WG3a: Task overview about SGS Parameterizations:

- Model Development:
  - Further development of the **TKESV-approach** : level-3 scheme
  - **3D-extensions for TURBDIFF** within the concept of scale separation
  - Implementing and extending the **restructured COSMO/ICON TURBDIFF**
  - Consolidation of **BL turbulence** and **SAT**
- Infrastructure:
  - Providing **COSMO-SC** for general application and component testing

PT ConSAT:

-> prolonged

An LES Study of Scalar-Flux Budgets in Cloudy Boundary Layers

(some results from the “Extramurale Forschung” project)

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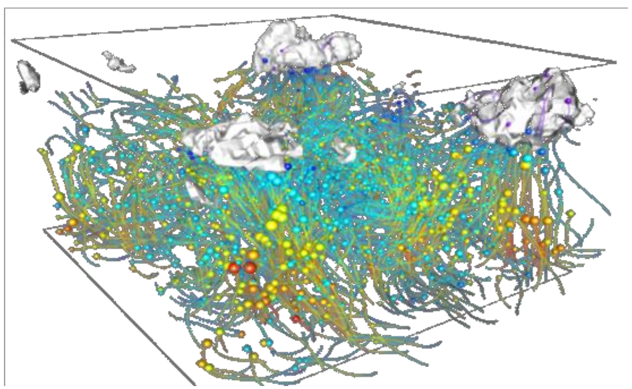
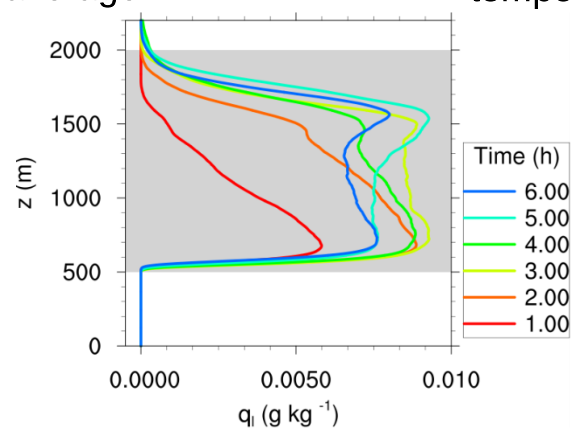
16th COSMO General Meeting, Eretria, Greece, 8 – 12 September 2014

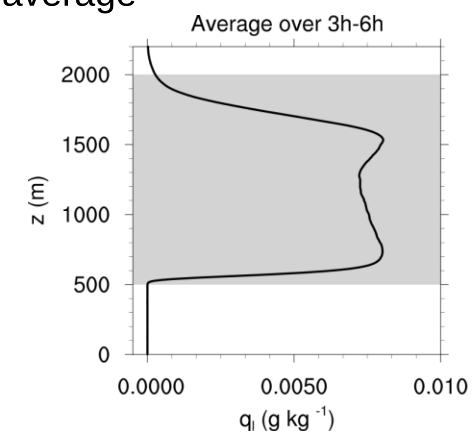
- Approximation to ensemble-mean budgets with LES:

horizontal average

temporal average



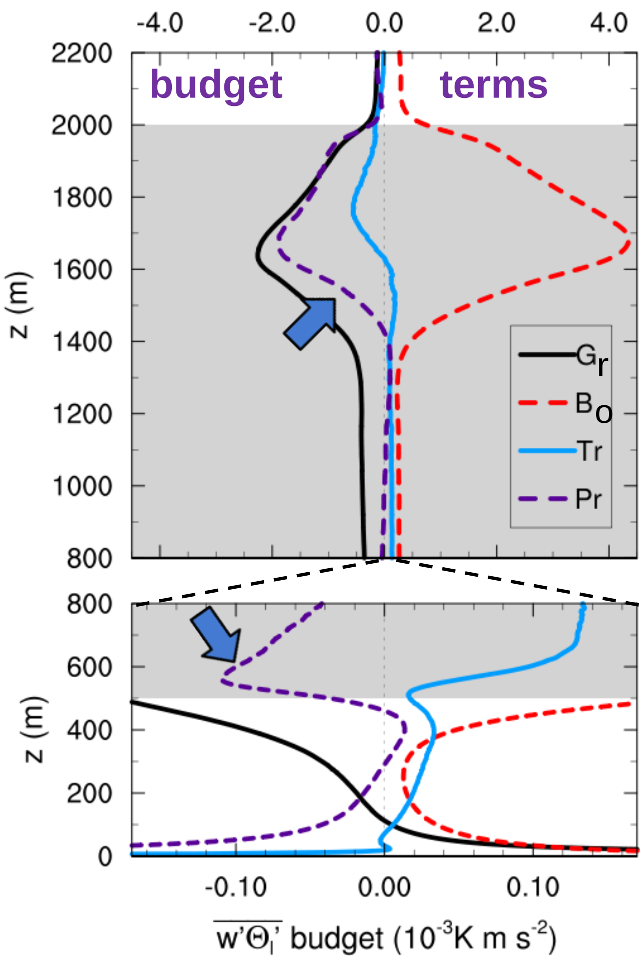




- Explicit consideration of sub-grid scale budgets → small residuals

- Simulations with PALM (palm.muk.uni-hannover.de)
  - Trade wind cumulus (BOMEX, Siebesma et al. 2003)
  - Nocturnal stratocumulus (DYCOMS-II (RF01), Stevens at al. 2005)

Budget of flux of liquid water potential temperature



BOMEX

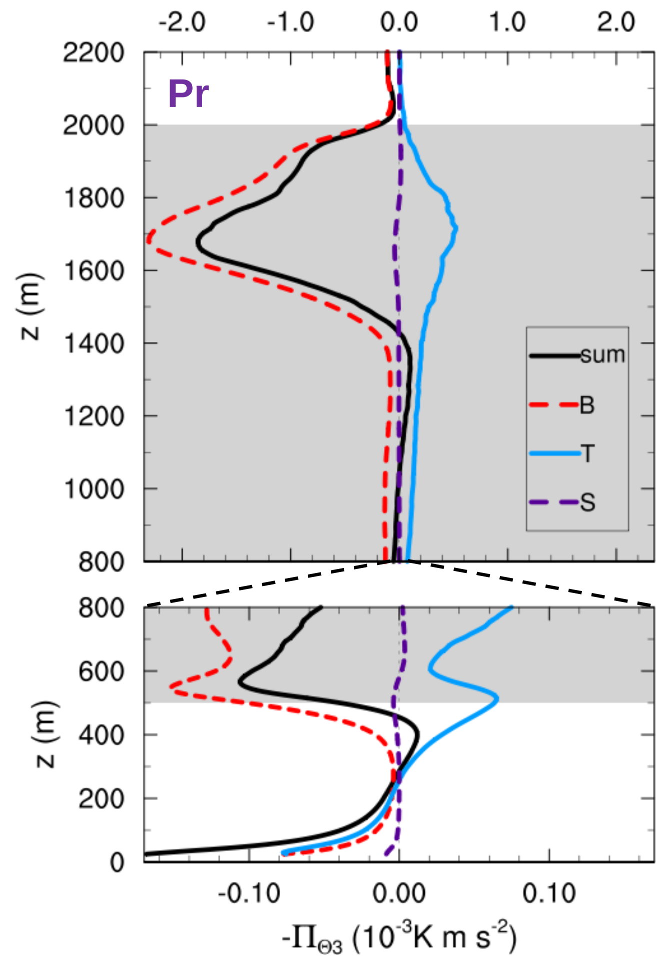
$$\frac{\partial}{\partial t}\overline{w'\theta_l'} = \boxed{-\overline{w'^2}\frac{\partial \overline{\theta_l}}{\partial z}} \boxed{+\frac{g}{\theta_0}\overline{\theta_l'\theta_v'}} \boxed{-\frac{\partial}{\partial z}\overline{w'^2\theta_l'}} \boxed{-\frac{1}{\rho_0}\overline{\theta_l'\frac{\partial p'}{\partial z}}}$$

mean gradient

buoyancy

transport

pressure term



⇒ Budgets are dominated by mean-gradient (**Gr**), buoyancy (**Bo**) and pressure-term (**Pr**)

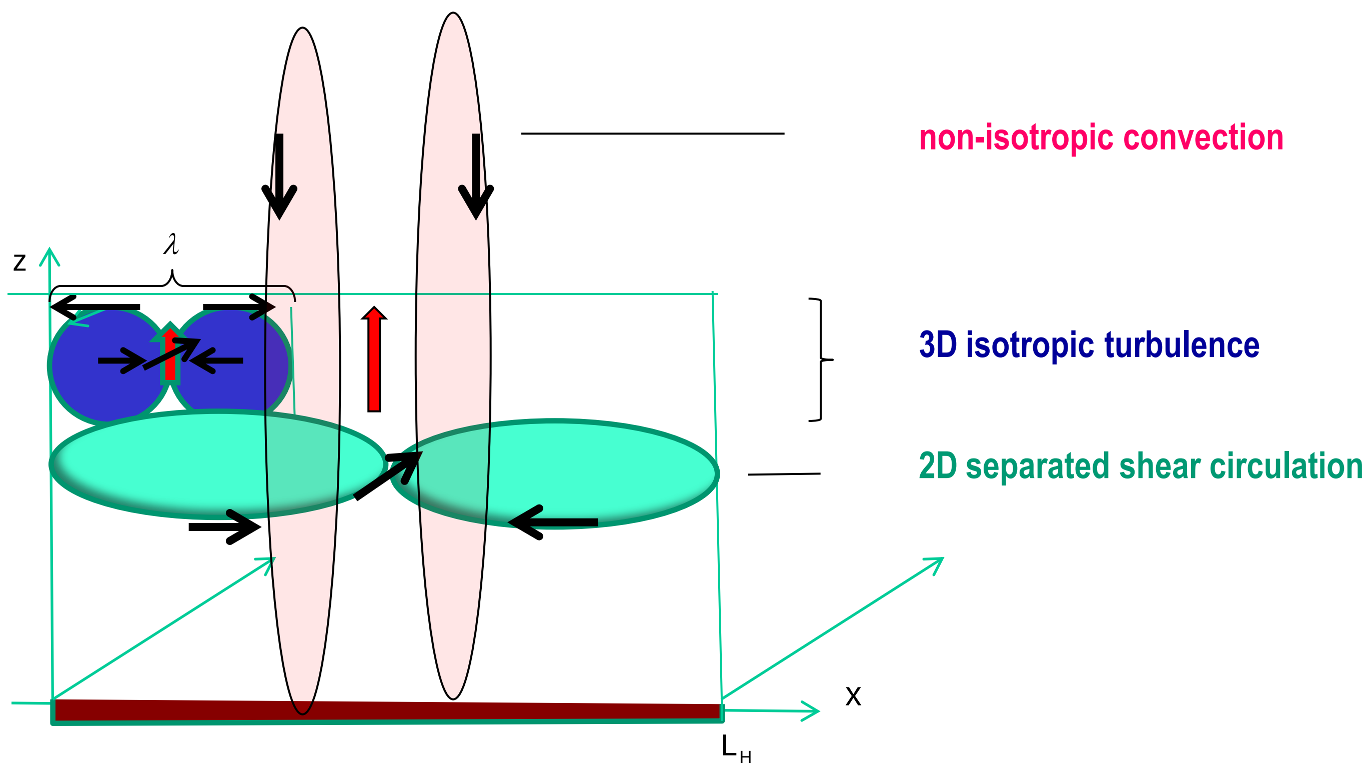
- Inserting the NS-equation, **Pr** again can be split in contributions **S** and **T** from momentum transport (rel. to shear and turbulent stress respect.), **B** from buoyancy (related to temperature fluctuations) and others of minor significance [which is similar to inserting a Bernoulli-equation for pressure]

➢ For (isotropic) turbulence only **T** is parameterized (according to Rotta), which is no longer valid for **all SGS modes above the BL** or **within a convective cloud regime**

Investigations of realizability and the so called stability functions

Review of closed 2-nd order equations in M/Y hierachy:	Ekatarina M.,	Dimitrii M.
Revision of the existing level 2.5 formulation:	Ines C.	Matthias R.

<u>The problem of a consistent parameterization for all SGS:</u>



- Discretized filtered budget equations contain *additional* ***2-nd order moments***
- **Closure assumptions can't be general valid** by definition

➢ **Scale separation** with adapted assumptions for scale classes

➢ Related with new **scale transfer terms** in budget equations for 2-nd order moments of turbulence

➢ Missing transfer terms cause **underestimation of pure turbulence** and **realizability problems**

Realizability problems of the M/Y schemes of level < 4:

- closed turbulent budgets for
  - trace of turbulent stress tensor (q^2=2*TKE) : prognostic (level >=2.5)
  - scalar variances: prognostic (level >=3.0)
  - all other 2-nd order moments: diagnostic source term equilibrium
- diagnostic equations build system for at least 15 2-nd order moments
  - Horizontal BLA -> Reduction to 2 equations for **stability functions S^M and S^H**
- Simultaneous solution of all equations only for level 2.0 scheme (all equations diagnostical)
  - ➢ quadratic system
- Iterative time step solution for level 2.5 and 3.0 (operational TURBDIFF is level 2.5).

prognostic equation for q = fnc (q0 , mean vert. gradients, S_0^M , S_0^H **)**

linear system for S^M and S^H dependent on q and mean gradients

Implicit vertical diffusion update for mean vert. gradients dependent on q , S^M and S^H

SC-solution with explicit TKE / Linear system:

$$r_p = \left(\frac{\bar{p}}{p_r}\right)^{\frac{R_d}{c_{p_d}}} \qquad r_v := 1 + \left(\frac{R_v}{R_d} - 1\right)\hat{q}_v - \hat{q}_c \qquad T_c = \frac{L_c}{c_{p_d}} \qquad \alpha := \partial_T q_{vs}(\hat{T}) \qquad r_T := \frac{1}{1+\alpha T_c}$$

saturation fraction

$$\vartheta_v := r_T \cdot \left(r_v \vartheta_c - \frac{R_v}{R_d}\hat{T} \right) \qquad \vartheta_w := \left(\frac{R_v}{R_d} - 1\right)\cdot \hat{\theta} + \frac{r_c}{r_p}\cdot \vartheta_v \qquad r_\theta := r_v - r_c \alpha \vartheta_v$$

$$F_T^M := (\partial_z \hat{u})^2 + (\partial_z \hat{v})^2 \quad + F_C^M \qquad F^H := \frac{g}{\hat{\theta}_v}\cdot\left(\vartheta_w \partial_h \hat{q}_w + r_\theta \partial_h \hat{\theta}_w\right) \qquad \frac{1}{\ell(z)} \approx \frac{1}{\kappa z} + \frac{1}{\ell_m} + a_{stab}\frac{\sqrt{F^H}}{q}$$

normal to grid scale surface **additional shear** normal to horizontal surface

---

$$\boxed{\partial_t\left(\frac{1}{2}\bar{\rho} q^2\right) + \partial_z\left[-\bar{\rho}\,\ell S^q q \partial_z\left(\frac{1}{2}q^2\right)\right] = \bar{\rho} q \ell \cdot \left[r^M S^M F_T^M - S^H F^H\right] - \frac{q^3}{\alpha^{MM}\ell}} \rightarrow G_T^M := \frac{\ell^2}{q^2}\cdot F_T^M \geq \mathbf{0} \qquad G^H := \frac{\ell^2}{q^2}\cdot F^H$$

$$\overbrace{\left[\frac{1}{\alpha^H} + \left(3 r^H \alpha^{HH} + 12\alpha^M\right)\cdot G^H\right]}^{=:a_{HH}} \cdot S^H + \overbrace{6 r^M \alpha^M G_T^M}^{=:a_{HM}} \cdot S^M = 1 - 3c^H =: b_H$$

$$\underbrace{\left[\left(9 r^H \alpha^H + 12\alpha^M\right)\cdot G^H\right]}_{=:a_{MH}} \cdot S^H + \underbrace{\left[\frac{1}{\alpha^M} + 9 r^M \alpha^H G_T^H + 6 r^M \alpha^M G_T^M\right]}_{=:a_{MM}} \cdot S^M = 1 - 3c^M =: b_M$$

SAI within roughness layer

$$\alpha^M = 0.92, \quad \alpha^H = 0.74, \quad c^M = 0.08, \quad c^H = 0.0, \quad \alpha^{MM} = 16.6, \quad \alpha^{HH} = 10.1 \qquad r^\phi := \Gamma\cdot\left(1 + \frac{k^\phi}{K^\phi}\right) \approx 1$$

$$S^H = \frac{b_H a_{MM} - b_M a_{HM}}{a_{HH} a_{MM} - a_{HM} a_{MH}} \qquad S^M = \frac{b_M a_{HH} - b_H a_{MH}}{a_{HH} a_{MM} - a_{HM} a_{MH}}$$

- The main problem:

i. very stable stratification:

- Level 2.0: **no solution** for super-critical Ri-Numer
- Level 2.5, 3.0: if only sink-terms in TKE-equation: q -> 0: **singularity**

Remedies: **+ considering posit. def. scale transf. terms (for all schemes)**

+ pos. def. implicit solution of prognostic TKE equation

ii. increasing turbulence (change from stable to unstable stratification)

- Level 2.5, 3.0: rapidly increasing stability functions:
  - at least non-converging time step iteration (oscillations, sudden peaks)
  - Or even a possible **singularity**

Remedies: **+ ideal scale separation of turbulence (can only be approximated)**

+ smoothing numerical solution

+ regularization (artificial or semi-physical extensions to allow for stable solutions for arbitrary states of the system)

The additional and (modified) shear terms:

- Additional shear terms are marked by F_C^M in the **total shear term** $r^M F_T^M := (\partial_z \hat{u})^2 + (\partial_z \hat{v})^2 + F_C^M$
- They are due to:
  - **horizontal isotropic** turbulent shear
  - additional shear by non-turbulent SGS circulations (as a consequence of scale separation of turbulence)
    - **separated horizontal shear modes**
    - **wake eddies** (due to SSO drag)
    - **convective vertical currents**

    non-turbulent production = scale transfer towards TKE

    $$P_C^{SKE}(q_C, L_C, \cdots) \approx \frac{q_c^3}{\alpha_c^{MM} L_C}$$
  - Laminar and roughness layer modifications (e.g. form drag) effects: r^M r^H
- They **are positive definite** and **neither dependent on** ℓ **nor on q**
- They prevent turbulence from **"dying"** in the absence of vertical shear and negative buoyancy (stable stratification)
- They make the turbulent scheme **realizable**, if turbulent closure assumptions are not valid for the given resolution
- They can help to get the set of GS parameterizations **more consistent and thus more realistic**
- They can help to **avoid numerical security measures**, which are due to singularities or a non stable numeric
  - possibly **no minimal diffusion coefficients**
  - possibly **no additional numerical horizontal diffusion**

Positive definite solution of prognostic TKE-equation:

VDif and optionally also HDif

optional vertical smoothing controlled by **'frcsmot'**

$$\boxed{\frac{q^2-q_0^2}{2\cdot\Delta t} \approx \left[Adv(q_0)+Dif(q_0)+\ell\cdot q\cdot\left(S^M r^M F_T^M - S^H F^H\right)\right]\cdot q - \frac{q_0}{\alpha^{MM}\ell}q^2}$$

$$\boxed{S_0^{M,H} = S^{M,H}}$$

$$\frac{1}{\tau} := \frac{1}{2\Delta t} + \frac{q_0}{\alpha^{MM}\ell} \qquad q_1 := \frac{\tau}{2}\cdot\left[Adv(q_0)+Dif(q_0)+\ell\cdot\underbrace{\left(S_0^M F_T^M - S_0^H F^H\right)}_{>'frcsecu'\cdot R_f^c\cdot F_T^M}\right] \qquad q_2^2 := \tau\frac{q_0^2}{2\Delta t} \geq 0$$

$$\boxed{q_0 = q} \qquad \boxed{t = t_0 + \Delta t} \qquad \boxed{S^{M,H} = 'stbsmot'\cdot S_0^{M,H} + (1-'stbsmot')\cdot S^{M,H}}$$

$$\boxed{q = q_1 + \sqrt{q_1^2 + q_2^2} > 0}$$

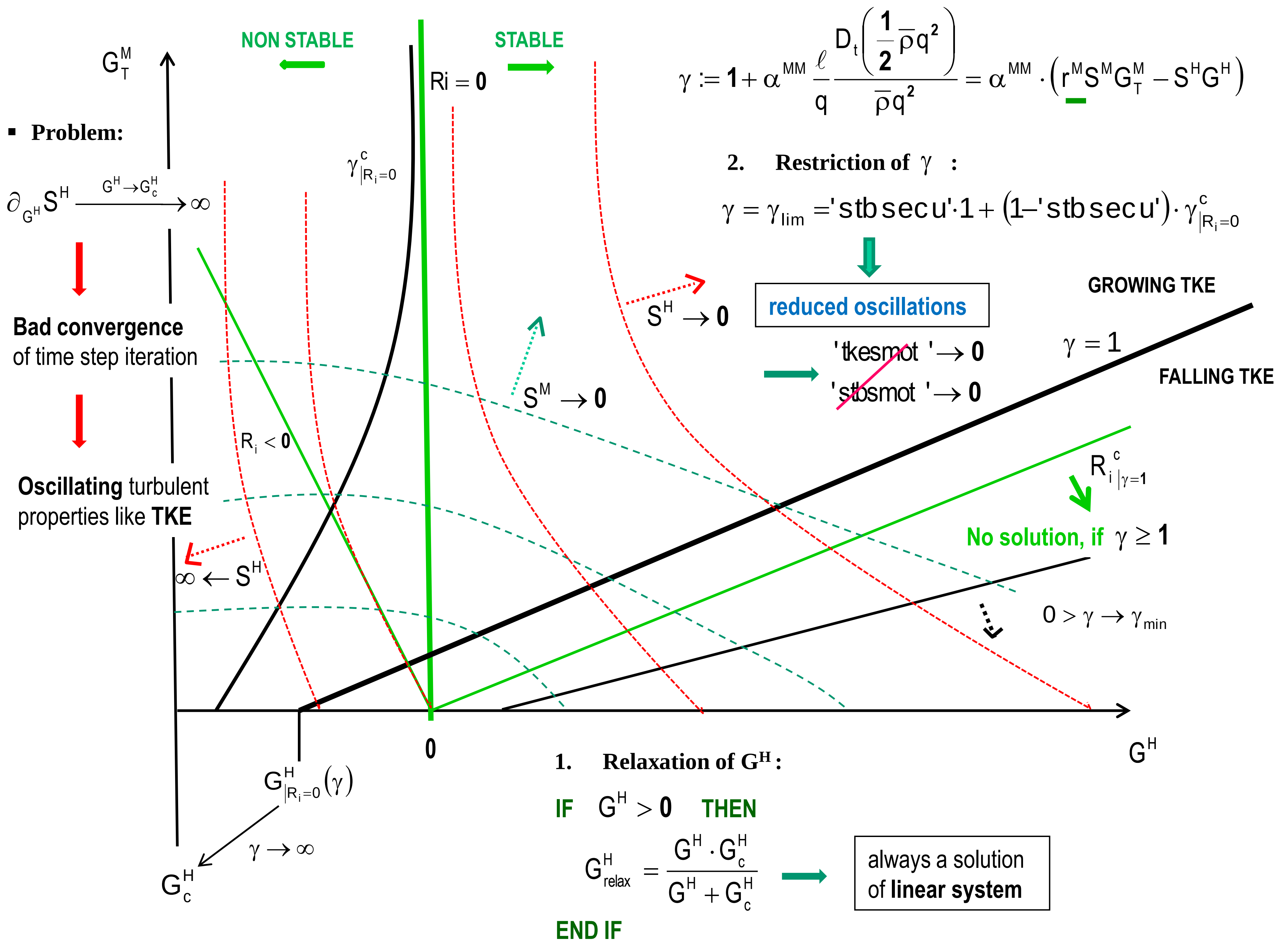
always a positive solution of TKE equation

$$\cancel{'frcsecu' \rightarrow -\infty}$$
$$\cancel{'tkesecu' \rightarrow 0}$$

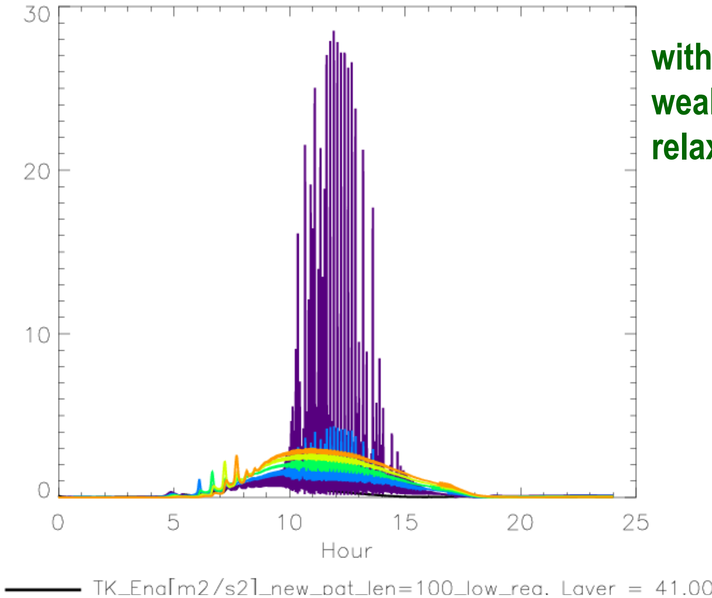
$$\frac{\ell^2}{q_c^2}\left(S^M F_T^M - S^H F^H\right) = \gamma^c_{|R_i=0} = \frac{\alpha^H\left(1-3c^M\right)}{f^H(1)}$$

$$\boxed{q = MAX\left\{'tkesecu'\cdot'vel\_min', 'tkesecu'\cdot q_c, 'tkesmot'\cdot q_0 + (1-'tkesmot')\cdot q\right\}}$$

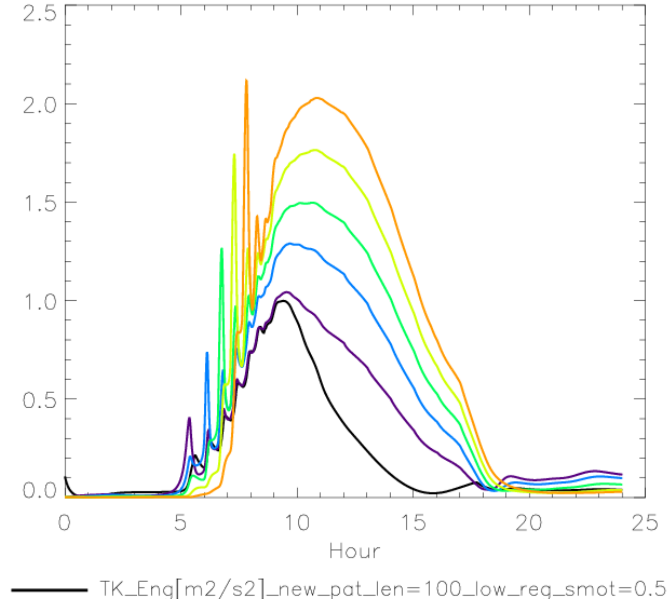
Calculation of stability functions : S^M, S^H



NON STABLE
STABLE
G_T^M
$\gamma := 1 + \alpha^{MM} \frac{\ell}{q} \frac{D_t\left(\frac{1}{2}\overline{\rho} q^2\right)}{\overline{\rho} q^2} = \alpha^{MM} \cdot \left(r^M S^M G_T^M - S^H G^H\right)$
Ri = 0
▪ Problem:
$\gamma^c_{|R_i=0}$
$\partial_{G^H} S^H \xrightarrow{G^H \to G^H_c} \infty$
2. Restriction of γ :
$\gamma = \gamma_{lim} = \text{'stbsecu'} \cdot 1 + (1 - \text{'stbsecu'}) \cdot \gamma^c_{|R_i=0}$
reduced oscillations
GROWING TKE
$S^H \to 0$
Bad convergence
of time step iteration
'tkesmot' $\to 0$
'stbsmot' $\to 0$
$\gamma = 1$
FALLING TKE
$S^M \to 0$
$R_i < 0$
$R^c_{i\,|\gamma=1}$
Oscillating turbulent
properties like TKE
No solution, if $\gamma \geq 1$
$\infty \leftarrow S^H$
$0 > \gamma \to \gamma_{min}$
0
G^H
1. Relaxation of G^H:
$G^H_{|R_i=0}(\gamma)$
IF $G^H > 0$ THEN
$G^H_{relax} = \frac{G^H \cdot G^H_c}{G^H + G^H_c}$
always a solution
of linear system
$\gamma \to \infty$
G^H_c
END IF

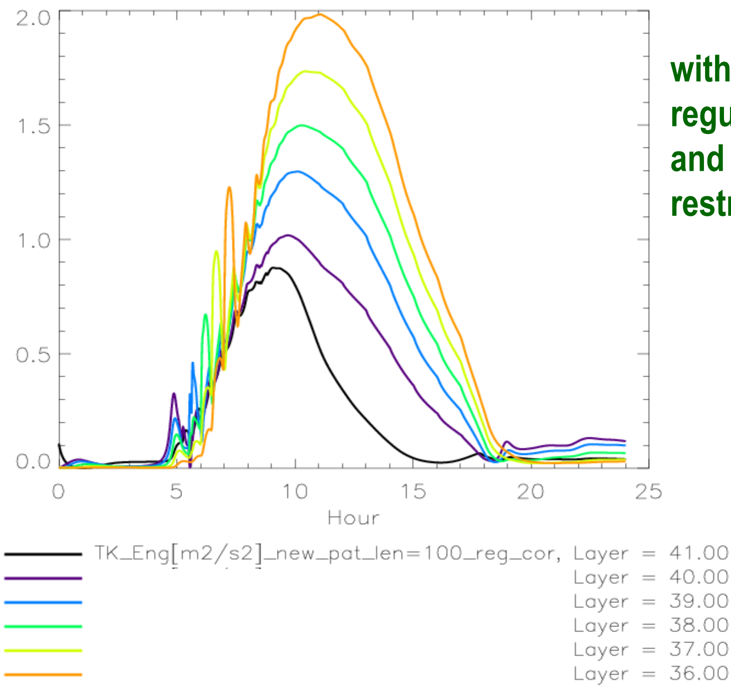


with only weak relaxation

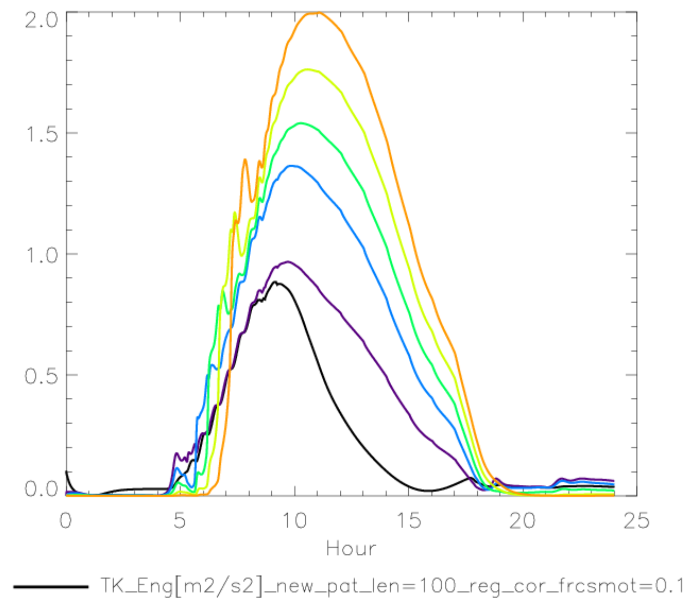


with weak relaxation but strong time step smoothing

similar behavior to ‘gama’-restriction only (operational)



with full regularization and ‘gama’-restriction



with full regularization, ‘gama’-restriction and weak vertical smoothing of forcing functions

Free SC-simulations with new formulations and initial data of a clear sky summer day

Regularization of stability functions:

- **emulate $\partial/\partial t$ and transport terms in Reynolds-stress and scalar-flux equations** (Rodi 1976, Gibson & Launder 1976, Helfand & Labraga 1988) according to:

IF $\gamma > 1$ (growing turbulence) THEN

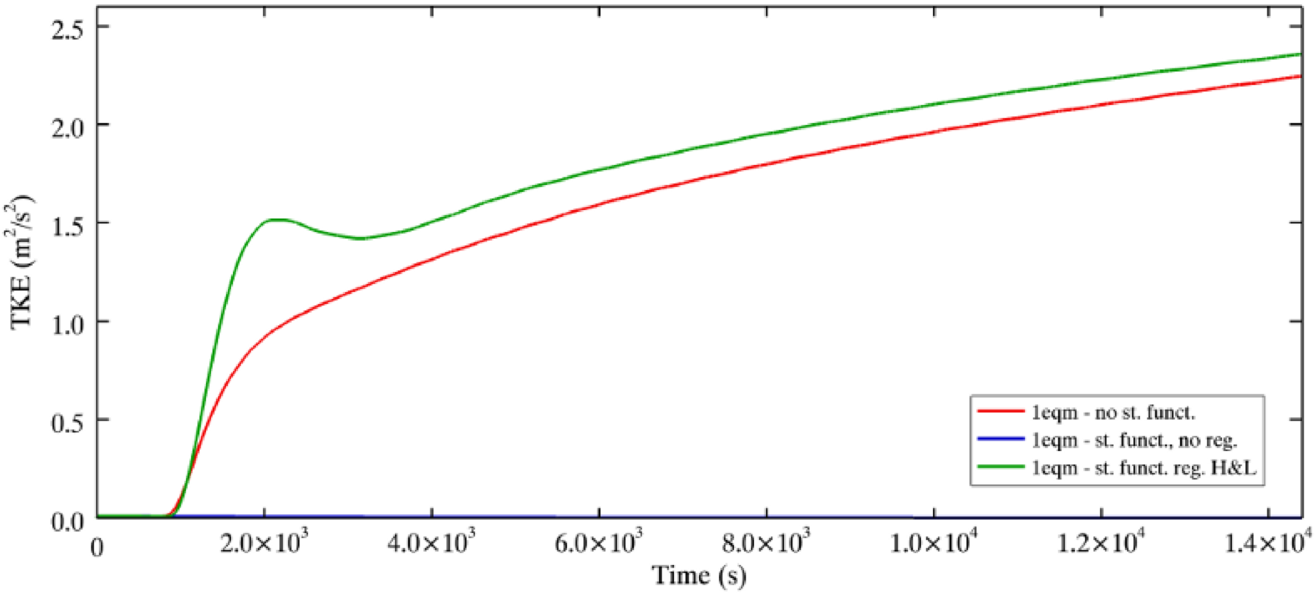
$$(\text{Transp} + \text{Tend})_x/\text{Prod}_x = (\text{Transp} + \text{Tend})_{TKE}/\text{Prod}_{TKE}$$

X stands for moment with diagnostic equations:
Reynolds stress or scalar flux (scalar variances)

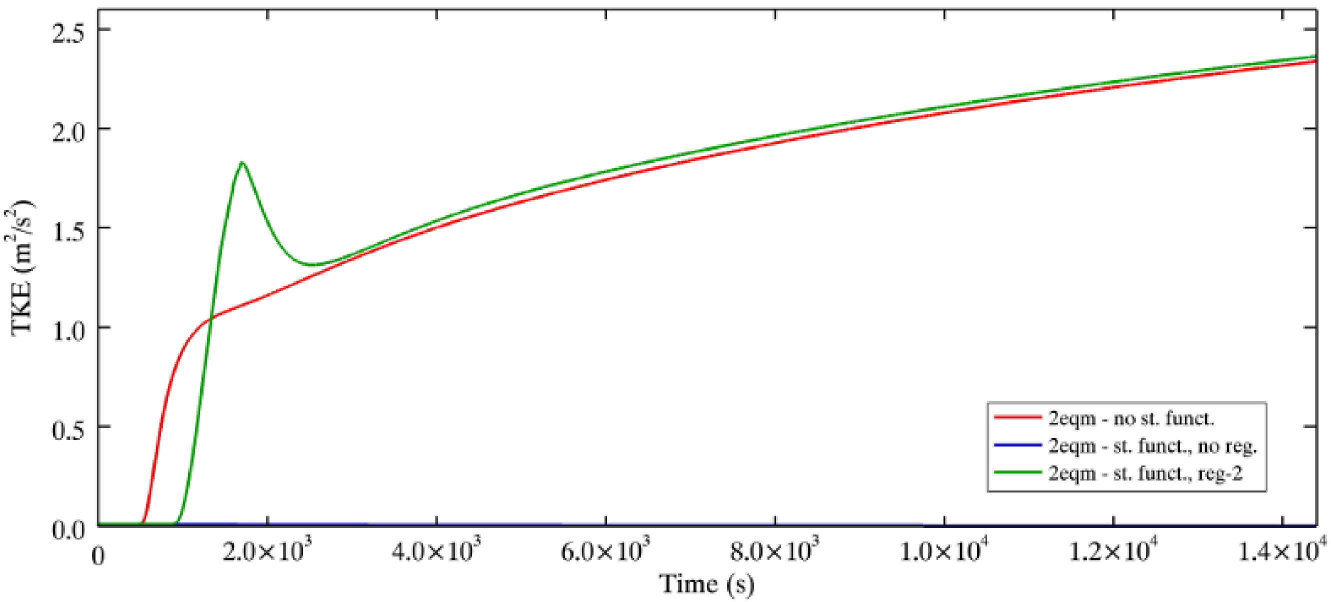
END IF

→
- No singularity possible any longer
- Alternative to relaxation (with some more physical intuition)
- some oscillations or peaks may persist as well)

Regularized Functions, levels 2.5 & 3



Level 2.5



Without stab. functions

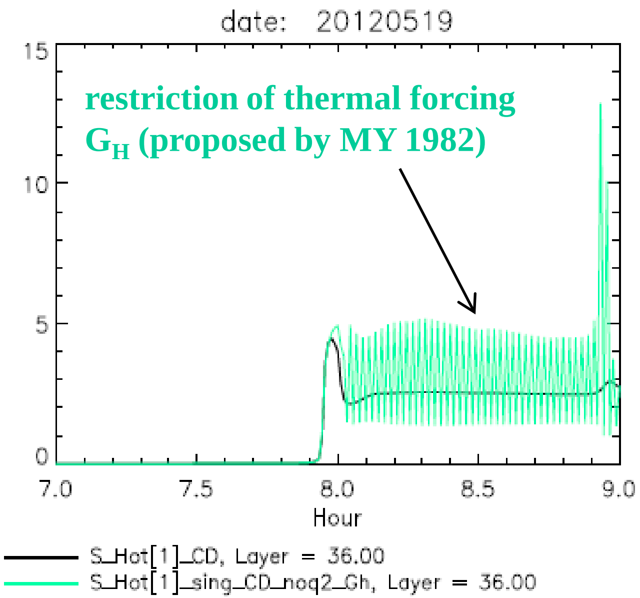
Without regularization

With regularization

Level 3

by Ekatharina M. and Dimitrii M.

- **Effect of potential singularity of the MY-level-2.5 scheme for growing turbulence and its interception gained form SC experiments (by Ines Cerenzia):**



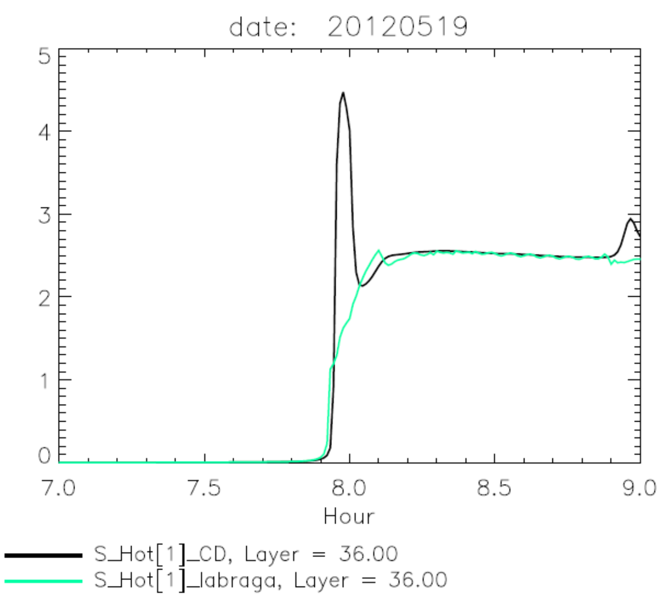
black line:

operational method by formulating the stability parameters as functions of deviation from TKE-equilibrium γ and Ri for non-stable situations (according to Raschendorfer)

green line lower right:

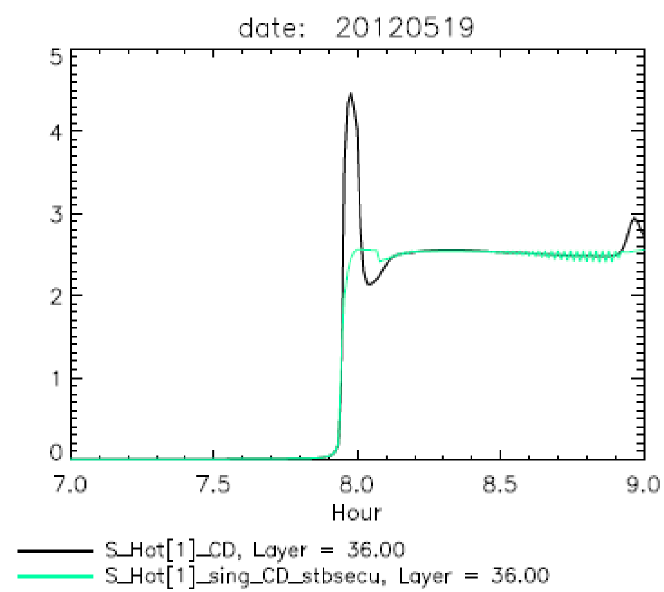
modification of operational method as implemented in new TURBDIFF (according to Raschendorfer)

S_Hot: stability parameter for heat flux



green line lower left:

account for deviation from source term equilibrium for 2-nd order moments apart form TKE (according to Helfand et Labraga 1988)



Implementation of 3D-components into TURBDIFF

Numerical formulation of horizontal diffusion and advection:

Jochen Förstner, Michael Baldauf, Uli Blahak, Oli Fuhrer

(already present before)

General aspects and modifications in TURBDIFF:

Matthias Raschendorfer

Adaptions of COSMO code and special aspects of TKE-advection:

Uli Blahak

DWD

3D-solution for isotropic turbulence:

- Complete linear system of all 2-nd order equations needs to be solved without BLA in principal

- Simplification for isotropic turbulence

$$\overline{\rho\phi_k'' v_j''}^{*} = \begin{cases} \overline{\rho\phi_k''v_j''} \approx -\bar{\rho} K^H \partial_j\hat{\phi}_k & ,\ \phi_k \ \text{is a scalar} \\ \overline{\rho v_i''v_j''} - \delta_{ij}\bar{\rho}\cdot\left(\frac{q^2}{3} + K^M\frac{2}{3}\cancel{\nabla\cdot\hat{\underline{v}}}\right) \approx -\bar{\rho} K^M\left(\partial_i\hat{v}_j + \partial_j \hat{v}_i\right) & ,\ \phi_k = v_i \end{cases}$$

trace-less tensor

$$\overline{\Delta Q^{v_i}_{\underline{\lambda}}\left(\underline{\phi}'',p'\right)} = -\overline{\partial_i' p'} - \partial_i\left[\bar{\rho}\cdot\left(\frac{q^2}{3}+K^M\frac{2}{3}\cancel{\nabla\cdot\hat{\underline{v}}}\right)\right] \leftarrow$$

form drag

kinematic pressure gradient

$$q^2 = \frac{1}{\bar{\rho}}\sum_{i=1}^{3}\overline{\rho v_i''^2}$$ 2 TKE

$$Q^{\mathbf{v}\cdot\mathbf{v}}_{3DS} = -\sum_{i,j}\overline{\rho v_i''v_j''}\,\partial_i\hat{v}_j \approx \bar{\rho}K^M\frac{1}{2}\sum_{i\neq j}\left(\partial_i\hat{v}_j+\partial_j\hat{v}_i\right)^2 - \sum_i\overline{\rho v_i''^2}\partial_i\hat{v}_i$$

$$\approx \bar{\rho}K^M\left[\underbrace{\frac{1}{2}\sum_{i\neq j}\left(\partial_i\hat{v}_j+\partial_j\hat{v}_i\right)^2 + 2\sum_i\left(\partial_i\hat{v}_i\right)^2}_{F^M_{3D}\leftrightarrow F^M} - \frac{2}{3}\cancel{\left(\nabla\cdot\hat{\underline{v}}\right)^2}\right] - \bar{\rho}\frac{q^2}{3}\cancel{\nabla\cdot\hat{\underline{v}}}$$

- Incompressible, outside roughness layer, always neutral stratification, no scale interaction:

$$\alpha^{MM}\ell^2 d\,F^M_{3D} \approx q^2 \qquad \left.\begin{matrix} K^M \\ K^H \end{matrix}\right\} \approx \ell\cdot\begin{Bmatrix} d \\ b \end{Bmatrix}\cdot q \approx \ell^2\cdot\begin{Bmatrix} d \\ b \end{Bmatrix}\cdot\sqrt{\alpha^{MM}\cdot d\cdot F^M_{3D}}$$

Problem: **Anisotropy of horizontal and vertical grid scales**

Convergence of approximations:

– Small grid scales (containing only isotropic shear driven turbulence): 3D-flux gradient form is appropriate:

2-nd order SC closure scheme for vertical direction ⟶ **Pure vertical fluxes of isotropic scheme, driven by shear only**

– Large grid scales (driven by vertical shear and buoyancy): Horizontal BLA is valid:

Horizontal flux terms of isotropic scheme ⟶ **Not present horizontal fluxes in 2-nd orderscheme**

➡ **Horizontal and vertical domain may be treated separately for more general (local isotropic turbulence (being in accordance with closure assumptions of the 2-nd order SC scheme)**

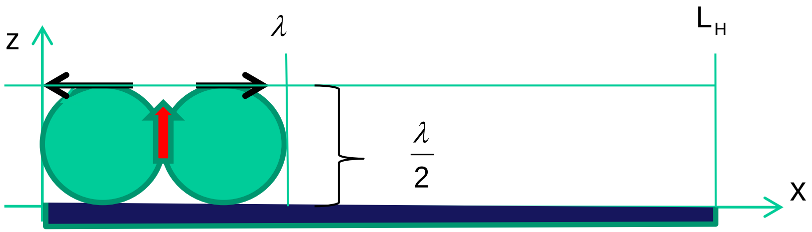
'tkv(m,h)': **valid for vertical direction**

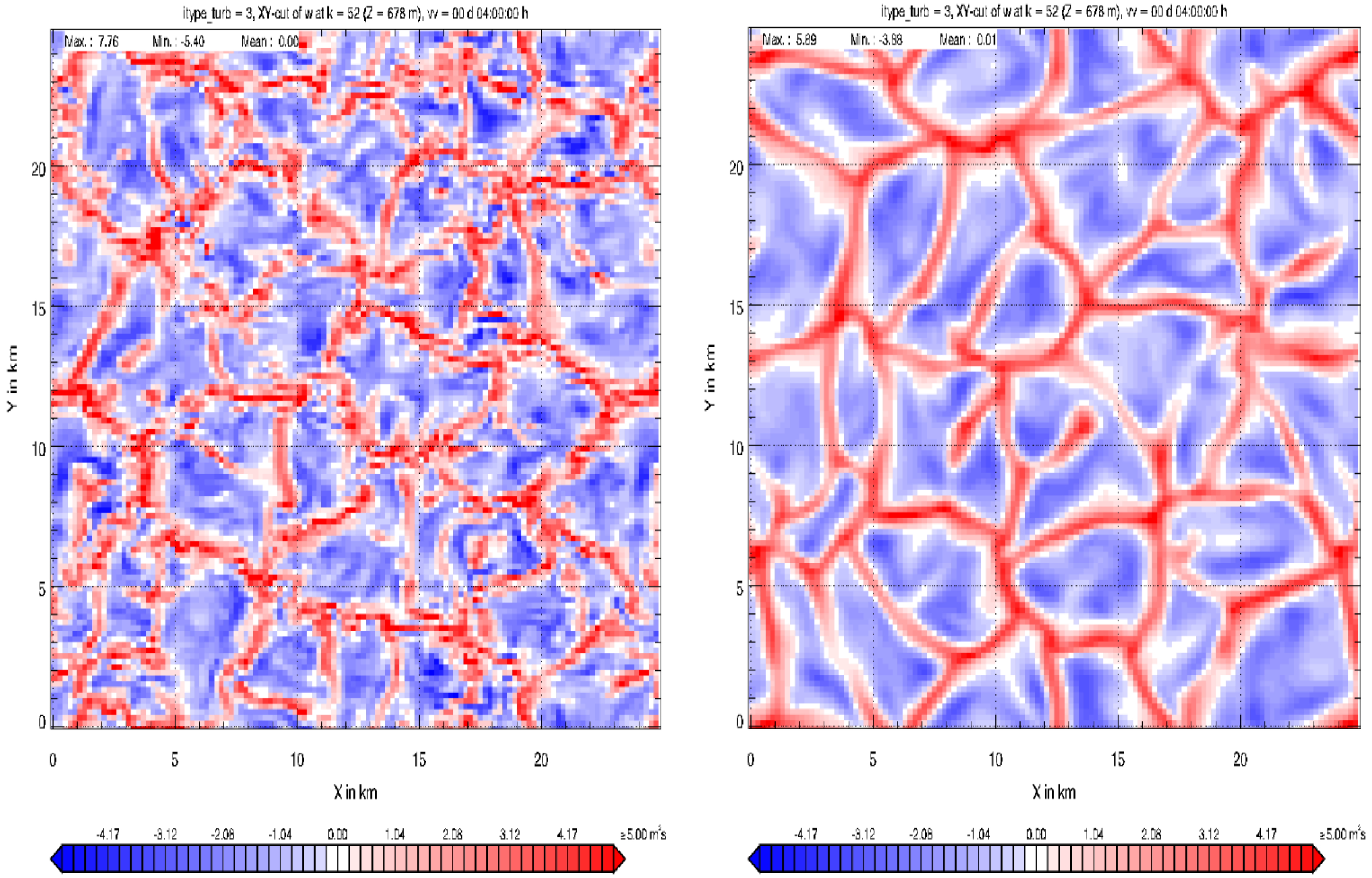
'tkh(m,h)' : **valid for horizontal directions**

Turbulent length-scale needs to be restricted proportional to horizontal grid scale L_H **:**

$$\ell = \kappa \cdot \mathrm{MAX}\left\{\frac{z \cdot z_m}{z + z_m}, \frac{L_H}{2}\right\}$$

z_m: maximal asymptotic turbulent distance





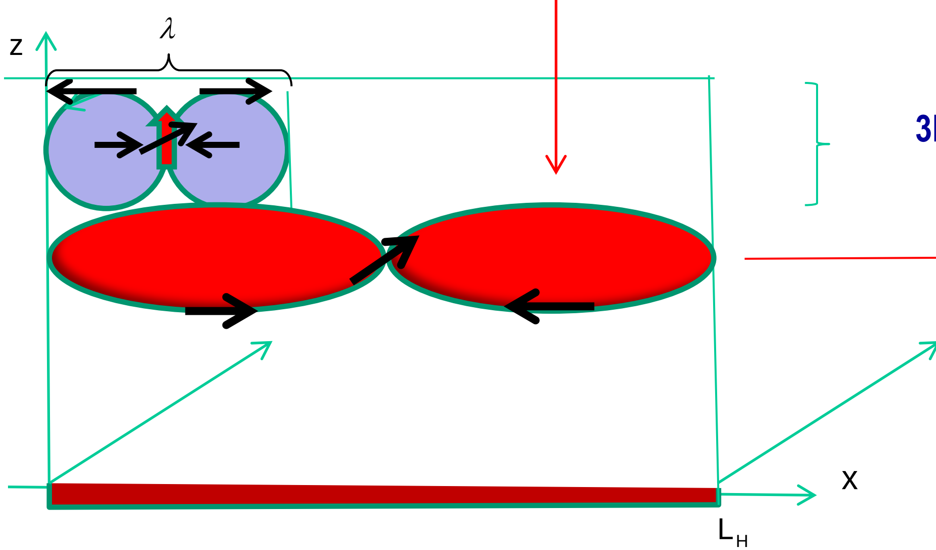
Test of horizontal diffusion (and TKE advection) for itype turb=3 done by U. Blahak:
LES-run with dX = 200m, heating by 300 W/m2
Vertical velocity after 4 h forecast time
Left: 1D-turbulence (and no TKE-advection), Right: 3D-turbulence (and TKE-advection)

Separated shear mode:

– Large SG scales may be completely non-isotropic:

- ➢ **Closure assumptions are no longer applicable**
- ➢ **Formal separation into**
  - ○ **Small scale turbulence (in accordance with closure assumptions)**
  - ○ **Larger scale circulations (requiring different closure assumptions and scale parameters)**
    - i. 3D-motions (like SSO wakes)
    - ii. Vertically accelerated motions with dominant vertical extent (SC-motions like convection)
    - **iii. Vertically damped motions with dominant horizontal extent (separated horizontal shear modes)**

controlled by 'itypeshear'

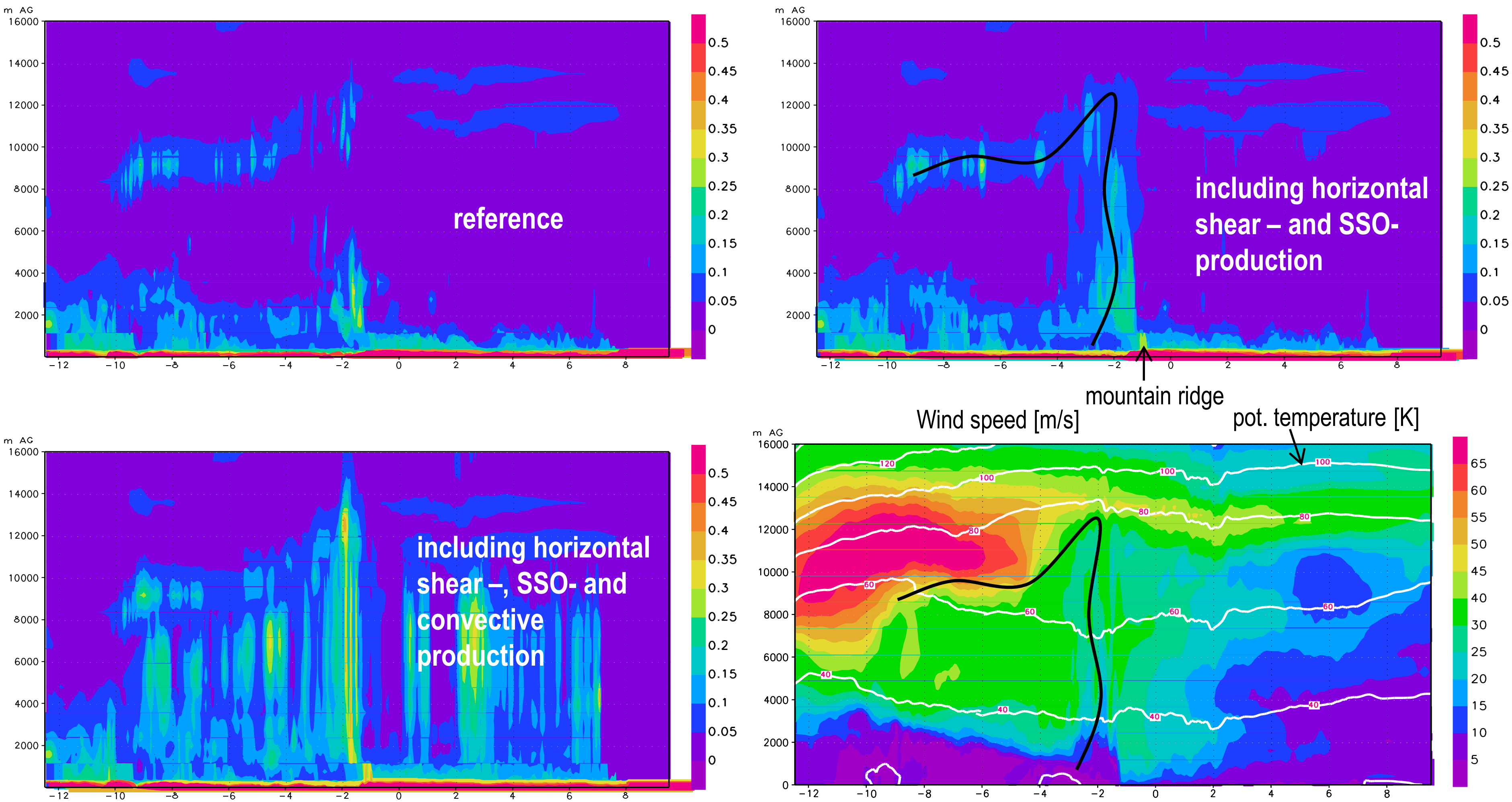


3D isotropic turbulence

2D separated shear circulation

- **Dependent on L_H**
- **Specific diffusion coefficients**
- **Much more effective horizontal mixing compared to pure turbulence**

pow_1/3 (eddy dissipation rate (EDR) [m^2/s^3])



COSMO-US: cross section across frontal line and Appalachian mountains

st_time=00z01may2010 pr_hour=18hr – 19hr

TKE-advection for TURBDIFF:

(by Uli Blahak)

- Implicit time integration scheme in itype_turb = 3, provisional value:

$$q^*_{n+1} = \mathrm{fct}\left(q_n, q^*_{n+1}, \mathrm{TEND}(q_n), \Delta t\right)$$

- Subsequent smoothing by exponential time filter (a = „tkesmot“)

$$q_{n+1} = (1-a)q^*_{n+1} + aq_n$$

- **Problem: if a > 0, transport of TKE is decelerated!**
- **Therefore:** first provisional value, advection only:

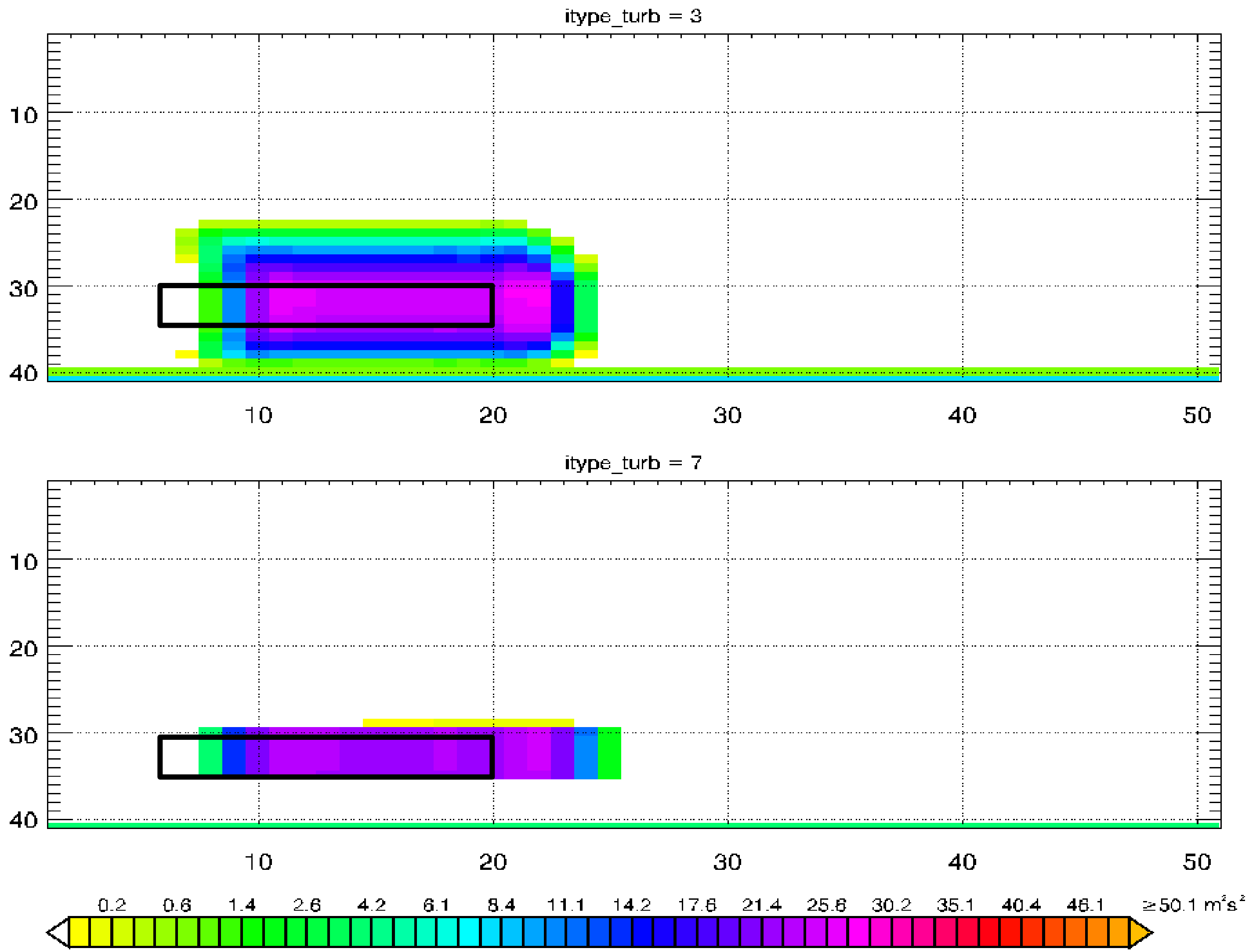
$$q^{**}_{n+1} = q_n + \mathrm{TEND}_{adv}(q_n)\Delta t$$

- Implicit scheme with advected value, next provisional value:

$$q^*_{n+1} = \mathrm{fct}\left(q^{**}_{n+1}, q^*_{n+1}, \mathrm{TEND}(q_n) - \mathrm{TEND}_{adv}(q_n), \Delta t\right)$$

- Subsequent smoothing only on the non-advected part:

$$q_{n+1} = (1-a)q^*_{n+1} + aq^{**}_{n+1}$$



Test of the TKE advection for itype turb=3 and 7 done by U. Blahak:
X-Z-cut along the 2D flow, U = 10 m/s, stable stratication (ICAO-standard atmosphere).
40 levels up to 22 Km, dX = 1.1 Km, dt = 10 s
after 2 minutes starting with the not filled TKE-box (40 m2/s2)

Status of 3D-extensions for TURBDIFF :

- **Already implemented into COSMO-5.1**:
- ➢ All modifications can be (de)activated
- ➢ First tests of the implementations by U. Blahak
- ➢ Main effects are expected for higher horizontal resolution, around steep orography or within frontal zones (large horizontal gradients)
- ➢ Positive impact possible for EDR-forecast (used by aviation)

- **Verification, Testing:**
  - COSMO-1: Only TKE-advection (Meteo-Swiss): rather neutral!
  - LES-tests: Much more realistic structures, with horizontal shear and horizontal diffusion
  - ICON: reduction of RMSE when activating separated horizontal shear (including Ri-number dependent empirical modification by G. Zängl)

- **Remaining work:**
  - Fixing a scaling factor for the separated horizontal shear mode and further generalization (e.g. **turbulent entrainment**)
  - Implement the **adaption of the turbulent length scale** in case of grid boxes with a smaller horizontal extent compared to the surface distance
  - Testing impact of TKE-advection related to CAT-forecast

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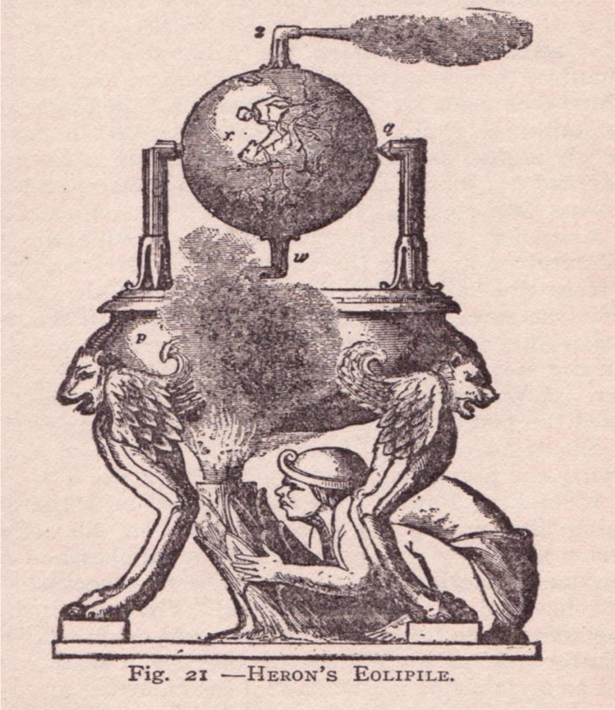
Turb-i-sim: convection, turbulence, and flows over topography



Jürg Schmidli/Steef Böing

Update for COSMO GM – September 2014

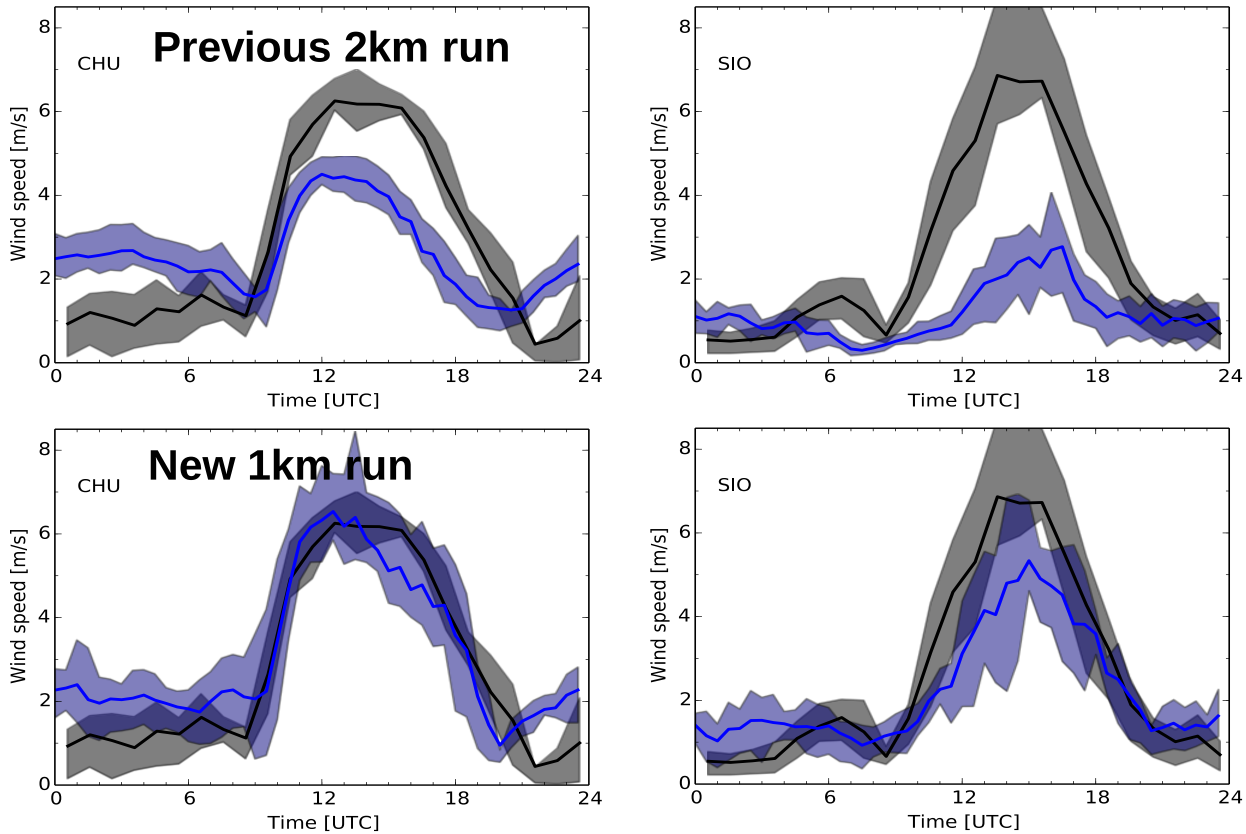
Valley winds
Diurnal cycle of mean wind speed

COSMO 5: setup similar to development version at MeteoSwiss

Chur (Rhein valley) **Sion (Rhone valley)**

observations

simulations

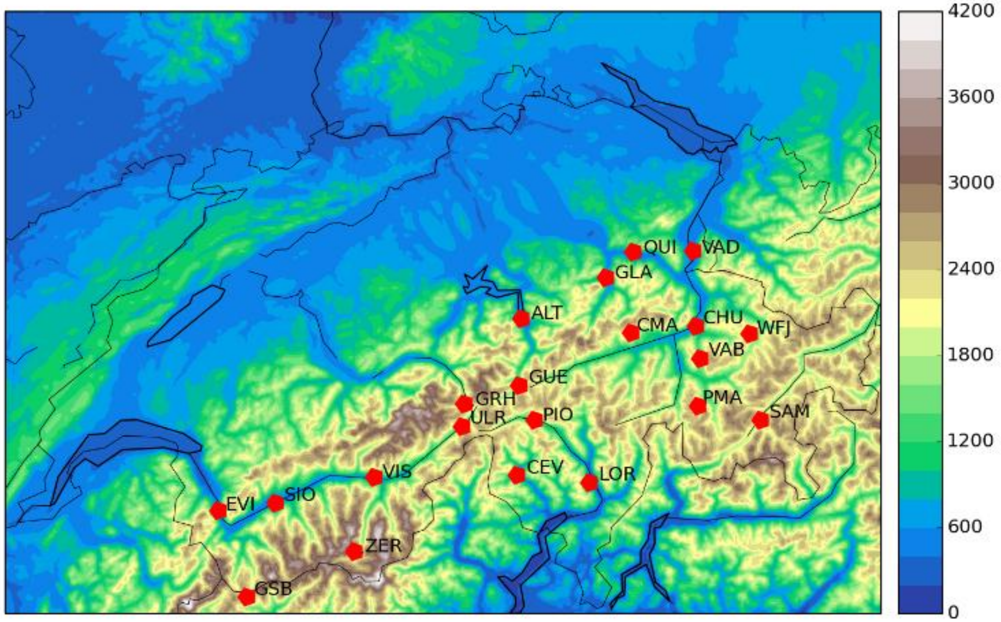


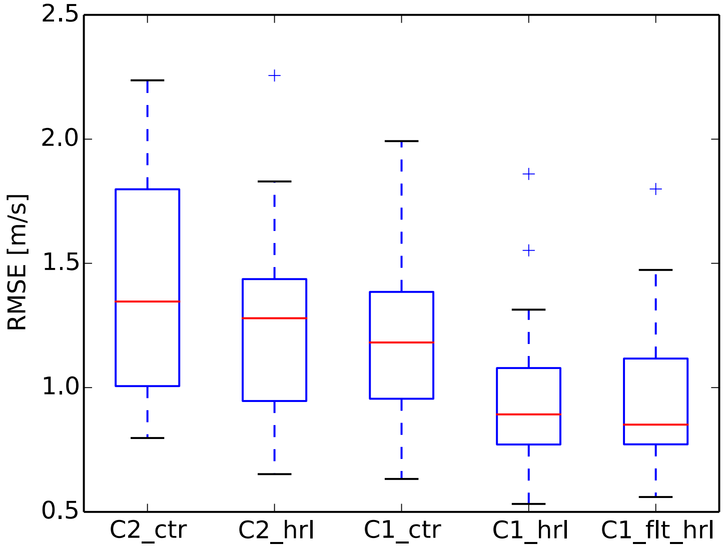
New high-resolution surface and soil data

- Soil initialized from
- 2km climate run (N. Ban)
- ASTER topography (30m)
- GLC2009 land cover
- (300m)
- HWSD soil type (1km)
- Raymond filter for
- topography (cutoff ~5 dx)

Impact of resolution, land surface, and filtering on RMSE of wind speed

“Valley wind” stations
(21 stations, mean maximum wind > 4 m/s)





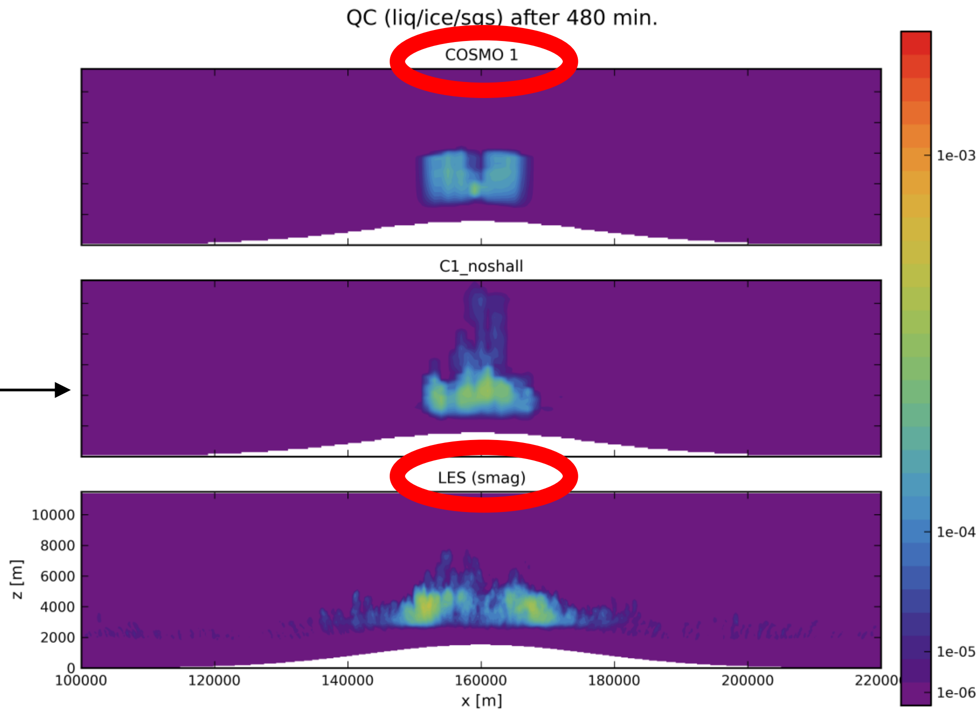
Significant improvement using COSMO-1

- But only with high-resolution surface data
- Further improvements with less filtering of topography
- Excellent skill in major valleys

Systematic comparison of COSMO-1 with COSMO LES

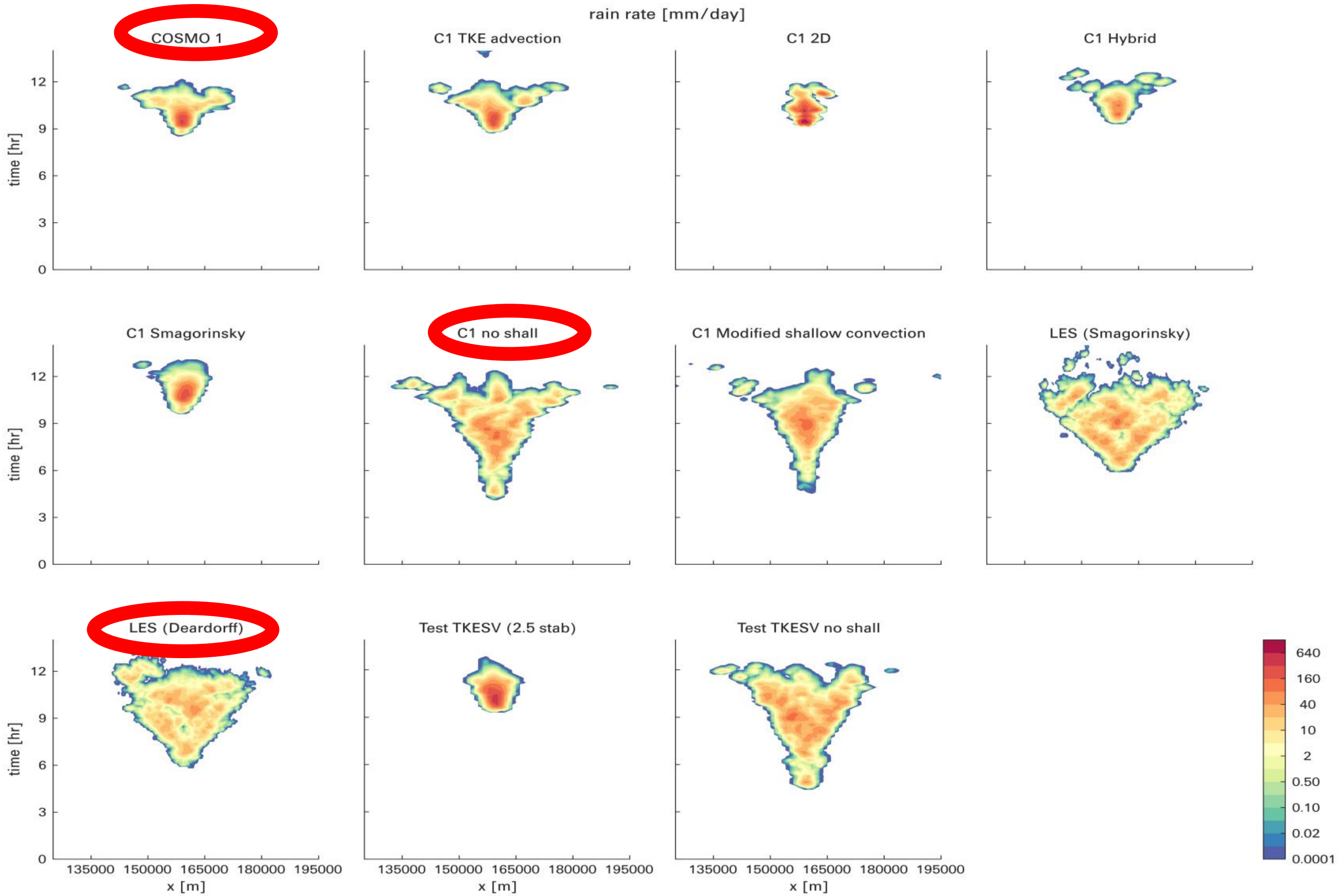
Use **documented cases** to influence of **turbulence and convection parameterization**, compare against **LES (100/200 m, 3D turbulence)**

- ARM SGP (Brown et al 2002: GCSS shallow continental cumulu
- BOMEX (Siebesma et al. 2003: GCSS shallow maritime cumulus)
- Schmidli (2013): slope flows
- Schlemmer et al. (2011): fast initiation of deep convection
- **Kirshbaum (2011): initiation of congestus over topography**



Systematic comparison of COSMO-1 with COSMO LES

Large influence of shallow convection scheme in 1 km simulations on rainfall (case: Kirshbaum, 2011)



Current status and future planning of ConSAT

Matthias Raschendorfer

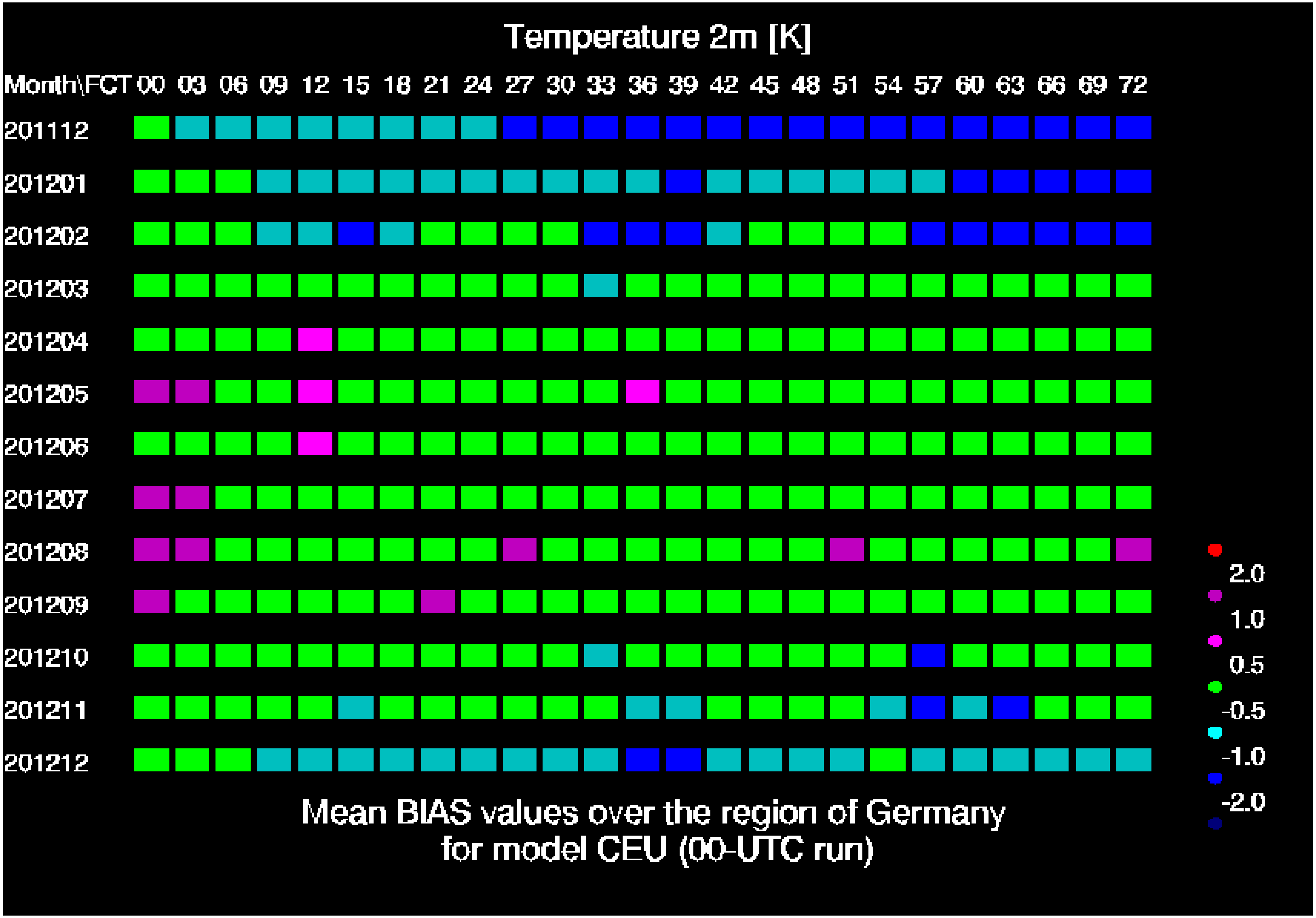
DWD

Main deficiencies of near surface variables in COSMO and some conditional statements:

1) Confirmed positive bias of T_2m during night and underestimation of nocturnal low level jet
   - Perhaps a systematic error in representing the **vertical profile functions during stable situations**
   - Perhaps too strong vertical mixing due to **numerical security measures** (e.g. minimal diffusion coefficient)
2) General negative bias during winter
   - Perhaps successive cooling during winter nights (too less low level clouds?)
   - Perhaps a general problem of interpolation onto 2m-level
3) **During summer too high T_2m maximum (without a SMA) and a too shallow mixing layer**
   - Perhaps too less heat transfer during non-sable stratification
4) Too large mean amplitude of daily soil temperature cycles
   - Overestimation of soil heat flux
5) Near surface values of grid points with large roughness length (in particular mountainous ones) bad in general
   - Too small amplitude in daily cycle of T_2m
   - Too small near surface momentum
   - Sometimes excessive downward sensible heat fluxes at snow-covered grid points with steep orography
   - Missing **vertically resolved roughness layer**
   - Even the definition of near surface variables is a problem

mean Bias of T_2m

december 2011 – december 2012, COSMO-EU



Initial PT:

WP I : Preparation of a **testbed using COSMO-SC** (Single Column model) and COSMO-3D with some test cases reflecting the daily cycle problem: summer case, winter case (with and without snow cover) for 48-h 3D-runs and some (as complete as possible) **data sets form measurement sites** (e.g. Lindenberg, or perhaps San Pietro Capofiume, possibly also a station surrounded by a water surface)

- ✓ COSMO-SC updated to COSMO 5.1
- ✓ COSMO-SC prepared for component testing
- ✓ Data selected from Lindenberg and San Pietro Capofiume (Ce)

WP II : Implementation of **different security limits** (related to the solution of TKE-equation or the calculation of stability functions) in COSMO-SC and performing sensitivity tests and component testing.

- ✓ Reorganization and substantial reformulation of module TURBDIFF
  - SAT and turbulence model CALL common SUBs 'solve_turbulent_budgest' and 'adjust_satur_equil'
  - Allowing treatment of cloud water in in the surface layer (fog)
  - Modified solution of turbulent budgets with more flexible treatment of security limits
  - SC test-runs performed with different combinations of security limits (Ce)

WP III : Implementation of the **modified vertical profile functions** in COSMO-SC and performing test runs in order to estimate the principal behaviour of that measure.

- ✓ Implemented in further test-version and successfully test of functionality within COSMO-SC

WP IV : Performing **COSMO-3D first test runs** with the implemented modifications going along with **detailed diagnostics** and a **documentation** of the resulting SAT-Scheme

- ✓ Test-version (without modified profile functions) ported to COSMO 4.29 and tested (Ce)

COSMO-SCM:

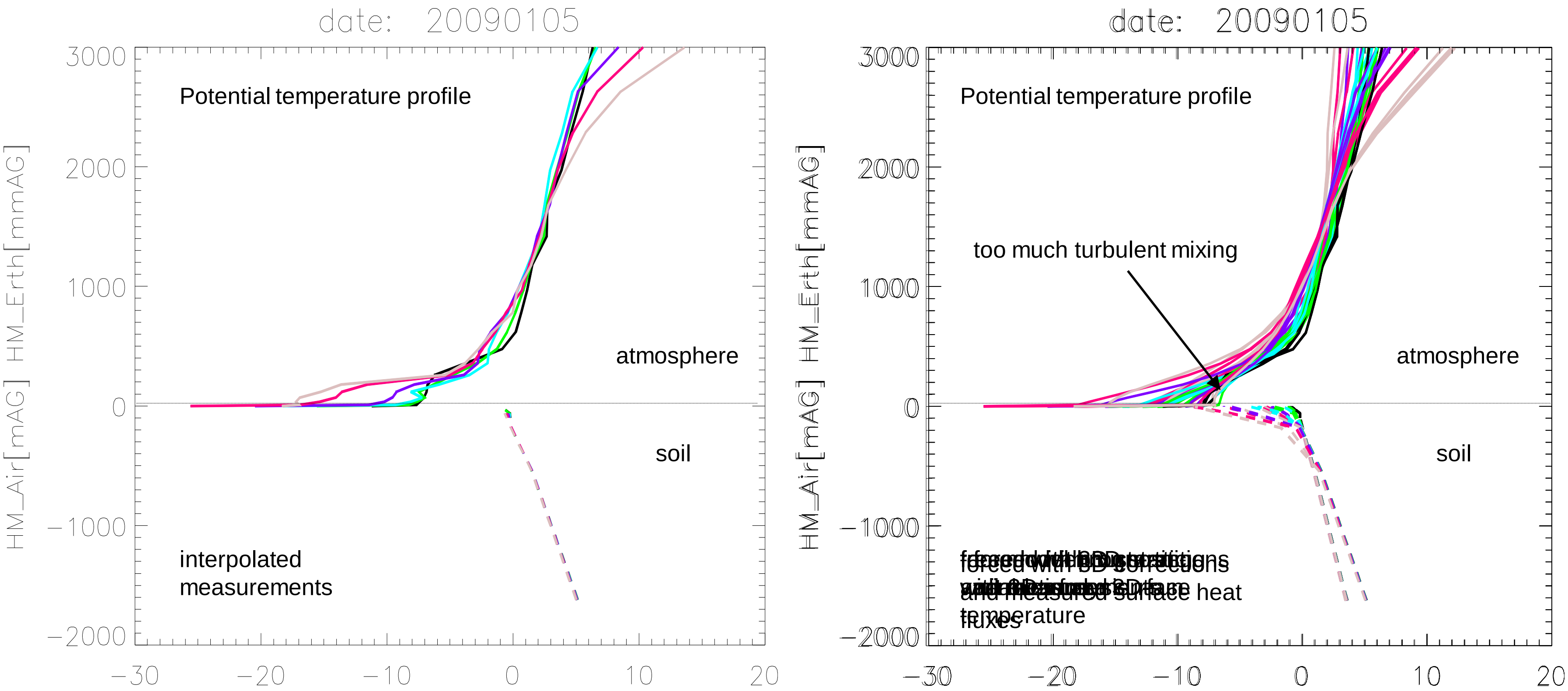
- The SC-framework has been upgraded to COSMO_5.0 (during the visit of Ines Cerenzia) :
  - Various adaptions to the **specific SC-code** mainly due to the TRACER-structure
  - Setting up a **run-script** for complex component testing runs
  - Some minor adaptions to the **main COSMO-code** → **COSMO-5.1**
  - Further adaptions to the **specific MAKEFILE** for compiling COSMO-SCM

Part of WP I: of initial ConSAT

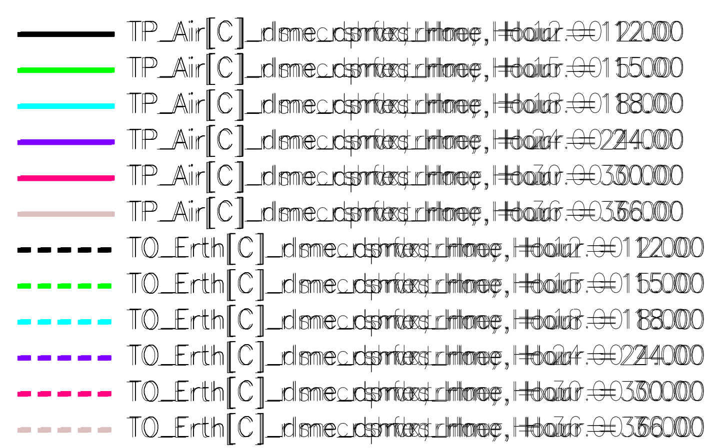
- SC-runs using COSMO-version 5.0 are carried out by workers in the "renewable energy projects" at DWD, by myself and by Ines Cerenzia at ARPA-SIMC.
- The future TURBDIFF-version for COSMO and ICON is being developed within this framework

- **Remaining work:**
  - Specific SC-code as part of COSMO source code administration
  - Automatic MAKEFILE-generation
  - Updated documentation

- **Remarks:**
  - The additional code of the SC framework is comprehensive and can't be inspected completely
  - It has been designed to be a test-bed only and is not optimized with respect to performance and is purely sequential.
  - User support can't be provided yet.



Stable stratification over snow at Lindenberg



Restructured COSMO/ICON TURBDIFF:

- **Content of new module TURBDIFF:**

sub 'turbdiff':

– vertical diffusion for T, qv, qc;
qi and pass. trac., TKE, …

➢ Diffusion tendencies

– turbulence model at atmospheric layers:

➢ TKE, TKV

sub 'turbtran':

– Turbulence model at surface layer (SAT):

➢ transfer resistances

➢ near surface model variables

new subroutines:

– **vert_grad_diff**
  • Flexible treatment of lower boundary condition
  • Non-gradient vertical flux densities included
    → Circulation term (TKE) and moist corrections (T, qv, qc) included
  – prep_impl_vert_diff:
    • save partly inverted tri-diag. matrix for similar variables
  – calc_impl_vert_diff

Common subroutines:

Part of WP II: of initial ConSAT

– **solve_turbulent_budgets**
  • modified solution with more flexible treatment of security limits and smoothing options
    → reduction of artefacts should be possible
  • positive definite solution of TKE-equation possible
– **adjust_satur_equil**
  • allowing treatment of cloud water in in the surface layer (fog)
  • mixed water/ice-phase can be implemented easily

- **Path of new module TURBDIFF:**

COSMO-4.25 (test) → **ICON**

COSMO-4.29 (test)

COSMO-5.2 (test)

TURBDIFF as default scheme (now even preoperational):

- Deactivation of measures with large impact on results
- New interface and Block-data structure
- Complete vertical diffusion with new routines in TURBDIFF
- Outsourced horizontal operations
- Special provisional measures: like stabil. depend. minim. values (of diffusion coefficients and the turbulent velocity scale)

1-st Prolongation :

WP I.1) : Cleaning the current ICON-version of TURBDIFF and implementing this as a common COSMO/ICON test-module into COSMO(-5.2). This includes basic testing of its behaviour, while the provisional stability dependency of minimal diffusion coefficients and the minimal velocity scale (introduced for ICON) is deactivated for the present.

WP I.2) : Testing all modifications (including those that have been not active even in ICON) aiming for an improved common configuration to be included into COSMO(-5.3).

WP II : Introduction of the modified vertical profile functions (already present in a COSMO-SC test-version) into the new common version of TURBDIFF.

WP III : Reformulation of the determination of profile function parameters without employing diffusion coefficients from above the CFL.

WP IV : Implementation of a first attempt to formulate an increased surface shear due to present larger SGS circulations.

WP V : Testing the new implementations within COSMO-SC by means of component testing using selected data from meteorological observatories and within full COSMO-3D runs, as well as final adjustment and documentation of the resulting SAT-scheme.

Time table:

Year:	0	¼	½	¾	1	
WP I.1 :	1,2----1,2					porting ICON-version to COSMO
WP I.2 :		2------ 2				testing not yet active modifications
WP II :		1----1				including modified profile functions
WP III :			1-------1			restricting to CFL diffusion coeffs.
WP IV :				1--------1		implementing increased surface shear
WP V :			2,1----------------2,1			testing new development and docum.

Contributors: 1: M. Raschendorfer (Ra) with 0.4 FTE (task leader)

2: I. Cerenzia (Ce) with 0.4 FTE

Restructured COSMO/ICON TURBDIFF:

- **Remaining work:**

  - Cleaning the ICON version: (mainly technical issues)
  - Interface providing variables in block-data structure and
    - Adaptions to modified subroutine structure
    - Wind components on mass positions
    - "Outsourcing" of calculation of 3D-shear including the treatment of separated horizontal shear
  - Adaptions to modified initialization of turbulent variables
  - Introduction of surface flux densities as global model variables
  - Various adaptions in order to use new generalized routine for vertical diffusion
  - Debugging and Testing

WP I.1 of prolonged ConSAT

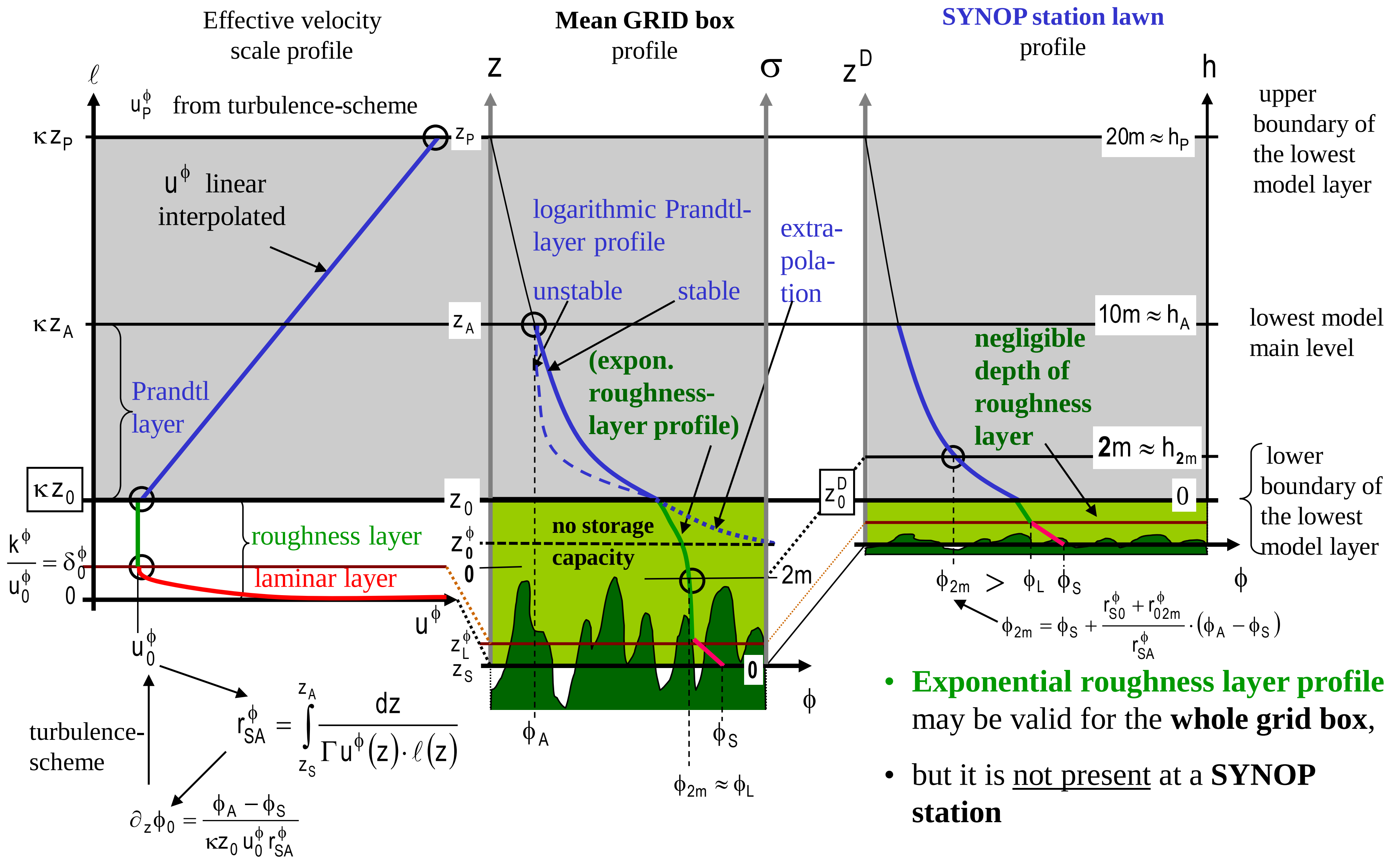
- Expected by end of 2014

  - Longer validation experiments →

COSMO-5.2+x

- Expected by end of March 2015

Transfer scheme and 2m-values with respect to a SYNOP lawn:



- **Exponential roughness layer profile** may be valid for the **whole grid box,**
- but it is <u>not present</u> at a **SYNOP station**

Further development:

- Common version with ICON: Revised organization, numerical schemes and security limits — **almost ready in ICON**

- Changing linear u^{ϕ}-profile above roughness layer by a hyperbolic function in accordance with solution form turbulence model — **running**

$$r_{0A}^{\phi} = \frac{1}{\kappa}\int_{\ell_0}^{\ell_A} \frac{d\ell}{\ell \cdot u^H} = \frac{1}{\kappa u_0^{\phi}} \cdot \begin{cases} \frac{1}{1-\gamma^{\phi}} ln\left(\frac{z_A}{z_0 + \gamma^{\phi} \cdot h_A}\right) \xrightarrow{\gamma^{\phi} \to 0 (\text{neutral})} ln\left(\frac{z_A}{z_0}\right) & s = 1 \quad (\text{lab}) \\ \left(1-\gamma^{\phi}\right) ln\left(\frac{z_A}{z_0}\right) + \gamma^{\phi}\frac{h_A}{z_0} \quad \boxed{\text{new branch}} & s = -1 \quad (\text{sta}) \end{cases}$$

- Resistance formulation without the node at level z_P — **just starting**

- Treatment of laminar effects without a laminar layer separation — **planned**

- Revised formulation of 10m-Wind and gusts valid within the roughness layer or exposed grid points on mountain tops — **planned**

- Partition of the vertically resolved part of the roughness layer — **planned**

- Documentation — **prepared**

Thank you for your attention