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Report for Deliverable 4.6 (D4.6): HYPE EURO4M Evaluation Report from UERRA WP4

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For this deliverable, the goal is to explore the use of observed discharge as an evaluation tool for accumulated precipitation over a catchment area to evaluate long term mean precipitation, for example from the EURO4M-HIRLAM reanalysis simulation. The main idea is to make use of observed records of discharge from river catchments across Europe, which in a long term mean can be expected to be balanced by the precipitation falling within the upstream area and the loss through evapotranspiration. The precipitation is given by EURO4M, whereas evapotranspiration can only be estimated. In a first part of the evaluation, the catchment delineation and routing routines of a large-scale hydrological model for Europe, E-HYPE, are used to accumulate the precipitation spatially over a catchment. Then the temporally and spatially aggregated precipitation is compared with observed discharge from the corresponding catchment. An accumulated precipitation less than the discharge (even without considering evapotranspiration) indicates inadequate precipitation. For the second part of the evaluation, simulations with E-HYPE are carried out, and similar analyses are performed as in part one, but using the simulated values of discharge, now including an estimated evapotranspiration.

Section 1: Introduction

Precipitation is a spatially and temporally highly inhomogeneous variable, and the amount of precipitation falling on two nearby locations can therefore vary substantially even in a climatological mean, especially in mountainous regions. High density gauge networks are therefore necessary to build a sufficiently detailed spatial map for evaluation of precipitation in model simulations. Such networks are not available for large enough regions, and statistical methods must be used to make estimations of the precipitation field between gauges. Furthermore, most gauges suffer from *under-catch* of precipitation, which is when a gauge is not able to collect the correct precipitation rate under certain circumstances, typically during windy and/or snowy conditions. Gauge estimations of precipitation might therefore suffer from systematic biases.

Precipitation falling on land can go directly back into the atmosphere through evaporation, into runoff and through river networks to eventually end up in the ocean, or it can go into several different buffers. These buffers are e.g. ground water, taken up by biota, or collected in lakes, wetlands and other freshwater reservoirs. Eventually, the water will continue through these buffers to the ocean, or by evapotranspiration into the atmosphere. Therefore, when observed over a longer time period, precipitation falling within a catchment should at minimum always be larger than the amount of water observed as discharge from the catchment. For most catchments, the discharge should rather be a smaller fraction of the accumulated precipitation, due to loss by evapotranspiration in the course of reaching the discharge station.

In this report, the pan-European hydrological model E-HYPE is used to accumulate precipitation to enable direct comparison to observed discharge, and also to model discharge for estimation of losses. The method of applying the hydrological model system E-HYPE is developed and used for evaluation of the EURO4M-HIRLAM regional reanalysis precipitation product.

Section 2: Model and Data

2.1. The E-HYPE model

The E-HYPE model is the European set up of the HYPE model (Hydrological Predictions for the Environment; Arheimer et al., 2008). It is a semi-distributed, process-based model that simulates hydrology following a multi-basin concept, where multiple catchments (here over all of Europe) are modelled in a consistent way (Figure 1). The landscape is divided into different classes according to altitude, soil type and vegetation. In E-HYPE there are over 35'000 catchments with an average size of 250 km^2, see Figure 2.

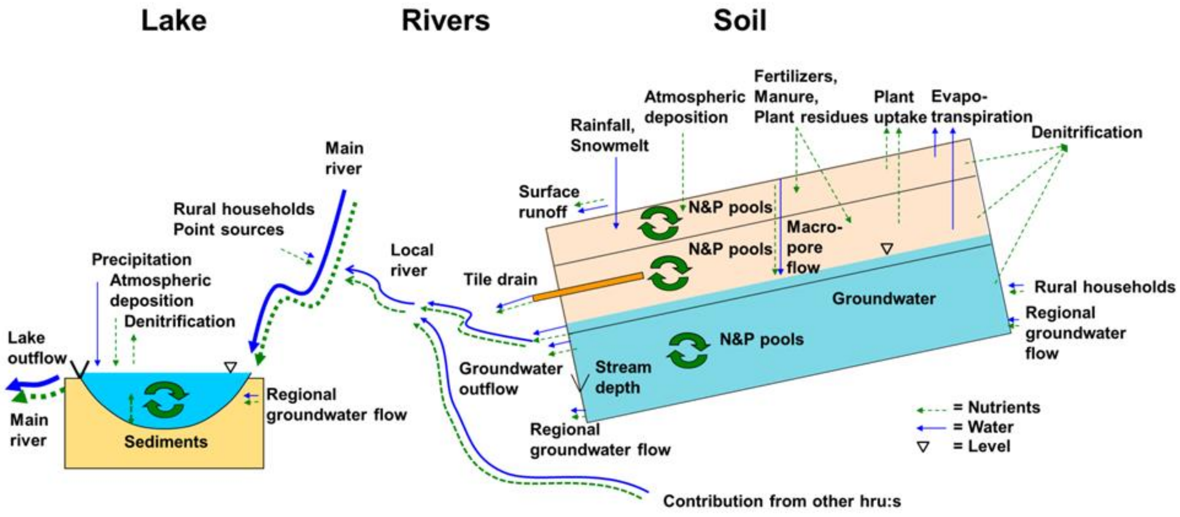

Figure 1: Conceptual schematic of the E-HYPE model.

E-HYPE is used for two purposes in this study: (i) to accumulate gridded precipitation over catchments to perform a simple routing of all water to the river mouth, and (ii) to simulate hydrological processes including retention in the soil, groundwater and lakes to make assessments of the loss of water to the atmosphere through evapotranspiration.

Precipitation is introduced to the model as single time-series for each catchment, and to arrive at those time-series, a pre-processing of the original gridded source precipitation data is necessary. This is carried out in two steps. First, each catchment area is assigned an area weighted average of all grid boxes of the precipitation field that overlaps the catchment. This determines the total amount of precipitation that falls within the catchment each day. There is a large range of catchment sizes in E-HYPE (from 2000 m^2 to 18000 km^2), and with increasing area, such averaging acts to remove much of the variability of rainfall intensity. So in the second step, a grid point from the precipitation data set that is deemed representative for the variability close to the center of the catchment is chosen. The time series of that grid point is then scaled to have the same average on a monthly time scale as the total of all precipitation falling within the catchment. Thus, water is conserved on a monthly timescale while the variability remains similar to that of a single grid point. The latter effect is important, e.g., for the simulation of flood and drought events. However, for the current study, the first step of water conservation is of main importance.

For the second aspect of the E-HYPE modelling of this study, evapotranspiration plays an important role, as besides routing of water, this is the only way water can leave the system. Evapotranspiration encompasses direct evaporation (sublimation) of water (snow) from soil moisture and open water, as well as transpiration from plants and trees. In the current set up of E-HYPE, evapotranspiration is calculated using a simple temperature exceedance relationship. This equation estimates the evapotranspiration assuming a linear relationship with the daily mean temperature above a threshold temperature, usually 0. This has been shown to achieve a sufficiently good simulation of evapotranspiration in a large range of catchment scales, climates and physiographies, such that the balance between precipitation, evapotranspiration and discharge is achieved (e.g. Oudin et al. 2005).

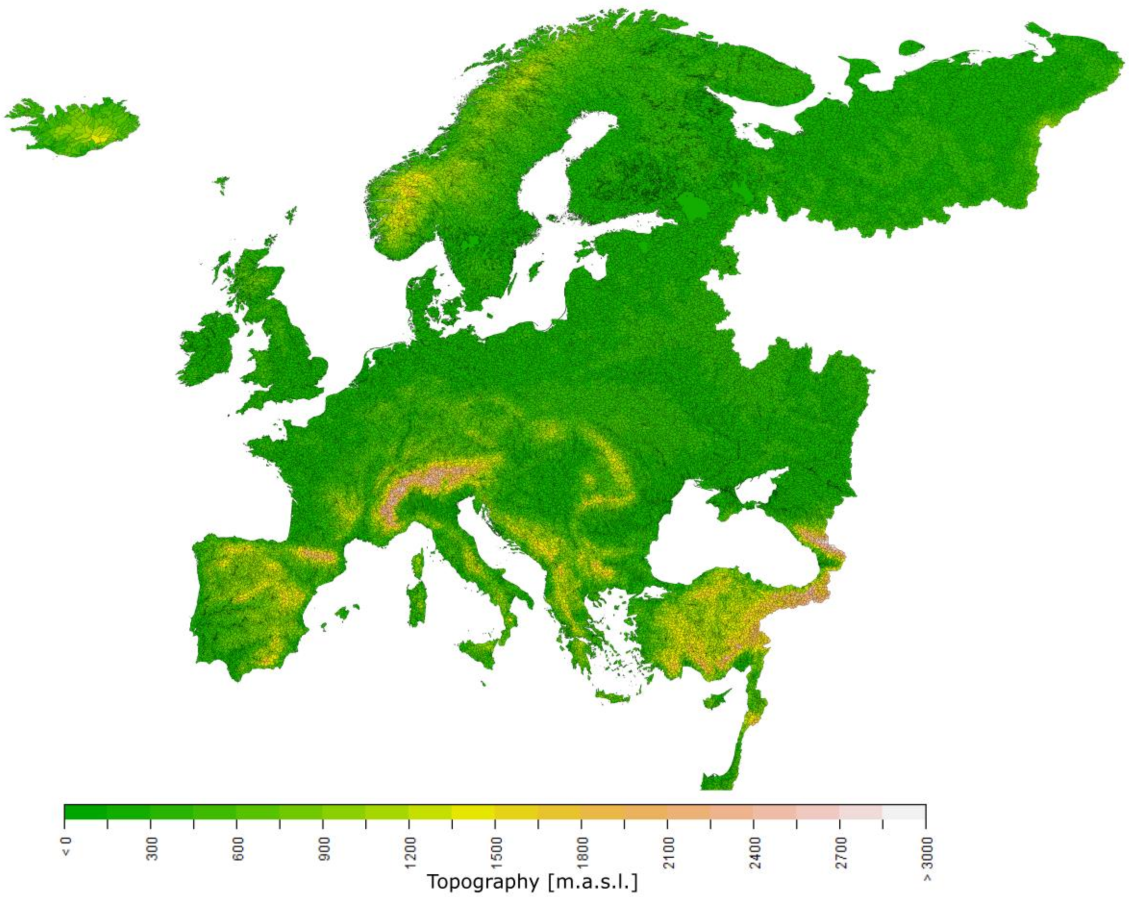

Figure 2: Topographical map of average altitudes of catchments in E-HYPE. The fine catchment delineation is marked with black contours.

2.2. Data sources and experiments

2.2.1 EURO4M-HIRLAM

The operational weather forecast model HIRLAM was in the EURO4M-project (http://www.euro4m.eu) used to perform reanalysis simulations of the ERA-Interim reanalysis (Dee et al., 2011). The reanalysis were performed by one-way nesting of HIRLAM, using ERA-Interim information at the lateral boundaries, including additional large scale constraint by ERA-Interim vorticity (Dahlgren and Gustavsson, 2012) and 3D-VAR assimilation of conventional observations. The simulation covers the period 1989-2010, and has about 20 *km* spatial resolution (0.2 *degrees*). Here, daily precipitation and surface temperature was used as inputs to E-HYPE.

2.2.1 WATCH Forcing Data Era-Interim (WFDEI)

WFDEI is a merged model and observational product (Weedon et al., 2011), using the ERA-Interim reanalysis (Dee et al., 2011) together with different gridded observational data sets. The procedure to calculate corrected data varies between variables, but the main principle for all variables is that each monthly mean value of ERA-Interim are corrected to that of the observational data set. For precipitation, the correction is performed toward GPCC (Rudolf et al., 2010) by first correcting the number of dry days (precipitation below 1 *mm/day*) following observations from the CRU data set (Mitchell and Jones, 2005), and then scaling precipitation for each time-step during one month with the ratio of the monthly accumulations of ERA-Interim and observations for that same month. This means that the monthly means of WFDEI agrees with the observations, and the sub-monthly timesteps are scaled to fit with that. In a last step, and under-catch correction, based on local estimates based on the gauge type and weather conditions, is applied. Thus a higher temporal resolution data set is constructed while retaining similar characteristics as the monthly time-scale observational data.

WFDEI is a global data set with a 50 *km* spatial resolution, and is currently used as a standard for setting up the E-HYPE model. Here, only temperature (corrected with CRU data) and precipitation are used.

2.2.2 Discharge observations

The discharge observations have been collected from various sources all over Europe. Initial quality checks have reduced the number of stations used for validation and calibration of the model to over 2500 stations. For the analysis presented here, we have further reduced the selection of stations to 637 by removing stations with too much missing data. For annual accumulations, years when the station has more than ten missing days are discarded in the climatological statistic. This is because missing data can have a large impact on the annual total discharge, depending on which time of the year the data gap occurs. Figure 3 shows the total percentage of missing data between 1991 and 2010 for each of the discharge gauges.

For reasons of availability of discharge data, and of local characteristics found in the analysis, this study will provide analyses for Scandinavia and the British Isles in particular, and Europe in general.

2.2.3 E-HYPE experiments

Simulations are performed for the period 1990-2010, with the first year used as a spin up and later discarded for the analysis. The WFDEI data set is used for the control simulation. Two additional simulations are performed using EURO4M-HIRLAM for both temperature and precipitation, and using EURO4M-HIRLAM for precipitation, but WFDEI for temperature.

2.3. Metrics and definitions

Discharge is normally described in units of m3/s, but for direct comparison to the precipitation falling in the upstream catchment it has here been converted to units of mm/day by dividing by the upstream area. Observed discharge is aggregated over each year, and then averaged over the time period to produce a climatological annual value. The same calculation is carried out for precipitation in the upstream area. In the analyses, all discharge information is used, and when there are observations in the upstream area of a discharge gauge, the catchment is divided in sub-catchments and the nearest upstream gauge is subtracted from the one studied, which is then compared to precipitation falling in the representative upstream area.

The balance between discharge (Q) and precipitation (P) is here described by the ratio Q/P*100 %, and when only precipitation is affecting discharge this ratio must always be below 100%. Releases from larger storages can increase discharge such that the ratio is larger than 100%, but this should in practice only affect very small catchments with large glacier coverage. Evapotranspiration can reduce the ratio below 100%. E-HYPE simulations will provide an estimation of the ratio to expect, making use of the different experiments performed. However, evapotranspiration is a complex process with large uncertainties, and very little observational records to evaluate with. The model estimate of the Q/P-ratio should therefore also be used cautiously.

All analyses are performed for the year 1991-2010.

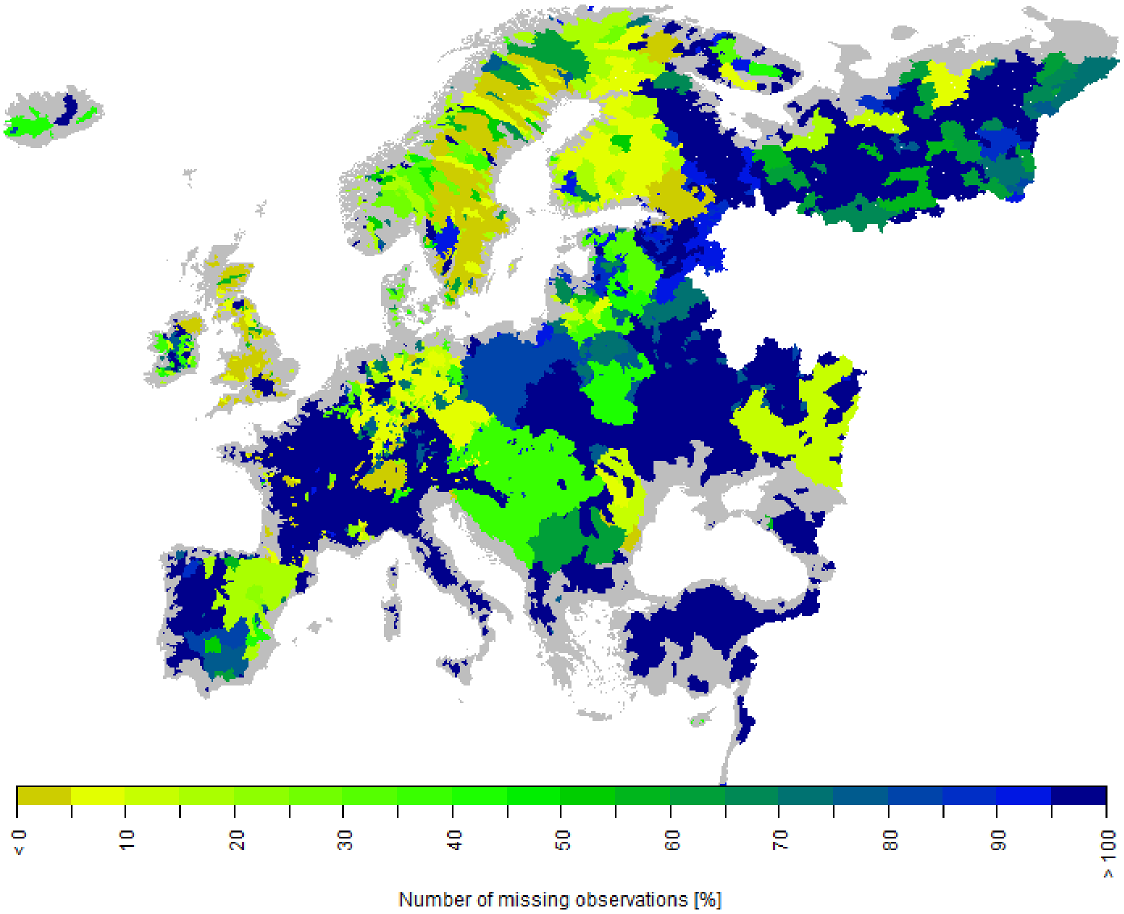

Figure 3: Amount of missing data in each observational discharge station mapped on the upstream area until the next discharge station.

3. Evaluation

3.1. Overview for Europe

EURO4M-HIRLAM is generally wetter than WFDEI on average over the year, see Figure 4. This is most clearly seen in mountainous regions throughout Europe with difference even above 100%. This indicates that it might in part be due to the difference in spatial resolution of the two data sets. But also regions with little orography tend to be wetter in EURO4M-HIRLAM. The two data sets deviate strongly for Iceland, and since this is a region poorly covered by observational data, we leave it out of the following analysis.

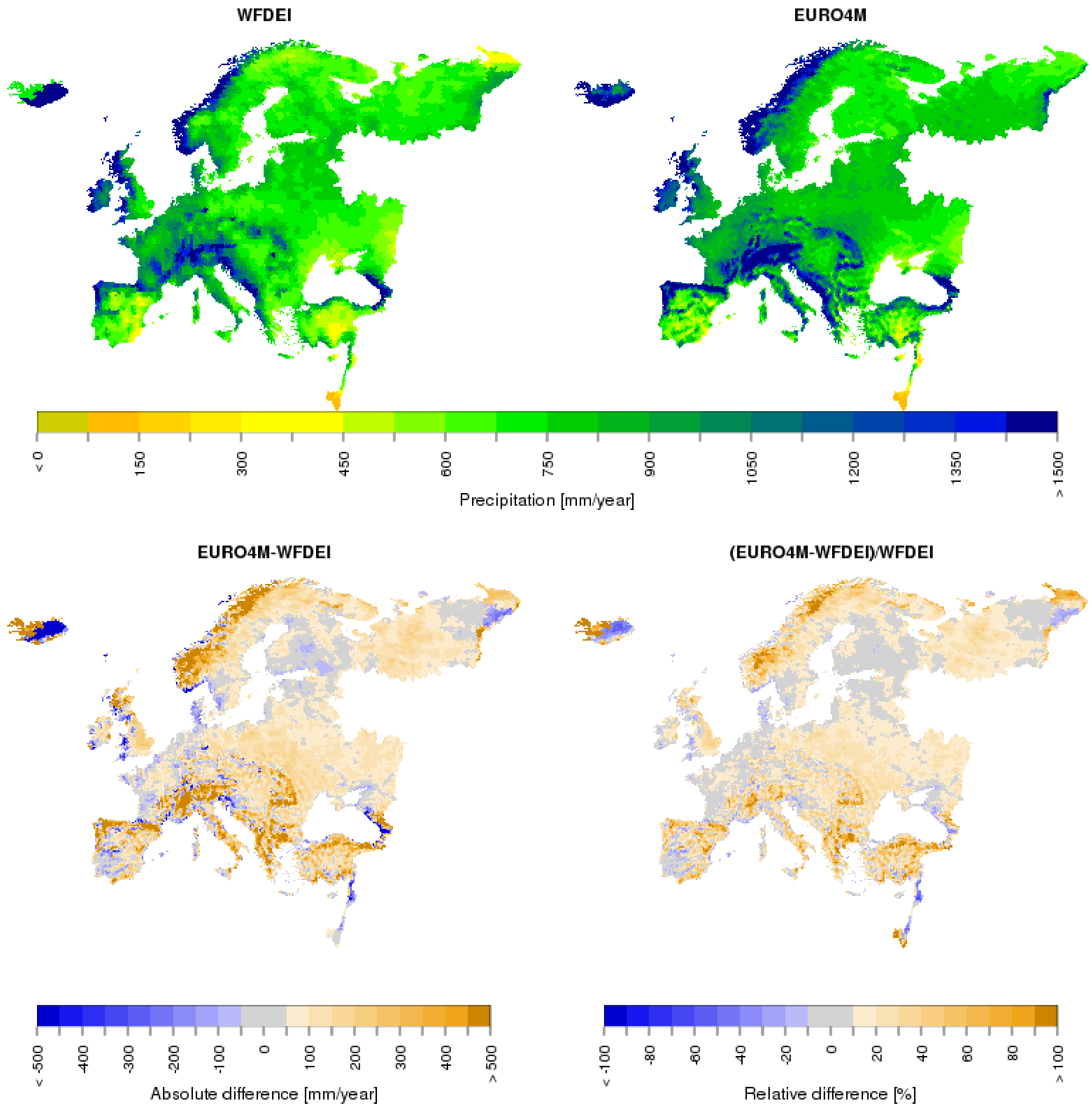

Figure 4 : Annual mean precipitation of WFDEI, EURO4M-HIRLAM and their absolute and relative differences, after distributing the data to the E-HYPE catchments.

Figure 5 compares measured discharge for stations across Europe with precipitation from EURO4M-HIRLAM. The Q/P-ratio is calculated directly with observed discharge, Q_{obs}, as well as with model simulated discharge, Q_{mod}. A few regions with ratios above 100% (black areas in Figure 5) are clearly visible in Scandinavia, Iceland and southern Poland, but there are also some regions in the British Isles. These indicate regions where precipitation is likely underestimated by EURO4M-HIRLAM. Interestingly, also the E-HYPE simulation sometimes produces a ratio higher than 100%, i.e. in northern Sweden and in north-eastern Iceland. The northern Sweden case is a river bifurcation not accounted for in the model, where routed water is exchanged between two adjacent catchments, and the large Q/P-ratio is therefore physically correct and balanced by a lower ratio in the other catchment. The results for both Iceland and Poland suffer from large uncertainties due to the small data sample (see Figure 3) and Iceland, furthermore, has a more complex geological structure which is not well simulated in the model. The results for these regions are therefore not investigated further in this report.

Comparing the Q/P-ratios for observed and simulated discharge, a pattern of generally lower ratios are seen for the model. Some main exceptions are seen for Scandinavia and north-west of the Alps, where the Q/P-ratios are higher for the model. These are mountainous regions, and the reason for the different behavior could be related to snow processes, and to some very limited extent to glaciers. Temperature biases could play a part in this behavior too as this affects the evapotranspiration calculation in the hydrological model.

Figure 6 present the results for WFDEI. Since this data set is generally drier than EURO4M-HIRLAM, also the Q_{obs}/P-ratios are higher for most parts of Europe. Contrary to the EURO4M-HIRLAM case, E-HYPE does not increase the Q/P-ratios when modeling discharge for the Alps and Scandinavia and for the rest of Europe there is a smaller change than before.

Temperature is the only difference between the EURO4M-HIRLAM and WFDEI simulations, besides precipitation. Therefore, a third experiment is carried out to investigate the impact of using WFDEI temperature together with the EURO4M-HIRLAM precipitation data. The new setup shows some differences to the pure EURO4M-HIRLAM case, but the main characteristics of higher Q/P-ratios in Scandinavia and the Alps remain (not shown). The three experiments indicate that the reason is likely a combination of cold climate processes, and biases in the distribution of precipitation over the annual cycle.

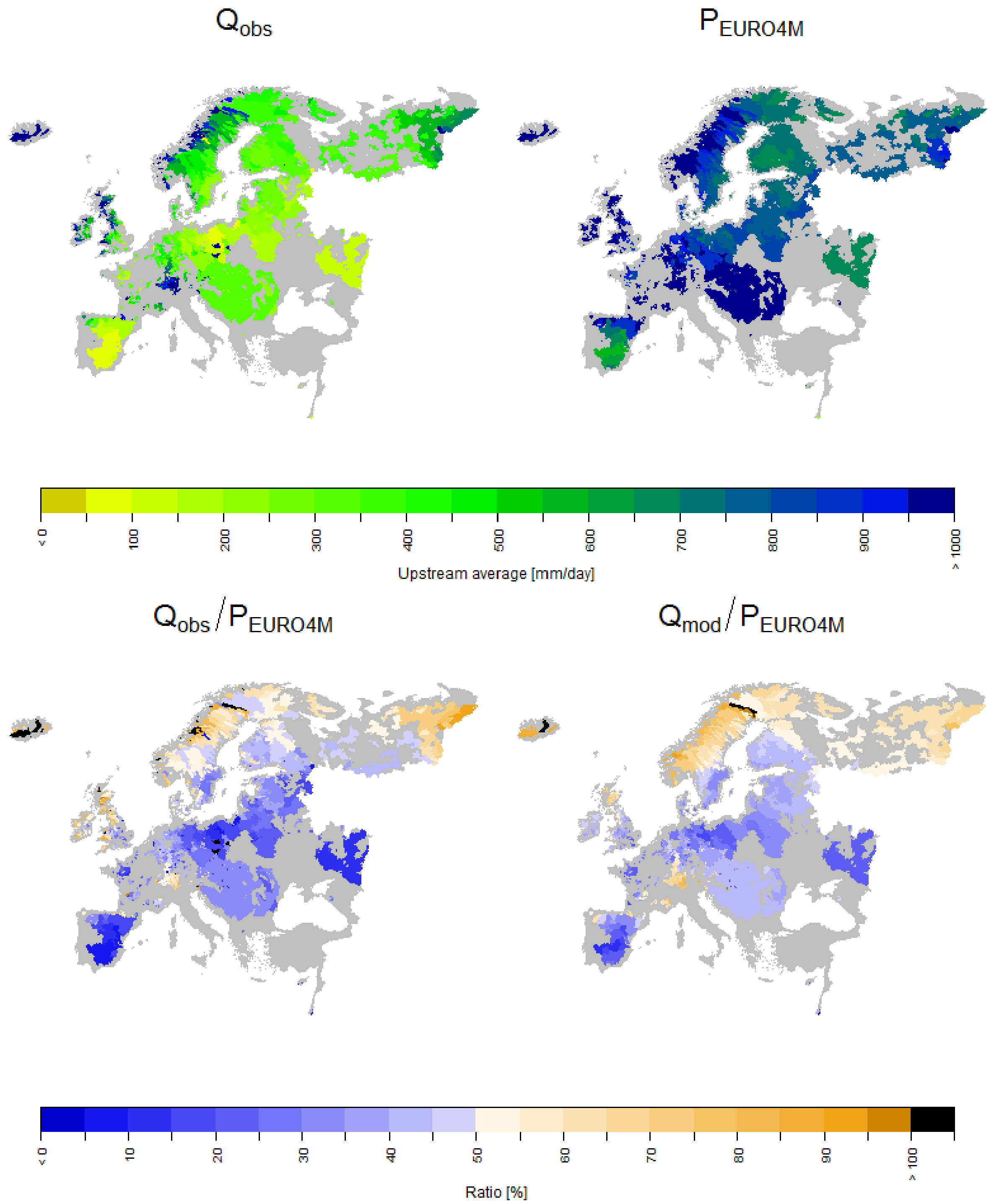

Figure 5 : (a) Discharge from observations, (b) precipitation from EURO4M-HIRLAM, (c) Q/P-ratio for observed discharge, and (d) Q/P-ratio for modeled discharge. All panels show annual means for the period 1991-2010. Values of discharge and precipitation are projected upon the upstream area of each Q-station.

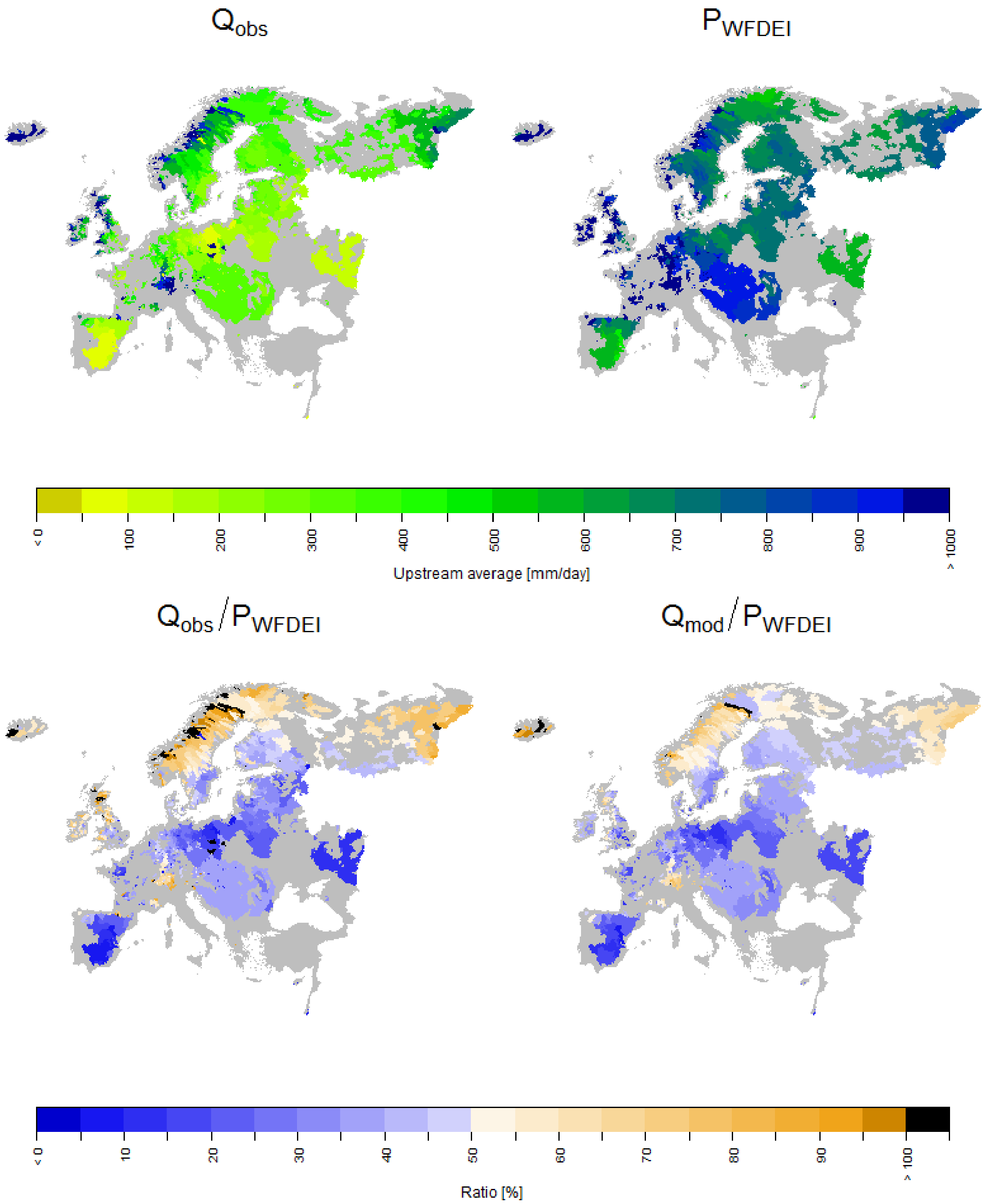

Figure 6: Same as Figure 5, but for WFDEI.

3.2. Scandinavia

The comparison of EURO4M-HIRLAM and WFDEI in Figure 4 indicated a wet bias over the Scandic Mountains of the former.

Figure 7 provides a more detailed image of Scandinavia, where it is clear that a few catchments have abnormally high Q/P-ratios (besides the bifurcation catchment in the north of Sweden already discussed). This indicates that there is locally not enough precipitation. These catchments tend to be on the Norwegian side of the mountain range, with discharge into the Atlantic. The E-HYPE simulation indicates that evapotranspiration has a rather small impact on the discharge, as seen from the Q_{mod}/P-ratios of above 60% in the mountain range. The observed discharge presents much lower values by a few tens of percentage units, especially on the eastern side of the mountain range. The western side is closer to the model estimates. This indicates that there is overall too little precipitation in EURO4M-HIRLAM, and that too large part of the precipitation falls west of the divider between easterly and westerly catchments.

Some glacier data are available for the Scandic Mountains, and the mass balance was calculated for the investigation period. It was found (not shown) that there are both growing and shrinking glaciers on the western side of the mountain range, but none of them correspond to catchments that deviate strongly in the Q/P-ratio analysis. The glaciers can have a strong impact on the discharge, but only on rather small catchments, with a large glacier fraction. There are, however, large uncertainties in the calculation of the glacier mass balances.

This region of Europe is dominantly affected by systems following the primarily westerly flow, and a reasonable speculation would be that the precipitation systems tend to penetrate too far over land, thus causing this erroneous climatological field. However, a detailed analysis of the meteorology/climatology of the model would be necessary to draw further conclusions.

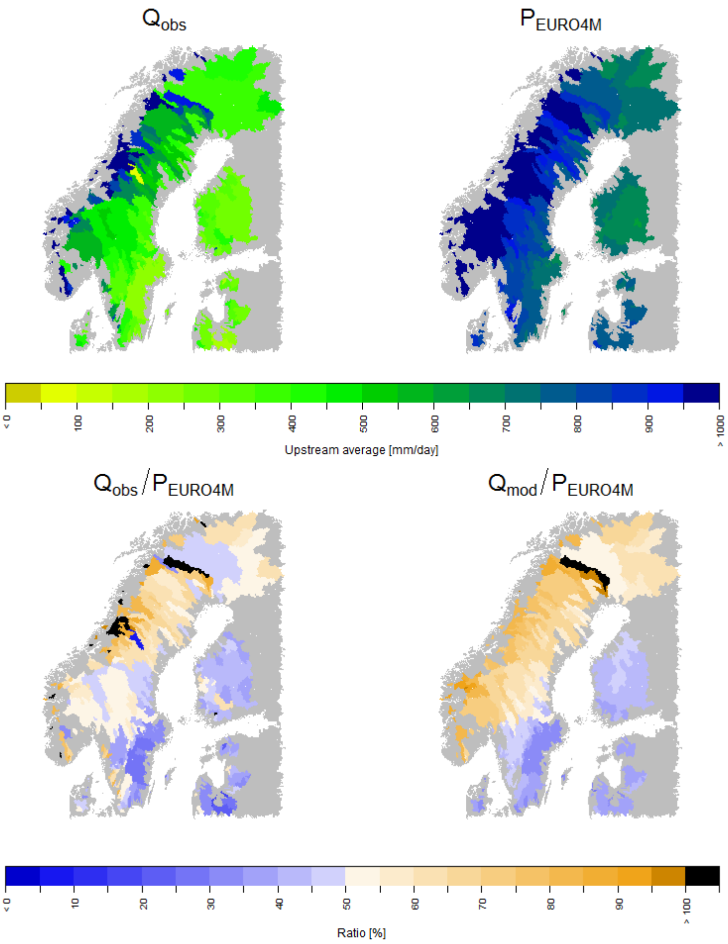

Figure 7: Same as Figure 5, but for Scandinavia.

3.3. The British Isles

The British Isles are, similarly to Scandinavia, dominantly affected by precipitation systems in the westerly flow. The comparison to WFDEI in Figure 4 showed that EURO4M-HIRLAM overestimates the precipitation amounts in the southeast, and underestimate in the west. This is directly reflected in the Q_{obs}/P-ratios which are lower in the southeast than in the west, which in some locations even reaches higher than 100%. Again, it seems like the precipitation is falling too far inland.

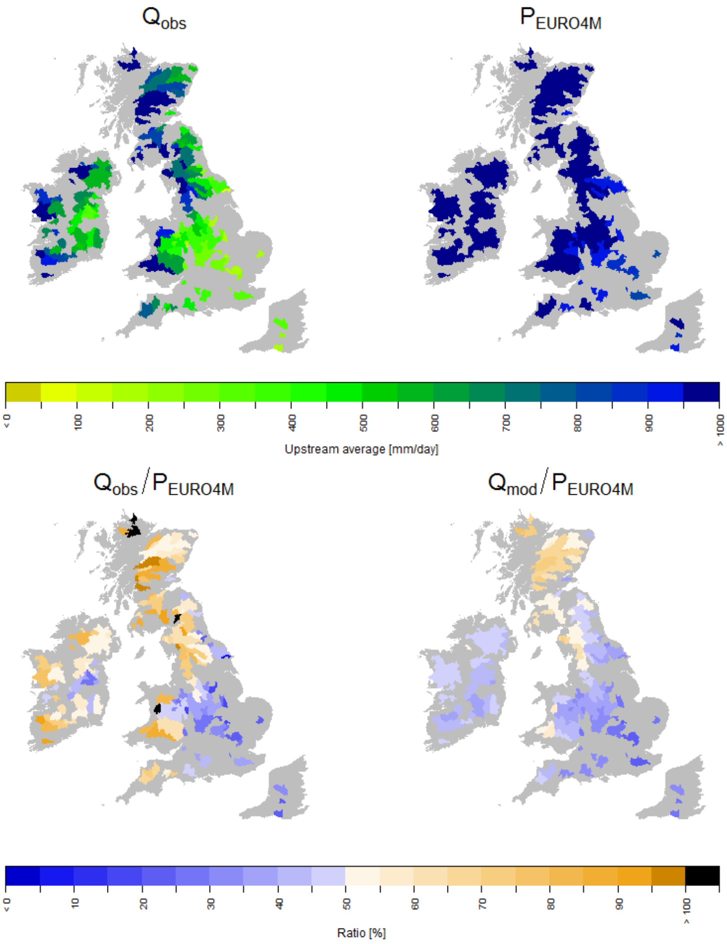

Figure 8: Same as Figure 5, but for the British Isles.

4. Discussion and Conclusions

In this study we explored a novel method of employing a multi-basin hydrological model together with discharge observations to evaluate precipitation data sets. The E-HYPE model framework was applied to distribute precipitation from the WFDEI and EURO4M data sets over the catchments of E-HYPE in order to evaluate the accumulated values in two separate steps. In a first step (i), the accumulated precipitation was compared to observed discharge at the river mouths, and in a second step (ii) E-HYPE simulations were carried out to estimate losses due to evapotranspiration or longer term storage. This was performed for average values for the period 1991-2010.

Both of the analysis steps have distinct uncertainties. The main uncertainty is the amount of loss of water between the precipitation event and the water leaving the catchment as discharge. E-HYPE can estimate evapotranspiration, but little observations are available for evaluation, and the more advanced parameterizations require more uncertain input data, e.g. near surface winds. A simple parameterization purely based on daily average temperature was therefore used in this study; although more advanced schemes can be explored in subsequent studies in UERRA.

Comparing the Q/P-ratios for both observed and modelled discharge revealed some interesting features for different regions. The east-west gradient of differences was highlighted for Scandinavia and the British Isles, where a likely explanation for the gradient is a too deep inland penetration of precipitating systems in the dominant westerly flow. Furthermore, a seasonality issue was observed for the Scandic and Alps mountain ranges. The value of the explored method is in indicating where such issues with the precipitation data are, but subsequent meteorological analyses are necessary to find the exact circumstances of the biases of the atmospheric model.

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