Distributed simulation of hydrological processes at the scale of Spain using the SAFRAN-SURFEX-RAPID (SASER) model

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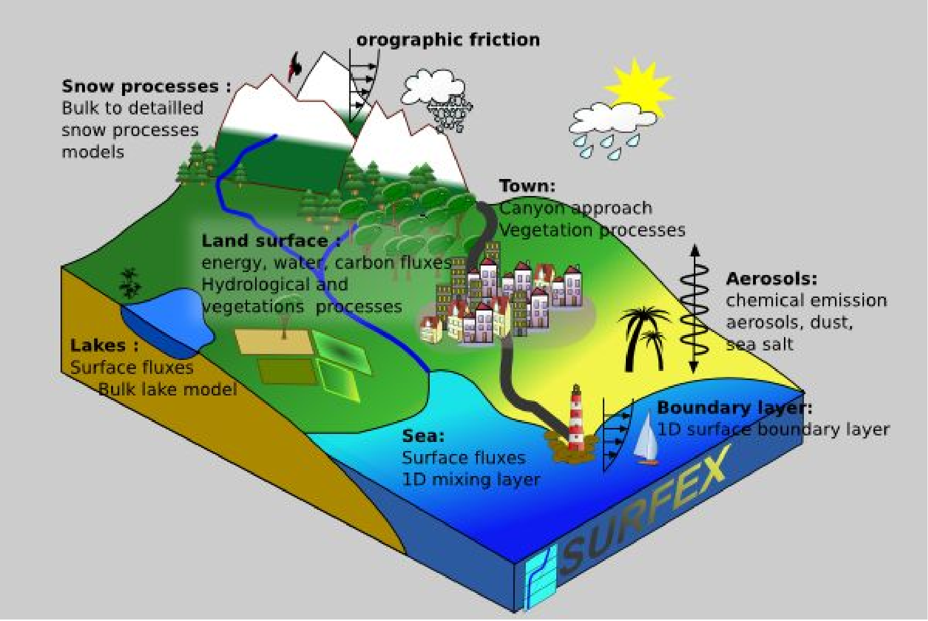
The land surface

- It is where we live!
- Part of the global hydrological, energy and carbon cycles.
- **Continental water cycle.**
  - Many benefits for us.
    - Water resources and energy.
    - Environmental services.
    - Leisure (landscape, sailing in lakes, sky, …)
  - We suffer its extremes.
    - Floods, droughts, etc.
- Lower boundary of the atmosphere.
  - Planetary boundary layer.
  - Energy fluxes.
  - Aerosols.
  - Wind energy.

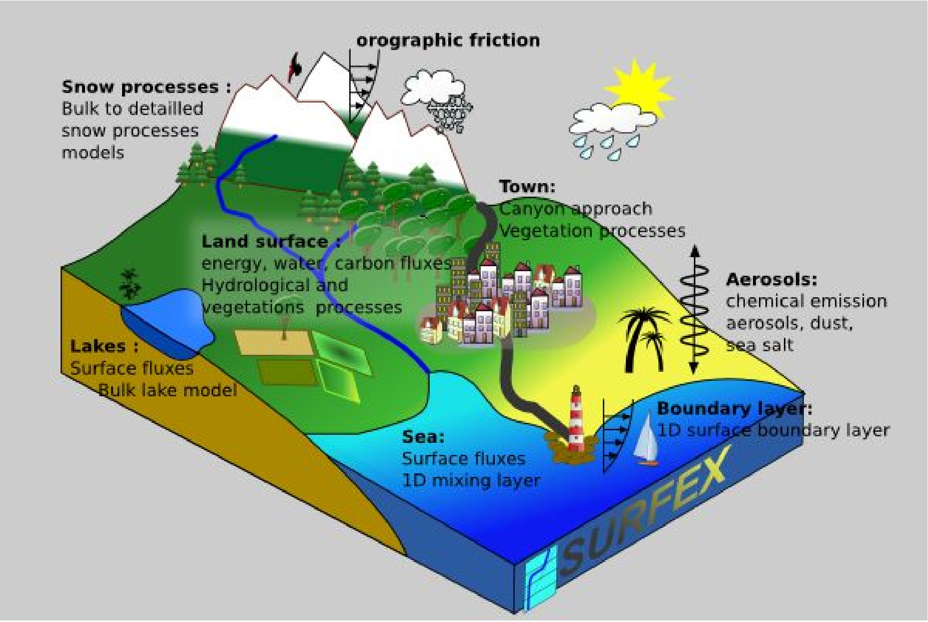


The SURFEX land-surface modeling platform.

- Meteorological and climate models need to correctly simulate the land surface.
- A correct understanding of hydrological processes is key for humankind.

What are land-surface models?

- Designed to simulate the exchange of surface water and energy fluxes at the soil-atmosphere interface.
- Meteorological and climatological models use them to describe the processes at the land surface.
- They can be used as distributed and physically based hydrological models.
- They are complex!
- I would not use them for flood prediction.
- They are good for process understanding, climate change studies, seasonal forecasting, long term reanalysis, data assimilation, etc.

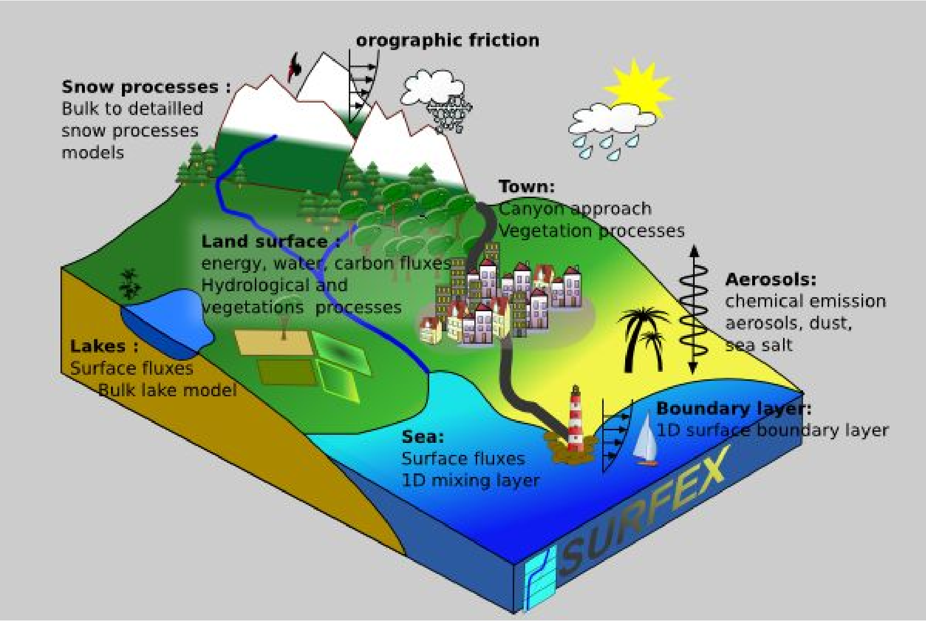


The SURFEX land-surface modeling platform.

Using LSMs, online vs offline simulations

Online

- Coupled to an atmospheric model (meteorological or climate).
  - Hindcast, seasonal forecast, climate scenarios ...
- Feedbacks between land-surface and atmosphere.
  - Heat waves, droughts, intense precipitation events, …
- It inherits the biases of the atmospheric model.



The SURFEX land-surface modeling platform.

Offline

- Forced by a gridded dataset of observations.
- Model improvement with an unbiased forcing, but without feedbacks with the atmosphere.
- Reanalysis, data assimilation, ...
- Future scenarios can be performed by downscaling and bias correcting the outputs of climate simulations.

Ours is an <u>offline</u> approach.
We need a good quality meteorological forcing dataset.

Meteorological forcing dataset

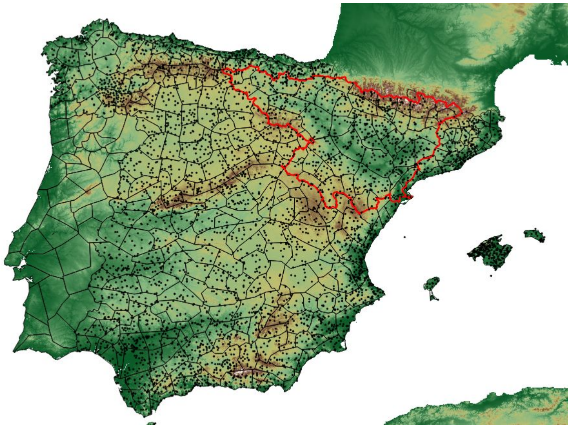
We developed a meteorological forcing dataset.

- Gridded dataset of all necessary screen-level atmospheric variables.

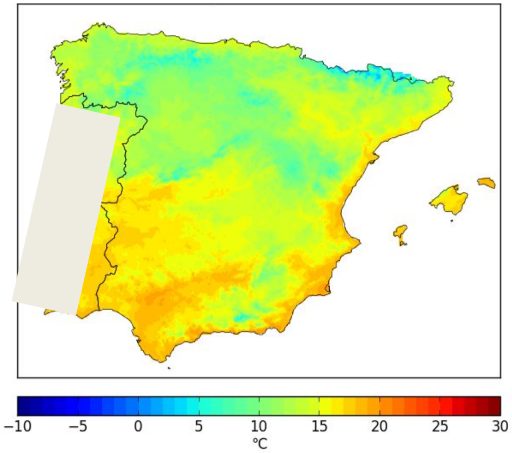
Our product is based on the **SAFRAN** meteorological analysis system (Météo-France)

  - Variables: P, T, W, RH, C.
  - Optimal interpolation method.
- Modelled downward VIS and IR radiation.
- Input:
  - 6h observed data, 24h for P (AEMET).
  - First guess (ERA-Interim).
- Output:
  - 1h time step,
  - 5 km resolution.
- Current dataset:
  - Mainland Spain and Balearic Islands.
  - 1979/80-2013/14.

SAFRAN zones and meteorological stations.



Mean annual temperature



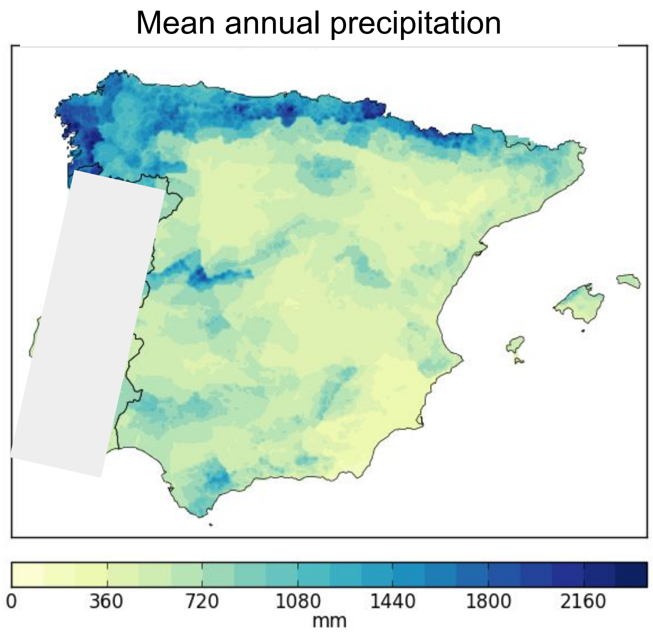
The dataset is available for download at the HyMeX database
http://dx.doi.org/10.14768/MISTRALS-HYMEX.1388

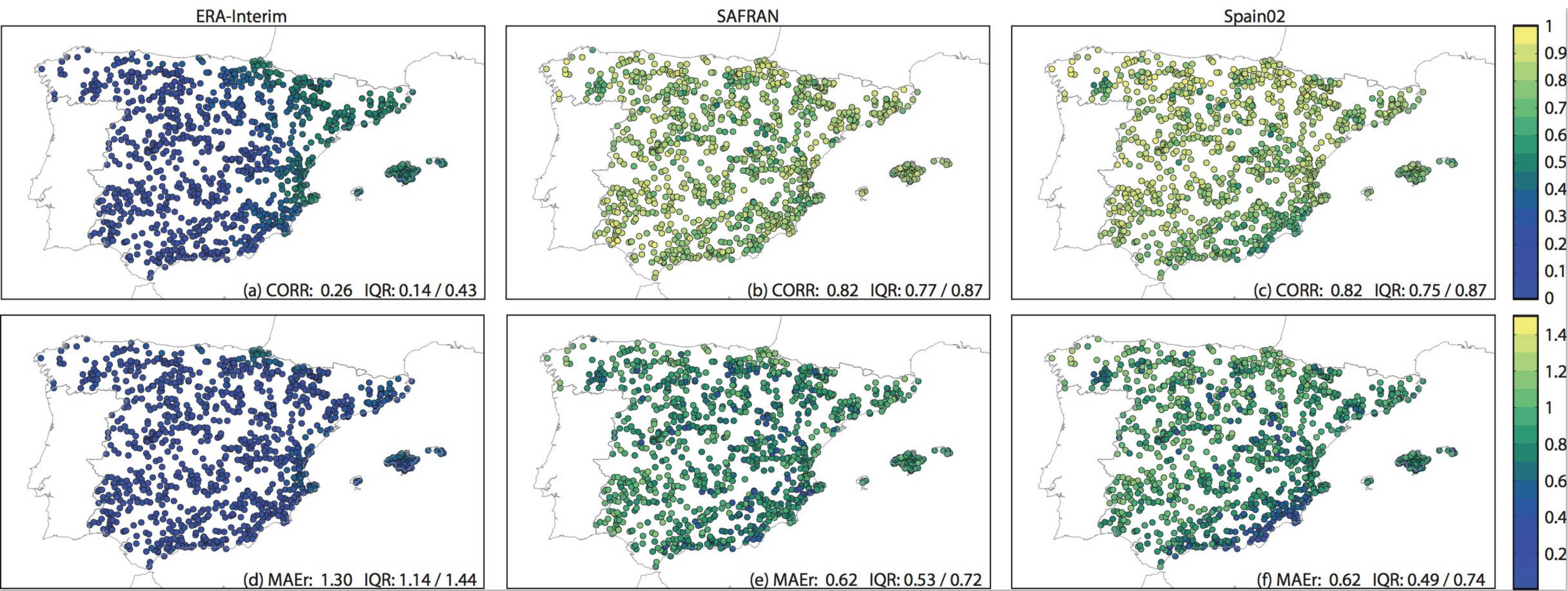
Validation of SAFRAN

Precipitation is the most difficult variable.

SAFRAN's daily precipitation is of good quality, comparable to Spain02 and it is much better than a global low resolution reanalysis.

The figures show, the correlation and the MAEr for each product, at each meteorological station.





SAFRAN precipitation

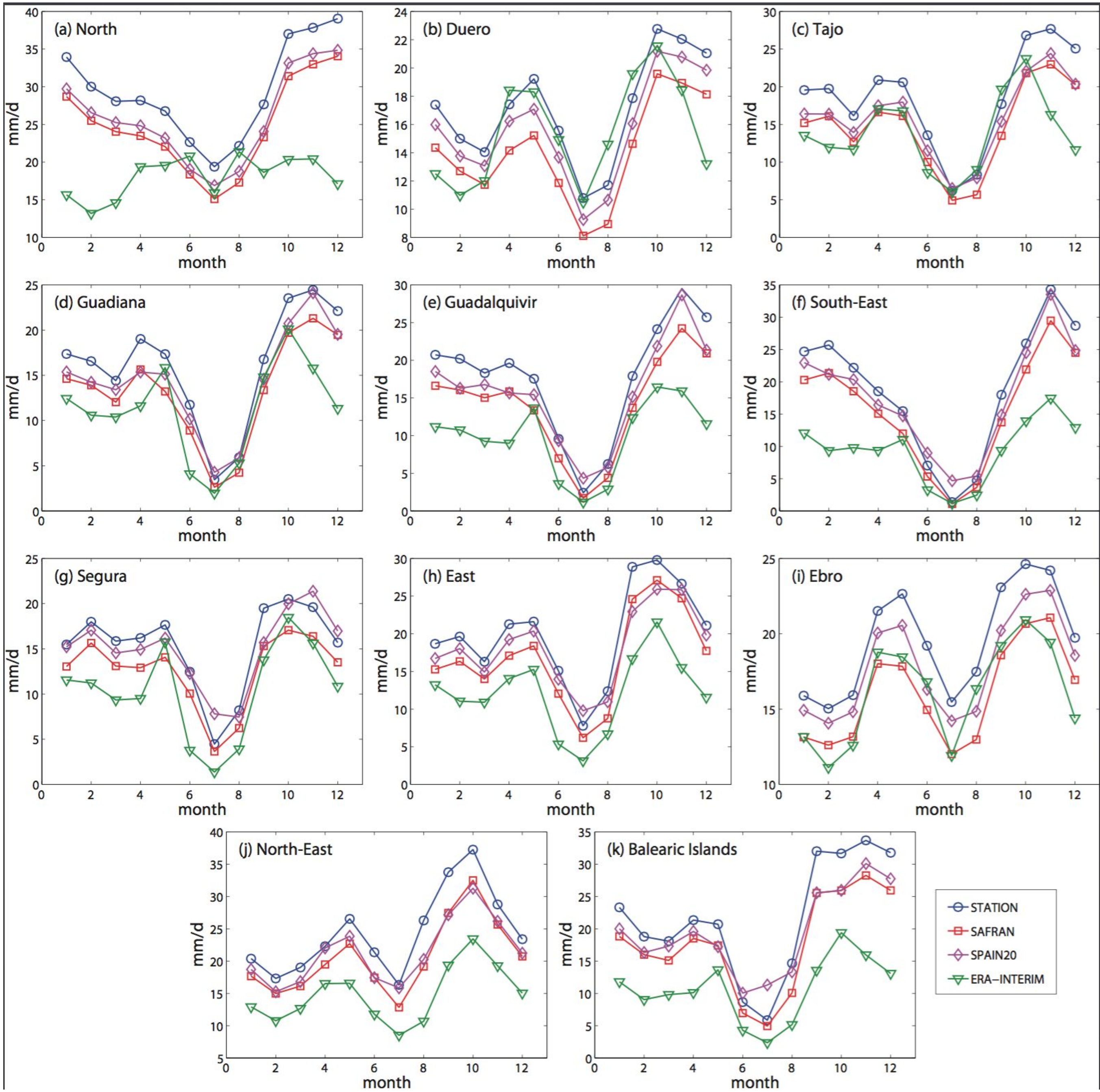
SAFRAN reproduces extreme precipitation quite well, even though it underestimates it a little bit more than Spain02.

Of course, the other variables have also been validated (but not shown in this presentation).

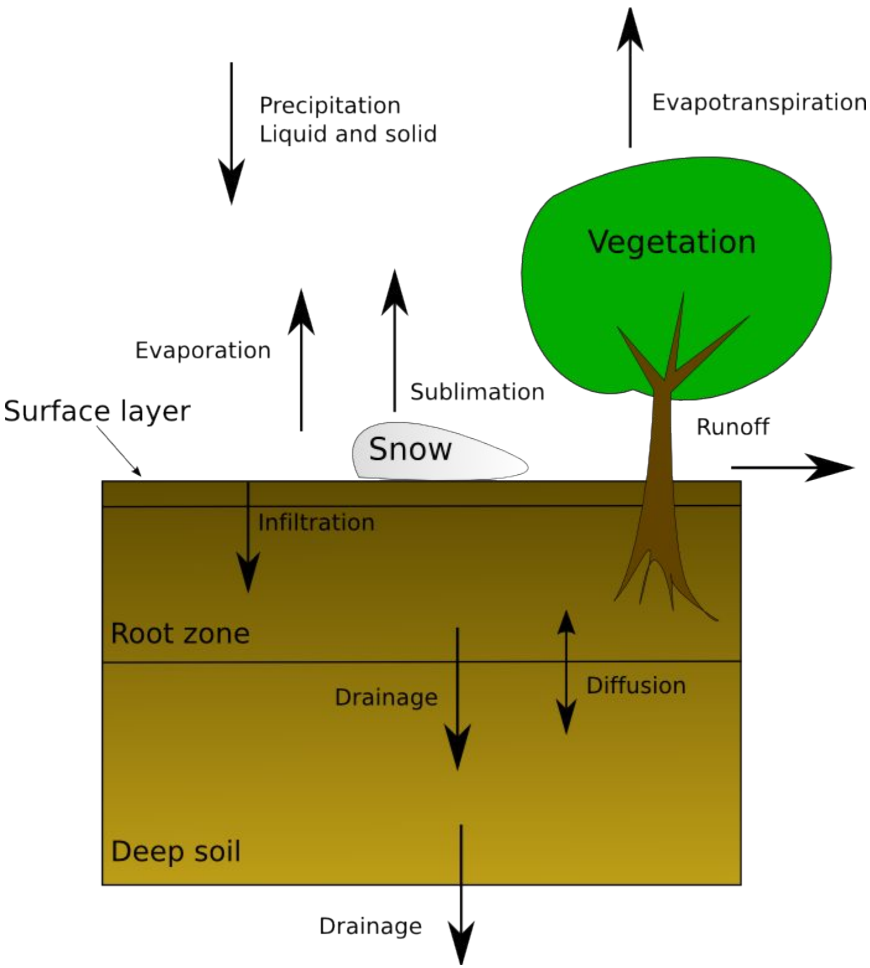
Papers on the Spanish application of SAFRAN:

- Quintana-Seguí et al. (2016a). Journal of Environmental Informatics.
- Quintana-Seguí et al. (2016b). HESS (in review).

Annual cycle of maximum 1-day precipitation (RX1D)



SURFEX land-surface modelling platform



Structure of ISBA-3L

- Developed at Météo-France.
- Used in meteorological and climatological models (not only in MF).
- It has schemes for natural surfaces, cities, lakes, etc.
- ISBA is the scheme for natural surfaces.

ISBA is the central part of our hydrological modeling approach within SASER

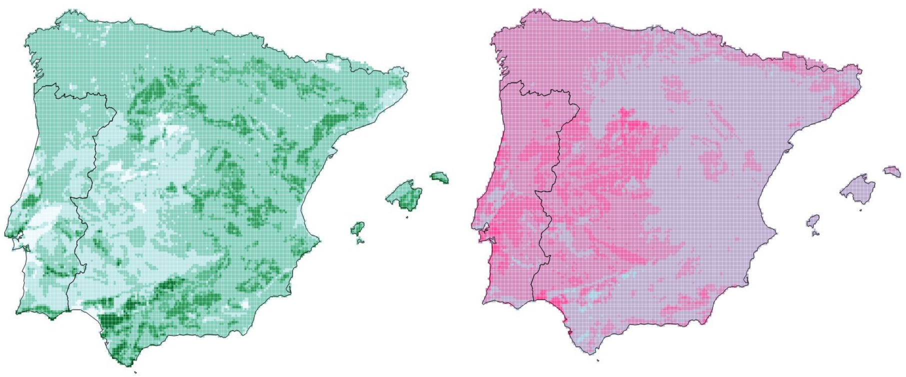
- It describes the vertical processes in the soil column and the vegetation and generates the outflows that will allow us to simulate the river-flow.
- Modular:
  - ISBA-3L, simple three layered description of the soil using a force restore approach.
  - ISBA-DIF, explicit multi-layer approach.
  - ISBA-A-gs, interactive vegetation.
- We run it on a 5 km grid for the whole Iberian Peninsula and the Balearic Islands.
- Limitations:
  - No horizontal transfers of water.
  - No routing.
  - No underground water.

Physiography : ECOCLIMAP database

- SURFEX is fully coupled with the global, 1km resolution, land cover database ECOCLIMAP.
    - Masson et al. (2003), Kaptué et al. (2010), Faroux et al., (2013).
- Based on cover maps and remote sensing data.
- More than 550 cover types all over the world.
- Vegetation variability that depends on location, climate and phenology.

SURFEX derives most of its parameters from the cover types (i.e. proportion of vegetation, root depth, stomatal resistance, etc.) and the soil texture.

Soil texture : % of clay and sand



- Topography (e.g. Gtopo30 at 1 km)
- Soil properties (texture, organic matter) derived from, e.g. FAO (FAO, 2006) or HWSD (Nachtergaele et al., 2012) databases.

Water balance

SURFEX, when forced by SAFRAN, allows us to simulate the water balance.

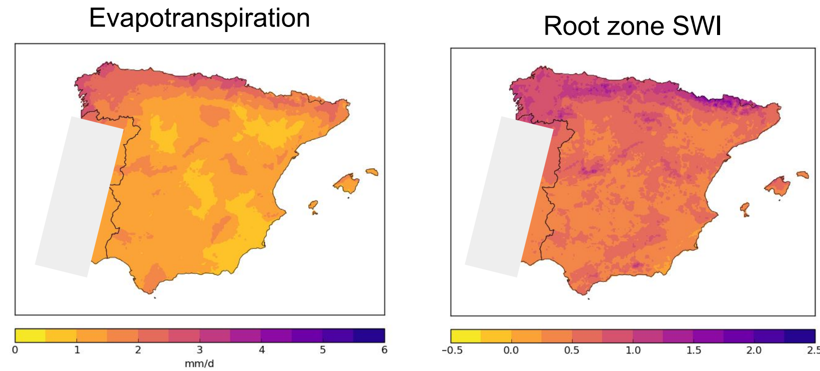
- **Water fluxes**: Evapotranspiration, runoff, and drainage.
- **Water Stocks**: Soil wetness, snow, interception.
- **Energy fluxes**: sensible and latent heat fluxes to the atmosphere.
- **Energy stocks**: energy in the vegetation, the soil, the snow, ...

Current resolution: 5 km.

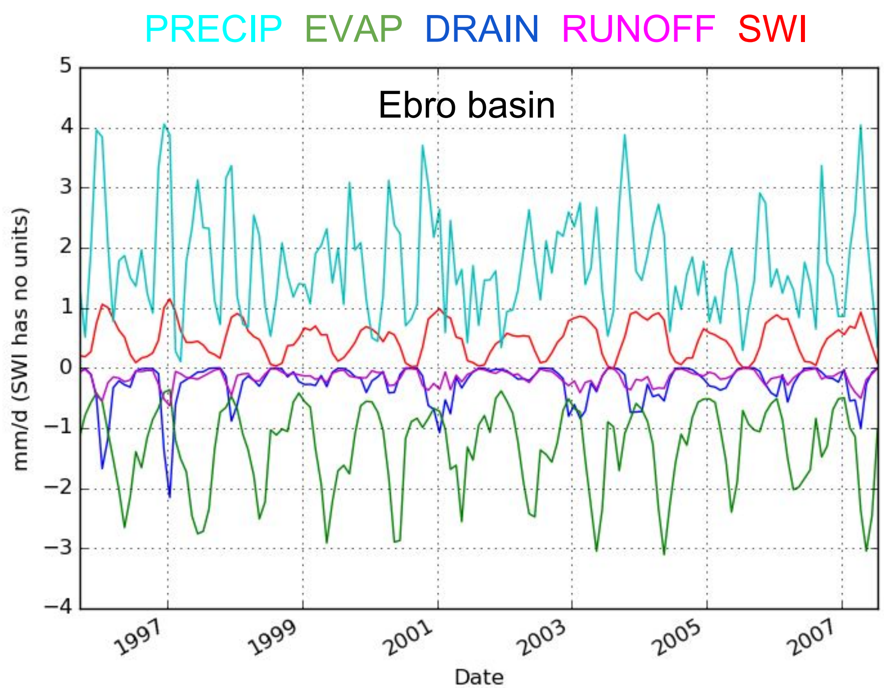
Important limitation: no lateral flows.

Further possibilities:

- Data assimilation (in-situ, remote sensing).
- Land-use change.



Monthly water balance of SURFEX for the Ebro basin



River flow

SURFEX does not simulate river flow. Thus, we need to transport SURFEX's runoff and drainage to the river (currently we do not simulate underground water processes) and then compute the river flow.

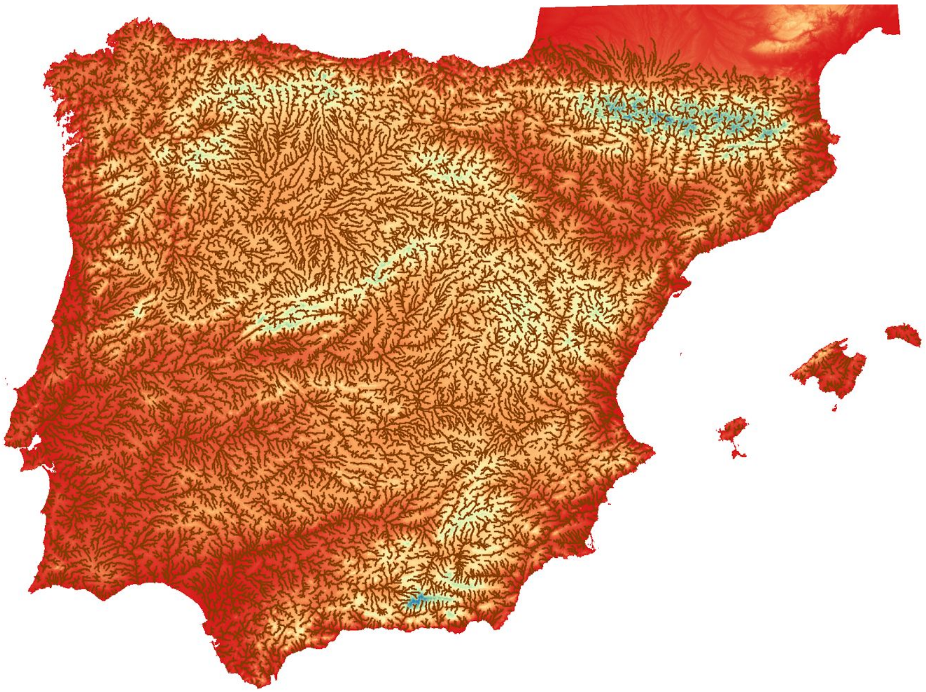
We chose **Eau-dyssée** to perform this task.

Eau-dyssée is a framework for hydrological modeling that allows to easily couple different models. Developed by CNRS (France).

- **ISO**: routes runoff to the river network using isochronal zones.
- **RAPID**: routing scheme
  - Muskingum type model.
  - Flow estimation at any river network point.
  - Parallel computation
  - **Inclusion of anthropic effects (dams)**
- It has other modules we don't currently use for underground water, etc.

Following the same approach as David et al,. 2011 and Habets et al. 2014.

Relief and Hydrosheds's river network.



Hydrography:

Hydrosheds (river network, drainage direction, flow accumulation).

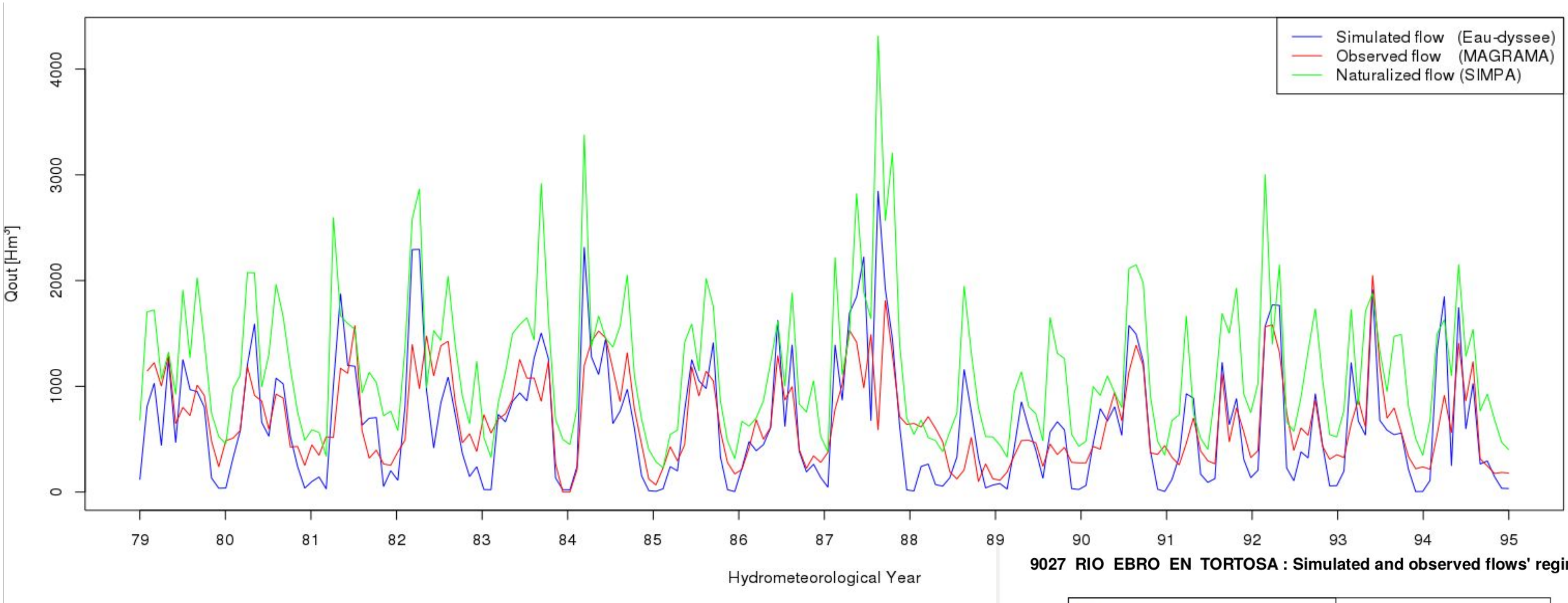
- Hydrosheds is a fine product, but it is not perfect.

SASER

- We call **SASER** the whole SAFRAN-SURFEX-Eaudyssée-RAPID modeling suite.

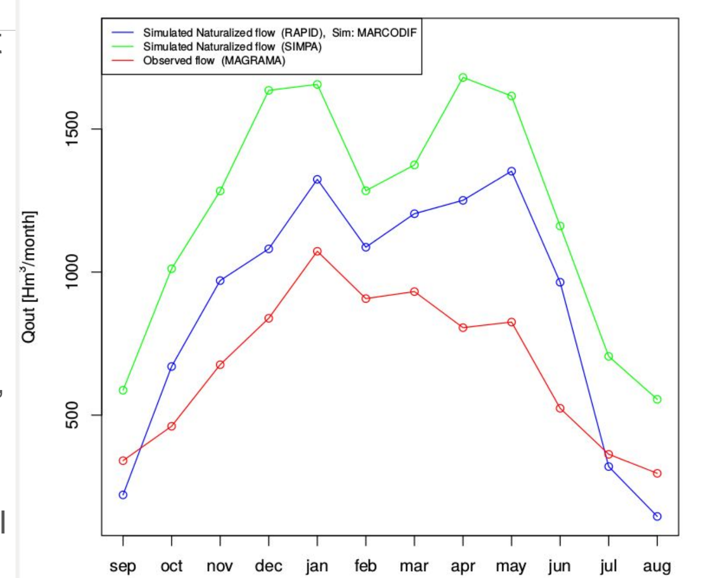
River flow (preliminary results)

Ebro at Tortosa (outlet): Simulated, Naturalized, and Observed monthly flows



- The model simulates natural flow (dams and irrigation are not simulated)
- **No calibrations or optimizations where applied at all.**
  - Most parameters depend on the physiography.
  - Those that are calibrated, use default values.
  - This is the approach climate models use!
- Next steps:
  - Full validation of the model (snow processes, evapotranspiration, soil wetness, etc.).
  - Detection of structural problems (alluvial aquifers, …).
  - Improvement of calibrated parameters (when justified by physical reasoning).

9027 RIO EBRO EN TORTOSA : Simulated and observed flows' regime



Water resources
and anthropic processes

Water management severely impacts the hydrology of Spanish river basins.

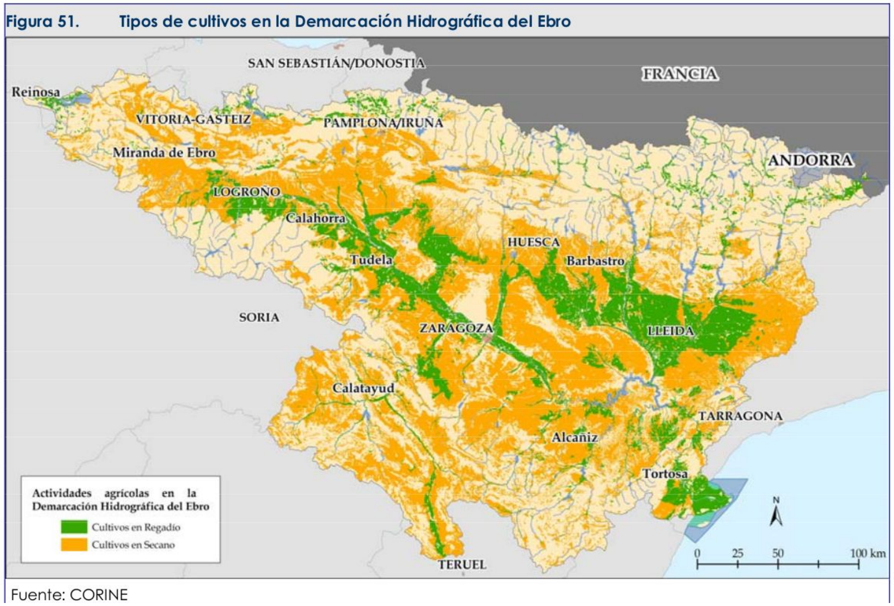
- Stockage of water during the wet season, to be used during the dry season.
- Transport of water from the runoff generating areas to the irrigation areas.
- Underground water.

Modelers need to tackle this issues.

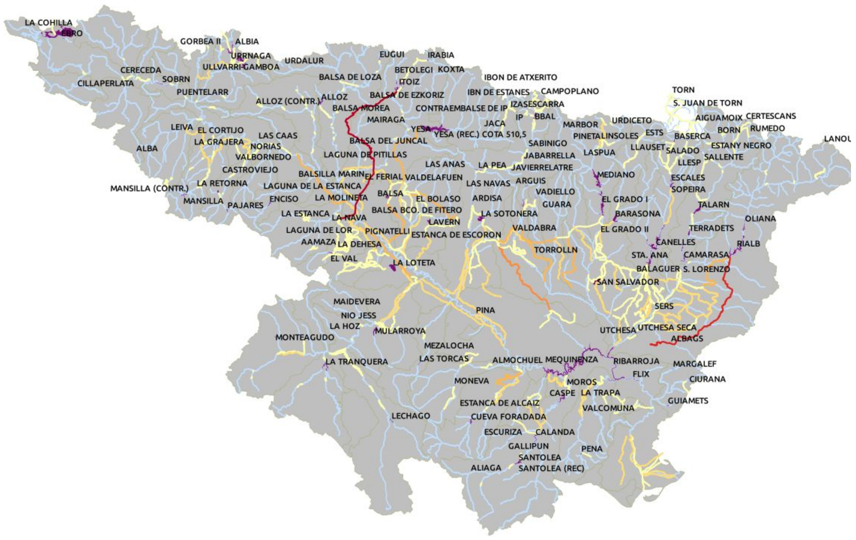
- Humans are part of the system.
- Feedbacks between the human and natural components.
- Adaptation to climate change.
- Ecological river-flows.

This is something we plan to introduce during the next years:

- With SURFEX it is possible to tackle the irrigation.
- With RAPID it is possible to simulate dams.



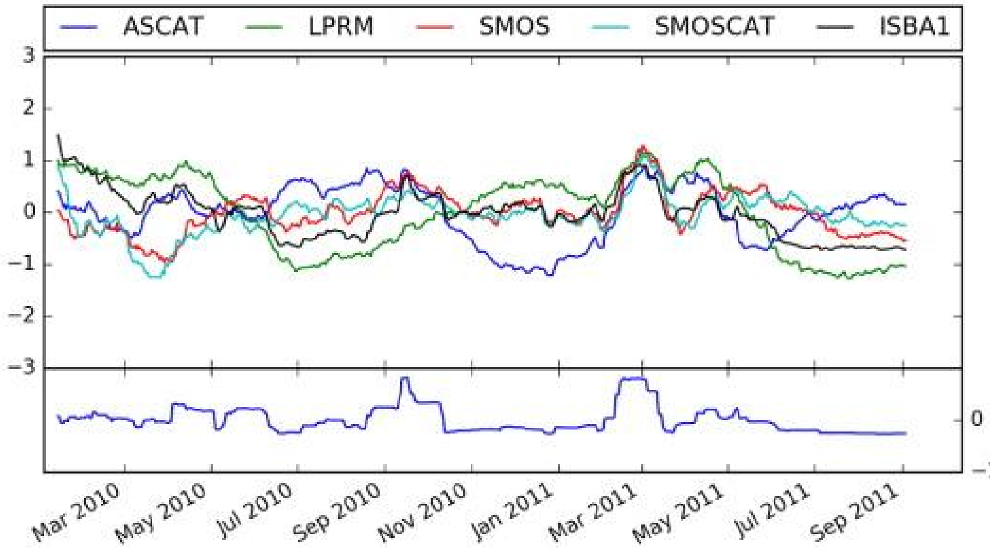
Irrigated areas within the Ebro river basin (source CHE).



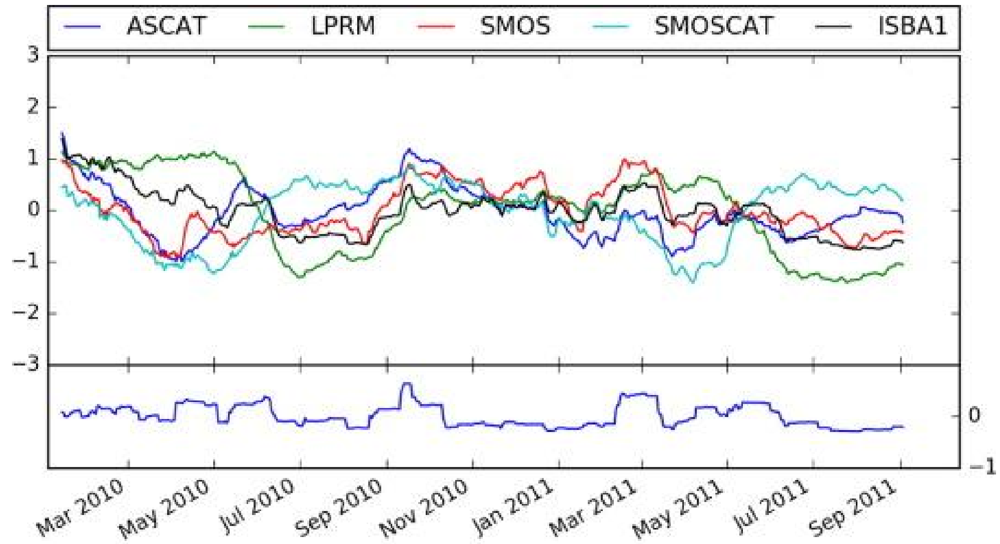
Dams and canals in the Ebro basin (data source CHE).

Synergies with remote sensing

- We have compared the simulated surface soil moisture with remotely sensed datasets.
- These comparisons allow us to learn about the behaviour of the different products, finding their strengths and weaknesses.
- This also allows us to check if the model and data are coherent before a (future) assimilation.



Temporal series of soil moisture z-values over a **dryland pixel** (Baix Ebre) using a 30-days window average.



Temporal series of ASCAT, AMSR-E, SMOS, SMOScat and SURFEX zvalues over an **irrigated pixel** in Urgell using a 30-days window average.

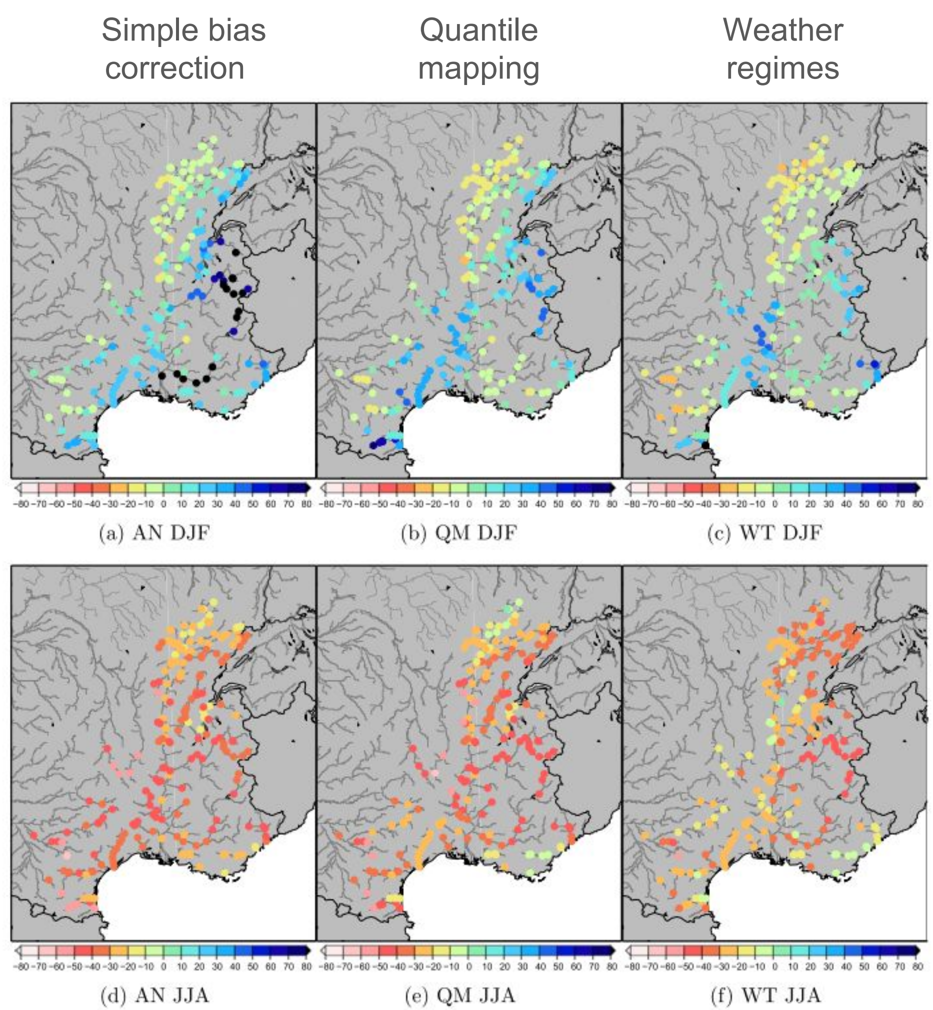
Escorihuela and Quintana-Seguí, Comparison of remote sensing and simulated soil moisture datasets in Mediterranean landscapes, Remote Sensing of Environment, Volume 180, 2016, 99–114, http://dx.doi.org/10.1016/j.rse.2016.02.046

Impacts of climate change

Discharge anomalies in winter (first row) and summer (second row) for the mid 21st century calculated using three different downscaling techniques (Quintana-Seguí et al.; 2010).

- Our tool is appropriate to study the impacts of climate change.
- The model is physically based (few calibrated parameters) →physics doesn't change with climate.
  - Of course it is more complex (our model has prescribed vegetation, etc.)
- SAFRAN can be used as training dataset for statistical downscaling of climate simulations.

The right hand figures show a study performed using the French SIM model, which uses the same philosophy as SASER.



Conclusions and future perspectives

- SASER is a new tool which allows to study the hydrological cycle at the scale of Spain.
- Physical approach (LSM).
  - This approach complements other methodologies used by the scientific community in Spain.
- This approach has interesting benefits.
  - Process understanding.
  - What-if scenarios.
  - Climate scenarios.
- We now have a v0 of the model.
- Next steps.
  - Extensive validation.
  - Structural improvements.
  - Some calibration (limited).
- Anthropization.
  - Dams and canals.
  - Irrigation.
  - Ecological river-flows.
- Understanding drought processes.
- Impacts of climate change.

This work is a contribution to the FP7 eartH2Observe project, to the *Plan Estatal* MARCO project and to the HyMeX program.

Thank You!

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Bibliography