New features of the common turbulence parameterization for COSMO and ICON

Remaining Characteristics:

- ✓ represented in the module TURBDIFF: now common for COSMO and ICON
- ✓ 2-nd order turbulence closure at level 2.5 according MY (prognostic TKE-scheme)
- ✓ scale-separated trough the constraints of specific closure assumptions
- ✓ applied also as the core of surface-to-atmosphere transfer (SAT) formulation

Matthias Raschendorfer

Main supplements of the revised ICON-formulation:

technical

- In block-data structure
- Stronger modularization
- Including an universal VDiff SUB for **ALL** main-. and half-level variables included in TURBDIFF
- Configurable by list of switches: including current COSMO-version

organization in COSMO

- Vertical diffusion optionally in "ICON-mode":
  - called together with turbulence model
  - applied to mass-centered profiles

turbulence model

- Optional 3D-turbulence: 3D-wind-shear, application horizontal-diffusion coefficients
- One additional STIC term (due to separated SGS horizontal shear circulations) reformulated and active
- Different numerical treatment of vertical diffusion and circulation term in prognostic TKE-equation
- Less restrictive prevention of possible singularities

SAT model

- Complete moist physics applied to surface level: SGS fog-description possible
- Near-surface interpolation of vertical profiles in conserved variables
- Zero-concentration condition for qi and qc at the surface: deposition of droplets

empirical parameterizations

- Substituting badly tunable parameters by functions of the model variables

tk(h,m)min, pat_len, a_hshr, rat_sea, alfa0, vel_min

The 3D-extension of TURBDIFF:

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

- Simplification by an analog extension of the SC-solution (similar to Smagorinsky-type schemes):

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

trace-less stress tensor

$$Q_{3DS}^{TKE} = -\sum_{i,j}\overline{\rho v_i'' v_j''}\,\partial_i\hat{v}_j \approx \bar{\rho}K^M\left[\underbrace{\frac{1}{2}\sum_{i\neq j}\left(\partial_i\hat{v}_j + \partial_j\hat{v}_i\right)^2 + 2\sum_i\left(\partial_i\hat{v}_i\right)^2}_{F^M \leftrightarrow F_{3D}^M} - \frac{2}{3}\cancel{(\nabla\cdot\hat{\underline{v}})}^2\right] - \bar{\rho}\frac{q^2}{3}\cancel{\nabla\cdot\hat{\underline{v}}}$$

complete direct 3D shear by the GS flow

$K^{M,H} = qS^{M,H}\ell$ **turbulent isotropic diffusion coefficients with stability functions similar to HBA but** $F^M \leftrightarrow F_{3D}^M$

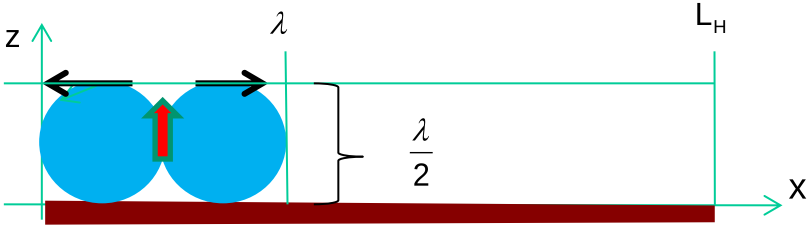
- Turbulent length scale restriction by horizontal grid scale L_H :

scale adaptivity

⇕

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

z_m: **maximal asymptotic turbulent distance 'tur_len'**



- Additional terms in budgets of ϕ_k by **convergence of additional horizontal fluxes** and (a not yet implemented) kinematic pressure correction

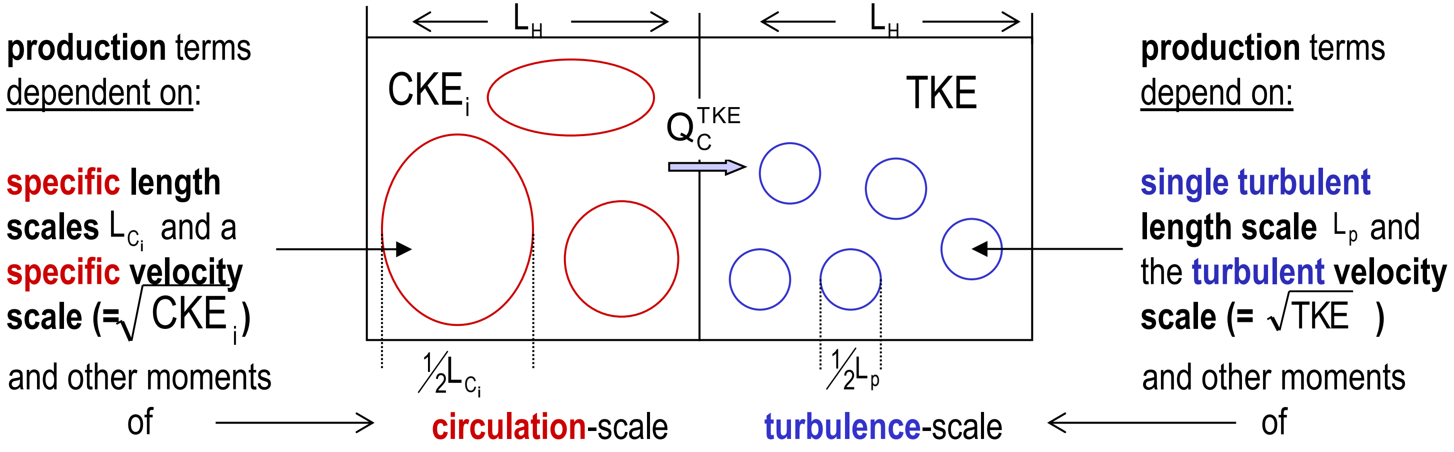
The coarse resolution extension of TURBDIFF:

→ **STIC**: **S**eparated **T**urbulence **I**nteracting with non-turbulent **C**irculations

- **Application of turbulence approximations only to small SGS scales** $\le L = \min\left\{L_p, L_H\right\}$
  - **separation of the sub grid scale flow in different classes with specific closure assumptions**
  - **by application of associated filter scales**

➢ **turbulent budgets with *additional* production terms due to shear terms with respect to the separated sub gird scale circulation flow of**

- **wake vortices by SSO (sub grid scale orography) blocking or gravity wave breaking** [operational in COSMO and ICON]
- **large separated horizontal shear vortices** [operational in ICON]
- **surface induced density flow patterns** [operational in COSMO and ICON]
- **shallow and deep convection patterns** [not yet operational active]



production terms dependent on:

specific length scales L_{C_i} **and a specific velocity scale** (=$\sqrt{CKE_i}$)

and other moments of → **circulation**-scale

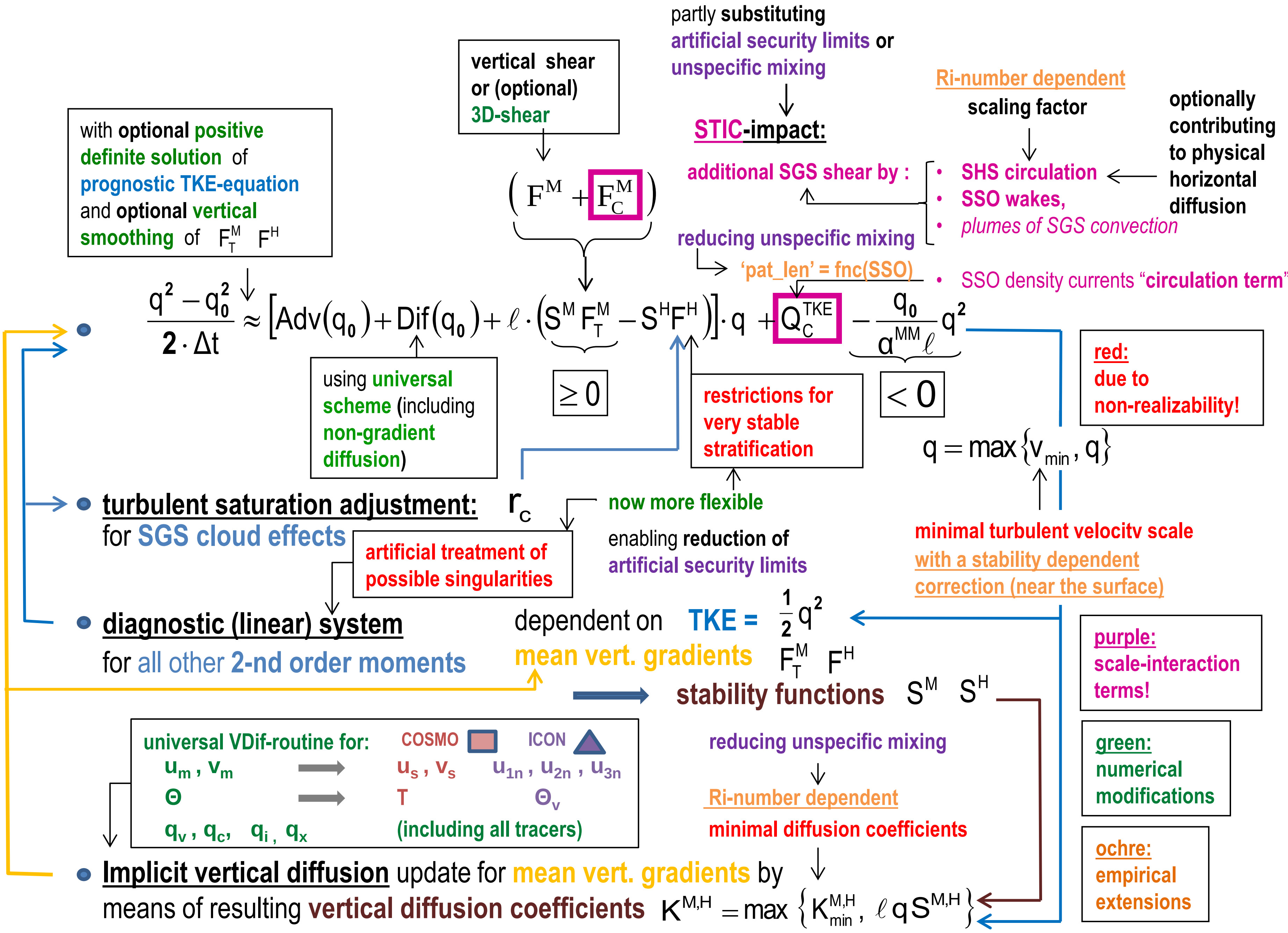
production terms depend on:

single turbulent length scale L_p **and the turbulent velocity scale** (= $\sqrt{TKE}$)

and other moments of → **turbulence**-scale

Q_C^{TKE} is the **scale interaction term** shifting SKE form the circulation part of the spectrum (CKE) to the turbulent part (TKE) **by virtue of shear** generated by the circulation flow patterns.

Practical solution within the time loop:



with optional **positive definite solution** of **prognostic TKE-equation** and optional **vertical smoothing** of F_T^M F^H

vertical shear or (optional) 3D-shear

partly **substituting artificial security limits** or **unspecific mixing**

STIC-impact:

additional SGS shear by :

- **SHS circulation**
- **SSO wakes,**
- *plumes of SGS convection*

Ri-number dependent **scaling factor**

optionally contributing to physical horizontal diffusion

reducing unspecific mixing

'pat_len' = fnc(SSO)

- SSO density currents "**circulation term**"

$$\underbrace{\left(F^M + \boxed{F_C^M}\right)}$$

- $$\frac{q^2 - q_0^2}{2\cdot\Delta t} \approx \left[Adv(q_0) + Dif(q_0) + \ell\cdot\left(\underbrace{S^M F_T^M}_{\boxed{\geq 0}} - S^H F^H\right)\right]\cdot q + \boxed{Q_C^{TKE}} - \underbrace{\frac{q_0}{\alpha^{MM}\ell}q^2}_{\boxed{< 0}}$$

using **universal scheme** (including **non-gradient diffusion**)

restrictions for very stable stratification

$$q = \max\{v_{min}, q\}$$

red: **due to non-realizability!**

- **turbulent saturation adjustment:** r_c
  for **SGS cloud effects**

now more flexible

enabling **reduction of artificial security limits**

artificial treatment of possible singularities

minimal turbulent velocity scale with a stability dependent correction (near the surface)

- **diagnostic (linear) system**
  for **all other 2-nd order moments**

dependent on **TKE =** $\frac{1}{2}q^2$

mean vert. gradients F_T^M F^H

stability functions S^M S^H

purple: **scale-interaction terms!**

universal VDif-routine for:	**COSMO** ▨	**ICON** ▲
u_m, v_m →	u_s, v_s	u_{1n}, u_{2n}, u_{3n}
Θ →	T	Θ_v
q_v, q_c, q_i, q_x	(including all tracers)	

reducing unspecific mixing

Ri-number dependent **minimal diffusion coefficients**

green: **numerical modifications**

ochre: **empirical extensions**

- **Implicit vertical diffusion** update for **mean vert. gradients** by
  means of resulting **vertical diffusion coefficients** $K^{M,H} = \max\left\{K_{min}^{M,H}, \ell q S^{M,H}\right\}$

The roughness layer extension of TURBDIFF:

⟶ **S**urface-to-**A**tmosphere **T**ransfer (**SAT**) expressed by turbulence scheme

- **Vertical integration of effective flux densities within a Constant Flux Layer (CFL) close to the surface**
  - **application of the turbulence scheme at the lower model boundary**
  - **considering surface enlargement by land use**
  - **using proper vertical interpolation function of turbulent velocity scale**

$$\tilde{f}^{\phi}(z) \approx -\underset{\uparrow}{\Gamma^{\phi}} \cdot \Big(\underset{\uparrow}{k^{\phi}} + \overbrace{qS^{\phi}\underset{\uparrow}{\ell}}^{v^{\phi}}\Big) \cdot \partial_z \hat{\phi} =: -\Gamma^{\phi} \underset{\uparrow}{u^{\phi}}(z) \cdot \ell(z) \cdot \partial_z \hat{\phi} = -\frac{\hat{\phi}(z_A) - \hat{\phi}(z_S)}{\underset{\uparrow}{r_{SA}^{\phi}}}$$

v^{ϕ} turbulent velocity scale

squared specific surface area index

molecular diffusion coefficient

turbulent length scale

effective velocity scale

total transfer **resistance**

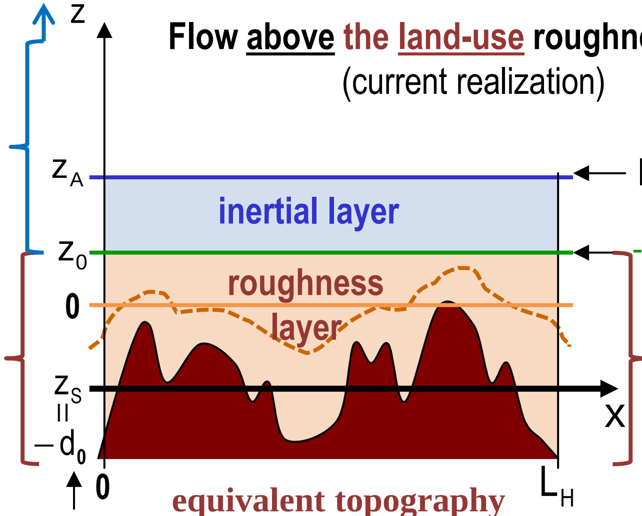
$$r_{SA}^{\phi} \longleftarrow = \boxed{\int_{z_S}^{z_0} \frac{dz}{\Gamma^{\phi} u^{\phi}(z) \cdot \ell(z)}} + \boxed{\int_{z_0}^{z_A} \frac{dz}{v^{\phi}(z) \cdot \kappa z}}$$

roughness layer resistance

inertial layer resistance

$$=: \int_{\underset{\uparrow}{z_0^{\phi}}}^{z_A} \frac{dz}{v^{\phi}(z) \cdot \kappa z} = \begin{cases} r_{SA}^{M} & , \phi \in \{v_1, v_2\} \\ r_{SA}^{H} & , \text{else} \end{cases}$$

specific roughness length: $z_0^H << z_0^M \approx z_0$



Flow above the land-use roughness layer:
(current realization)

atmospheric part of the model
(may contain SSO-roughness)

only acting as **transport resistance**:
neither **mass-** nor **heat-capacity**

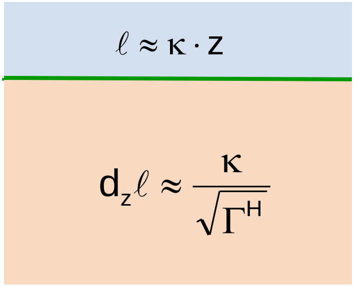
displacement height

equivalent topography covered by GS-model layers

lowest full model level

lower atmospheric model boundary

due to land-use and laminar effects

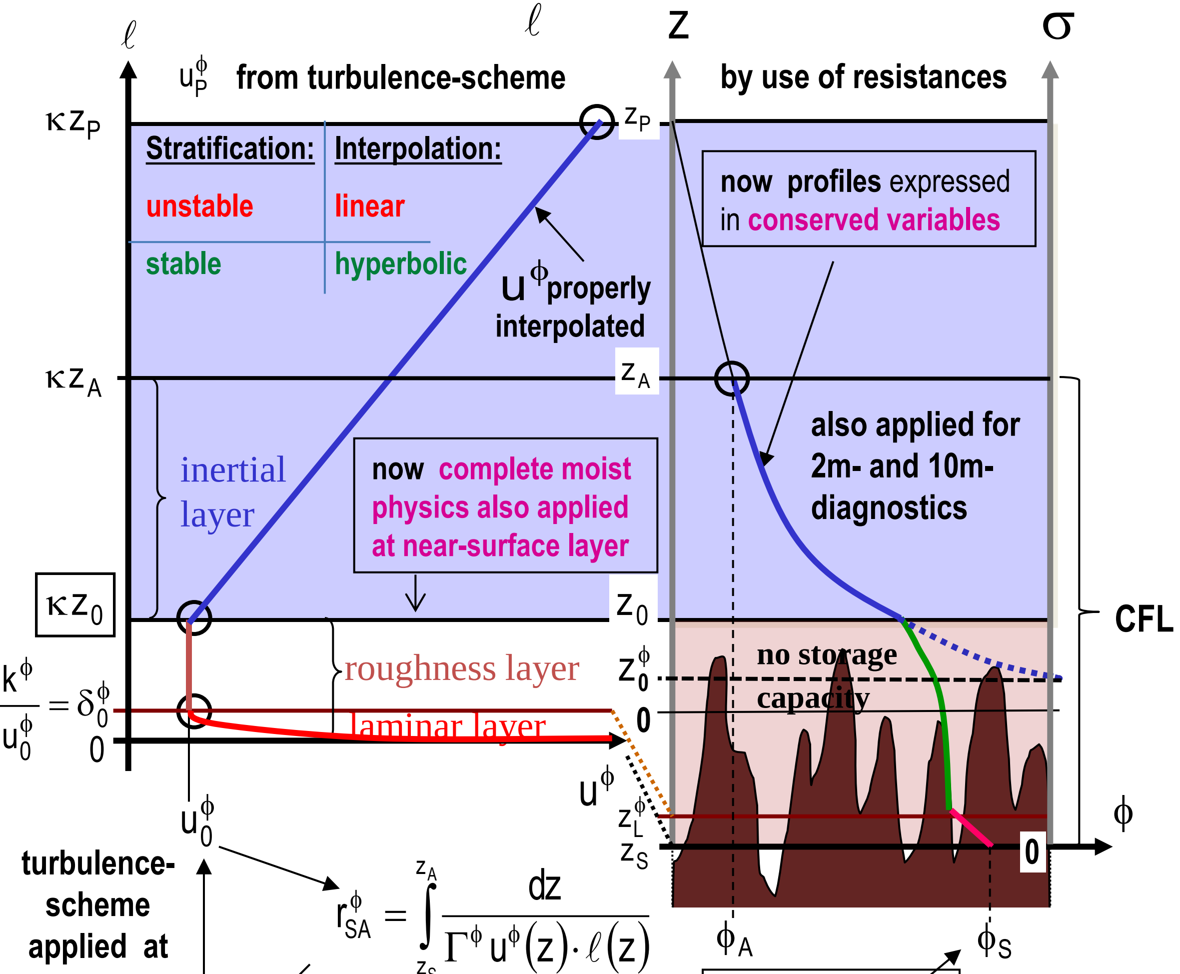


Main differences in surface-layer part:

expected to be necessary for **strong stable stratification** and a **homogeneous surface**

Effective velocity- scale profile $u^\phi := \frac{K^\phi + k^\phi}{\ell}$

Mean variable profile



Stratification:	**Interpolation:**
unstable	linear
stable	hyperbolic

u^ϕ properly interpolated

now complete moist physics also applied at near-surface layer

now profiles expressed in conserved variables

also applied for 2m- and 10m-diagnostics

$$\frac{k^\phi}{u_0^\phi} = \delta_0^\phi$$

turbulence-scheme applied at near-surface layer

$$r_{SA}^\phi = \int_{z_S}^{z_A} \frac{dz}{\Gamma^\phi u^\phi(z)\cdot\ell(z)}$$

$$\partial_z\phi_0 = \frac{\phi_A - \phi_S}{\kappa z_0\, u_0^\phi\, r_{SA}^\phi}$$

now with a zero- surface condition for qc

Roughness-layer resistance for scalars:

$$r_{S0}^H = \frac{1}{\kappa u_0^H \cdot S_{Al_0}} \cdot \left(\lambda^H + \ln\frac{\kappa z_0 u_0^H}{k^H}\right)$$

effective value of $\sqrt{\Gamma^H}$

now with a laminar scaling parameter dependent on $\partial_z\theta_0$ **over see surfaces**

Inertial-layer resistance:

stability-parameter of vertical profile-function

now optionally without using the upper interpolation node u_P^ϕ

$$\gamma_s^\phi := \frac{z_0}{z_P - z_0}\left[\frac{u_P^\phi}{u_0^\phi} - 1\right] = 1 - \frac{u_*}{u_0^\phi}\,\frac{S_0^\phi}{S_0^M}$$

now optionally with the additional stable branch

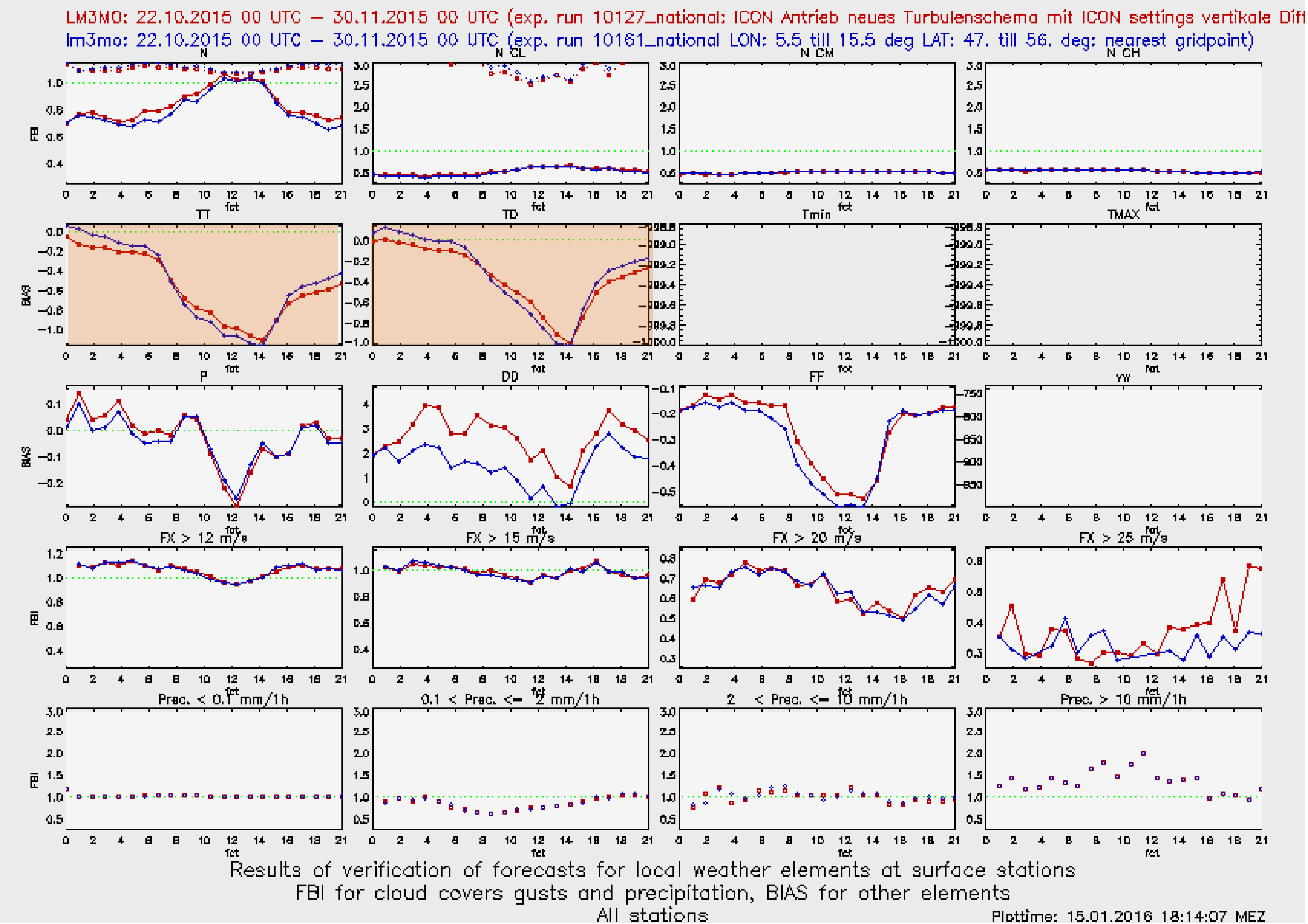
stable

$$r_{0A}^\phi = \frac{1}{\kappa u_0^\phi \cdot \left(1 - \gamma_s^\phi\right)} \cdot \begin{cases} \ln\left(\frac{z_A}{z_0}\right) - \gamma_s^\phi\,\frac{z_A - z_0}{z_0} & , \gamma_s^\phi < 0 \\ \ln\left[\frac{z_A}{z_0 + \gamma_s^\phi\cdot(z_A - z_0)}\right] & , \gamma_s^\phi \ge 0 \end{cases}$$

unstable

operational <-> new TURBDIFF (ICON-settings; ICON-like V-Diff):

BIAS for late Autumn 2015:


LM3MO: 22.10.2015 00 UTC – 30.11.2015 00 UTC (exp. run 10127_national: ICON Antrieb neues Turbulenzschema mit ICON settings vertikale Dif

lm3mo: 22.10.2015 00 UTC – 30.11.2015 00 UTC (exp. run 10161_national LON: 5.5 till 15.5 deg LAT: 47. till 56. deg: nearest gridpoint)

N, N CL, N CM, N CH

TT, TD, Tmin, TMAX

P, DD, FF, VV

FX > 12 m/s, FX > 15 m/s, FX > 20 m/s, FX > 25 m/s

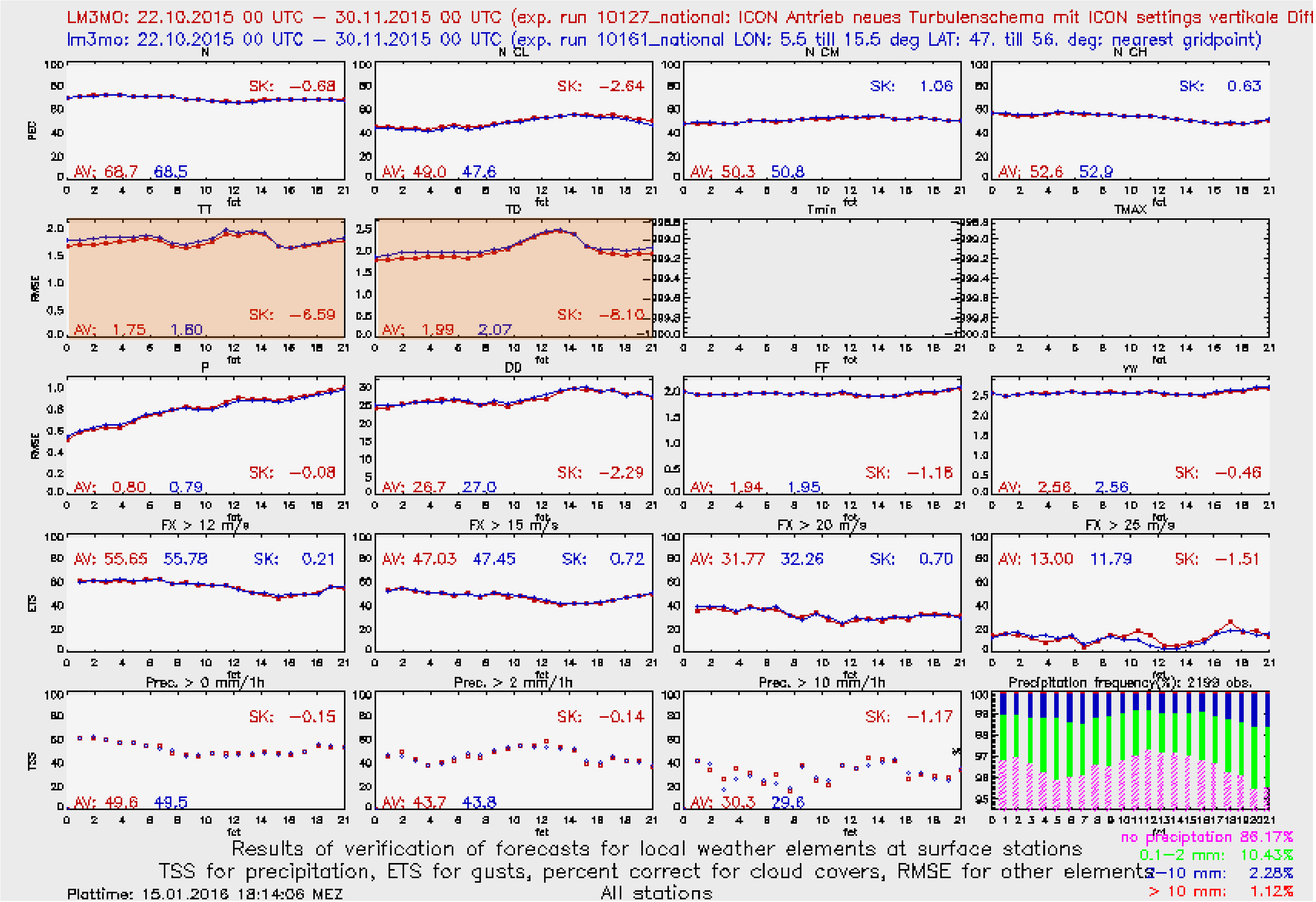
Prec. < 0.1 mm/1h, 0.1 < Prec. <= 2 mm/1h, 2 < Prec. <= 10 mm/1h, Prec. > 10 mm/1h

Results of verification of forecasts for local weather elements at surface stations
FBI for cloud covers gusts and precipitation, BIAS for other elements
All stations

Plottime: 15.01.2016 18:14:07 MEZ

operational <-> new TURBDIFF (ICON-settings; ICON-like V-Diff):

RMSE for Autumn 2015:



LM3MO: 22.10.2015 00 UTC – 30.11.2015 00 UTC (exp. run 10127_national: ICON Antrieb neues Turbulenschema mit ICON settings vertikale Diff

lm3mo: 22.10.2015 00 UTC – 30.11.2015 00 UTC (exp. run 10161_national LON: 5.5 till 15.5 deg LAT: 47. till 56. deg: nearest gridpoint)

Results of verification of forecasts for local weather elements at surface stations

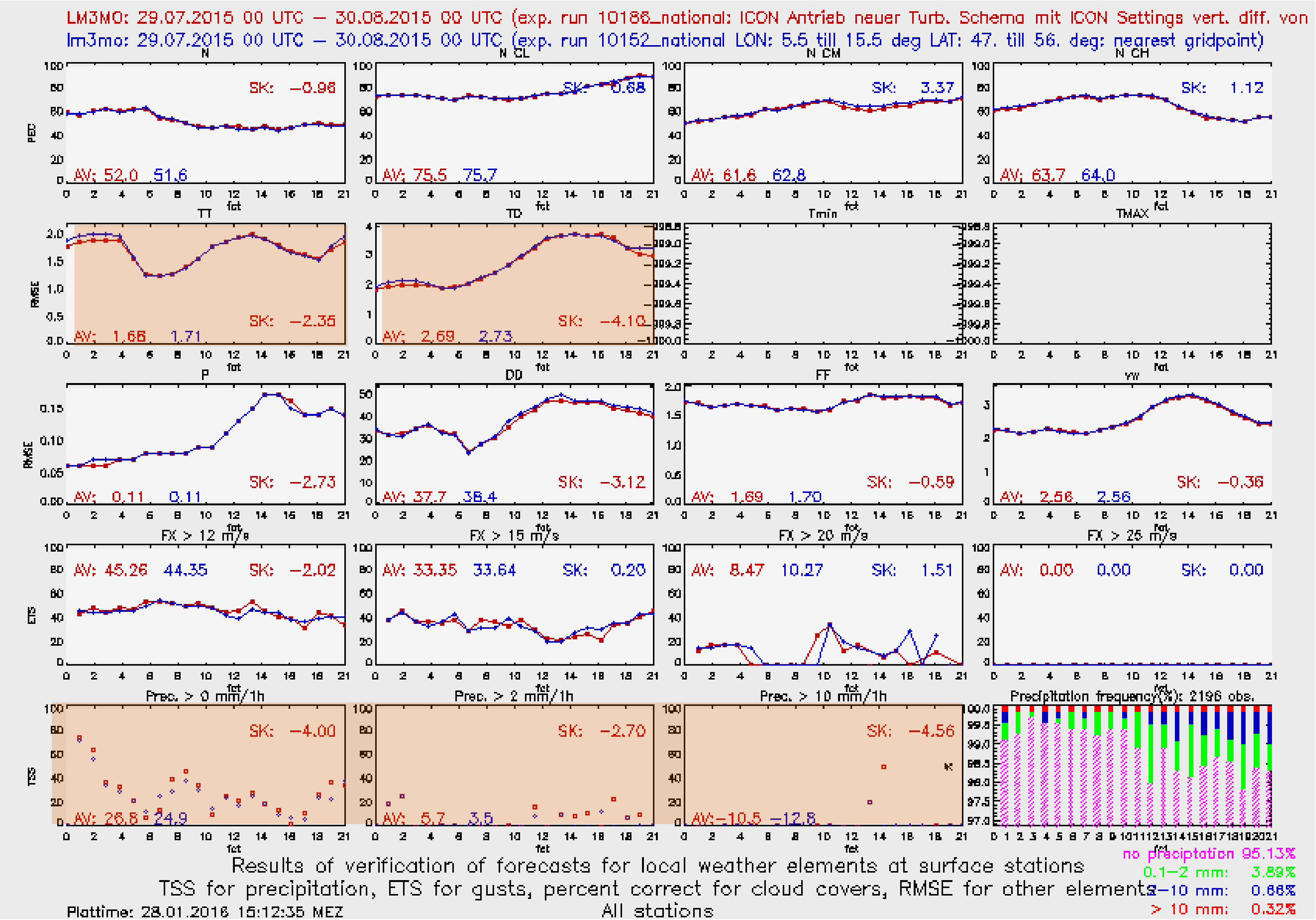
TSS for precipitation, ETS for gusts, percent correct for cloud covers, RMSE for other elements

Plottime: 15.01.2016 18:14:06 MEZ

All stations

operational <-> new TURBDIFF (ICON-settings; ICON-like V-Diff):

RMSE for August 2015:



LM3MO: 29.07.2015 00 UTC – 30.08.2015 00 UTC (exp. run 10186_national: ICON Antrieb neuer Turb. Schema mit ICON Settings vert. diff. von

lm3mo: 29.07.2015 00 UTC – 30.08.2015 00 UTC (exp. run 10152_national LON: 5.5 till 15.5 deg LAT: 47. till 56. deg: nearest gridpoint)

Results of verification of forecasts for local weather elements at surface stations

TSS for precipitation, ETS for gusts, percent correct for cloud covers, RMSE for other elements

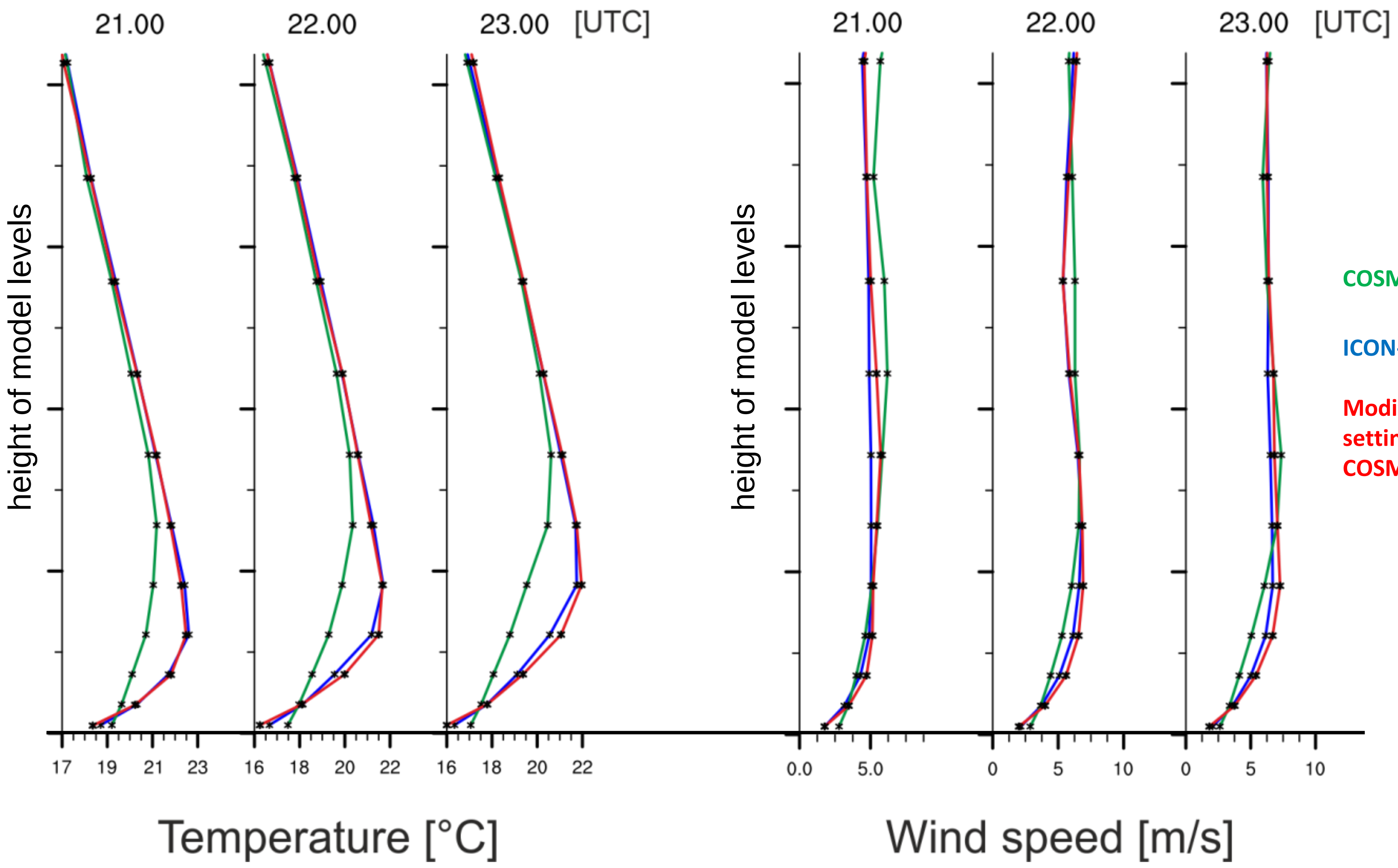
Plottime: 28.01.2016 15:12:35 MEZ

All stations

Vertical profiles at night hours (for different TURBDIFF-configurations):

Falkenberg, July 03, 2014

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



COSMO-settings

ICON-settings

Modified ICON-settings and COSMO-like V-Diff

EWeLiNE

Deutscher Wetterdienst Wetter und Klima aus einer Hand — 50hertz — TenneT Taking power further — amprion — Fraunhofer IWES

provided by Andrea Steiner (DWD)

A conclusion:

- **Too much unspecific mixing and security measures had been active before**

⟹ **Double strategy:**

- **Improving physical parameterizations:**
  - **More specific and complete scale interaction terms**

    dependent on model parameters

- **Optimization of parameter values:**
  - **Reduction of unspecific background mixing to the necessary minimum**
  - **Improving empirical/statistical parameterizations:**
    - ○ **Substituting non-tunable parameters by functions of the model state**

      dependent on regression parameters

Diagnostics of the special SAT-approach in TURBDIFF:

- Our generalizations are due to a direct application of the turbulence scheme and its generalizations:

explicit description of the roughness-and laminar-layer resistance → substituting a specific roughness length for scalars being an unspecific parameter

scale interaction terms → additional shear → reduced Ri-numbers for stable stratification → physically based "tail" for stable stratification mainly at heterogeneous surfaces

- The desired additional mixing for stable stratification is rather too intensive than too weak!

  a) What is the effect of remaining unspecific turbulence enhancing measures?

  b) Is the scheme in accordance to a MOS solution, which is valid for a homogeneous surface?

Definitions of boundary layer properties:

$\underline{r}^{\phi} := \Gamma^{\phi} \cdot \left(\frac{k^{\phi}}{v^{\phi} \ell} + 1 \right)$ correction factor for roughness and laminar effects

$\boxed{F_T^M := F^M + F_C^M}$ generalized squared wind shear frequency
(**including contribution by non turbulent circulations**)

$G_T^M := \frac{\ell^2}{q^2} \cdot F_T^M \geq 0$

$F^H := \frac{g}{\hat{\theta}_v} \partial_z \hat{\Theta}_v$ generalized square for Brunt-Väisälä-frequency
(**including contribution by sub grid scale condensation**)

$G_T^H := \frac{\ell^2}{q^2} \cdot F^H$

$R_i := \frac{F^H}{r^M F^M}$ Richardson number

$R_f := \frac{S^H}{S^M} R_i$ Richardson flux number

$u_*^2 := \underline{r}^M v^M \sqrt{F_T^M}$ generalized square friction velocity

$u_* \theta_* := -\frac{\hat{\theta}_v}{g} \underline{r}^H v^H F^H$ generalized buoyancy heat flux

$L_{MO} := -\frac{u_*^2 \hat{\theta}_v}{g \theta_*}$ Monin-Obukhov stability length scale

vertically constant
in transfer layer

$\boxed{\psi^{\phi} := \frac{v^{\phi}}{u_*}}$ vertical profile functions

MY-like SC-solution with a quasi-diagnostic TKE-equation:

$$\gamma := 1 + \alpha^{MM} \frac{\ell}{q} \frac{D_t\left(\frac{1}{2}\overline{\rho} q^2\right)}{\overline{\rho} q^2} = \alpha^{MM} \cdot \left(\underline{r}^M S^M G_T^M - S^H G^H\right) \qquad \chi := \frac{R_f}{1 - R_f}$$

$$\alpha^{MM} \underline{r}^M S^M G_T^M = \gamma \cdot (1 + \chi)$$

$$S^H \quad + \overbrace{\left[\gamma \frac{\alpha^H}{\alpha^{MM}} \left(3\underline{r}^H \alpha^{HH} + 18\alpha^M\right)\right]}^{=:a} \cdot \chi \quad = \quad \alpha^H \left[\left(1 - 3c^H\right) - 6\gamma \frac{\alpha^M}{\alpha^{MM}}\right] =: b =: S_0^H$$

$$S^M \quad + \left[\underbrace{\gamma \frac{\alpha^M}{\alpha^{MM}} \left(9\underline{r}^H \alpha^H + 18\alpha^M\right)}_{=:c} + \underbrace{\gamma \frac{\alpha^M}{\alpha^{MM}} \left(9\underline{r}^M \alpha^H\right)}_{=:e} \frac{S^M}{S^H}\right] \cdot \chi \quad = \quad \alpha^M \left[\left(1 - 3c^M\right) - 6\gamma \frac{\alpha^M}{\alpha^{MM}}\right] =: d =: S_0^M$$

$$a = 2.09, \quad b = 0.49, \quad c = 1.29, \quad e = 0.37, \quad d = 0.39 \qquad \alpha := \frac{(a + b - e) \cdot R_i + d}{d + c} \qquad \beta := \frac{b}{d + c} R_i$$

critical Ri-number

$$R_i < \overset{\downarrow}{R_i^c} := \frac{da - bc}{e \cdot (a + b)} > \mathbf{0}$$

$$R_f = \frac{\alpha}{2} - \sqrt{\frac{\alpha^2}{4} - \beta}$$

$$\boxed{S^H = b - a\chi \qquad S^M = \frac{(d - c\chi) \cdot (b - a\chi)}{b - (a - e)\chi}}$$

The revised vertical profile function in accordance with turbulence model:

$$R_f \cdot \frac{r^H}{\underline{r^M}} \frac{L_{MO}}{\ell} = \psi^M = \left[\frac{\alpha^{MM}}{\underline{r^M}} S^{M^3} \cdot (1-R_f) \right]^{1/4}$$

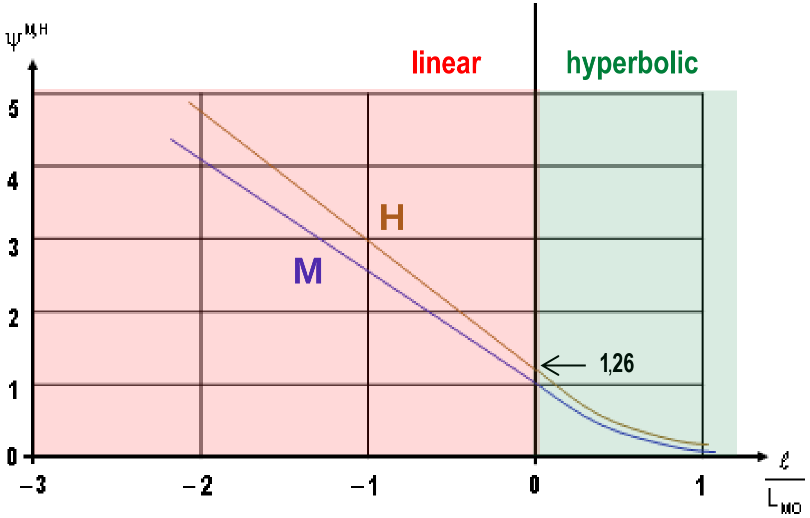
S^M, S^H are function of R_f

$$\psi^H = \frac{S^H}{S^M} \psi^M$$

$$\psi_0^M = 1$$

constant dependent on r^M and r^H

$$\frac{v^\phi}{u_*} = \psi^\phi \approx \psi_0^\phi \cdot \begin{cases} 1+\alpha^\phi \dfrac{\ell}{L_{MO}} & \text{unstable} \\ \left(1+\alpha^\phi \dfrac{\ell}{L_{MO}}\right)^{-1} & \text{stable} \end{cases}$$



- ➢ In accordance with **MOS-solution** as well as **measurements** (Businger-profiles) above **homogeneous surfaces**, where $F_T^M = F^M$

- <u>Notice:</u>
  - **Parameters of MY-scheme** have been evaluated in order to <u>match</u> with these measured profile functions!
  - **Artificial "long tail"** substituted by **decreasing** $\left|\frac{\ell}{L_{MO}}\right|$ due to **additional TKE-sources**
- Can this finding be confirmed by **component tests** for **inertial layer resistance**?

next talk