Implementation of water table dynamics in SURFEX based on explicit diffusion equations

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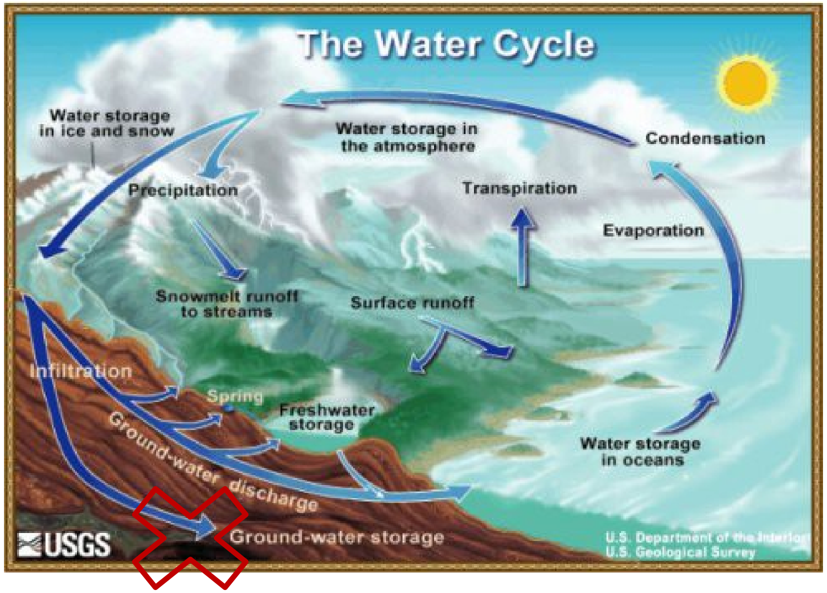
MOTIVATION

- Groundwater reservoir is usually neglected in land surface models.



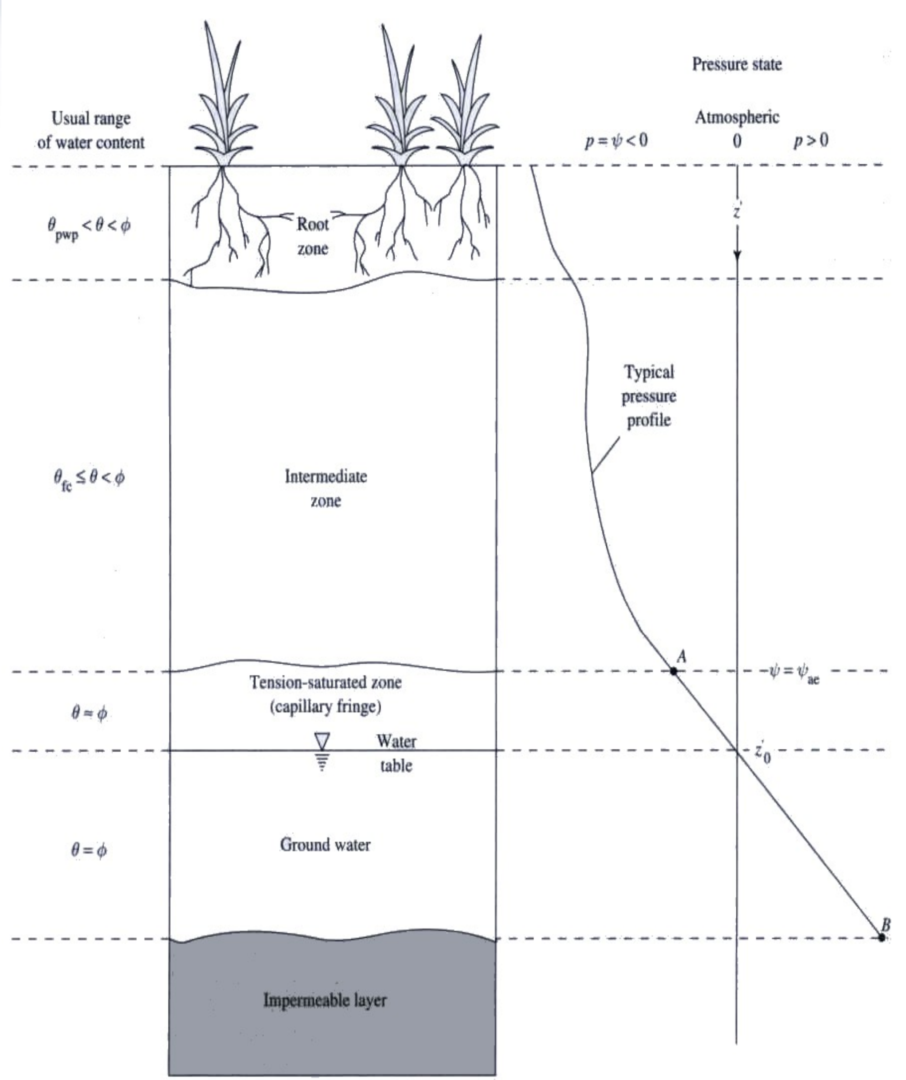
The water cycle is not closed!

What is the water table?

- It is the upper surface of the saturation zone. It can be free water in a confined aquifer or the level where the soil is saturated. Above the WT the soil is not saturated and below it is saturated

Why is it important?

- Better and more realistic soil water and energy fluxes between land surface and atmosphere
- Important for climate/long simulations over regions with shallow WT (e.g. near rivers and big reservoirs of groundwater like aquifers).
- Water balance better closed



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MOTIVATION

- Several studies demonstrate that **groundwater** in the saturation zone may have a strong **influence** on near **surface soil moisture distribution**.

- Where WT is shallow, the impact of groundwater on near surface soil moisture can potentially affect **land-surface fluxes** (ET), precipitation and, hence, **climate**.

Liang X, Xie Z, Huang M (2003) A new parameterization for surface and groundwater interactions and its impact on water budgets with the Variable Infiltration Capacity (VIC) land surface model. J Geophys Res 108: 8613, doi:10.1029/2002JD003090.

Maxwell RM, Miller NL (2005) Development of a coupled land surface and groundwater model. J Hydrometeorol 6: 233-247.

Yeh PJF, Elthahir EAB (2005a) Representation of water table dynamics in a land surface scheme, Part I: Model development. J Climate 18: 1861-1880.
Yeh PJF, Elthahir EAB (2005b) Representation of water table dynamics in a land surface scheme, Part II: Subgrid variability. J Climate 18: 1880-1901.

Yu Z, Pollard D, Cheng L (2006) On continental-scale hydrologic simulations with a coupled hydrologic model. J Hydrology 331: 110-124.

Niu GY, Yang ZL, Dickinson RE, Gulden LE, Su H (2007) Development of a simple groundwater model for use in climate models and evaluation with GRACE data. J Geophys Res. doi:10.1029/2006JD007522

Miguez-Macho G, Fan Y, Weaver CP, Walko R, Robock A (2007) Incorporating water table dynamics in climate modeling: 2. Formulation, validation, and soil moisture simulation. J Geophys Res. doi:10.1029/2006JD008112
Miguez-Macho G, Li H, Fan Y (2008) Simulated water table and soil moisture climatology over North America. Bull Am Meteorol Soc 5: 663-672.

Jiang XY, Niu GY, Yang ZL (2009) Impacts of vegetation and groundwater dynamics on warm season precipitation over the Central United States. J Geophys Res 114: D06109, doi:10.1029/2008JD010756.

Modelling the water table

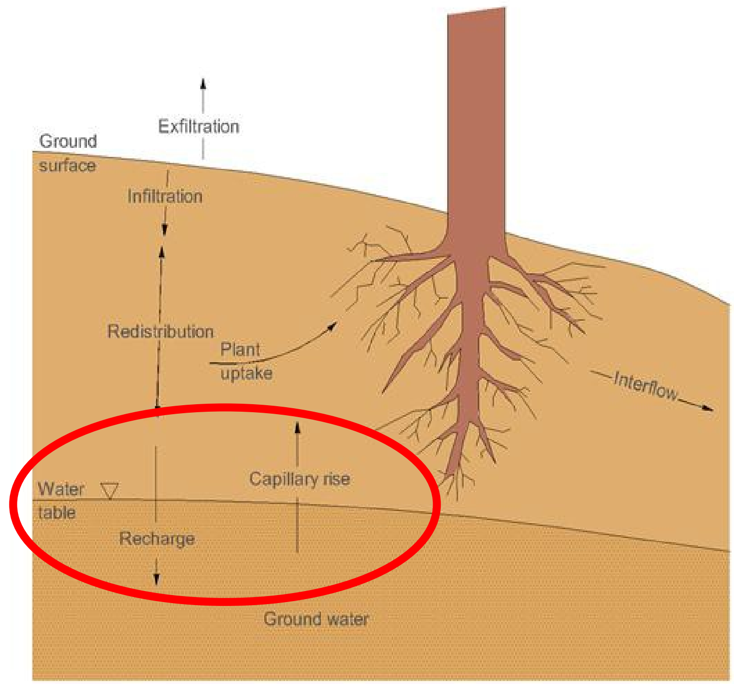
- Most commonly used lower boundary condition in LSMs:

SURFEXv7.3

  - **Free-drainage approach:** soil water surplus is allowed to **drain out** of the land column at a rate constrained by the hydraulic conductivity. The water drained out of the lowest layer is **no longer available** for subsequent dry-periods.

- What if we used the **water table (WT)** as the lower boundary condition for the unsaturated soil?

  - **Groundwater** acts as a **sink** in humid conditions (recharge) and as a **source** in dry conditions (through capillary rise).
  - Upward capillary fluxes can keep soils in wet conditions near the surface, even in the absence of precipitation!



With limitations
SURFEXv8
CGROUNDW='DIF'

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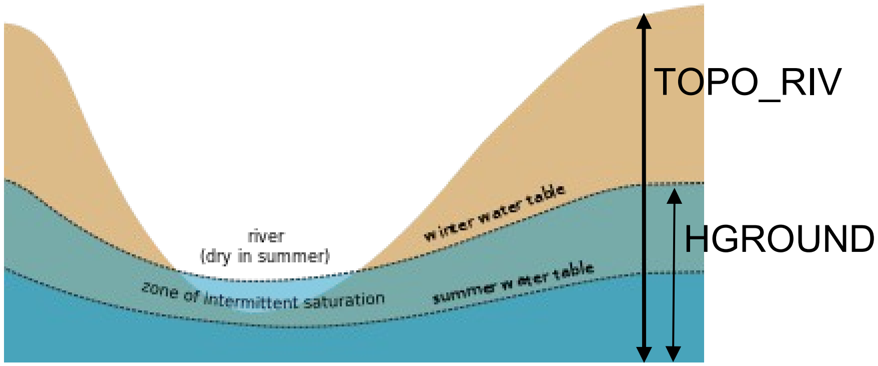
Water table (WT) in SURFEXv8

- SURFEX v8 includes a water table parametrization (not in previous versions). The water table depth (WTD) is calculated in the river routing model (TRIP) as a diagnostic variable (WTD=HGROUND-TOPO_RIV) after calculating the flow between neighbour cells and the groundwater level (HGROUND). Then it is passed to the land part (LSM) of SURFEX at coupling times. The LSM uses the WTD as a boundary condition for calculating the flux at the last model layer but DO NOT UPDATE neither humidity nor WTD.



- The WTD is calculated only at gridpoints marked as aquifers gridpoints and the river routing model only makes calculations over these predefined gridpoints. In other gridpoints WTD is undefined in TRIP. The model reads an aquifer mask (1: aquifer point, 0: no aquifer)

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Water table (WT) in SURFEX v8

- The Richard's diffusion equations are resolved in the vertical (1D) in the LSM. The number of layers for the diffusion calculation varies from point to point. At the bottom the boundary condition consists of assuming that the soil is saturated below the water table depth. This is imposed and not calculated from the fluxes.

- This WT parametrization assumes that WTD=100m for no aquifer gridpoints, which is equivalent to a free drainage bottom boundary condition. The model only calculates the WTD into the river/aquifer mask used by TRIP. In the other places it assumes free drainage as in previous SURFEX versions. In all cases, fluxes at the bottom go to drainage and do not change the water content below the lowest model diffusion layer.

- The SURFEX drainage is used in TRIP to update the HGROUND level at the beginning of the time step. After horizontal fluxes calculation a new HGROUND is obtained at the end of the time step and this value is used to update the WTD (WTD=HGROUND-TOPO_RIV).

- This approach is a good aproximation when WT is into the resolved model layers and water can move free horizontally, not so good when WT is below resolved model layers.

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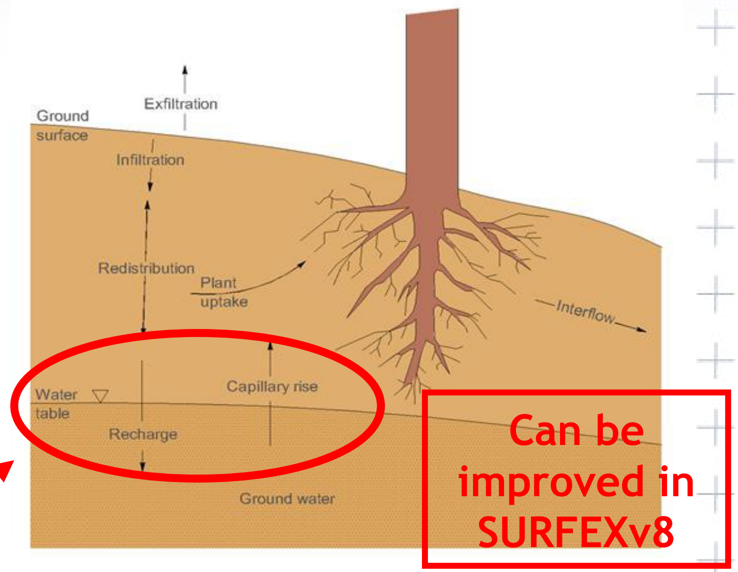
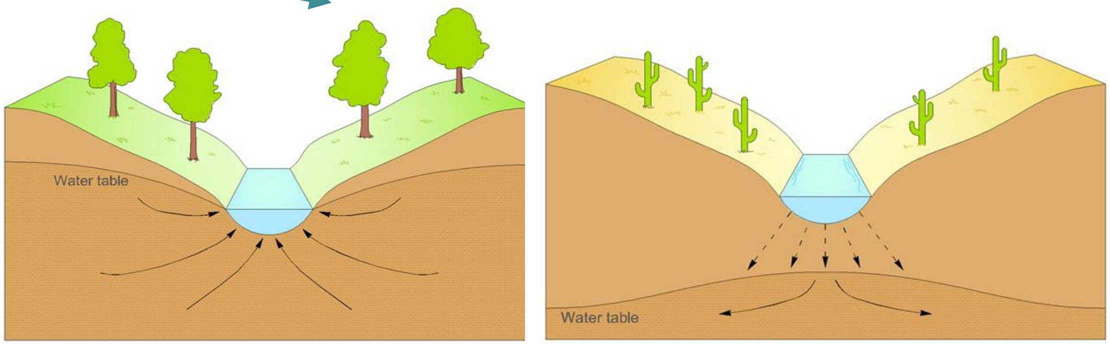
LEAFHYDRO

- LSM that simulates groundwater dynamics.
- Explicit water table simulation:
  - 2-way coupling between soil and GW
  - 2-way coupling between river and GW



OK in SURFEXv8



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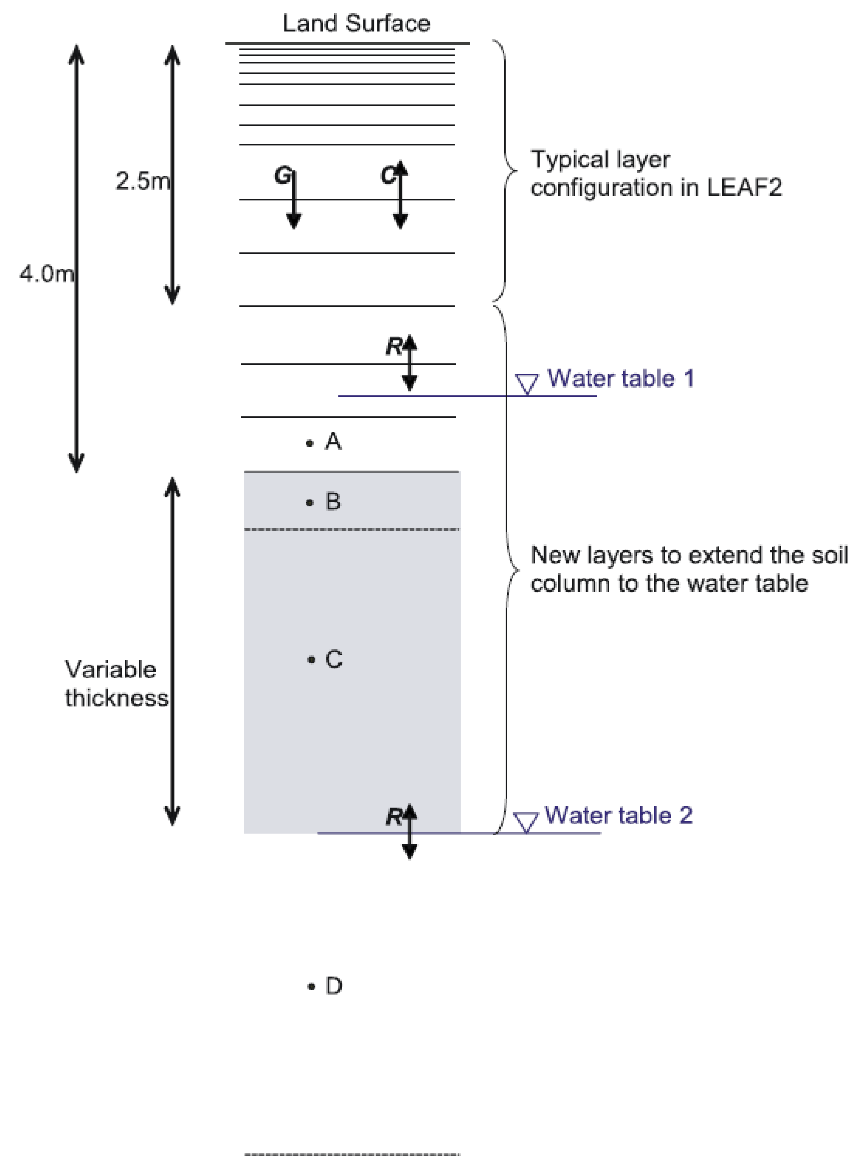
LEAFHYDRO

Soil-GW coupling

- **Diffusive scheme**: it solves Richards' equations in the soil column.

- If WT is below the model soil column we **extend the soil column** down to the water table depth by adding two new layers of variable thickness.

- This new implementation allows **exchanges of soil water between the groundwater reservoir and the unsaturated vertical resolved layers.**



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New WT parametrization (from LEAFHYDRO)

- The specific humidity (WG) of these new layers is calculated from the fluxes between layers and the water excess of each layer. The initial WG of the added layers is initialized from the initial water table depth (WTD) and the initial WG of the resolved layers, read as initial conditions at the beginning of the simulation. (May need some years to make the spin-up).
- The final WTD after each LSM step is calculated from the new WG of the layers after the fluxes between them.
- As the WT is calculated in every point the global water balance is better closed, without assuming free drainage and without using any aquifer mask.

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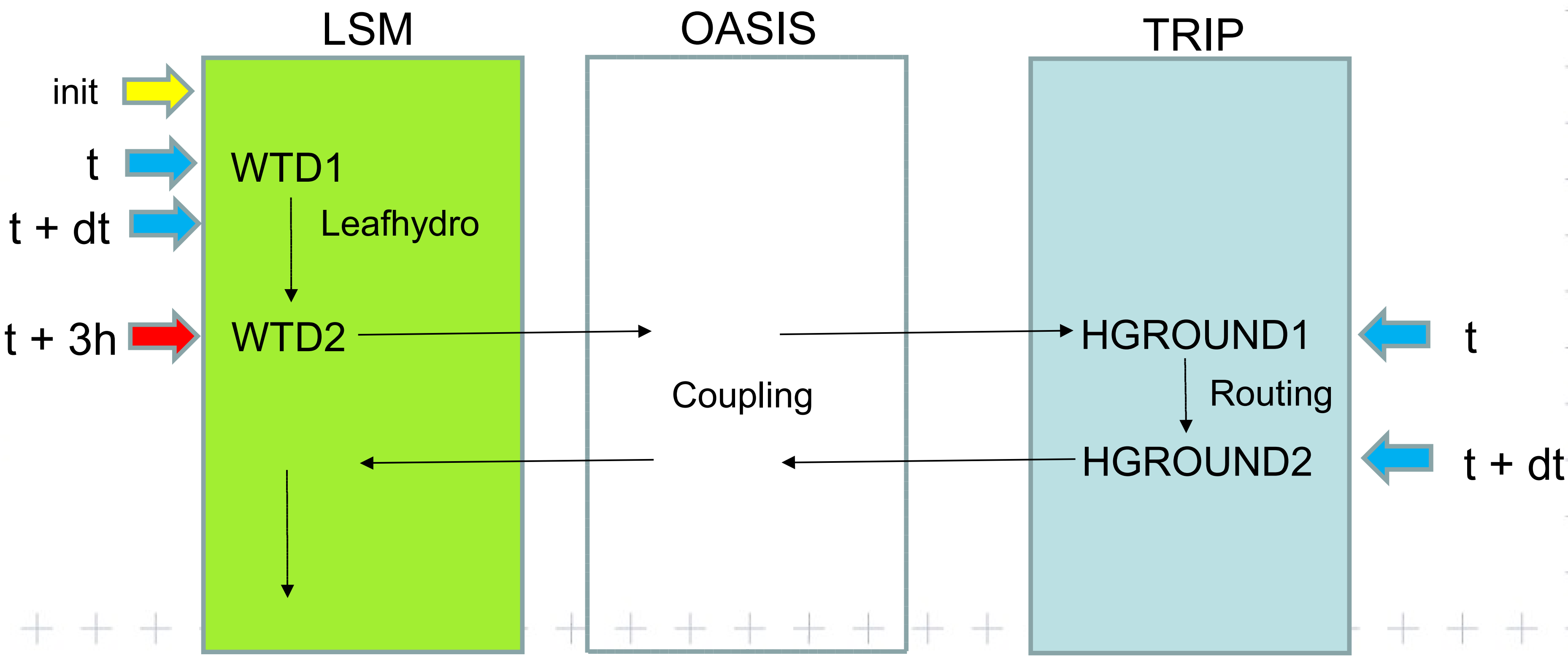
New WT parametrization (from LEAFHYDRO)

- The WTD is calculated in the LSM with the LEAFHYDRO approach and sent to TRIP where updates the HGROUND variable. With this starting value TRIP calculates horizontal fluxes and the new HGROUND which is sent back to the LSM updating the WTD



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Steps followed to include the new WT parametrization in SURFEX

1) MeteoFrance have provided us the output file of the WTD at 0.5 degrees over Spain from a simulation made with SURFEXv8 for 10 years and also the initial files and forcing fields of this simulation. We take this simulation as reference. In order to start from the same point we set-up and run SURFEX v8 coupled with TRIP, out-of-the-box code, with the initial files and forcings provided by MeteoFrance. Our WTD output overlaps theirs as expected (almost same code and same initial files)

2) We introduce in the code a new coupling WTD variable to send from LSM to TRIP. This new variable is sent and received in both parts (LSM and TRIP) but keeps the value set by the original SURFEXv8. We get a new simulation that overlaps in almost all points with the MeteoFrance simulation; the coupling doesn’t change the results.

3) We introduce a random sinusoidal perturbation in the LSM part. We see some differences with respect to the reference but still very similar to the reference.

4) We introduce LEAFHYDRO code. Clear differences with respect to the reference.

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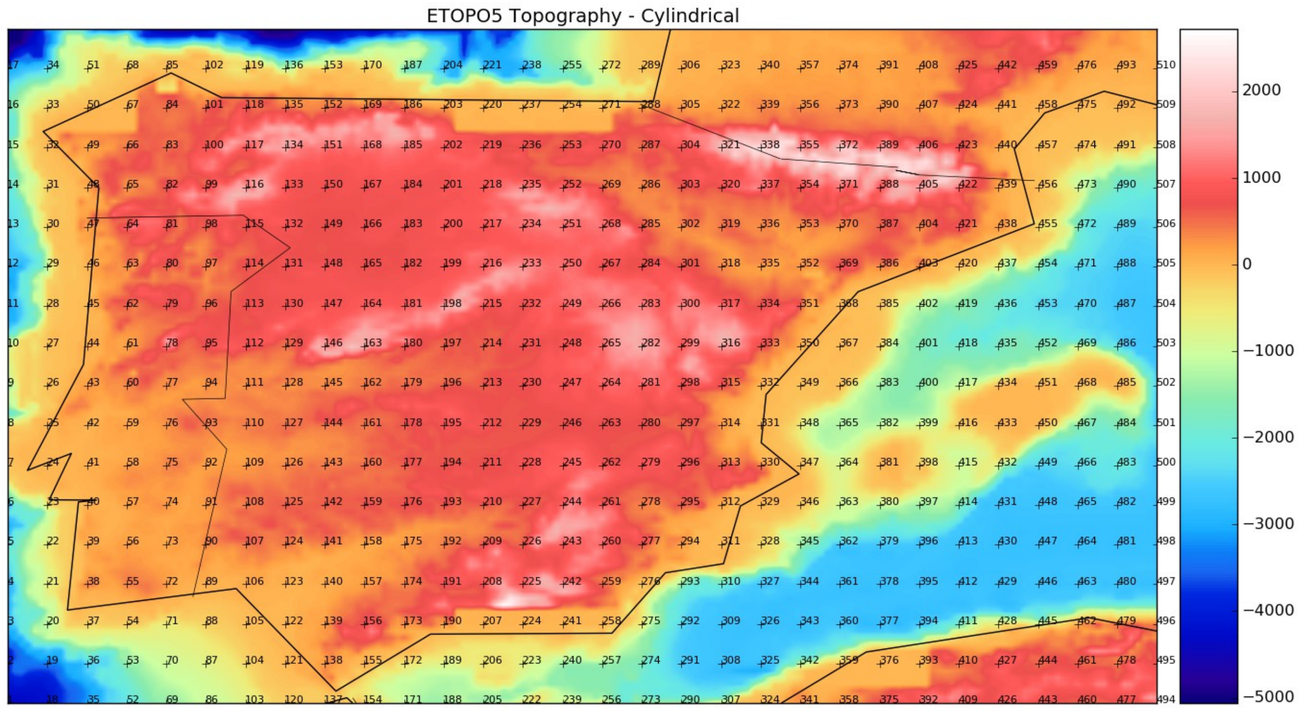
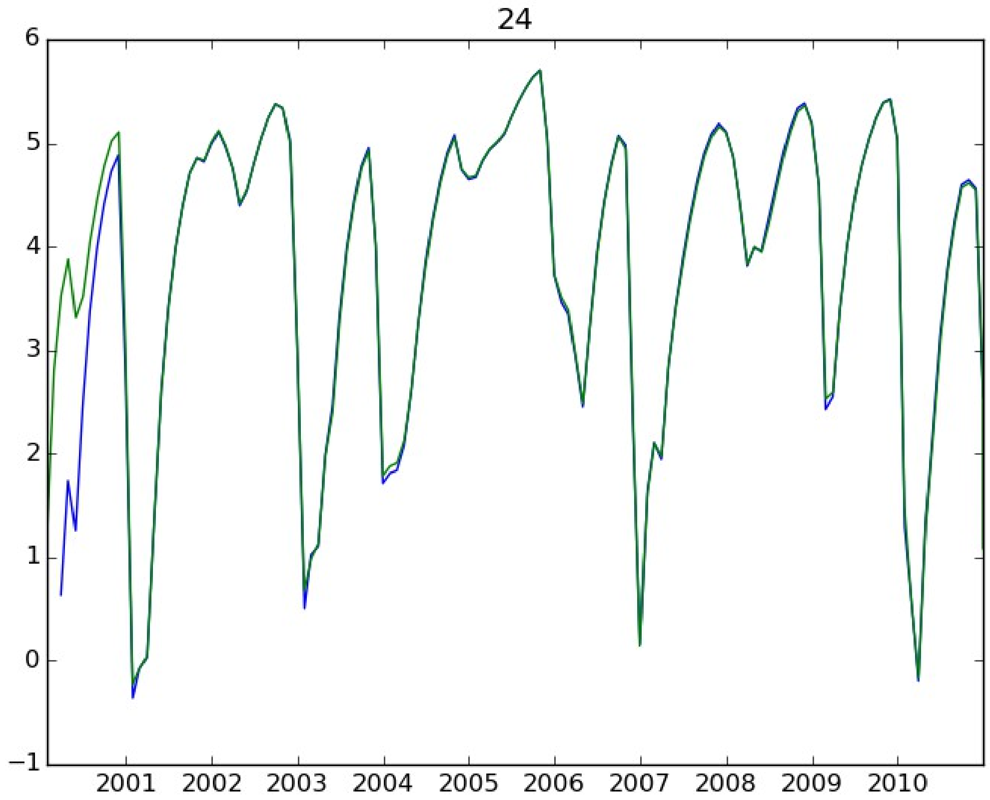
GRID and TOPOGRAPHY



1) Reproduce the WTD of the reference

Comparison at some grids points of a simulation made at MeteoFrance and another at AEMET with SURFEXv8 codes slightly differents but the same initial files and the same forcing fields. In blue the MeteoFrance simulation. In green the AEMET simulation. x axis represents time and y axis represents WTD month means (m)



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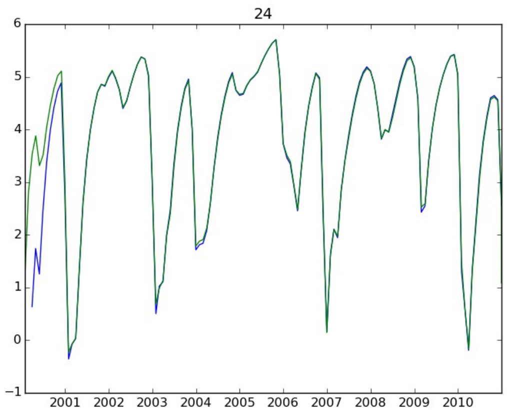
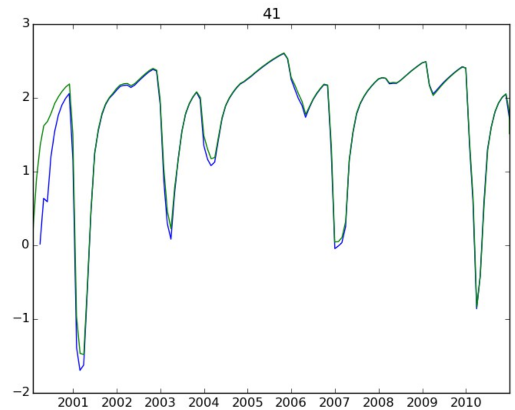
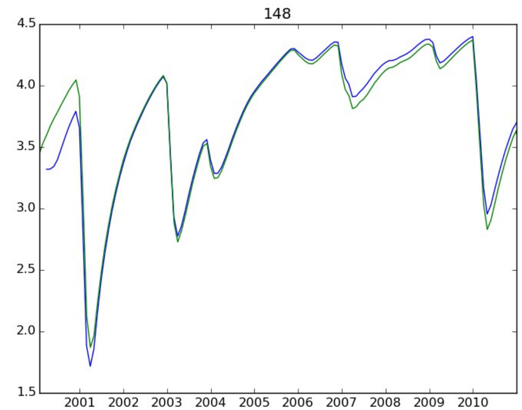
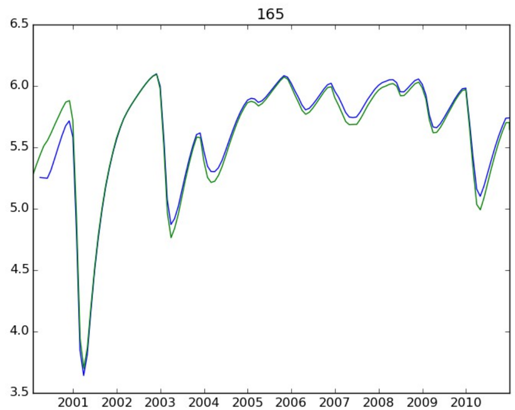
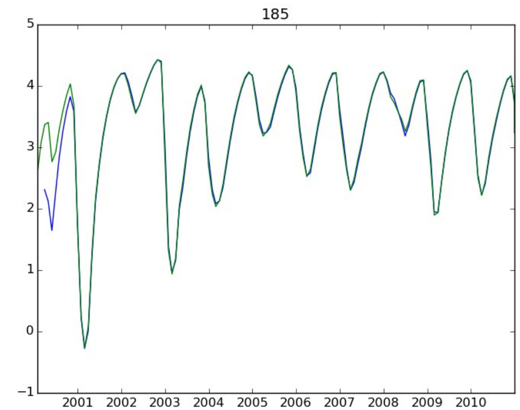






In blue the MeteoFrance simulation. In green the AEMET simulation. x axis represents time and y axis represents WTD month means (m)





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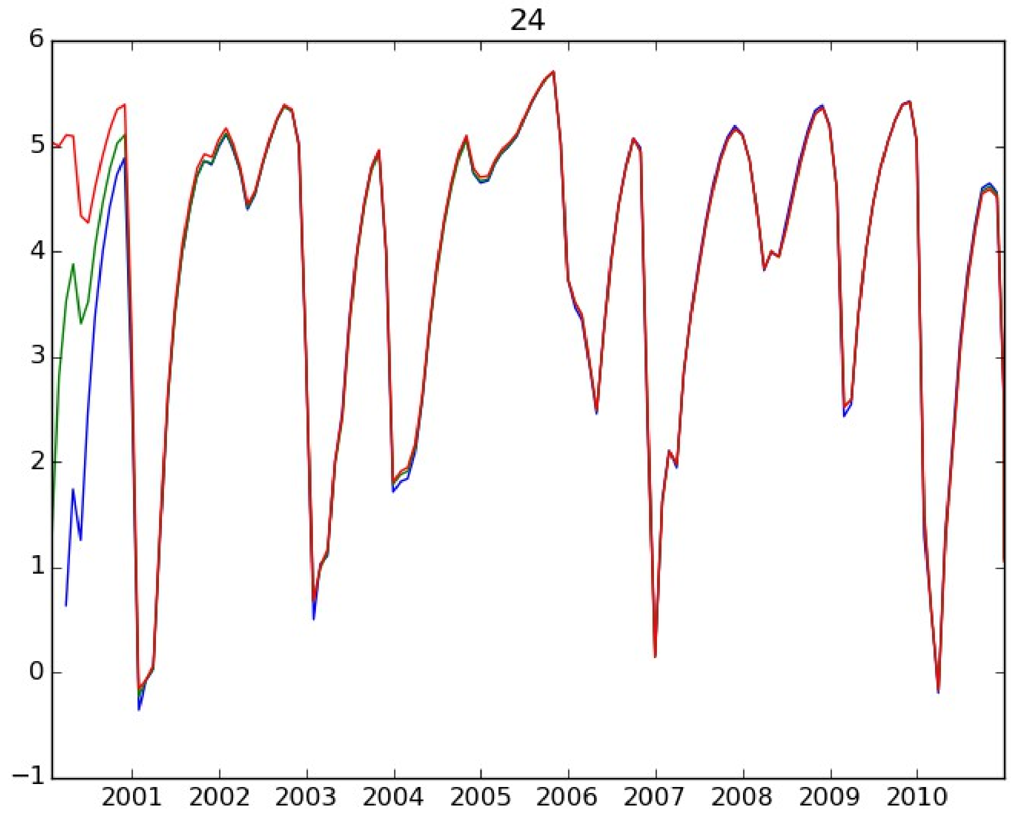
2) Introduce a new WTD coupling variable

Comparison at some grids points of a simulation made at MeteoFrance (blue), and other two at AEMET: with SURFEXv8 "as is" (green) and with a new WTD coupling variable (red). This DOES NOT includes LEAFHYDRO param, just to test the coupling.



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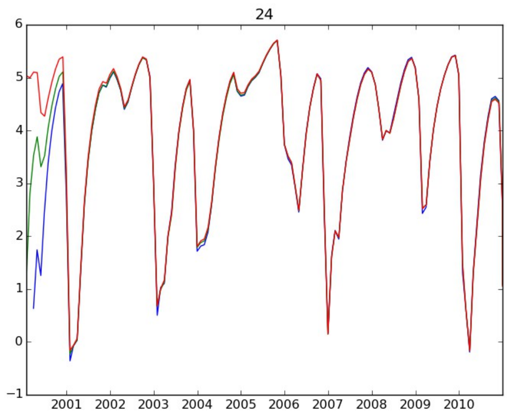
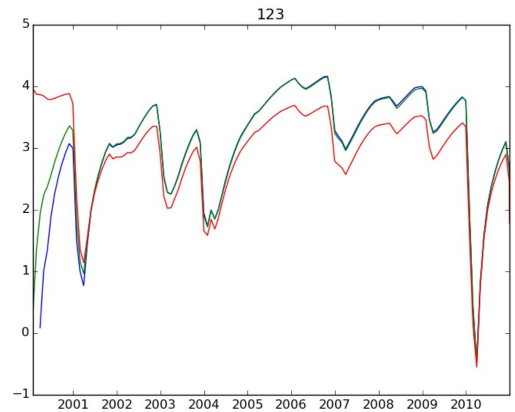
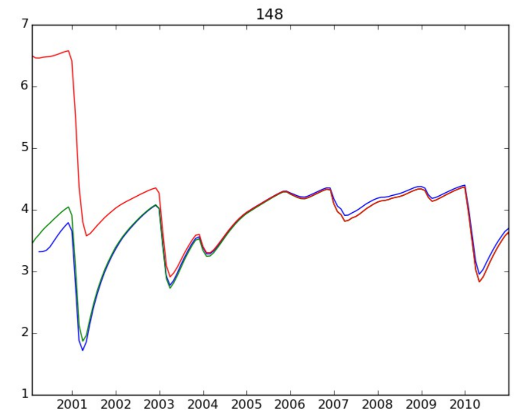
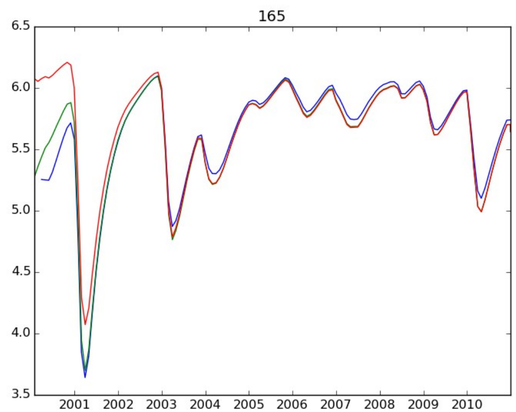
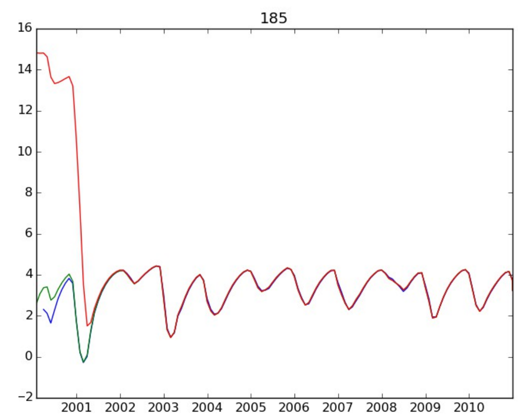






In red is represented the simulation with new coupling variable for WTD. x axis represents time and y axis represents WTD month means (m)





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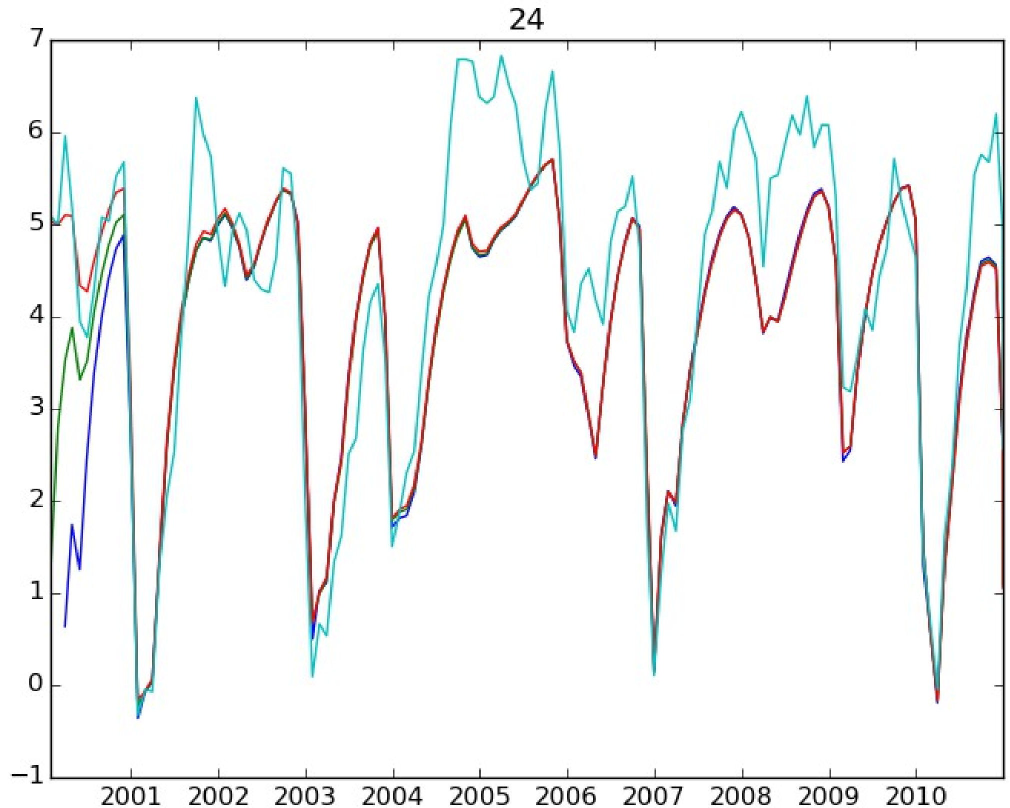
3) Introduce a random sinusoidal perturbation

Comparison at some grids points of a simulation made at MeteoFrance (blue) and other three at AEMET: with SURFEXv8 “as is” (green), with a new WTD coupling variable but not updating it (red), and a random sinusoidal perturbation added to the WTD (light blue).



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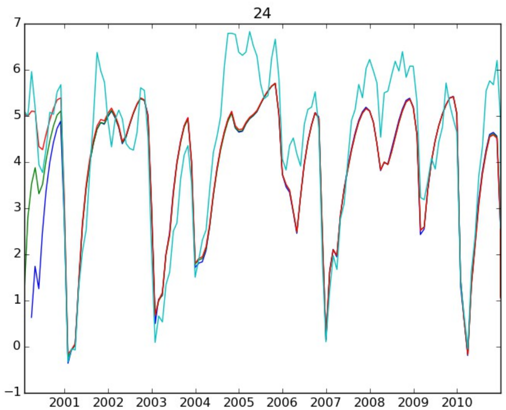
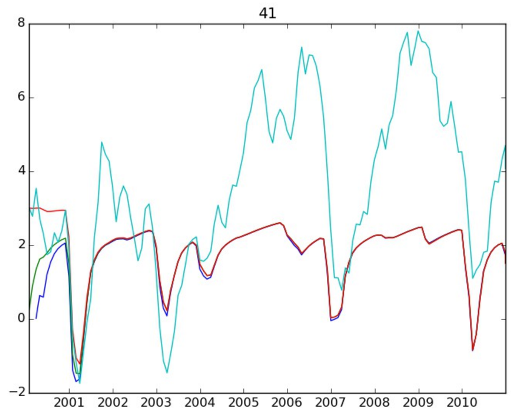
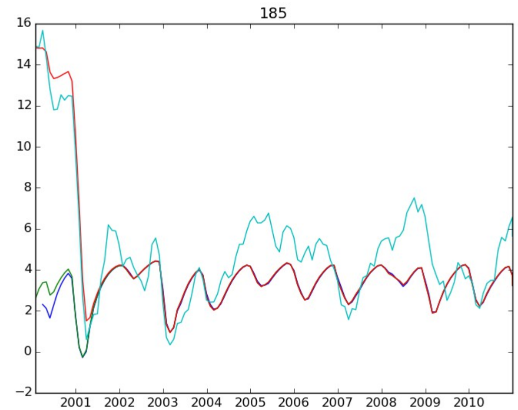
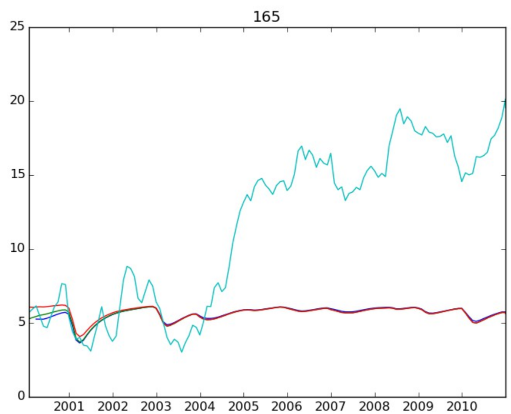
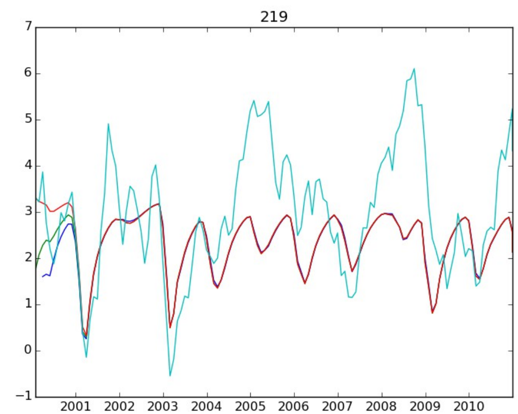






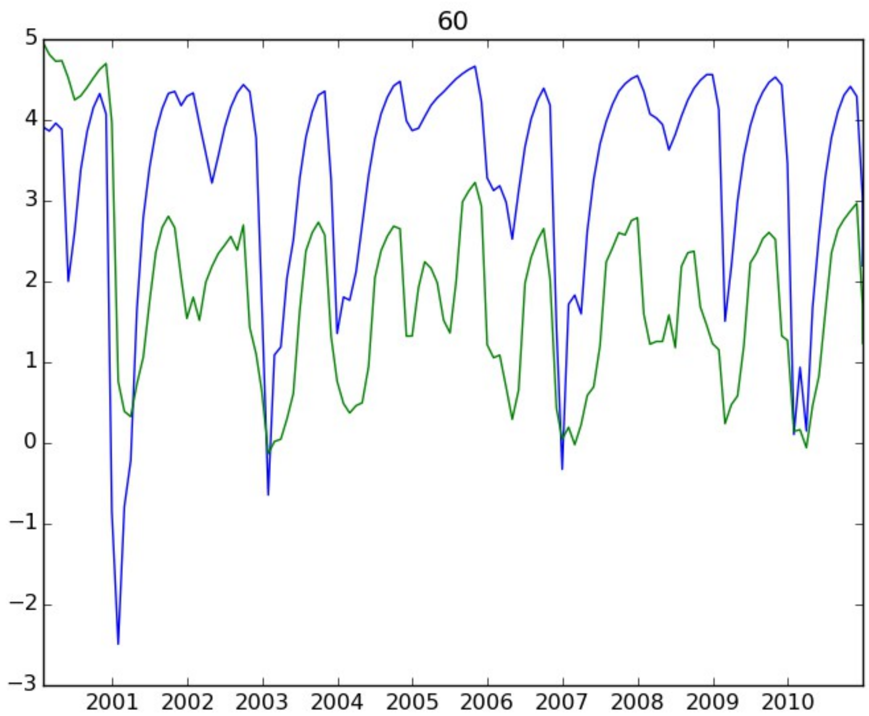
In ligth blue a simulation with a random perturbation added to the WTD. x axis represents time and y axis represent WTD month means (m)

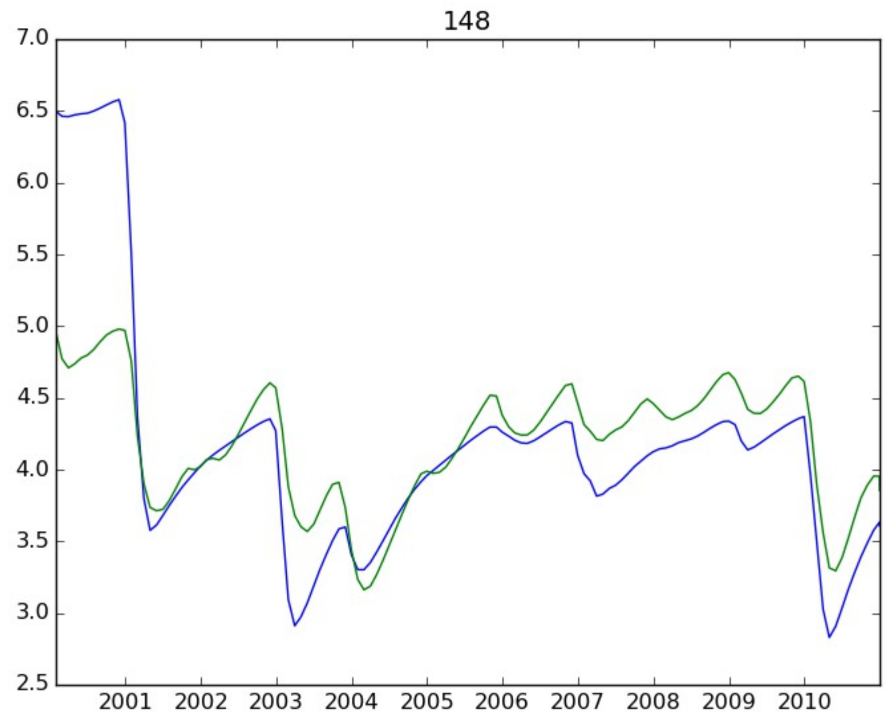




3) Introduce the LEAFHYDRO parametrization

Comparison at some grids points of a simulation with SURFEXv8 with a new WTD coupling variable but not updating it (blue), and another with the LEAFHYDRO parametrization for the WTD (green).





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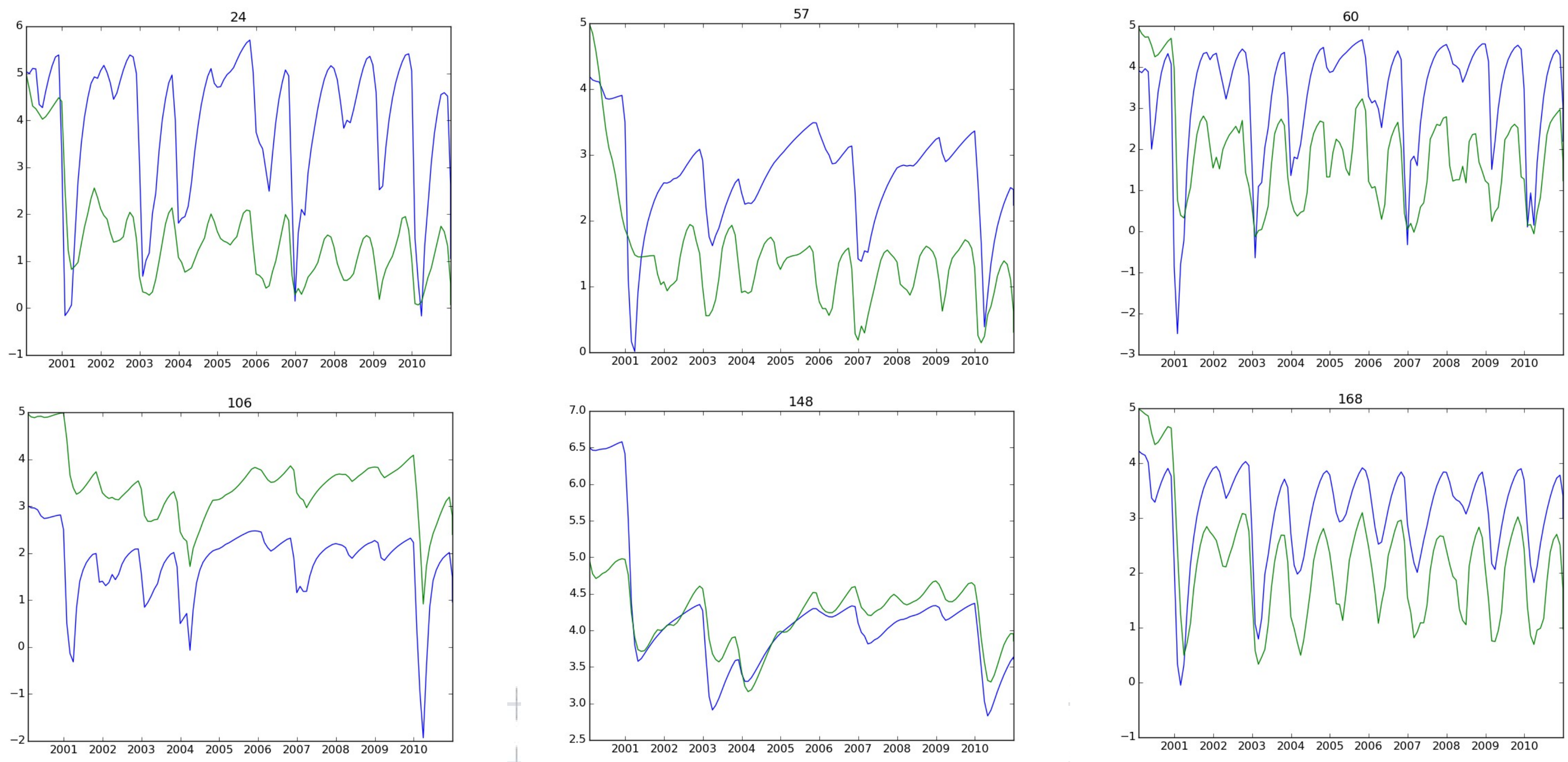
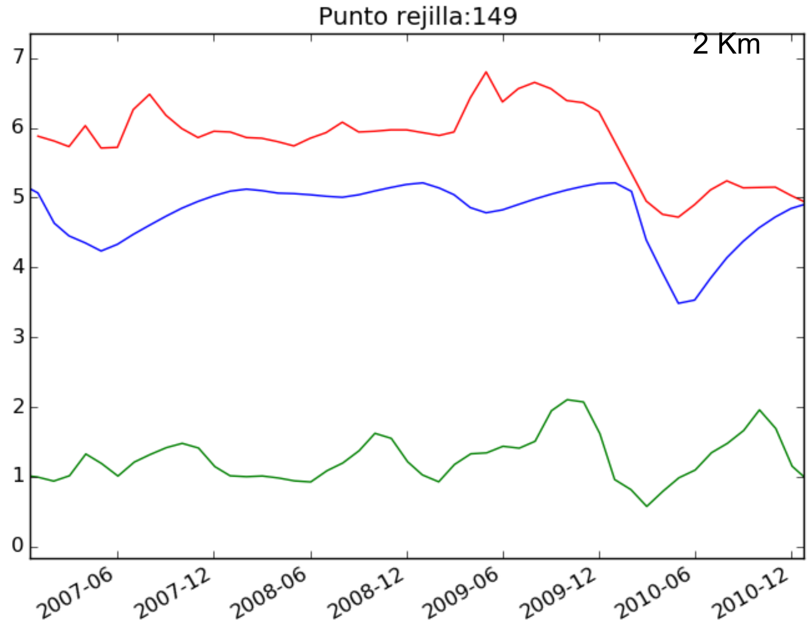
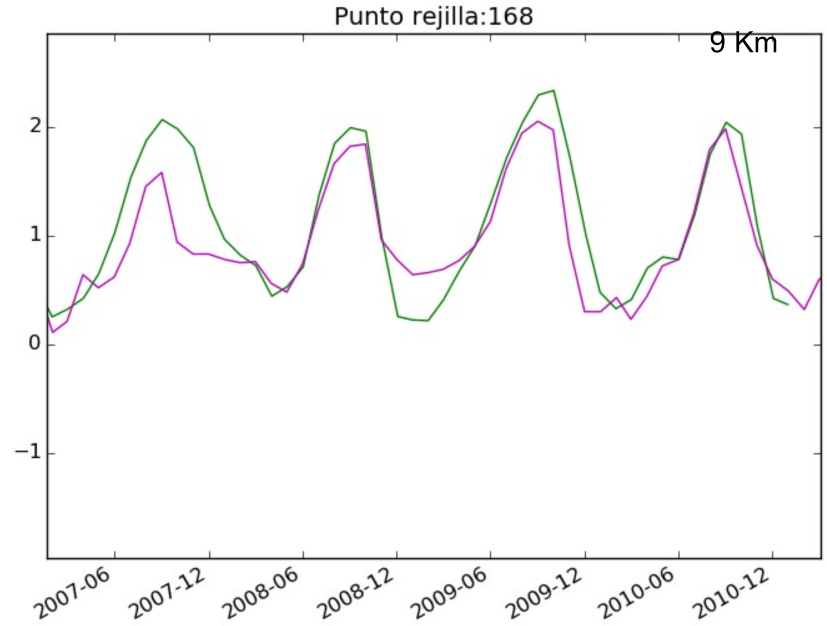


Comparing with observations (I)

Comparison at some grids points of a simulation made at MeteoFrance (blue) with the original SURFEXv8, another with the LEAFHYDRO parametrization for the WTD (green) and piezometer observations in other colours. Only the overlapping period with observations has been represented in every point. The distance between the piezometers and the grid points is represented in every picture





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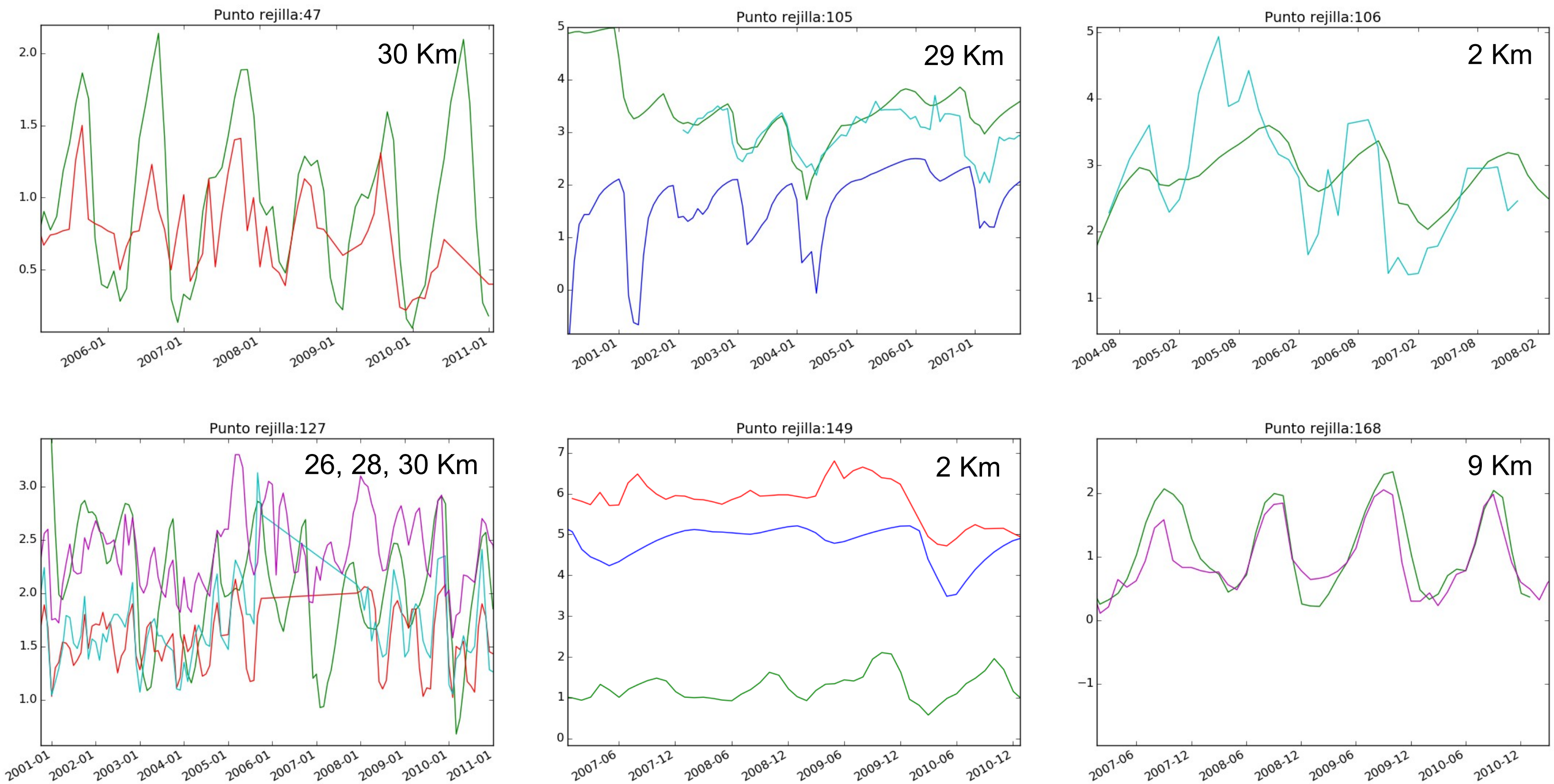

Comparing with observations (II)

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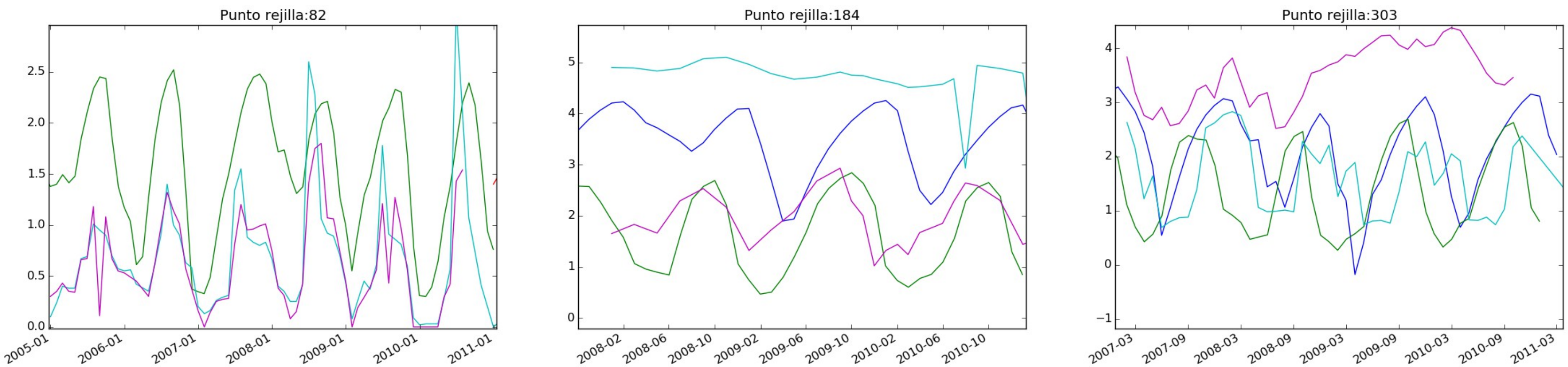

Main differences in parametrizations

SURFEXv8 + LEAFHYDRO

- WT is calculated in all land grid cells.
- Physic model: groundwater reservoir and unsaturated soil are coupled via 2 way fluxes. Fluxes and humidities explicitly calculated.

SURFEXv8 original

- WT is only calculated at aquifer grid cells.
- WG is supposed to be saturated below the WTD, not calculated

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• CONCLUSIONS

- The first results of the LEAFHYDRO parametrization in SURFEX are very promising, realistic, compatible with the observations of WTD and similar to the original SURFEX parametrization.
- The LEAFHYDRO simulated WTD graphs show a more gradual variation than the original SURFEX WTD (less sharp peaks). Also they show more oscillations/resolution but of less amplitude than the original parametrization.
- The LEAFHYDRO parametrization doesn't use the WTD as a boundary condition and is based in physics principles for calculating fluxes and humidities even below the resolved diffusion layers, so the water balance is closed in a more realistic way.
- This parametrization is able to simulate a WTD at every gridpoint with or without aquifer. Also it can run independently from TRIP (i.e. without running TRIP) but in this case there wouldn't be horizontal fluxes and the simulation would be only in the vertical (1D).

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- # NEXT STEPS

- Check surface fluxes to see the model behaviour
- Test combinations of coupling parameters which can affect the simulations, specially coupling times and LAGs of both models
- Find good (unperturbed) observations and compute different scores for WTD and surface fluxes
- Run this parametrization into HARMONIE/CL
- May be... , introduce this new parametrization in next SURFEX versions as a new option for diffusion.

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MERCI BEAUCOUP !!

THANK YOU !!

In any case, the level to which water rises when measured at any given point in a confined aquifer is referred to as the potentiometric (or piezometric) surface. By measuring water levels at many locations in a confined aquifer or aquifer system, a map showing the potentiometric surface can be produced. The potentiometric surface is somewhat of an abstract concept because, in the absence of wells, the overlying confining unit prevents the water level from rising above the top of the aquifer; instead, the aquifer is under pressure. The elevations of the potentiometric surface and water table are typically different at any given point in the landscape because they are related to different bodies of rock or sediment. The water table is almost always higher than the potentiometric surface below major uplands, while the reverse is usually true beneath major lowlands, such as river valleys.
In general, horizontal flow is predominant in most large aquifers, whereas vertical flow is typically greater across thick confining units