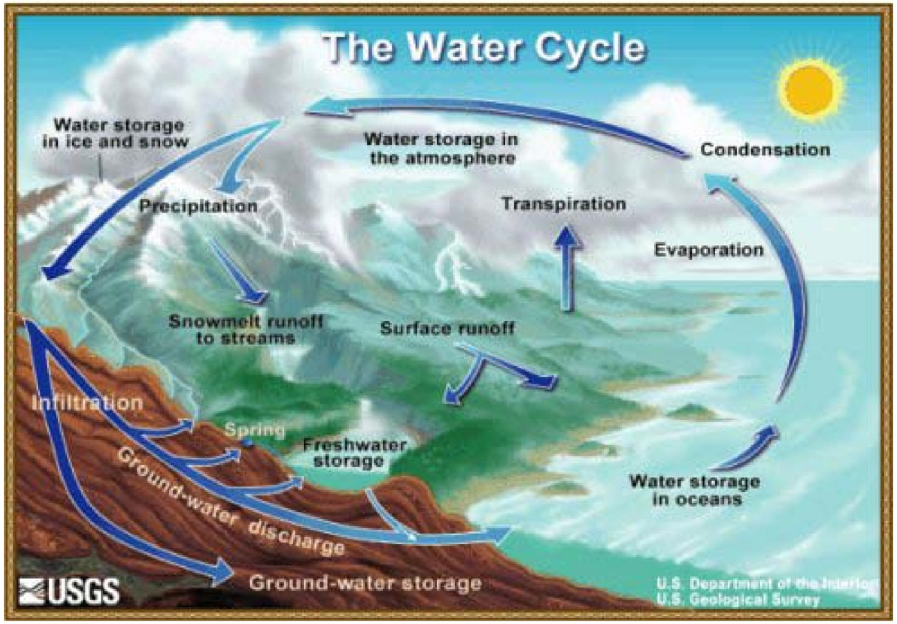
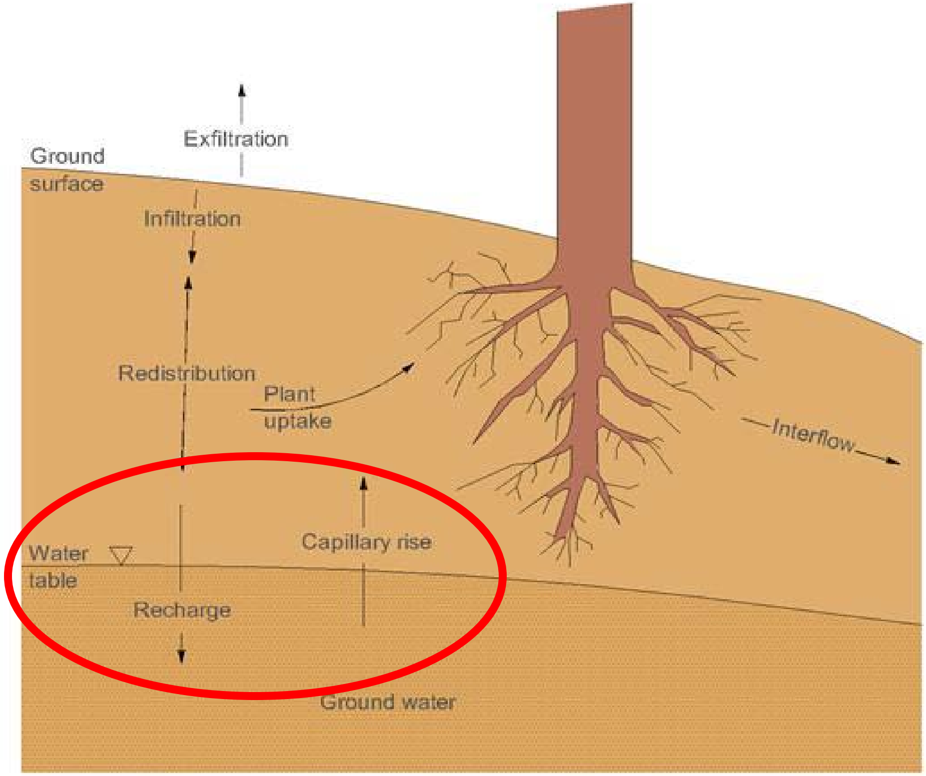
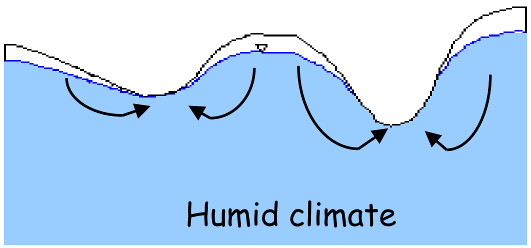
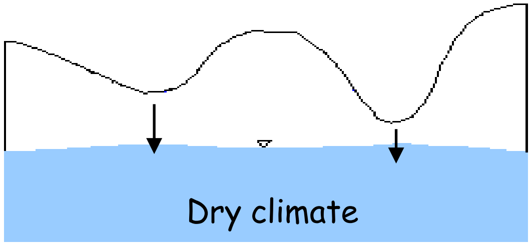




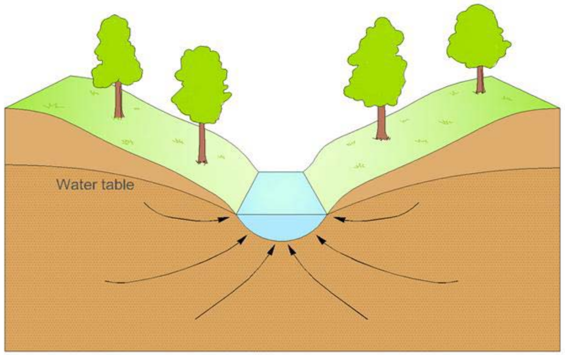
– **Groundwater** is the sub-surface water within the saturated layers of the soil. The upper surface of the groundwater reservoir (saturated zone) is the **water table**.

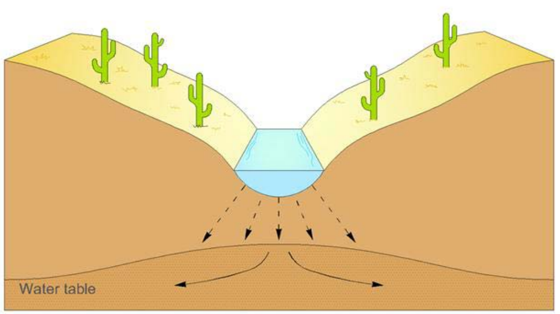


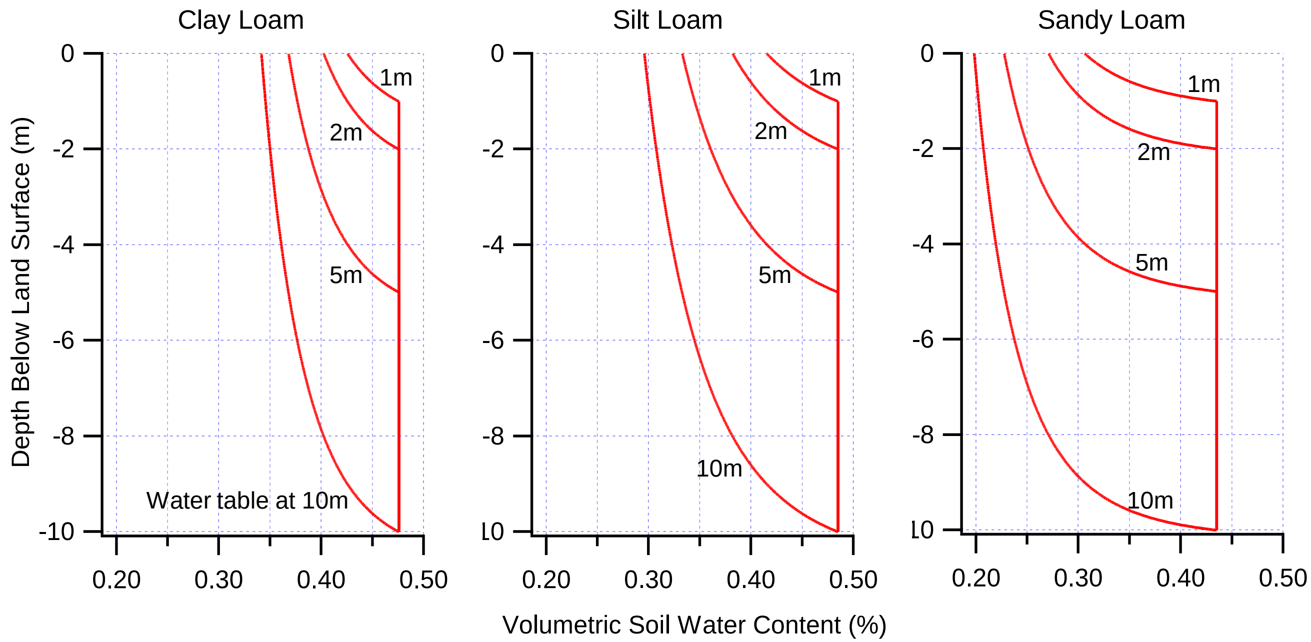


- The distance from land surface to the water table (water table depth) varies from place to place.
  - The water table is usually is deeper under the mountains and shallower in the valleys due to lateral transport driven by gravity.
  - It rises with increased recharge from infiltration or lateral flow convergence and declines in response to upper soil crust ET demands, lateral flow divergence or excessive pumping.

- Groundwater also interacts with rivers.
  - In humid regions rivers receive groundwater discharge (gaining rivers).
  - In dry regions, rivers lose water to the groundwater reservoir (losing rivers).







Equilibrium soil water profile above a water table at four depths (1, 2, 5, and 10m) for three typical soil types.

The water table acts as a lower boundary condition for the unsaturated soil

Incorporating water table dynamics into WRF (LEAF-HYDRO LSM)

Equations:

Mass balance in groundwater storage:

$$\frac{dS_g}{dt} = \Delta x \Delta y R + \sum_{1}^{8} Q_n - Q_r$$

Darcy's Law for lateral groundwater flow:

$$Q_n = w \cdot \left(\frac{\int_{wtd_n}^{\infty} K_n \cdot dz + \int_{wtd}^{\infty} K \cdot dz}{2} \right) \left(\frac{h_n - h}{s} \right)$$

Darcy's Law for groundwater – river exchange:

$$Q_r = \left(h - \overline{z}_{rb}\right) \left(\frac{\overline{K}_{rb}}{\overline{b}_{rb}} \right) \left(\overline{w}_r \sum L_r \right)$$

Mass balance in surface water storage:

$$\frac{dS_s}{dt} = Q_h + Q_r + \sum_{1}^{7} I_n - Q_s$$

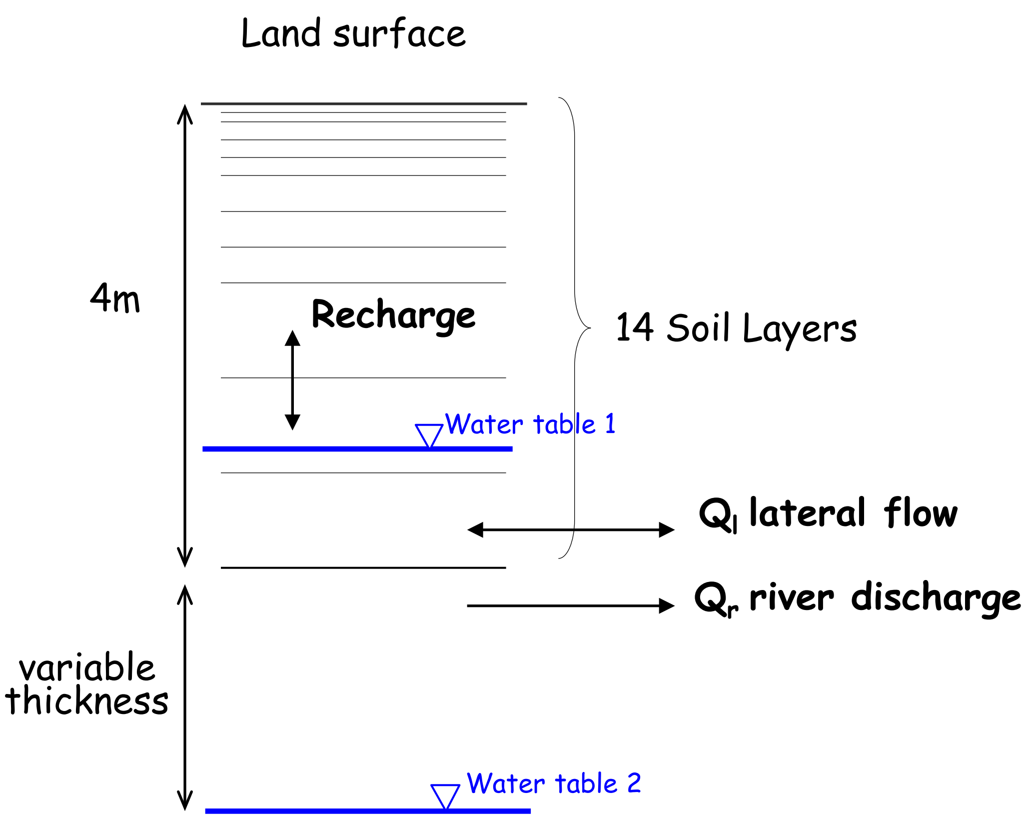
River flow routing from cell to cell to the ocean:
(linear reservoir model)

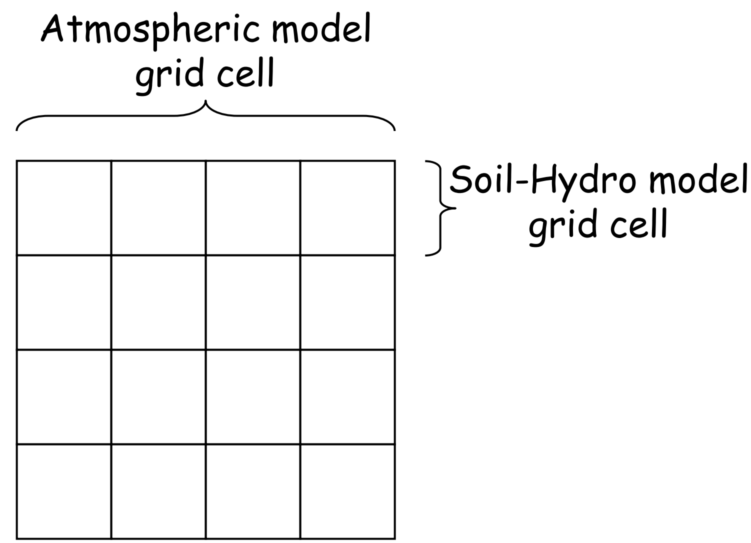
$$Q_s = S_s / k_s$$

Mass balance

$$\frac{dwtd}{dt} = R + \sum_{1}^{8} Q_n - Q_r$$

Water table depth
Recharge
Lateral flow
Discharge to rivers





Lateral flow

$$Q_n = w \cdot \left(\frac{\int_{wtd_n}^{\infty} K_n \cdot dz + \int_{wtd}^{\infty} K \cdot dz}{2} \right) \left(\frac{h_n - h}{s} \right)$$

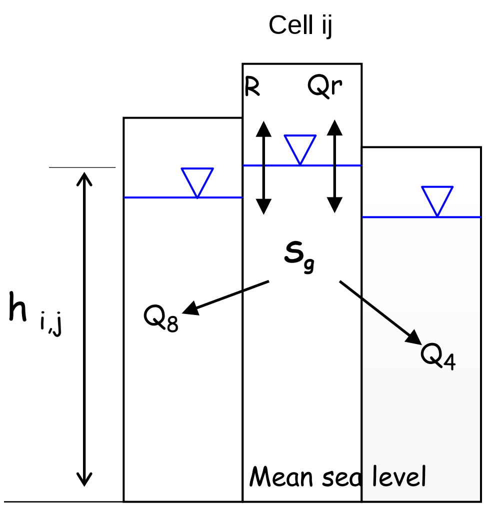
conductivity

width of flow cross section

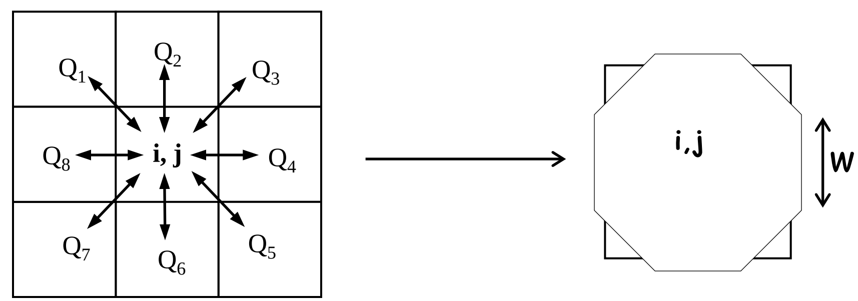
Transmisivity

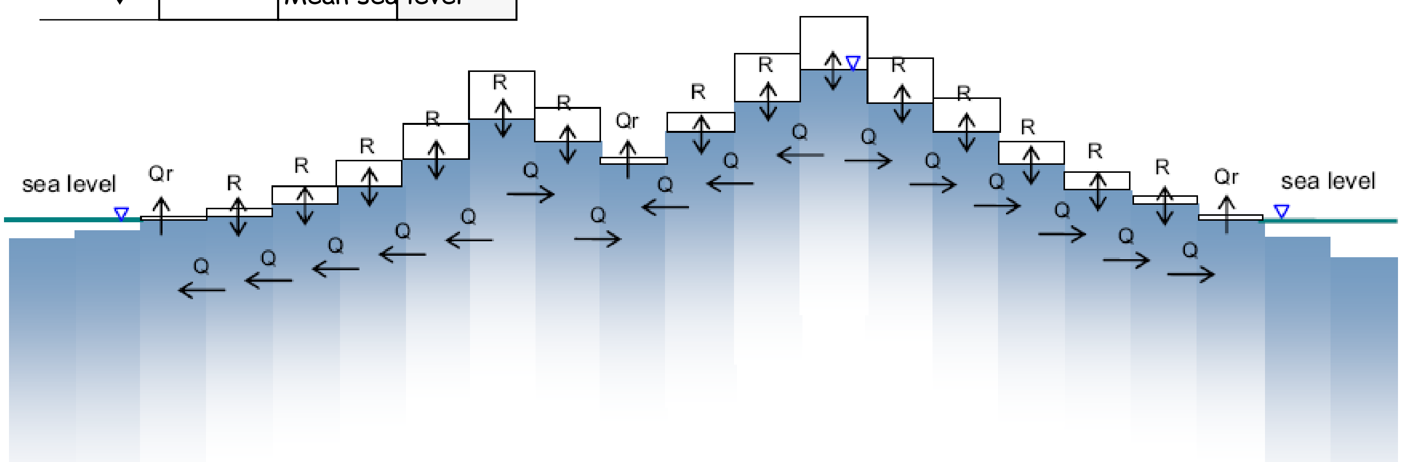
Head difference divided by distance

Cross section view



Plan view





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Surface water (rivers and lakes)

Mass balance ⇨

$$\frac{dS_s}{dt} = Q_h + Q_r + \sum_{1}^{7} I_n - Q_s$$

- Q_h: Surface runoff
- Q_r: Groundwater discharge
- $\sum_{1}^{7} I_n$: River inflow from neighboring cells
- Q_s: River outflow

$$Q_r = rcond \cdot (wtd - rbed)$$

- $rcond$: River conductance
- wtd: Water table depth
- $rbed$: River bed depth

$$Q_s = \frac{S_s}{k_s}$$

- k_s: Residence time

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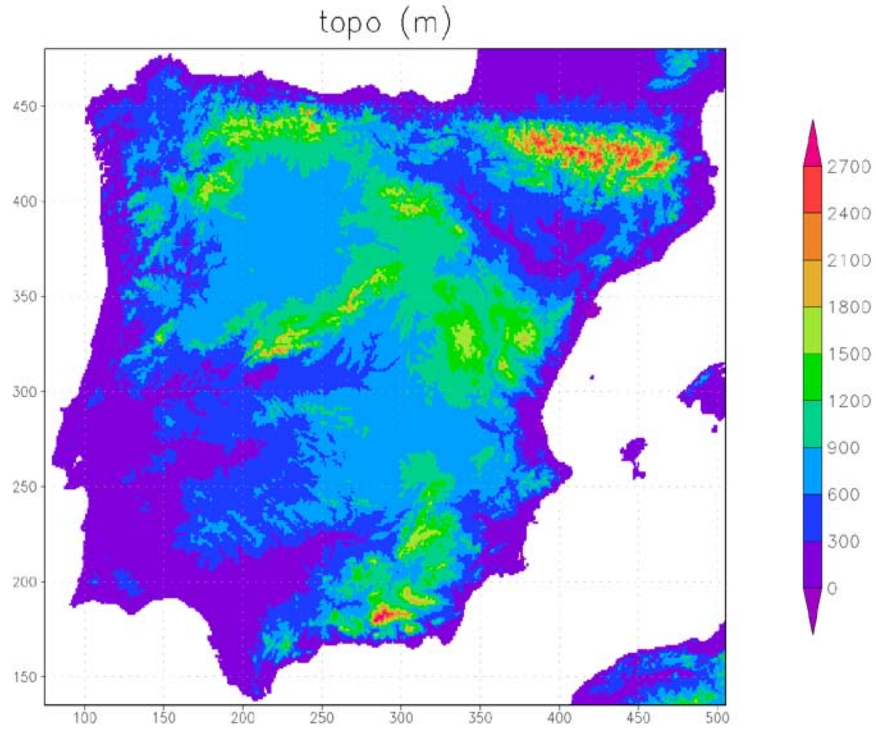


•Nested grid of 1500 km x 1500 km covering the Iberian Península.

• 5 km horizontal resolution (2.5 km res. land surface).

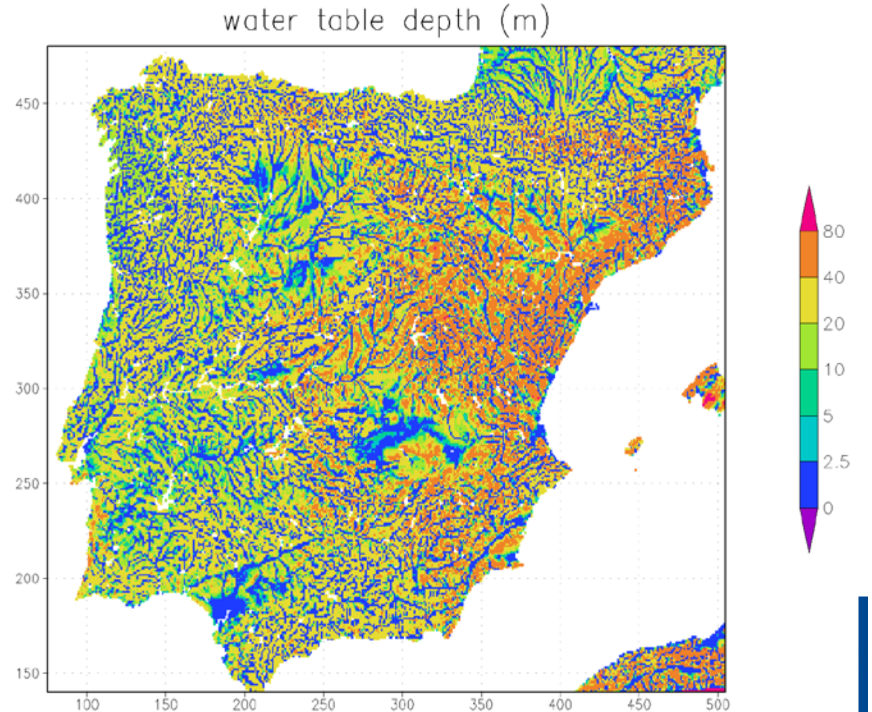
• Parent grid (20 km res.) using **spectral nudging**.

•We assume convection is resolved in the nested domain (convective parameterization is turned off).

•Test simulation for 1 month (May 2008).

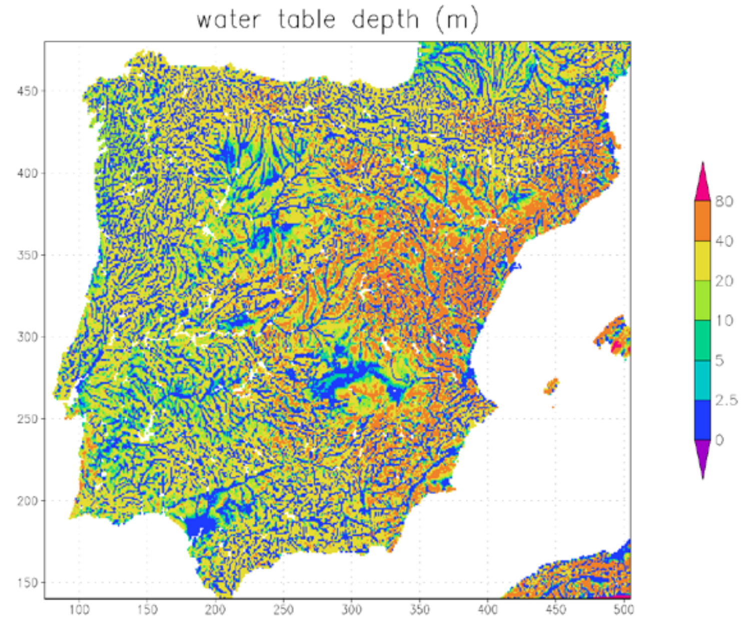
•Initial conditions for the water table depth are from an offline equilibrium simulation at 9 arcsec resolution, validated with thousands of obs. over Spain and Portugal.

•Initial soil moisture: equilibrium profile from the water table.

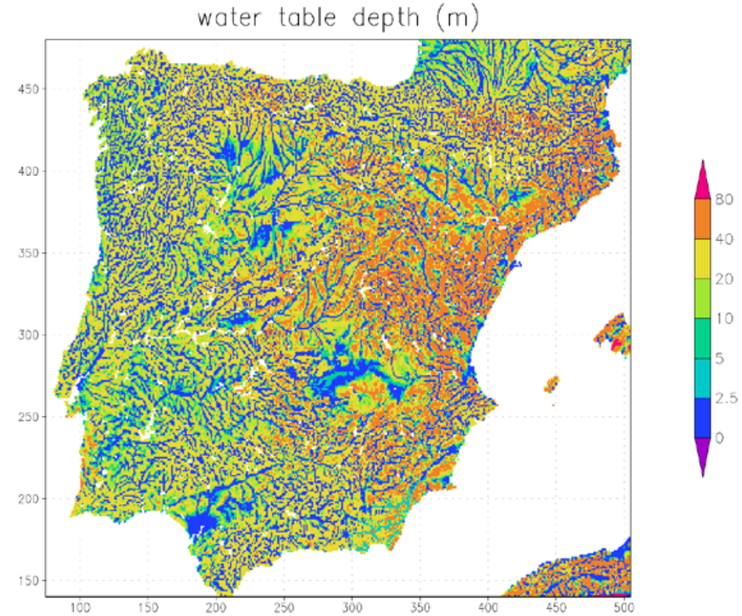


Beginning of month

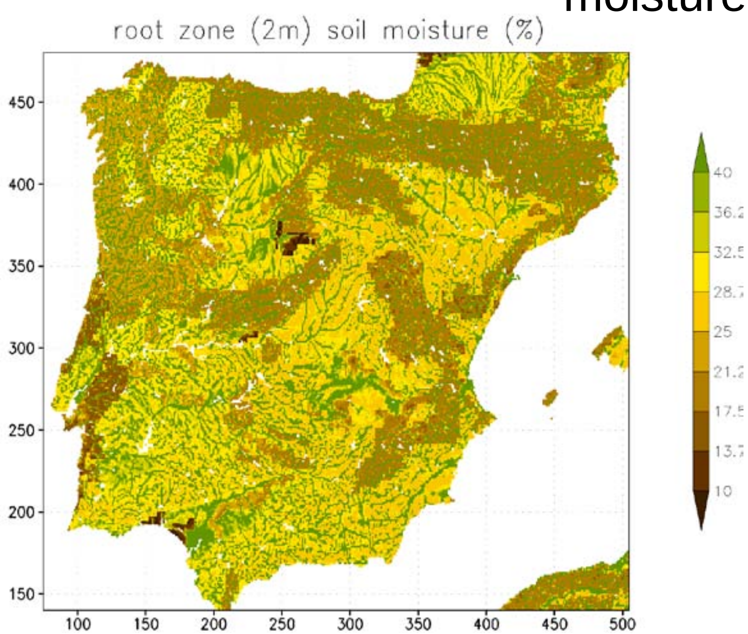
End of month



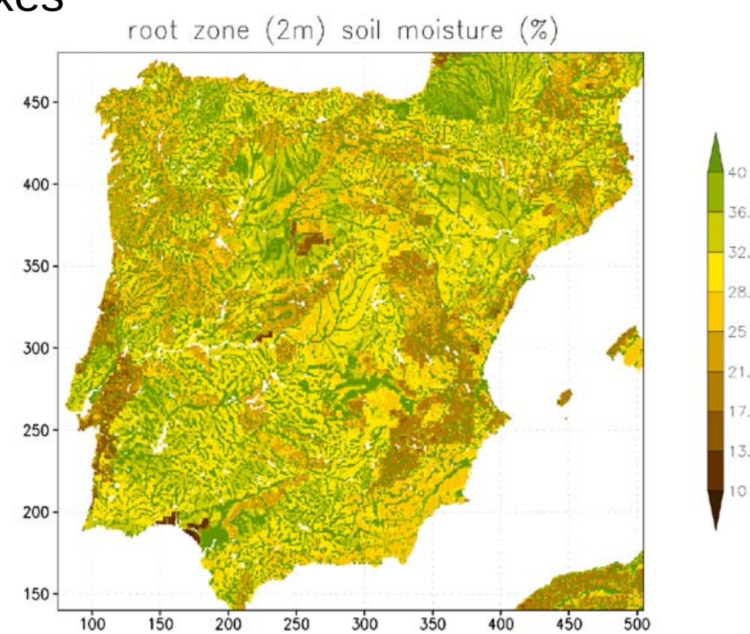
The water table evolves slowly



The water table is coupled to soil moisture through 2-way fluxes



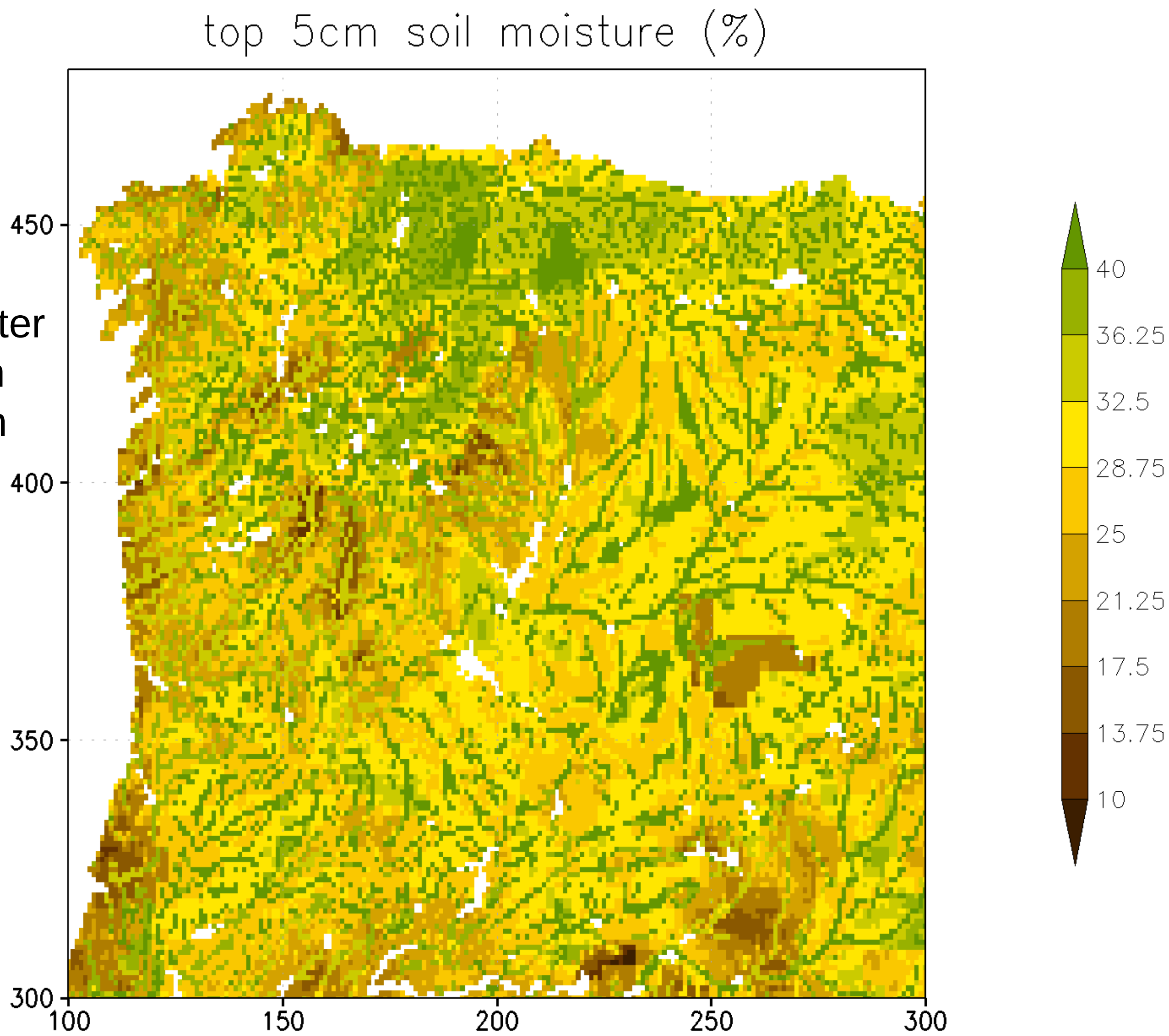
A shallow water table increases persistence of root zone soil moisture



The signature of the water table is very apparent in the soil moisture pattern after 1 month into the coupled simulation:

-wetter soils where the water table is shallow,

-dryer soils where the water table is deep.



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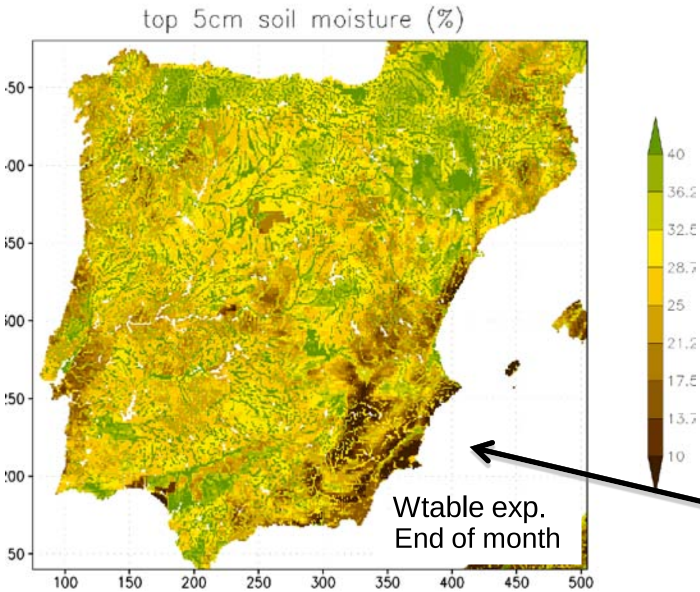
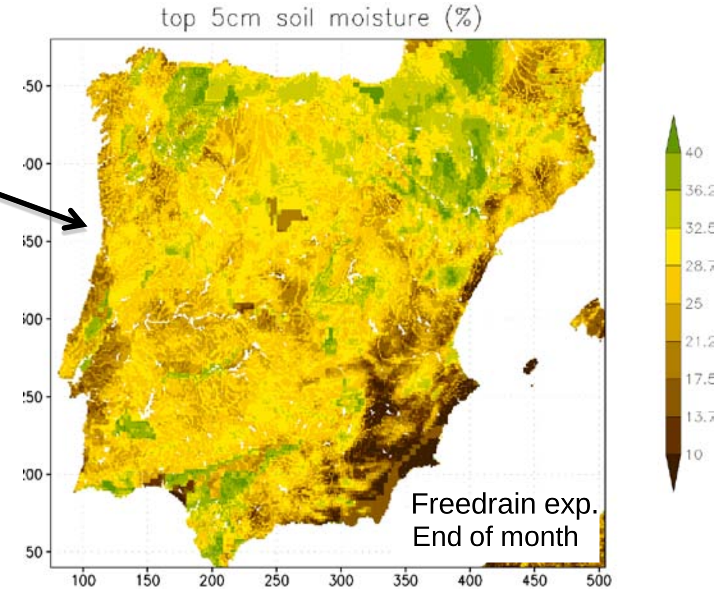
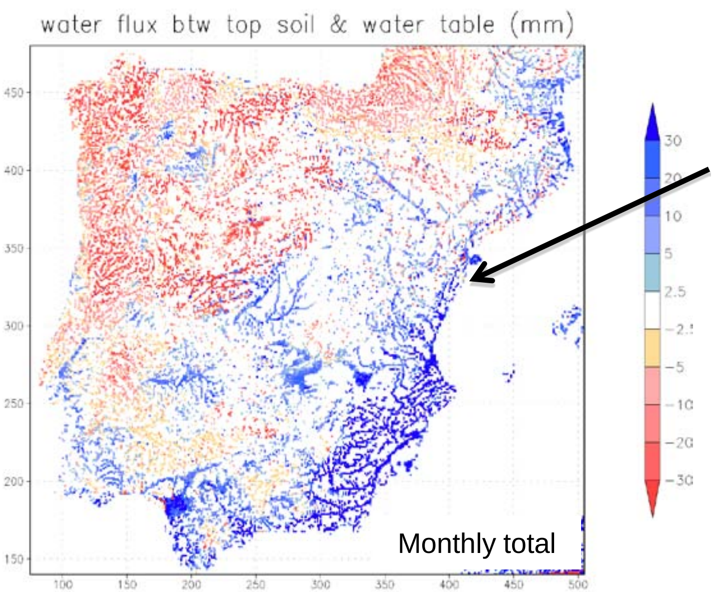
Comparison to an experiment with no water table
(same initial, boundary conditions and model settings)



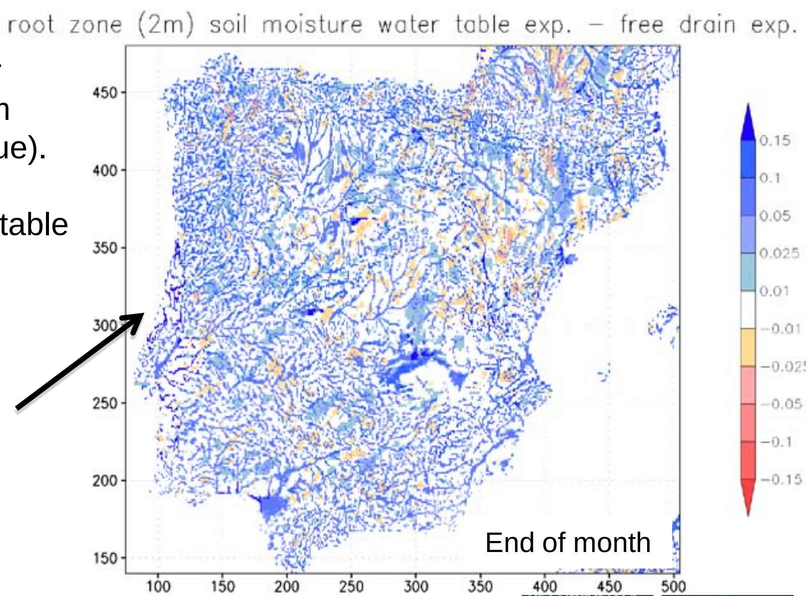
At the end of the month, in the exp with no water table soil moisture depends only on soil texture and atmospheric forcing



In the exp. with water table the pattern of the water table depth is imprinted in the soil moisture pattern

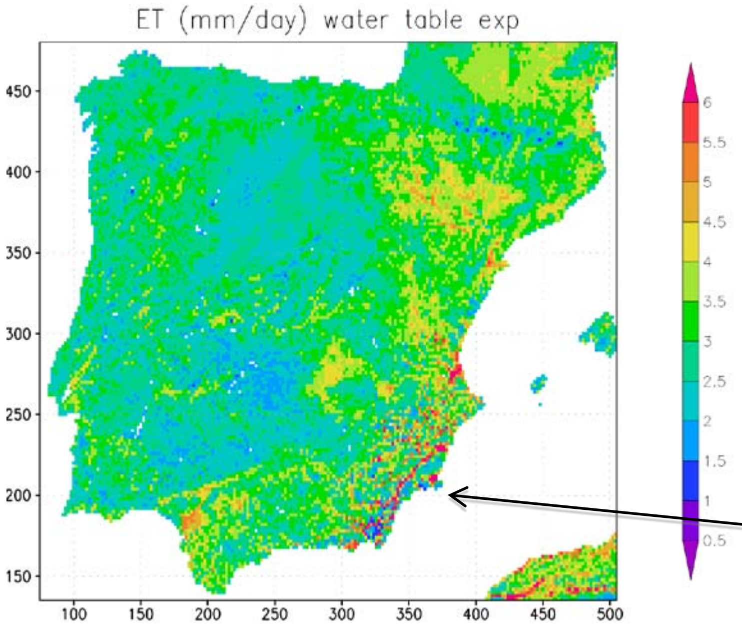


In dry areas, the water table wets the soil from below (upward flux, blue). In humid areas the presence of the water table slows down drainage.



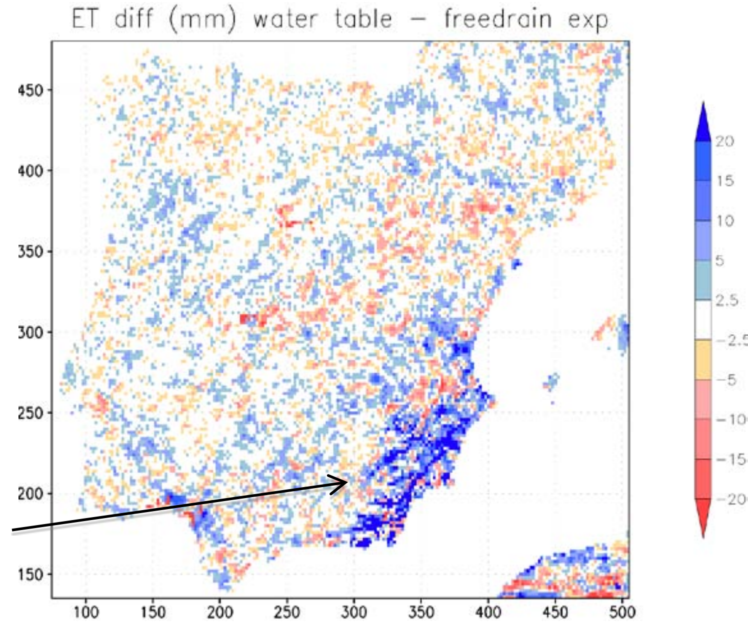
Soils are wetter where the water table is within reach of the top soil.

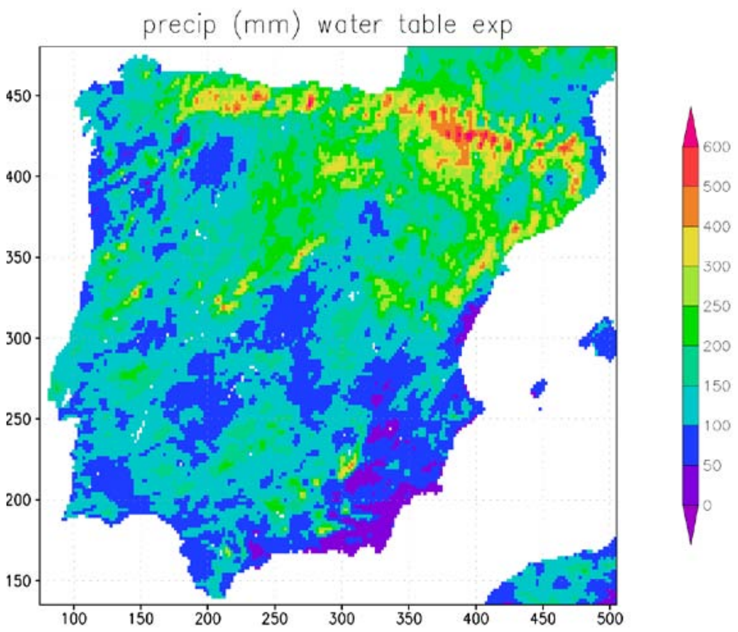
How do the differences between water table and freedrain experiment affect ET and precipitation?



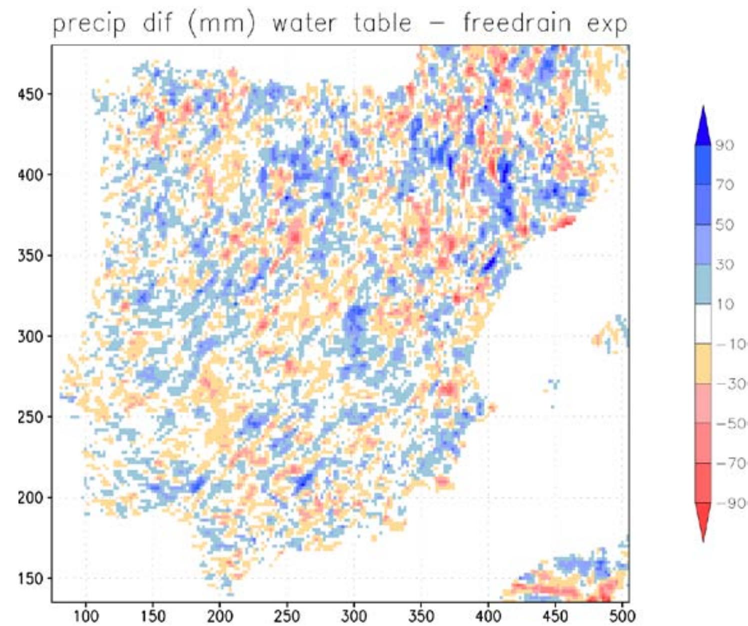
Soil moisture values and differences translation into ET fluxes is complex because ET depends on atmospheric demand as well

Where it stays dry, more soil moisture leads to more ET

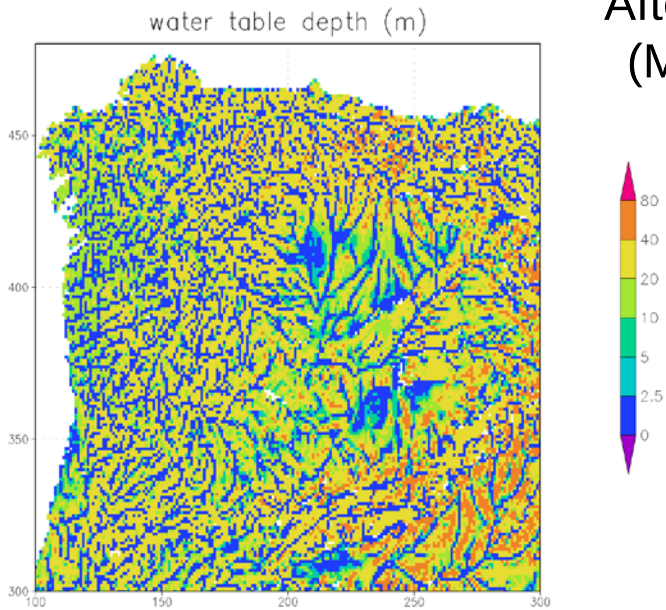


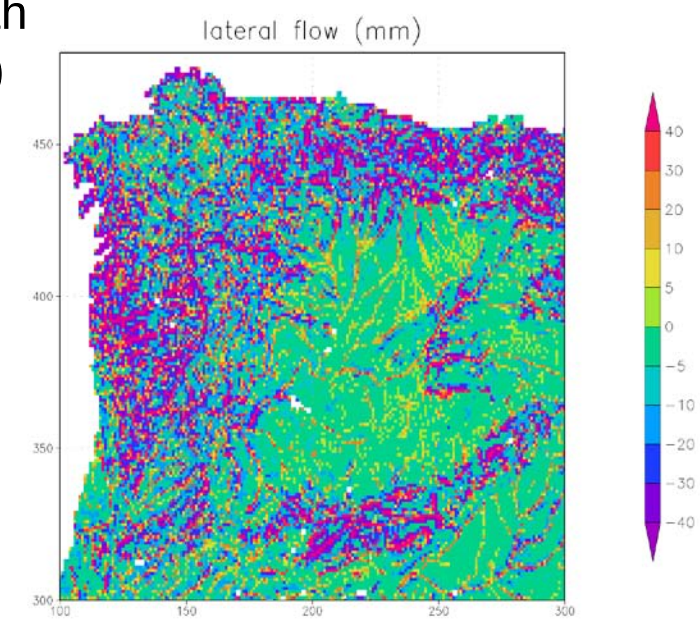


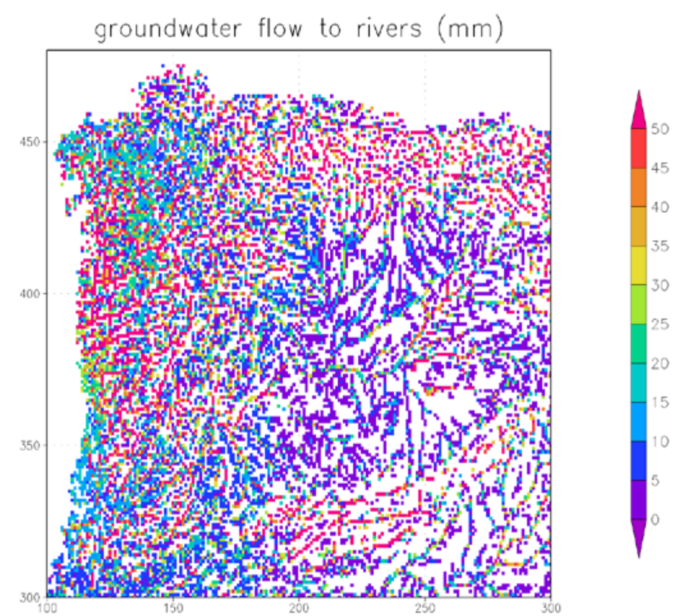
Precipitation differences do not have a consistent pattern with soil moisture differences. 1 month simulation is too short, especially when starting from the same soil moisture conditions. Differences take time to rise.



After 1 month
(May 2008)







The model redistributes soil moisture laterally and the drainage of groundwater by the river network is parameterized

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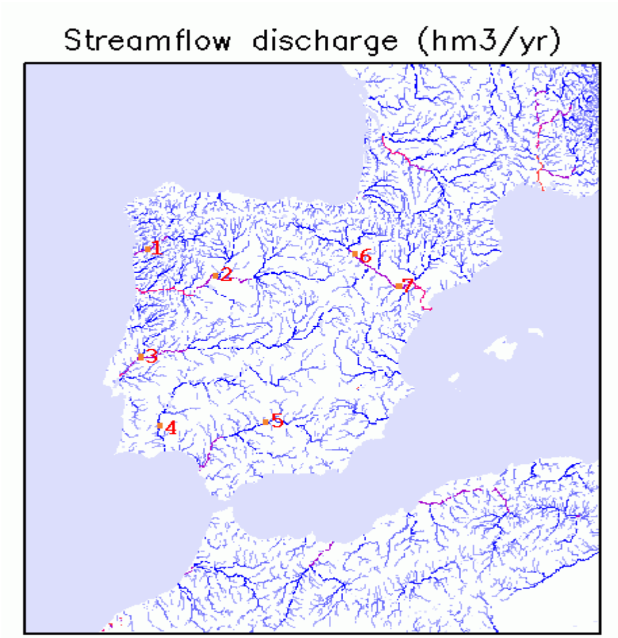
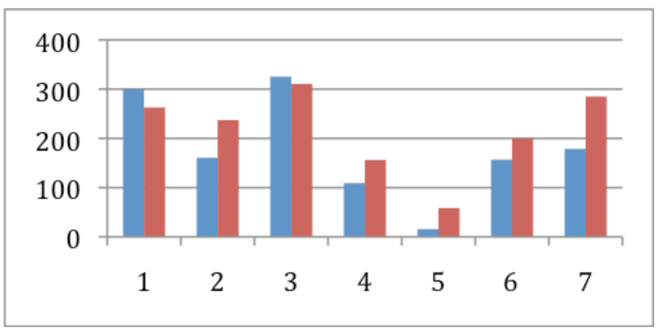
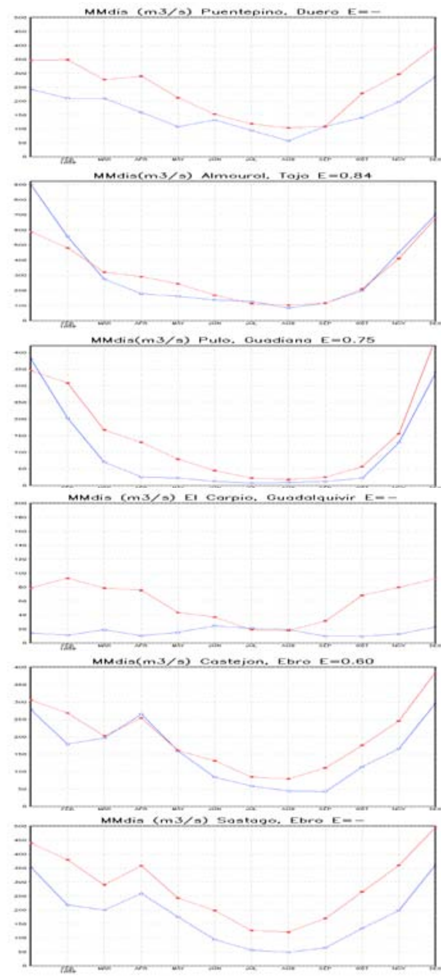
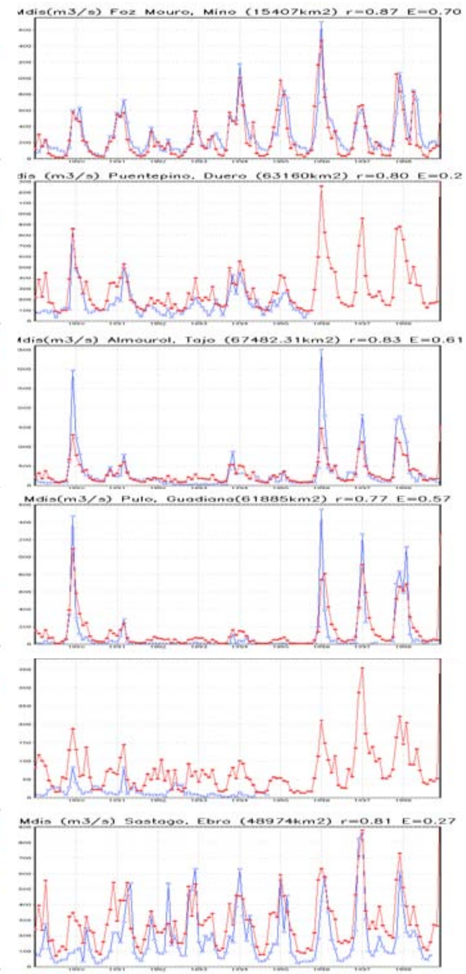
Example of calculated streamflow:
offline simulation for the same grid, forced by 10 years of ERA-interim atmospheric data and CRU precip.









Red: model
Blue: obs

CONCLUSIONS

•Where the water table is shallow, groundwater and soil moisture are coupled via 2-way fluxes.

-Groundwater wets the soil from below. In dry periods a shallow water table can supply the top soil with water to sustain ET through upward capillary fluxes.
-The water table receives infiltration in wet periods and delivers water to the rivers. Where shallow, it slows down drainage via upward capillary fluxes.

•Groundwater has a strong influence on near surface soil moisture distribution at regional scale. Soil moisture large scale spatial structure mimics that of the water table (wet soils where the water table is shallow, drier soils where it is deep), with transient differences arising when rain falls, and fading away afterwards.

•The impact of the water table on soil moisture can potentially affect land-surface fluxes and precipitation. Groundwater should not be neglected in land-surface models.

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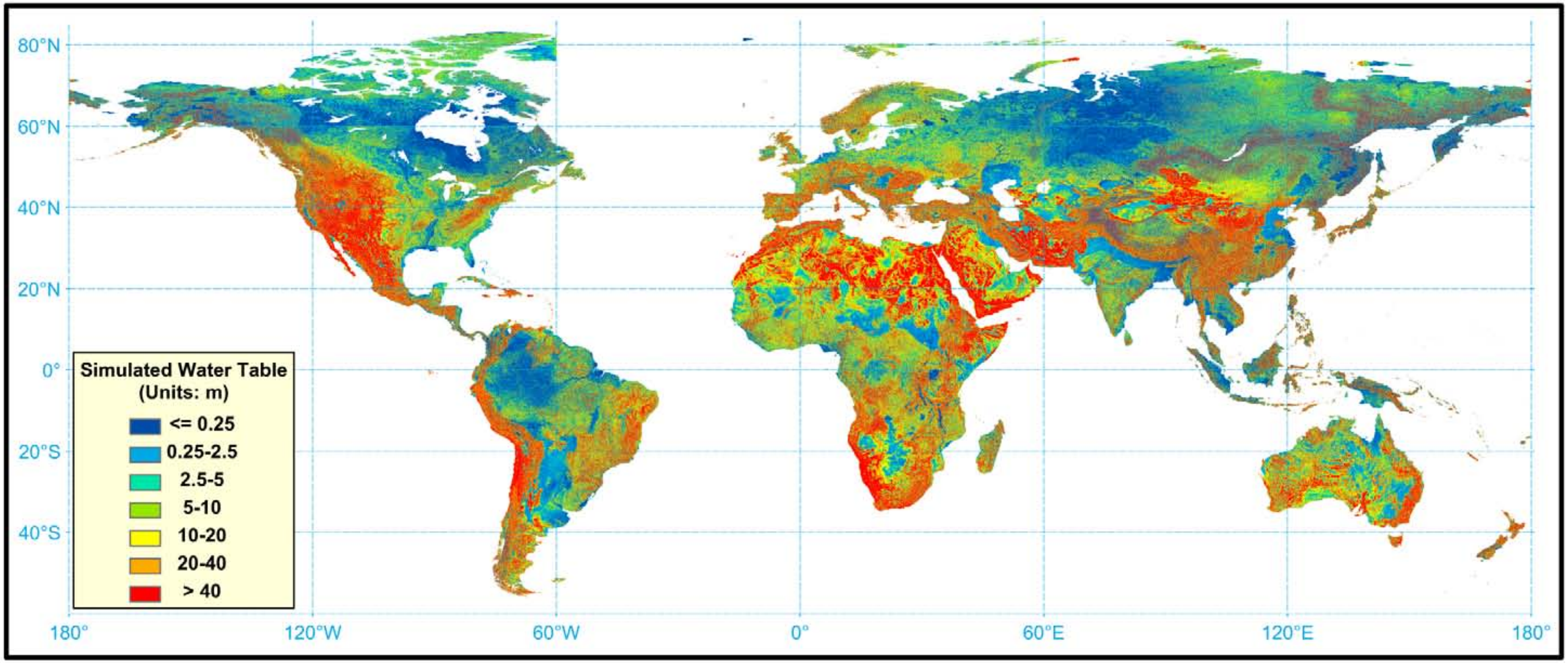
Global water table depth map



Shallow water tables cover large areas of the continents and can modulate soil moisture and land surface fluxes at global scale.

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