SPECIAL PROJECT FINAL REPORT

Project Title:	Integrated Simulations of the Terrestrial System over the European CORDEX Domain
Computer Project Account:	spdekoll
Start Year - End Year :	2015 - 2015
Principal Investigator(s)	Stefan Kollet
Affiliation/Address:	Institute of Bio- and Geosciences - Agrosphere (IBG-3), Forschungszentrum Jülich GmbH
Other Researchers (Name/Affiliation):	Jessica Keune (Meteorological Institute, University of Bonn) Fabian Gasper (IBG-3, Forschungszentrum Jülich) Klaus Görgen (JSC, Forschungszentrum Jülich) Florian Pappenberger (ECMWF)

Summary of project objectives

The objective of this study was to perform high-resolution fully coupled aquifer-to-atmosphere simulations over the European CORDEX domain. The simulations were performed with the integrated Terrestrial Systems Modeling Platform, TerrSysMP (Shrestha et al., 2014, Gasper et al., 2014), consisting of the 3D surface-subsurface flow model ParFlow, the Community Land Model CLM3.5 and the numerical weather prediction model COSMO of the German Weather Service, which was set up with a spatial resolution of 0.11° (12.5km) at the ECMWF during the first project year. The setup of TerrSysMP and its implementation within ECFLOW was finalized. First fully coupled simulations over the heat wave 2003 were performed and the sensitivity of large-scale flow to spectral nudging above the planetary boundary layer was analyzed.

Summary of problems encountered

No significant problems were encountered.

Experience with the Special Project framework

Our experience has been positive with all administrative aspects.

Summary of results

The results of the project in 2015 can be subdivided into two parts, technical and scientific results. The technical part constitutes most of the progress in 2015 and is the basis for the continuation of the project in 2016 and 2017.

Technical results

The Terrestrial Systems Modelling Platform, TerrSysMP (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. The modelling system was setup over the European CORDEX domain illustrated in Figure 1. In a first step, the test simulations were performed and checked for consistency.

Additionally, the existing initial and boundary data set was replaced with an *online* update of the boundaries from ERA-Interim. Therefore, a workflow including (1) the retrieval of ERA-Interim and (2) the interpolation to the CORDEX EUR-11 domain was set up. A MARS script was implemented to fetch the necessary ERA-Interim data from the archive. The pre-processing program INT2LM, which interpolates the initial and boundary data to the required CORDEX-EUR11 grid, was ported to the CCA, compiled and successfully tested on the CCA.

Furthermore, post-processing routines for long-term simulations for all modelling system components were developed. Finally, the entire workflow was implemented into ECFLOW with four families (*fetch_era, pre-proessing, terrsysmp* and *post-processing*) and restarts were successfully tested.

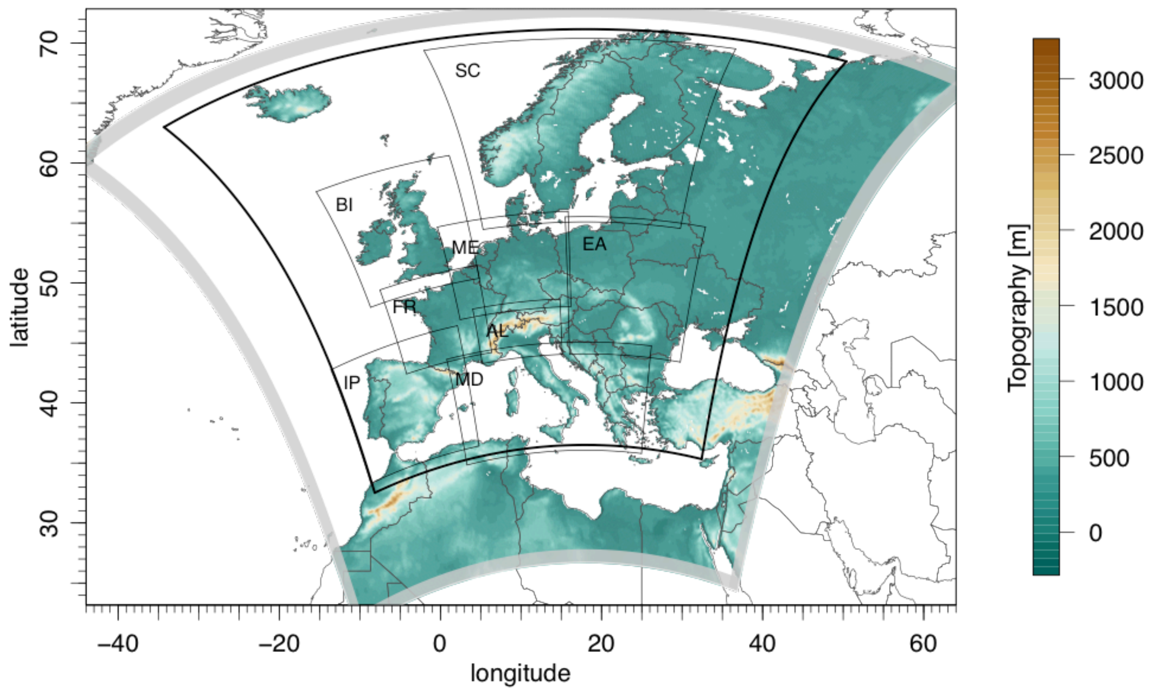

Figure 1. European CORDEX domain including the different PRUDENCE focus regions.

Scientific results

In 2015, the limited compute time was used to find the optimal simulation setup for long-term simulations of the fully coupled aquifer-to-bedrock system, which will be carried out in the continuation of the special project in 2016 and 2017. 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. 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.

Spectral nudging in general

Spectral Nudging was introduced to regional climate modelling by Waldron et al. (1996) and von Storch et al. (2000) considering an additional term in the modelled tendencies, which forces the model solution to follow the low-resolution driver. For any prognostic variable Q, the spectrally nudged tendency equation is

$$\frac{dQ}{dt} = L(Q) - \sum_{|n|\le N} \sum_{|m|\le M} \alpha\left(Q_{mn} - Q_{o,mn}\right) e^{ik_m x} e^{ik_n y},$$

with the model operator L. The second term describes the deviation of the model solution Q_{mn} from the driving field $Q_{o,mn}$, summarized over all nudged wave numbers $m \le M$ and $n \le N$ in x and y direction, respectively. The nudging is applied with a nudging coefficient α.

Spectral nudging setup

The spectral nudging technique is implemented in the atmospheric model COSMO in TerrSysMP and was tested using TerrSysMP during one month of the heat wave 2003. The implementation of spectral nudging is similar to the setup prescribed in von Storch et al. (2000). Accordingly, *U*- and *V*-wind were spectrally nudged above the planetary boundary layer at approximately 850hPa with a constant coefficient α. In order to analyze the sensitivity of the models to spectral nudging, the wave numbers and the nudging coefficient were varied. Two nudging coefficients were chosen: a coefficient of α=0.05 was applied according to von Storch et al. (2000) and compared to an increased coefficient of α=0.5. Additionally, effective resolutions of 4, 5 and 6 grid points in the ERA-Interim reanalysis were assumed, resulting in a set of simulations with varying wave numbers of 23, 17 and 14. These simulations were then compared to a reference simulation, where no spectral nudging was applied. Consequently, 7 simulations were performed. Table 1 gives an overview of these simulations and their spectral nudging setup.

Table 1. Spectral nudging simulation setup with varying wave numbers and nudging coefficients.

	REF	S23	S17	S14	S23A	S17A	S14A
wave numbers (x,y)	-	23,23	17,17	14,14	23,23	17,17	14,14
variables	-	U,V	U,V	U,V	U,V	U,V	U,V
alpha	-	0.05	0.05	0.05	0.5	0.5	0.5
Pressure level	-	< 850 hPa	< 850 hPa	< 850hPa	< 850hPa	< 850hPa	< 850 hPa

Spectral nudging results

The average differences between the 7 simulations and the downscaled ERA-Interim reanalysis for the *U*- and *V*-wind at 850hPa and at the lowest model layer are compared. Figure 2 shows the average *U*-wind at 850hPa in ERA-Interim over the simulation period and the respective differences of the 6 spectral nudging experiments to the reanalysis. Figure 2b shows that large deviations of the simulated wind and circulation patterns in the inner parts of the domain are apparent, if the model is run in a free transient mode and driven by lateral boundaries only. However, these differences are significantly reduced if spectral nudging is applied and mostly smaller scale differences remain. These differences are almost independent of the different wave numbers and nudging coefficients applied, as indicated by Figures 2c-h. Similar results are observed for the *V*-wind at 850hPa, as shown in Figure 3, and for different levels above the boundary layer (not shown). Only minor differences to the reference simulation were observed below the boundary layer (not shown).
Furthermore, the spatial kinetic energy spectra was calculated according to Bierdel et al. (2012) for each simulation and ERA-Interim and the resulting temporally averaged spectra are illustrated in Figure 4. This figure shows that any spectral nudging application is adjusting the large-scale patterns beyond ~400km towards the driving fields from ERA-Interim. Again, only minor differences between the spectral nudging experiments are observed.
Finally, we compared the runtimes of COSMO for the spectral nudging experiments. Here, significantly different runtimes were observed with increasing runtime for increasing wave numbers, almost independently of the nudging coefficient applied.
In conclusion, spectral nudging can be applied within TerrSysMP in order to keep the large-scale patterns of simulations over the European CORDEX domain similar to the circulation of the low-resolution driver ERA-Interim. Furthermore, it is assumed that any spectral nudging setup is suitable, as only minor differences between the tested setups are visible. However, the runtime for the spectral nudging experiments suggests to nudge the lowest wave numbers tested in this study.

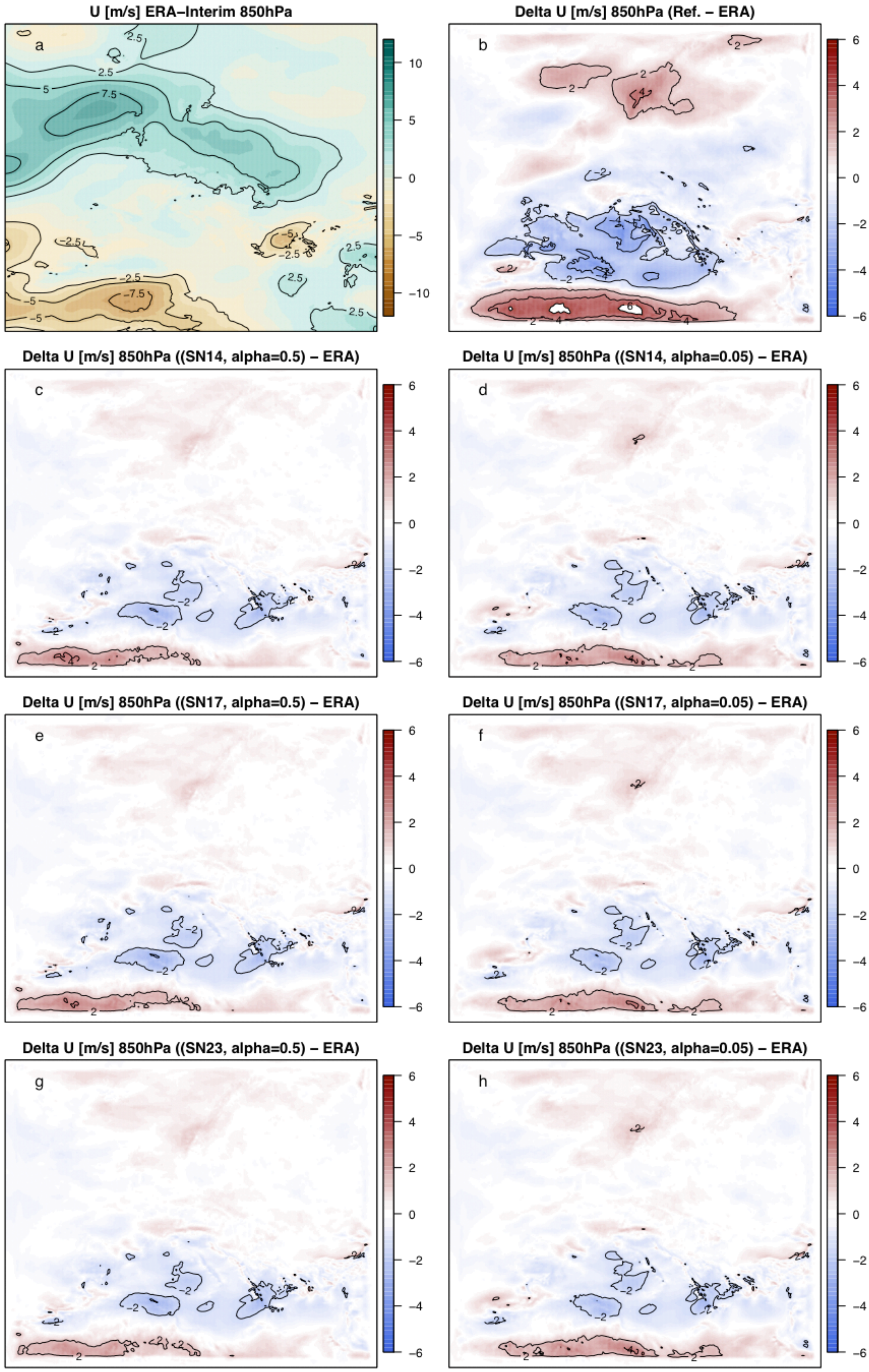

Figure 2. (a) Averaged *U*-wind at 850hPa from downscaled ERA-Interim reanalysis over 08/2003. **(b)** Averaged differences of *U*-wind at 850hPa from the TerrSysMP reference simulation and ERA-Interim as in (a). **(c-h)** Averaged differences of *U*-wind at 850hPa from the TerrSysMP spectral nudging simulations and ERA-Interim as in (a).

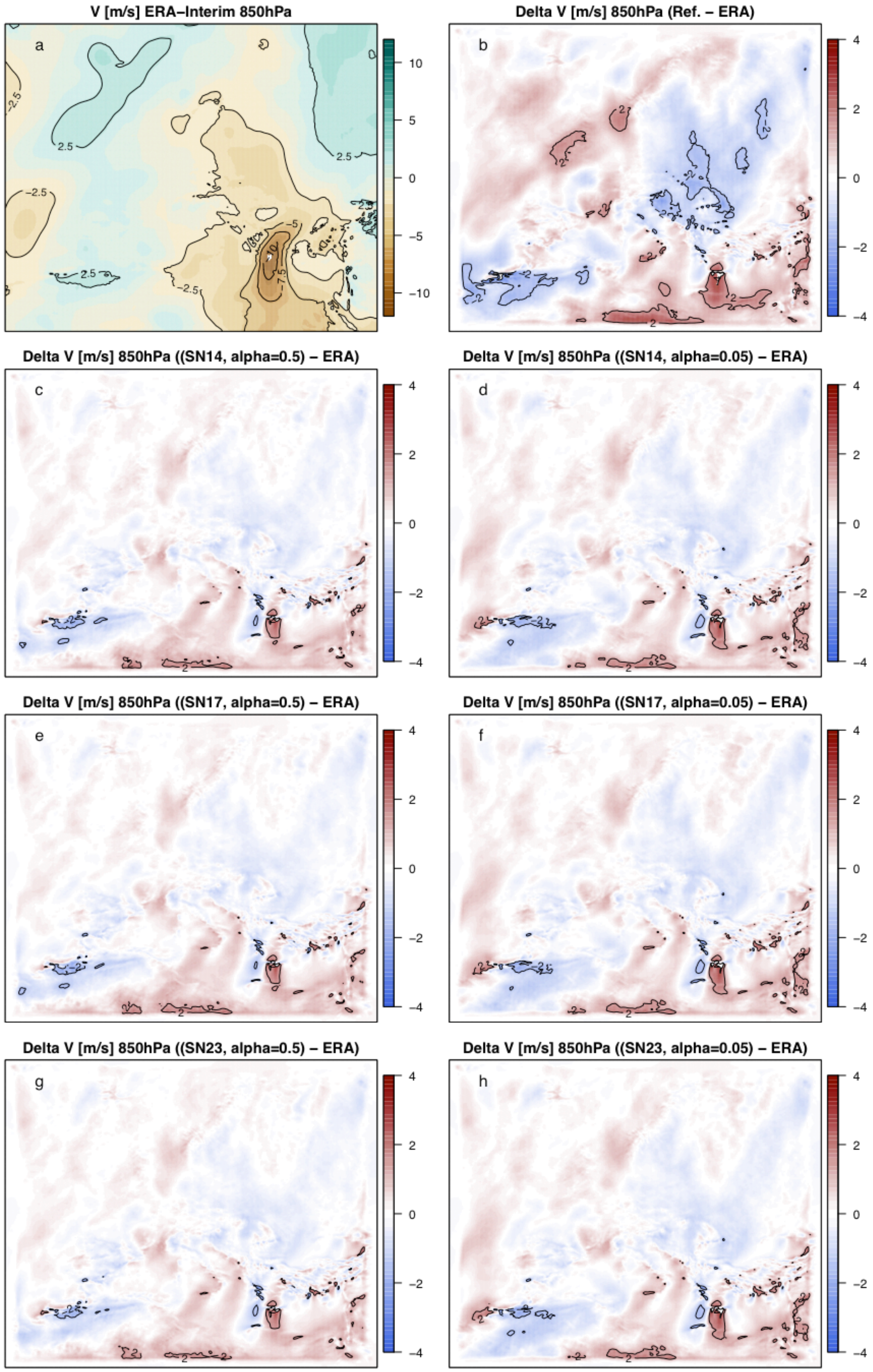

Figure 3. Same as in Figure 2 but for the *V*-wind at 850hPa.

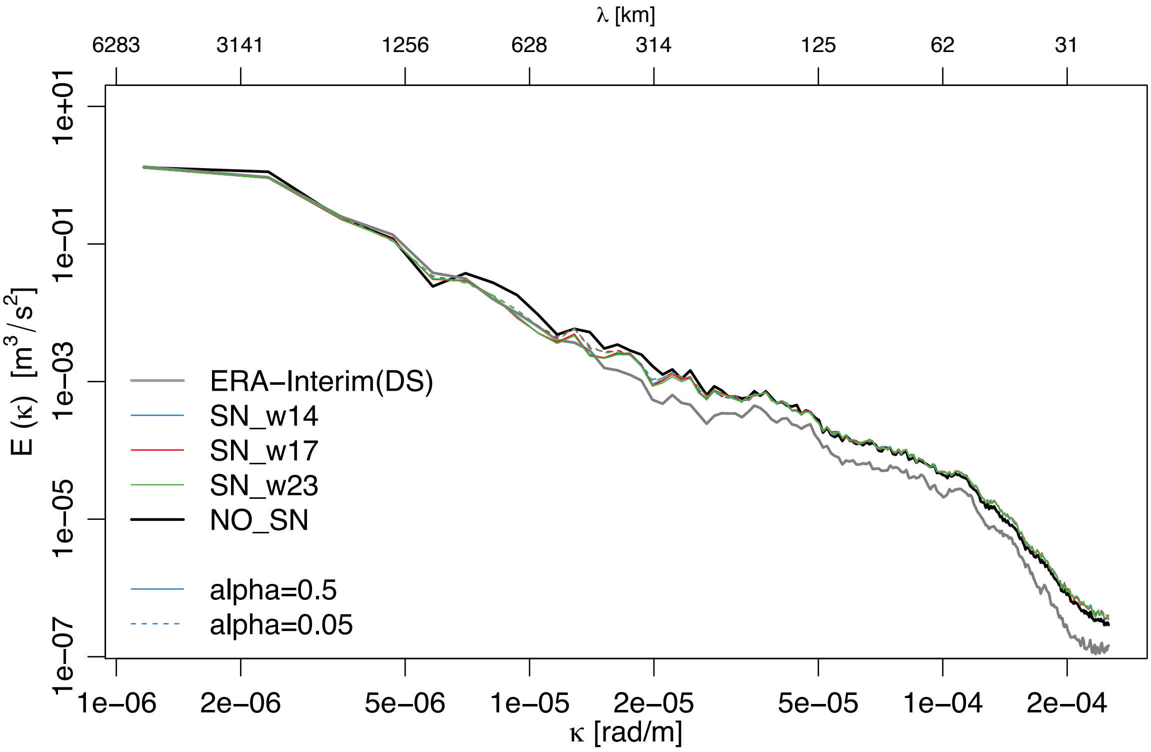

Figure 4. Temporally averaged spatial kinetic energy spectra for the downscaled ERA-Interim fields, the TerrSysMP reference simulation and the spectral nudging experiments.

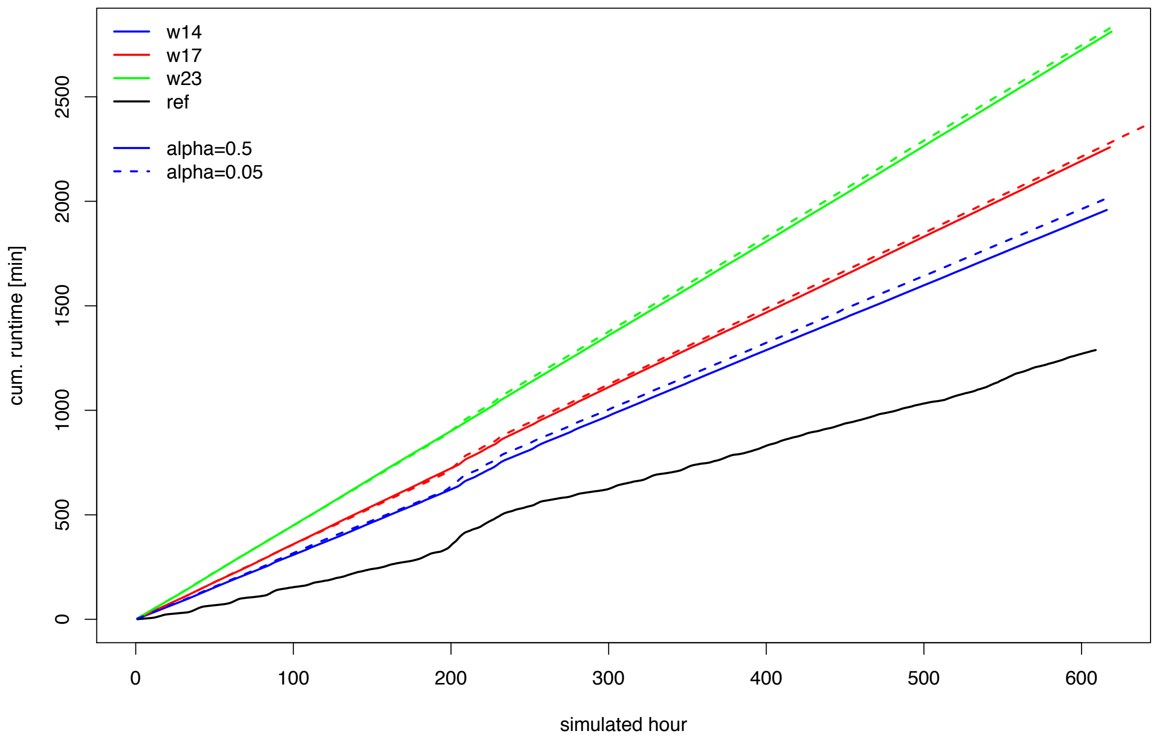

Figure 5. Cumulated runtime of the atmospheric model COSMO in TerrSysMP for the spectral nudging experiments.

List of publications/reports from the project with complete references

No publications in 2015.

Future plans

With the additional compute time for 2016 and 2017, we will perform long-term, fully-coupled bedrock-to-atmosphere simulations with TerrSysMP over the European CORDEX domain in 0.11° resolution. While the system has now been fully tested on the CCA and over short periods, such as the heat wave 2003, the effect of the groundwater configuration on multi-year simulations in the context of regional climate modelling has not been addressed yet. We are planning to perform multiple simulations over more than 3 years, considering different groundwater configurations (3D physics against a 1D free drainage approach). Furthermore, we account for the subsurface uncertainty by applying different subsurface characteristics and initial conditions.
With completion of this special project in 2015 and the sensitivity study using different spectral nudging setups, all preparations for the continuation of the project were completed and long-term simulations with TerrSysMP commenced.

References

Bierdel, L., Friederichs, P., & Bentzien, S. (2012). Spatial kinetic energy spectra in the convection-permitting limited-area NWP model COSMO-DE. Meteorologische Zeitschrift, 21(3), 245–258. doi:10.1127/0941-2948/2012/0319.

Gasper, F., Goergen, K., Shrestha, P., Sulis, M., Rihani, J., Geimer, M., & 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.

Miguez-Macho, G. (2004). Spectral nudging to eliminate the effects of domain position and geometry in regional climate model simulations. Journal of Geophysical Research, 109(D13), D13104. doi:10.1029/2003JD004495.

Shrestha, P., Sulis, M., Masbou, M., Kollet, S., & 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.

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

Waldron, K. M., Paegle, J., & Horel, J. D. (1996). Sensitivity of a Spectrally Filtered and Nudged Limited-Area Model to Outer Model Options. Monthly Weather Review, 124(3), 529–547.