SPECIAL PROJECT PROGRESS REPORT

Reporting year	2017
Project Title:	Integrated Simulations of the Terrestrial System over the European CORDEX domain
Computer Project Account:	SPDEKOLL
Principal Investigator(s):	Jessica, Keune, Stefan Kollet, Fabian Gasper, Klaus Goergen
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Name of ECMWF scientist(s) collaborating to the project	Florian Pappenberger
Start date of the project:	01.01.2016
Expected end date:	31.12.2017

Computer resources allocated/used for the current year and the previous one

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	32.750.000	32.750.000	30.000.000	30.000.000
Data storage capacity	(Gbytes)	60.000	60.000	60.000	60.000

Summary of project objectives

The objective of this study is to perform high-resolution fully coupled aquifer-to-atmosphere simulations over the European CORDEX domain. The simulations are performed with the integrated Terrestrial Systems Modeling Platform, TerrSysMP, consisting of the three-dimensional surface-subsurface model ParFlow, the Community Land Model CLM3.5 and the numerical weather prediction model COSMO of the German Weather Service (Shrestha et al., 2014; Gasper et al., 2014). The simulation results are used to interrogate the two-way feedbacks of groundwater and soil moisture dynamics with essential climate variables, such as air temperature and precipitation, at continental scales. Event-based simulations are performed, focusing on the heat wave in 2003.
The continuation of this project includes the integration of human water management into the modeling system and addresses the impact of groundwater-fed irrigation on the terrestrial water cycle.

Summary of problems encountered

We discovered two issues in the coupling of our modelling system, TerrSysMP:

(1) Due to an issue with the coupling over the ocean introduced by the coupling of CLM and COSMO, a subset of the planned simulations had to be repeated.
(2) Simultaneously, we increased the time steps of CLM and ParFlow (from 1 hour to 3 minutes) in order to better account for non-linearities in the exchange flux, which lead to an increase of compute time.

Furthermore, some technical problems by running ecflow on the cca rather than ecgate, were encountered. We would like to acknowledge the prompt and productive help from the help-desk and Carsten Maass regarding these difficulties.

Summary of results of the current year

The results of the project in the first half of 2017 are a continuation of previous work in 2016.
The new version of the TerrSysMP modelling system, i.e. version 1.2.0MCT, was successfully implemented, and the spin-up of the hydrologic compartments of this modelling system was finalized.
The setup regarding the spectral nudging technique (von Storch et al., 2000; Miguez-Macho, 2004) was tested, evaluated and finalized. A workflow including (1) the retrieval and (2) interpolation of ERA-Interim fields as atmospheric boundary data for COSMO, (3) the setup and (4) restarts of TerrSysMP, and (4) a more flexible and sophisticated post-processing of simulation results of all three models, was successfully implemented in ecflow. Simulations with varying groundwater configurations, initial conditions and hydro facies distributions, were performed. A paper (Keune et al., 2016) was published in Journal of Geophysical Research – Atmospheres.

For the continuation of the project, we decided to include the human impact on the terrestrial water cycle in the simulations, instead of running fully coupled long-term simulations with TerrSysMP. Up-to-date, the consideration of groundwater-fed irrigation in fully coupled bedrock-to-atmosphere simulations is new and offers new insights on the human alteration of the terrestrial water cycle. Hence, we continued simulating the heat wave in 2003, thereby expanding the experiment design and addressing additional uncertainties. Due to an issue with the coupling, a subset of these simulations is currently repeated. This continuation of the project is summarized in the following, using preliminary results.

Water management simulations

Anthropogenic impacts on the terrestrial water cycle are considered by applying actual daily estimates of irrigation and groundwater abstraction from Wada et al. (2012, 2016) and Siebert et al. (2010), Siebert and Döll (2010), as a source at the land surface and explicit removal of groundwater from aquifer storage, respectively. Figures 1 and 2 illustrate the spatial distribution of irrigation and total groundwater abstraction in 2003 for both data sets. Simulations of the fully coupled system (ParFlow-CLM-COSMO) are performed over the full year 2003, including the European heat wave. Irrigation and groundwater abstraction are applied in a daytime schedule, i.e. from 6 pm to 6 am.

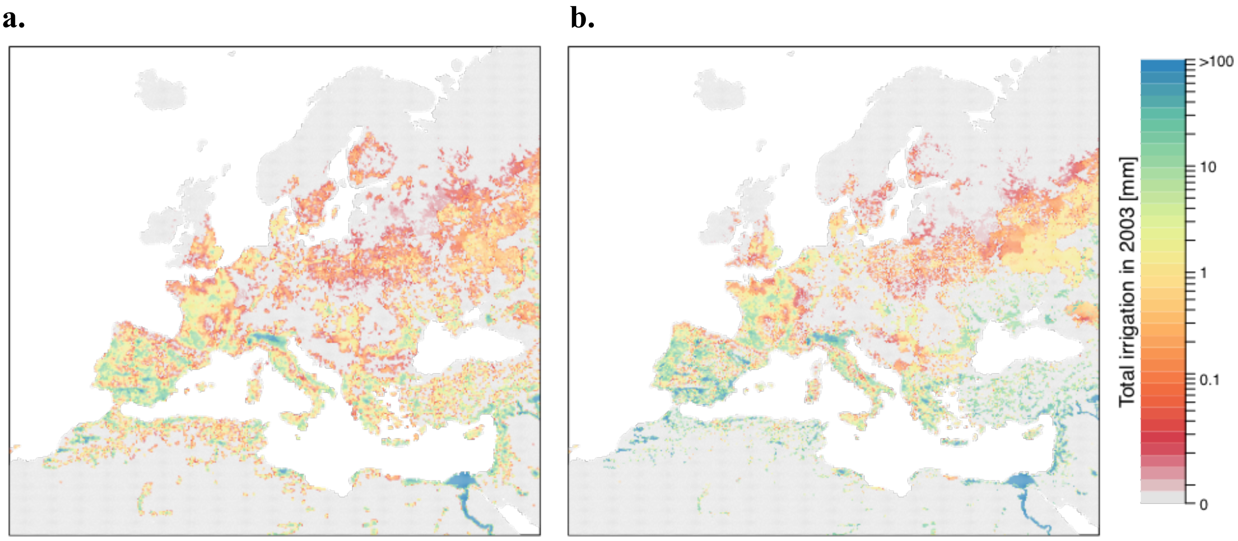

Figure 1. Total irrigation in 2003 [mm/m2] over the European CORDEX domain from (a) Wada et al. (2012, 2016) and (b) Siebert et al. (2010) and Siebert and Döll (2010).

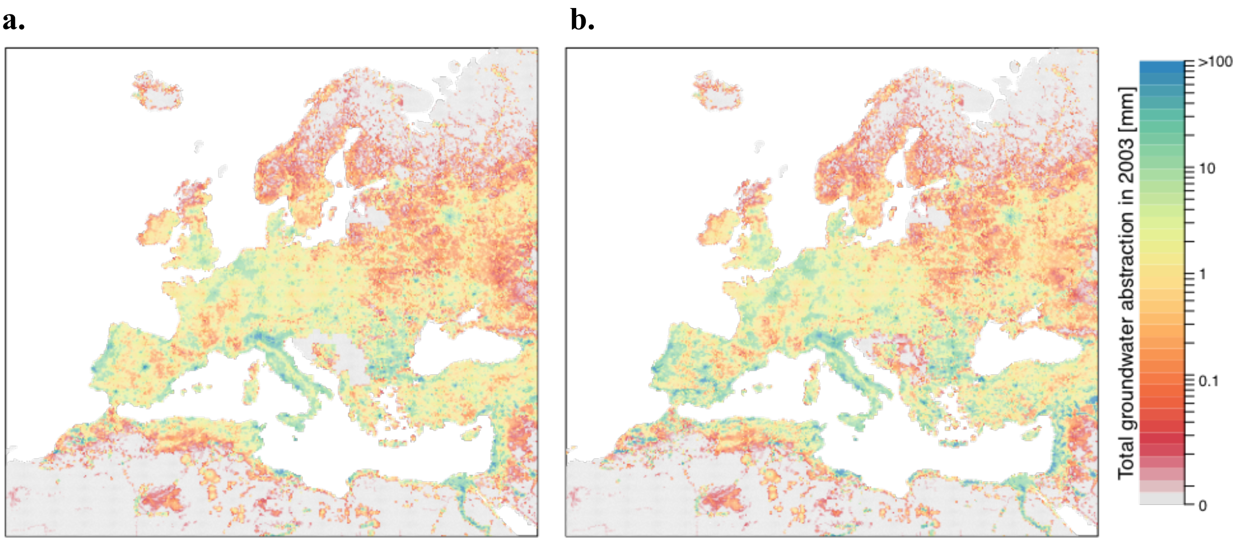

Figure 2. Total groundwater abstraction for all sectors (agriculture, domestic and industry) in 2003 [mm/m2] over the European CORDEX domain from (a) Wada et al. (2012, 2016) and (b) Siebert et al. (2010) and Siebert and Döll (2010).

The two water management scenarios

- **HUM1**: water management simulation including irrigation and groundwater abstraction from Wada et al. (2012, 2016)
- **HUM2**: water management simulation including irrigation and groundwater abstraction from Siebert et al. (2010) and Siebert and Döll (2010)

are compared to a reference simulation (**NAT**), which does not consider human alteration of the terrestrial water cycle. We study the space and time characteristics of the terrestrial water cycle components and their impact on the evolution of temperature extremes and the heat wave. The two water management simulations are used to interrogate the feedback uncertainty arising from the estimates of human water management data.

Preliminary results of the water management simulations

This section gives and overview of the preliminary results from the two water management scenarios with a focus on the alteration of the terrestrial water cycle via soil moisture-precipitation feedbacks.

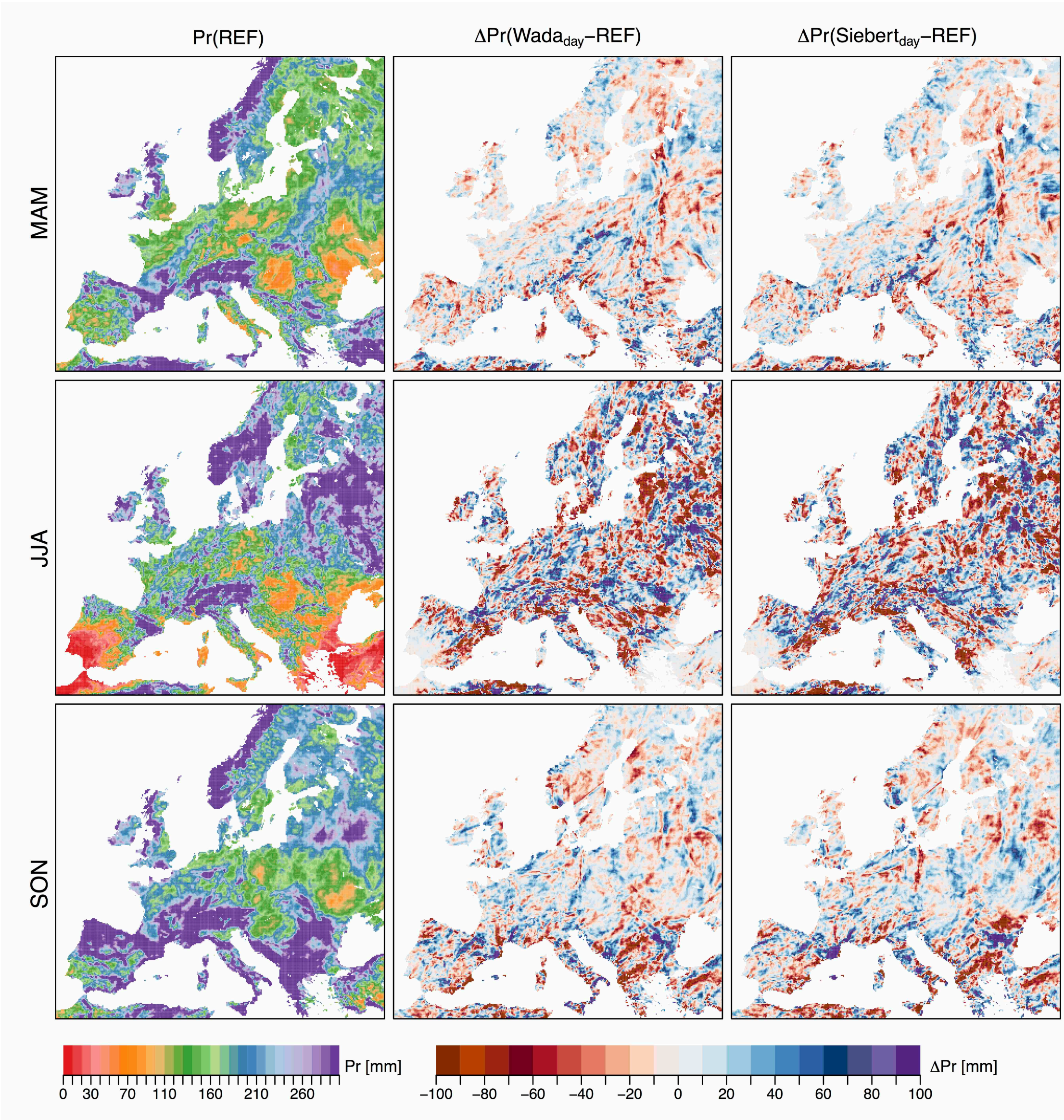

Figure 3. Seasonal precipitation of the reference simulation, and precipitation differences between the water management scenarios and the reference simulation (Δ=TerrSysMP(wateruse)-TerrSysMP(reference)), for spring (MAM), summer (JJA) and fall (SON), respectively.

First**,** it is shown that small human interventions in the terrestrial water cycle can lead to comparatively large atmospheric feedbacks. Figure 3 shows seasonal precipitation differences between the two water management simulations and the reference simulation. The feedback on precipitation exceeds in both scenarios the irrigation and groundwater abstraction amounts, as well as the direct feedback at the land surface via evapotranspiration (not shown). Remarkably, the spatial pattern of the precipitation difference of both scenarios to the reference run is very similar. The largest differences are simulated for summer precipitation with much more localized structures emerging from convective precipitation events.

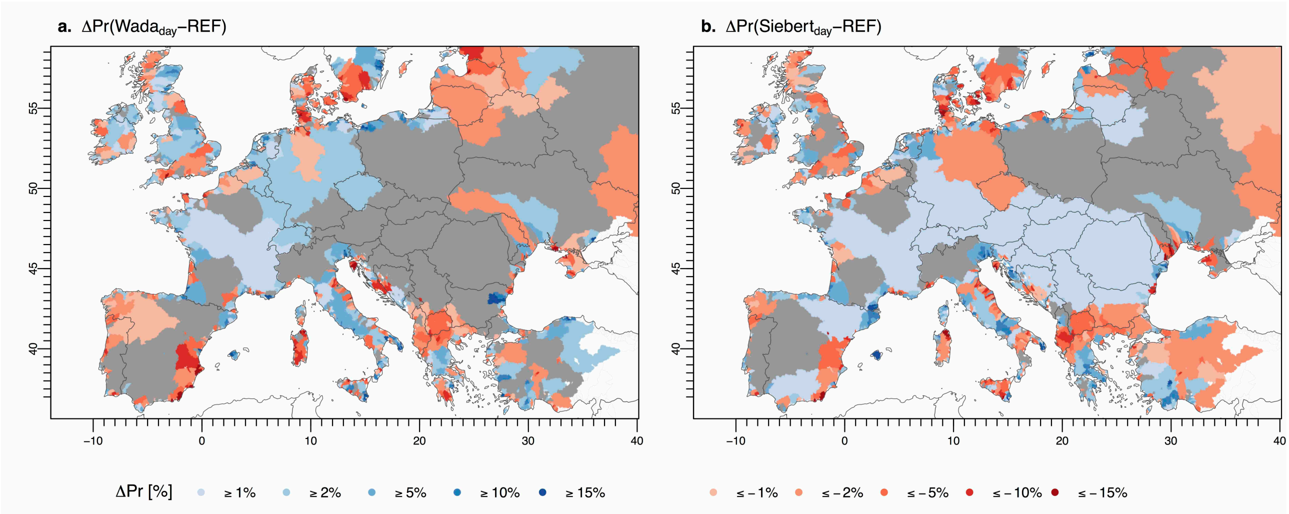

Figure 4. Annual precipitation changes [%] over European watersheds due to human water management for the two water management scenarios: **(a)** using estimates from Wada et al. (2012,2016), **(b)** using estimates from Siebert and Döll (2010) and Siebert et al. (2010). Red colours indicate a decrease of annual precipitation, blue colours indicate an increase of precipitation. Changes between -1% and 1% are considered insignificant and masked grey.

However, at the catchment scale, the difference between the two water management scenarios and hence, the uncertainty associated with the respective processes, gets clear. Figure 4 shows the annual precipitation changes over European watersheds due to human water management. Over the full year, the two water management simulations indicate significant differences in precipitation feedbacks with respect to NAT. The large watersheds on the Iberian Peninsula, such as Ebro and Guadalquivir, are an example of diverging soil moisture-precipitation feedback mechanisms. Both scenarios simulate and increase in precipitation of 1-2% over large watersheds in France, i.e. Loire and Rhone, due to human water use. In these areas, water use in Europe potentially alleviates the heat wave. Comparing the two water management simulations, there is tendency towards more precipitation in HUM2 compared to HUM1, possibly as a result of the increased irrigation amounts.

Secondly, how does the alteration of the hydrologic cycle, and the subsurface drying/wetting affect daily maximum temperatures? Figure 5 shows the annually averaged daily maximum temperature differences between the two water management simulations and the reference simulation. We observe local differences in soil moisture-temperature feedbacks, but an overall consistency between both water management scenarios for all seasons. For summer and fall, both scenarios simulate an irrigation cooling effect over Southern parts of the Iberian Peninsula with a local heating along the East coast of Spain. It is noted that this illustrates the combined effects of direct irrigation, its feedbacks on evapotranspiration and precipitation, and further the precipitation feedbacks on soil moisture and evapotranspiration. Hence, it is difficult to disentangle the source of the feedback pathways. However, the strong precipitation deficit along the East coast strongly coincides with the heating in summer and autumn.

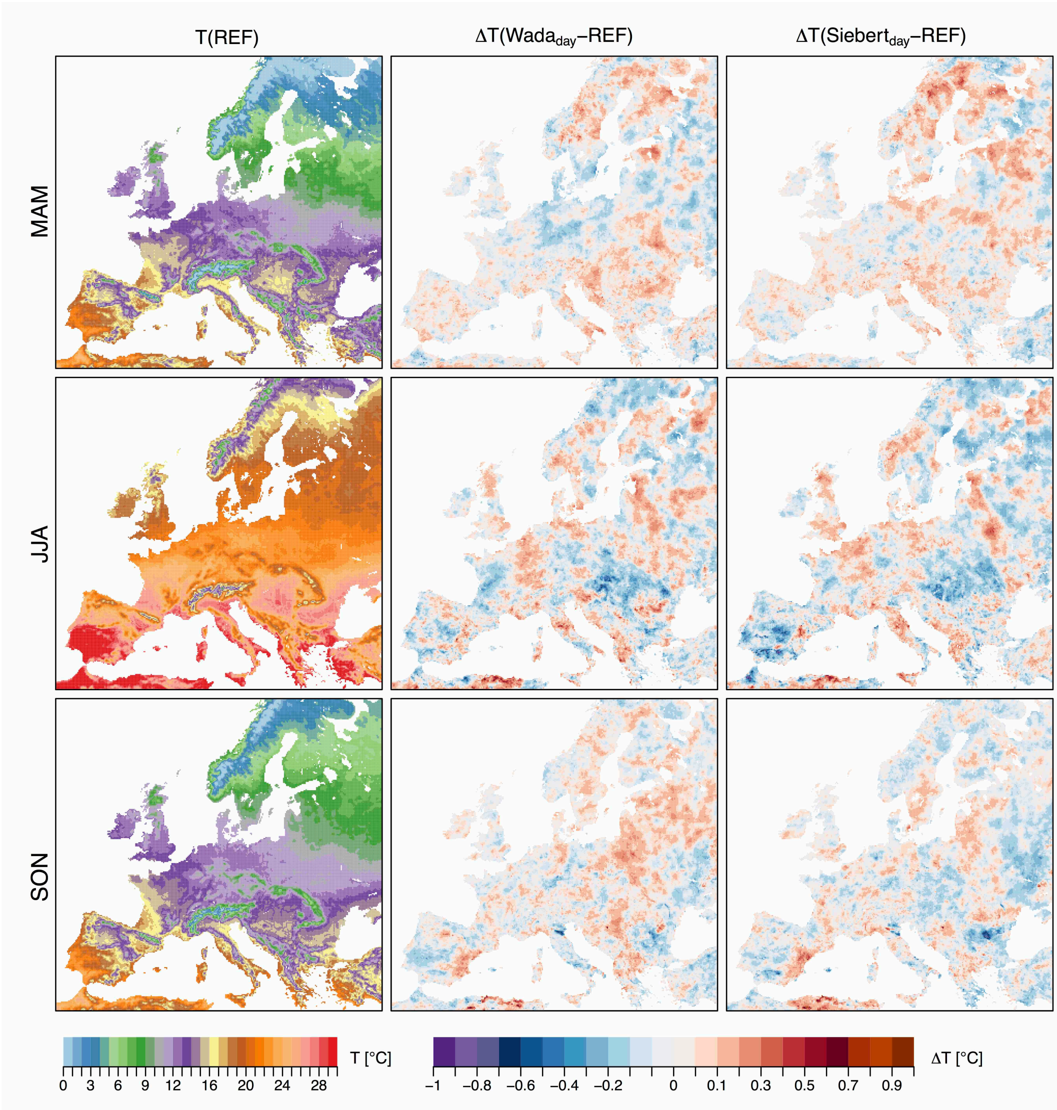

Figure 5. Seasonally averaged daily maximum 2m temperature of the reference simulation, and temperature differences between the water management scenarios and the reference simulation (Δ=TerrSysMP(wateruse)-TerrSysMP(reference)), for spring (MAM), summer (JJA) and fall (SON), respectively.

Finally, we evaluate the effect of human water use and its induced atmospheric feedbacks on heat wave duration and length. Figure 6 illustrates the response on summer days (daily maximum temperature larger than 25°C) and consecutive dry days (precipitation smaller than 1mm). Compared to the reference simulation, we simulate a shift of the heat in terms of summer days in Western parts of France. Whereas the coast areas suffer less summer days under water use conditions, Central France experiences an increase in summer days. This is consistently simulated by both water management simulations, but the spatial extend is slightly different.

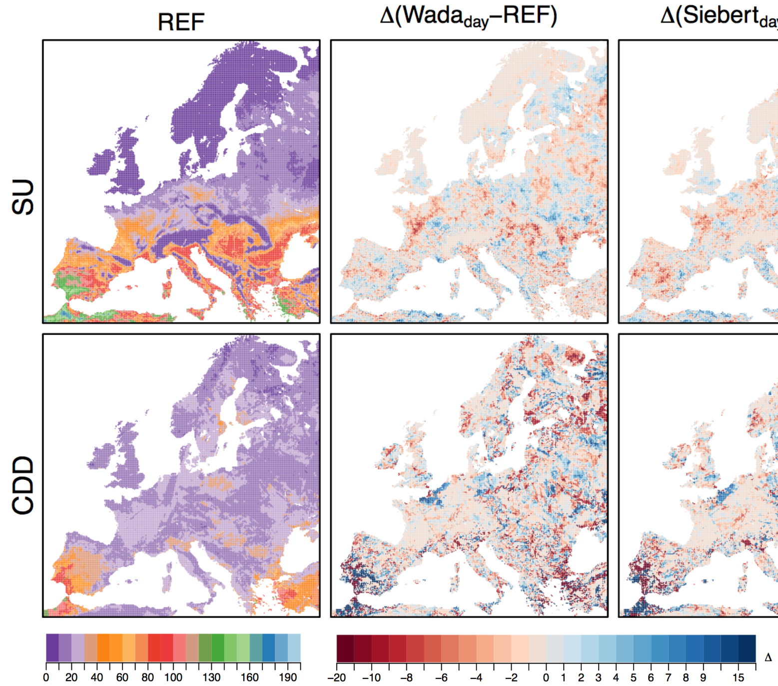

Figure 6. Summer days (SU [days]) and consecutive dry days (CDD [days]) of the reference simulation and their difference (Δ=TerrSysMP(wateruse)-TerrSysMP(reference)) for the entire year 2003.

List of publications/reports from the project with complete references

Keune, J., Gasper, F., Goergen, K., Hense, A., Shrestha, P., Sulis, M., and Kollet, S. (2016). Studying the influence of groundwater representations on land surface-atmosphere feedbacks during the European heat wave in 2003. Journal of Geophysical Research: Atmospheres. http://doi.org/10.1002/2016JD025426

Keune, J., Sulis, M., Kollet, S., Siebert, S. and Wada, Y. (2017). Potential impacts of human water management on the European heat wave 2003 using fully integrated bedrock-to-atmosphere simulations, European Geosciences Union General Assembly 2017, Vienna, oral presentation, April, 27, 2017, http://meetingorganizer.copernicus.org/EGU2017/EGU2017-12936.pdf

Summary of plans for the continuation of the project

In order to assess additional uncertainties in the feedback pathway, we are currently running two additional water management simulations, which apply irrigation and groundwater abstraction during nighttime, i.e. from 6 pm to 6 am. The simulations will be evaluated from a water-balance perspective.

For the future and a continuation of the project, long-term simulations including water management, are desirable. Additionally, we would like to expand the simulation framework including additional water management scenarios in order to address the feedback strengths and detect possible human impacts on the mitigation of extremes (Thiery et al., 2017; Leng et al., 2017).

References

Gasper, F., Goergen, K., Shrestha, P., Sulis, M., Rihani, J., Geimer, M., and Kollet, S. (2014). Implementation and scaling of the fully coupled Terrestrial Systems Modeling Platform (TerrSysMP v1.0) in a massively parallel supercomputing environment – a case study on JUQUEEN (IBM Blue Gene/Q). Geoscientific Model Development, 7(5), 2531–2543. doi:10.5194/gmd-7-2531-2014.

Keune, J., Gasper, F., Goergen, K., Hense, A., Shrestha, P., Sulis, M., and Kollet, S. (2016). Studying the influence of groundwater representations on land surface-atmosphere feedbacks during the European heat wave in 2003. Journal of Geophysical Research: Atmospheres. http://doi.org/10.1002/2016JD025426

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Siebert, S., and Döll, P. (2010). Quantifying blue and green virtual water contents in global crop production as well as potential production losses without irrigation. Journal of Hydrology, 384(3–4), 198–217.

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Shrestha, P., Sulis, M., Masbou, M., Kollet, S., and Simmer, C. (2014). A scale-consistent Terrestrial Systems Modeling Platform based on COSMO, CLM and ParFlow. Monthly Weather Review, 140422120610007. doi:10.1175/MWR-D-14-00029.1.

Thiery, W., Davin, E. L., Lawrence, D. M., Hirsch, A. L., Hauser, M., and Seneviratne, S. I. (2017). Present-day irrigation mitigates heat extremes. Journal of Geophysical Research: Atmospheres, 122(3), 1403–1422. http://doi.org/10.1002/2016JD025740

von Storch, H., Langenberg, H., and Feser, F. (2000). A Spectral Nudging Technique for Dynamical Downscaling Purposes. Monthly Weather Review, 128(10), 3664–3673.

Wada, Y., L. P. H van Beek, and M. F. P. Bierkens (2012), Nonsustainable groundwater sustaining irrigation: A global assessment, Water Resources Research, 48, W00L06, doi: 10.1029/2011WR010562.

Wada, Y., I. E. M. de Graaf, and L. P. H. van Beek (2016), High-resolution modeling of human and climate impacts on global water resources, J. Adv. Model. Earth Syst., 8, 735–763, doi: 10.1002/2015MS000618.

Supplementary Material

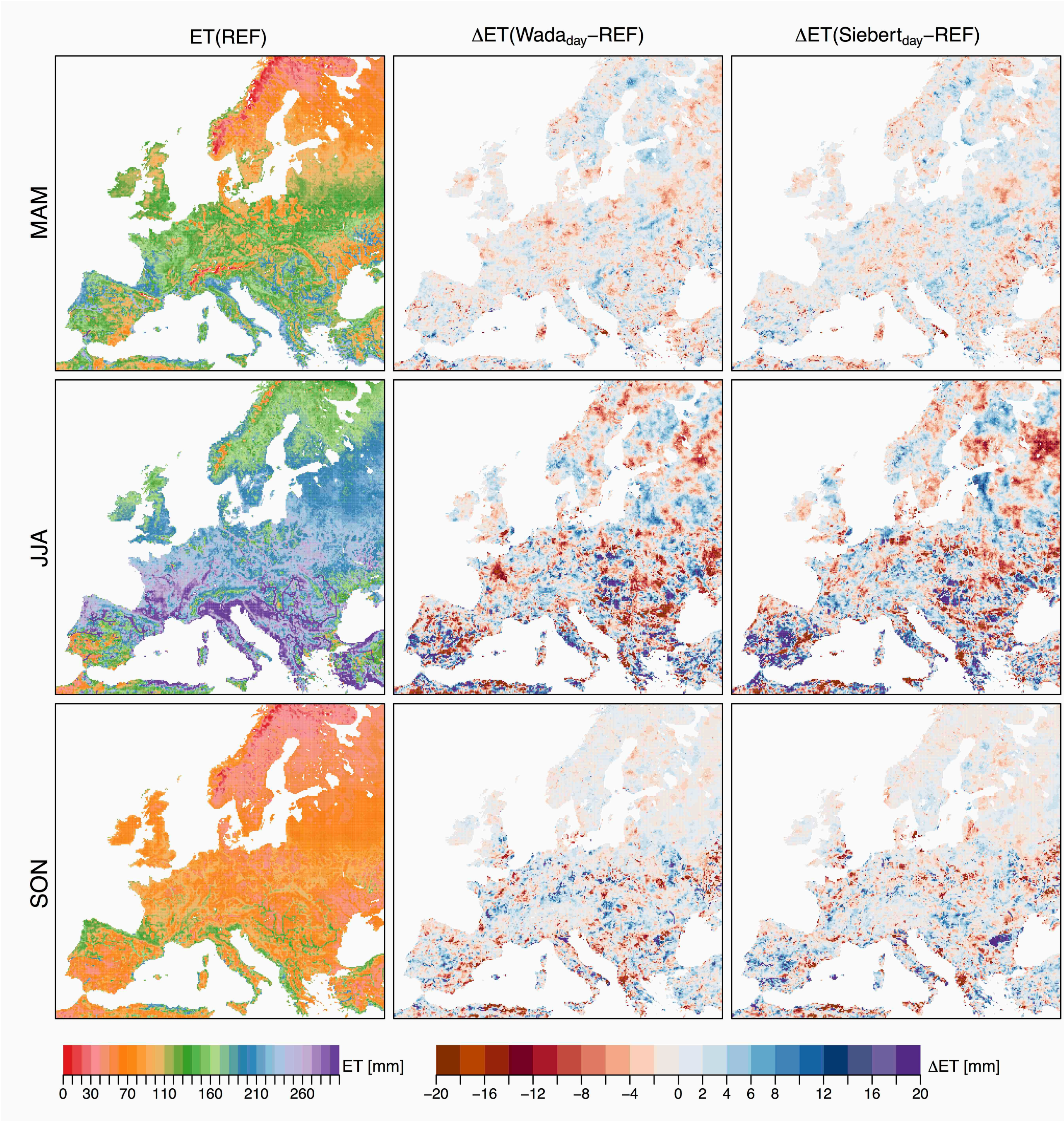

Figure S1. Seasonal evapotranspiration of the reference simulation, and evapotranspiration differences between the water management scenarios and the reference simulation (Δ=TerrSysMP(wateruse)-TerrSysMP(reference)), for spring (MAM), summer (JJA) and fall (SON), respectively.

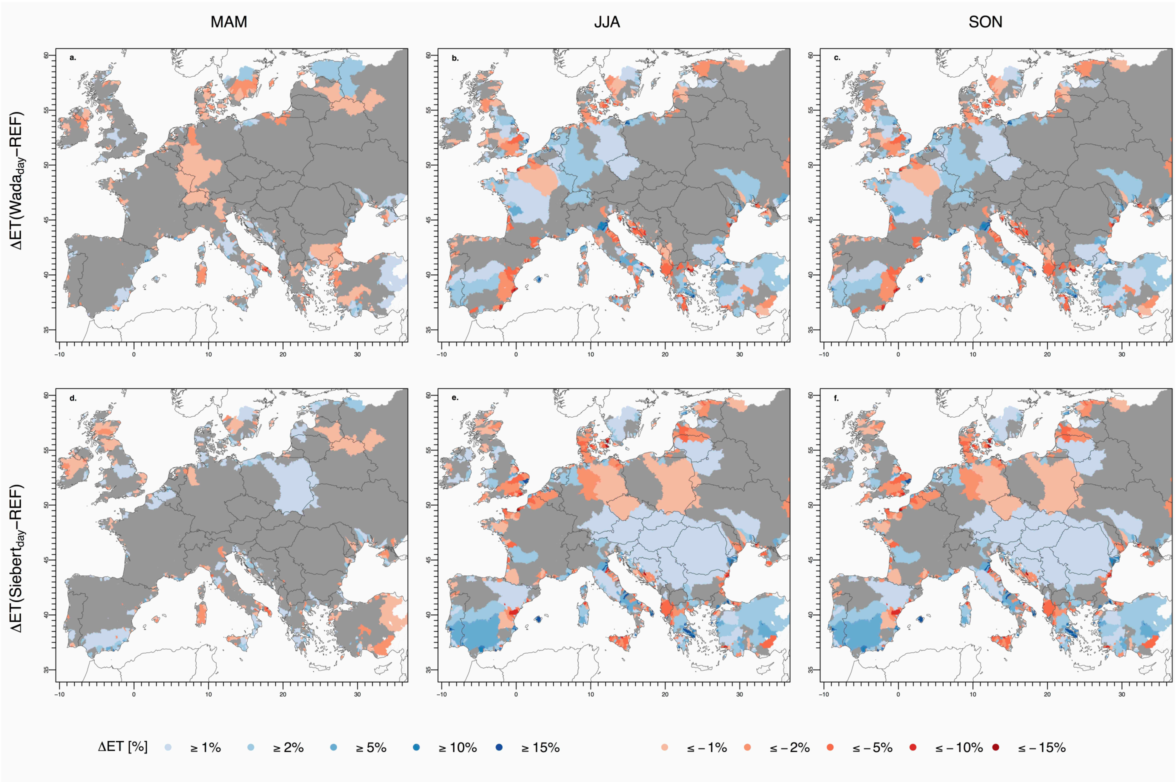

Figure S2. Seasonal evapotranspiration differences to the reference simulation (Δ=TerrSysMP(wateruse)-TerrSysMP(reference)) [%] over European watersheds for spring (MAM), summer (JJA) and fall (SON), and the two water management scenarios, using estimates from Wada et al. (2012,2016), using estimates from Siebert and Döll (2010) and Siebert et al. (2010), respectively.

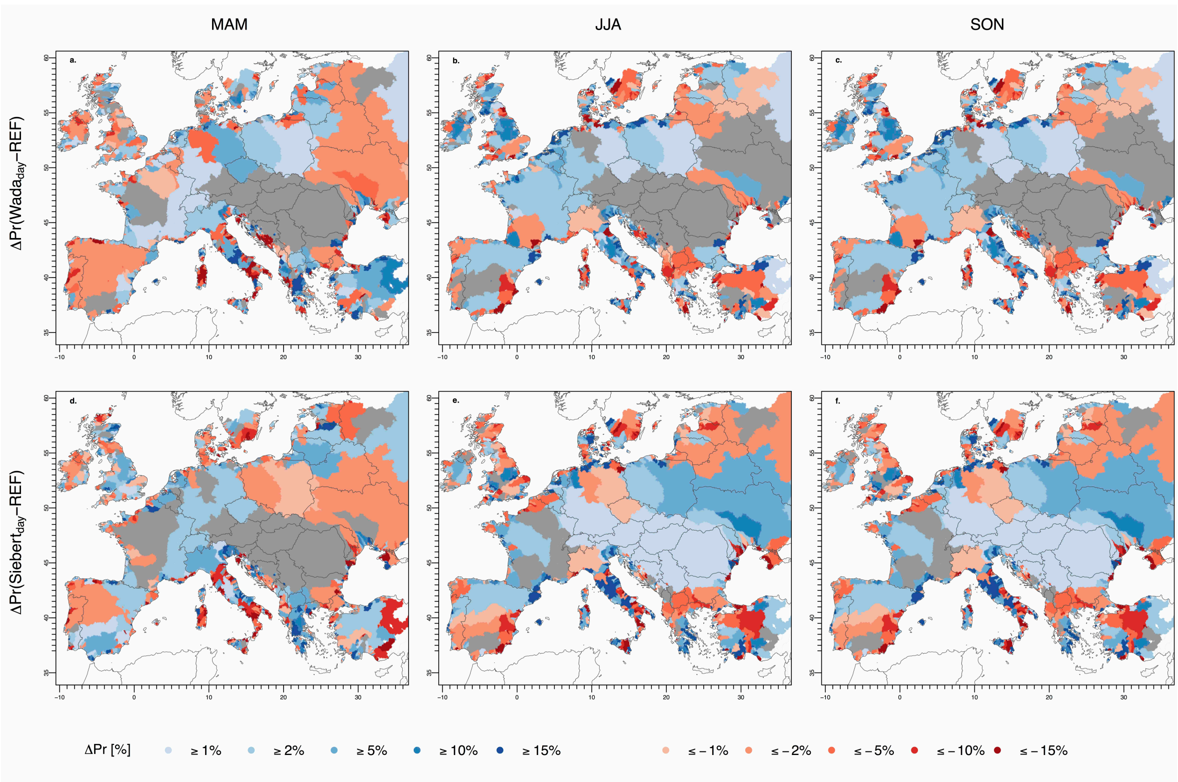

Figure S3. Seasonal precipitation differences to the reference simulation (Δ=TerrSysMP(wateruse)-TerrSysMP(reference)) [%] over European watersheds for spring (MAM), summer (JJA) and fall (SON), and the two water management scenarios, using estimates from Wada et al. (2012,2016), using estimates from Siebert and Döll (2010) and Siebert et al. (2010), respectively.