Priority Project
CALibration of the COSMO **MO**del
CALMO

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Outline

- Motivation
- Goals of CALMO
- Overview of the method
- Discussion

Motivation

- NWP/Climate models **are subject to high parametric uncertainty** due to poorly confined model parameters of parameterized physical processes
- Uncertainty of unconfined model parameters is constrained through **expert tuning during model development**.
- **Lacks** transparency, proper documentation, does not **follow a well defined strategy**, does not take parameter interactions into account.
- **Hinders implementation of new model developments** due to error compensation.
- Perturbation of model parameters based on subjective expert ranges.

Currently no consensus emerged on how to deal with parameter uncertainty in computationally expensive high-resolution models!

Goal of CALMO

Objective parameter calibration and perturbation of high-resolution NWP models

- **Objectives:**
  - Transparent parameter estimation which takes parameter interactions into account and follows a pre-defined strategy
  - Mainly automatised framework for re-calibration after new model developments , resolution changes, or new model domains
  - Determine observationally constrained parameter ranges for perturbed physics ensembles in EPS systems

- **Methodology:** Based on regional climate model calibration

  „Objective calibration of regional climate models". Bellprat et.al (2012)

Steps for CALMO

- Find an optimal model configuration in terms of simulation length/period, initial conditions (soil) and data assimilation.
- Select a subset of model key parameters to be used for calibration.
- Achieve goal: Gain knowledge on both optimal model configuration and parameter selection for a cost-effective parameter estimation of COSMO

Challenges for CALMO

- Establish the calibration framework from Bellprat et al. (2012) in NWP mode for an integrated validation.
- Key Aspects:
  - Framework effective also for NWP configurations?
  - Is COSMO over-tuned and needs to be re-calibrate for new developments?
  - Is a re-calibration beneficial for new model domains (e.g. Greece)?
- Achieve goal: Delevopment of an automatised tool to re-calibrated COSMO for new model developments/target domains

Opportunities for NWP

- A framework that allows to generate statistically consistent physics ensembles and can improve probabilistic forecast systems.

CALMO Overview

- Started on January 2013
- Will be completed at the end of December 2014.
- 2.35 FTE's are assigned.
- The scientists involved at the project are
  - O.Bellprat / ETHZ 0.66 FTE
  - J.M. Bettems/MeteoSwiss 0.06 FTE
  - F. Grazzini/ARPA-SIMC 0.1 FTE
  - A.Voudouri / HNMS 1.53 FTE (project leader)
- This priority project was assigned to Working Group 3b.

Method:Tuning parameters

RCM Calibration

Many unconfined parameters in different parameterizations

Turbulence

gkdrag	[0.075*,0.2,0.5]
gkwake	[0.2,0.5*,1]
securi	[0.1,0.85*,0.9]
tkhmin	[0,1*,2]
tkmmin	[0,1*,2]
turb_len	[100,500*,1000]
a_heat	[0.1,0.5,0.74*]
a_mom	[0.5,0.8,0.92*]
d_heat	[12,15,10.1*]
d_mom	[12,15,16.6*]
c_diff	[0.01,0.2*,10]

Radiation

uc1	[0.2,0.5*,0.8]
zuc0	[0.75,0.85,0.95]
q_crit	[1,4*,7,10]
clc_diag	[0.2,0.5*,0.8]
hincrad	[0.5,0.75,1*]
conv_clc	[0.7,1*,1.3]

Convection

rmfdeps	[0.2,0.35*,0.5]
rcucov	[0.01,0.05*,0.5]
rtau	[0.5,1*,1.5]
rprcon	[1.5,1,15*,20,150]e-3
entrsc	[0.0001,0.001]
entrpen	[0.0004,0.0008*,0.0012]
entrmid	[0.0004,0.008*,0.0012]
entrscv	[0.001,0.003*,0.01]
clccon	[0.15,0.35*,0.55]
cmfctop	[0.2,0.33*,0.55]
Tmpmin	[260,265,270]
zdnoprc	[0,2,4]
maxevap	[0.6,.8,1]
iclthrld	[e-8,e-7,e-8]

Microphysics

cloud_num	[5e7,5e8*,1e9]
qi0	[0,0.01*]
zxstar	[.33,2.6*,7.25]e-09
zv0s	[10,15*,30]
iclthld	[0.6,0.8*,1.0]
maxevap	[E-8,E-7*,E-6]

Surface layer

rlam_heat	[0.1,3*,5,10]
rat_sea	[1,10*,50,100]
rat_can	[0,1*,10]
rat_lam	[0.1,1*,10]
c_sea	[1,1.5*,10]
c_soil	[0,1*,10]
c_lnd	[1,2*,10]
z0m_dia	[0.001,0.1*,10]
patlen	[10,100,500*,1000]
e_surf	[0.1,1.5*,10]

Vegetation and Soil

crsmin	[50,200,300*]
maxalb	[0.6,0.7*,0.9]
rootdp	[0.5,1*,1.5]
cf_w	[1e-3,1.5e-3*,2e-3]
csalb_p	[0.1,0.15*,0.2]
eversalb	[0.1,0.2*,0.5]
snowfr	[0.5,1.5,*2.5]

Overview of the method

D23115 BELLPRAT ET AL.: OBJECTIVE CALIBRATION OF RCMS D23115

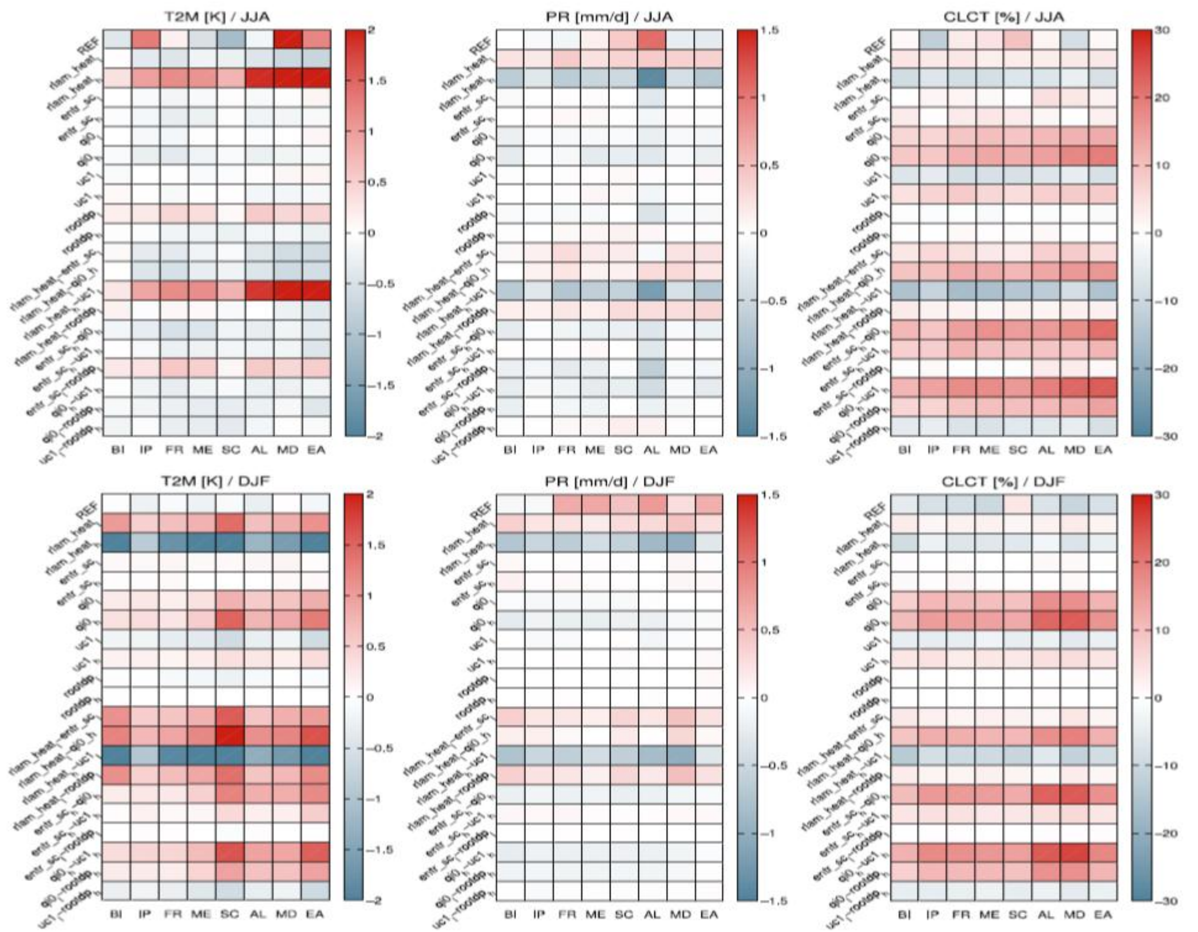


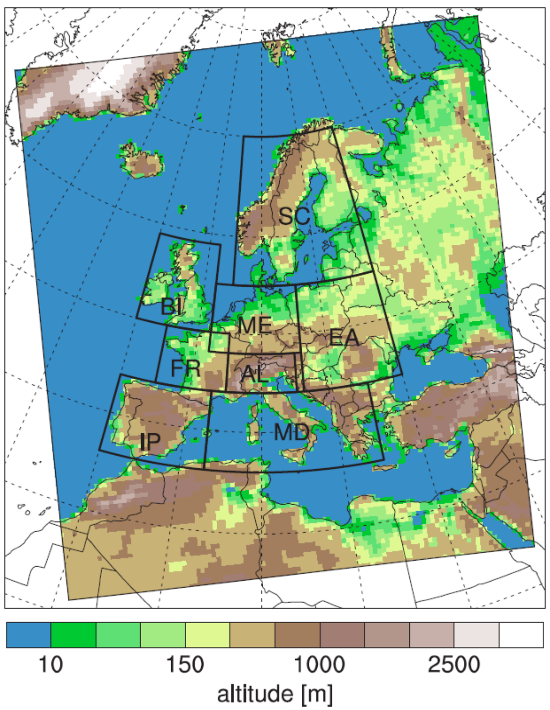
Figure 3. Sensitivity of reference simulation REF with respect to parameter perturbations for (top) JJA and (bottom) DJF. The vertical axes of each panel list the parameter perturbations. The effect of the perturbations is shown by color shading, for seasonal and regional means of T2M, PR, and CLCT averaged over the PRUDENCE regions on the horizontal axes. In the first row of each panel, the biases of the reference simulation are shown. The subsequent rows show the perturbations when using either a minimum or maximum value for single parameters, or when perturbing two parameters simultaneously. The subscripts of the experiment labels in the vertical axis denote whether the lower ("l") or higher ("h") bound of parameter has been chosen.

Method: Performance score

RCM Calibration

Multiobjective performance measure for climate applications

Used to select 5 important model parameters



Performance Score (PS)

$$PS = exp\left(-0.5\sqrt{\left\langle \frac{(m-o)^2}{(\sigma_{err}+\sigma_{iv}+\sigma_{inter})^2} \right\rangle}\right)$$

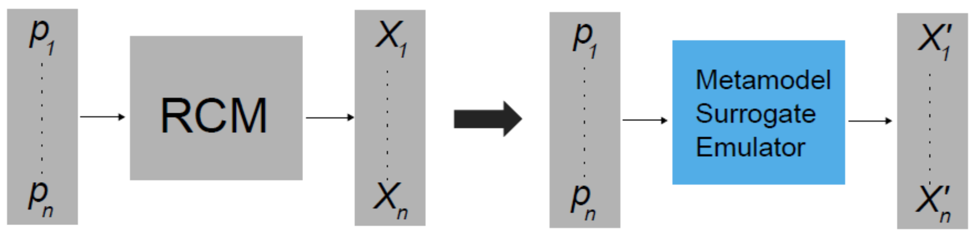
Least-squares error of monthly timerseries for T2M, PR and CLCT and for all PRUDENCE regions. (4DVar)

m=model output, o=observations

Method: Parameter sampling

Sample multidimensional parameter space using a computationally efficient **metamodel**

To estimate the metamodel for **5 parameters only 21 simulations needed**



Multivariate quadratic model (Neelin, (2010), low resolution).

Metamodel

$$X' = X_s + \vec{p} \cdot \vec{a} + \vec{p}^T \cdot B\vec{p}$$

X': Model field (e.g. T2M,PR,CLCT), $\vec{p}$: Parameter vector, a, B: Coefficient matrices

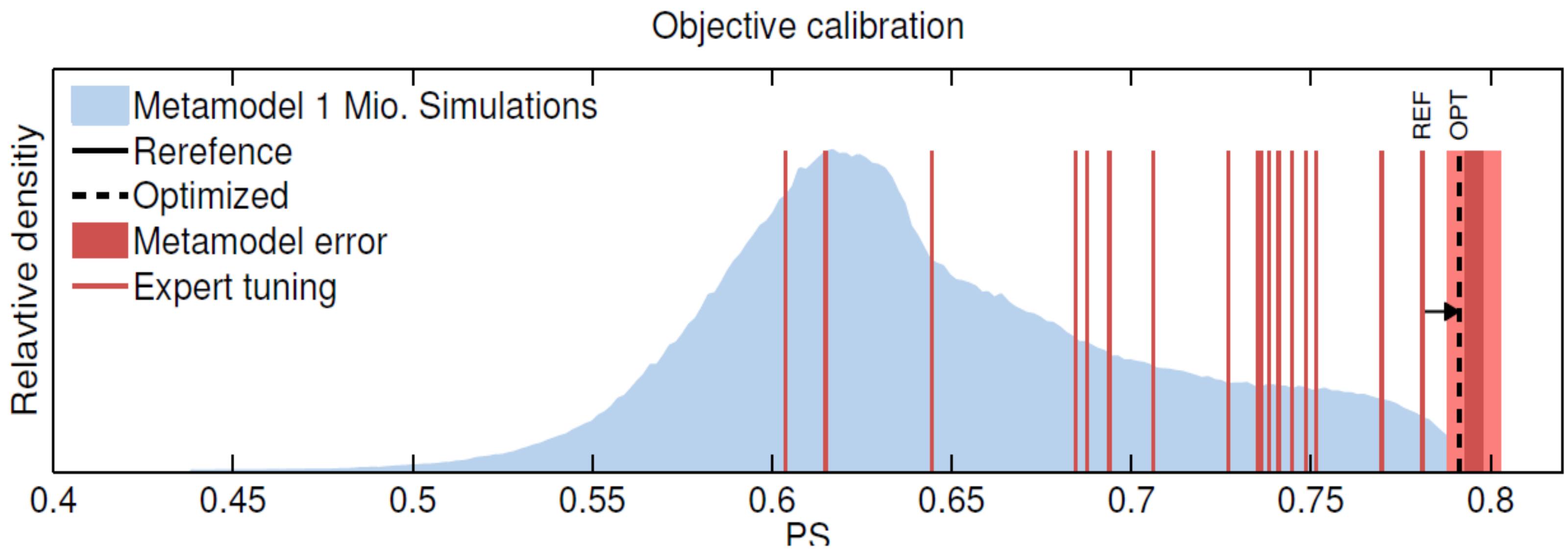
ΕΘΝΙΚΗ ΜΕΤΕΩΡΟΛΟΓΙΚΗ ΥΠΗΡΕΣΙΑ
HELLENIC NATIONAL METEOROLOGICAL SERVICE

CONSORTIUM FOR SMALL SCALE MODELING

Methods: Calibrations

RCM Calibration

Objective calibration beats expert tuning and leads to additional model improvement

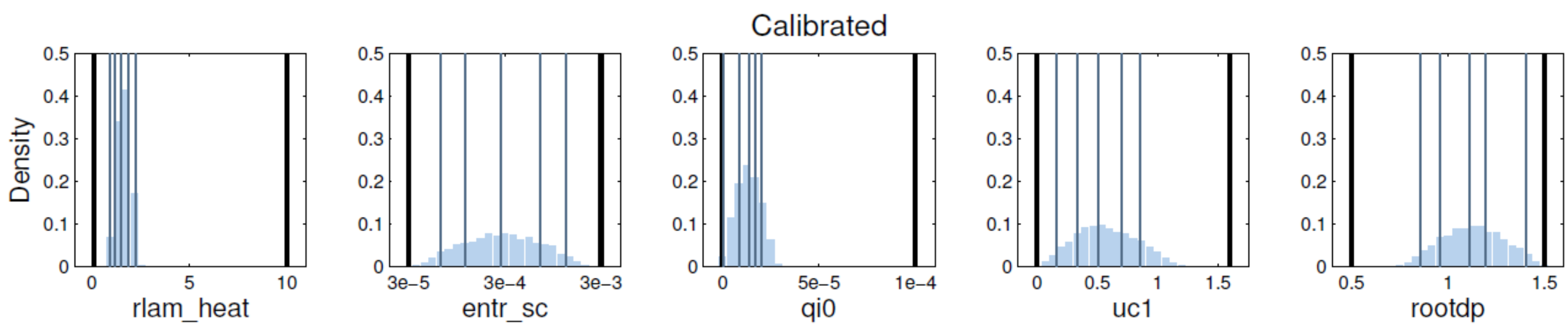


Methods: Constrained parameters

RCM Calibration

Calibration allows to define **posterior parameter distributions** which agree with the observations.

Allows for physical perturbations with **equally likely but different parameter configurations** for ensemble prediction systems



CALMO Tasks

- Administration and support (Task 0)
- Preliminary work (Task 1)
- Adaptation of the method (Task 2)
- Sensitivity with respect to target region (Task 3)
- Practicability of the method (Task 4)
- Documentation (Task 5)

Task 1

- **Literature survey of relevant scientific papers……. an ongoing process.**
- **Adaptation of the statistical measures (performance score) to be used.** It is proposed to use **COSI Index** already implemented in VERSUS as well as timeseries of RMSE for the selected parameters.
- Discussions on possible modification of the parameterization schemes scheduled (change parameters under consideration)
- Adaptation of the documented list of tuning parameters delivered at the framework of Task 2.1.
- The necessary computing resources for model simulation have been calculated and guaranteed on CSCS.

Task 2 and Task 3

- **Task 2: Adaptation of the method**
  - 2.1: Documentation of tuning parameters and choice of parameters subspace
  - 2.2: Selection of performance function(s)
  - 2.3: Identification of key-variables for NWP
  - 2.4: Experimental set-up.
  - 2.5: Collection of data
  - 2.6: Compute experiments and analyse results

Task 3: Sensitivity with respect to target region
  - 3.1: Application of the method over different regions
  - 3.2: Analyse results

Structure of the individual steps for the calibration approach

- Three major parts that operate independently from each other define the calibration:
  - the simulations of COSMO using specified design parameter points (already started),
  - the computation of the verification scores for each simulation,
  - the optimization, determining the optimal parameter values.

- It is propose that the interface for the calibration algorithm should be independent from the choice of the verification score. Could this cause in-accuracies in the optimization procedure?

- A documentation of the optimization procedure is planned by the end of the year 2013.

Year selection

- The year selected should be a climatological representative year (alternatively only summer and winter)
- Following the Annual Bulletin on the Climate in WMO Region VI as well as literature review:
  - 2011 was the warmest year over the past 100 years
  - Winter 2009/2010 was extremely cold.
- Thus **2008** was selected (against years examined 2009, 2010 and 2011.

Development of methodology

- All simulations are carried out on CSCS Piz Daint using the COSMO version 4.26.
- The model configurations are those currently in production at MeteoSwiss (07.2013).
- The assimilation cycle uses all available conventional observations (a single data assimilation cycle - to be discussed) .
- Snow analysis and soil moisture analysis are disabled.
- Latent heat nudging is switched off.
- Boundary conditions are directly interpolated from the COSMO-7 analysis available in the MeteoSwiss archive.
- Initialized with an equilibrium soil state (3 months spin-up phase could also be considered).
- The simulations are performed for the full year 2008.
- The year is simulated using one-day (24 or 36h lead time starting at 12UTC) .

CALMO: Parameter selection

- Depending on the number of parameters to be optimized the minimum number of model runs required is

  2N+N(N-1)/2

  where N is the number of parameters
- Parameters normally adjusted during tuning are related to fast processes such as convection and radiation (Schirber et al., 2013)
- Model sensitivity to these parameters should be evident even in short integrations such as those used in NWP (Rodwell and Palmer, 2007)

CALMO: Parameter selection

On the base of :

a) previous sensitivity studies conducted with COSMO-CLM version over Europe and N-America (Bellprat 2012, 2013)

b) The outcome of the COSMO-QPF project whose aim was to investigate the sensitivity in different implementation of operational model respect to initial conditions and model/tuning parameters changes (Dierer, 2008)

c) additional settings from different COSMO operational model implementations.

initially a list of 6 tuning parameters from to start the optimization experiments **5 finally.**

These six tuning parameters are all included in the Tuning Namelist and some of them (laminar scalar factors and minimal diffusion values) are further investigatied in **Consolidation of Surface to Atmosphere Transfer (ConSAT) ?????**

Processes	Parameter name	Parameter description	Range*	Main sensitivity
Clouds-radiation feedbacks	"radfac" (no name)	Fraction of cloud qi, qs seen by radiation	[0.3,0.5,1]	Strong effect on cloud / radiation interactions
	rlam_heat	scalar for laminar boundary layer roughness	[0.1,**1**,10]	Strong effect on T2m clouds and precip
	rat_sea (to be excluded, similar to rlam_heat)	scalar for laminar boundary layer roughness sea	[1,**20**,100]	Strong effect on T2m clouds and precip
Boundary and surface layer processes	tkhmin (to be discussed)	minimal diffusion coeff. for heat (m^2/s)	[0,0.4,**1**,2]	Strong sensitivity on T2m and clouds
	tur_len	turbulent lenght	[100,250,**500**,1000]	Moderate sensitivity on cloud and precip(convective)
Surface PBL feedbacks	facroot_dp	factor for the root depth for the entire field	[0.5,**1**,1.5]	Moderate sensitivity on T2m and clouds in summer)

* numbers in bold represent default values, in green setting operated ad DWD if different from default, red settings operated by MeteoSwiss if different from def.

Domain size and model resolution

1. Size of the model domain strongly affects the computational demands of the calibration
2. COSMO is initially calibrated on a small domain COSMO-CH. It covers the boarders of Switzerland, is about 10 times smaller (area) than COSMO-2 *~40x60 grid points*.
3. A smaller domain COSMO-CHS to be discussed. COSMO-CHS covers only the Northern Midlands and Alps of Switzerland and is about 25 times smaller than COSMO-2.
4. Model resolution*:* 7 km (convection parameterized) version of COSMO for the COSMO-CH domain.(2.2 km (convection resolved) km to be tested. The comparison of the calibration results allows to test whether different optimal parameters are found depending on the resolution and definition of the physics.

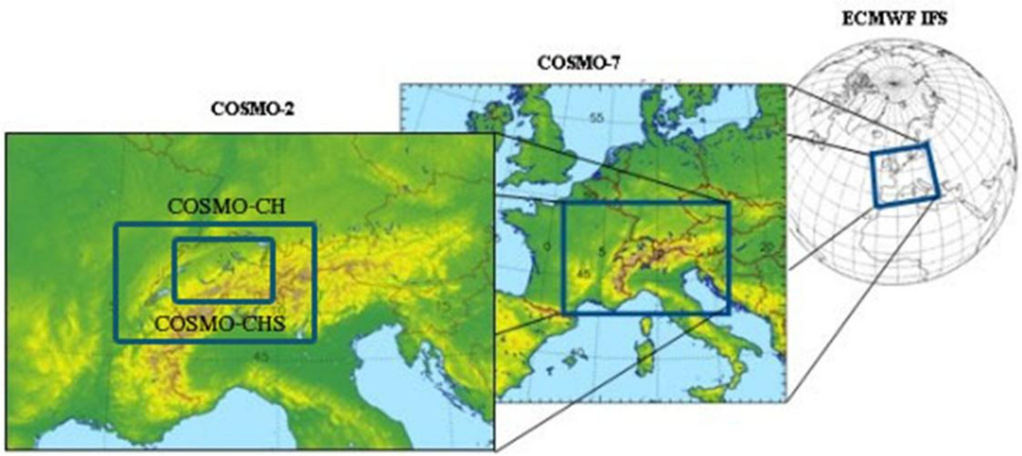


Fig. 1: Model domain and topography of COSMO-7 and COSMO-2, with an additional potential domain COSMO-CH to test effect of domain size

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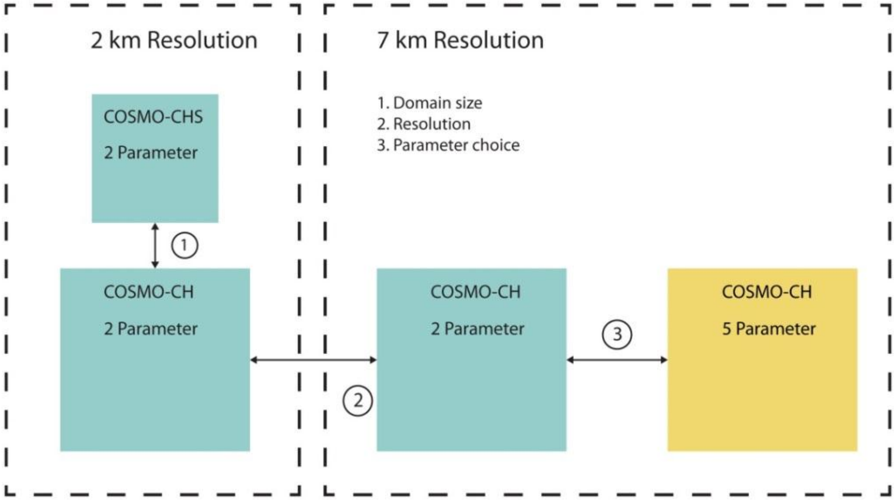
Parameter selection

- The calibration suites with two parameters only (rlam_heat or tkhmin and tur_len, to be discussed …..)~ *7 simulations*
- To test the effect when using more parameters a calibration with 7 km for the COSMO-CH domain with additional parameters (rlam_heat, tur_len, tkhmin, fac_rootdp, radfac) will be performed.
- Sensitivity is ultimately depending on the parameter interactions of the selected parameters which are found to be relatively small in Bellprat et al. (2012)

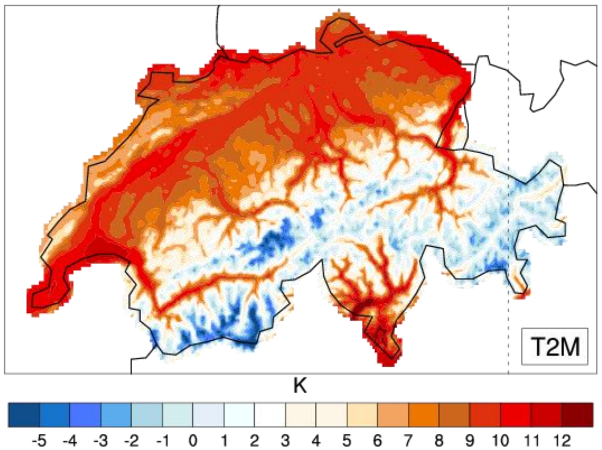
Fig. 2: Calibration suites to evaluate the sensitivity with respect to domain size, resolution and parameter choice



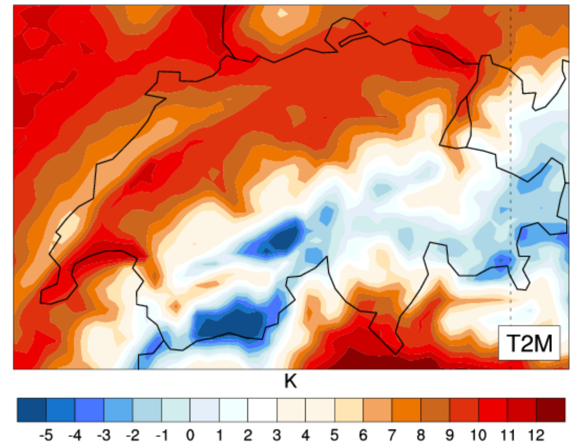
Observations

COSMO 7 (CALMO)

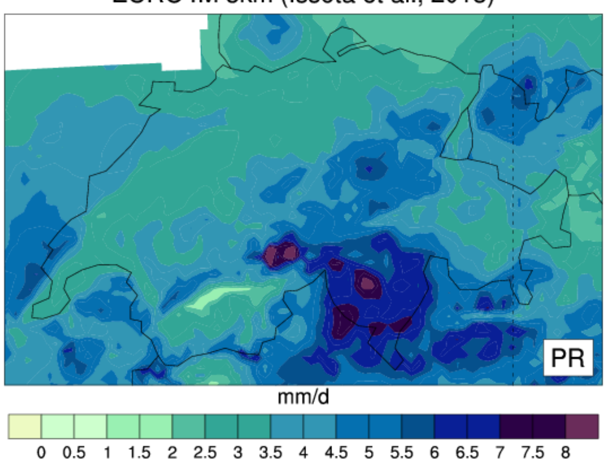
MeteoSwiss 1km (Frei et al., 2013)



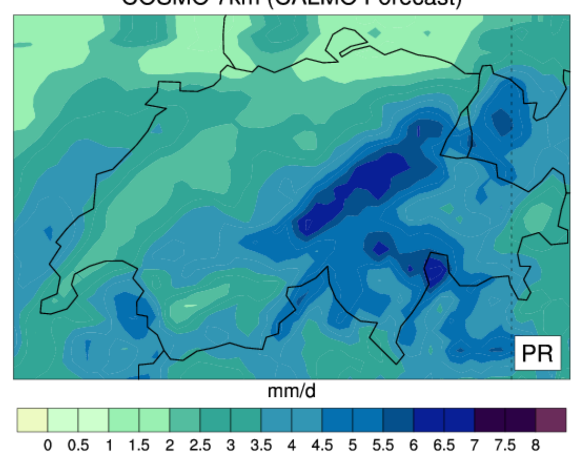
COSMO 7km (CALMO Forecast)



EURO4M 5km (Issota et al., 2013)



COSMO 7km (CALMO Forecast)



Validation

- Measuring model performance in terms of model variables considered and validation metrics.

- Potential variables to be considered: 6h precipitation, **24h precipitation, hourly T2m** and Td, T 850 , V 850, satellite cloud forward operators (top, middle, low).

- Integrated measures to be used? COSI, RMSE

Metrics selection

- Definition of Cosi Index already implemented in VERSUS and used by DWD .
- The COSMO Index (henceforth called COSI) is a measure of the forecasting skill of the different COSMO models implementation in COSMO consortium. A score is calculated for each forecast included in COSI. The individual scores are then c
- COSI is compiled from the following parameters
  - Near-surface (2m) temperature
  - Near-surface (10m) wind speed & direction as wind vector
  - Precipitation yes/no (at least 0.2, 2.0 and 10.0 mm over the preceding 6 hours)
  - Total cloud amount (0-2, 3-6 and 7-8 oktas) for a total of two thresholds

Summary

- Primary step of CALMO is to demonstrate the applicability of the approach using a computationally cost-effective framework.
- COSMO-7 for a small model domain (Switzerland) will be used for a first demonstration study and for a starting framework to test several sensitivities in the configuration choices.
- Use of COSMO-2 for small model domain with boundary conditions provided by the COSMO-7 analysis, may generate problems with regard to the different vertical stratifications and different treatment of convection.
- This would lead to inhibited development of convective systems at the western domain boundaries which would lead to bad verifications results.
- In order to define a cost-function for the model calibration it is suggested to use the meteorological verification at a station level, routinely performed for Switzerland. This verification should take into account uncertainties in the observations and limitations of the model predictability.

References

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- Kaufmann, P. 2008: Association of surface stations to NWP model grid points. COSMO Newsletter 9, 54-55.

Any suggestions, comments, remarks?

http://mail.cosmo-model.org/mailman/listinfo/cosmo-calmo

Open Issues

- Adaptation of the statistical measures (performance score) to be used.
- Discussions on possible modification of the parameterization schemes scheduled (change parameters under consideration).
- Selected parameters (rlam_heat, tur_len, tkhmin, fac_rootdp, radfac) to be calibrated.

Management issues

FTE's used

Countries involved	TASK 0	TASK 1	TASK 2	TASK 3	Total FTE's per country
Switzerland	0.02	0.12	0.19		**0.33**
Greece	0.06	0.17	0.25	0.1	**0.58**
Italy			0.1		**0.1**
Total FTE's per Task	**0.08**	**0.29**	**0.54**	**0.1**	**1.01**

Management issues

FTE's to be used for the next COSMO Year

Countries involved	TASK 0	TASK 1	TASK 2	TASK 3	TASK 4	TASK 5	Total FTE's per country
Switzerland	0.02		0.15	0.05		0.15	**0.37**
Greece	0.05	0.05	0.1	0.2	0.2	0.1	**0.7**
Total FTE's per Task	**0.07**	**0.05**	**0.25**	**0.25**	**0.2**	**0.25**	**1.07**

~ 0.35 FTE's will be used by the end of the project 12.2014

Approach

Application of a score like the UK-index - basic values

$$\mathrm{rmse} = \sqrt{\frac{1}{n}\sum_{n}(t_f - t_o)^2}$$

Continuous elements

$$\mathrm{rmsvwe} = \sqrt{\frac{1}{n}\sum_{n}\left|\mathbf{V}_f - \mathbf{V}_o\right|^2}$$

Wind

$$SS = 1 - \frac{r_f^2}{r_p^2}$$

Skill score for wind and continuous elements related to persistence

$$ETS = \frac{R - \text{"chance"}}{T - \text{"chance"}}$$

Skill score for categorical elements related to chance

Approach

Application of a score like the UK-index - **final score**

$$S = \frac{1}{\sum_i w_i}\left(\sum_i (w_i SS_i)\right)$$

The Index, I, is normalised so that the value is equal to 100 on 31st March 2000.

Thus, the Index is defined as:

$$I = \frac{S}{S_0} \times 100$$

where: S_0 is the value of S on 31st March

Scores in MOVI and UKMO

- Continuous parameters: Reduction of variance

  $RV = 1 - (RMSE\ prog\ /\ RMSE\ ref)^2$

  where ref = persistence

- Categorical parameters: ETS
  - ETS = (R – „chance") / (T –"chance")

    R= number of obs events correctly forecast

    T = number of events which were either observed or forecasted

⌦ global score S like

$$S = \frac{1}{\sum_i w_i}\left(\sum_i (w_i SS_i)\right)$$

COSMO-index COSI = S/S_0 x100

Parameters

- total cloud amount [threshold: 0-2, 3-6, 7-8
  temperature [t2m, later: tmin, tmax]
- 10m- windvector
- precipitation [thresholds: 0.2, 2, 10 mm/6h]

Verification frequency

- Every 3h
  - T2m, 10m-wind and cloudiness:
    - @ 00, 03,…, 18, 21 UTC

  later on: tmin & tmax over 12h

- 6h-sums: precipitation

Verification frequency

- Cloud cover wind and temperature

03 06 09 12 15 18 21 24 **Forecast day**

03 06 09 12 15 18 21 24 **Persistence one day before forecast day**

- 6h-sums: precipitation

06 12 18 24

Final definition of the score: 1

Continuous elements,
sum over 8 time steps:
(start: vv=3, end: vv=24, step: 3)
Equal weights for all forecast times!

$$SK_j = \frac{1}{8}\sum_{i=1}^{8} sk_{i,j}$$

$$SK_j \; : \quad Skill-Score\ for\ element\ j$$

$$sk_{i,j} \; : \quad Skill-Score\ for\ element\ j\ at\ time\ step\ i$$

Final definition of the score - 2

Categorical elements,
sum over N time steps:
(start: vv=vvb, end: vv=vve, step: vvs)
Cloud cover: vvb=3, vve=24 vvs=3
Precipitation: vvb=6, vve=24 vvs=6
Equal weights for all forecast times and categories!

$$SK_j = \frac{1}{M * N} \sum_{l=1}^{M} \sum_{i=1}^{N} sk_{i,j,m}$$

$$SK_j \quad : \quad Skill - Score \; for \; element \; j$$

$$sk_{i,j,m} \quad : \quad Skill - Score \; for \; element \; j \; at \; time \; step \; i \; in \; category \; m$$

Final definition of the score - 3

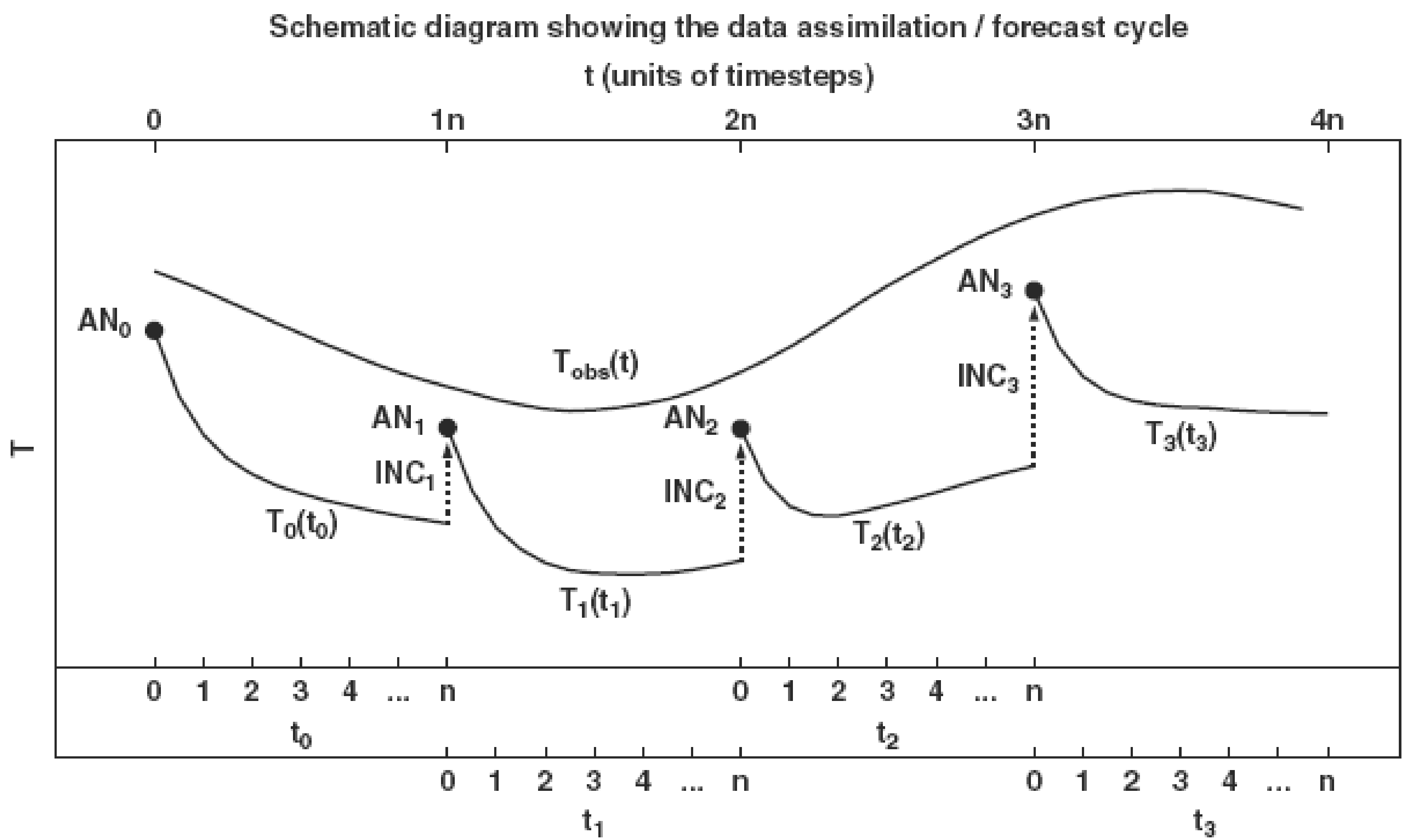
Sum over all elements:
Equal weights for all elements!

$$SK = \frac{1}{N_E} \sum_{j=1}^{N_E} SK_j$$

COSMO-index COSI = S/S_0 x100

……………………………………….to be discussed with Wg5

Schematic of the data assimilation process



(from Rodwell and Palmer, 2007)