Principal Investigator: Dr Antigoni Voudouri

Project Title: Objective calibration of weather prediction models

Duration of the project: The original allocation period was one year, and was extended for a second year.

List of milestones and goals of your original project proposal and statement of your achievements.

Numerical weather prediction (NWP) and climate models use parameterization schemes for physical processes which often include free or poorly confined parameters. Model developers normally calibrate the values of these parameters subjectively to improve the agreement of forecasts with available observations, a procedure referred as expert tuning. The practicable objective multi-variate calibration method that has been developed by Bellprat et al. (2012[1]) and implemented for a regional climate model has shown to be at least as good as expert tuning. The overarching goal of this project was to investigate how to transfer this method to NWP applications.

*The **specific goals*** of the project are:

• Provide an objective methodology for NWP models that can substitute expert tuning: Establish a standard procedure (tool) that objectively improves NWP model performance by optimally determining unconfined parameters.

• Understand the sensitivity of the NWP model quality with respect to the model parameter space.

• Optimize the calibration procedure with respect to the required amount of computing resources for each re-calibration.

As a demonstration vehicle, the target COSMO configuration calibrated in this project is the 1.1 km mesh-size COSMO model version developed at MeteoSwiss. Prior to this project, a feasibility study was conducted with the CPU version of the COSMO model, on a coarse resolution grid, 7 km, for three unconfined parameters.

The ***main milestones*** to achieve the above stated goals are (1) refinement, testing and

[1] Bellprat, O., S. Kotlarski, D. Lüthi, and C. Schär. 2012. Objective calibration of regional climate models. *Journal of Geophysical Research,* **117**, D23115.

calibration of a 2.2 km mesh-size COSMO version, during the first three months of the project, and (2) devoting the following 4 to 12 months to a full year simulations with 1.1 km resolution and 8 perturbed parameters.

First milestone

Simulations using COSMO with a 2.2 km mesh size have been successfully performed to test the calibration method for a convection-permitting COSMO configuration over an entire year. The simulation period was significantly increased from 40 days of 2008, prior to this project, to the entire year of 2013 by using Piz Daint resources; a one year period consistently incorporates the weather development on a seasonal basis and is considered a strong asset toward the operational value of this work. Furthermore, following an extensive sensitivity study, the number of calibrated parameters has been increased from 3 to 6.

During this phase, the Meta-Model has been significantly consolidated and extended, adding in particular the option not to average Tmax/Tmin over regions, adding the prediction of multiple vertical profile characteristics, and supporting new geographical regions. The RMSE-type performance score was adjusted and a new COSI performance score, a COSMO standard, was included. A new method for logarithmic transformation of selected parameters was developed along with an iterative method to obtain the optimal parameters via convergence in a 6-dimensional parameter space of exceptional cardinality.

Following these adaptations, the calibration was performed using 4 different methods, and the optimal parameters combination was obtained. With the exception of dew point temperature, the verification showed an overall improvement of the COSMO model, although the model had already undergone expert tuning over a period of almost one decade. This is remarkable, given the fact that the history of the soil was mistakenly switched off in the configuration of this calibration experiment.

The calibration framework obtained at that point of the project is fully described in two COSMO Technical Reports (one already published, the number 25, and one in preparation, see http://www.cosmo-model.org/content/model/documentation/techReports/default.htm), and in a submitted to a peer reviewed journal (Voudouri et. al) paper, as well as a second one under preparation.

Second milestone

This milestone has only been partially reached. Configuration and setup of the COSMO-1 configuration was finalized, including this time the soil memory and the prior 3 years soil spin up, and calibration has been performed, but for 5 model parameters (tur_len, tkhmin, crsmin, entr_sc and csoil) instead of 8, and for one month instead of the full year 2013. Note that for this milestone a wide verification area is also used, including Northern Italy in addition to Switzerland (the same tools are used independently from the verification region, but

different sets of observations have to be collected). Analysis of the calibration of the 1.1 km configuration is on-going, and the sampling size is small being limited to the month of January, but preliminary results show an improvement of the COSI score of the order of 10%, which is considerable.

All project resources have been focused to make as much progress as possible in this second milestone. This has made possible the fulfilment of the two first goals of the project, but no resources were left for the third important objective which was to optimize the calibration procedure with respect to the required amount of computing resources. This is still an open issue at the end of this project, and a follow-up project will be proposed to the COSMO Steering Committee to tackle this important topic.

Description of problems that have prevented you from using the entire granted allocation (if applicable) or in general that have prevented to successfully complete your project.

The main tool used for NWP simulations in this project was the refactored version 5.0 of the COSMO model capable of running on GPU-based hardware architectures (referred to as RC) developed during the COSMO-NExT[2] project at MeteoSwiss, and the POMPA[3] project in COSMO. In the original project proposal it was assumed that a suitable version of the RC code would be available by the time the allocation period starts. However, due to many technical (e.g. additional GPU porting work required for physical parameterization) and managerial issues in particular the coordination of the work within the COSMO Consortium, access to a stable RC code was significantly delayed with respect to the original planning. Thus the systematic use of computer resources started only on September 2015.

The number of simulations required to calibrate the model depends on the number of model parameters which are considered. But, in addition, the exact set of experiments required for the calibration process has to be evaluated iteratively. For a robust calibration of six parameters for the COSMO 2.2km configuration the number of simulations was more than 60, instead of the 28 initially expected. Doubling the number of simulations led to a substantial delay in reaching the first milestone.

The consideration of the history of the soil over the whole simulation period, which is a very important feature, and the need to make a daily off-line update of the sea surface temperature, forces the simulation to be composed of a large set of small and dependent computational units (slurm jobs). This considerably degraded the computational throughput through accumulated pending time.

[2] http://www.meteoschweiz.admin.ch/web/en/research/current_projects/forecast/COSMO-NExT.html

[3] http://www.cosmo-model.org/content/tasks/priorityProjects/pompa/default.htm

Further delays were caused by the manual intervention required to restart the simulations each time Daint or the associated file systems were affected by technical problems, or after a maintenance session.

Coarse grain parallelism was achieved by using the fact that simulations for different sets of model parameters are independent. However, it was never possible to submit more than 10-12 jobs at the same time; when the number of submitted jobs was larger, the additional jobs were just ignored and had to be submitted again. Although CSCS help had been contacted the problem could not be fully identified and the issue was not solved.

The amount of raw data produced during the simulations was huge and the post-processing software had to be configured to support an aggressive data thinning policy. A disk space increase of approximately 10TB had been approved by the CSCS, but still the available disk space during the COSMO 1.1km simulations had to be carefully re-considered, resulting in small additional minor delays.

Finally, the effort to overcome several technical difficulties when running multi-years COSMO simulations, especially in the context of a project distributed amongst different countries, had been grossly under-estimated.

List of papers published already (if any) or in preparation related to the project.

1. Avgoustoglou E., A. Voudouri, P. Khain, F. Grazzini and J.M. Bettems, 2017: Design and Evaluation of Sensitivity Tests of COSMO Model Over the Mediterranean Area. Perspectives on Atmospheric Sciences, Vol.1, Springer, pp 49-55
2. Khain P., I. Carmona, A. Voudouri, E. Avgoustoglou, J.-M. Bettems, F. Grazzini, 2015: The Proof of the Parameters Calibration Method: CALMO Progress Report. COSMO Technical Report, 25.
3. Khain P., I. Carmona, A. Voudouri, E. Avgoustoglou, J.-M. Bettems, F. Grazzini, P. Kaufman, 2017: The Success of the Parameters Calibration Method: CALMO Progress Report 2. COSMO Technical Report (under preparation).
4. Voudouri A., E. Avgoustoglou and P. Kaufmann, 2017: Impacts of Observational Data Assimilation on Operational Forecasts. Perspectives on Atmospheric Sciences, Vol.1, Springer, pp 143-150
5. Voudouri A., Khain P., Carmona I., Bellprat O., Grazzini F., Avgoustoglou E. , Bettems J.M and Kaufmann P., 2017: Objective calibration of numerical weather prediction models. Atm. Res. (submitted)
6. Voudouri A., Khain P., Carmona I., Avgoustoglou E., Bettems J.M., Kaufmann P and Grazzini F.: Optimization of COSMO model performance over a very fine grid (under preparation)