Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement des Innern EDI
Bundesamt für Meteorologie und Klimatologie MeteoSchweiz

CALMO & CALMO-MAX

… or how to beat the experts …

Jean-Marie Bettems

Federal Office of Meteorology and Climatology, MeteoSwiss

Jean-marie.bettems@meteoswiss.ch

APN Info, Carte Blanche

The problem

- Model uncertainties related to **poorly confined model parameters** (e.g. c_soil - evaporating fraction over land)
- **Expert tuning**: calibration of these parameters typically done once by model developers
  - *For one certain target area*
  - *For one certain model configuration*
  - *Very difficut to replicate*
- Is the expert tuning **still valid** for
  - *Different target climatology (e.g. mediterranean)*
  - *Different model configuration (e.g. free soil)*
  - *New physical package (e.g. TERRA vs. CLM)*

The context in 2012

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

From the abstract:

„Here we present an approach to **objectively calibrate a regional climate model**, using reanalysis driven simulations and building upon a **quadratic metamodel** presented by Neelin et al. (2010) that serves as a computationally cheap surrogate of the model. [...] In comparison to an ensemble of the same model which has undergone **expert tuning**, the calibration yields similar optimal model configurations, but leading to an **additional reduction of the model error**.“

The priority project CALMO
01.2013 – 12.2016

Can the method developed by Bellprat, for a regional climate model, be transposed to NWP applications?

→ CALMO: develop a method supporting an objective calibration of the unconfined parameters of a NWP model, based on a previous work by O.Bellprat (2012).

See

http://www.cosmo-model.org/content/tasks/priorityProjects/calmo/default.htm

The Method

- For a **specific** model domain and model configuration
- Define a set of **unconfined model parameters**, including plausible range, significant for this model configuration, with a clear model sensitivity
  → ***expert knowledge required!***
- Define a **scalar quality score** representative of the model performance
  → ***set of model fields with associated observations required!***
  → ***decision on most important model focus required!***
- The optimal model parameters are the ones **optimizing** the quality score
  → ***definition of a representative time period for the calibration!***

- But … optimizing the quality score with the full model is **prohibitively expensive** (e.g. for 5 model parameters, using 10 bins in each dimension and a 1 year time period, would require 100'000 year simulation)
- So… **emulate** the dependency of the quality score on the model parameters, in the plausible range, with an analytical function, the so called **meta-model**

The Meta-Model

Theory

$$F_{i,r} \cong F^d_{i,r} + c_{i,r} + a^{(1)}_{i,r}x_1 + B^{(1,1)}_{i,r}x_1^2 + a^{(2)}_{i,r}x_2 + B^{(2,2)}_{i,r}x_2^2 + a^{(3)}_{i,r}x_3 + B^{(3,3)}_{i,r}x_3^2 +$$
$$+B^{(1,2)}_{i,r}x_1x_2 + B^{(1,3)}_{i,r}x_1x_3 + B^{(2,3)}_{i,r}x_2x_3$$

Where:

$$x_1 = \frac{rlam\_heat - rlam\_heat_d}{rlam\_heat_{max} - rlam\_heat_{min}}; x_2 = \frac{tkhmin - tkhmin_d}{tkhmin_{max} - tkhmin_{min}};$$

$$x_3 = \frac{tur\_len - tur\_len_d}{tur\_len_{max} - tur\_len_{min}}$$

- 3 model parameters x_1, x_2, x_3 (e.g. rlam_heat, tkhmin, tur_len)
- One COSMO field $F_{i,r}$ (e.g. daily minimum of T2m)
- Index *i* stands for time (e.g. day), index *r* stands for region (e.g. grid point)

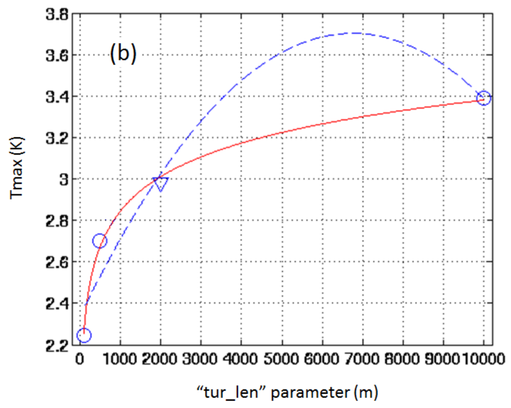
- Approximate **$F_{i,r}(x_1, x_2, x_3)$, x_i in $[x_{i,min}, x_{i,max}]$** with a second order polynomial function → **meta-model**

The Meta-Model
Theory

- **$F_{i,r}(x_1, x_2, x_3)$, x_i in $[x_{i,min}, x_{i,max}]$** as second order polynomial function
  - model parameters x_1, x_2, x_3
  - COSMO field $F_{i,r}$
  - Index *i* stands for time, index *r* stands for region

- A **unique** polynomial function for each day, for each region, for each COSMO field

- **Full model simulations**, providing $F_{i,r}$ for different combinations of x_i, allows the definition of the polynomial coefficients. At least 2N + 0.5*N*(N-1) + 1 full simulations are required, where N is the number of x_i (e.g. 10 simulations for 3 parameters).



The Calibration

Theory

$$S_p = \frac{1}{12 \sum_{\Psi=1}^{18} \omega_\Psi} \left\{ \sum_{\Psi \neq 3} \omega_\Psi \sum_{mon=1}^{12} \left[1 - \frac{\sum_{\Psi regs} \sum_{\Psi days} (F_{\Psi,p,d,r,mon} - O_{\Psi,d,r,mon})^2}{\sum_{\Psi regs} \sum_{\Psi days} (O_{\Psi,d-1,r,mon} - O_{\Psi,d,r,mon})^2} \right] + \omega_3 \frac{\sum_{mon=1}^{12} \sum_{\Psi regs} \sum_{\Psi thr} ETS_{p,r,mon,thr}}{N_{\Psi days,mon} N_{\Psi regs,mon}} \right\} \tag{5}$$

- ***S_p*** is the quality score, for a combination of unconfined parameters ***p***

- It is based on the COSMO COSI score, i.e. **standard deviation** for continuous fields, **ETS** for discontinuous fields
- S_p requires the model fields $\boldsymbol{F_\Psi}$ for each day *d*, for each region *r*, for each combination of model parameters *p*; this is **provided by the meta-model**

- Computing the **extremum of $\mathbf{S_p}$** defines the optimal values of the model parameters
  - A *time period* has to be defined for the optimization
  - The *relative weights* of the contributing model errors have to be specified
  - The more model fields *Ψ* are included, the less the risk of *over-fitting*

COSMO-2 calibration
Configuration

- COSMO-2 domain and configuration
- Calibration based on **full year 2013** (climatologically ‘standard’ year)
- For each set of parameters, compute a **daily 36h forecast,** based on a reference analysis and on reference boundary conditions (all taken from MeteoSwiss operational analysis for this year)

- Note: because the analysis used to compute the daily forecast is the same for any set of model parameters, **the effect of the soil memory is not active** (i.e. the effect of a different set of parameters can not accumulate over the year)…

COSMO-2 calibration
Configuration

- Set of **unconfined parameters**:
  - **rlam_heat**, heat resistance of laminar layer, {0.1, **1**, 2}
  - **tkhmin**, minimal values for turbulence coefficients, {0.1, **0.4**, 1}
  - **tur_len**, define turbulence length, {100, **150**, 1000}
  - **entr_sc**, define shallow convection efficiency, {0.05e-3, **0.3e-3**, 2.e-3}
  - **v0snow**, define snow terminal velocity, {10, **20**, 30}
  - **c_soil**, evaporating fraction of land pixel, {0, **1**, 2}

COSMO-2 calibration
Configuration

- Set of **model fields** used in quality score:
  - Daily min and max of **T2m** (grid points, CH and Northern Italy)
  - Daily accumulated **precipitation** (regions, CH and Northern Italy)
  - Total column **water vapor** (11 sounding)
  - **Wind shear** 500-700 / 700-850 / 850-1000 hPa (11 soundings)
  - **U, V, T** and **RH** at 500, 700 and 850 hPa (11 soundings)

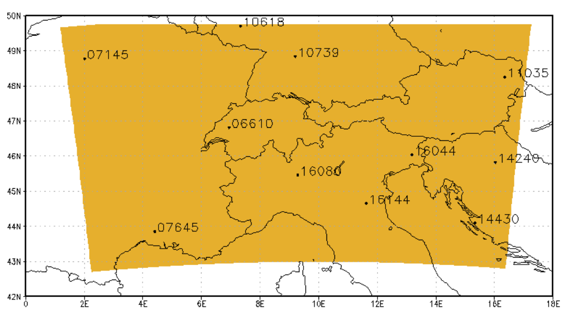


Figure 3: Available soundings inside CALMO-stages 2 and 3 domains.

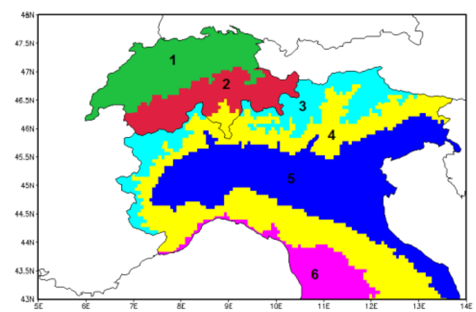


Figure 2: Geographically unique regions for precipitation averaging: 1-green: Swiss plateau (300m<h<1500m); 2-red: Swiss Alps (1500m<h); 3-cyan: Italian Alps (1500m<h); 4-yellow: Italian hills and Ticino (300m<h<1500m); 5-blue: Po Valley (h<300m); 6-magenta: Italian north-west coast (mainly h<300m).

COSMO-2 calibration

Meta-model validation

- The **meta-model prediction** is compared with the full model prediction for the maximum daily temperature (this slide) and the daily accumulated precipitation (next slide). An arbitrary combination of model parameters, not used for building the meta-model, was used to create these plots.

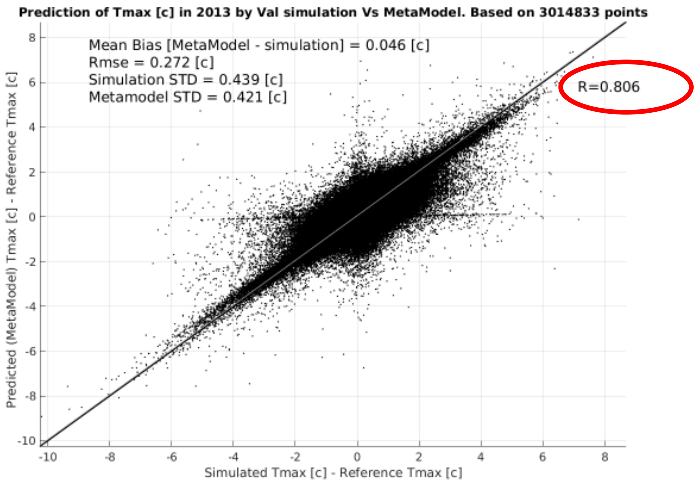


Figure 6: Tmax Meta-Model prediction for the tested parameter combination, vs COSMO simulation results during the year 2013. X axis presents the simulated Tmax minus the reference simulation. Y axis presents the Meta-Model Tmax minus the reference simulation.

COSMO-2 calibration

Meta-model validation

- Same as previous slide, for precipitation.

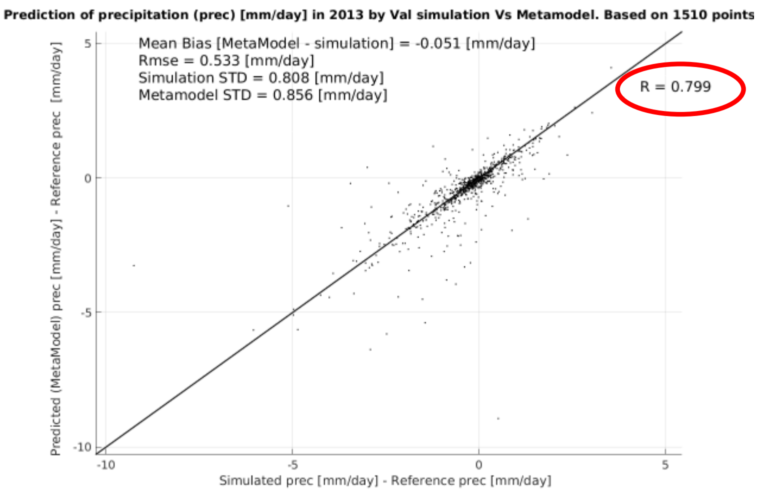


Figure 8: Pr Meta-Model prediction for the tested parameter combination, vs COSMO simulation results during the year 2013. X axis presents the simulated Pr minus the reference simulation. Y axis presents the Meta-Model Pr minus the reference simulation.

COSMO-2 calibration

Optimal parameters

Dependency of COSI score in model parameter space

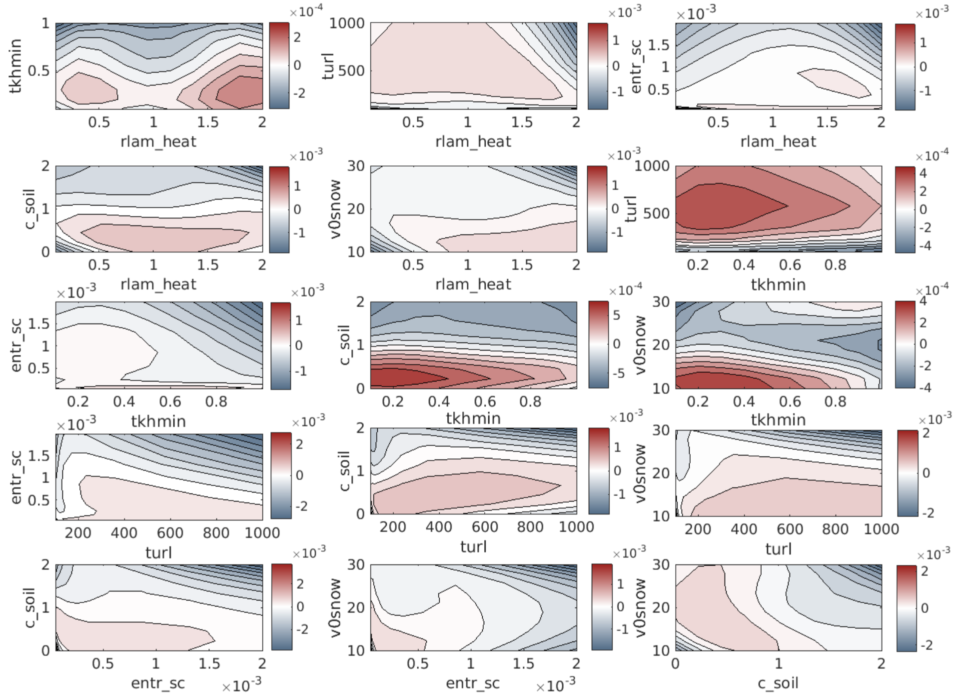


Figure 13: Method IV - Contours of score deviation $S_p - \overline{S}_p$ (eq. 5), for pairwise parameters combinations. Lower $S_p - \overline{S}_p$ areas represent better parameters combinations.

Higher

COSMO-2 calibration

Optimal parameters

Score distribution in model parameter space and extremum

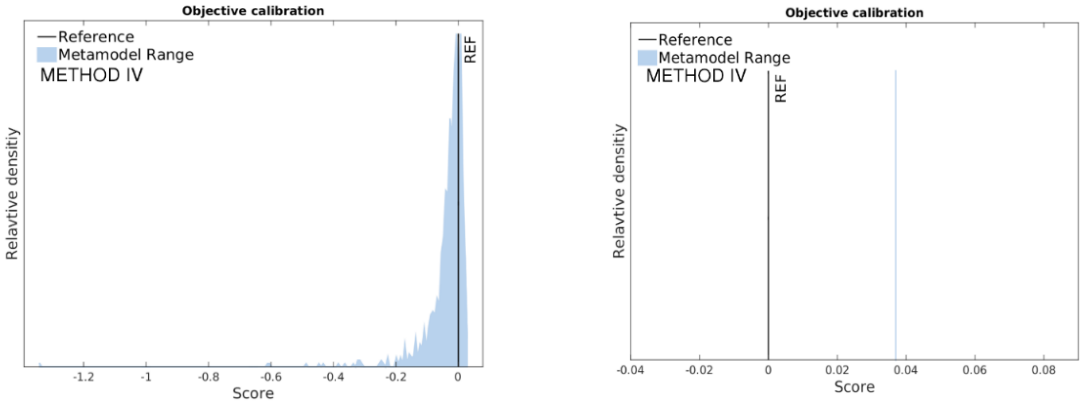


Figure 22: S_p scores distributions after **first** iteration (left) and **last** iteration (right), together with the scores of the reference (REF) simulation. For convenience, the distributions are presented as function of $\widetilde{S}_p = S_p/S_{p,REF} - 1$. Higher $\widetilde{S}_p > 0$ means better score with respect to the REF simulation.

COSMO-2 calibration
Optimal parameters

The optimal parameters leads to a 3-4% improvement of the COSI score, with parameters that significantly differ from their default values.

- rlam_heat=1.273 instead of the default 1.0. Uncertainty: [1.149 1.390];
- tkhmin=0.266 instead of the default 0.4; Uncertainty: [0.205 0.351];
- tur_len=346.5 instead of the default 150; Uncertainty: [294.6 409.9];
- entr_sc=0.0001607 instead of the default 0.003; Uncertainty: [0.0001261 0.0002104];
- c_soil=0.588 instead of the default 1.0; Uncertainty: [0.515 0.664];
- v0snow=12.3 instead of the default 20; Uncertainty: [11.6 13.3].

Furthermore, a strong seasonal dependency of the optimal parameters is observed.

Independent verification of optimal configuration shows small and mixed impact.

COSMO-1 calibration
Optimal parameters

- **COSMO-1 hindcast**
- Three years spin-up with TERRA standalone to initialize the experiments
- With **active soil memory**
- *Only* one month (01.2013)
- *Only* 5 parameters (tur_len, tkhmin, entr_sc, c_soil, *crsmin*)

The optimum parameters leads to a 11-12% improvement of the COSI score, with parameters that significantly differ from their default values, but also from the optimal set found for COSMO-2

CALMO
Learnings and shortcomings

- The method developed at ETHZ has been adapted to NWP, and was applied to calibrate 6 parameters of COSMO-2
- **Tools** and **documentation** are available on the COSMO web site
- **Knowledge** is available at HNMS and at IMS

- The **meta-model** is able to reasonably reproduce the dependency of the model on the unconfined parameters
- A small (mixed) impact on the COSMO-2 **performance** is observed.
This is expected, the chosen model configuration being very similar to the configuration used by the COSMO core development team, which has undergone considerable expert tuning.
- Hint to **much larger impact** when a different configuration is used or when seasonal dependency is considered.

- No definitive answer on the possibility to **improve the model performance**
- No full assessment of the effect of the **soil memory**
- Optimization of the method in terms of **computing resources** is pending

What's now ?

- No definitive answer on the possibility to **improve the model performance**
- No full assessment of the effect of the **soil memory**
- Optimization of the method in terms of **computing resources** is pending

- CALMO has shown that the calibration of a NWP model with a quadratic meta-model is possible, but open issues remain
- Large spectrum of applications if these remaining issues are solved
- Tools and knowledge are available
- ➢ **Follow-up project CALMO-MAX, 06.2017 – 09.2019, PL A. Voudouri**

The priority project CALMO-MAX

06.2017 – 09.2019, PL A. Voudouri

- [09.2017 – 09.2018] **Optimize** the method to find a compromise between the quality of the calibration and the computer costs. Use a one year COSMO-1 calibration as test bed for this purpose.
- Establish CALMO as a **permanent optimization tool** within COSMO. Create a demonstration framework at ECMWF. Create and maintain a database of unconfined model parameters.
- Apply the method to **different climatology** (e.g. Mediterranean). This will be used to demonstrate the applicability of the permanent framework.
- Investigate and implement **specific calibrations**, like a calibration for extreme events or a season dependent calibration.

See

http://www.cosmo-model.org/content/tasks/workGroups/wg3b/default.htm#CALMO-MAX

Thank you for your attention!