Contributions to CALMOMAX at BTU Cottbus-Senftenberg

Andreas Will

COSMO GM 2019, 9. September, Roma

Brandenburgische Technische Universität Cottbus

1. Computational Ressources

Matlab

- unlimited number of licenses on all linux machines

Computers

1. mccoy, linux server, 8 cores, 100 GB (backup)
2. spock, linux server, 20 cores, 250 GB (new)
3. Heraklit, linux cluster, 256 cores

   (will be replaced soon)

Storage

- 200 TB installed, 20 TB available
- 200 TB will be installed this year

2. Cooperations

1. Optimization procedures

- Prof. Fügenschuh, mathematics, BTU

2. Numerics

- Prof. H. Schmidt, mechanical engineering
- Prof. Dr. rer. nat. Carsten Hartmann, Stochastics

3. Research

1. Phosphor Model Optimization

- Optimization of environmental modelling of phosphor load in fresh water lakes
  - Optimum model by own procedure (finished)
  - Optimum model by application of CALMO-MAX procedure (planned for 2019/2020)

2. COSMO model optimization (Alps, Brandenburg)

- Planned for 2019/2020

3.2 Phosphor load in fresh water lakes – optimum model

- Correction of lake data (ong.)
- New mining lakes (finished)
- Phosphor load model (1st vers.)
- Soil data BUEK300 in TERRA (started)

3.2 Phosphor load in fresh water lakes – optimum model

$$
\begin{array}{ccccc}
\frac{dP_l V}{dt} = & P_i Q_i & - P_l Q_o & - \sigma_l P_l V & - \sigma_i r_i P_i V \\
\left(\frac{g}{m^3}\frac{m^3}{y}\right) & \left(\frac{g}{m^3}\frac{m^3}{y}\right) & \left(\frac{g}{m^3}\frac{m^3}{y}\right) & \left(\frac{1}{y}\frac{g}{m^3}m^3\right) & \left(\frac{1}{y}\frac{m^3}{m^3}\frac{g}{m^3}m^3\right)
\end{array}
$$

- Stationary solution: $P_l(\tau_i, P_i) = \dfrac{1 - \sigma_i r_i \tau_i}{1 - \frac{\tau_i}{\tau_e} + \sigma_l \tau_i} P_i$

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3.2 Phosphor optimum model: Sedimentation Model

$$
\begin{aligned}
\sigma_l(\tau_i, FeP, SO4) &= \sigma_{l,0} + c_1\tau_i^c + d_1(FeP)^d + e_1(SO_4)^e \\
&\quad + n_{cd}\tau_i^c(FeP)^d + n_{ce}\tau_i^c(SO_4)^e + n_{de}(FeP)^d(SO_4)^e \\
&\quad + n_{cde}\tau_i^c(FeP)^d(SO_4)^e \\
\sigma_i(\tau_i, FeP) &= \sigma_{i,s,0} + f_{1,s}\tau_i^f + g_{1,s}(FeP)^g + n_{fg,s}\tau_i^f(FeP)^g \\
r_i(D) &= r_{i,0} + h_{1r}(D)^h
\end{aligned}
$$

- General models of sedimentation. No strict solution known.

3.2 Phosphor optimum model: Standard Models

$$
\begin{aligned}
P_{m,V} &= \frac{P_{io}}{1+\tau_o\sigma_l} = \frac{P_{io}}{1+\gamma_0\tau_o/\sqrt{\tau_o}} = \frac{P_{io}}{1+\gamma_0\sqrt{\tau_o}} \quad \text{with} \quad \gamma_0 = 1/\sqrt{s} \\
&= \frac{\tau_o}{\tau_i}\frac{P_i}{1+\gamma_0\sqrt{\tau_o}}
\end{aligned}
$$

$$
\begin{aligned}
P_{m,OE} &= a\left(\frac{P_i}{1+\gamma\sqrt{\tau_o}}\right)^b \\
&= \quad \text{with} \quad a_r = 1.55 \quad \text{and} \quad b_r = 0.82
\end{aligned}
$$

- Standard models violate the budget equation !!!

3.2 Phosphor optimum model: Observations

VAR [Unit]	BO	BE	GR	SC	BA	SE	DR	CO	HA	MA	WE	KU
V $[10^6 m^3]$	53.0	330.0	92.9	9.4	139.5	67.0	32.8	107.0	25.0	59.4	6.3	27.0
A $[10^6 m^2]$	2.78	9.60	4.25	1.42	12.05	10.00	2.81	4.41	3.39	2.49	0.63	1.57
P_i $[mg/m^3]$	209.0	199.0	116.0	70.0	177.0	102.0	70.0	139.0	60.0	38.0	84.0	92.0
δP_i []	0.30	0.01	0.10	0.30	0.01	0.01	0.30	0.1	0.10	0.1	0.10	0.10
P_l $[mg/m^3]$	18.0	17.8	12.8	11.0	9.5	14.6	6.6	2.5	4.0	2.5	3.8	7.0
τ_i $[y]$	26.9	6.84	13.83	1.81	3.37	2.98	3.31	48.26	7.01	26.39	17.45	25.86
v_f $[m/y]$	0.0	$5.03 - v_e$	0.24	0.00	2.06	1.10	0.00	0.00	0.00	0.16	$0.58 - v_e$	0.00
FeP []	20.1	16.8	66.4	36.5	134.8	46.3	107.2	73.1	78.2	68.5	57.9	38.2
SO_4 [?]	662.0	98.0	442.0	364.7	364.7	197.0	500.0	1030.0	953.5	968.0	818.0	888.0

- High variability of Pl and forcing (Pi, tau, FeP, …)

3.2 Phosphor optimum model: Budget equation models

$$\begin{aligned} P_{m,M2} &= \frac{a(P_i)^b}{1+\tau_i/\tau_e+\sigma_l(\tau, FeP, SO4)\tau_i} \\ &= \frac{a(P_i)^b}{1+v_e\tau_i/D(c_1\tau^c+d_1(FeP)^d+e_1(SO_4)^e+n_{cd}\tau_i^c(FeP)^d+n_{cde}\tau_i^c(FeP)^d(SO_4)^e)\tau_i} \end{aligned} \quad (30)$$

$$\begin{aligned} P_{m,M4} &= \frac{1-\sigma_{ir}\tau_i}{1-\tau_i/\tau_e+\sigma_l\tau_i}P_i = \frac{1-\sigma_{ir}\tau_i}{1+(\sigma_l-v_e/D)\tau_i}P_i \\ \text{with} \quad & \sigma_{ir} = n_{fg}\tau^f(FeP)^g + n_{fh}\tau_i^f D^h + n_{fgh}\tau_i^f(FeP)^g D^h \\ \text{and} \quad & \sigma_l = n_{cd}\tau_i^c(FeP)^d \end{aligned}$$

- Total number of parameters is more than 10 !!!

3.2 Phosphor optimum model: Norms used

$$L_1\text{-norm}: \qquad L_1 = \frac{1}{N}\sum_{i=1}^{N} ||P_{m,i} - P_{l,i}||$$

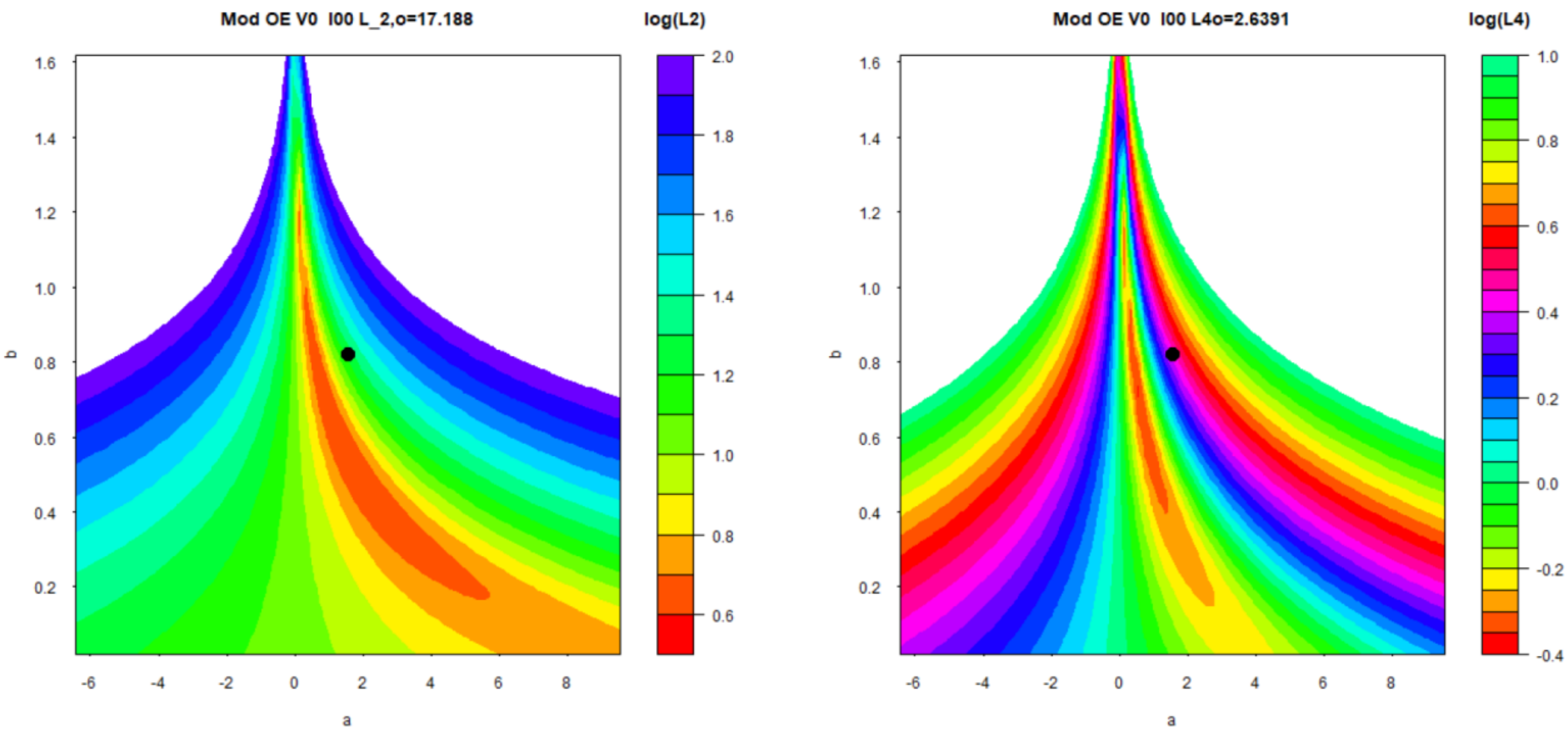
$$L_2\text{-norm}: \qquad L_2 = \sqrt{\frac{1}{N}\sum_{i=1}^{N} (P_{m,i} - P_{l,i})^2}$$

$$L_{2l}\text{-norm}: \qquad L_{2,l} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} (\log(P_{m,i}/P_{l,i}))^2}$$

$$L_{2r}\text{-norm}: \qquad L_{2,r} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} (||\frac{P_{m,i} - P_{l,i}}{P_{l,i}}||)^2}$$

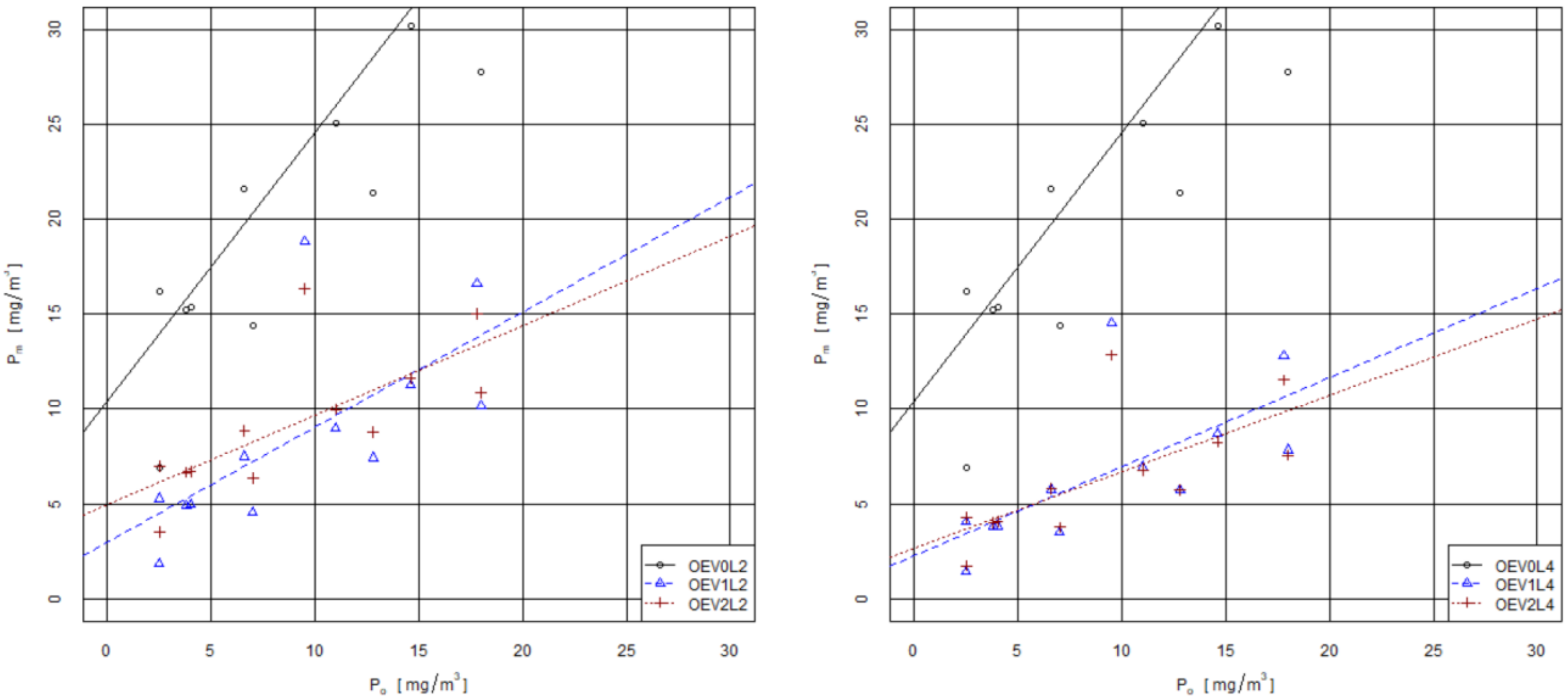
- Each norm means another weighting of the spread of deviations between model and observations

3.2 Phosphor optimum model: OECD model, norm dependency



- The optimum depends on the norm if the error is substantial

3.2 Phosphor optimum model: OECD model, otpimization effect



- Optimization corrects the mean behaviour not the spread

3.2 Phosphor optimum model: OECD model, optimum results

	$\mathcal{F}(P_i)$		$\mathcal{F}(\tau)$		$\mathcal{F}(FeP)$		$\mathcal{F}(SO_4)$		Norm
Tuning P.	a	b	c_1	c	d_1	d	e_1	e	
OE(L_2V_0)	1.55	0.82							17.180
OE(L_4V_0)	1.55	0.82							2.639
OE(L_2V_1)	0.302	1.0							4.369
OE(L_4V_1)	0.232	1.0							0.439
OE(L_2V_2)	1.045	0.665							3.975
OE(L_4V_2)	0.361	0.864							0.432

- The optimum norm exhibits 40% deviation from observations

3.2 Phosphor optimum model: M3 model, optimum results

MODEL M3		$\mathcal{F}(P_i)$		$\mathcal{F}(\sigma_i)$									Norm	
LAKES 1-12		$\mathcal{F}(P_i)$		factors σ_i					exponents σ_i			σ_0		
V	L	a	b	h_1	n_{fg}	n_{fh}	n_{gh}	n_{fgh}	f	g	h	$\sigma_{i,0}$	L_i	$Max(\delta p_i)$
1	4	0.1643	0.862	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0159	0.3492	4.55e-14
4	4	0.8382	0.661	0.0	5.78e-02	0.0	0.0	1.0	-0.6667	0.413	0.0	-0.0073	0.2288	9.77e-06
6	4	0.1915	1.0	0.0	1.14e-01	0.0	0.0	1.0	-0.8104	0.310	0.0	0.0	0.2697	9.15e-06
7	2	0.618	0.736	-0.036	-0.0555	0.19	7.83e-08	0.0555	-0.368	3.06025	-0.0374	-0.0037	1.15	1.64e-01
7	4	0.0825	0.999	1.750	-9.05e-06	-12.175	8.13e-05	2.70e-04	-0.6318	2.260	-1.3217	-0.0066	0.0711	8.19e-02
8	4	0.9999	0.632	0.0	1.35e-01	-14.613	0.0	1.09e+01	-0.6747	0.086	-0.9373	0.0	0.1565	1.22e-06
9	4	0.1538	1.0	0.0	1.09e-01	-35.261	0.0	2.00e+01	-0.6447	0.146	-1.5150	0.0	0.2303	1.95e-05
11	4	0.1173	1.0	0.0	9.17e-13	1.060	0.0	0.0	0.1724	5.211	-1.7281	0.0	0.1680	5.96e-10
21	4	0.1646	1.0	-0.183	-3.60e-08	0.287	3.87e-09	3.61e-08	-0.1029	3.998	-0.0432	0.0	0.1261	3.05e-07
22	4	0.1188	1.0	0.0	0.0	0.329	0.0	2.88e-09	0.2713	4.266	-1.4286	0.0	0.1580	1.86e-11
23	2	5.001	1.0	0.0	0.0	0.0	0.0	0.935702	-0.997	0.00695	0.006110	0.0	2.58	1.91e-08
23	4	0.1065	1.0	0.0	0.0	0.0	0.0	1.59e-04	0.0331	1.916	-1.1488	0.0	0.2109	2.44e-06

Table 7: Model parameter values and norms for optimum configurations of Model M3and optimisation for lakes 1-12.

- Low dependency on the norm and small spread by application of budget equation and appropriate parameterisation.

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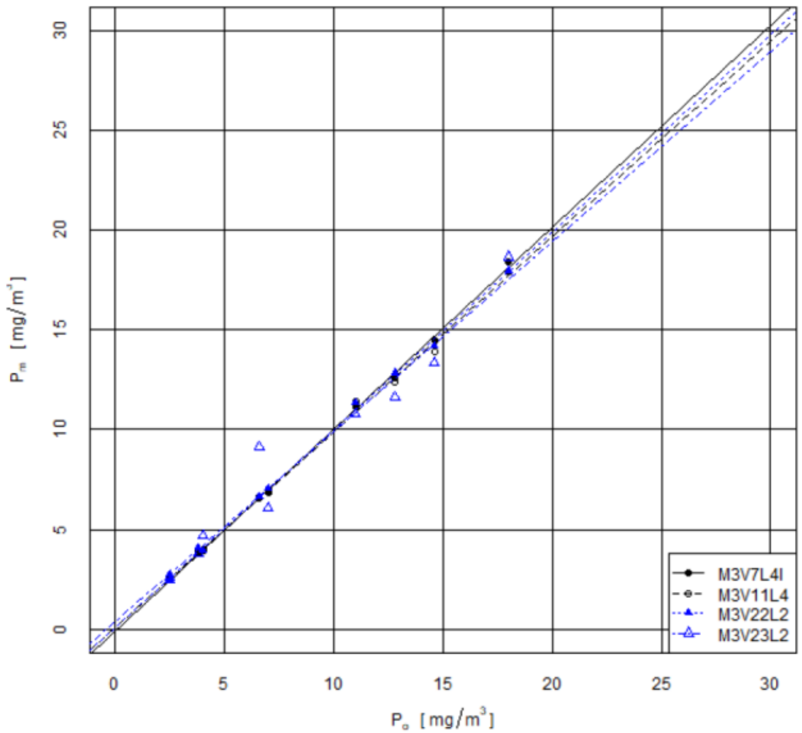
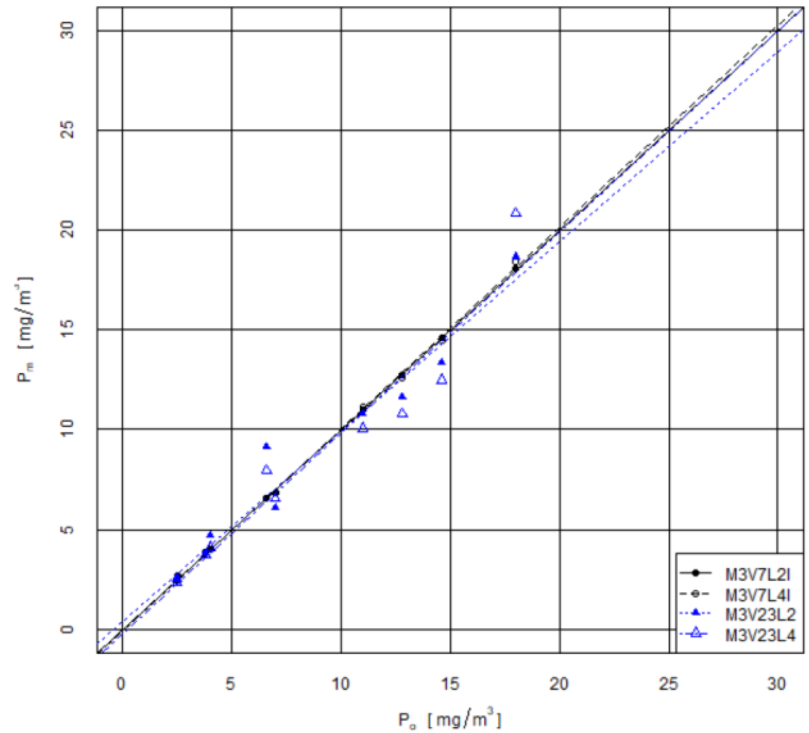
3.2 Phosphor optimum model: M3 model, otpimization effect





- Optimization of M3 gives nearly perfect results

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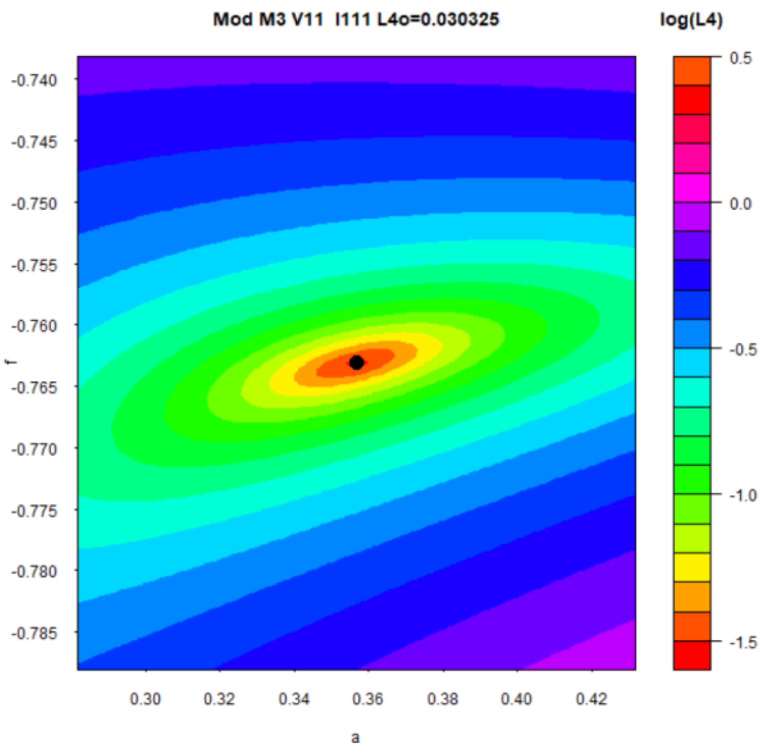

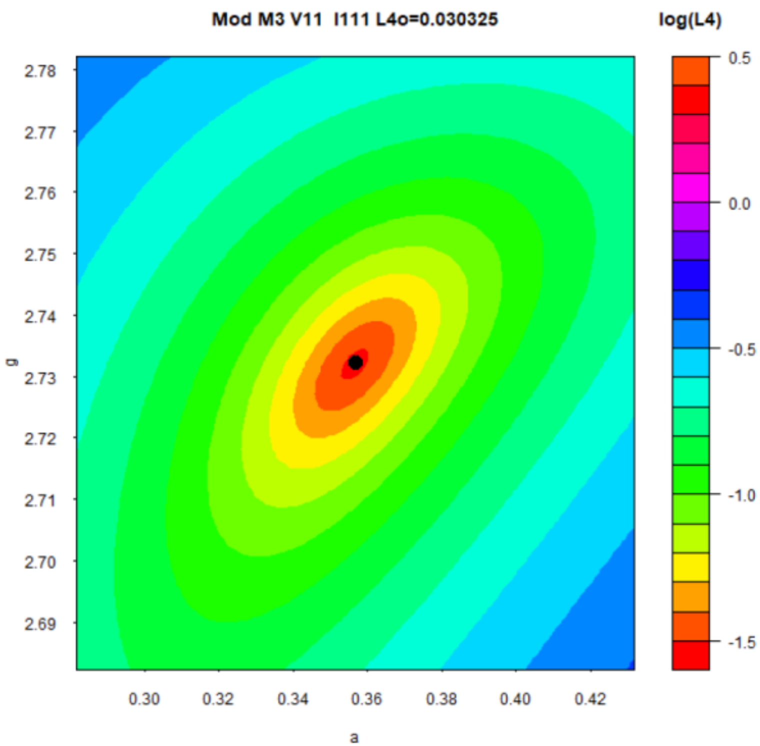

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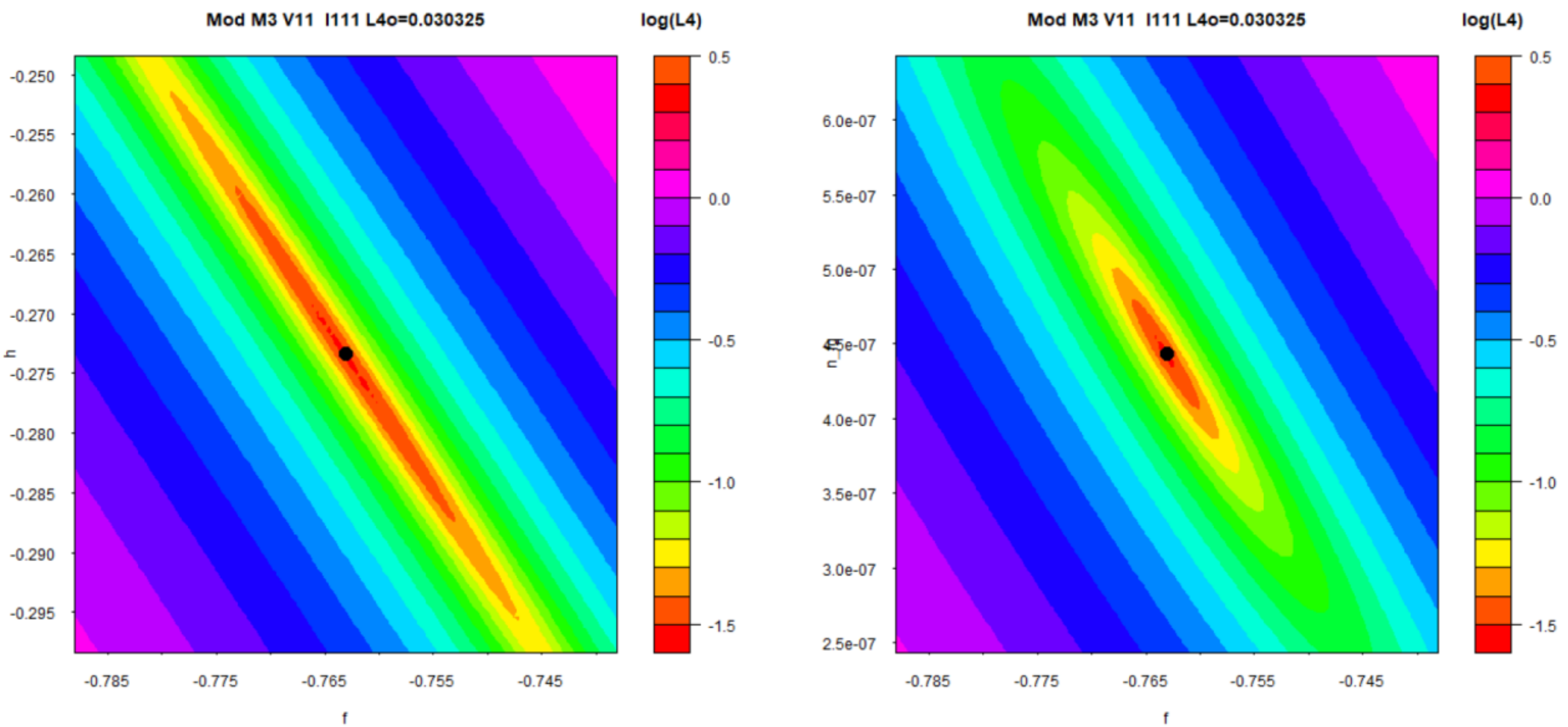
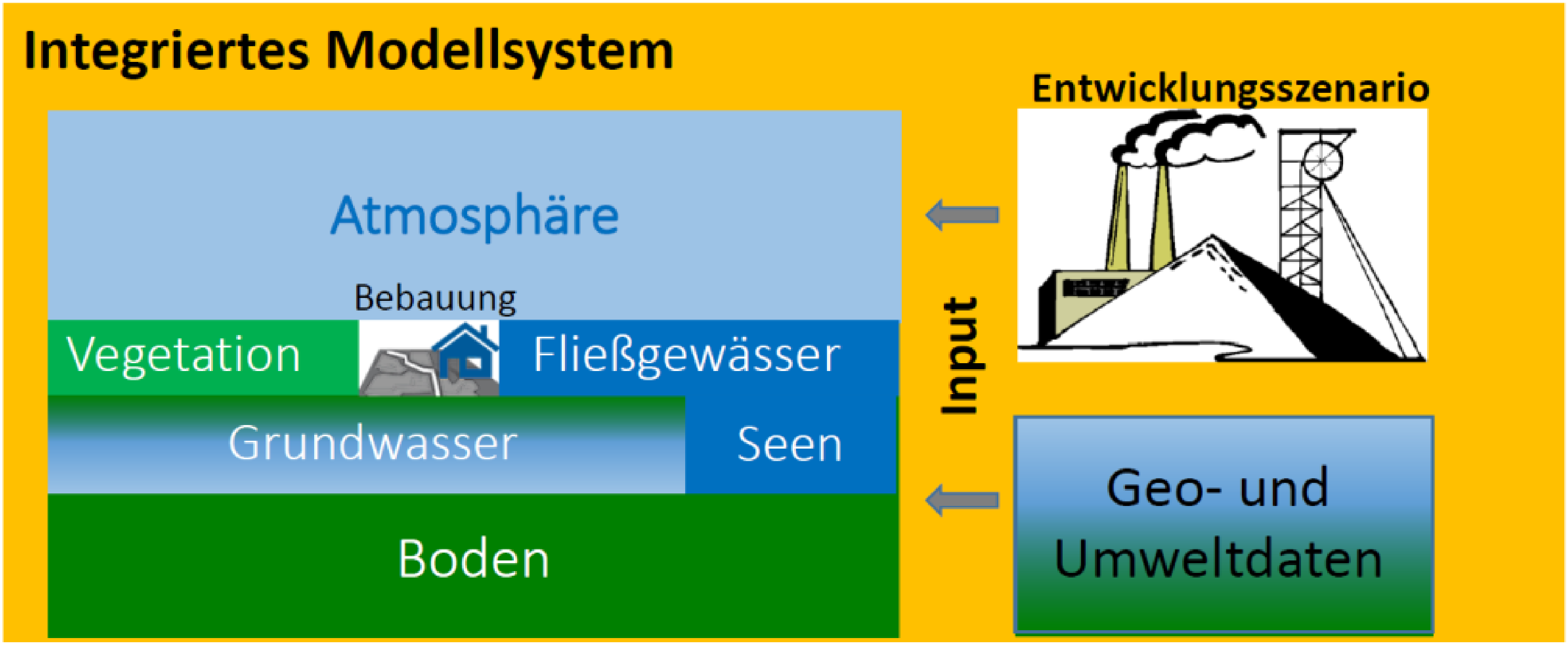


- Exponents f and h exhibit a dependency

3.2 Brandenburg-Berlin Model Status of Development

Andreas Will (BTU)



- Correction of lake data (ong.)
- New mining lakes (finished)
- Phosphor load model (1st vers.)
- Soil data BUEK300 in TERRA (started)

3.1 Simulation results: resolution, physics and numerics

List of simulations

EXPID	IBC	HR	DOM	CONF
S4p4d0.25Ct-dynamics				
TEU006	ERAINT	50 km	EUL	CCLM
CEU011	TEU006	7 km	EU	COSMO-EU
CDE011	CEU011	2.8km	DE	COSMO-DE
C3p2d0.0Cs-dynamics				
TEU007	ERAINT	50 km	EUL	CCLM
CEU012	TEU007	7 km	EU	COSMO-EU
CDE014	CEU012	4.5km	DE	COSMO-DE
CDE012	CEU012	2.8km	DE	COSMO-DE

IBC: Initial and Boundary Conditions

HR: Horizontal model resolutions: 2.8km, 7km

DOM: Domain simulated

CONF Model configuration used

3.1 Simulation results:
resolution, physics and numerics

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IBC: Initial and Boundary Conditions
HR: Horizontal model resolutions: 2.8km, 7km
DOM: Domain simulated
CONF Model configuration used

3.1 Simulation results: Simulation configuration

Simulations in COSMO-EU or COSMO-DE domain using the recommended configuration of CLM-Community or DWD for the domain and horizontal resolution

Convergence X convergence order of the numerical error

Advection CX upwind discretisation of order X (reference)

SX symmetric discretisation of order X

Pressure pX pressure gradient term discretisation of order X

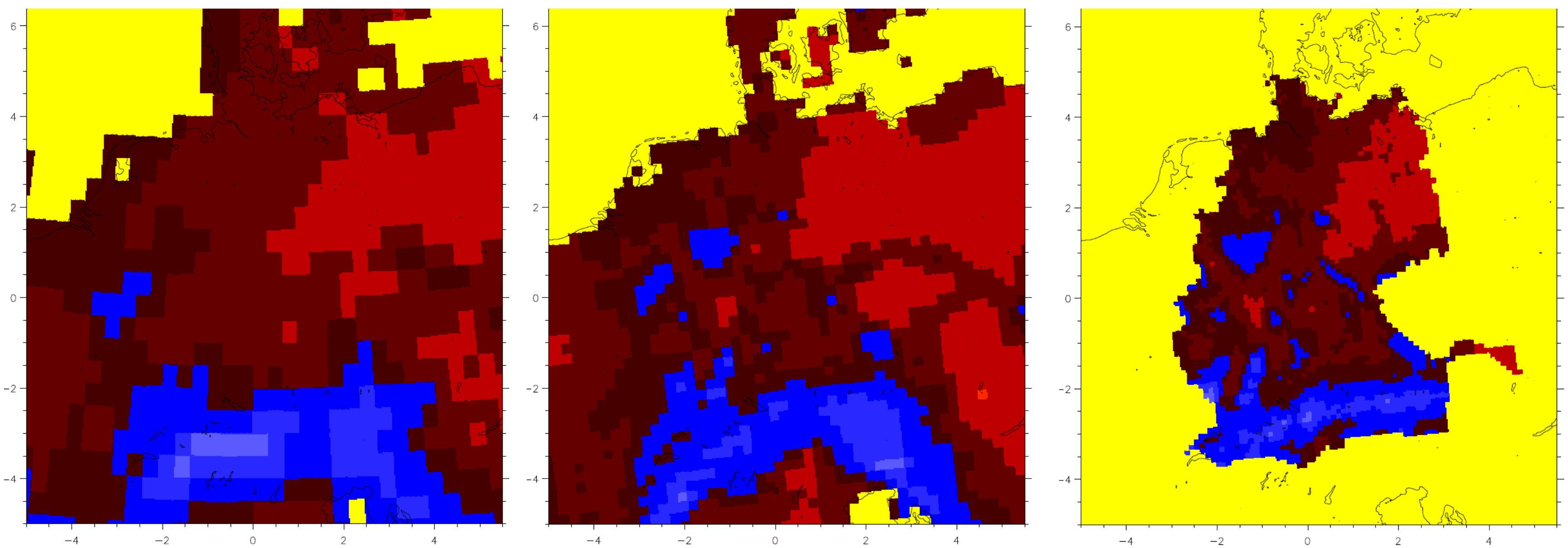
Diffusion dY horizontal numerical diffusion of strength Y

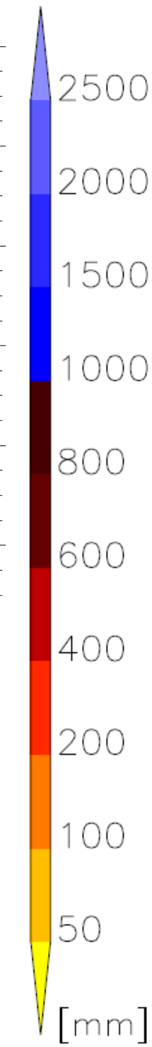
Convection CT Convection parameterisation

- T=t Tiedtke deep convection parameterization
- T=0 No deep convection parameterization,
- T=s shallow convection parameterisation only

3.1 TOT_PREC
mean annual sum 2000-2010

CRU **ECAD** **HYRAS**



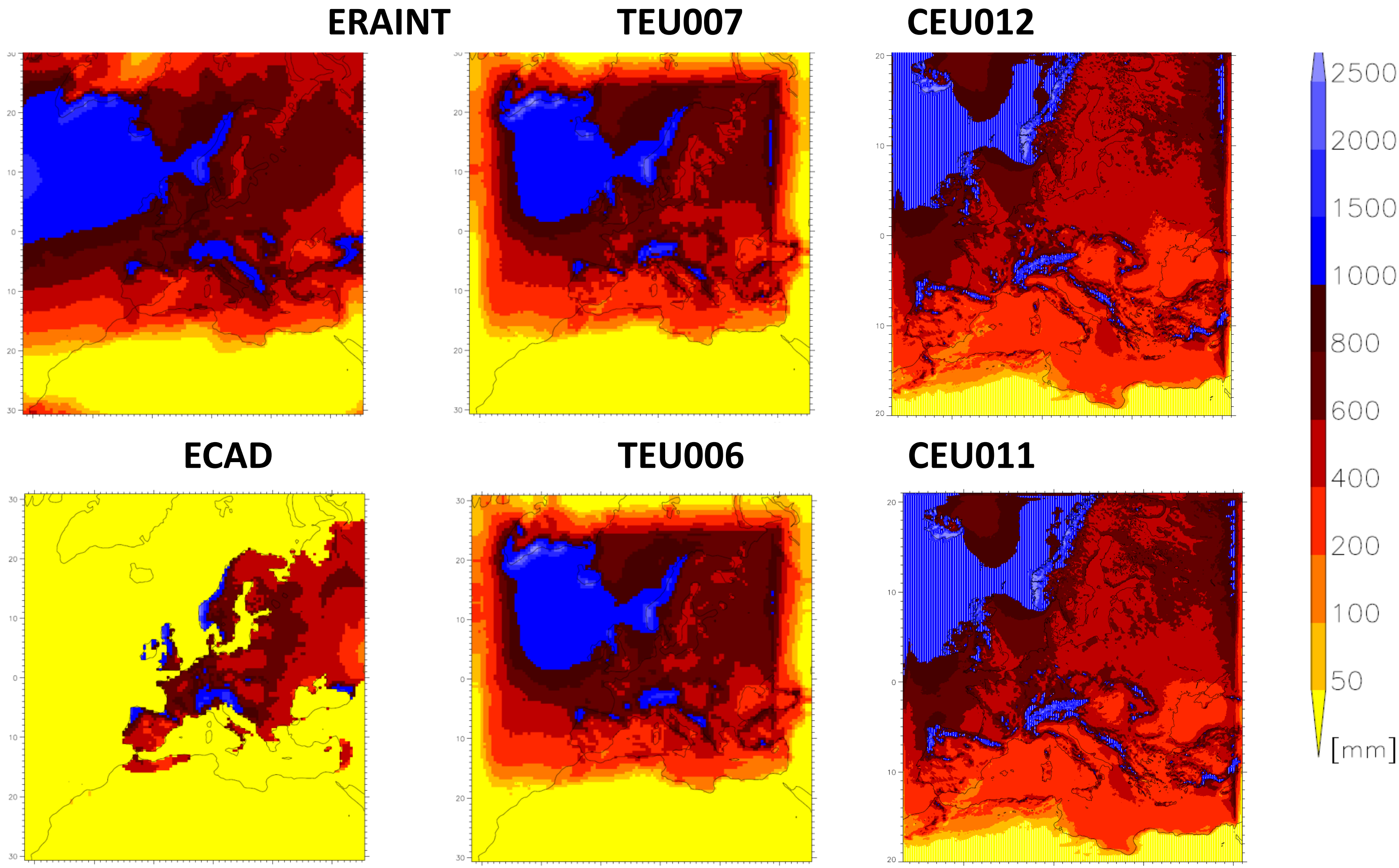


Observations:

CRU **Globl gridded observations (50km resolution)**
ECAD gridded observations for Europe (25 km resolution)
HYRAS **gridded observations for Germany (4km resolution)**

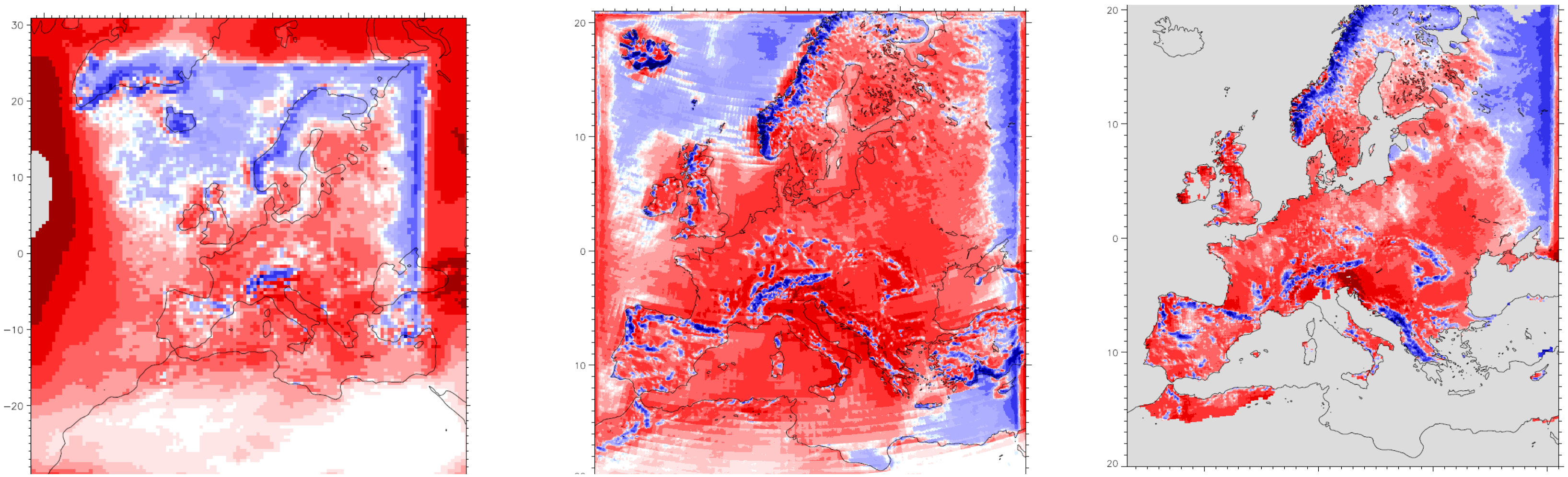
3.3 Resolution, numerics and model physics

3.1 TOT_PREC
mean annual sum 2000-2010

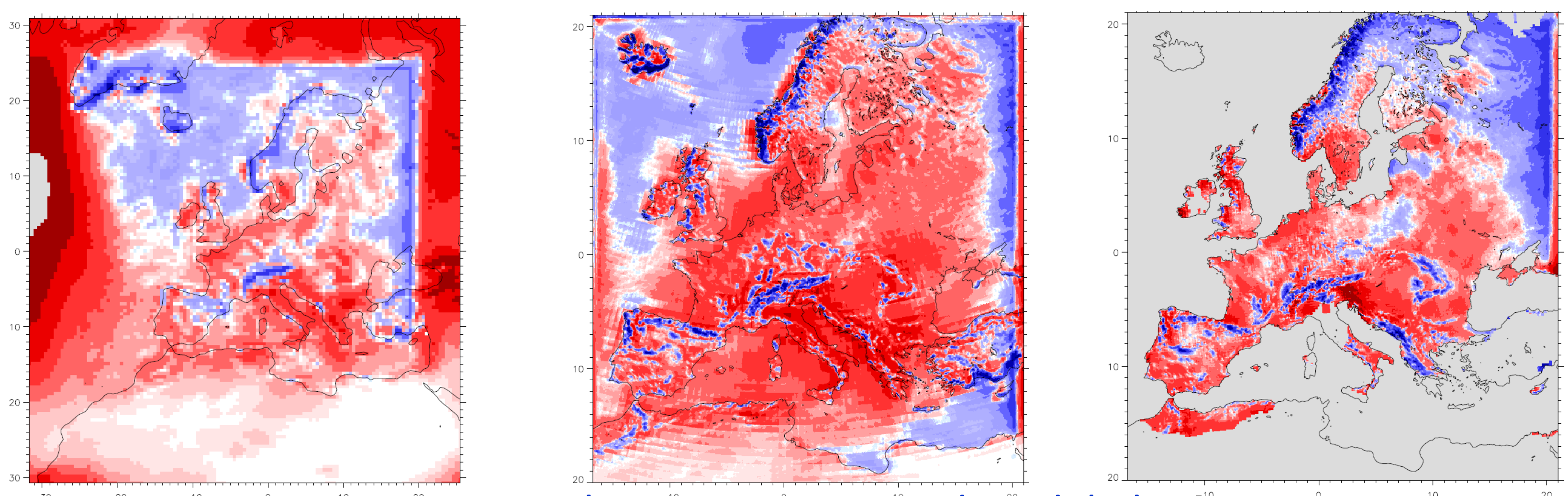


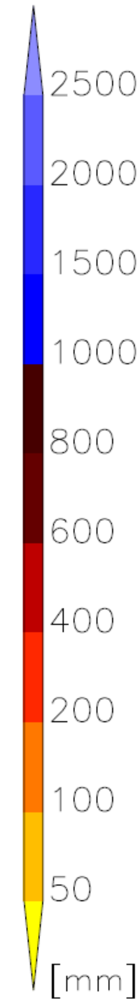
3.1 TOT_PREC
mean annual sum 2000-2010

TEU007- ERAINT CEU012-ERAINT CEU012-ECAD



TEU006- ERAINT CEU011-ERAINT CEU011-ECAD





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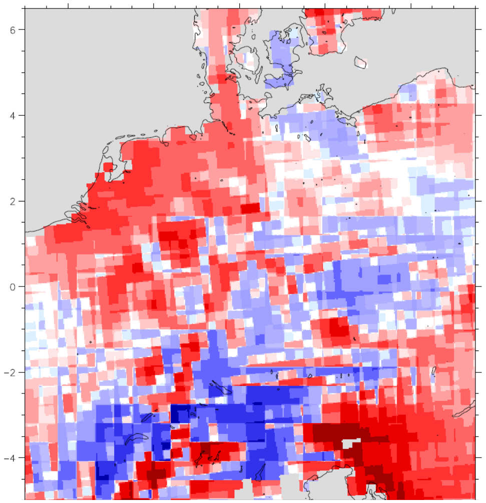
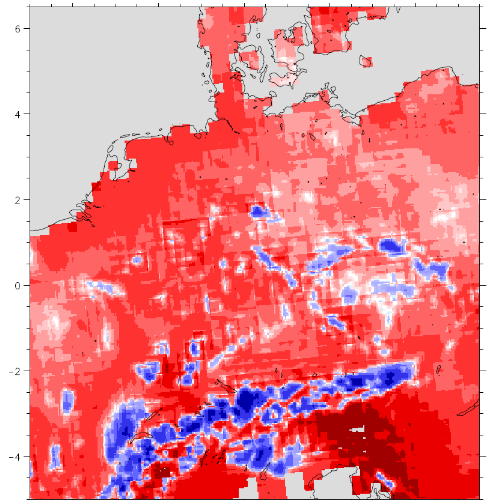
mean annual sum 2000-2010

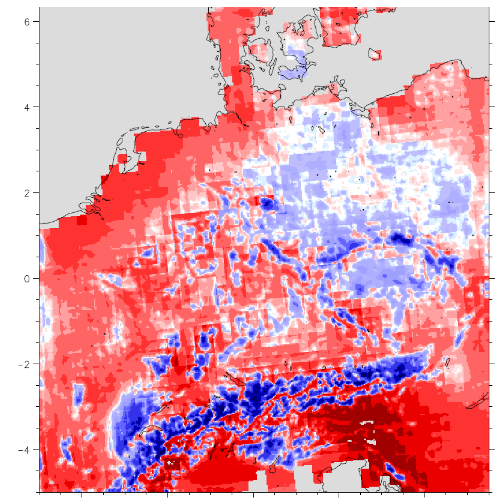
TEU007-ECAD



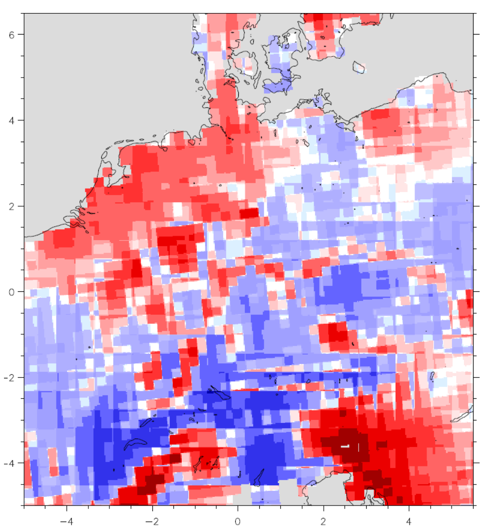
CEU012-ECAD



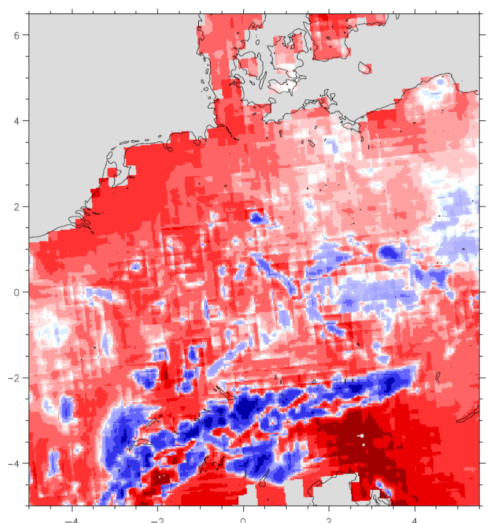
CDE012-ECAD



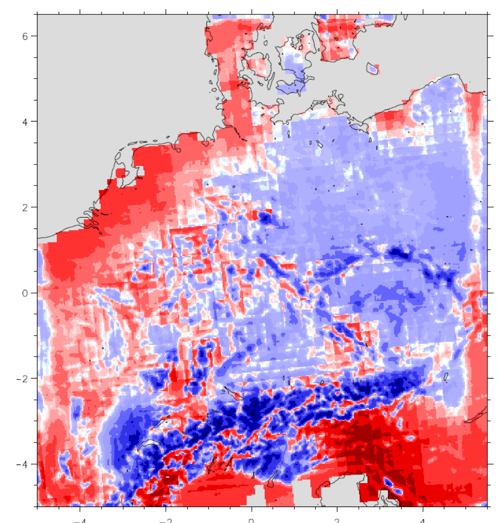
TEU006-ECAD

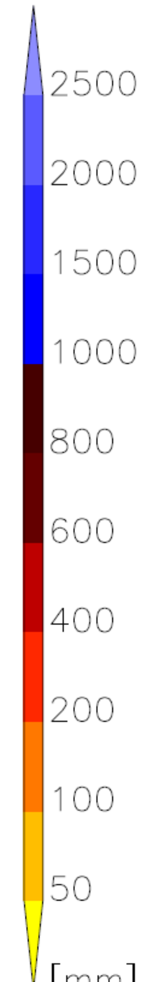


CEU011-ECAD



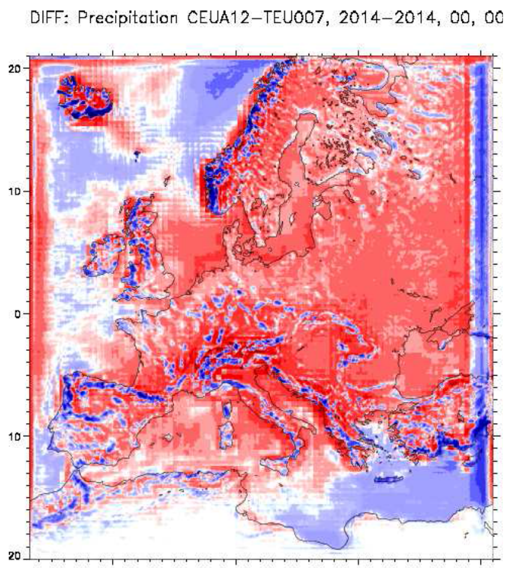
CDE011-ECAD

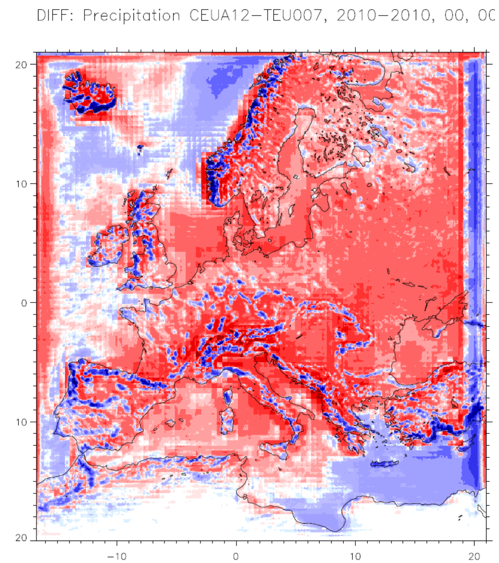




3.3 Resolution, numerics and model physics

3.1 TOT_PREC
mean annual sum 2000-2010



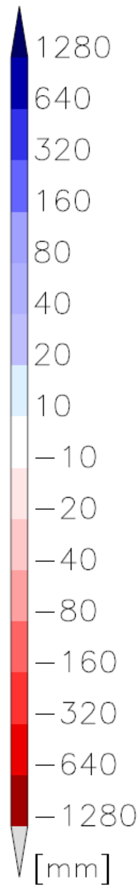


Impact of resolution+BC

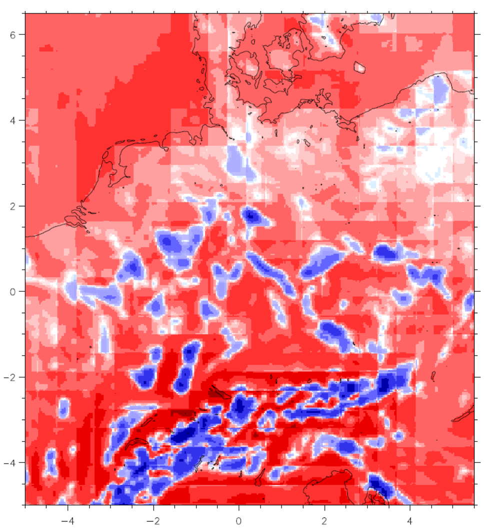
CEU011-TEU006:, f=7,C3p2D0.25

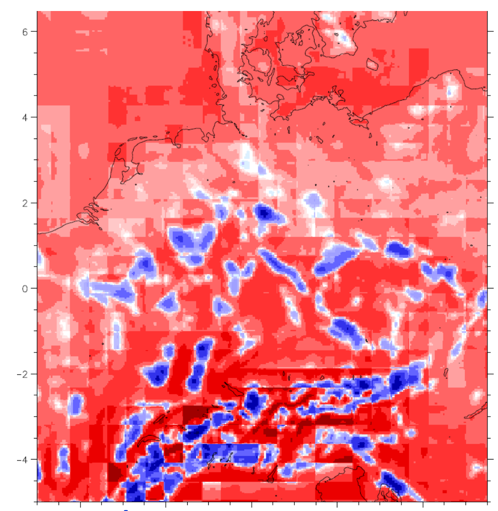
CEU012-TEU007:, f=7, S4p4D0

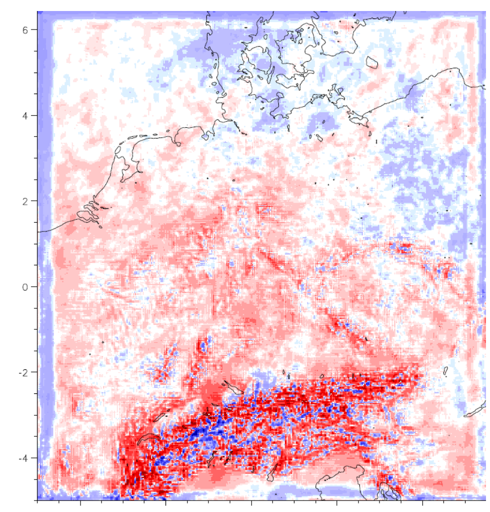
CDE012-CDE014: f=1.5, S4p4D0



CEU011-TEU006 CEU012- TEU007 CDE012-CDE014

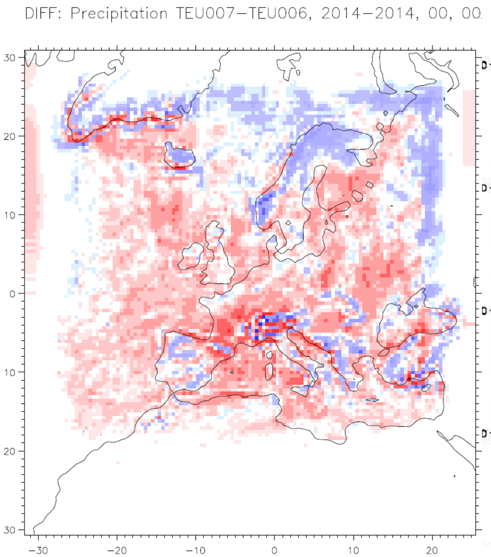


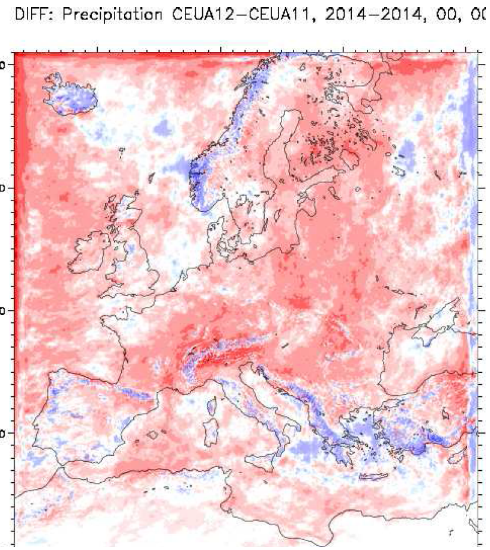




3.3 Resolution, numerics and model physics

3.1 TOT_PREC, 2000-2010





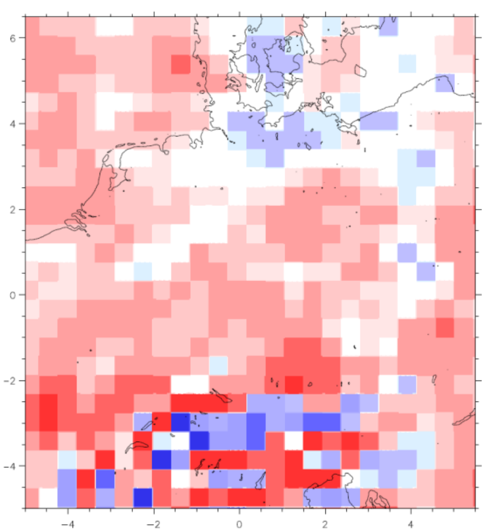
Impact of numerics + hor. diffusion:
(S4p4D0.0 – C3p2D0.25)

TEU007-TEU006: 50km, Ct

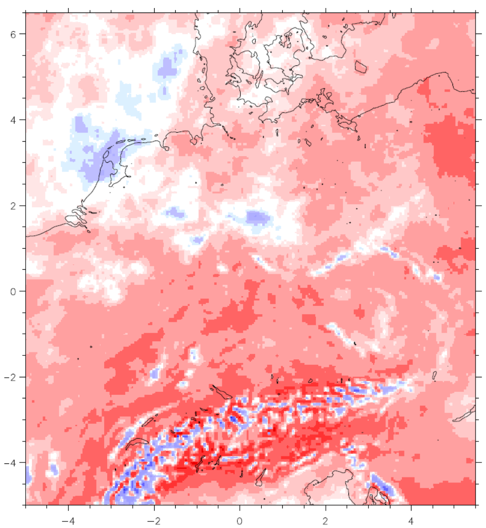
CEU012-CEU011: 7km, Ct.

CDE012-CDE011: 2.8km, D0C0

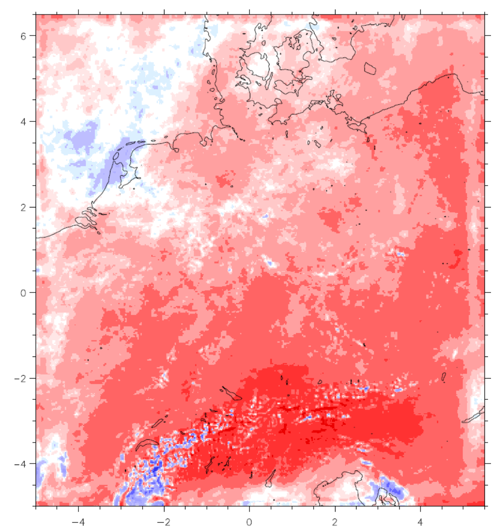
TEU007-TEU006

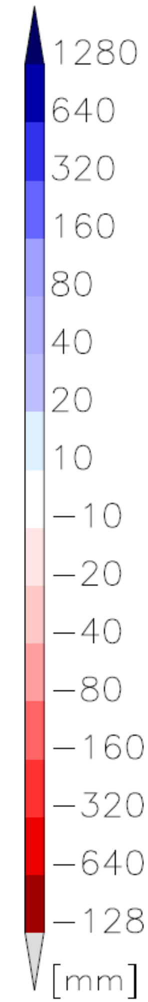


CEU012-CEU011



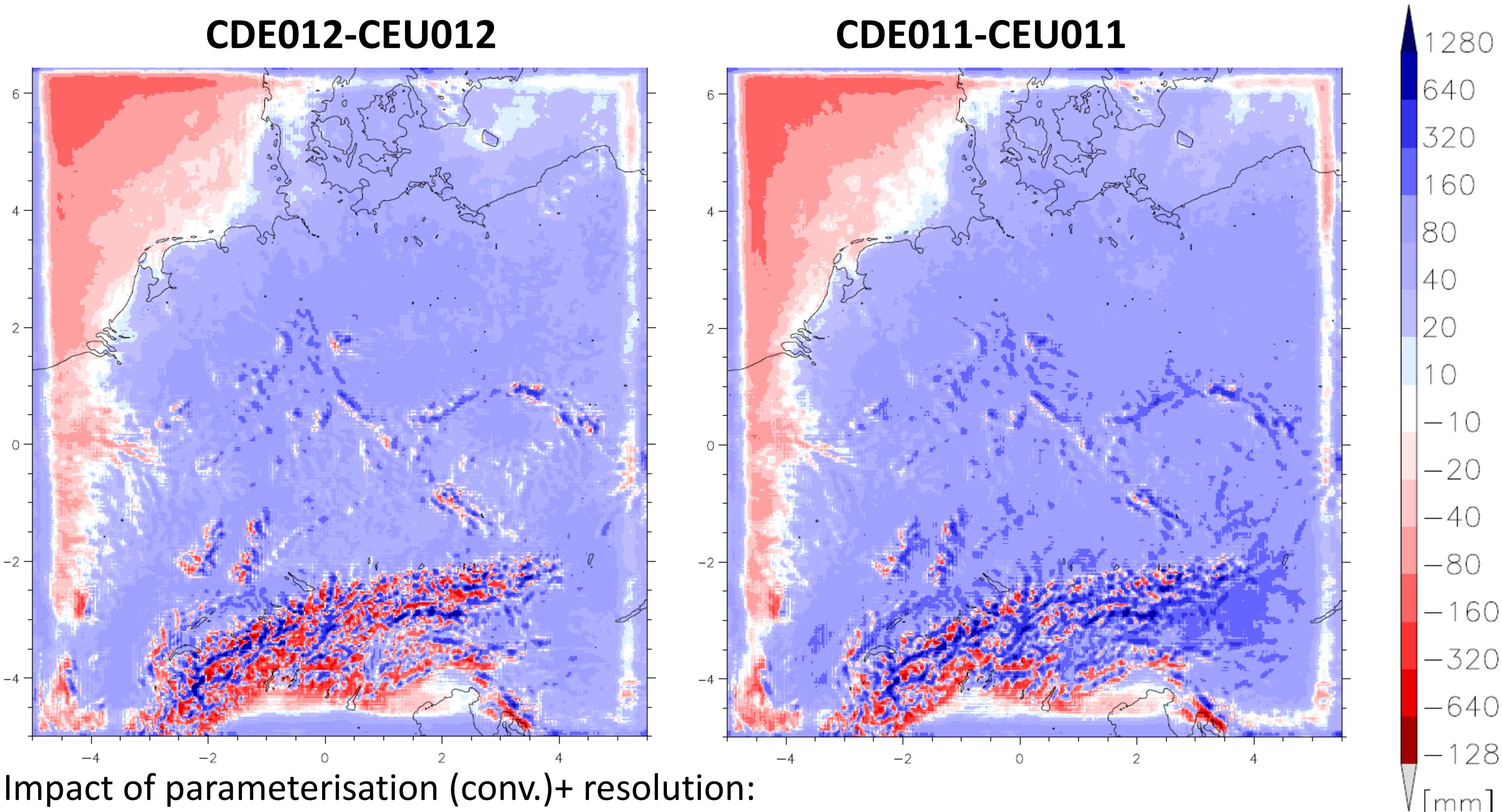
CDE012-CDE011





3.3 Resolution, numerics and model physics

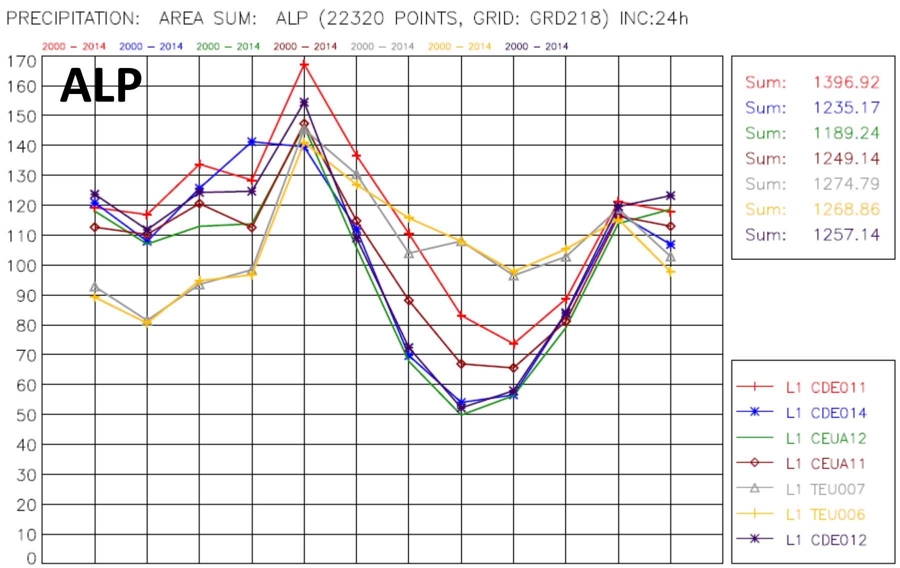
3.1 TOT_PREC, 2000-2014

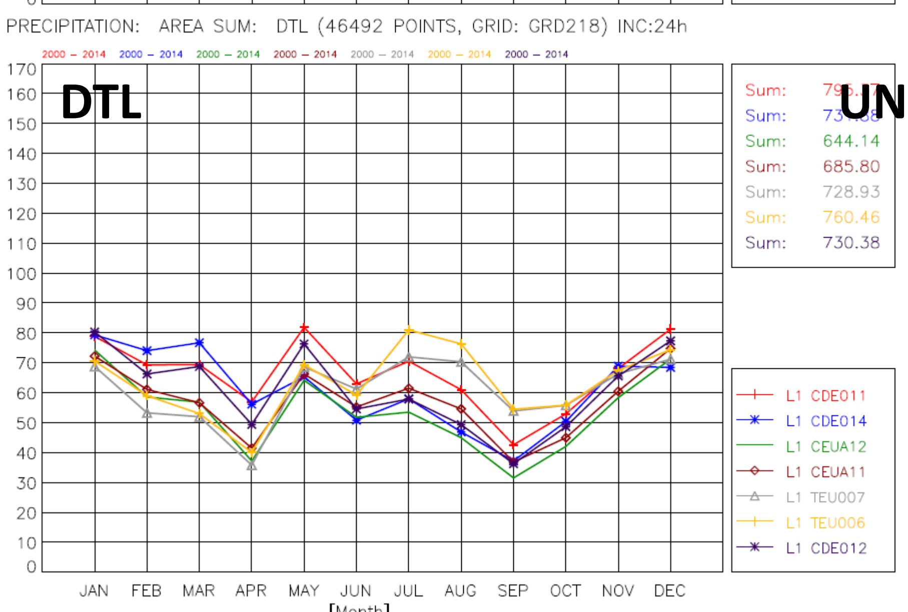


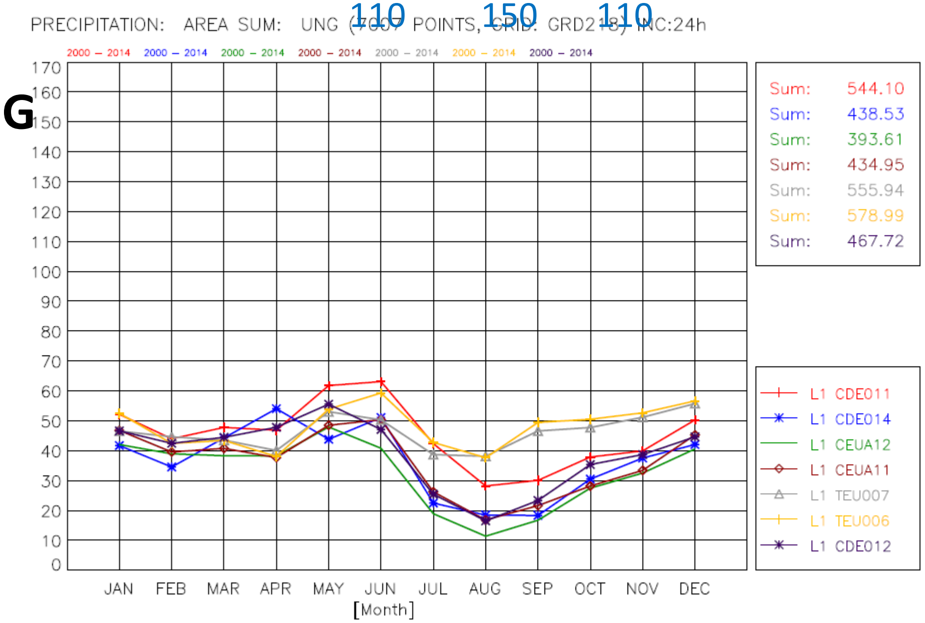
Impact of parameterisation (conv.)+ resolution:
CEU012-CDE012: +80 mm/y, D0, S4p4
CEU011-CDE011: +40 mm/y, D0.25, C3p2

3.1 TOT_PREC, 2000-2014

	DTL	ALP	UNG	
Impact of resolution+BC				
CEU011-TEU006:	-75	- 40	-145	f=7,C3p2D0.25
CEU012-TEU007:	-85	- 85	-160	f=7, S4p4D0
CDE012-CDE014:	- 2	20	30	f=1.5, S4p4D0
Impact of numerics + hor. diffusion: (S4p4D0.0 – C3p2D0.25)				
TEU007-TEU006:				50km, Ct
CEU012-CEU011:	-30	- 15´	- 25	7km, Ct.
CDE012-CDE011:	-40	- 60	- 40	2.8km, C0
Impact of parameterisation (conv.)+ resolution:	-65	-140	-80	
CDE012-CEU012:				D0, S4p4
CDE011-CEU011:	85	70	70	D0.25, C3p2
	110	150	110	







3.3 Resolution, numerics and model physics

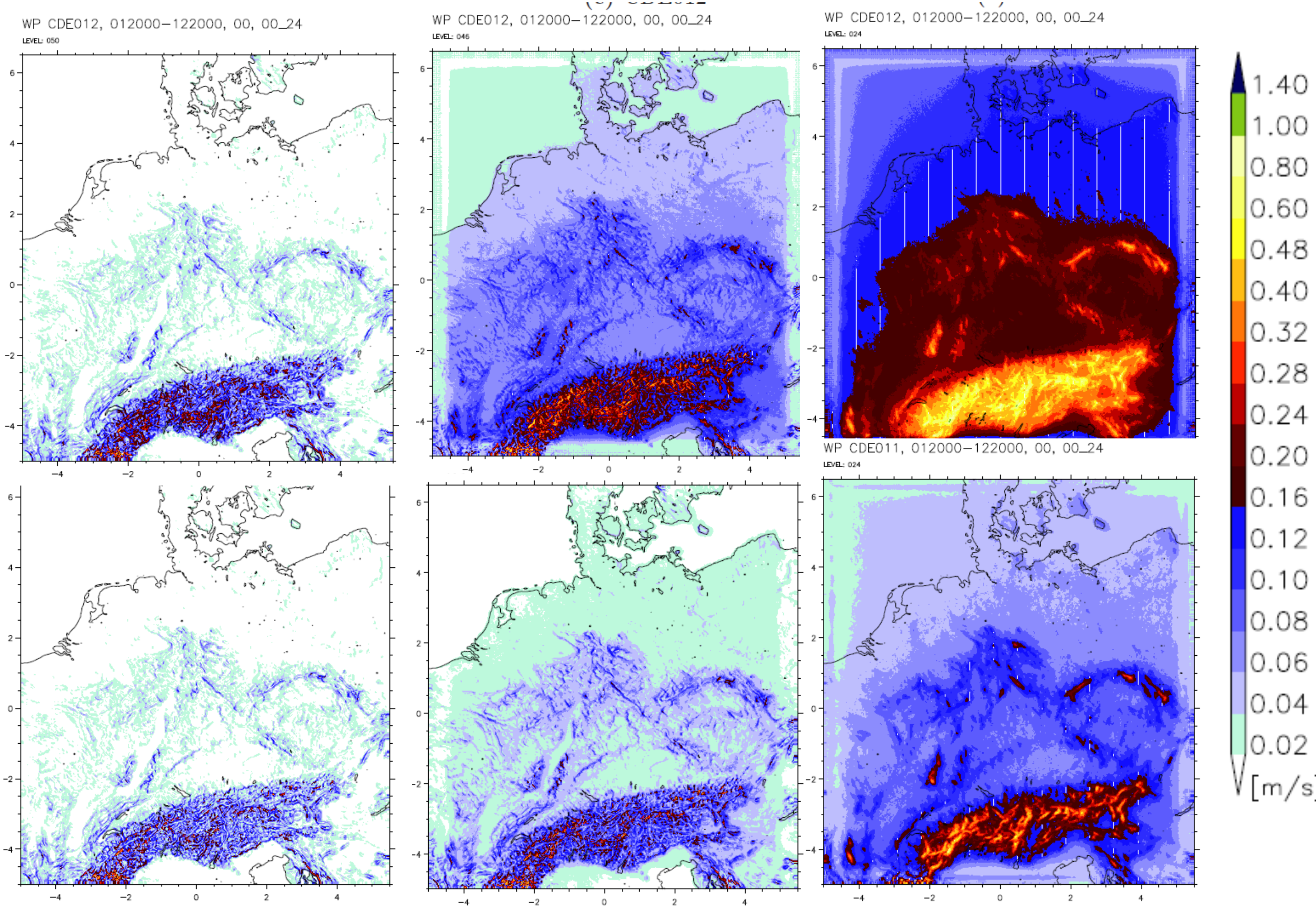
3.1 RESULTS for WP (W>0)

mean 2000

P= 998 hPa 975 hPa 500 hPa

CDE012

CDE011



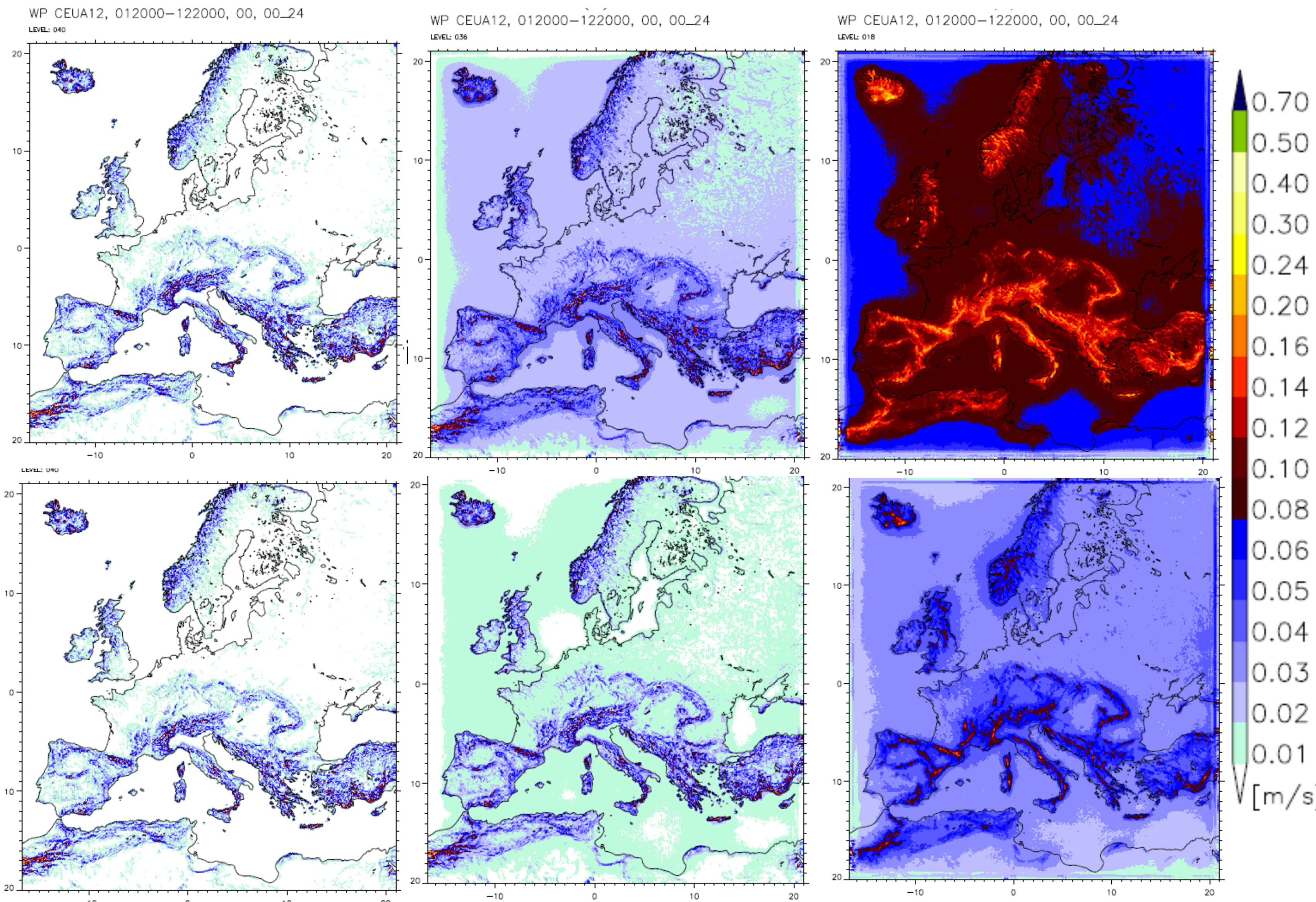
3.1 RESULTS for WP = W>0

Mean 2000

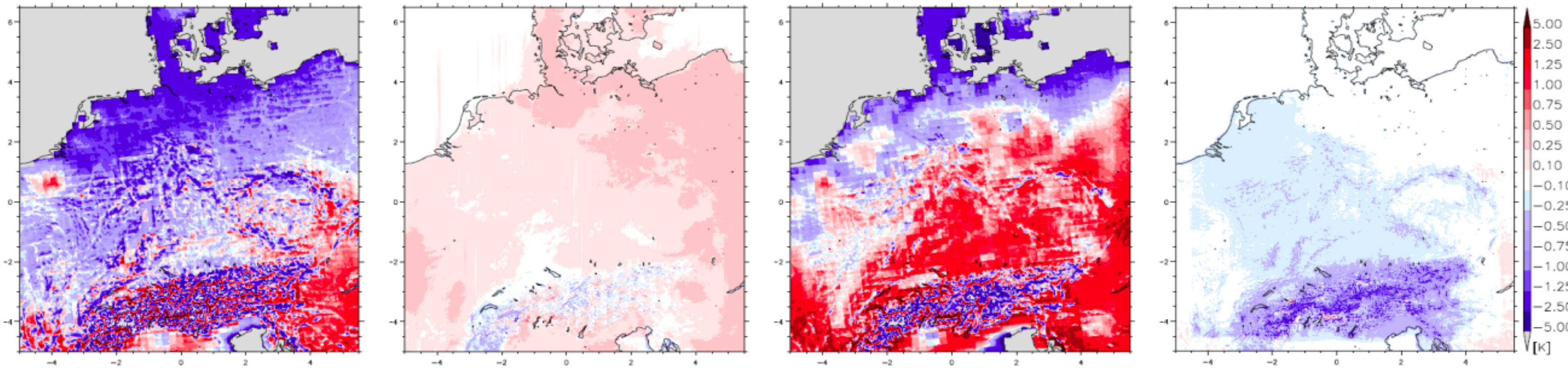
P= **998 hPa** **975 hPa** **500 hPa**

CEU012

CEU011



Mean daily MIN/MAX 2m Temperature, 2000-2010



TMAX_2M, CDE012-ECAD **TMAX_2M, CDE012-CDE011** **TMIN_2M, CDE012-ECAD** **TMIN_2M, CDE012-CDE011**

Fig.3: Mean Min/Max 2m Temperature differences, 2000-2010, S4p4d0.00-C3p2d0.00 at 2.8km resolution:. The results exhibit an overall improvement of daily temperature range at convection permitting scales. The mean temperature is nearly unchanged.

Local circulation in Rhone Valley

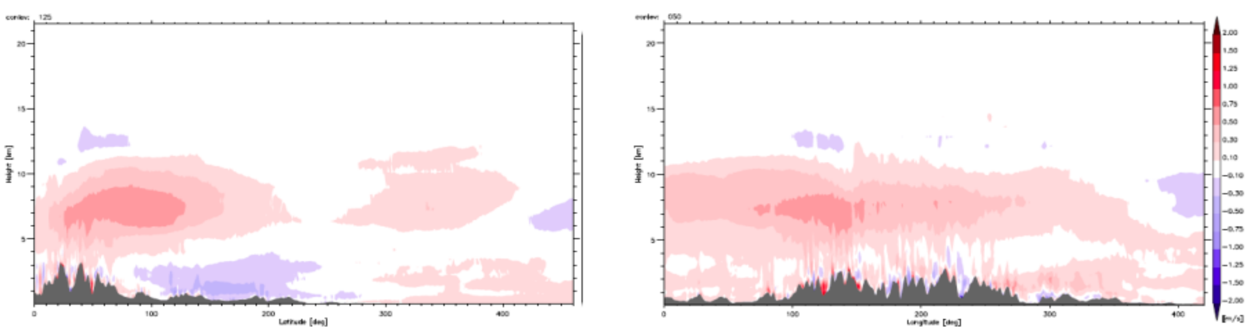


Fig.4: Mean December zonal wind 2000-2014 at $d\lambda = 0.25°$**, S4p4d0.00-C3p2d0.00: Vertical-latitudinal at** $ny = 50$ **(left) and Vertical-longitudinal at** $nx = 125$ **(right)** cross sections.

At 2.8km resoltuion an increase of winter zonal velocity in the troposphere is found of up to 1m/s over the Alpine region. An increase of mean winter velocity of up to 2 m/s is found in Sitten in Rhone valley (grid points (nx=125, ny=50). This valley wind is known to be significantly underestimated by COSMO, even at 1km resolution.

3.1 Impact of resolution, numerics and model physics

- **orographic forcing, land-sea and earths rotation dominate the pattern**
- **higher model resolution by factor 2 reduces the precipitation by 5%**
- **Numerical Diffusion is increasing and**
- **Deep Convection is decreasing the precipitation by 10 to 20 % with different spatial structures.**
- **Long simulation times (>5 years) are necessary to investigate the impact on the annual cycle, even more for the diurnal cycle.**

•INTERPRETATION:

- Convection parameterisation has an infinite speed. The potential energy is transported vertically immediately when buoyancy is positive. The physical convection has a finite speed. The convective motion is suppressed as long as the convection parameterisation is used.

- Parameterised convection is tuned to produce the correct amount with numerical diffusion.

- Numerical Diffusion is a disturbance of dynamics. This increases the precipitation since the atmosphere has to balance this disturbance

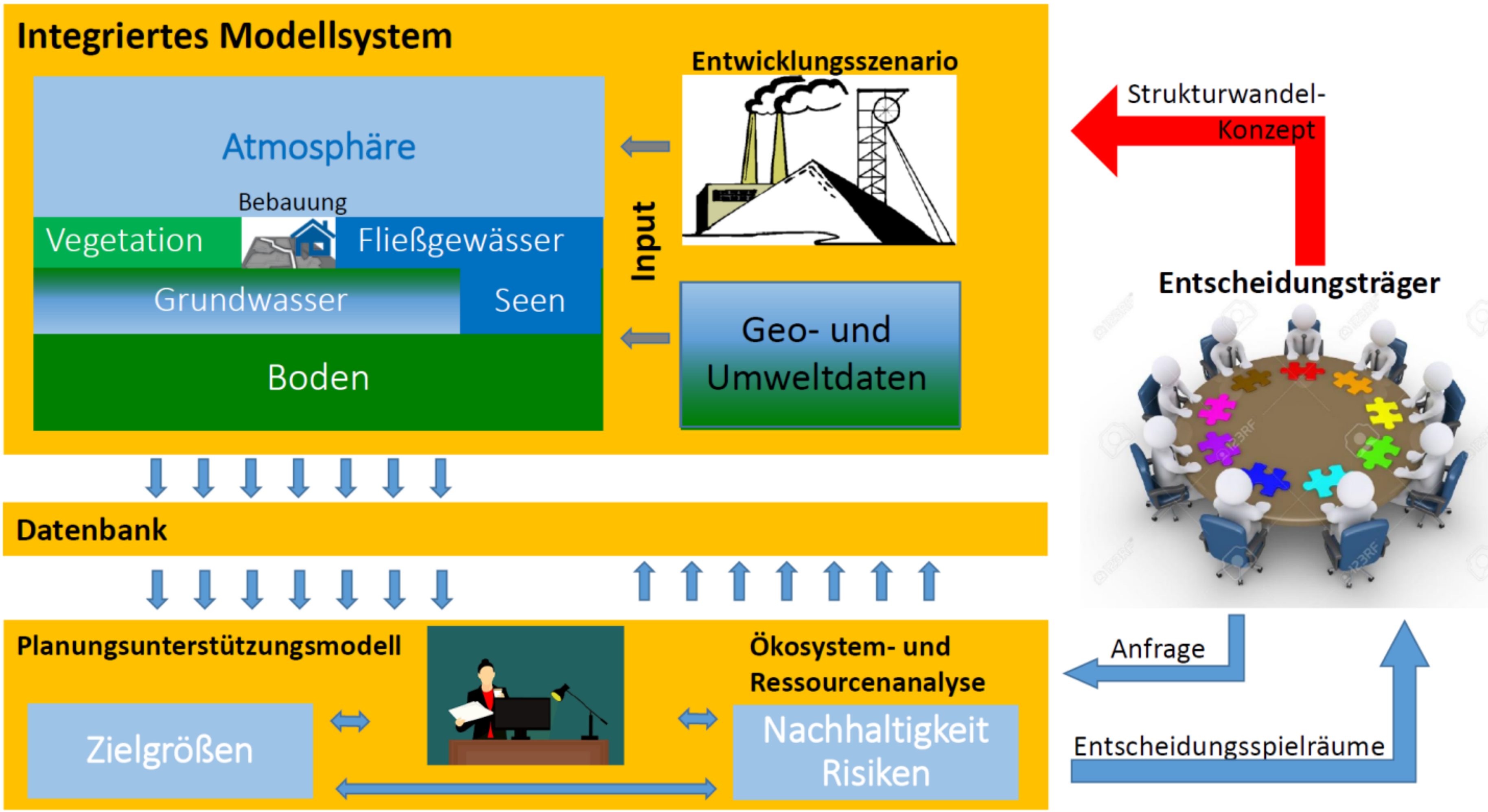
- An Increase of horizontal resolution is reducing the size of the air parcels. Smaller air parcels have higher vertical velocity and thus the system is faster in aequilibrium. This is reducing the precipitation because precipitation occurs if the system is out of aequilibrium.

- Retuning of precipitation is necessary without numerical diffusion.

Further Model development concept

Brandenburg-Berlin Model

Andreas Will (BTU) , Ingo Kirchner (FU Berlin), Sebastian Schubert (HU Berlin),
Instituete of Environmental Sciences (BTU Cottbus)



Model Concept

Target Model versions:

COSMO-CLM_5.6_hos_twc_

Two-Way Coupled model system: COSMO-COSMO

2WC_CC:	**COSMO-COSMO (Reduce boundary effect)**
TERRA-INH	**TERRA for vertically inhomogeneous soil (w_so -> p_so + BUEK200)**

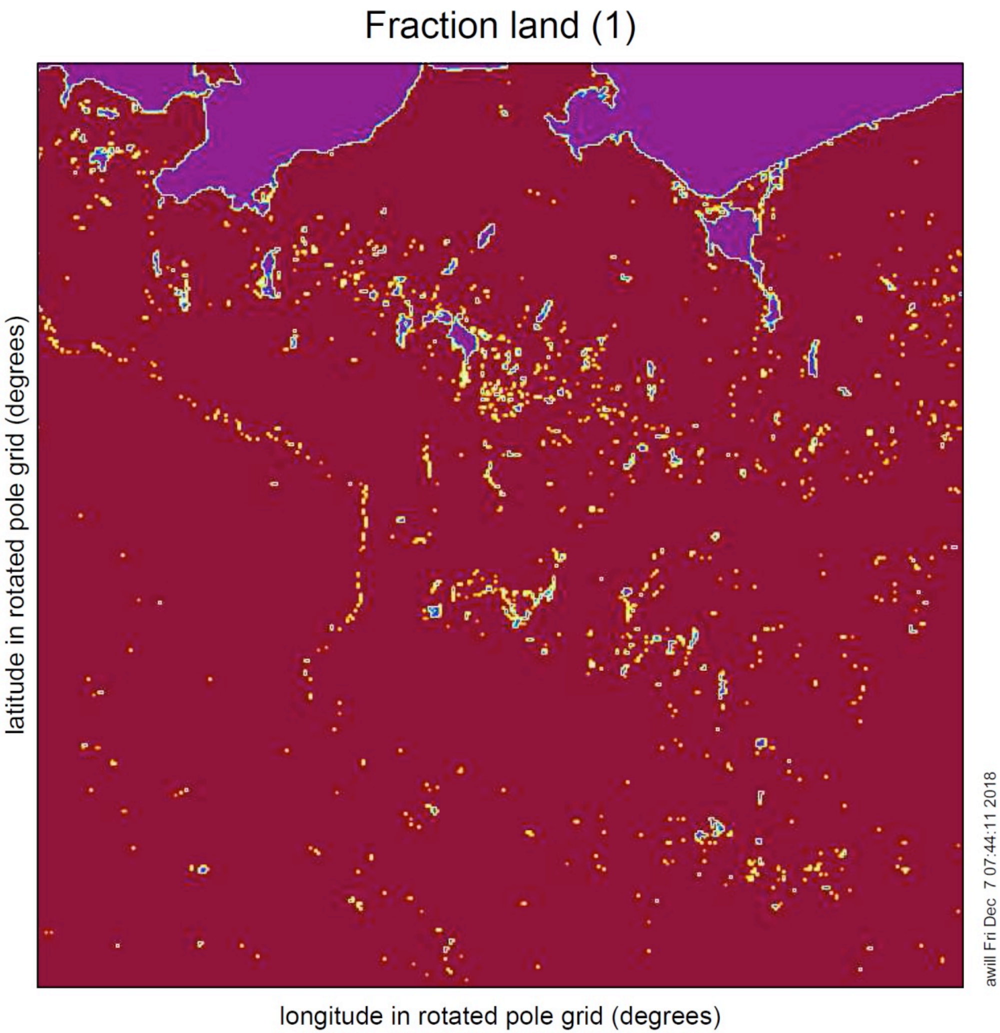
Reference Configurations:

Coupled Regions:	CORDEX-EU	COSMO-BRB
horiz. Res.	$\Delta\lambda=0.0625°$	$\lambda=0.01°$

OASIS3-MCT2: Reference configurations for sequential coupling:

Rgion BRB

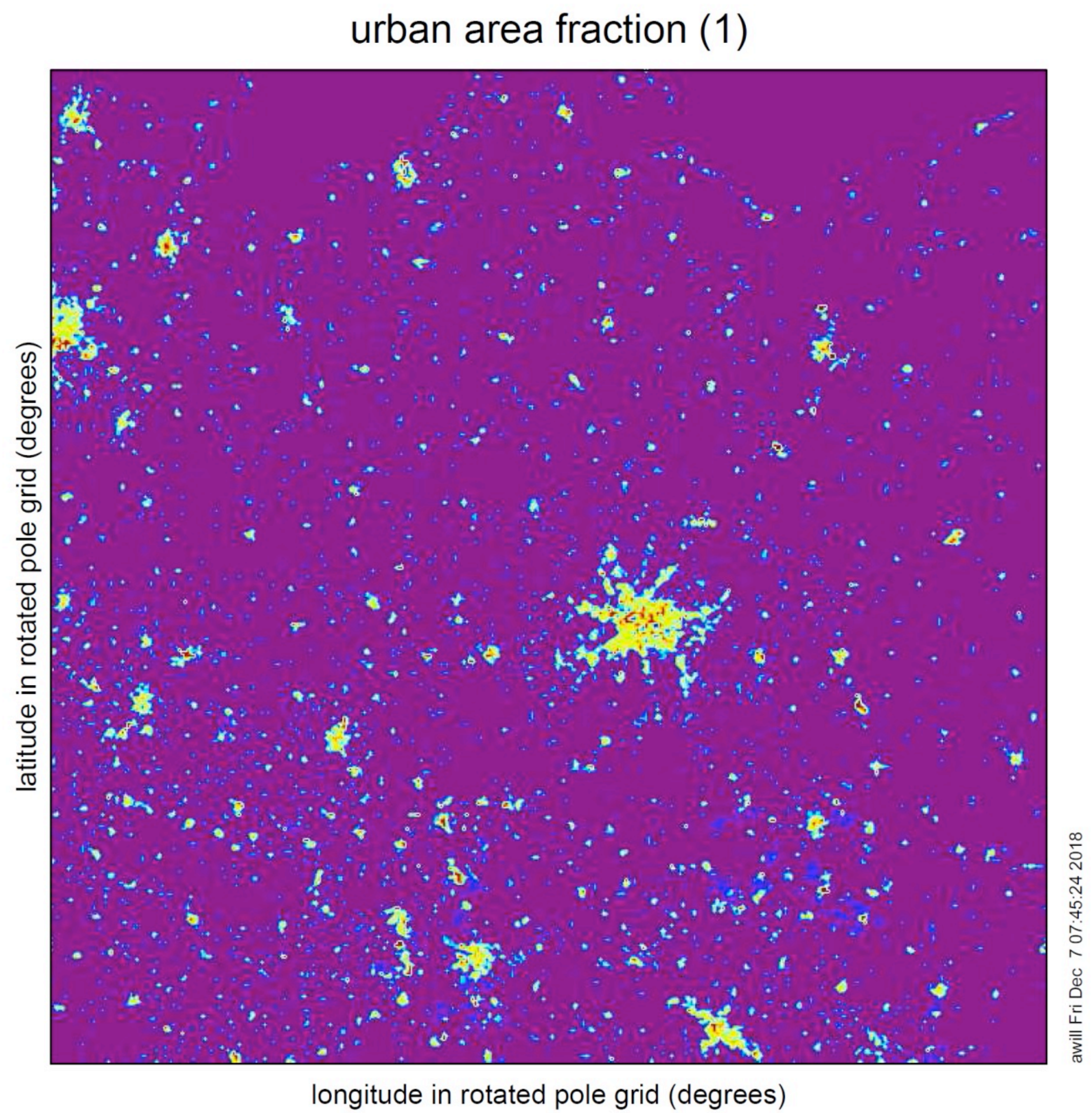
Fraction Land



Rgion BRB

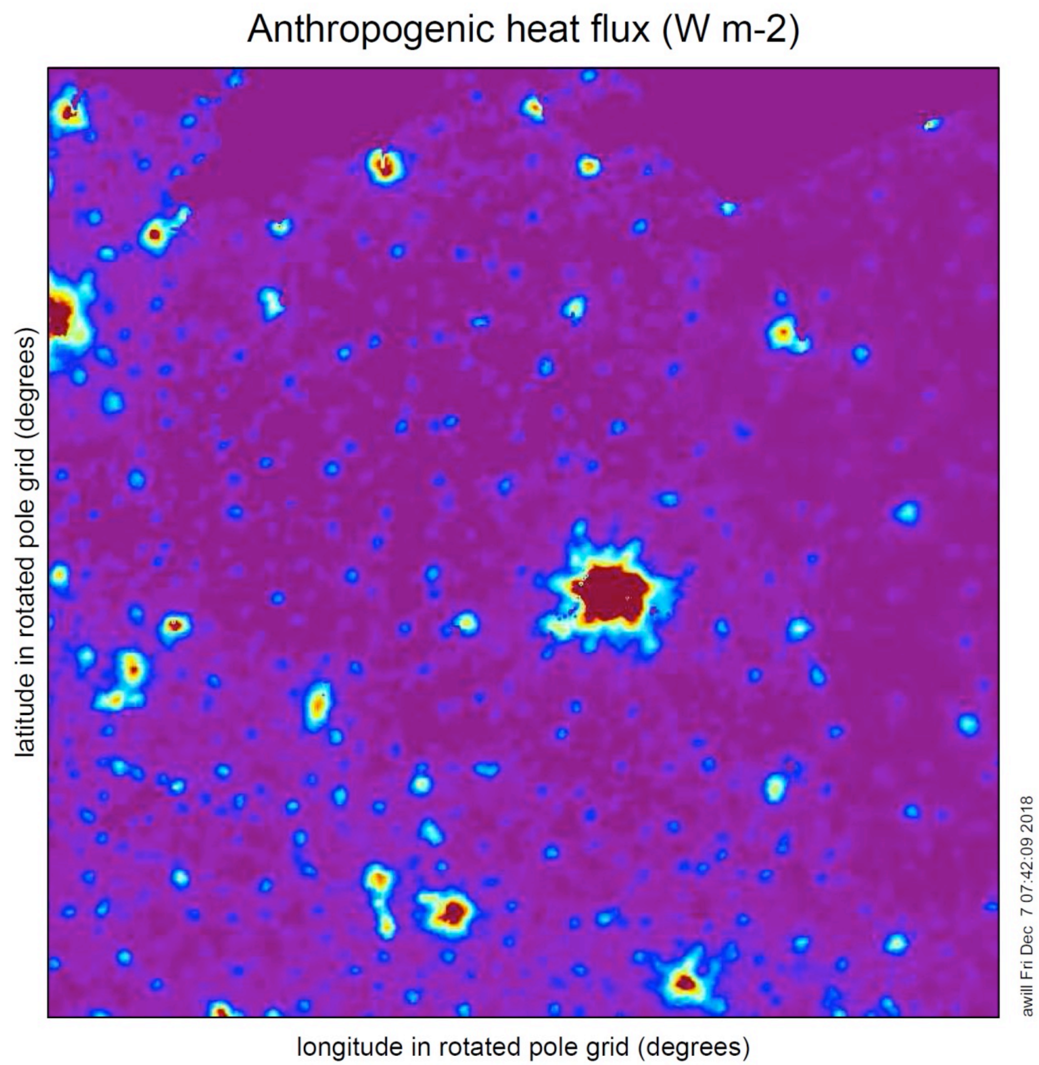
Urban fraction

- **One City: Berlin**



Rgion BRB

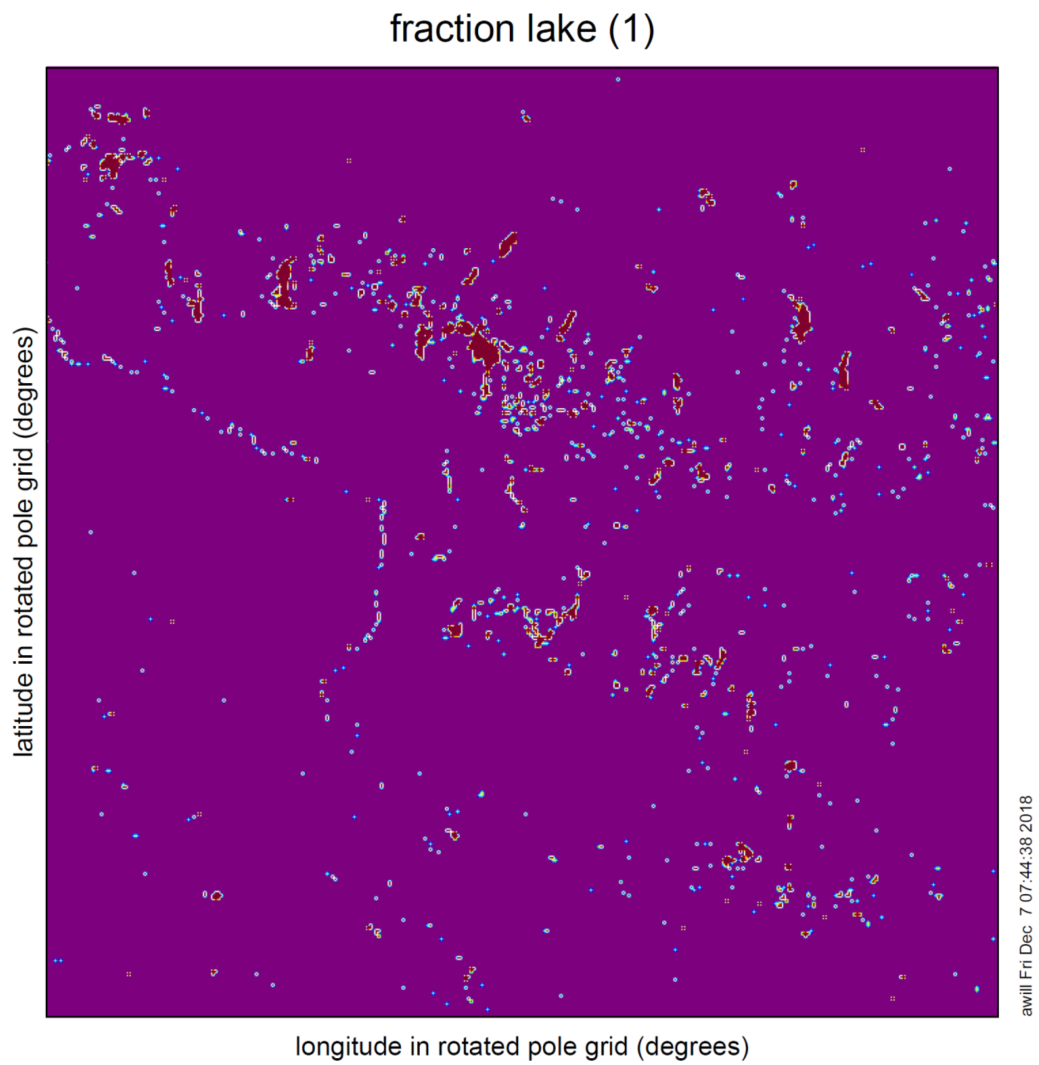
Anthropogenic Heat Flux



Rgion BRB

Fraction Lake

- **Many small lakes**
- **20 New Lakes after coal mining**



Development of

COSMO-COSMO

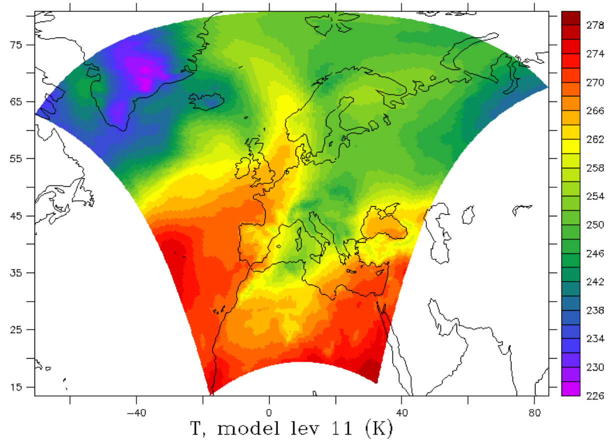
Two –way Coupling

TWC COSMO-COSMO : Field Exchange

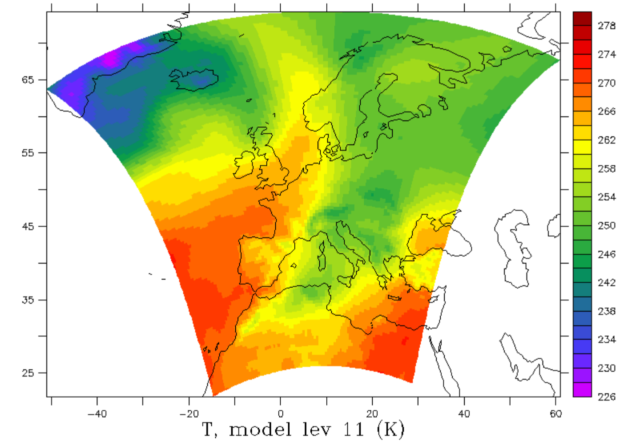
Parent

Child

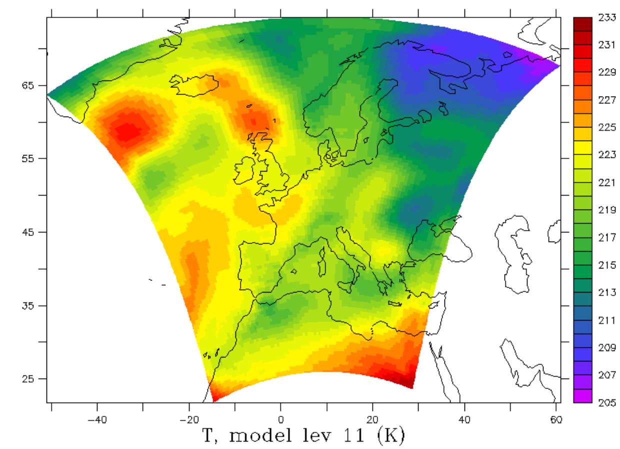
Parent, source



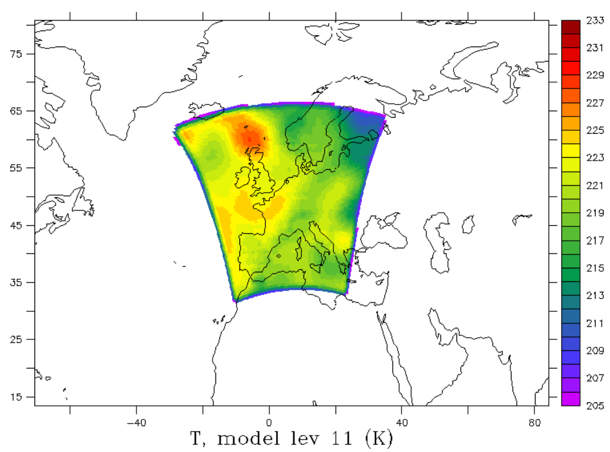
Child, target



Child, source



Parent, target (weighted incoming field)



Summary

- No obvious unphysical behavior of the two-way coupled system
  - The lack of precipitation was solved by considering different saturation adjustments in COSMO and MPIESM

Mean pressure interpolation accuracy of 1 Pa +/- 3 Pa achieved

Substantial noise reduction by

- iteration of the hydrostatic pressure adaption of vertical interpolation
- extrapolation instead of interpolation at the lower boundary

Open Issue:

- Adjustment to COSMO 300 hPa level