Recent development in upper-air COSMO Physics

- ✓ **Revision of cloud optical properties**
- ✓ **Results from monitoring the operational LPI in COSMO-DE**
- ✓ **Experiences with the stochastic boundary layer perturbation**
- ✓ **EDP-forecast for aviation derived from TURBDIFF within ICON**
- ✓ **Recent verification results of the common TURBDIFF for ICON and COSMO**
- ✓ **Investigation of the tiling effect on TURBDIFF for the stable PBL**

➢ effect of single-precision radiation calculations on results

Testing & Tuning of (Revised Cloud Radiation Coupling) $T^2(RC)^2$:

Harel Muskatel, Pavel Khain (IMS)
Uli Blahak (DWD)
Natalia Chubarova (RHM)

and others

Revised parameterization of optical ice-cloud properties:

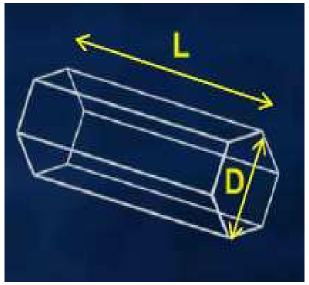
- In the COSMO radiation scheme (Ritter & Geleyn 1992)
  - **Optical properties** of ice-clouds are described **crudely** and don't **include precipitation products**

    extinction coeff. β_e , **single scattering albedo** ω ,
    asymmetry factor $\check{g}$, **delta-transmission factor f_d**

  - Effect of inhomogeneity is taken into account by means of a constant reduction factor **radqcfact=0.5** applied to the mass fractions.

➔ New parameterizations of **optical properties** based on idealized calculations according to **Fu**

- **Visible-bands**: **Ray-tracing** for randomly orientated hexagonal ice particles (Fu 2007)
- **IR-bands**: weighted average of **Mie-scattering** and related methods (Fu et al. 1998)



- **Optical properties** are treated as functions of **effective arguments**
  - **effective radius** **R_{eff}**
  - **aspect ratio** **AR**

  and wave-length

- **Arguments** deduced from inherent assumptions in terms of **particle size distribution N(L)**, **mass size relation m(L)** and **particle shapes** (expressed by **L** and **D)**:
  - Suitable also for **complicated ice particles** (bullet rosettes, aggregates with rough surfaces, fractional crystals)
  - **Extending particle size range (5µm - 300 µm)** by using 7000 size-modified **Generalized Gamma-Distributions N(L)**
- **Fitting** the calculated relations between **optical properties** and **effective arguments**
  - In terms of **rational functions** using **spectral averaging** for **8 distinctive spectral bands**

Problem: New cloud-radiation scheme depends on 30 parameters!

- **Perform idealized COSMO simulations**
  - **for many parameter combinations**
  - **and special cloud types**

Cirrus	Stratus	Mixed phase	SGS Strato-cumulus	Shallow convective cumulus	Anvil of Cumulonimbus

- **Replace attenuation of radiation (in %) by an analytic function (quadratic form) of the parameters (meta-model):**

$$R\,(\underbrace{p_1\,,\,p_2\,,\cdots}_{\text{scaled dimensionless parameters}})$$

scaled dimensionless parameters
ranging from -1 to 1

- **Calculate sensitivity of each parameter** p_i : $\partial_{p_i} R$
  - **most sensitive parameters: automatic tuning by CALMO**
  - **less sensitive parameters : "expert-tuning"**

- **List of 8 most sensitive parameters :**

Selectors:

- Operational / new scheme
- Include rain, snow & graupel

Real numbers:

- Assumed number concentration of cloud droplets
- Properties of sub-grid water clouds
- Representation of sub-grid variability

Extended effective -Radius R_{eff} calculation for water clouds based on an aerosol-climatology:

Currently: grid scale clouds: $\mathbf{R_{eff}}$ is a function mainly of cloud mass fraction $\mathbf{q_C}$

sub-grid clouds: using a fixed $\mathbf{R_{eff}}$ as a tuning parameter

New: using

- Tegen-climatology: (Tegen et al., 1997), later: prognostic aerosols (**COSMO-ART**)
  - o Optical thickness for 5 aerosol categories:
    - sea-salt, mineral dust, black carbon, organics
  - o Assumed specific extinction coefficients => grid-column-integrated aerosol-mass per m^{-2}
  - o Assumed mean particle radius and density
  - o Assumed exponential vertical decrease

  => aerosol number concentration $N_{CN}(z)$ in m^{-3}

- cloud-activation parameterization according to Segal/Khain (2006):
  - o aerosol number concentration N_{CN}
  - o effective updraft wind speed:

$$w_{eff} = \max\left\{ w_{grid-scale} + \mathbf{0.7}\sqrt{\frac{TKE}{\mathbf{3}}} - \frac{c_{pd}}{g}\partial_t T\Big|_{radiation},\ w^* \right\}$$

w^*: convective velocity scale

=> effective radius: valid for cloud water q_c composed by all scales

$$R_{eff} = c_1 \cdot \left(\frac{q_c \cdot \exp\left(-\frac{z - z_{cb}}{\Delta z_{cb}}\right)}{N_{CCN}(N_{CN}, w_{eff})} \right)^{c_2}$$

z_{cb}: height of cloud base

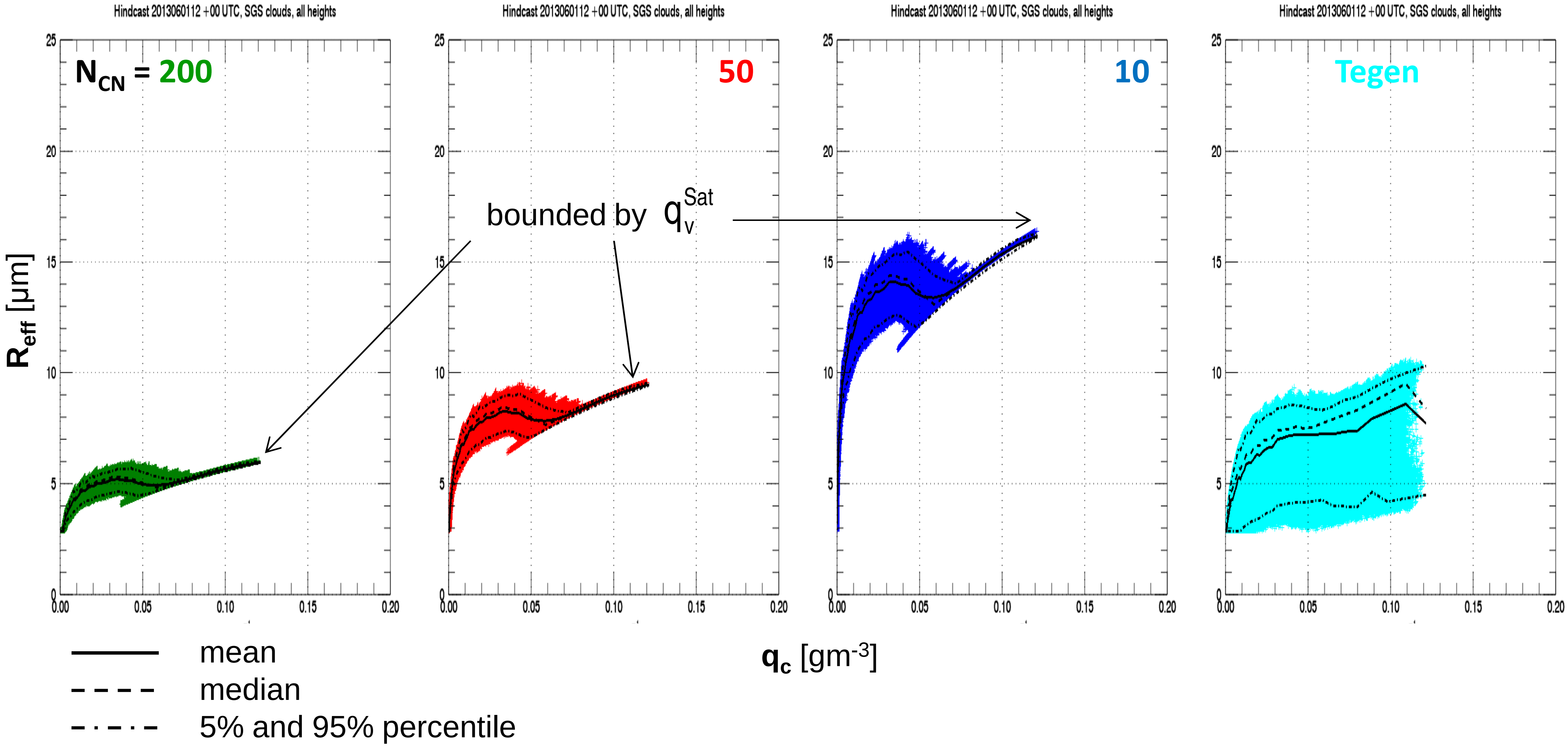
Δz_{cb}: characteristic cloud depth

c_1 and c_2: tuning parameters

N_{CCN}: (activ.) cloud number concentration

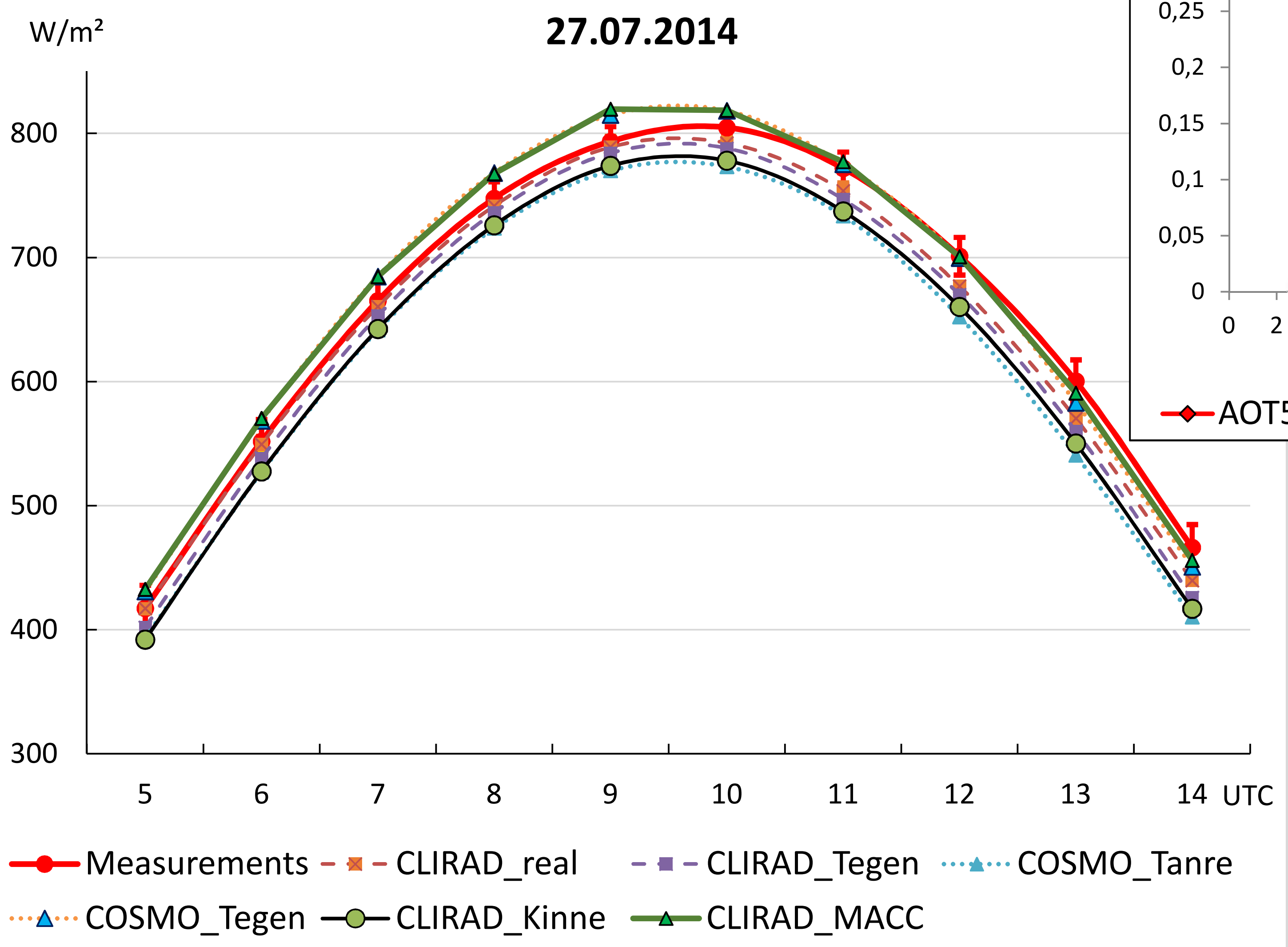
R_{eff} [μm] distribution as a function of q_c [gm^{-3}]

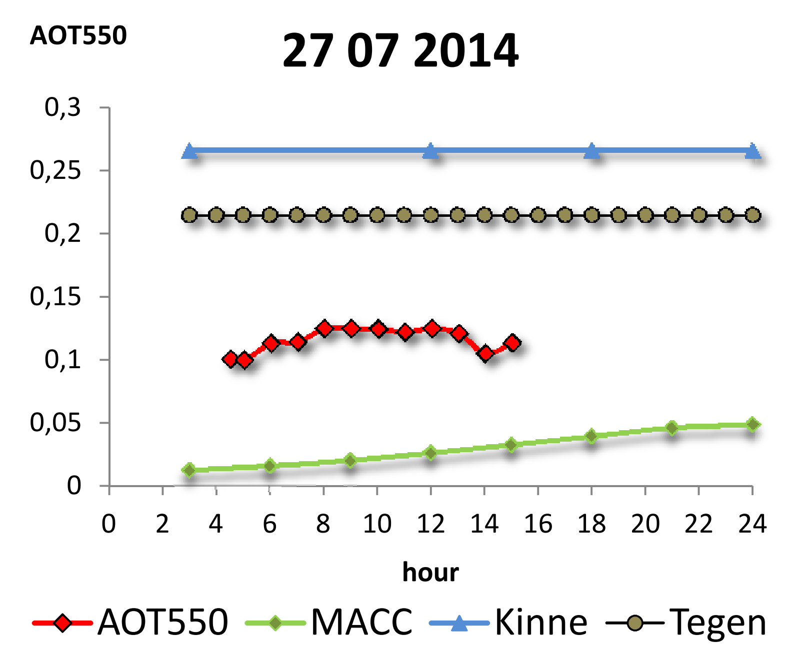
for pure water clouds in all heights (w_{eff} incl. w^*):



COSMO radiation with different climatologies against measurements:

measurements from observatories at
Moscow state university
for clear sky conditions





CLIRAD: sophisticated broadband shortwave radiation code of Moscow state university

Lightning Potential Index

derived from COSMO-DE

Ulrich Blahak (DWD)

Concept of the LPI

- Yair et al. (JGR, 2010), Lynn and Yair (Adv. Geosci., 2010)
- Charge separation in thunderstorms is correlated with the **simultaneous presence** of **updrafts**, **super-coolded liquid water**, **graupel** and other frozen hydrometeor types („**cloud ice**“, „**snow**“)
- This concept was modeled by the authors resulting into a LPI-Index:

adapted by U. Blahak ($f_1 f_2$)

$$\mathrm{LPI} = f_1\, f_2\, \frac{1}{H_{-20^\circ\mathrm{C}} - H_{0^\circ\mathrm{C}}} \int_{H_{0^\circ\mathrm{C}}}^{H_{-20^\circ\mathrm{C}}} \epsilon\, w^2\, g_{(w)}\, dz$$

local updraft filter ($g_{(w)}$):
contribution only for: $w \geq 0.5\,\mathrm{ms}^{-1}$

column updraft filter (f_1):
contribution only if: 10X10Km^2-horiz. average of **column-maximum updraft velocity** is large

column buoyancy filter (f_2):
contribution only if: 20X20Km^2-horiz. average of **CAPE** is large

$$\epsilon = \frac{2\sqrt{q_L\, q_F}}{q_L + q_F}$$

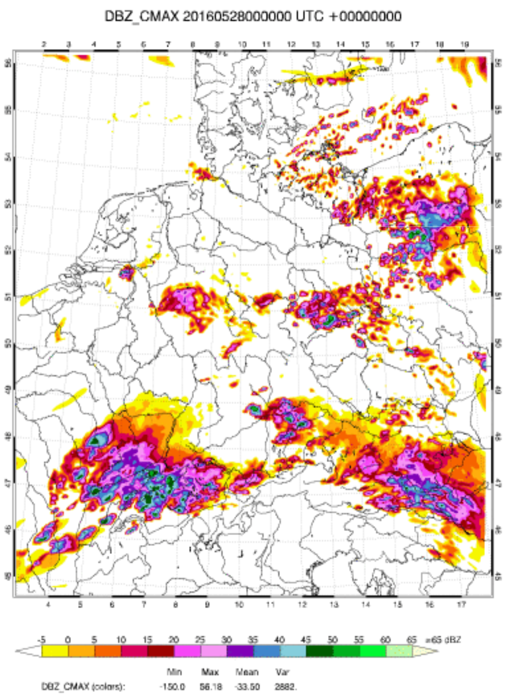
$$q_L = q_c + q_r$$

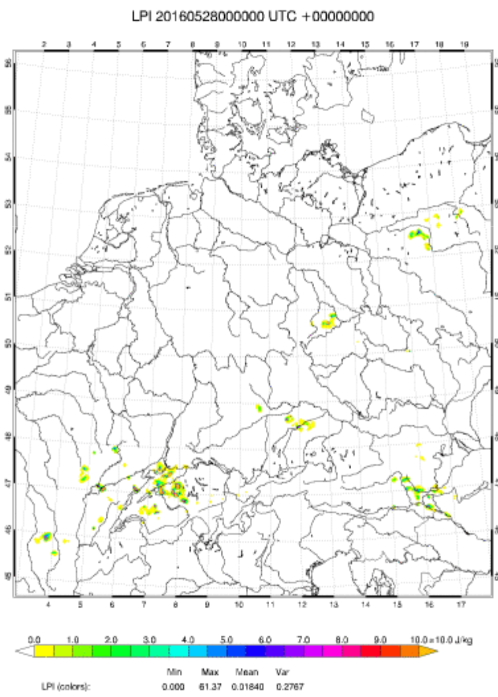
$$q_F = \frac{q_g}{2}\left[\frac{2\sqrt{q_i\, q_g}}{q_i + q_g} + \frac{2\sqrt{q_s\, q_g}}{q_s + q_g}\right]$$

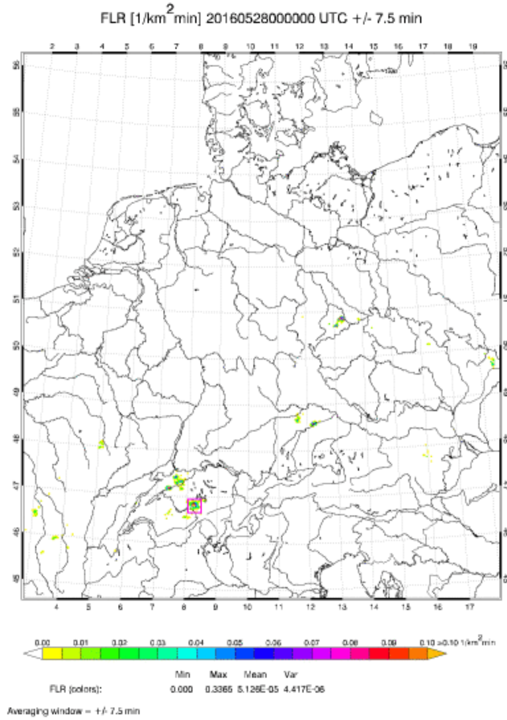
COSMO-DE oper. forecast 28.5.-31.5.2016,

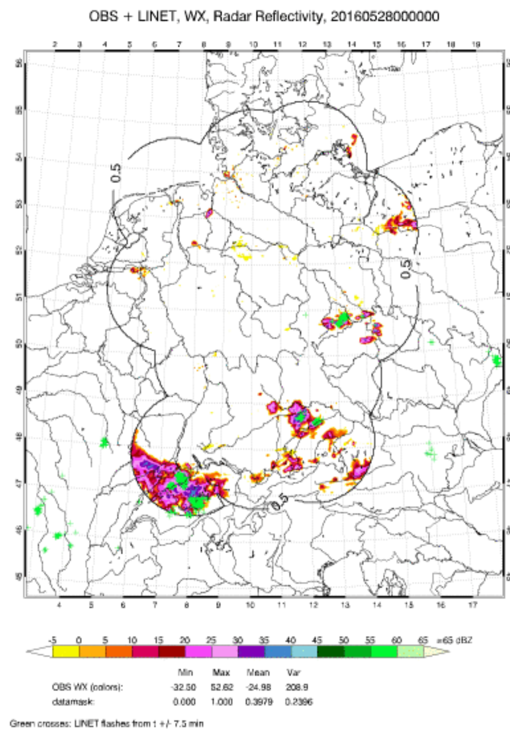
combined 00 UTC runs until vv=23 h

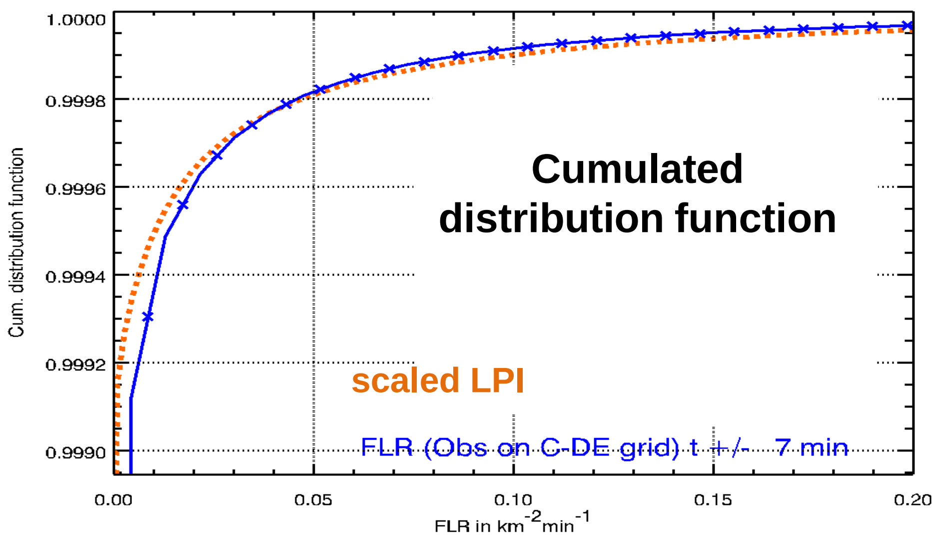
sim. dBZ_max	sim. LPI	obs. FLR t +- 7.5 min	obs. dBZ + LINET











Probability-matched relation on COSMO-DE grid:

FLR in km^{-2} min^{-1} ≈ 0.017 * LPI in J/kg

➔ **1 flash per grid cell per 15 min (due to obs „+- 7.5 min") equals LPI ≈ 2.0 J/kg**

➢ An accurate simulation of super-cooled liquid water is essential!

Boundary layer perturbations for convection triggering in COSMO-DE

Ulrich Blahak[2] (DWD), Kirstin Kober[1] (LMU)

[1] Original inventor
[2] Implementation and testing at DWD

The method

- perturbed physical tendencies within ABL dependent on turbulent variances
- aiming to reflect unresolved effects in variability of surface fluxes on convection initiation

tuning-parameter

$$\partial_t \bar{\phi}\big|_{pert} = \partial_t \bar{\phi} + c \cdot \frac{\ell}{\Delta x} \cdot rnd \cdot \frac{\sqrt{\overline{\phi'^2}\big|_{turb}}}{\Delta t}$$

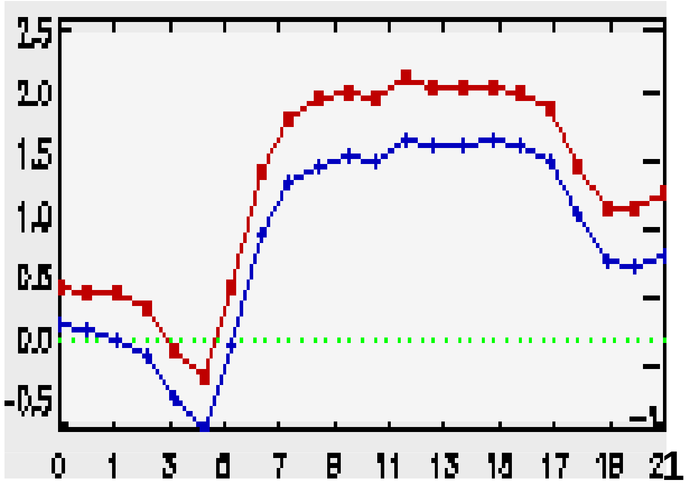
- from **TRUBDIFF**
- modif. By U. Blahak:
  - 0, above BLH
  - maximal BL-value below

For :

- temperature
- specific humidity
- vertical velocity

- **2D-field of Gussian random numbers**, folded by a Gaussian **smoothing kernel** to generate **spatially coherent patterns**.
- It **is updated every 10 minutes** (approximate eddy turnover time in shallow convection).
- The spatial width of the kernel is specified as a multiple of horizontal grid length Δx .
- According to **Teixeira and Reynolds** (2004), described in **Kober, Craig et al.** (2015)

$T_{2m} - TD_{2m}$



COSMO-DE experiments with EDA driven by ICON-EU for August 2015:

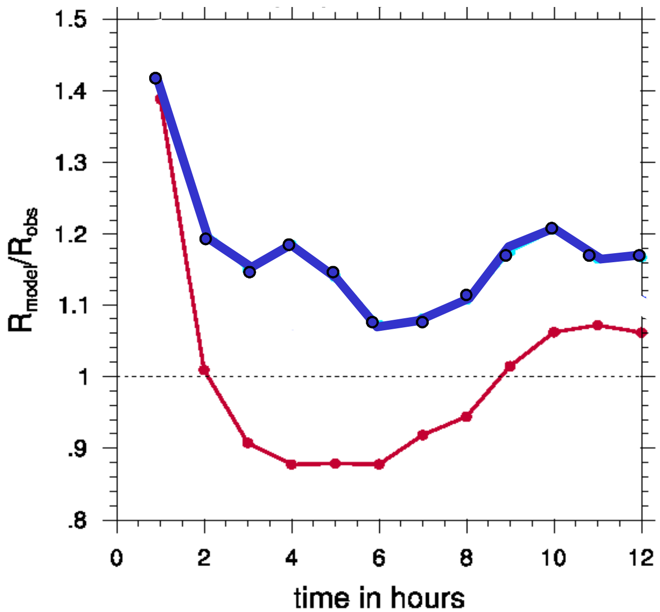
- with stoch. BL-Pert
- reference

- strong dry BIAS
  - o due to overdrawn precipitation already during assimilation?

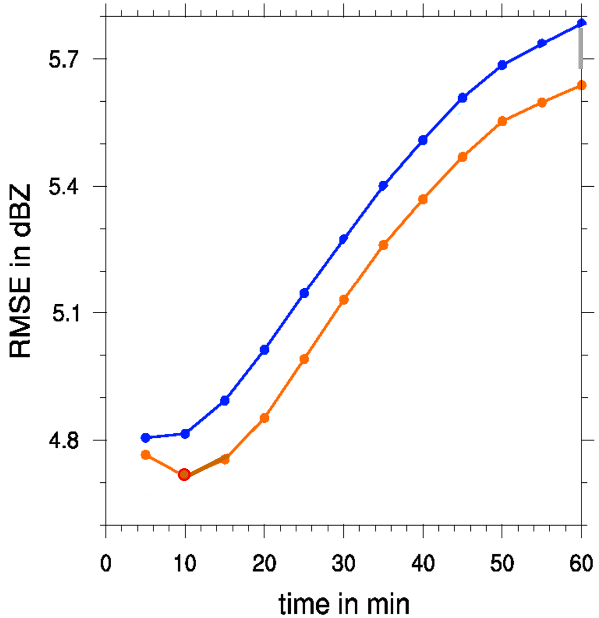
COSMO-DE-KENDA experiment (Axel Seifert):

- Tot. Prec. Rate + stoch. BL-Pert
- Tot. Prec. Rate (reference)

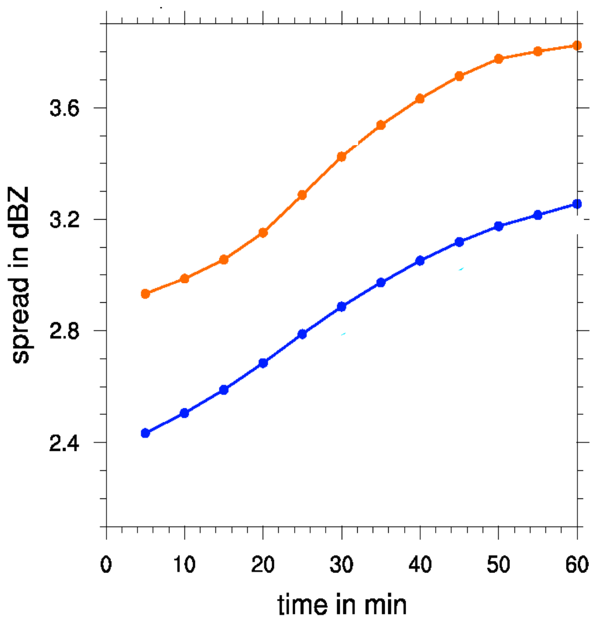
domain averaged precipitation-rate vs. obs.



ens. mean fisrt guess RMSE



ens. spread



- strong spin-down for precipitation
- improved spread/RMSE – ratio for 1h assimilation cycle

> ➢ not yet effective for triggering more convective precipitation!

Eddy Dissipation Rate (EDR) forecasting derived from TURBDIFF
- Global Validation with ICON -

Matthias Raschendorfer, Axel Barleben, Tobias Göcke,
Ekaterina Machulskaya

(all DWD)

EDR from prognostic TKE-equation:

Matthias Raschendorfer

not yet added to TKE-equation

so far only added to TKE-equation in ICON

always added to TKE-equation

Enabled by the concept of :

STIC: Separated Turbulence Interacting with (non turbulent sub-grid scale) Circulations

$$\text{dTKEcon} \text{ — GRIB}$$
$$+ \text{ dTKEshs — (GRIB)}$$
$$+ \text{ dTKEsso — (GRIB)}$$

independent on model grid scale

GRIB

contains only (isotropic) turbulence up to a separation scale **L**

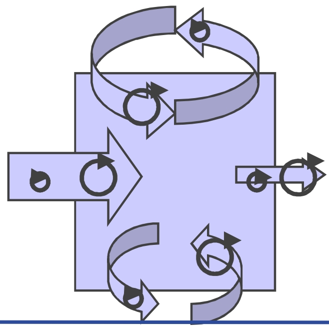
(GRIB)

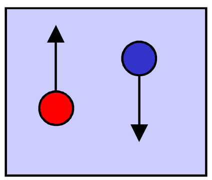
$$\partial_t(\rho \cdot \mathrm{TKE}) = \mathrm{Adv} + \mathrm{Dif} + \mathrm{Boy} + \mathrm{Shr} + \mathrm{CShr} - \mathrm{EDR}$$

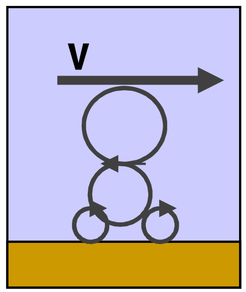
main contribution above BL

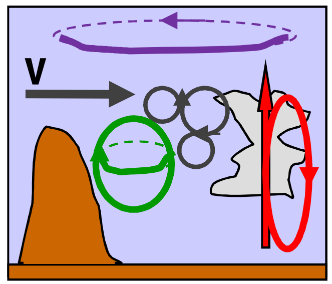
$$\partial_t\left(\bar\rho \cdot \frac{1}{2}\overline{q|_L^{\,2}}\right) = \frac{1}{2}\nabla\cdot\left(\begin{array}{c}\bar\rho\,\overline{q^2_{|L}}\,\hat{\mathbf{v}} \\ + \sum_{i=1}^{3}\overline{\left(\rho v_i''^2\,\tilde{\mathbf{v}}''\right)_{|L}}\end{array}\right) + \underbrace{\frac{g}{\hat\theta_v}\overline{\rho\theta_v''w''|_L}}_{=:-\bar\rho\,\overline{q|_L}\,\ell S^H F^H} + \underbrace{\left[-\sum_{i=1}^{3}\overline{\rho v_i''\tilde{\mathbf{v}}''|_L}\cdot\nabla\hat v_i\right]}_{=:\bar\rho\,\Gamma\,\overline{q|_L}\,\ell S^M F^M} + \underbrace{\left[-\sum_{i=1}^{3}\overline{\rho v_i''\tilde{\mathbf{v}}''|_L{}'\cdot\left(\nabla\hat v_i\right)_{|L}{}'}\right]}_{=:\bar\rho\,\Gamma\,\overline{q|_L}\,\ell S^M F^M_C} + \left[-\bar\rho\,\frac{\overline{q|_L}^{\,3}}{\alpha^{MM}\ell}\right]$$

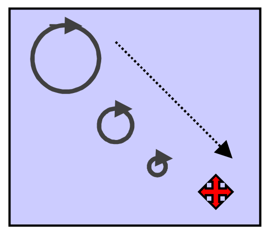
time tendency	transport (advection + diffusion)	buoyancy production	shear production by the mean flow	shear production by sub grid scale circulations	eddy-dissipation rate (**EDR**)
		labil: > 0 neutral: $= 0$ stabil: < 0	≥ 0	≥ 0	< 0







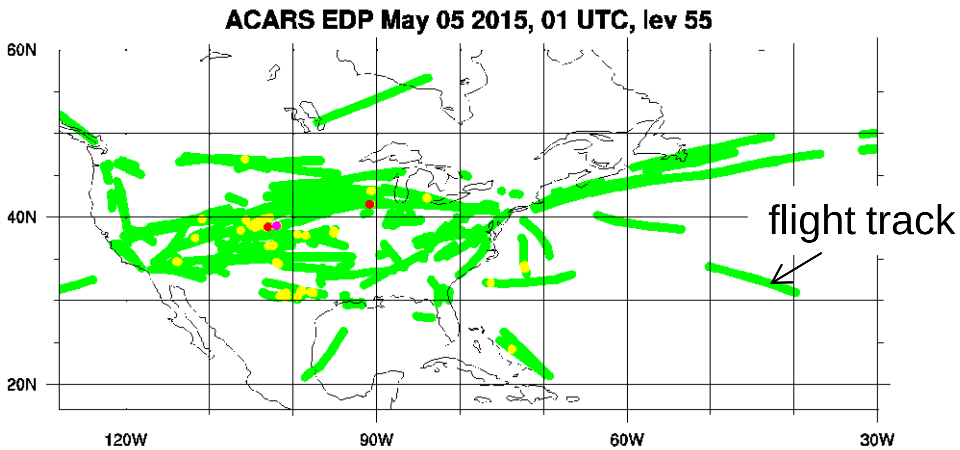


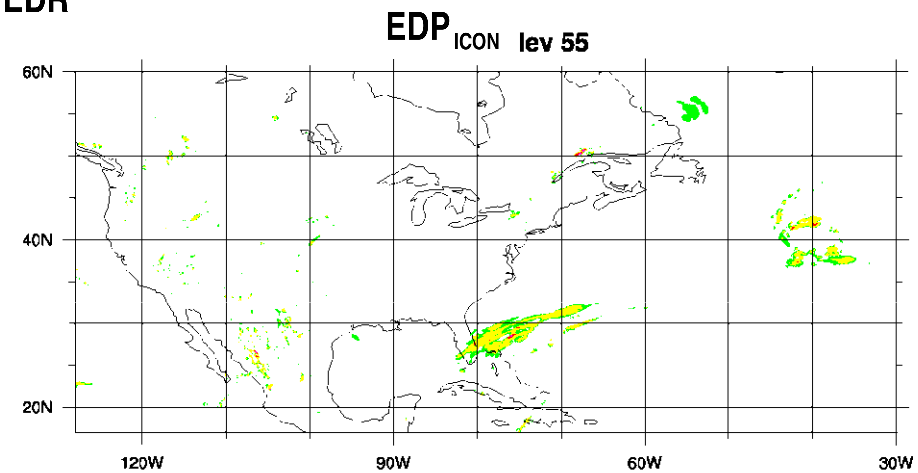


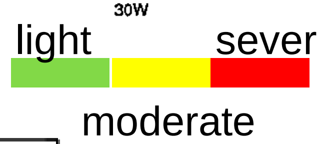
Effect of Convection as additional TKE source:

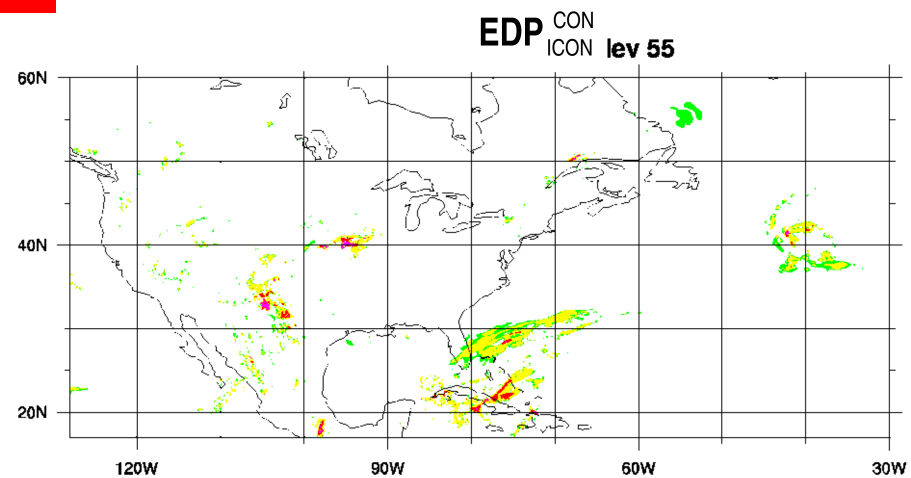
Tobias Göcke, Ekaterina Machulskaya

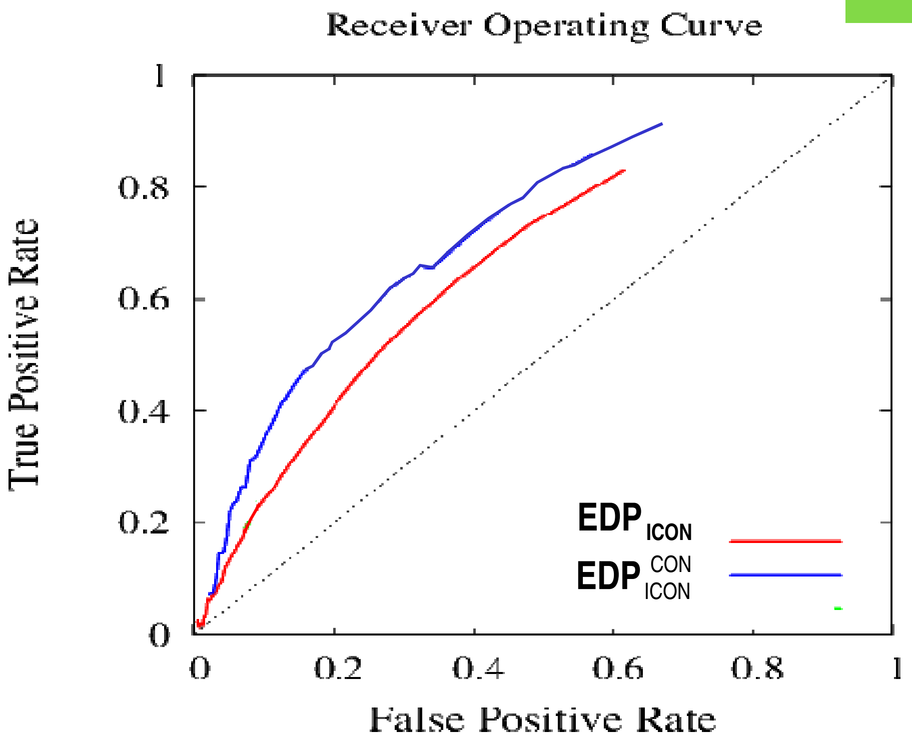
$$EDP := \sqrt[3]{EDR}$$











EDR_{ICON} : already contains **dTKEsso + dTKEshs**

EDR^{CON}_{ICON} : **dTKEcon** added to EDR_{ICON} in **post-processing**

Revision of the combined turbulence- and SAT-scheme TURBDIFF for ICON and COSMO:

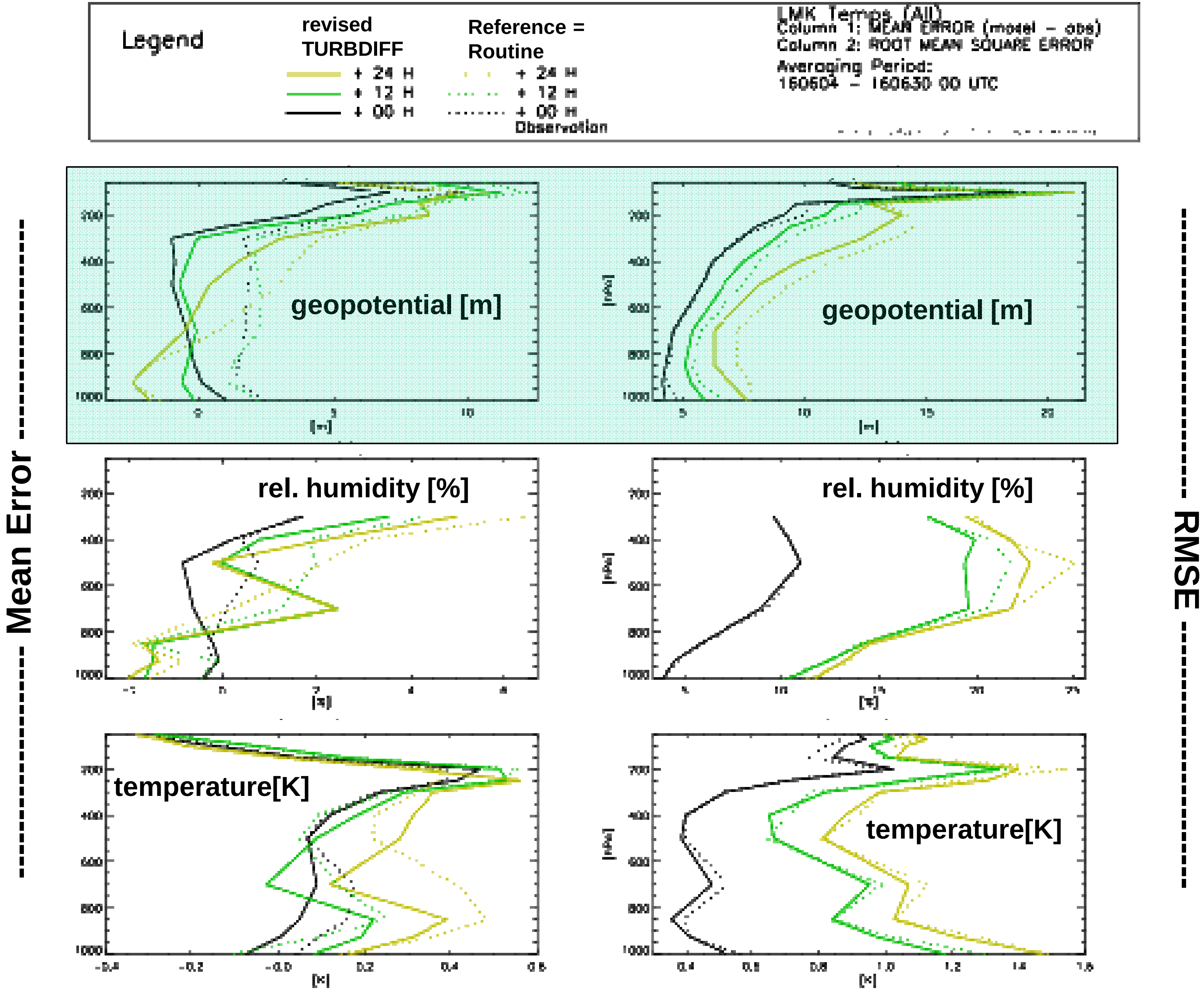
Matthias Raschendorfer (DWD)

- In block-data structure and with stronger modularization
- Generalized semi-implicit vertical diffusion (also for non-gradient fluxes)
- One additional STIC-term active (due to separated SGS horizontal shear circulations)
- Increased shear –production of TKE by STIC-terms also considered for Ri-number
- Less restrictive prevention of possible singularities
- Application of some first empirical hyper-parameterizations (by Günther Zängl):

  Some parameters of the scheme formulated as a function of model-state variables:

  e.g. "minimal diff-coeff" = fnc ("Ri-number", "height above ground")
- Complete moist physics applied to surface level (including turbulent cloud diagnostics)
- Near-surface interpolation of vertical profiles in conserved variables
- Zero-concentration condition for qi and qc at the surface (e.g. impaction of fog)

Upper air verification with COSMO-DE for June 2016:

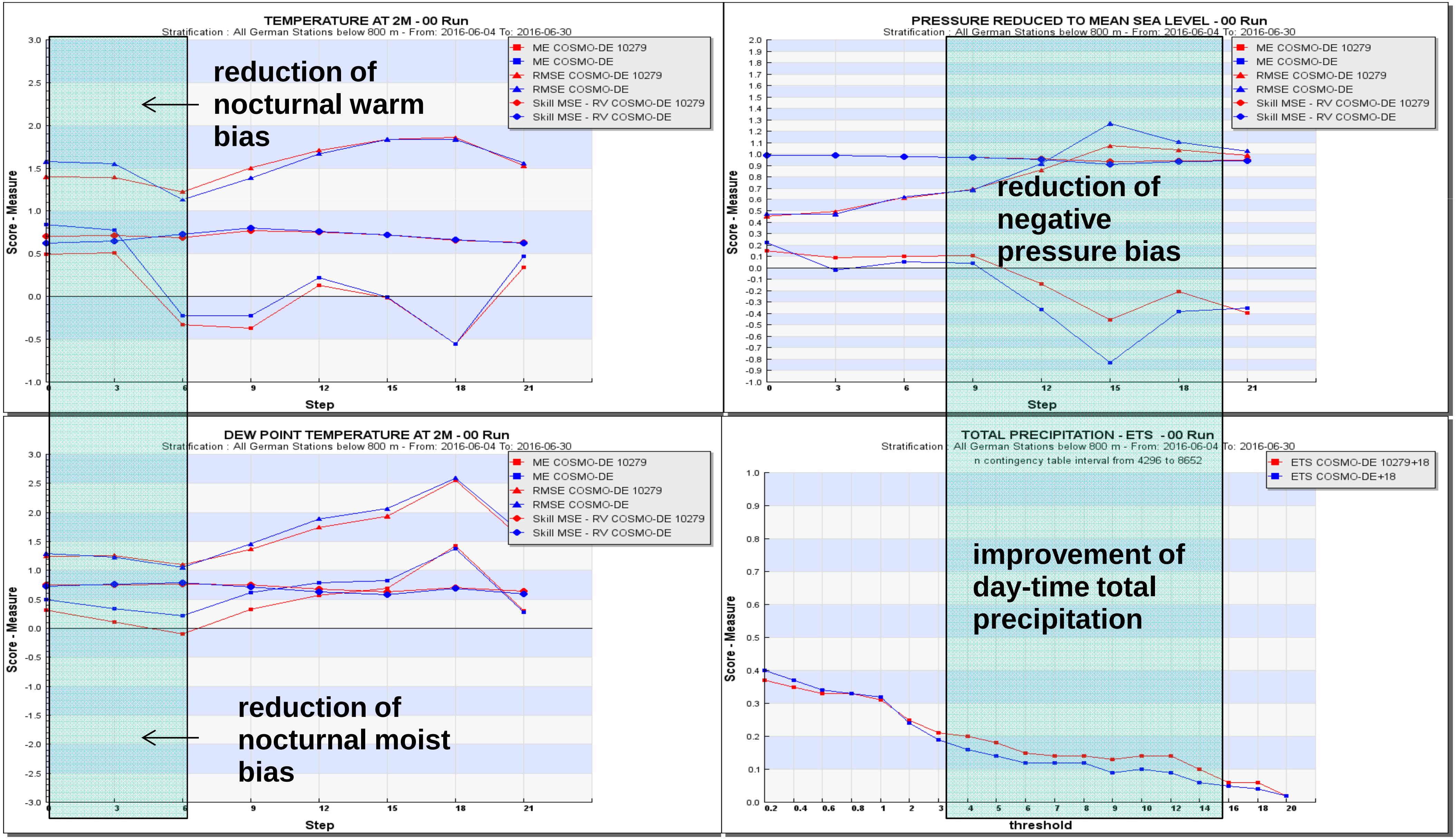


Near surface verification with COSMO-DE for June 2016:

revised version of TURBDIFF

Reference = Routine

below 800 m



10m-wind : only small differences

upper air-wind : indifferent variations

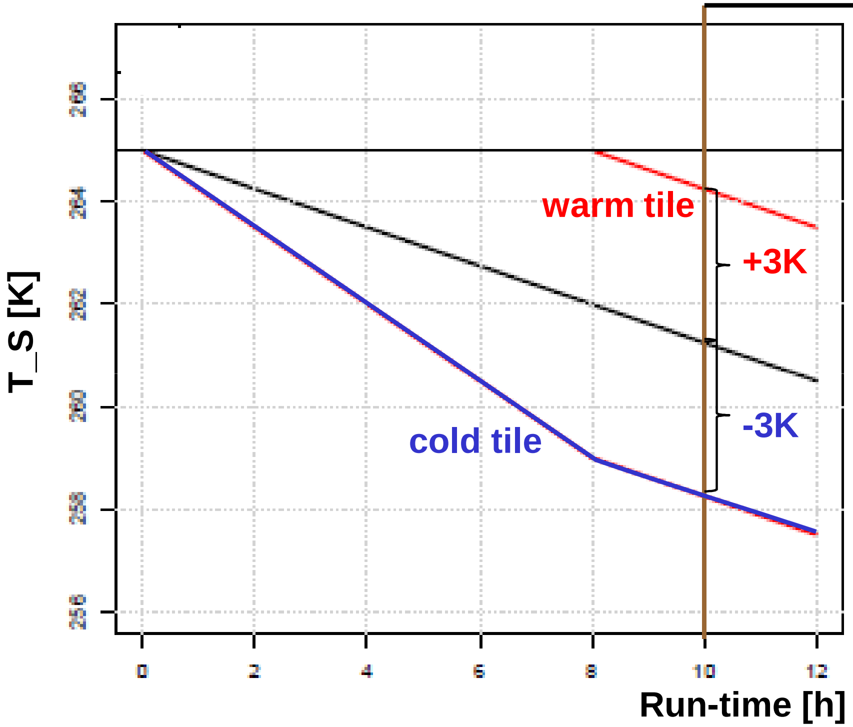
Subgrid scale thermal surface heterogeneity treatment in the turbulence scheme for stable PBL

Ines Cerenzia[1,2]
Ekaterina Machulskaya[3]

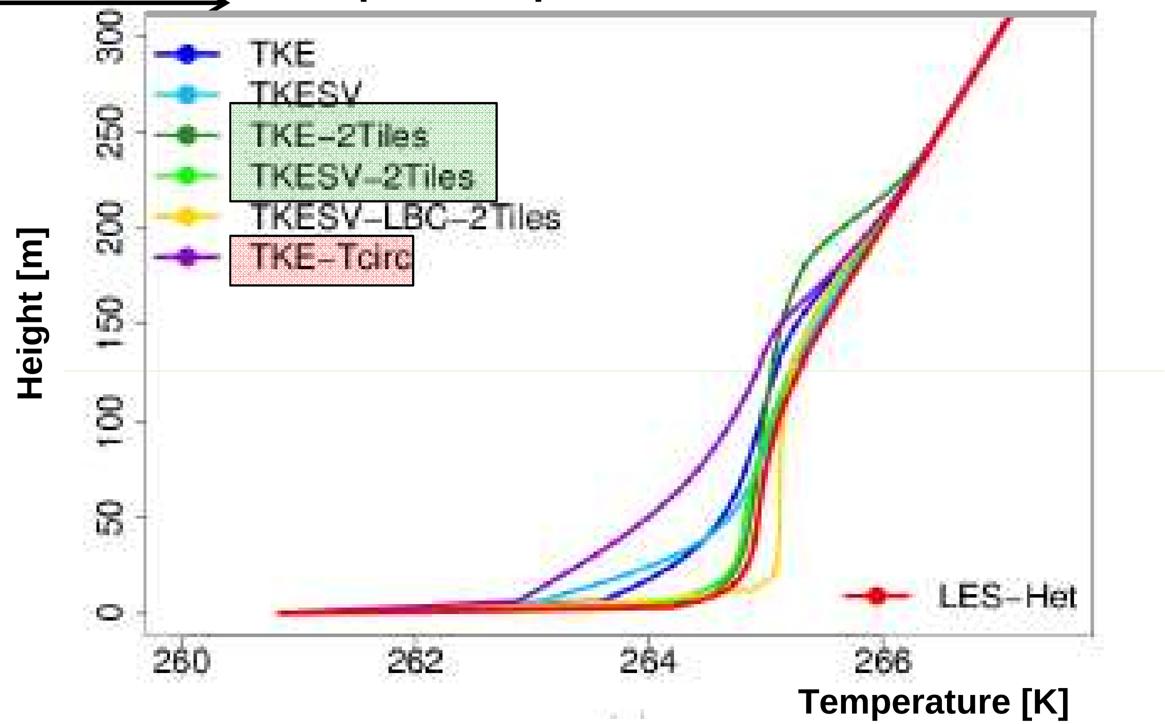
[1] University of Bologna, Italy
[2] Arpae-Emilia Romagna SIMC, Italy
[3] Deutscher Wetterdienst, Germany

Idealized simulation of the stable BL above thermal surface patterns:

decreasing surface temperatures



temperature profiles after 10 hours



Experimental setup:

- simulation with COSMO-Single-Column
- representing column above a 400X400m^2 idealized flat surface
- with 100X100m^2 checker board elements (of ΔT_S=6K after 8h)
- using TURBDIFF (with):
  - surface tiling (2Tiles),
  - a STIC-term for thermal driven near surface circulations (Tcirc)
  - progn. scalar variances (SV), (with) Var(T_S) as lower BC (SBC)
- COSMO-LES: 3.125 m horizontal resolution

Results:

- patterns of T_S even sharpen decoupling of surface
- already represented by tiling

- non-linearity of "flux=K*grad(T)" dominates against extra mixing by thermal circulations
- Tcirc is a thermal SSO-term and (in contrast) produces MORE mixing. It should not be active at flat surfaces!

Physical Process in COSMO			Method		Name	Authors
Local Parameteriz. of atmospheric source terms	**Radiation Transport**		δ two-stream; revised optical cloud properties			Ritter and Geleyn (1992) Blahak (->)
	Microphysics		1-moment; 3 prognostic ice phases; prognostic rain and snow			Doms (2004) Seiffert (2010)
			optionally 2-moment version			
Grid-scale Parameteriz. of sub-grid scale atmospheric processes **(dependent on horizontal resolution)**	**any other not yet considered process (e.g. SSO driven thermal circulations or horizontally propagating GW)**					
	Convection	**deep** **shallow**	2-class (updraft-downdraft) mass-flux equations with moisture convergence closure and simplified microphysics			Tiedke (1989), update by Bechthold et al. (2008) optionally
	Sub-grid Scale Orography (SSO) effects		orographic blocking and breaking of vertically propagating Gravity Waves (GW)			Lott and Miller (1997)
	Quasi-Isotropic Turbulence		2-nd order closure; progn. TKE with addit. scale-interaction terms (**STIC**); horizont. BL-approx. with opt. 3D-extensions; turb. sat.- adjustm.		TURBDIFF	Raschendorfer (2001,->)
	Surface-to-Atmosphere Transfer and Roughness Layer effects		transfer resistances based on constant **turbulent**/laminar diffusion fluxes normal to roughness-covering surfaces; separate heat budget of roughness elements (shading)	not yet tiled	TURBTRAN	
Modelling the Non- atmospheric part below the surface	----		---		TERRA	---

Physical Process in COSMO			Method		Name	Authors
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Modelling the Non-atmospheric part below the surface	**Vertical Heat and Water Transport of the Soil including Vegetation and a Snow-cover**		1- layer snow; m.- layer soil; freezing of soil water; resistances for vapor from stomata of leaves and soil pores; moisture and root mass dep. conduct.; coupled with roughness-layer concept		TERRA	Heise and Schrodin (2002), Schulz (2016, ->), Helmert (->), Raschendorfer (->)
			optional m.-layer snow			Maschulskaya (->)
	Heat Transport and Phase Change of Lakes		1-layer with an assumed shape function of temperature profiles; including freezing of lake water and a possible snow-cover		FLAKE	Mironov (2008)
	Heat Transport and Amount of Sea Ice					

Calling frequency of radiation code computational cost versus quality gain: