

SPECIAL PROJECT PROGRESS REPORT

Reporting year 2016

Project Title: Integrated Simulations of the Terrestrial System over the European CORDEX domain

Computer Project Account: SPDEKOLL

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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

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)			30.000.000	2.755.000
Data storage capacity	(Gbytes)			60.000	12.000

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 will be 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. In the beginning, event-based simulations are performed, focusing on the floods in the early summer of 2013 and 2014, and the heat wave in 2003.

Summary of problems encountered

Due to the upgrade of the CCA to Broadwell processors and associated update of libraries, we encountered some problems in getting TerrSysMP running after the update. However, the ECMWF user desk was very helpful and we were able to solve the problems efficiently. In addition, we observed slow runtimes of our atmospheric model COSMO (version 4.21 within TerrSysMP) when applying spectral nudging. The problem itself and the mitigation is described in the following section.

Summary of results of the current year

The results of the project in the first half of 2016 are a continuation of previous work in 2015. Here, a better performance of the code is pursued, especially with regard to the applied spectral nudging. This technical progress is summarized in the first part (technical progress). In addition, the spinup of the hydrological compartments of TerrSysMP is ongoing and almost finished. Therefore, we are well in line with the proposed workplan. The evaluation of these simulations is briefly summarized in the second part (evaluation).

1. Technical progress

Setup

First, the Terrestrial Systems Modelling Platform, TerrSysMP version 1.0 (Shrestha et al., 2014; Gasper et al., 2014), which is based on the multiple program multiple data paradigm, was ported to the CCA including all necessary input data sets. The build environment was adapted to the specific machine configuration and the system was successfully compiled using GNU compilers. The modelling system was setup over the European CORDEX domain and test simulations were performed and checked for consistency.

Furthermore, the ECFLOW workflow was improved. It includes (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 elaborated post-processing of simulation results of all three models.

Spectral Nudging

For the long-term simulations carried out at the end of 2016 and in 2017, the spectral nudging technique will be applied. In previous studies, it was found that the domain size and position of the European CORDEX domain allows for large internal variability if only lateral atmospheric boundary conditions are used, similar to studies from Miguez-Macho et al. (2004).

This internal variability impedes local (grid point to grid point) sensitivity studies of subsurface-land-atmosphere feedbacks, which are the focus of future long-term simulations. In order to overcome this challenge, the spectral nudging technique (von Storch et al., 2000; Miguez-Macho et al., 2004) is used to drive the atmospheric model not only at the lateral boundaries but furthermore impose large-scale patterns from the low-resolution driver within the domain. This technique is increasingly used in the context of dynamical downscaling and regional climate modelling and can be used to correct possible biases occurring in, e.g., precipitation, in time and space (Miguez-Macho et al., 2004). In the present case, TerrSysMP is nested into ERA-Interim and consequently, the spectral nudging technique is used to keep the inner domain large-scale patterns comparable to ERA-Interim reanalyses.

A few simulations with varying spectral nudging parameters (i.e., wave length and nudging coefficient) have been performed with TerrSysMP v1.0 in order to test the sensitivity to these parameters. Only small differences between the simulations with spectral nudging were observed, but significant improvements of the large-scale patterns were shown. Figure 2 shows the temporally averaged spatial kinetic energy spectra for the respective experiments, and that large-scale patterns follow ERA-Interim more closely..

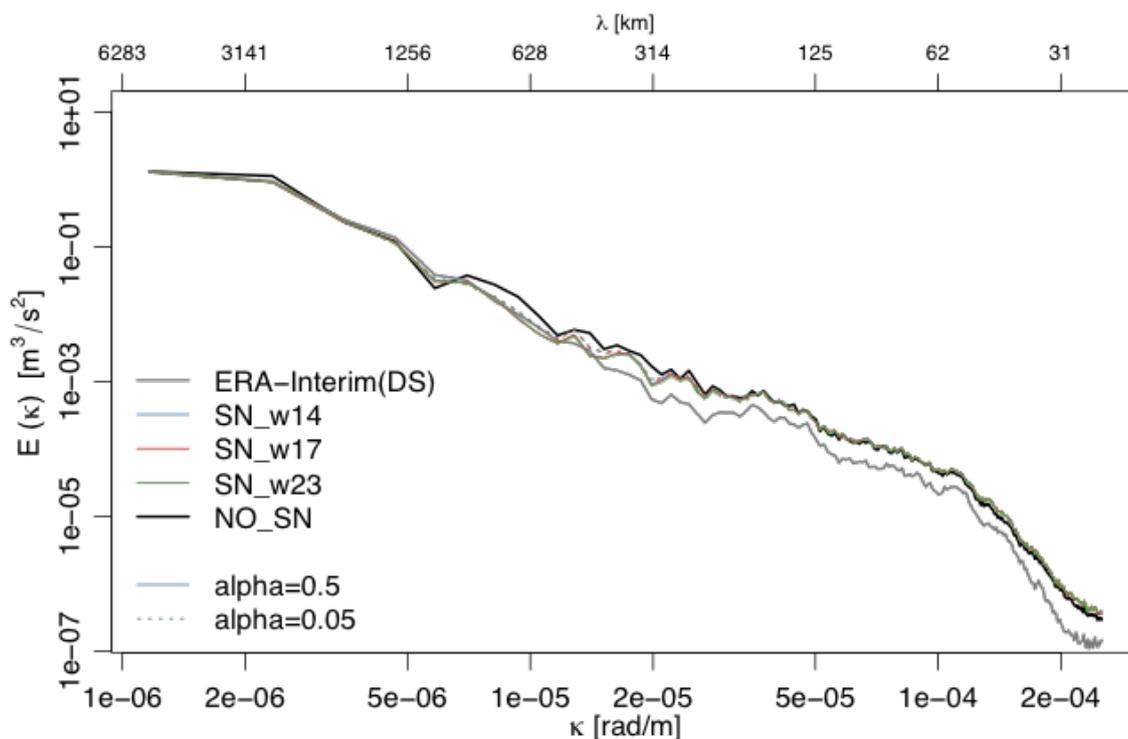


Figure 1. Temporally averaged spatial kinetic energy spectra for the downscaled ERA-Interim fields, the TerrSysMP reference simulation and the spectral nudging experiments.

However, significant differences in the runtime of the atmospheric weather prediction model COSMO (4.21) were observed. Figure 1 shows the runtime of the spectral nudging experiments with varying wave numbers (i.e., 14, 17, and 23) and varying spectral nudging coefficients (alpha=0.05 and alpha=0.5) relative to a free forecast (ref), where only lateral boundaries are imposed. In the present case, the runtime was at least doubled when spectral nudging was applied.

In order to identify the source of the increased runtime, 4 test simulations over 24 hours were setup, i.e. COSMO v4.21 standalone (with and without spectral nudging) and the fully coupled system (ParFlow-CLM-COSMO4.21, with and without spectral nudging). The spectral nudging (wave number 14, alpha=0.5) is applied consistently at the default time increment. Table 1 summarizes the setup and the respective runtimes.

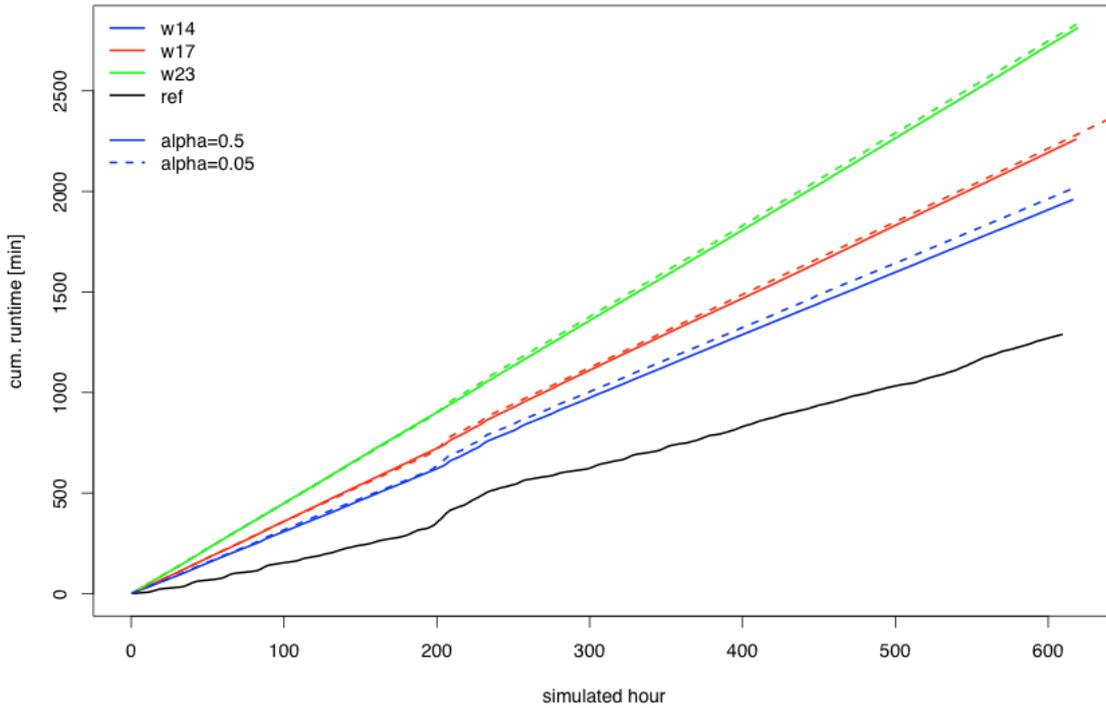


Figure 2. Runtime of the spectral nudging experiments over 1 month with varying wave numbers (14, 17 and 23) and varying spectral nudging coefficients (0.05 and 0.5), relative to the runtime of a reference run without spectral nudging.

Table 1. Runtime for a 24-hour simulation using COSMO 4.21 standalone or in the fully coupled system.

			COSMO_REF	COSMO_SN	FULL_REF	FULL_REF2	FULL_SN
Setup	Model setup	COSMO 4.21	X	X			
		TerrSysMP			X	X	X
	Spectral Nudging			X			X
		frequency	-	t=1	-	-	t=1
	Number of procs (nodes)	COSMO 4.21	324 (9)	324 (9)	324 (9)		324 (9)
		CLM			36 (1)	36 (1)	36 (1)
		ParFlow			36 (1)	144 (4)	36 (1)
Total		324 (9)	324 (9)	396 (11)	504 (14)	396 (11)	
Runtime [s]	COSMO	500	4397	932	525	4494	
	Average /h	20	183	38	22	187	

We found that the spectral nudging technique implemented in COSMO 4.21 does not account for a spectral nudging frequency. Thus, the 3-hourly boundary data fields were interpolated in time to the 60s-time step applied in COSMO. This resulted in increased runtimes.

In order to avoid this interpolation, COSMO 5.1 was setup on the CCA and the same experiments, using COSMO standalone, were repeated. Table 2 summarizes the runtime of COSMO 4.21 and COSMO 5.1 for the respective experiments, additionally varying the spectral nudging frequency in COSMO 5.1.

Table 2. Runtime for the same 24-hour simulation using COSMO 5.1 and in comparison to COSMO 4.21 (both standalone).

		COSMO 4.21		COSMO 5.1		
		COSMO_REF	COSMO_SN_1	COSMO_REF	COSMO_SN_1	COSMO_SN_30
Setup	Spectral nudging frequency	-	X t=1	-	X t=1	X t=30 (half-hourly)
	Number of procs (nodes)	324 (9)	324 (9)	324 (9)	324 (9)	324 (9)
Runtime [s]	COSMO	500	4397	576	1908	617
	Average /h	20	183	24	79	25

Significant improvements in runtime are observed for COSMO 5.1 due to improved interpolation and spectral nudging subroutines. Consequently, we pursue using COSMO 5.1 within TerrSysMP. Here, some technical implementations are currently done and will soon be finished. In the meantime, the sensitivity of simulations to the spectral nudging frequency is tested in more detail.

2. Evaluation

In addition, the event-based simulations with TerrSysMP and the spinup are ongoing. We evaluate the simulated soil moisture fields during the heatwave 2003 with combined soil moisture measurements from ESA-CCI (Dorigo et al., 2015), which were updated recently and contain newly retrieved AMSR-E measurements for 2003.

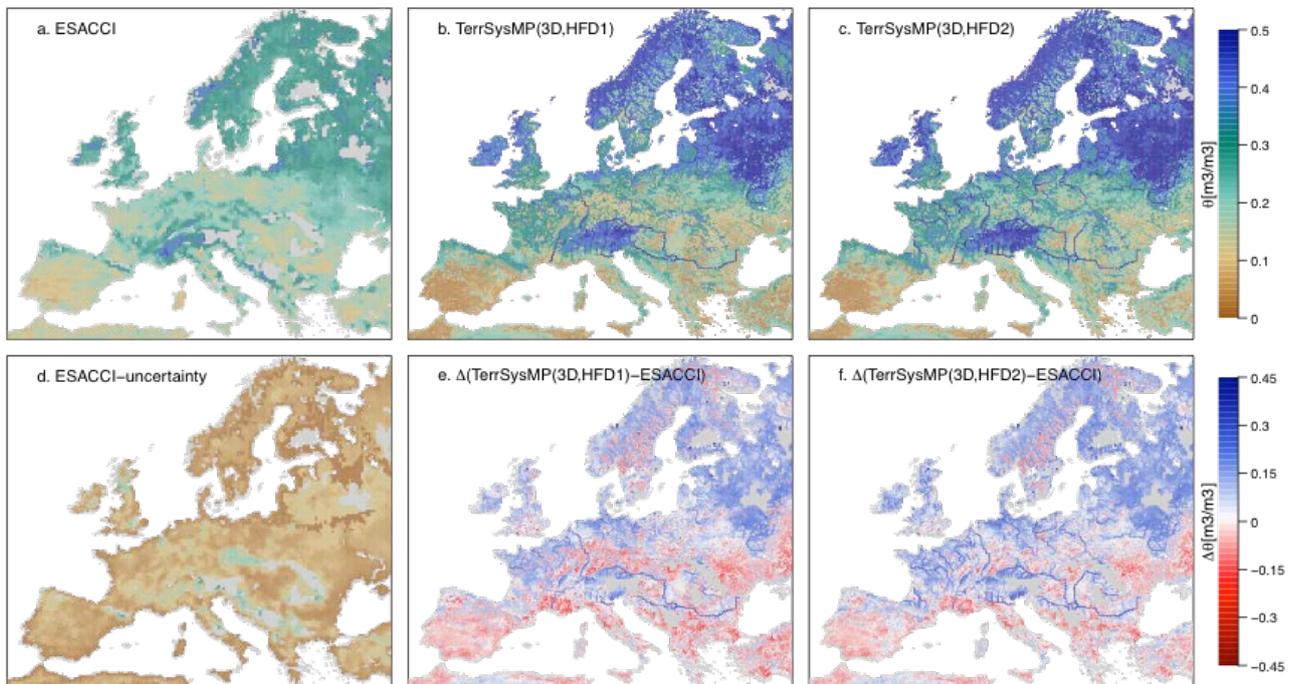


Figure 3. Monthly-averaged soil moisture [m³/m³] fields from (a) ESA-CCI, (b) TerrSysMP(3D,HFD1) and TerrSysMP(3D,HFD2), (d) uncertainty provided by ESA-CCI, and differences (e) between TerrSysMP(3D,HFD1) and ESA-CCI, and (f) TerrSysMP(3D,HFD2) and ESA-CCI.

Here, a set of simulations containing two different groundwater configurations (a 3D-physics-based setup (3D) and a 1D-free-drainage approach (FD)), two different hydro-facies distributions (HFD1 and HFD2) and 5 different initial conditions, are performed and the resulting soil moisture fields are evaluated with ESA-CCI soil moisture observations.

Figure 3 shows the monthly- and ensemble-averaged soil moisture fields from ESA-CCI, its estimated uncertainty and simulated soil moisture from TerrSysMP(3D) for two different hydro facies distributions (HFD1 and HFD2) with the physics-based groundwater configuration (3D). The results indicate that TerrSysMP(3D) is too wet in relatively dry regions, such as Spain. In contrast, a wet bias is observed for northern parts of Europe and the Alpine region. This may be a result of the resolution applied, as shown in earlier studies (Shrestha et al., 2015; Sulis et al., 2011).

However, all simulations capture the trend during the heatwave 2003. The respective soil moisture trend over August 2003 is illustrated in Figure 4, averaged over all PRUDENCE regions. In the present case, the free-drainage configuration yields better results than the physics-based 3D setup, as it is draining out quickly.

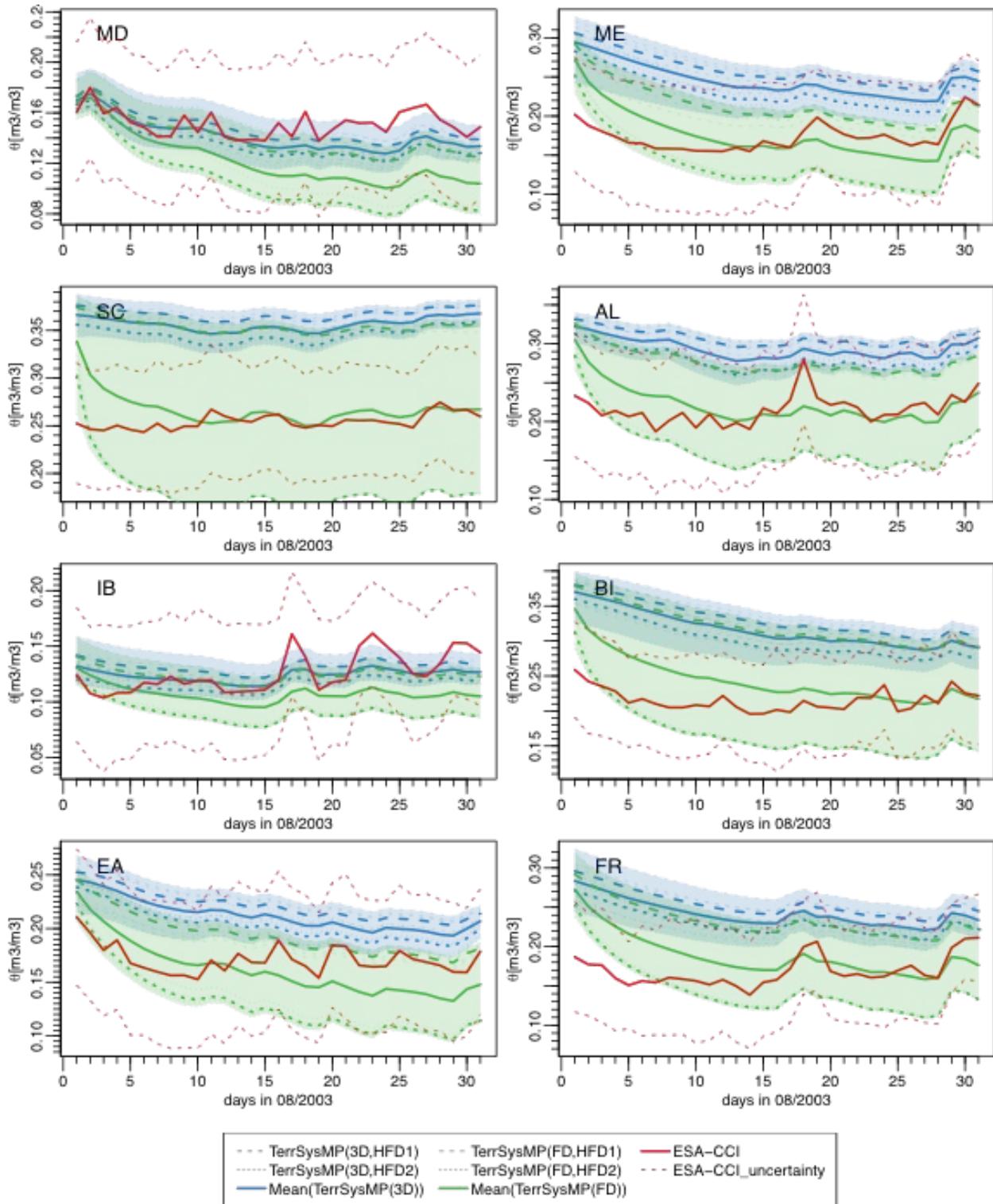


Figure 4. Spatially averaged soil moisture trend over the PRUDENCE regions (MD=Mediterranean, ME=Mid-Europe, SC=Scandinavia, AL=Alps, IB=Iberian Peninsula, BI=British Islands, EA=Eastern Europe, FR=France) simulated with TerrSysMP(3D, HFD1), TerrSysMP(3D,HFD2), TerrSysMP(FD,HFD1) and TerrSysMP(FD,HFD2) for 5 ensemble realizations arising from 5 different initial conditions. The polygons indicate the total range of the respective groundwater configuration (3D or FD). The red lines show the averaged observed soil moisture trend from ESA-CCI and its associated uncertainty.

References

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List of publications/reports from the project with complete references

No publications in 2016.

Summary of plans for the continuation of the project

With the complete integration of COSMO 5.1 into the current version of TerrSysMP, the technical part of this project is finally finished and fully-coupled long-term simulations of TerrSysMP will be started. Here, we account for the uncertainty of the subsurface by applying two hydro facies distributions (i.e. two different hydraulic conductivities) and multiple physically consistent subsurface initial conditions. The resulting hydrologic states and fluxes within this bedrock-to-atmosphere system will be compared to a typical 1D-free-drainage approach in order to identify systematic differences emerging from physics-based groundwater dynamics.