Calibration of high resolution COSMO model over Switzerland: CALMO-MAX results

Voudouri A.[1], Carmona I.[2], Kaufmann P.[3], Avgoustoglou E.[1], Levi Y.[2], E. Bucchignani [4] and J.M.Bettems [3]

1 Hellenic National Meteorological Service
2 Israel Meteorological Service
3 MeteoSwiss
4 CIRA
e-mail: antigoni.voudouri@hnms.gr

1 Introduction

One of the main goals of the CALMO-MAX priority project is a robust implementation of the objective calibration method originally performed by Bellprat et al., 2012a and 2012b on COSMO-CLM and later by Voudouri et al., 2017 and 2018 on COSMO-NWP. More specifically, in this work, the calibration procedure has been applied to a fine horizontal resolution of 0.01o (approximately 1km) over a mainly continental domain covering the Alpine Arc. The CALMO methodology aims at substituting expert tuning, by which free or poorly confined model parameters are tuned using mainly expert knowledge (Duan et al., 2006; Skamarock, 2004;Bayler et al., 2000), with a more replicable and automatic approach. This methodology optimizes an overall model performance score by adjusting the values of a set of unconfined model parameters. The core of the calibration process is the determination of the metamodel (model emulator), which represents (using a simple mathematical function) the dependency of some representative model fields on the selected model parameters. The mathematical function at the core of the metamodel is constrained by a set of full model simulations over a time period long enough to represent the variability of the atmospheric conditions. Once fully specified, the metamodel supports a fast sampling of the parameter space to find an optimal combination of the model parameters. Detailed description of the procedure is available in Khain et al. (2015, 2017) and Voudouri et al. (2017a).

In the present work, the calibration is performed using a set of five unconfined model parameters. The selection of parameters is constrained by the fields used in the overall performance score, which should be sensitive to the chosen parameters. Because the overarching goal of the calibration in this project is to improve the quality of daily operational forecasts, the fields considered in the performance score are meteorological quantities used by bench forecasters, such as minimum and maximum 2m temperature, precipitation and wind speed. Although the number of parameters is limited, the main parameterization schemes affecting turbulence, soil-surface exchange and radiation are represented by these parameters. It is worth mentioning at this point that a strong dependency of the parameters optimum on the time of the year has been observed, as described in Voudouri et al. (2019); this reflects the dependency of the optimum on the atmospheric flow (or weather pattern). For this reason, if the primary goal of the calibration is to improve the daily operational forecast with a unique set of parameters, a climatologically representative set of weather patterns should be used in the calibration.

The steps followed, such as model setup and selection of parameters, are briefly described in Section 2, while in Section 3 results of CALMO-MAX applied over Switzerland are discussed. Conclusions are given in Section 4 and perspectives on further developments are summarized in Section 5.

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2 Data and Methodology

2.1. Model setup

COSMO model was computed for the years 2013 and 2017, with a horizontal resolution of 0.01o (approximately 1km) over a domain including the Alpine Arc (in particular the wider area of Switzerland and Northern Italy), in hindcast mode (in particular no data assimilation active). The grid extends vertically up to 23.5 km (30hPa) with 80 model levels. Initial and boundary fields for all tests are provided by the MeteoSwiss operational forecasting archive system at 0.01ohorizontal resolution (1km). Note also that the soil history is considered for all the CALMO-MAX simulations, and a prior 3 years soil spin up has been computed using terra standalone (TSA). The code used is the refactored version of the COSMO model (Lapillonne and Fuhrer, 2014) based on the version 5.03 of the model, capable of running on GPU-based hardware architectures, operationally used by MeteoSwiss.

2.2. Data and selected parameters

NWP models, including COSMO, describe physical processes through parameterization schemes in which many unconfined, ‘free’ parameters exist. These parameters are related to sub-grid scale turbulence, surface layer parameterization, grid-scale cloud formation, moist and shallow convection, precipitation, radiation and soil schemes (Doms et al., 2011, Gebhardt et al., 2011).

In the framework of CALMO-MAX, an extended preliminary set of twelve parameters covering turbulence (tur_len, tkhmin, tkmmin), surface layer parameterization (rat_sea, rlam_heat, crsmin), grid-scale precipitation (v0_snow), moist and shallow convection (entr_sc), radiation (rad_fac, uc1) and the soil scheme (c_soil) have been tested. Several sensitivity experiments have been performed and the most sensitive parameters have been selected for calibration (Avgoustoglou et al., 2020). Specifically, the five model parameters chosen for CALMO-MAX are:

1. Minimal diffusion coefficients for heat, tkhmin[m2/s].
2. Scalar resistance for the latent and sensible heat fluxes in the laminar surface layer, rlam_heat [no units].
3. A factor in the terminal velocity for snow, v0_snow[no units].
4. Parameter controlling the vertical variation of critical relative humidity for sub-grid cloud formation, uc1 [no units].
5. The fraction of cloud water and ice considered by the radiation scheme rad_fac [no units].

These parameters were calibrated with respect to daily minimum and maximum 2m temperature (T_max and T_min respectively), hourly, 6h and 24h accumulated precipitation(Prec), and vertical profiles (TEMP). For temperature, available measurements of daily mean surface air temperature selected at the station network of MeteoSwiss were used.

For precipitation, observations over Switzerland were available through the gridded MeteoSwiss radar composites corrected by rain gauges and interpolated to the model grid. Over Northern Italy, observations interpolated to the model grid were used. In addition, vertical model profiles at grid points near soundings locations were considered.

2.3. Methodology

The calibration methodology used in CALMO-MAX was discussed in details in Voudouri et al. 2017 and 2018. It relies on the metamodel proposed by Neelin et al., (2010 and 2010a) and modified by Bellprat et al.,(2012a) that approximates the parameter space using a multivariate quadratic regression in an n-dimensional model. The gain/loss in model quality is assessed using the "COSMO Index" score (COSI) developed by Ulrich Damrath (2009). The score is a combination of both RMSE-type for continuous variables and ETS (Equitable Threshold Score) for categorical fields, and has been used to estimate the overall model performance.

3 Results

The aim of this work was to calibrate COSMO-1, using a full year of statistics. The year 2013 has been chosen as climatologically representative for the target area. Once the simulations for the 5 parameters (tkhmin, rlam_heat, v0_snow, rad_fac and uc1) have been completed, the optimum set of parameters was calculated using the metamodel. It should be noted that although calibration is performed over the entire year, optimum parameter values are extracted over sets of 10-days periods.

An average for these 36 periods is then produced to extract the best optimum parameter set over the entire year. The optimum parameter values are as follows: tkh_min = 0.279 (m2/s), rlam_heat= 0.929, v0_snow = 18.95, rad_fac = 0.6775 and uc1= 0.7686.

The default parameter values (proposed by model developers) were replaced by these "optimal" values, and model simulations for 2013 have been performed again to investigate the improvement in model performance. Additionally, simulations for 2017 have been performed to examine whether the optimum parameter set, calculated for the year of the calibration, is also beneficial for a different independent year.

The verification of simulations using default parameter values (tkh_min = 0.4 (m2/s), rlam_heat = 1, v0_snow = 20, rad_fac = 0.6 and uc1=0.8) (DEF) against the one using optimum parameter set (BEST) for 2m temperature, and hourly accumulated precipitation are presented in Table 1 and Table 2 for both years.

More specifically, statistical measures such as mean error (ME), root mean square error (RMSE), minimum (MINMOD) and maximum (MAXMOD) model values, minimum (MINOBS) and maximum (MAXOBS) observed values are shown. Categorical scores such as Equitable threshold (ETS), False Alarm Ratio (FAR) and Probability of detection (POD) for a small threshold (0.1mm) are also calculated for hourly precipitation in Table 2.

A decrease in the mean error of the 2m temperature is observed when using the optimized configuration that is 0.12°C instead of 0.43°C for 2013, and 0.14°C instead of 0.24°C for 2017. An improvement of the yearly maximum 2m temperatureis also observed for the 2013 experiment (forecasted 38.4°C and 37.4°C for DEF and BEST simulations respectively, against the observed 37.1°C).
An improvement of approximately 0.3°C in RMSE during daytime is also well visible in the daily cycle of the 2m temperature RMSE for the year 2013 (figure 1,RMSE averaged over a full year, blue line is with DEF and red line with BEST parameters). Statistics of hourly accumulated precipitation when using the set of optimum parameter values, for both years, against the values recommended in the default model setup are presented in Table 2.

Table 1: Statistics of 2m temperature for years 2013 and 2017

Year	2013		2017	
Measure/Simulation	DEF	BEST	DEF	BEST
ME	0.43	0.12	0.24	0.14
RMSE	2.2	2.16	2.35	2.33
MINMOD	-28.67	-28.67	-29.64	-28.77
MINOBS	-28.7		-29.5	
MAXMOD	38.43	37.41	40.0	40.0
MAXOBS	37.1		36.9	

Table 2: Statistics of the hourly accumulated precipitation for years 2013 and 2017

Hourly precipitation	2013		2017	
Measure/Simulation	DEF	BEST	DEF	BEST
ME	0.032	0.029	0.027	0.025
RMSE	0.771	0.771	0.8	0.8
MAXMOD	56.07	47.17	48.59	58.24
MAXOBS	48.5		60.8	
ETS(0.1)	0.35	0.33	0.35	0.35
FAR(0.1)	0.44	0.45	0.45	0.45
POD(0.1)	0.64	0.62	0.63	0.63

Unlike the 2m temperature, no clear benefit from the calibration is visible. Although ME for both years is slightly reduced and maximum modeled values are closer to the observed ones when using the optimum values, categorical scores such as ETS and POD are degraded. More specifically, when choosing a small threshold such as 0.1mm, ETS slightly decreases from 0.35 to 0.33, for 2013. This is also the case for thresholds of 1mm and 10mm (not shown in Table 2). For year 2017, no effects on these categorical scores have been observed.This model response could be attributed to deficits of the precipitation scheme in representing the prevailing weather patterns during 2013 and 2017, however further investigation is needed.

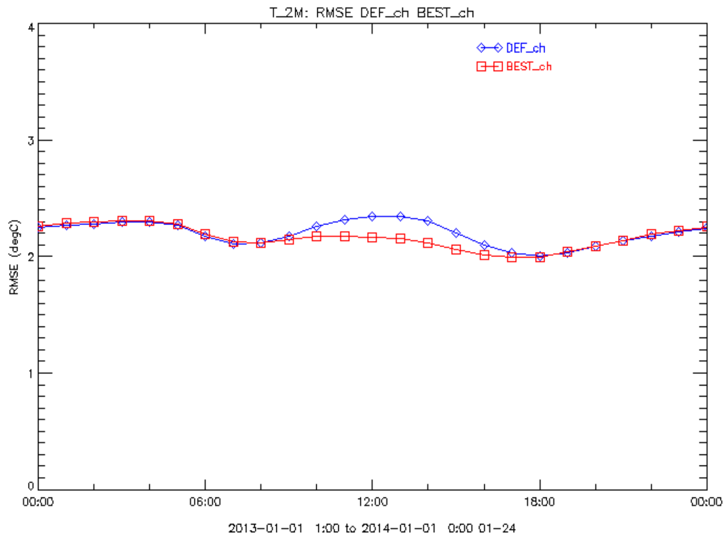

Figure 1: Daily cycle (averaged over the entire year) of 2m temperature RMSE when using default (blue line) and optimum (red line) parameter values for 2013

4 Conclusions

CALMO-MAX is the COSMO priority project for the implementation and consolidation of a robust objective calibration method. In the present work the MeteoSwiss COSMO-1 configuration has been calibrated, selecting five model parameters, using a full year statistic, with the history of the soil included (hindcast),to demonstrate the benefits of the methodology. A different year has been used to have an independent assessment of the impact of the optimization process. Although the chosen model configuration, based on the operational model of MeteoSwiss and close to the DWD configuration, was already a well-tuned configuration, results showed that a slight model performance gain is obtained by using the CALMO methodology.

A remaining issue for a broader use of this methodology is its computational cost, due to the necessity to run multi-years simulation of a high-resolution model to constrain the meta-model. A first consideration which may alleviate this issue is to consider calibrating a lower resolution configuration than the target model; a factor of two in the horizontal resolution does not significantly change the characteristics of the forecasts (e.g. as observed at MeteoSwiss), but reduces the cost of a single simulation by a factor eight. Another consideration, if the history of the soil is not a dominant factor, is to restrict the weather sampling to a set of representative periods, instead of using a full year; typically, choosing 60 days reduces the cost of the calibration by a factor six. A last consideration is to partition the set of considered parameters into (relatively) independent subsets, and to calibrate each subset in turns; this approach reduces the number of simulations required, given that the number of full model simulations is O(N2) where N is the number of parameters to calibrate.

Besides the costs associated with the meteorological model, the specification and the use of the meta-model may also become expensive, in particular when a large number of observations are considered. A lot of meta-model optimizations have already been done and further ideas about the optimization process are under consideration.

To demonstrate the feasibility of these ideas, a new calibration is currently applied over a large Central- and Eastern-Mediterranean domain, covering mainly marine instead of continental area. This application will prove whether the CALMO methodology can be used as an affordable and useful tool to define the optimal calibration over a different target area of interest (or a significantly different model configuration).

5 Future Work

A new Swiss National Fund project in the group of Prof. C. Schaer / ETHZ has been accepted (trCLIM), and, in particular, a 3 years PhD focusing on calibration will start in autumn 2020. Furthermore, as already stated, a lot of developments have been done in the meta-model by the CALMO team, and further ideas and considerations about the optimization process have been proposed at a BTU / Cottbus meeting beginning of 2020. This shows the necessity to synchronize the COSMO and the ETHZ developments anew, and to provide a unified, consolidated, portable (Octave or Python) and well documented (user guide) meta-model code, with the possibility to define any meaningful model performance score in an easy way. This will be a very useful tool for both the Climate and the NWP communities and this could be implemented in a future COSMO PT or PP.

An important aspect shown in previous work is the strong dependency of the parameters optimum on the time of the year, which reflects the dependency of the optimum on the atmospheric flow (or weather pattern), and the implicit dependency of some tuning parameters to the model state variable. This was expected, but the intra-annual fluctuations of the optimum are large. Practical consequences of this fact on the use of the CALMO methodology have to be considered in the future.

Finally, it should be noted that this methodology is essentially “model independent” and can be applied to any NWP or climate model. The only pre-requisite is an up-to-date and well-documented list of tunable model parameters, which supports a first screening of relevant parameters for the planned calibration. In fact, plans to calibrate ICON with the CALMO methodology are already considered by some COSMO partners.

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