SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	2015-2016
Project Title:	The role of soil moisture and surface- and subsurface water flows on predictability of convection
Computer Project Account:	SPDEARNA
Principal Investigator(s):	Dr. Joel Arnault
Affiliation:	Karlsruhe Institute of Technology, Institute of Meteorology and Climate Research (KIT, IMK-IFU)
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Thomas Rummler, Prof. Harald Kunstmann
Start date of the project:	1 September 2015
Expected end date:	30 June 2019

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

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)			2 000 000	2 348 273
Data storage capacity	(Gbytes)			1 500	< 1000

This project is part of the DFG (German Research Foundation) Collaborative Research Center 165/1 “Wave to Weather”, funded for the period 07/2015 – 06/2019.

Summary of project objectives
(10 lines max)

- Provide soil moisture data for Germany and West Africa using the hydrologically enhanced version of the Weather Research and Forecasting (WRF) model, i.e WRF-Hydro.
- Investigate the sensitivity of simulated precipitation from NWP to this soil moisture dataset.
- Identify meteorological situations when the role of soil moisture, surface and subsurface water flows on precipitation is enhanced.
- Quantify soil moisture-related processes on precipitation with water budgets and water tracking.
- Assess the potential of a stochastic parameterization to account for soil moisture effects on boundary layer processes.

Summary of problems encountered (if any)
(20 lines max)

- The compilation of WRF-Hydro on the ECMWF computing system was not straightforward, as the “Hydro” part of the WRF-Hydro code does not support OPENMP. A successful porting could be done thanks to the help of Carsten Maas.
- Some model bugs making the code crash after a few days of simulation where identified and fixed. All these tests used about 1 100 000 SBU.
- A new WRF-Hydro setup has been selected, with a rotated pole grid of 550x550 points at 2.8 km resolution and 50 vertical levels for the atmosphere, and a horizontal grid of 5500x5500 points at 280 m resolution with four soil layers for the terrestrial hydrology. This is to facilitate collaboration with other projects of “Wave to Weather” (W2W) investigating the effect of surface variability on convective precipitation with COSMO-DE. This setup was not originally planned because the technique to construct the hydrological grid, including the river network, on a rotated pole grid was not known by the members of this project at that time. However, this setup is much more computational demanding than the original setup (see the request for additional resources). So far a 9-month simulation in 2014 could be done, which used about 1 200 000 SBU. The plan is to extend this simulation to the end of 2016 in order to cover the heat wave episode of 2015 in Germany, and potential case-studies related to the W2W field campaign in September-October 2016. Additional resource is therefore necessary to continue this project.

Summary of results of the current year (from July of previous year to June of current year)
This section should comprise 1 to 8 pages and can be replaced by a short summary plus an existing scientific report on the project

A 9-month WRF-Hydro simulation has been conducted on the Cray for the period January-October 2014. Soil moisture data derived from this simulation are used to investigate the impact of soil moisture initial condition on short term simulations (<36 hours) with WRF and WRF-Hydro. The comparison between WRF and WRF-Hydro short term simulations allows to investigate the role of resolved lateral water flows on precipitation. Section 1 describes the “long term” WRF-Hydro simulation used for deriving a soil moisture dataset. Developed methods to quantify soil moisture-precipitation interaction in short term simulations are detailed in section 2. Results for a case-study on 8 July 2014, when strong precipitation occurred all over Germany, are finally given in section 3.

1. WRF-Hydro "long term" simulation for deriving a soil moisture dataset

a – Model setup

In this setup atmospheric processes are resolved with the Weather Research and Forecasting WRF model (Skamarock and Klemp 2008) on a rotated pole grid at 2.8 km resolution (Fig. 1a) with 50 vertical levels, a model top at 10 hPa and a timestep of 10s, and surface fluxes are determined with the one-dimensional Noah Land Suface column model (Chen and Dudhia 2001). Overland flow, streamflow and subsurface flow are additionally computed on a so called "routing grid" at 280 m resolution (Fig. 1b). Soil moisture and surface water are successively disaggregated / aggregated between the two grids in order to include feedbacks of the additionally resolved soil moisture processes on the simulated atmosphere (Gochis et al. 2014).

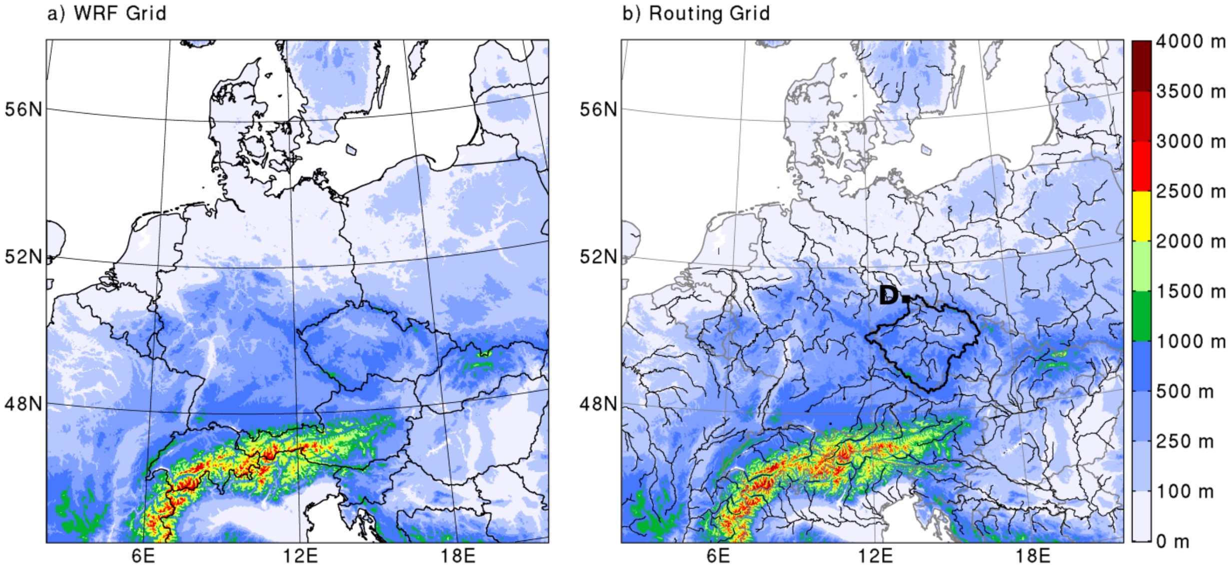


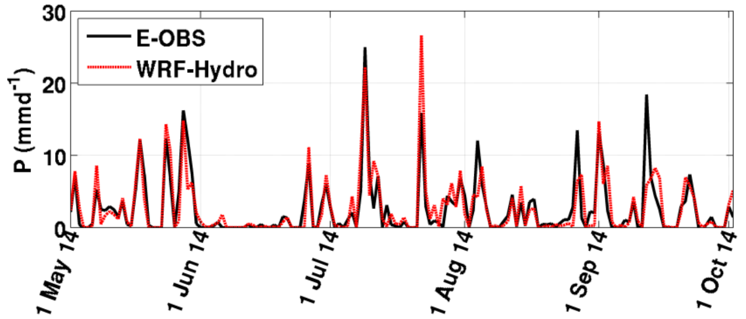
Figure 1. *a) Topography of the WRF domain at 2.8 km resolution. b) Topography of the routing grid at 280 m resolution. Thin black lines indicate river channels. The bold black contour gives the Elbe river catchment with an outlet at Dresden (see letter D)*

At the initial and lateral boundary conditions the WRF domain is forced with the ECMWF operational analyses. A suitable physical parameterization setup has been identified from an ensemble of simulations for 2008 conducted on the computing facility of the Karlsruhe Institute of Technology KIT (ForHLR1). The selected setup includes the boundary layer parameterization from Pleim (2007), the microphysical scheme from Hong and Lim (2006), and the long and short-wave radiation schemes from Mlawer et al. (1997) and Dudhia (1989), respectively. WRF-Hydro specific parameters have been tuned based on experiences from Arnault et al. (2016a). On the ECMWF computing facility this setup has been run for a 9-month period in 2014.

b – Preliminary results

Results for the Elbe river catchment (see bold black contour in Fig. 1b) for the period May-September are shown in Fig. 2, as an example. The first four months of the simulation are considered as a spinup time for soil moisture. Catchment-averaged daily time series of precipitation are relatively close to that from the E-OBS dataset (Haylock et al. 2008), with a correlation coefficient of 0.84 and a total volume difference of 4 % for the considered 5-month period (Fig. 2a). WRF-Hydro-derived discharge at Dresden is also shown (Fig. 2b), although the gauge data from the Global Runoff Database Center (GRDC) is not yet available to assess this result. It is noted here that Nash-Sutcliffe Coefficients (NSC) ranging from 0 to 0.8 where obtained for simulations using a similar setup conducted at ForHLR1 for 2008 (not shown).

a) Precipitation in Elbe-Dreseden catchment



b) Discharge at Elbe-Dreseden

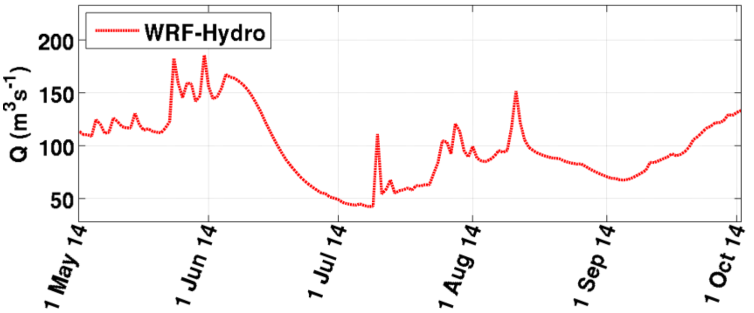


Figure 2. *a) Daily time series of precipitation averaged for the Elbe river cachment (see location in Fig. 1b), from E-Obs and a WRF-Hydro simulation initialized on 00 UTC 1 January 2014. b) Daily discharge at Dresden (see location in Fig. 1b) from WRF-Hydro.*

Soil moisture can be derived for each output of this WRF-Hydro simulation, at an hourly interval in this case. Fig. 3 displays the soil moisture field at 00 UTC 8 July 2014 from the ECMWF (a) and from the WRF-Hydro simulation (b). This date is shown here as it corresponds to the initial condition of the case-study investigated in section 3.

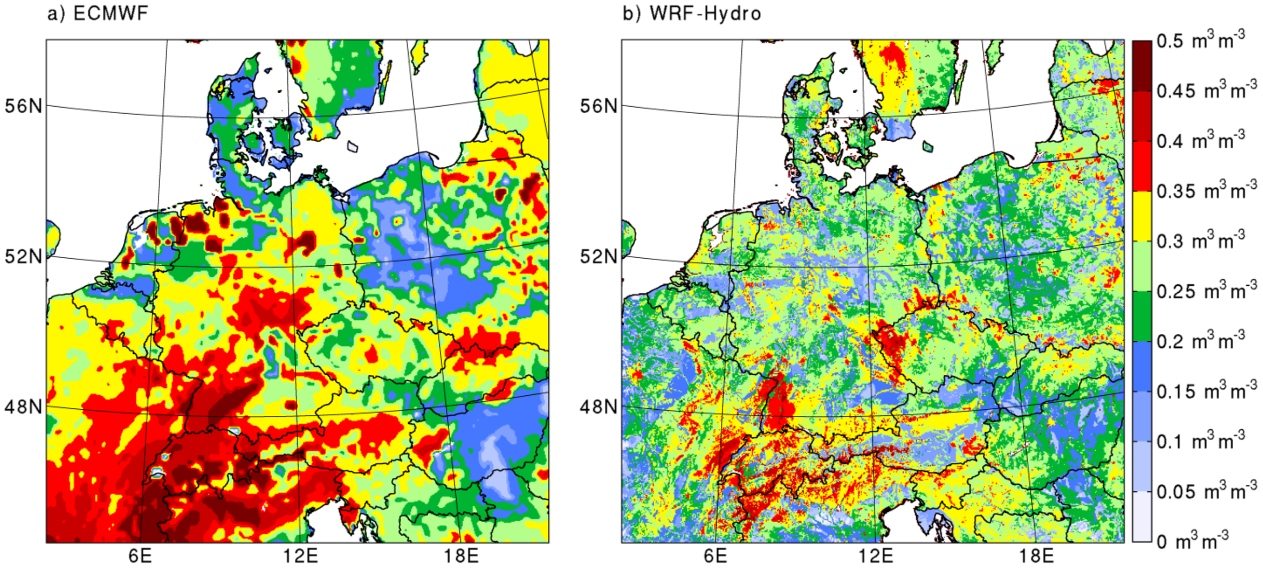


Figure 3. *a) Soil moisture at 00 UTC 8 July 2014 from the ECMWF operational analysis. b) As in a), except from a WRF-Hydro simulation initialized on 00 UTC 1 january 2014.*

2. Developed methods for quantifying soil moisture-precipitation interaction

a – Precipitation tagging

In order to quantify and compare physical processes resolved in WRF and WRF-Hydro simulations, it has been decided to develop an online tagging method to track precipitation, first in the soil, and second in the atmosphere if this precipitation eventually re-evaporates. This water tagging requires a soil moisture tagging method recently developed in WRF/WRF-Hydro, and a surface evaporation tagging method that was already available (Arnault et al. 2016b). It is noted here that the surface evaporation tagging from Arnault et al. (2016b) was only available for the 5-class Single Moment Microphysic scheme (WSM5) and the YSU PBL scheme from Hong et al. (2006). This has been updated to other physical parameterizations considered in this study, which are the 6-class Single Moment Microphysic scheme (WSM6) from Hong and Lim (2006) including graupel, and the Asymmetrical Convective Model V.2 (ACM2) and the Mellor-Yamada-Janjic (MYJ) boundary layer schemes from Pleim (2007) and Janjic (1994), respectively.

Furthermore, tagging results are quantified with a joint tagged atmospheric-terrestrial budget analysis implemented in WRF/WRF-Hydro, adapted from Arnault et al. (2016b).

$$\begin{aligned} \textit{source precipitation} = \; & \textit{tagged soil storage change} \\ & + \textit{tagged surface runoff} \\ & + \textit{tagged evaporation/sublimation} \\ & + \textit{tagged atmospheric water change} \\ & + \textit{tagged atmospheric water transport} \\ & + \textit{tagged precipitation} \\ & + \textit{residuum} \end{aligned} \qquad \textit{Eq. 1}$$

Eq. 1 relates the source precipitation to be tracked, for example the precipitation falling on land, to other soil-atmospheric water fluxes: tagged soil storage change, tagged surface runoff, tagged evaporation/sublimation, tagged atmospheric water changed, tagged atmospheric water horizontal transport, tagged precipitation, and a residuum.

b – Joint atmospheric-terrestrial budget

In order to further assess the impact of soil moisture initial condition and additionally resolved soil moisture processes on precipitation, it has been chosen to jointly analyse the online atmospheric water budget (Eq. 2) based on Arnault et al. (2016b), with the terrestrial water budget (Eq. 3) available in original model outputs.

$$\begin{aligned} \textit{soil storage change} = \; & \textit{precipitation} \\ & - \textit{evaporation/sublimation} \\ & - \textit{surface runoff} \\ & + \textit{residuum} \end{aligned} \qquad \textit{Eq. 2}$$

$$\begin{aligned} \textit{atmospheric water change} = \; & \textit{evaporation/sublimation} \\ & - \textit{precipitation} \\ & + \textit{atmospheric water horizontal transport} \\ & + \textit{residuum} \end{aligned} \qquad \textit{Eq. 3}$$

3. Case-study

a – Precipitation recycling

The case of 8 July 2014 is simulated with the WRF model using default soil moisture initial condition (Fig. 3a), and land precipitation tagging. Terms of Eq. 1 computed for the 24-hour period are shown in Fig. 4 (the residuum, one order of magnitude below the other terms, is not shown).

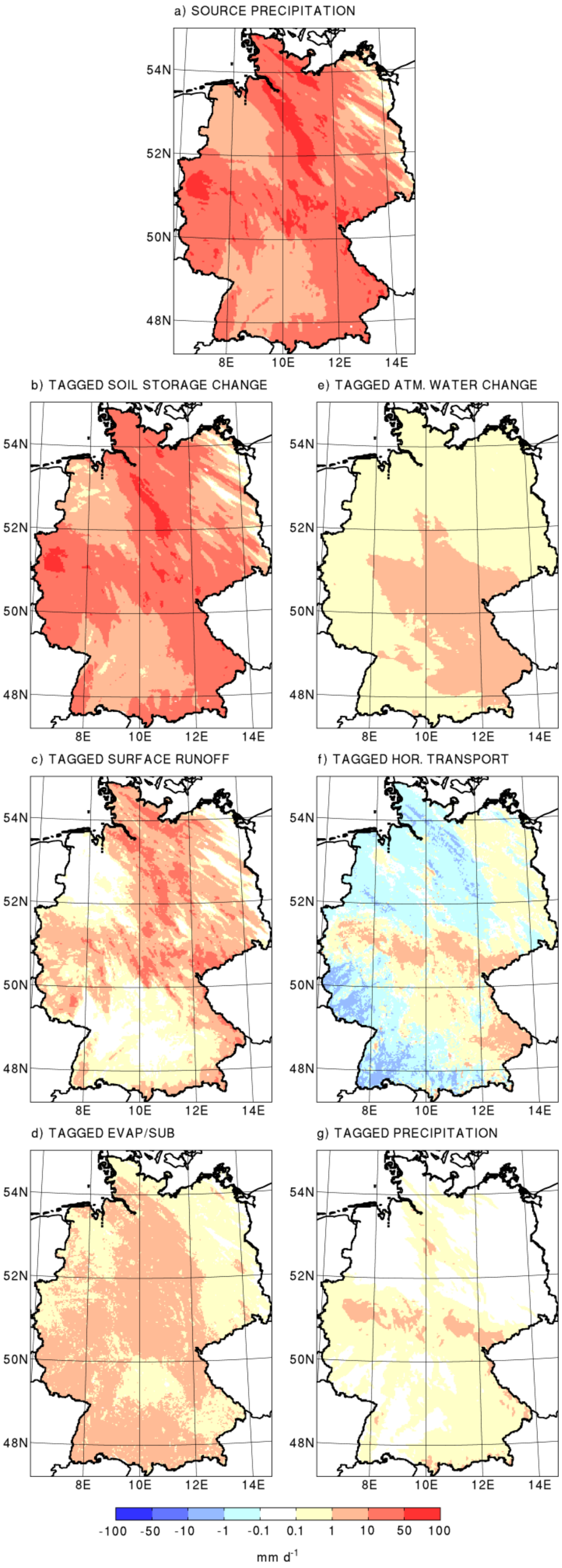


Figure 4. *Terms of Eq. 1 in mm d^{-1} plotted on a subdomain covering Germany, summed for a 24 hour- period on 8 July 2014, computed from a WRF simulation initialized on 00 UTC 8 July 2014.*

It shows that part of the precipitation falling during the day (Fig. 4a) does evaporate within the same day (Fig. 4d), and even contributes to precipitation during this day (Fig. 4g), with a recycling up to 5% in some areas (not shown).

b – Impact of soil moisture initial condition

The case of 8 July 2014 is simulated with the WRF model using default and enhanced soil moisture initial condition (Fig. 3a and 3b, respectively). The joint atmospheric-terrestrial water budget of Eq. 2 and 3 is then computed as the difference between these two simulations (Fig. 5). The evaporation/sublimation term (Fig. 5c) is mainly negative, in relation with the fact that the default initial soil moisture condition (Fig. 3a) is wetter than the WRF-Hydro-derived one (Fig. 3b). Accordingly, the WRF simulation initialized with WRF-Hydro soil moisture produces less evaporation/sublimation, up to 1 mm d^{-1}. On the other hand precipitation differences are rather related to differences in the atmospheric water transport term and soil storage change (compare Figs 5a, 5e and 5f). This suggests that soil moisture initial condition-induced differences in evaporation/sublimation did affect the atmospheric circulation, so that differences in precipitation would be mainly a consequence of perturbed atmospheric water transport. Differences in the soil storage change term would then be a consequence of the modified precipitation field.

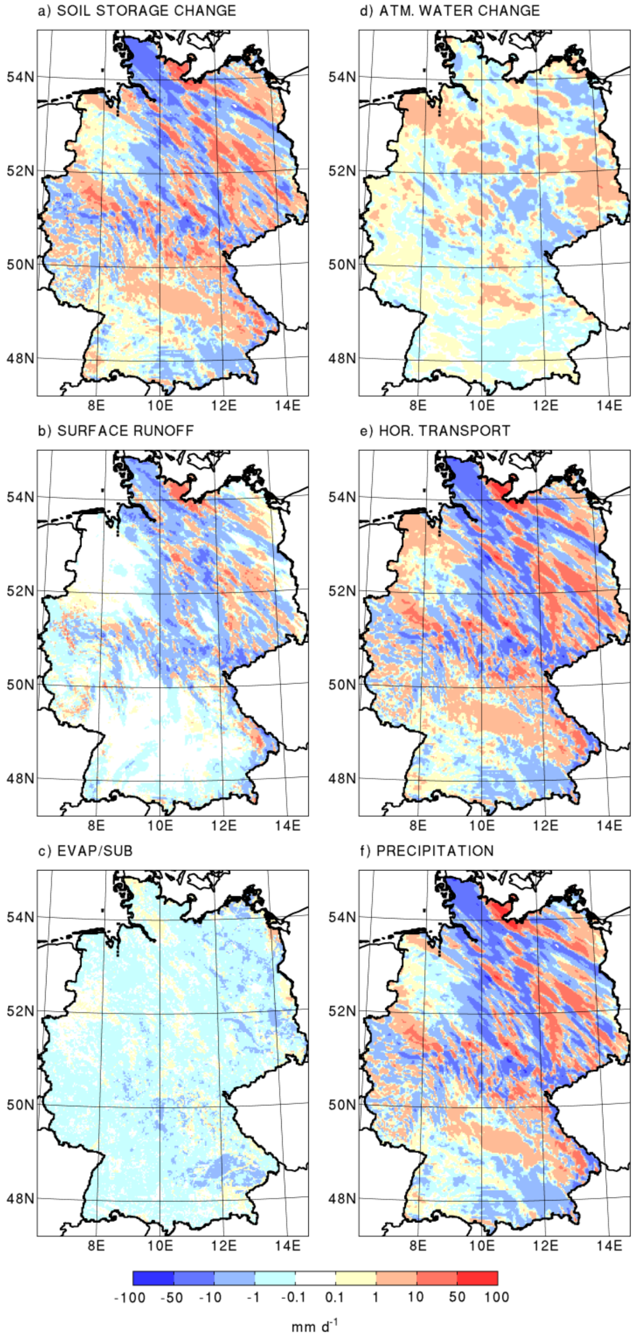


Figure 5. *Terms of Eqs. 2 and 3 in mm d^{-1} on a subdomain covering Germany, summed for a 24 hour-period on 8 July 2014, computed as the difference between a WRF simulation initialized with default soil moisture (Fig. 3a), and a WRF simulation initialized with WRF-Hydro soil moisture (Fig. 3b).*

c – Impact of resolved lateral water flows

The case of 8 July 2014 is simulated with both WRF and WRF-Hydro models. The joint atmospheric-terrestrial water budget of Eq. 2 and 3 is then computed as the difference between these two simulations (Fig. 6). The surface runoff term (Fig. 6b) is mainly negative, in relation with the fact that WRF-Hydro redistributes most of the WRF surface runoff to the soil. This is probably more realistic since WRF-Hydro is able to simulate river discharge (Fig. 2b), but not WRF. On the other hand induced differences in evaporation/sublimation are very small (Fig. 6c), so that differences in precipitation are mainly related to differences in atmospheric water transport (compare Figs. 6e and 6f), as in previous case (section 3b, Fig. 5). It is questionable here by which mechanisms these perturbations in atmospheric water transport amplify, and if there is a difference from case to case?

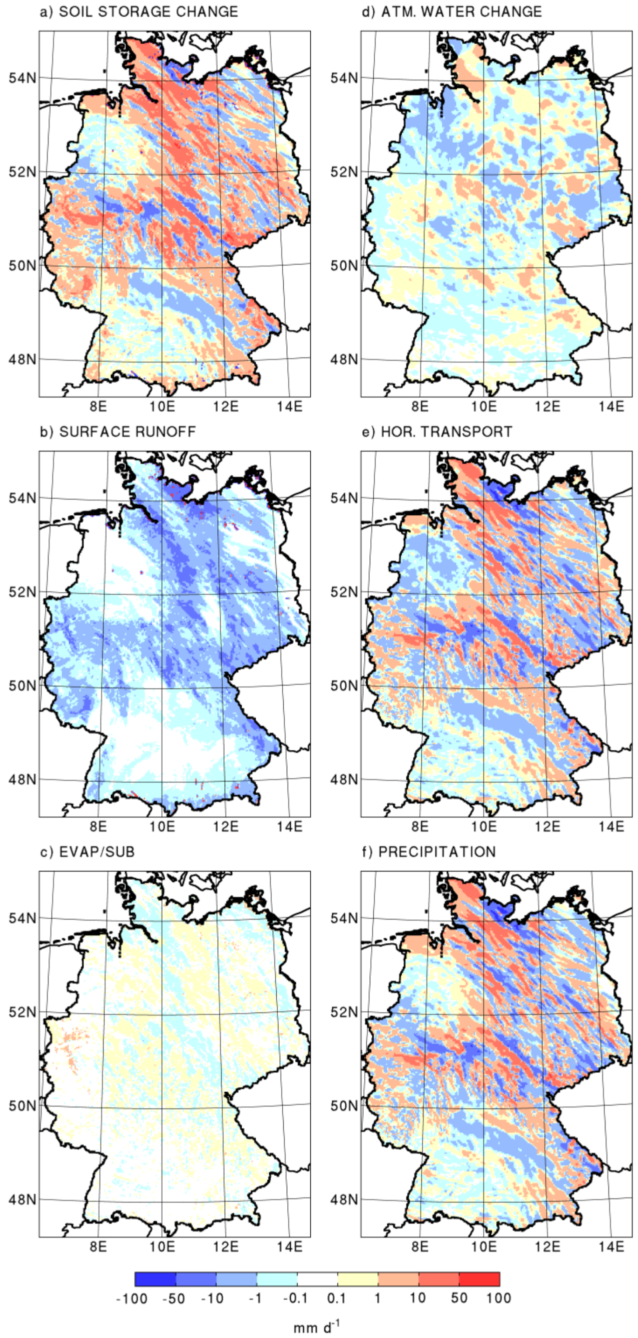


Figure 6. *As in Fig. 5, except between WRF-Hydro and WRF simulation.*

Bibliography

Arnault, J., S. Wagner, T. Rummler, B. Fersch, J. Bliefernicht, S. Andresen, and H. Kunstmann, 2016a: Role of runoff-infiltration partitioning and resolved overland flow on land-atmosphere feedbacks: A case-study with the WRF-Hydro coupled modelling system for West Africa. J. Hydrometeor.

Arnault, J., R. Knoche, J. Hui, and H. Kunstmann, 2016b: Evaporation tagging and atmospheric water budget analysis with WRF: A regional precipitation recycling study for West Africa. Water Resour. Res.

Chen, F., and J. Dudhia, 2001: Coupling an Advanced Land Surface-Hydrology Model with the Penn State-NCAR MM5 Modeling System. Part I: Model Implementation and Sensitivity. Mon. Wea. Rev., 129, 569-585.

Dudhia, J.,1989: Numerical study of convection observed during the Winter Monsoon Experiment using a mesoscale two-dimensional model. J. Atmos. Sci., 46, 3077-3107.

Gochis, D. J., Yu, W., Yates, D. N., 2014. The WRF-Hydro model technical description and user's guide, version 2.0. NCAR Technical Document. 120 pages. Available at: WRF-Hydro 2.0 User Guide.

Haylock, M. R., N. Hofstra, A. M. G. Klein Tank, E. J. Klok, P. D. Jones, and M. New, 2008: A European daily high-resolution gridded dataset of surface temperature and precipitation. J. Geophys. Res (Atmospheres), **113**, D20119.

Hong, S.-Y., J. Dudhia, S.-H. Chen, 2004: A Revised Approach to Ice Microphysical Processes for the Bulk Parameterization of Clouds and Precipitation. Mon. Wea. Rev., 132, 103-120.

Hong S.-Y. and J. J. Lim, 2006: The WRF single-moment 6-class microphysics scheme (WSM6). Korean Meteorol Soc 42:129–151.

Janjic Z. I., 1994: The step-mountain eta coordinate model: further developments of the convection, viscous sublayer and turbulence closure schemes. Mon Weather Rev 122:927–945.

Mlawer, E. J., S. J. Taubman, P. D. Brown, M. J. Iacono, and S. A. Clough, 1997: Radiative transfer for inhomogeneous atmosphere: RRTM, a validated correlated-k model for the long-wave. J. Geophys. Res. 102(D14), 16663–16682.

Pleim J. E., 2007: A combined local and non-local closure model for the atmospheric boundary layer. Part 1: model description and testing. J Appl Meteorol Clim 46:1383–1395.

Skamarock, W. C. and J. B. Klemp, 2008: A time-split nonhydrostatic atmospheric model for weather research and forecasting applications. J. Comp. Phys., 227, 3465-3485.

List of publications/reports from the project with complete references

Arnault, J., T. Rummler, H. Kunstmann, 2016: Precipitation- and soil moisture variability in Germany: Fully coupled WRF-Hydro vs. standard WRF, European Geosciences Union General Assembly 2016, Vienna, poster presentation, April, 20, 2016, http://meetingorganizer.copernicus.org/EGU2016/EGU2016-9266.pdf

Summary of plans for the continuation of the project

(10 lines max)

- Extend this simulation to the end of 2016 in order to cover the heat wave episode of 2015 in Germany, and potential case-studies related to the W2W field campaign in September-October 2016. It is indeed expected that resolved lateral water flows play a larger role on precipitation when soils are dry (Arnault et al. 2016).
- Further validate the long term WRF-Hydro simulation with additional datasets (GRDC: discharge, SMAP: soil moisture)
- Conduct ensemble simulations of more case-studies in order to further understand in which cases and by which mechanisms the role of soil moisture and lateral water flows on precipitation is enhanced
- Apply the methodology to West African cases and compare