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Report for Deliverable 4.8 (D4.8): CTRIP evaluation from UERRA WP4

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Abstract

The goal of the deliverable is to describe the use of the CTRIP river routing model as an evaluation tool for the UERRA reanalysis, a complex system composed of a 3D-VAR atmospheric analysis, a surface analysis for 2-meter air temperature and relative humidity and a 24-hour precipitation analysis. The upper air and surface analysed fields are used as input for the SURFEX land surface model, which aims to simulate the energy and water balances over the reanalysis domain. In particular, SURFEX will compute the surface runoff, soil infiltration and evapotranspiration. The CTRIP model coupled to SURFEX will route surface runoff into the river network and soil infiltration into groundwater towards aquifers and compute the time evolution of the water table height and the river discharge for the main rivers. The knowledge of the partitioning between total precipitation, surface runoff, infiltration to the water table and evapotranspiration is used in combination to the modelled discharge evolution to discuss of the model behaviour. The direct comparison of river discharges to long-term measurements is used to evaluate the SURFEX-CTRIP model performances and to assess the model deficiencies in some particular conditions like for instance melting periods or low flow seasons.

Section 1: Introduction

River discharge are highly dependent on precipitation, which is spatially and temporally inhomogeneous, particularly in mountainous areas. Partitioning of total precipitation into solid and liquid precipitation and furthermore of rainfall reaching ground into surface runoff and infiltration are key issues to address the ability of hydrological models to accurately represent river discharges. For more than 20 years, CNRM has developed a modelling strategy to evaluate numerical simulations using independent data like river discharges. Such an approach is based on the coupling between land surface and hydrological models, where no calibration is required, neither for the land surface model or the hydrological one. Using a land surface model enables a physically-based representation of the processes involved in the exchanges between vegetated areas, snow, soils and the atmosphere. The Interaction Surface Biosphere Atmosphere (ISBA) model (Noilhan and Planton, 1989) is used within the SURFEX modelling platform (Masson et al., 2013) to represent such processes, in particular water transfers between atmosphere, surface and soil, and accounting for plant evapotranspiration, snow melting and sublimation, surface runoff and soil infiltration. The computation of the soil water storage defines whether enough water is available to infiltrate below the plant roots and contribute to the groundwater supply.

Using such a coupled approach between land surface and hydrological models helps understanding the water flow from the atmosphere to the groundwater and can be used to assess the ability of the land surface model to correctly partition water between runoff, infiltration, evapotranspiration and storage, in other words to validate the energy and water budgets.

In this report, the hydrological model CTRIP (Decharme et al., 2012) has been designed over the pan-European domain. CTRIP stands for CNRM-TRIP and is an update of the original TRIP model (Oki and Sud, 1998) where coupling to the soil has been implemented and flooding accounted for. The method of applying the hydrological model system CTRIP is developed and used for evaluation of the UERRA regional reanalysis products.

Section 2 presents the surface and hydrological models involved, as well as the atmospheric forcing used by the off-line simulations and the measurements used for the evaluation of the system. In section 3, the main results in terms of hydrology are presented, but also the different components of the water balance at the basin scale for several European catchment areas. Finally, section 4 discusses the approach, the results and draw some conclusions.

Section 2: Models, Data, and Methods

2.1 Models

2.1.1 The CTRIP model

The original TRIP river routing model was developed by Oki and Sud (1998) at the University of Tokyo. It was first used at Meteo-France to convert the simulated runoff into river discharge using a global river channel network at 1° resolution. In the new ISBA-TRIP continental hydrologic system (Decharme et al., 2012), TRIP takes into account a simple groundwater reservoir which can be seen as a simple soil–water storage and a variable stream flow velocity computed via the Manning's formula.

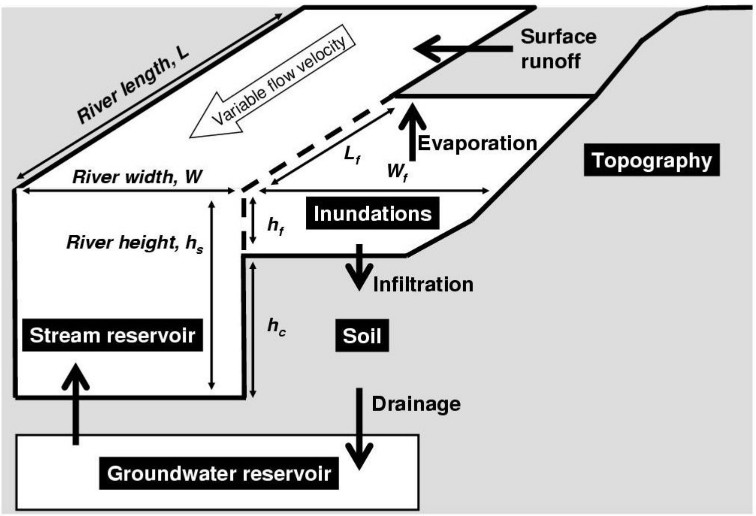


Figure 1: Principle of CTRIP (from Decharme et al., 2012).

2.1.2 The SURFEX model

SURFEX is an externalized land and ocean surface platform that describes the surface processes and simulates surface fluxes and their evolution for four types of surfaces: nature, town, inland water and ocean. It is mostly based on pre-existing, well-validated scientific models that are continuously improved. The motivation for the building of SURFEX is to use strictly identical scientific models in a high range of applications in order to mutualise the research and development efforts.

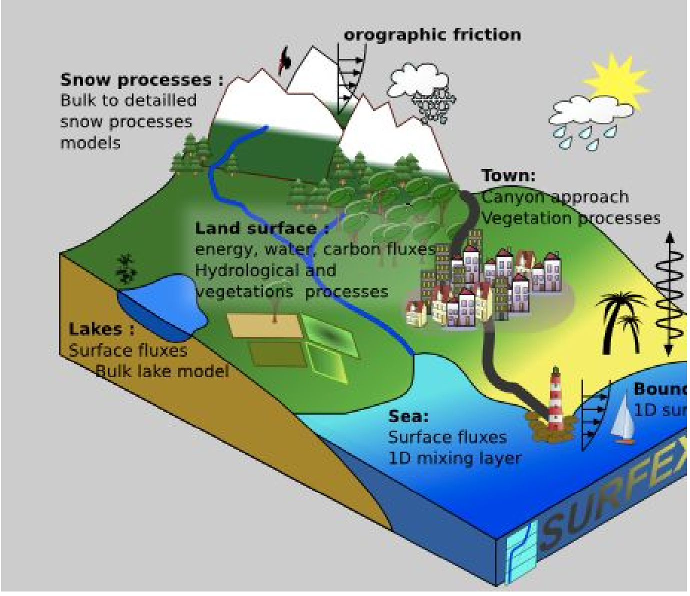


Figure 2: Schematic of SURFEX (from Masson et al., 2013).

In UERRA the land surface model ISBA of SURFEX is used to represent the processes that govern exchanges between the atmosphere the surface and the soil. In particular SURFEX will redistribute total precipitation into surface runoff, soil infiltration and evapotranspiration. Transfers of heat and water in the soil like in the snow use a diffusive approach. The soil is discretized into 14 layers whereas 12 layers are used to represent the snowpack.

2.1.3 Coupling CTRIP and SURFEX

The grid used for the upper air and surface reanalysis is based on a Lambert II conformal projection, and the horizontal resolution is 5.5km. Originally developed for climate applications, CTRIP model has been designed on a regular latitude-longitude grid at a 0.5° resolution. Surface runoff and deep drainage (infiltration) calculated by SURFEX flow respectively in the river and the deep reservoir. The river has a rectangular shape which simulates a water height and velocity. Flooding occurs when the water level exceeds the riverbed height. The size of the inundated reservoir is then calculated using a subgrid topography and the water that participates to flooding can re-evaporate or infiltrate into the ground. The coupling between CTRIP and SURFEX is done every 3 hours, whereas SURFEX time step is 10 minutes. Both models are coupled via the OASIS coupler developed by CERFACS, a French research organism in France. OASIS is part of SURFEX and allows to couple models that are defined on different grids and/or projections.

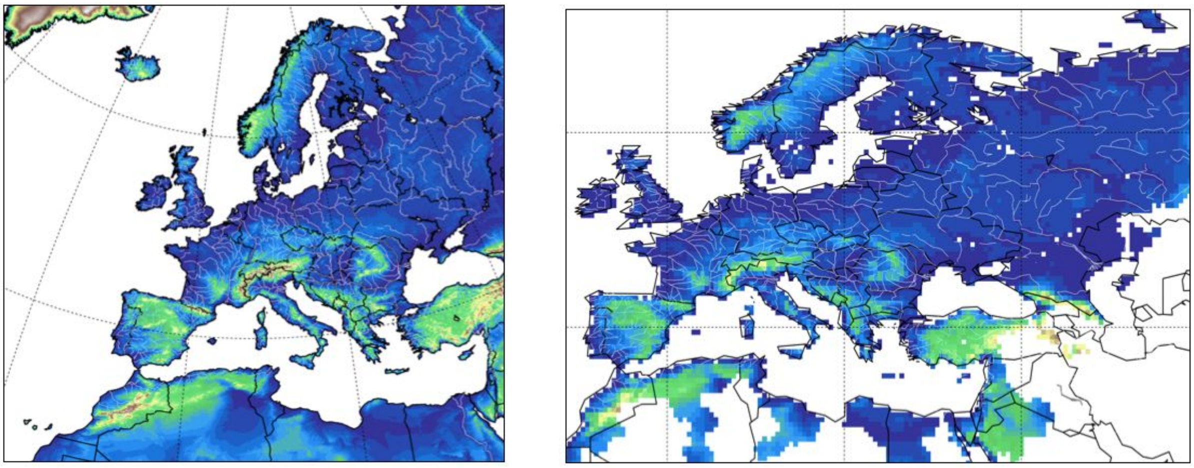


Figure 3: Grid, topography and river network used (i) by the 3D-VAR or MESCAN analysis and (ii) by the CTRIP model.

2.2 Data

2.2.1 Forcing data

Upper air variables from 3D-VAR analysis are downscaled from 11km to 5.5km. These are 6-hourly solar and infrared radiations, total precipitation, wind speed, surface pressure, 2m temperature (T2M) and relative humidity (RH2M). Downscaled T2M, RH2M are used as first guess in the MESCAN surface analysis of temperature and humidity. Downscaled precipitation is accumulated daily and used as guess for another MESCAN analysis dedicated to precipitation. 6-hourly rain and snow rates are deduced from the 24h precipitation analysis. All these data can then be used as input to drive SURFEX-CTRIP simulations. The annual total precipitation averaged for the 1961-2010 period is shown in Figure 5 as example.

2.2.2 Discharge measurements

River discharge measurements are extracted from the Global Runoff Data Centre (GRDC). Among the more than 20000 available observations, a subset of 117 stations is used corresponding to those that are simulated by the CTRIP model at 0.5° resolution and that have continuous measurements for comparisons. Measurements are available over a time window covering that of the reanalysis, but however limited to 2010. Figure 4 shows the location of the GRDC stations, which discharge can be simulated by CTRIP. Although the density of gauging stations looks rather sparse, centre Europe is well documented, and some large rivers like the Danube river are modelled.

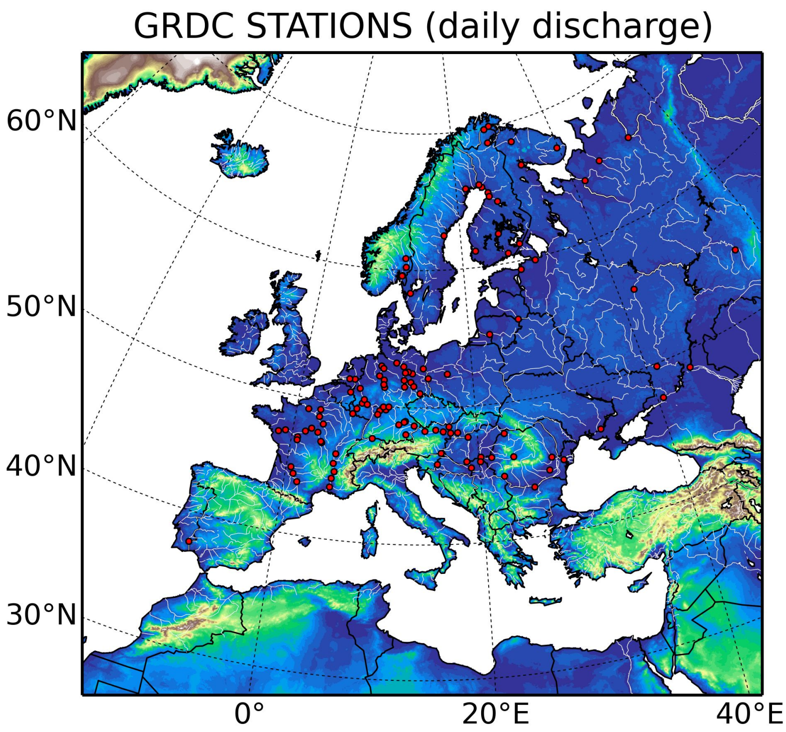


Figure 4: Localisation of gauges stations over Europe.

2.3 Methods

The upper air and surface reanalysis variables covering the period 1961 to 2010 were used to drive SURFEX off-line (i.e. without feedback to the atmosphere) simulations. Two types of simulations using MESCAN-SURFEX-TRIP were run. The first one consisted in using the 50-yr 6-hourly data produced by the reanalysis as input to SURFEX-TRIP and the second one in running off-line simulations driven by the 8 members ensemble MESCAN-SURFEX-ENS data, these latter covering the period 2006-2010.

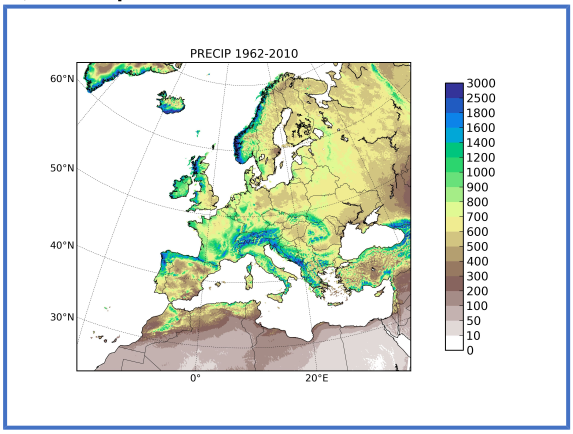
Using a 6-hourly solar radiation interpolated linearly is not suitable to accurately represent the diurnal cycle in SURFEX. Indeed, a linear interpolation leads to a large underestimation of the downwards solar radiation, that can reach more than 25% in some areas. To avoid such energy loss at the surface, the time interpolation was improved in SURFEX and considered the solar energy rate as constant over the 6 previous hours and combined this information with the solar zenith angle. Even if not fully conservative, this method has shown that the underestimation was removed and the diurnal cycle largely improved.

Section 3: Results

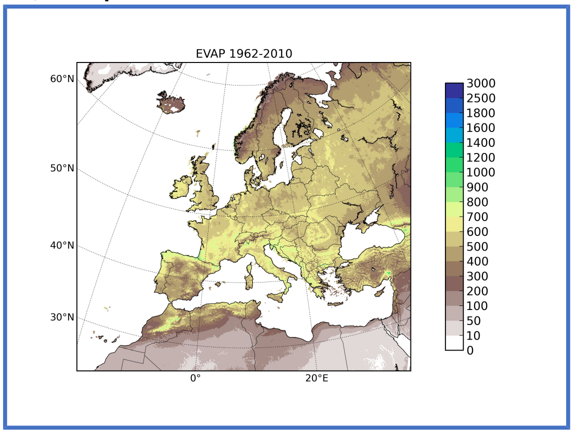
3.1 Water budgets

Water budget is the first component to look at to analyse the partitioning of precipitation into surface runoff, infiltration and evaporation. Soil moisture content is then the residual of this balance. A climatology over 1961-2010 was realised for these fields and is shown in Figure 5.

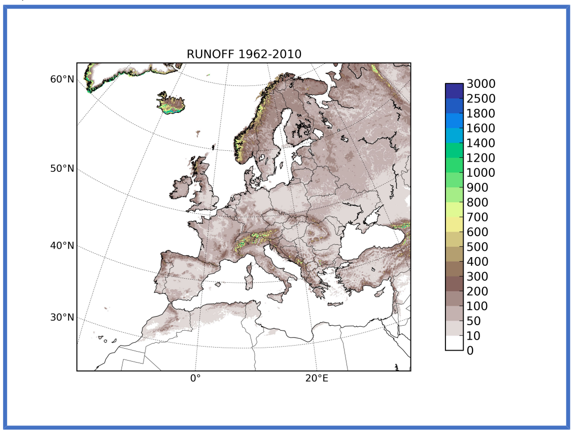
a) Precipitation



b) Evaporation



c) Surface runoff



d) Soil infiltration

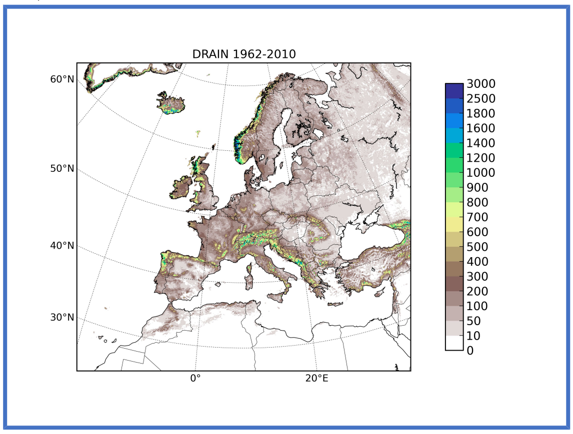


Figure 5: Averaged annual total a) precipitation, b) evaporation, c) surface runoff, and d) soil infiltration.

3.2 Evaluation of discharges

3.2.1 Reanalysis 1961-2010

Figure 6 shows the Nash-Sutcliffe criterion computed over Europe for the stations simulated by the hydrological model CTRIP. The criterion was computed over the 1961-2010 period using monthly data.

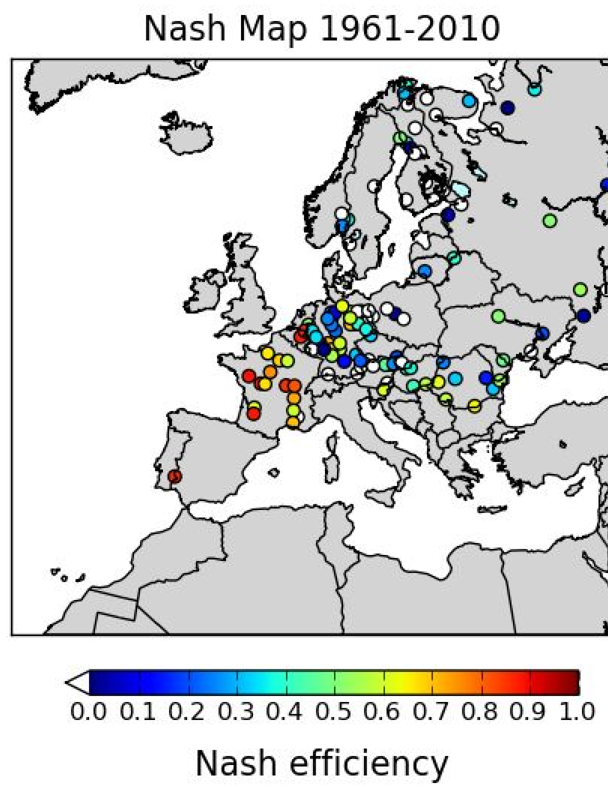


Figure 6: Nash efficiency over Europe (1961-2010).

The Nash efficiency coefficient, usually used to assess the predictive power of hydrological models, ranges from negative values to values close to 1. The closer the model efficiency is to one, the more accurate the model is. In France, Belgium and western Germany, the main rivers are correctly simulated with a Nash coefficient ranging from 0.6 to almost 1. In northern and centre Germany, the Nash coefficient can be very low indicating that the simulation did not perform very good. When going further to the East, only the Danube river is satisfactorily simulated, and finally the scores in Scandinavian regions are not very good.
Figure 7 shows the ratio between simulated and measured discharges computed for the 1961-2010 period on a monthly basis. This ratio is complementary to the Nash coefficient presented in Figure 6.

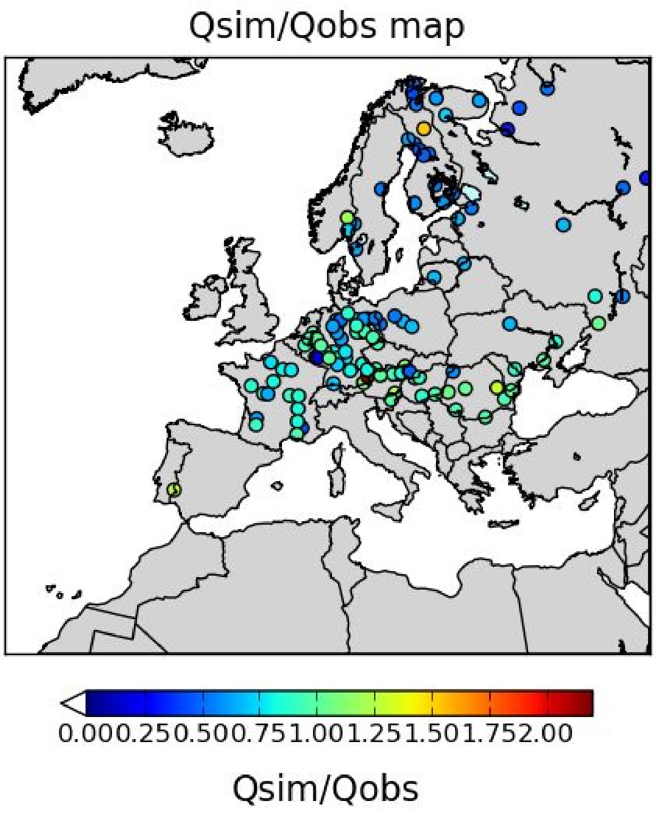
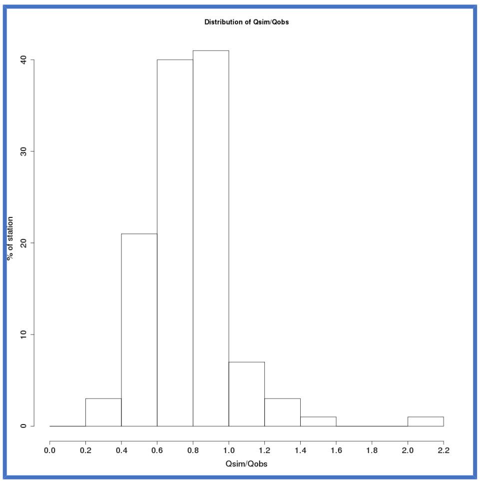


Figure 7: Discharge ratio over Europe (1961-2010).

Regions where the Nash coefficient was higher than 0.6 are those with a ratio close to 1, but slightly lower. Visually, the domain seems split in two parts separated by the Danube river. Regions located south of this limit exhibit a very good ratio, close to 1., whereas further north the ratio is relatively small with values that can approach 0.1, which means that 90% of the discharge was missed by the simulation.



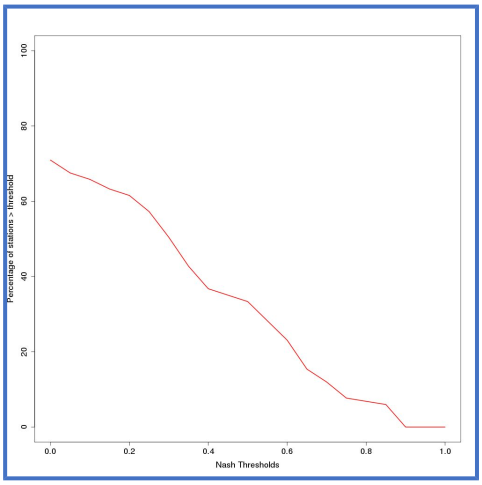


Figure 8: a) Histogram of the discharge ratio over Europe (left) and b) diagram of Nash cumulated frequencies (right).

This is confirmed in Figure 8a showing the distribution of the discharge ratio Qsim/Qobs among the percentage of stations. It indicates that simulated discharges are in most cases lower than the observed ones, confirming the tendency to underestimation. For example, about 25% of the stations underestimates the discharges by about 50%, and less than 20% of the stations in total overestimate discharges. As a consequence, the drawback is a degradation of the Nash scores, which is summarized in figure 8b, showing the Nash thresholds on the x-axis and the percentage of stations having a Nash greater than this threshold on the y-axis. Unsurprisingly, the amount of stations exhibiting very good scores (Nash>0.8) is very small and less than 10%. Only about 35% of the stations have a Nash greater than 0.5, which is still an acceptable efficiency.

After having drawn the main characteristics of discharges over the domain, we then focused on some particular rivers. The first example is the Danube river, which is known to be the second European longest river. Danube is about 3000km long and flows from west to east from Germany to the Black Sea, encountering very contrasted landscapes and climates. A comparison between simulation and measurements for the Danube upstream and downstream river discharge is shown in figures 9a and figure 9b, respectively. The upstream is represented by the Regensburg gauging station in Germany, north to Munich, and the downstream is taken at the Zimnicea gauging station in Romania, south to Bucarest. The outlet at Horsova to the Black Sea was not chosen because the measurements between 1995 and 2010 exhibit a strong drift that didn't seem realistic.

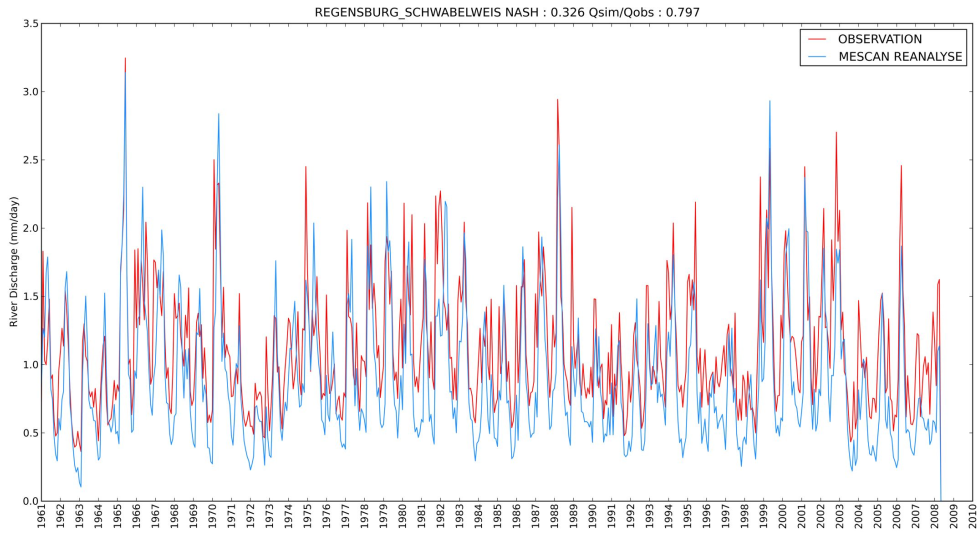


Figure 9a: Monthly discharge time series for the upstream Danube river.

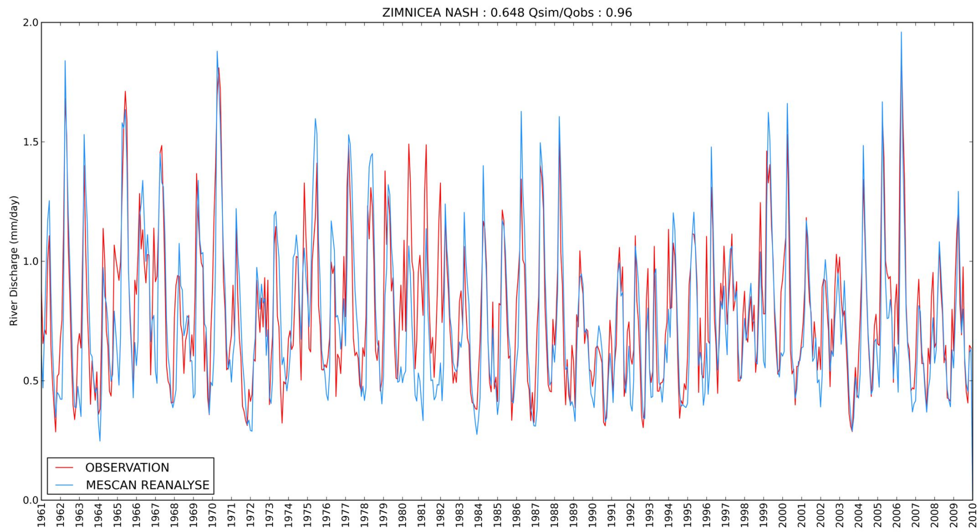


Figure 9b: Monthly discharge time series for the downstream Danube river.

The upstream discharge exhibits a significant systematic underestimation of low-flows mainly during summertime. The averaged Nash criterion equals 0.326 and the discharge ratio 0.797. When analysing downstream discharge, it turns out that this underestimation is removed for nearly all years and at the same time the peaks are better simulated. The Nash criterion equals 0.648 and the discharge ratio 0.6, which is a very good score. However, the average annual cycle of the Danube downstream discharge (Figure 9c) shows that there is an underestimation of the river flow from October to March, with a maximum in January-February. This underestimation is partly compensated from April to

October where the simulated discharges tend to be higher than the observed ones.

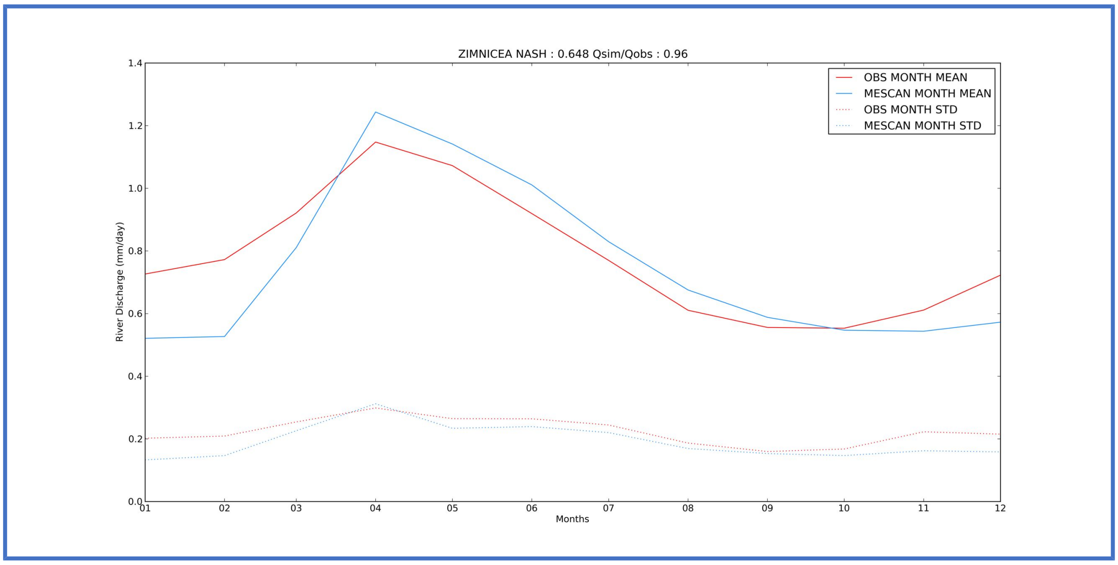


Figure 9c: Annual discharge time series for the downstream Danube river.

We then extracted precipitation, surface runoff, infiltration, evaporation over an area corresponding approximately to the Danube river catchment to study the mean annual cycle of these variables. Due to technical issues, it was not possible to make the extraction for the exact catchment area, which corresponds to the green region in Figure 10. The area hat was chosen to represent the catchment area corresponds to the two grey boxes in Figure 10 and the mean annual cycle of the water balance components are plotted in Figure 11.

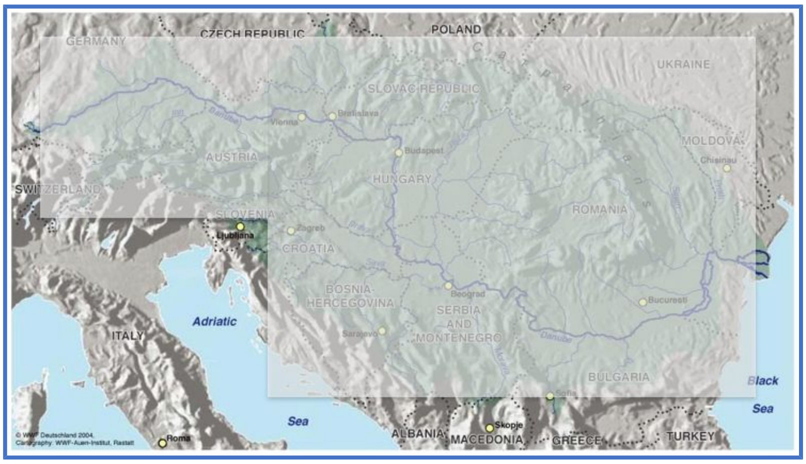


Figure 10: Boxes (grey) superimposed to Danube river catchment (green).

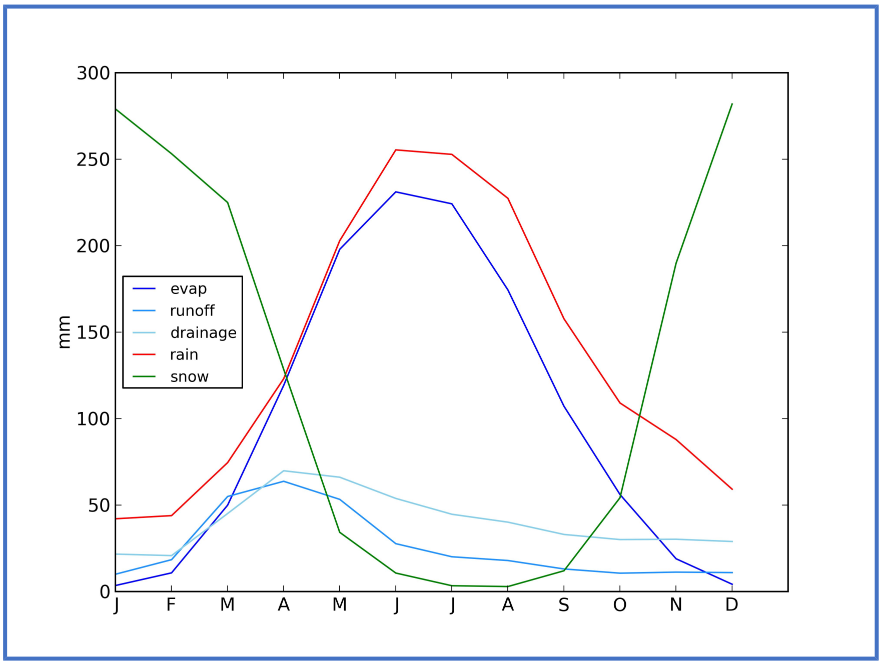


Figure 11: Mean annual cycle of water balance components.

Precipitation over the Danube area representative of a mountainous area dominated by rain during summertime and snow during winter. The region contains effectively a part of the French Alps and the Carpathian region. There's a balance between precipitation and evaporation whereas runoff and infiltration remain low, except during Spring when snow melts.

The second example (Figure 12) is the Loire river in France, which is the station where the best scores are obtained, for Nash but also for the discharge ratio.

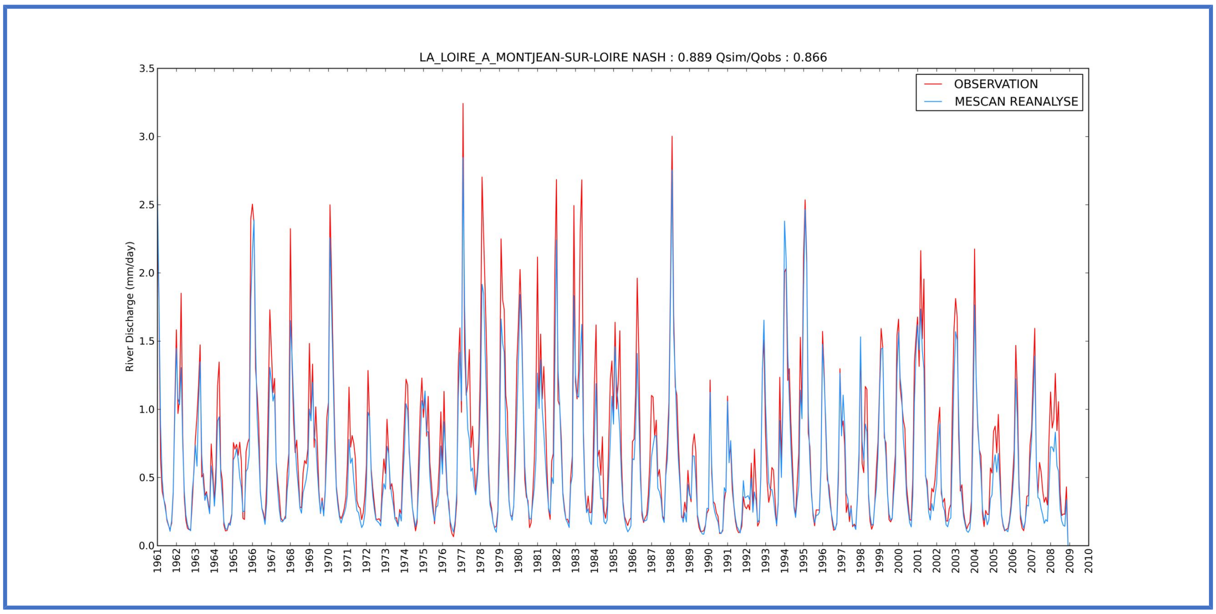


Figure 12: Monthly discharge time series for the Loire river.

The averaged Nash efficiency is 0.89 and the discharge ratio close to 0.87 which shows that the simulation performs very well on average. The inter-annual variability is also well captured and both low and high-flows are well reproduced. The average annual cycle of the discharge (not shown) exhibits a small underestimation during Spring and Winter seasons.

3.2.2 Ensemble 2006-2010

The MESCAN-SURFEX-ENS data sets (Bazile et al., 2017 UERRA report D2.9) were used to drive off-line simulations with SURFEX-TRIP for the period 2006-2010. The idea was to study of the various forcing were impacting the river discharges and more particularly how the spread of the ensemble was comparing to measurements. The Danube river was chosen to illustrate how the different forcing were impacting the discharge simulations.

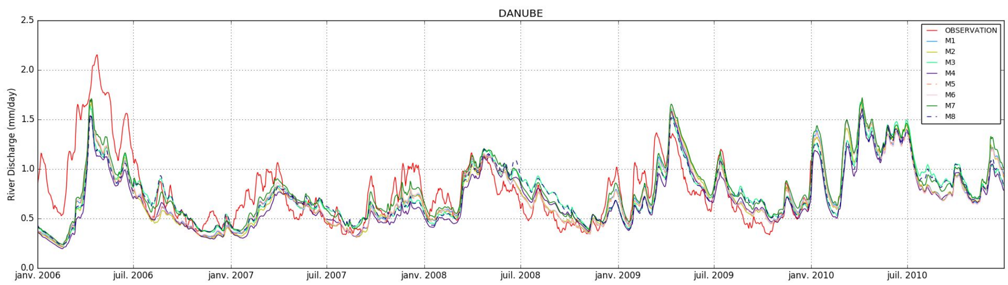


Figure 13: Ensemble of monthly discharge time series for the Danube river

Figure 13 shows the Danube downstream discharge for the 8 members and the measured discharge at the Black Sea. At the beginning of the period, the measured and simulated discharges are quite different due to the initialisation. Such simulations are expensive in terms of CPU-consumption, therefore the spin-up dedicated to each simulation was limited to 3 years, which is obviously too short to properly reach a balance of soil moisture and water table. For that reason, there is a large difference in January 2006 between the members and the observation. The situation improves already the second year. The inter-annual variability is well captured at the monthly time scale. If we look more carefully to the ensemble spread for the Danube downstream discharge, it turns out that on average the spread is about 0.2mm/day during floods for a peak value ranging from 1mm/day to 1.5mm/day. During low flows the spread is about 0.1mm/day for a flow of 0.5mm/day. This highlights that the spread is almost constant and can be quantified as about 20% of the absolute discharge.

Section 4: Conclusion

This report describes how off-line numerical simulations were set up, in which the SURFEX land surface model was coupled to the CTRIP hydrogeological model to assess their quality by comparing measured and simulated discharges. The main advantage of the method was to use independent variables for its evaluation (snow depths (not discussed in this report), discharges, etc.). Such off-line simulations were driven by the MESCAN reanalysis, combining surface analysis of 2-meter temperature and humidity and precipitations to upper air downscaled fields. The simulations were carried out for the period 1961-2010.

The surface and soil data produced are archived in the ECMWF MARS archive system and available for users. CTRIP output are however not archived at ECMWF since their archive was not mandatory, they have been used to assess the reanalysis ability. They are however stored in Meteo-France archiving system and, as any product of the UERRA project, can be made available for users. Anyway, the approach developed and consisting in coupling a land surface model (SURFEX) to a hydrological model (CTRIP) can be reused for hydrological or validation purposes.

CTRIP has also simulated flooded areas and this SURFEX-CTRIP output could have been compared to other European products such as those from the EFAS system or the EU-HYPE hydrologic systems. The water table height variations were also simulated but as flooded areas, due to a lack of time comparison to measurements could not be achieved.

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