INSTITUTE FOR ATMOSPHERIC AND CLIMATE SCIENCE

Calibration activities for regional climate simulations

Silje Lund Sørland

With input from

Omar Bellprat, Jean-Marie Bettems, Roman Brogli, Xavier Lapillonne, Katherine Osterried, Emmanuele Russo, Christoph Schär, Antigoni Voudouri

Outline

- Overview of the objective calibration method used in a regional climate modeling framework
- Studies that has used the Objective calibration method with the COSMO-CLM model
- Ongoing work with the calibration framework
- trCLIM: Exploiting km-resolution climate models in the tropics to constrain climate-change uncertainties

Calibration framework: Determining optimal parameter values

The calibration approach based on Bellprat et al. 2012, 2016:

Relies on a statistical approximation of a climate model (i.e. metamodel) that predicts the model response to parameter configurations.

List of tuning parameters in COSMO-CLM (>33)

Turbulence		
Minimal diffusion coefficients for heat ($m^2 s^{-1}$)	Tkhmin	[0, **1**, 2]
Minimal diffusion coefficients for momentum ($m^2 s^{-1}$)	Tkmmin	[0, **1**, 2]
Turbulent length scale (m)	turb_len	[100, **500**, 1000]
Factor for turbulent heat dissipation	d_heat	[12, 15, **10.1**]
Factor for turbulent momentum dissipation	d_mom	[12, 15, **16.6**]
Factor for turbulent diffusion of TKE	c_diff	[0.01, **0.2**, 10]
Land surface		
Scalar for laminar boundary layer roughness	rlam_heat	[0.1, **1**, 3, 5, 10]
Scalar for laminar boundary layer roughness sea	rat_sea	[1, 10, **20**, 50, 100]
Factor for canopy height	rat_can	[0, **1**, 10]
Ratio of laminar boundary layer thickness for *q* and *h*	rat_lam	[0.1, **1**, 10]
Surface area index of the waves over sea	c_sea	[1, **1.5**, 5, 10]
Surface area index of the (evaporative) soil	c_soil	[0, **1**, 10]
Surface area index of grid points over land	c_lnd	[1, **2**, 10]
Roughness length of a typical synoptic station (m)	z0m_dia	[0.001, **0.1**, 10]
Length scale of subscale surface patterns over land (m)	patlen	[10, 100, **500**, 1000]
Exponent to get the effective surface area	e_surf	[0.1, **1.5**, 10]
Stomata resistance	crsmin	[50, 200, **300**]
Convection		
Fractional mass flux for downdrafts at LFS	rmfdeps	[0.2, **0.35**, 0.5]
Assumed convective cloud cover (%)	rcucov	[0.01, **0.05**, 0.5]
Factor for the time scale for cape closure	rtau	[0.5, **1**, 1.5]
Coefficient for determining conversion from cloud water to rain	rprcon	[0.000 15, 0.001, **0.0015**, 0.002, 0.015]
Penetrative entrainment rate ($1\ m^{-1}$)	entrpen	[4e-5, **8e-5**, 12e-5]
Midlevel entrainment rate ($1\ m^{-1}$)	entrmid	[4e-5, **8e-5**, 12e-5]
Entrainment rate for shallow convection ($1\ m^{-1}$)	entrsc	[5e-5, 1e-4, **3e-4**, 1e-3, 2e-3]
Microphysics		
Cloud droplet concentration ($1\ m^{-3}$)	cloud_num	[5e7, **5e8**, 1e9]
Cloud water threshold for autoconversion	qi0	[**0**, 0.000 01, 0.0001, 0.001, 0.01]
Separating mass between cloud and rain (kg)	zxstar	[3.36e-11, **2.6e-10**, 7.25e-09]
Factor for fall velocity of snow	zv0s	[10, **15**, 30]
Radiation		
Subgrid-scale cloud height scalar	uc1	[0.2, **0.5**, 0.8]
Critical value for normalized oversaturation	q_crit	[1, **4**, 7, 10]
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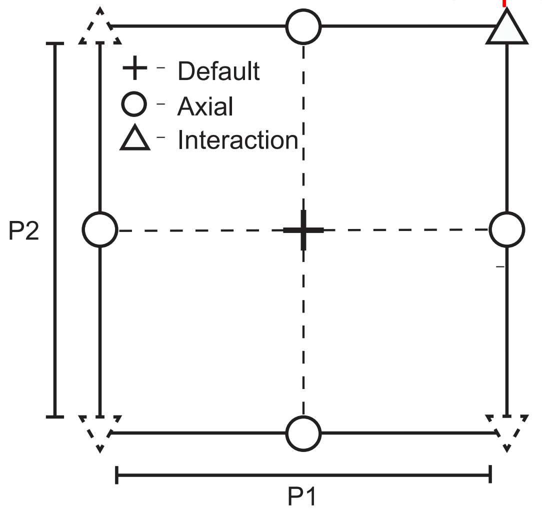
Example



1. **Reference simulation** with all parameter at the default value (1 simulation)
2. **Sensitivity simulations** with one of the parameters set to either extreme value (2*N simulations)
3. **Sensitivity simulations** where 2 different parameters are set to either extreme value (N*(N-1)/2 pairs with 4 possible combinations => 2*N*(N-1) simulations)
4. A total of 1 + 2*N*N simulations

for N=8: 129 simulations

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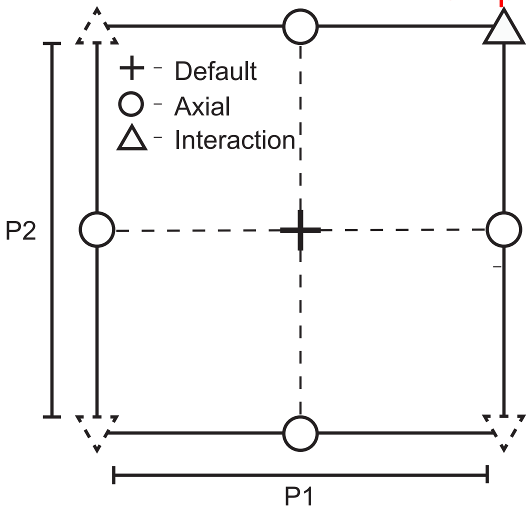

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Performance score (PS)

Same as in in Bellprat et al. 2012

$$PI = \left\langle \frac{\sqrt{(m-o)^2}}{(\sigma_o + \sigma_{iv} + \sigma_\epsilon)} \right\rangle, \qquad PS = \exp(-0.5PI^2).$$

Observations are used to assess the performance.

Observations of

- 2m temperature (T2M, E-OBS)
- Precipitation (PR, E-OBS)
- total cloud cover (CLCT, CRU)

Calibratio

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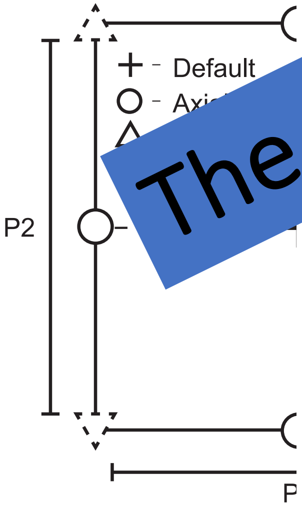
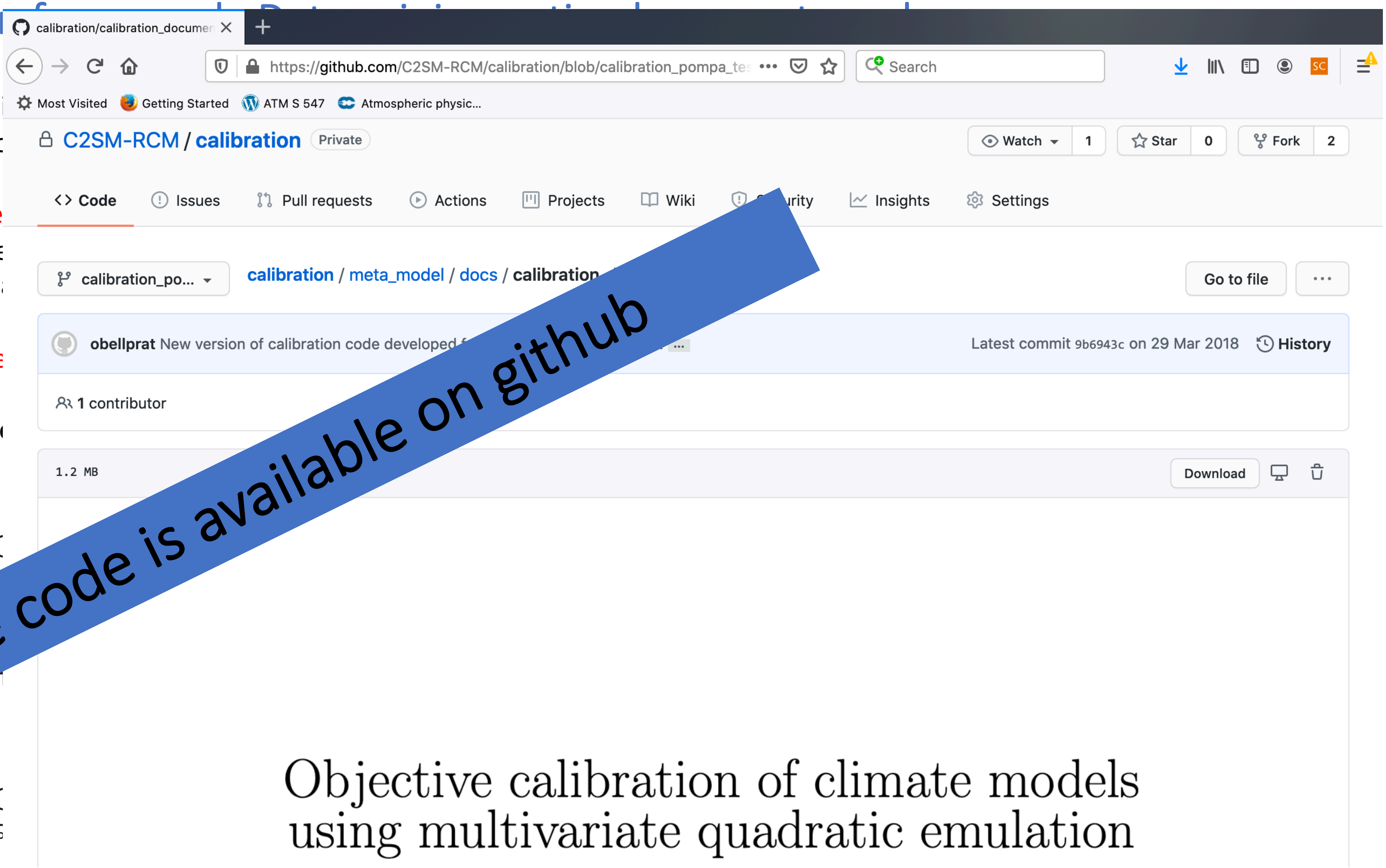
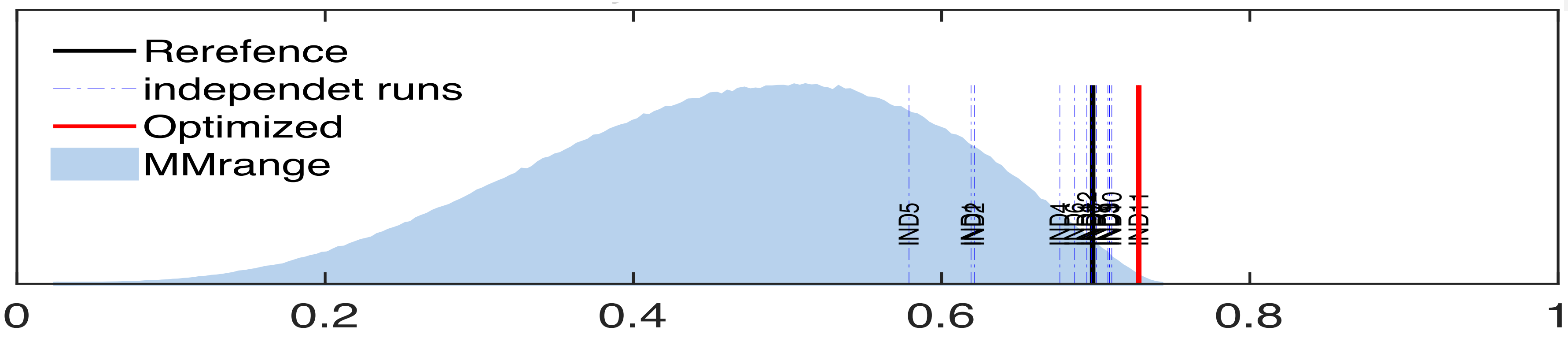


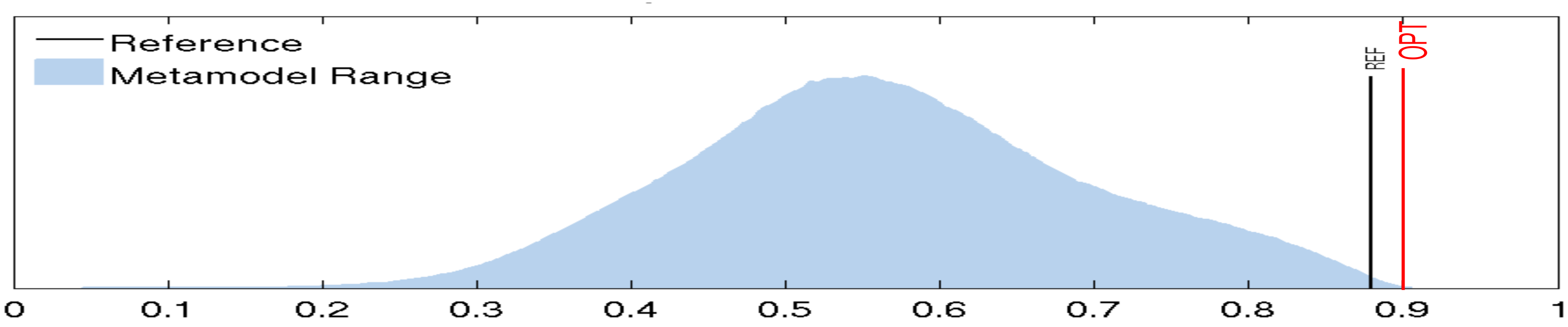


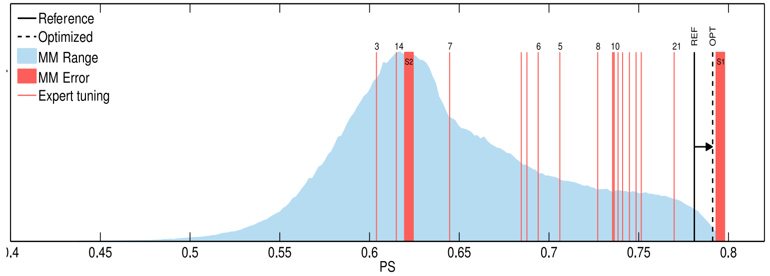
The code is available on github

Objective calibration over Europe with different versions of the COSMO-CLM model

We now have good experience with the calibration method over Europe







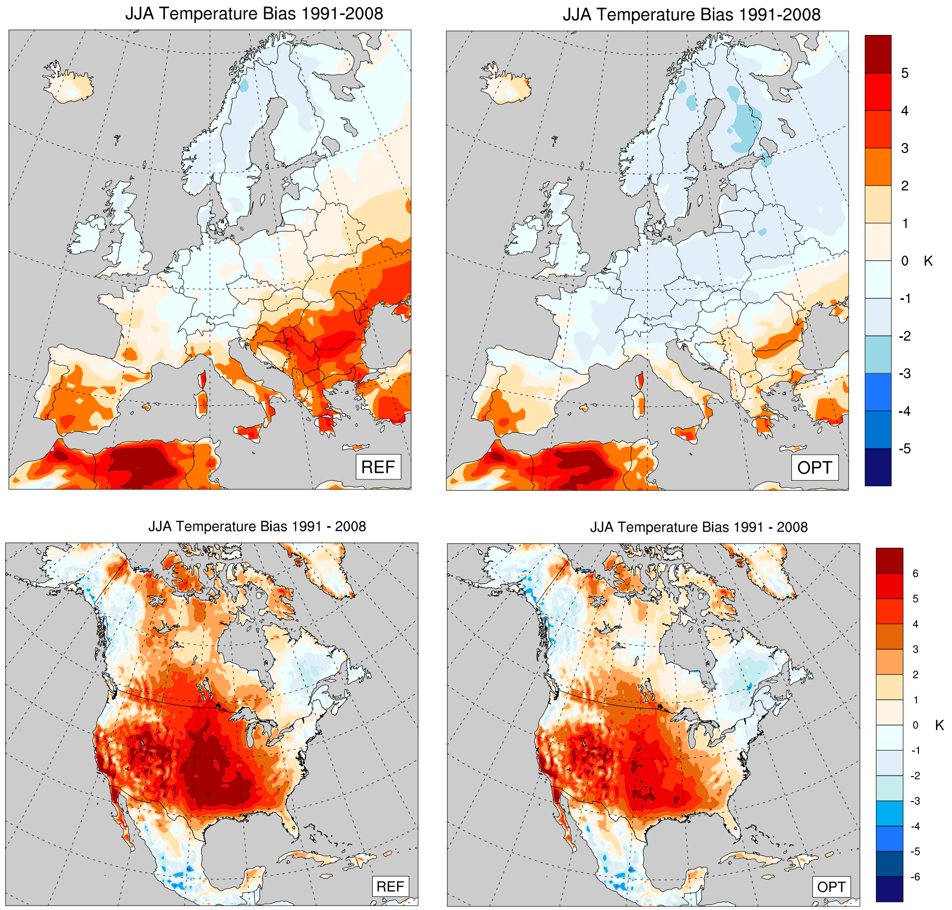
Model version	Δx	period	Parameters
COSMO-crCLIM-v1-1	50km	2005-2010	7 rlam_heat, uc1, tur_len, fac_rootdp2, tkhmin &tkmmin, radfac, l_g, v0snow
COSMO5.0_clm6	50km	1994 - 1998	8 rlam_heat, uc1, qi0, fac_rootdp2, entr_sh, tkhmin, radfac, soilhyd
COSMO4.8_clm17	50km	1994 - 1998	5 rlam_heat, uc1, qi0, fac_rootdp2, entr_sh

Performing Objective calibration over Europe and North-America

JJA Temperature bias

Before the calibration

After the calibration

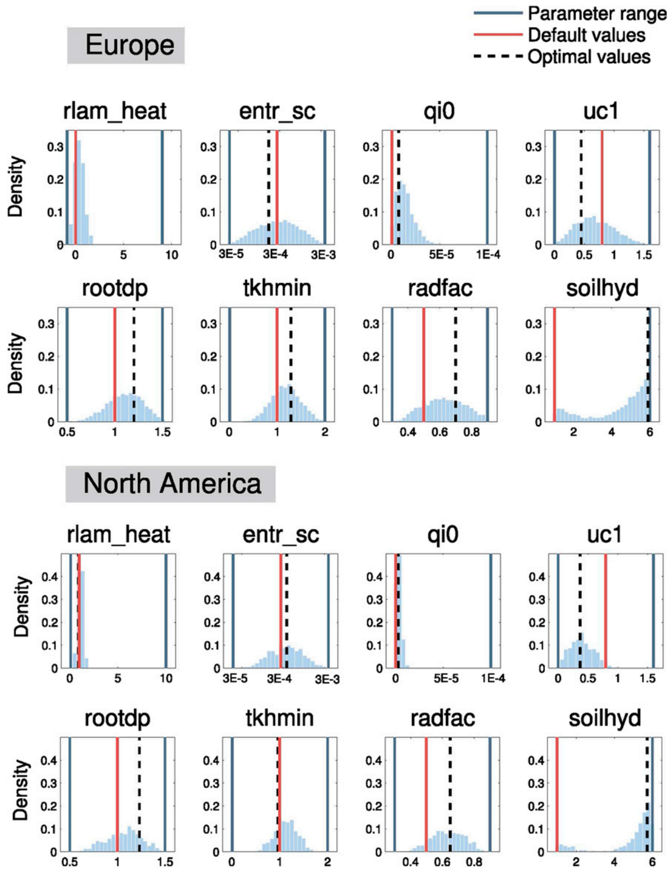


Reduction of the biases with the OPT settings

The calibration yields almost identical optimal values over the two domains.

→ This supports the robustness of the calibration methodology

→ The method addresses uncertainties in the model physics that are common among different regions.

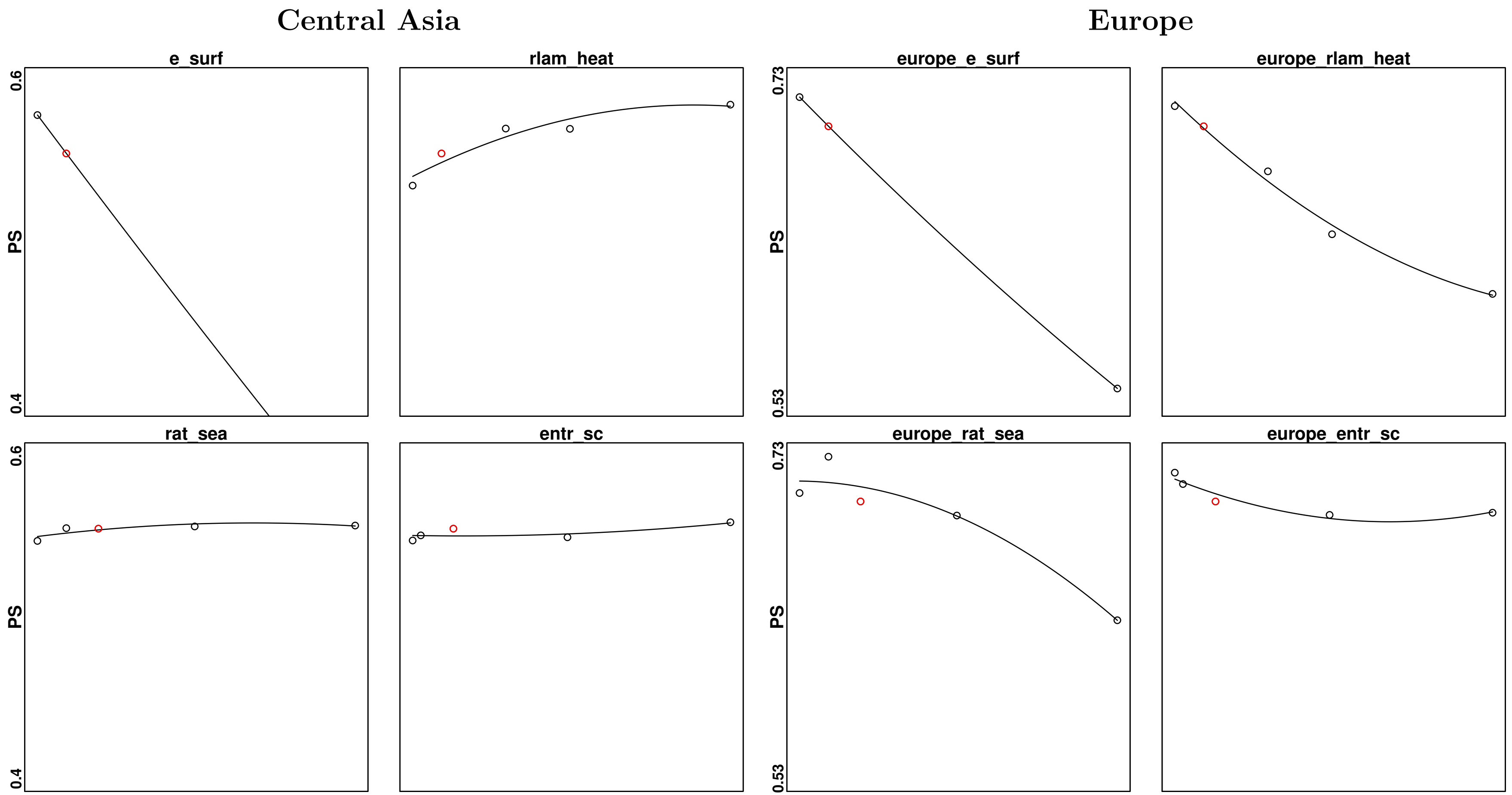


But how about uncertainties in model parameters for regions with very different climate from the European climate?

Bellprat et al. 2016

Perturbed physics experiment for Central Asia

Goal: Characterize the parameter uncertainty in COSMO-CLM for the Central Asia region (Russo et al. in review in GMD)



PS score (1 the best) combined for T2M, PR, CLCT calculated for different values of

- e_surf (land-surface scheme)
- rlam_heat (land-surface)
- rat_sea (and-surface)
- entr_sc (convection)

The values of the parameters are the same in the two cases, and red dots represent the considered parameter values for the default simulation.

The sensitivity of the model to parameters perturbation for Central Asia is different than the one observed for Europe.

→ The climate over Central Asia is very different than for Europe.

→ Thus an RCM should be re-tuned, and its parameter uncertainty properly investigated, when setting up model experiments to new domains

Ongoing work with the calibration framework

- Exploring alternative observations

Lukas Joss, Jesus Vergara, Christoph Schär, ETHZ

- An Bsc thesis exploring the PS score by using alternative observation dataset, and systematically comparing 12km climate simulations with the convection on/off.

- Structural Behaviour of the COSMO-CLM Under Different Forcings

Emmanuele Russo, Uni Bern

- The sensitivity in COSMO-CLM to parameters perturbation is investigated under different climate forcings by performing the perturbed physics ensemble.
- The results will be presented at the CLM-assembly on Thursday 17th September from 13:50 to 14:40.

trCLIM: Exploiting km-resolution climate models in the tropics to constrain climate-change uncertainties

Main objective: Investigate the Climate sensitivity and clouds in tropical Atlantic

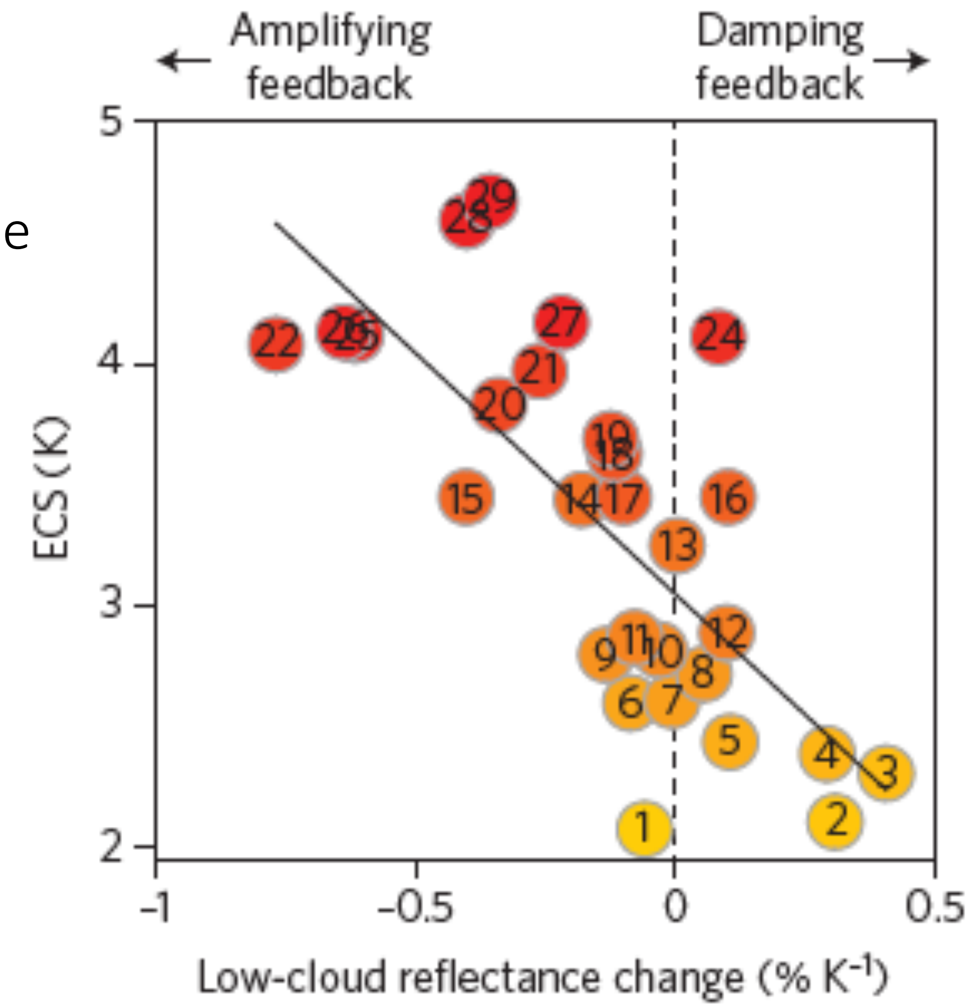
A SNF funded project (2020-2023)

Christoph Schär (PI, ETHZ), Xavier Lapillonne (CO-PI, MeteoSwiss), Silje Lund Sørland (ETHZ/NORCE) Jean-Marie Bettems (MeteoSwiss), Martin Wild (ETHZ), Roman Brogli (ETHZ)

- Two PhD-studens:

→Christoph Heim: Convection-Resolving Simulations of Marine Low Clouds in the subtropics of the Southern Atlantic

→Shuchang Liu: Objective model calibration



(Schneider et al. 2017, Nature CC; see also Bony et al. 2015, NGS)

trCLIM: Exploiting km-resolution climate models in the tropics to constrain climate-change uncertainties

Tools:

- GPU-version of COSMO model

(Graphics Processing Units: faster and cheaper)
Rewritten code by MeteoSwiss, CSCS, ETH
- dynamical core rewritten in C++ and CUDA
- parameterizations use OpenACC
Also used for operational NWP (D=1 km)
Runs on Piz Daint (Cray XC50, CSCS)
Limited-area model with large computational domains

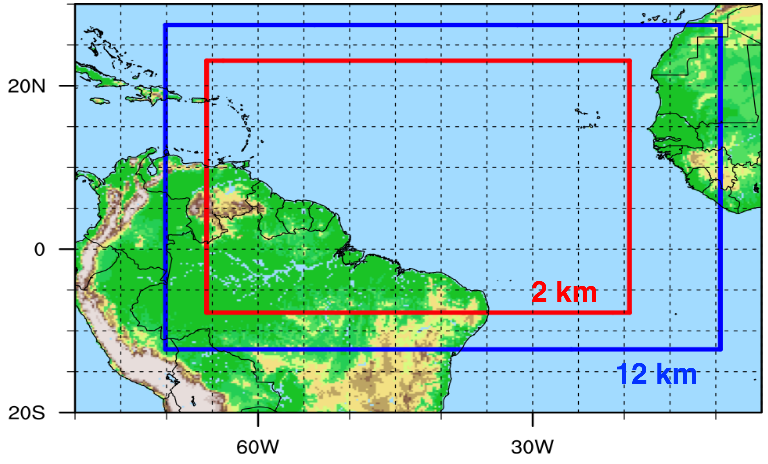
Piz Daint: Linpac peak performance: 20×10^{15} Flop/s

- Pseudo-Global Warming Approach

Control simulations driven by reanalysis,
PGW simulations using GCM changes
Previously used (Hentgen et al. 2019; Brogli et al 2020)

- Objective model calibration

Constrain uncertain parameters with objective calibration,
using observational data. Based on Bellprat et al. (2012, 2016)



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Objective model calibration in the trCLIM-project

- Identify the most sensitive parameters:

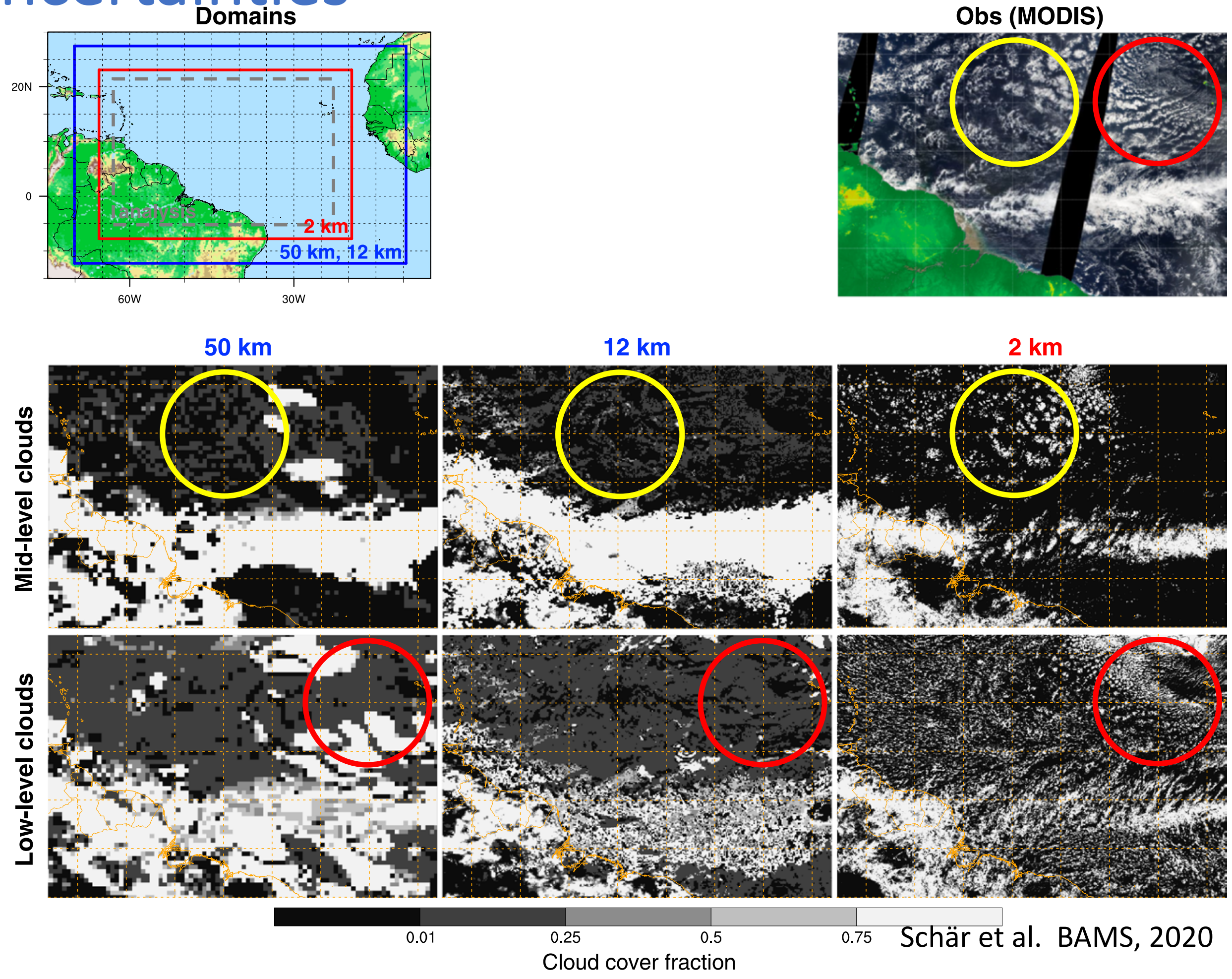
What are the most sensitive semi-empirical parameters in a CRM modelling configuration over the subtropical and tropical Atlantic?

- The resolution effect:

To what extent is the objective calibration method sensitive to the vertical and horizontal resolution and the definition of the performance score?

- Climate change response:

How does the tropical climate-change response depends upon the model parameter configurations?



Schär et al. BAMS, 2020

The 2 km simulation with explicit convection reproduce the characteristic cloud structures more realistically than convection-parameterized simulations at 50 and 12 km

Thank You