Status and results of PT ConSAT

(and related STIC-implementations)

Content:

- main goals of ConSAT
- The common module TURBDIFF for COSMO and ICON
  - general properties
  - implementation in COSMO
  - modifications in the atmospheric part
  - modifications in the surface part
- Investigation of thermal stratification damping in the SAT-scheme

together with Ines Cerenzia, ARPA

Matthias Raschendorfer DWD

Promising related activity

(still basic research, not yet implemented, not really started)

- Turbulence-Interaction with Micro-Phys. beyond pure saturation adjustment:
  - Consideration of turbulent statistics in MP

    Axel Seifert
  - Deriving missing correlations between model variables and MP-source-terms in 2-nd order budgets for turbulence

    Dimitrii Mironov, Axel Seifert
- Increasing the range of scales included to turbulence closure:
  - coherent structures with skewed distributions, TKESV

    Dimitrii Mironov, Ekatarina Maschulkaya
- Dealing with statistical parameterizations
  - substituting intended model-parameters to reduce systematic model errors

    staff from ICON or special projects at DWD (renewable energy)
- Developing stochastical parameterizations
  - simulating the not closed remaining stochastic discretization error

    Ekatarina Maschulskaya

PT: Consolidation of Surface to Atmosphere Transfer (ConSAT)

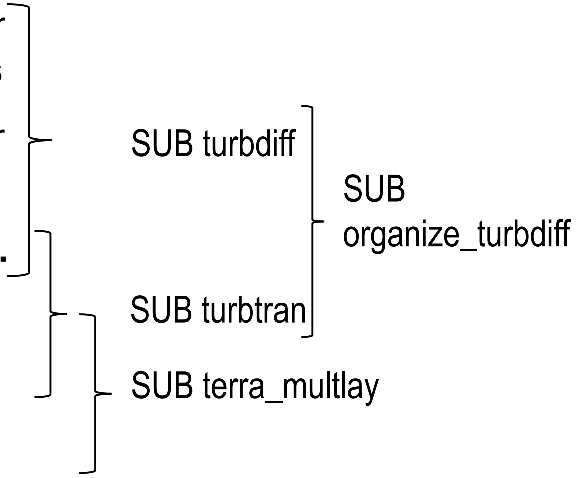
- slightly updated definition -

- 2-nd phase -

- **Long-term goal:**
  - Improving the **overall performance** (in particular for **stable stratification) of parameterization- and numerical schemes** included into the **SAT-process**, which is:

    turbulent (and molecular) **diffusion** between **atmospheric layers including the surface** and **interpolation onto near-surface levels**, as dependent on:

    - **turbulence model** (interacting with other **SGS flow-patterns,** under consideration of the **thermodynamics of non-precipitating clouds**
    - **numerical formulation of vertical diffusion** (of 1-st and 2-nd order model variables
    - treatment of the **roughness layer** ……………………………………….
    - representation of **surface fluxes** by vertical integration of the turbulence model along the **transfer layer**
    - determination of atmospheric concentrations just at the surface



- **Strategy:**
  - Sequence of one-year tasks from the continuous cycle of the 6 **W**orking **C**omponents:

    I) Detection of crucial processes
    II) Maxing out the existing formulations together with existing extensions
    III) Analysis and revision of related parameterizations and numerical procedures
    IV) Implementation of revised formulations into the code
    V) Validation of the modifications
    VI) Reporting and Documentation of the modified parameterizations

    general process of improvement

  - Current implementation tasks:

    1) **Revision of numerical security limits in the SAT-scheme and the associated turbulence model** with respect to **systematic errors mainly for stable stratification**.
    2) **Changing the vertical profile functions of the turbulent-velocity-scale** used for the vertical integration in the SAT scheme (which currently are always **linear** functions in the vertical distance) **into a different form for stable stratification** fitting better to the solution of the constant flux profile functions arising from the turbulence model in agreement with empirical functions..
    3) **Implementing the ICON-version of TURBDIFF and merging the COSMO-development with all the ICON-modifications** including the introduction of some dependency on the model state to so far constant model-parameters (such as the minimal diffusion coefficient) and **trying to formulate all the extensions above the current COSMO-version as switchable options** together with a related **bug-checking**.
    4) **Fixing the parameters of the profile function without using the lowest diffusion-coefficient above the Constant Flux Layer** (CFL) as a node, and hence **reducing the numerical damping of the stratification effect on the transfer coefficients**. <-> PT TSA
    5) **Revision of the implementation of turbulent diffusion** (based on a turbulence scheme with a prognostic TKE equation) **in the framework of different data-structures and different sets of 1-st order prognostic model equations in COSMO and ICON**.

implemented but **not yet tested nor validated**; reference-MO-solution implemented and used for comparison

Restructured TURBDIFF for COSMO and ICON:

- **Content of new module TURBDIFF (installed name by Uli S.: 'turbulence_turbdiff'):**

sub 'organize_turbdiff':

- Preparations
- Task-selection

➢ Dependent on [internal switches]

sub 'turbdiff':

- **vertical diffusion** for
  - u; [lumdif]
  - v; [lvmdif]
  - T, qv, qc; qi and pass. trac.; [lscadif]
  - TKE, … (at half-levels) ["for tub.mod."]
  - ➢ Diffusion tendencies, surface fluxes

new subroutines (common ´for 1-st and 2-nd order variables (including e.g. passive tracers and TKE) at full and half-levels):

- 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
    - optional matrix conditioning (-> tiled cover-layer of roughness elements (e.g. vegetation)

- **turbulence at atmos. layers**: [lturatm]
  - ➢ TKE, TKV(M/H), RCLD

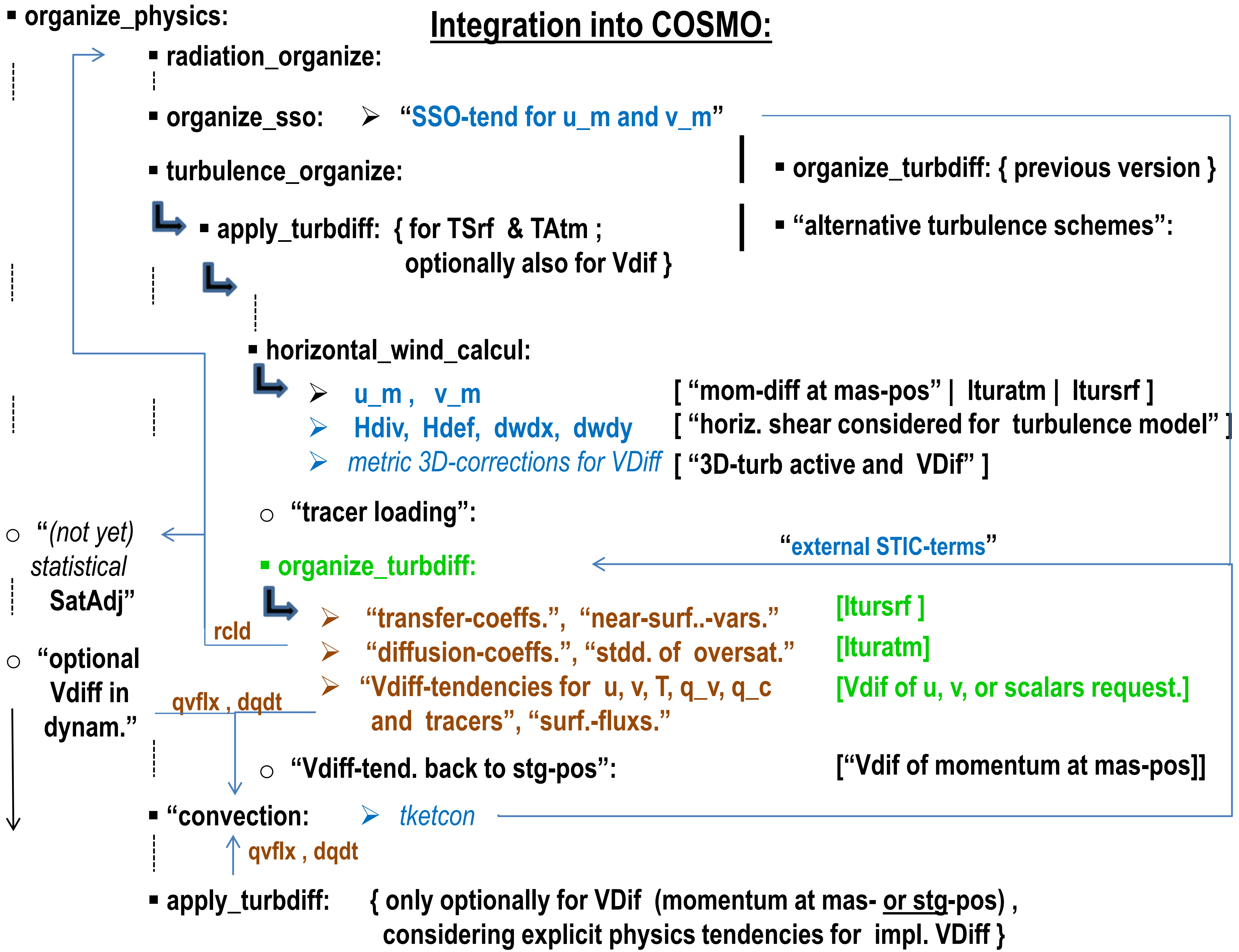
sub 'turbtran':

- **turbulence at surface layer**: [ltursrf]
  - ➢ *TC(M/H)*, TV(M/H)
  - ➢ near surface model variables

new subroutines common for 'turbdiff' and 'turbtran':

- 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

Integration into COSMO:



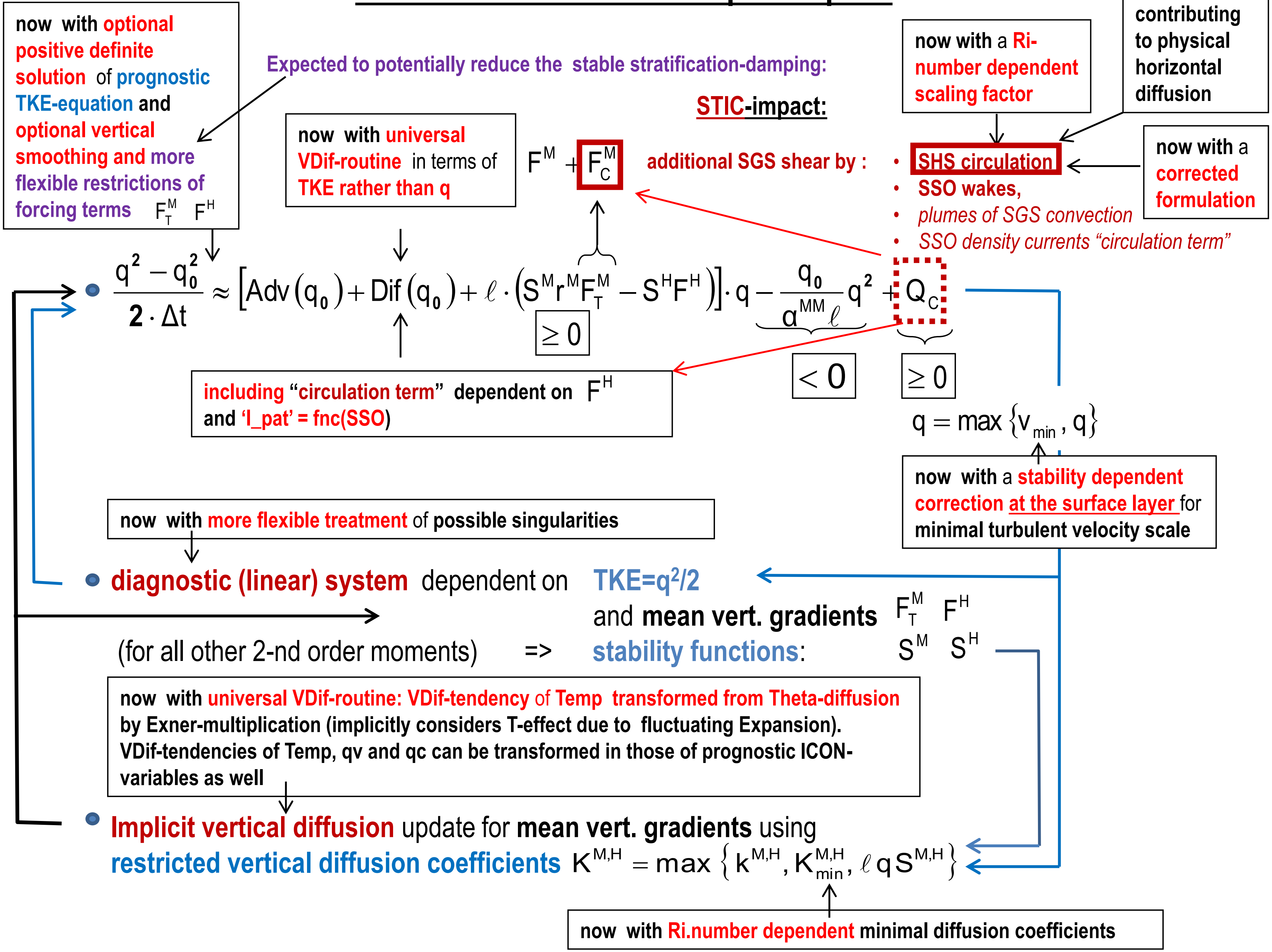
- organize_physics:
  - radiation_organize:
  - organize_sso: ➢ “SSO-tend for u_m and v_m”
  - turbulence_organize:
    - apply_turbdiff: { for TSrf & TAtm ; optionally also for Vdif }
      - horizontal_wind_calcul:
        - ➢ u_m , v_m [“mom-diff at mas-pos” | lturatm | ltursrf]
        - ➢ Hdiv, Hdef, dwdx, dwdy [“horiz. shear considered for turbulence model”]
        - ➢ *metric 3D-corrections for VDiff* [“3D-turb active and VDif”]
      - ○ “tracer loading”:
      - **organize_turbdiff:**
        - ➢ “transfer-coeffs.”, “near-surf..-vars.” [ltursrf]
        - ➢ “diffusion-coeffs.”, “stdd. of oversat.” [lturatm]
        - ➢ “Vdiff-tendencies for u, v, T, q_v, q_c and tracers”, “surf.-fluxs.” [Vdif of u, v, or scalars request.]
      - ○ “Vdiff-tend. back to stg-pos”: [“Vdif of momentum at mas-pos]]
  - “convection: ➢ *tketcon*
  - apply_turbdiff: { only optionally for VDif (momentum at mas- or stg-pos) , considering explicit physics tendencies for impl. VDiff }

- organize_turbdiff: { previous version }
- “alternative turbulence schemes”:

○ “*(not yet)* *statistical* SatAdj”

○ “optional Vdiff in dynam.”

Main differences in atmospheric part:



now with optional positive definite solution of prognostic TKE-equation and optional vertical smoothing and more flexible restrictions of forcing terms F_T^M F^H

Expected to potentially reduce the stable stratification-damping:

now with universal VDif-routine in terms of TKE rather than q

STIC-impact:

$F^M + \boxed{F_C^M}$ additional SGS shear by :

- SHS circulation
- SSO wakes,
- *plumes of SGS convection*
- *SSO density currents "circulation term"*

now with a Ri-number dependent scaling factor

optionally contributing to physical horizontal diffusion

now with a corrected formulation

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

including "circulation term" dependent on F^H and 'l_pat' = fnc(SSO)

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

now with a stability dependent correction at the surface layer for minimal turbulent velocity scale

now with more flexible treatment of possible singularities

- **diagnostic (linear) system** dependent on **TKE=$q^2/2$**

  and **mean vert. gradients** F_T^M F^H

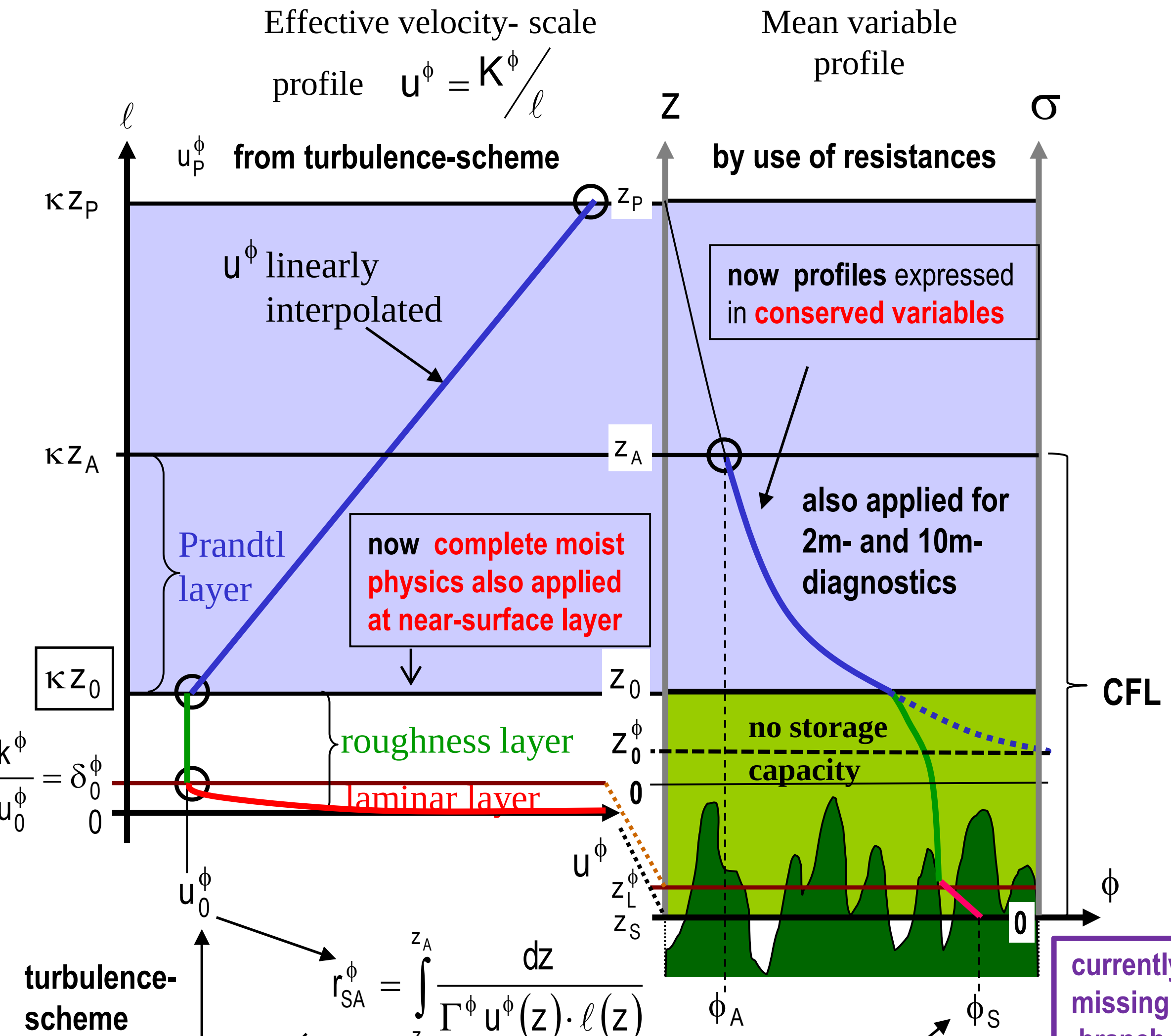
  (for all other 2-nd order moments) => **stability functions**: S^M S^H

now with universal VDif-routine: VDif-tendency of Temp transformed from Theta-diffusion by Exner-multiplication (implicitly considers T-effect due to fluctuating Expansion). VDif-tendencies of Temp, qv and qc can be transformed in those of prognostic ICON-variables as well

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

now with Ri.number dependent minimal diffusion coefficients

Main differences in surface-layer part:



now profiles expressed in **conserved variables**

also applied for 2m- and 10m-diagnostics

now complete moist physics also applied at near-surface layer

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

$K_0^\phi = \kappa z_0 \cdot u_0^\phi \leftarrow$ **now with an extrapol. from level P** instead **of laminar initialization**

Roughness-layer resistance for scalars:

$$r_{S0}^H = \frac{1}{\kappa S_0 \cdot u_0^H} \cdot \left(\lambda^H + \ln \frac{\kappa z_0 u_0^H}{k^H} \right)$$

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

Prandtl-layer resistance:

Expected to be main reason for thermal-stability-damping:

current version with using u_P^ϕ as an upper interpolation node

stability-parameter of vertical profile-function

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

now optionally with using friction velocity →

$$u_*^2 = K_0^M \sqrt{F_{T\,0}^M}$$

now optionally with the additional **stable branch**

currently missing branch → **stable**

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

unstable

Specific treatment over Sea-Surfaces and related problems:

- SS-roughness is dependent on surface shear:

dynamic contribution

laminar limit

contains also shear by SGS wind

$$z_0 = \underset{\uparrow}{\alpha_0}\,\frac{u_*^2}{g} + \underset{\uparrow}{\alpha_1}\cdot\frac{k^M}{u_*} \qquad \overset{\downarrow}{u_*^2 = K_0^M\sqrt{F_{T\,0}^{M}}}$$

now with a Charnock parameter dependent on 10m-wind-speed

now explicitly considered

- SS-roughness and surface shear are also related to the stability parameter γ_s^ϕ

  and the solution is taken by direct time-step iteration

- Where the iteration is stable when calculating the stability according to $\gamma_s^\phi = \frac{z_0}{z_P - z_0}\left[\frac{u_P^\phi}{u_0^\phi} - 1\right]$

  this might not be the case for, if using instead $\gamma_s^\phi = 1 - \frac{u_*}{u_0^\phi}\frac{S_{neut}^\phi}{S_{neut}^M}$

  without the turbulence-impact form the above level P

- Without the upper node, STIC-terms (which are only present at atmospheric levels so far) can’t be effective yet for SAT

Current state:

- The common TURBDIFF module merges the past development of COSMO and ICON
- It contains additional development of the current ConSAT-task
  - Some optional implementations are not yet tested and need further development
- It has been considerably restructured to allow for various configurations, e.g.:
  - Similar to operational COSMO-version
  - Similar to operational ICON-version
- The full implementation is available as COSMO-5.3_beta
- Compared to the previous release (distributed by of Uli Schättler), it is now
  - Corrected and more complete
  - Thoroughly tested and further developed
- For the time being the former module can be selected as well
- Vertical diffusion can be run in different modes (either with the still present routines in module ‘src_slow_tendencies_rk’ or with the new routines in the common module.

- The COSMO-configuration proves to be only marginal different from the operational version
- The different modes of vertical diffusion cause only marginal differences

- Two parallel experiments will start very soon (one with COSMO- another with ICON-config)
- The new code (first of all with COSMO-config) should become operational soon.

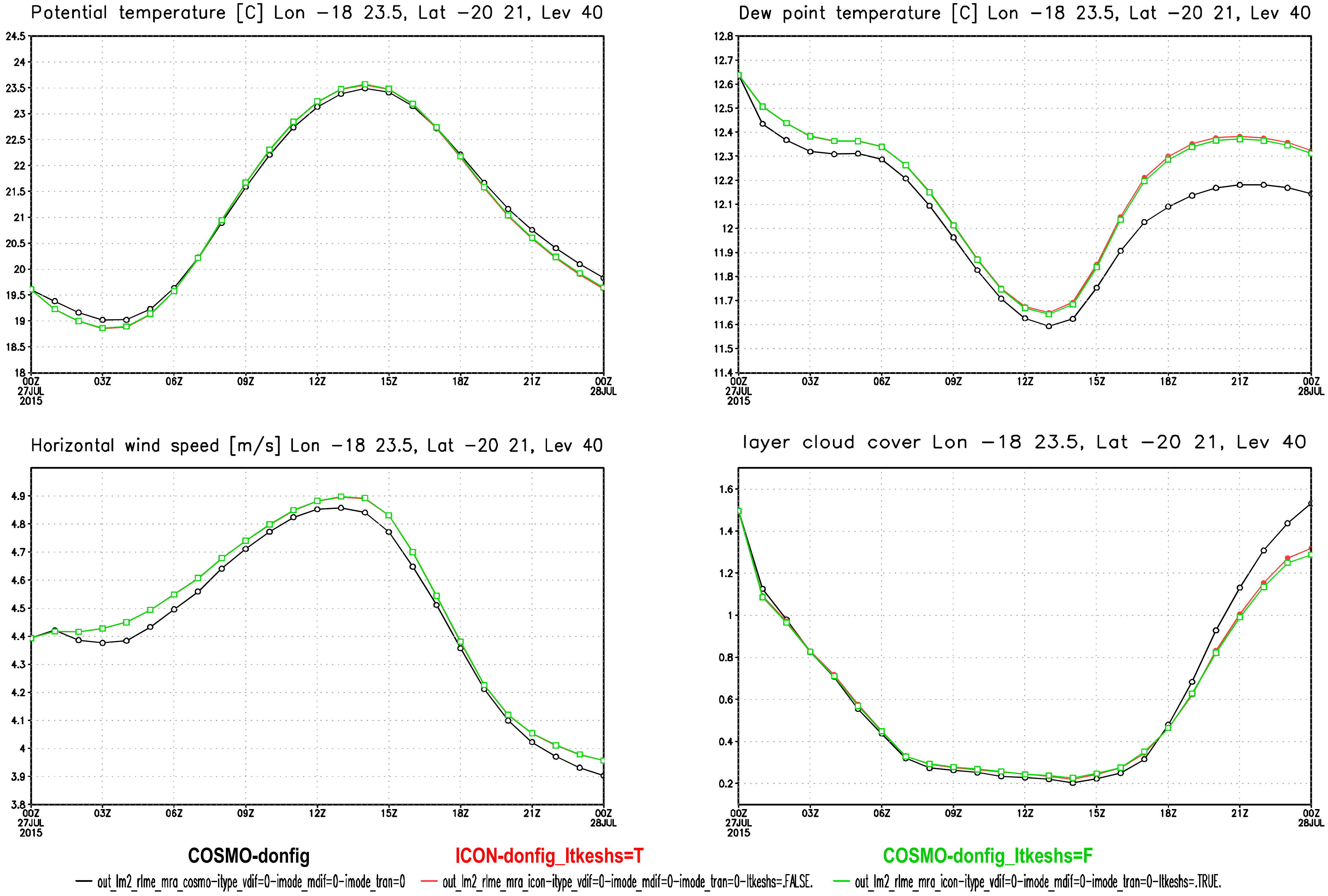
First results:

- Based on a single-day test-runs (used for testing the new implementation):

1. The ICON-configuration causes significant differences compared to the current COSMO-configuration:

Time series of model-domain-averages

COSMO-EU: common TURBDIFF



Potential temperature [C] Lon -18 23.5, Lat -20 21, Lev 40

Dew point temperature [C] Lon -18 23.5, Lat -20 21, Lev 40

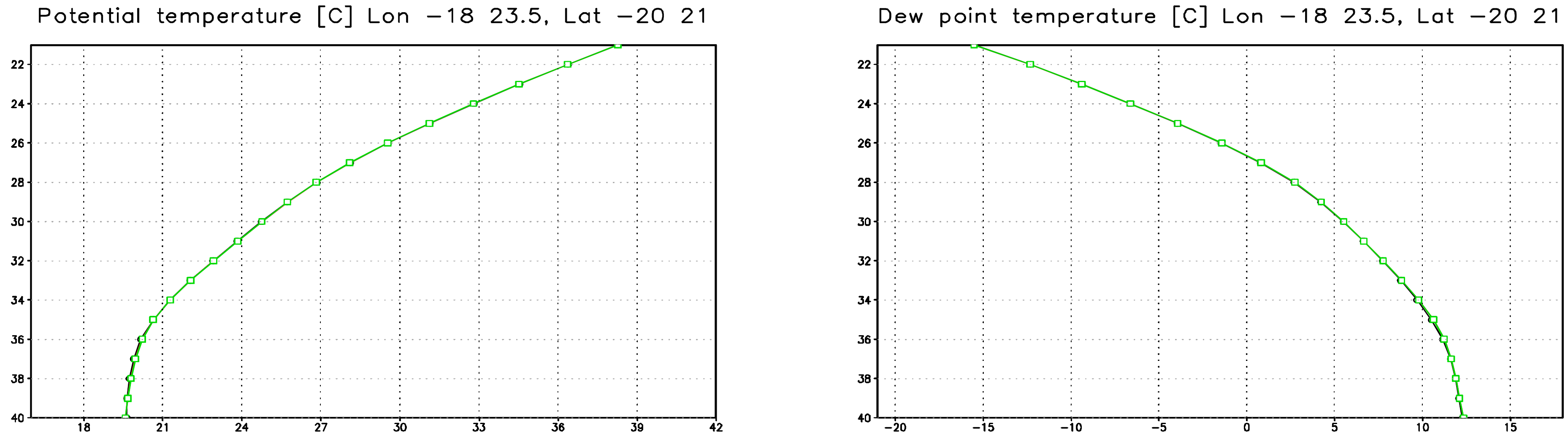
Horizontal wind speed [m/s] Lon -18 23.5, Lat -20 21, Lev 40

layer cloud cover Lon -18 23.5, Lat -20 21, Lev 40

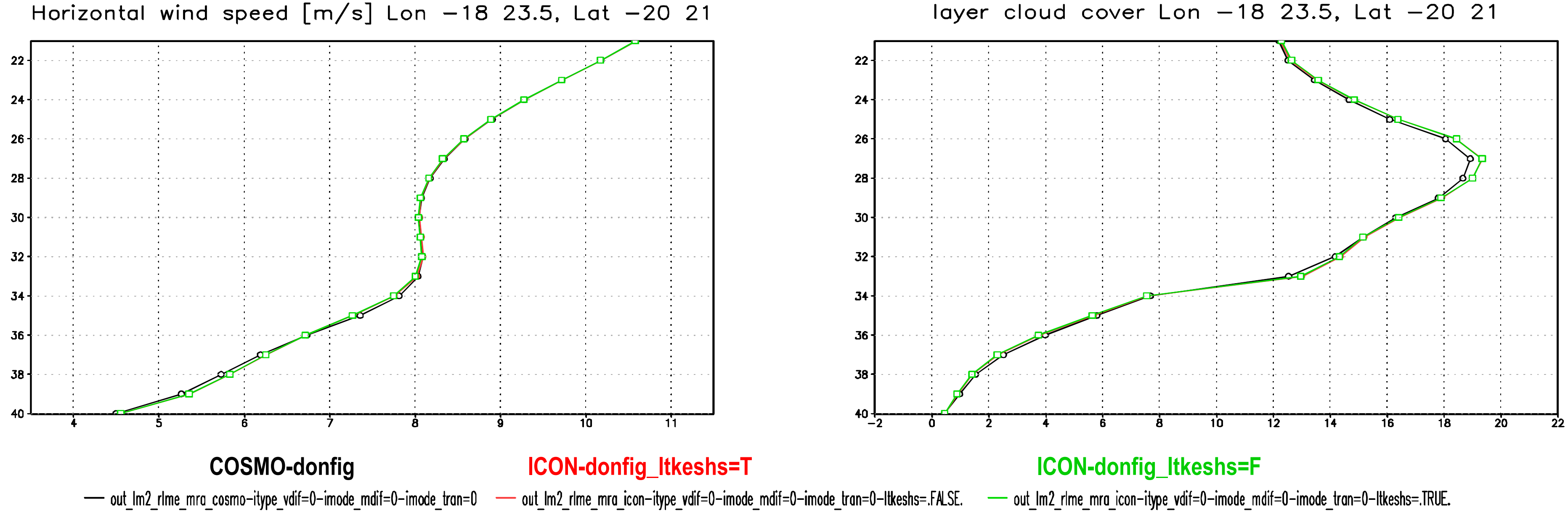
COSMO-donfig **ICON-donfig_ltkeshs=T** **COSMO-donfig_ltkeshs=F**

vertical profiles of model-domain-averages

COSMO-EU: common TURBDIFF



COSMO-EU: common TURBDIFF



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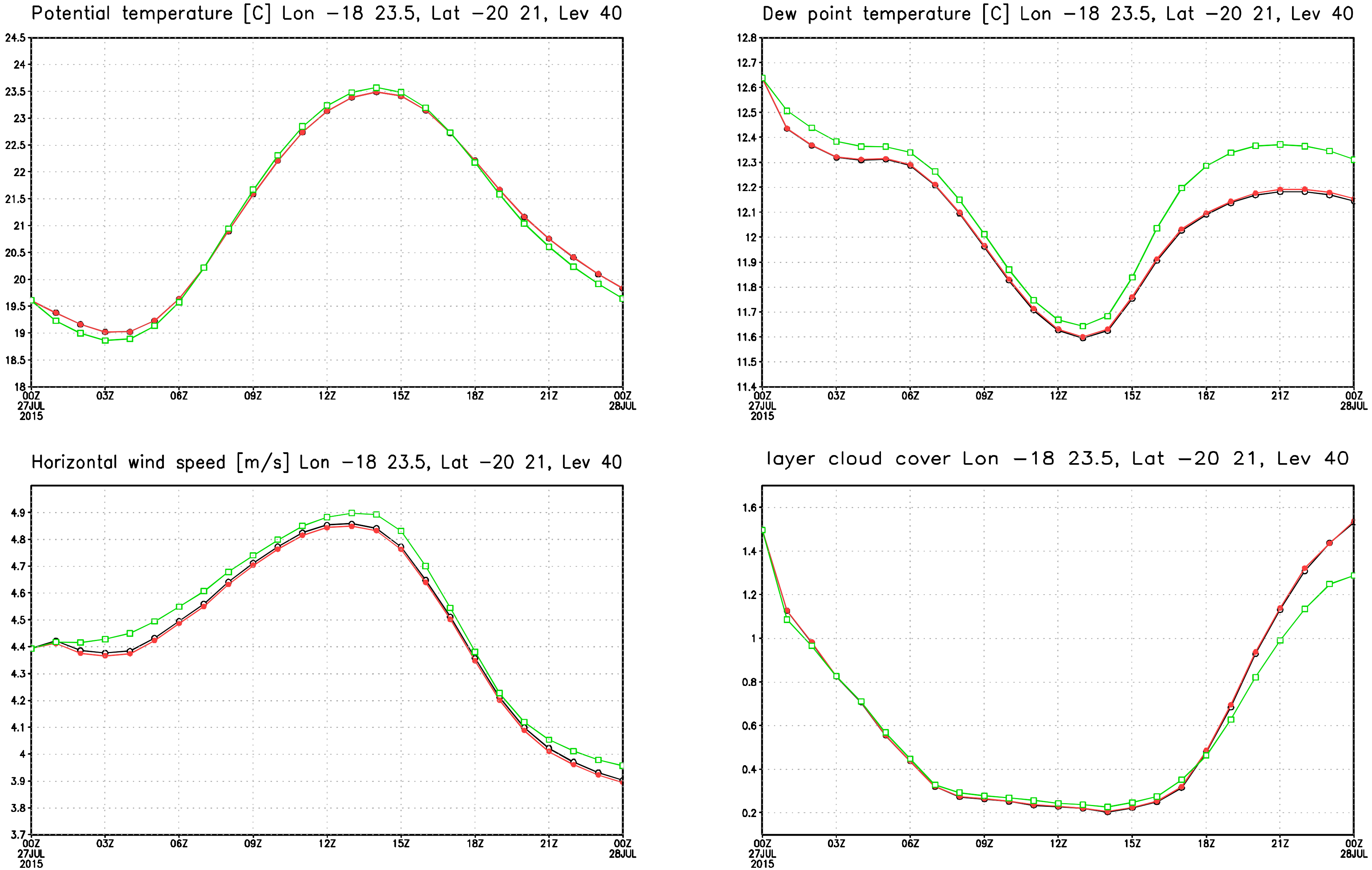
First results:

2. The introduction of the stable branch for the resistance-integration of profile functions in the case of using the upper velocity-scale node makes only slight differences compared to those from the ICON-configuration

Time series of model-domain-averages

COSMO-EU: common TURBDIFF



COSMO-donfig **COSMO-donfig + stable P-layer-profile-funct.** **ICON-donfig_ltkeshs=T**

— out_lm2_rlme_mra_cosmo-itype_vdif=0-imode_mdif=0-imode_tran=0 — out_lm2_rlme_mra_cosmo_tr3-itype_vdif=0-imode_mdif=0-imode_tran=0 — out_lm2_rlme_mra_icon-itype_vdif=0-imode_mdif=0-imode_tran=0-ltkeshs=.TRUE.

Next steps

Diffusion part:

- Introducing metric corrections for vertical diffusion in case of 3D-diffusion
- Decision for one of the possible modes

Turbulence part:

- Finding an optimal configuration by varying available options
- Testing not yet activated (new and even older) development
  - positive-definite TKE-solution, less restrictive relaxation of singularities in stb.funct.
  - Deardorff-restriction of turbulent master-scale for stable stratification, …
- Implementing further extensions
  - Prognostic equations for scalar variances
- Restructuring of the initialization part
- Only flux-input form turbtran to turbdiff (for better enabling flux aggregation of a tiled surface)
- Implementing more rigorous statistical hyper-parameterizations substituting some of the so far rather crude ICON-fixes of the form: former-model-parameter = fnc(model-variables)
- Further completion of the STIC-implementation

Analysis of current thermal stability damping of the SAT-scheme:

- Turbulence scheme applied to CFL → Resistance representation of surface fluxes
  - Usual parameter values
  - TKE-equilibrium
  - No STIC-terms

  Resistance representation of surface fluxes
  - Representing Dyer-Businger Profile-function
  - In accordance with MO-similarity
  - Solution similar to former Louis-Scheme

  - Linear u^{ϕ} -profile for non-stable SL-stratification (currently used)
  - Hyperbolic stable SL-stratification (new extension)
  - Profile-parameter according to $\gamma_s^{\phi} = \frac{z_0}{z_P - z_0}\left[\frac{u_P^{\phi}}{u_0^{\phi}} - 1\right]$ and sufficient shallow lowest model-layer

  or according to $\gamma_s^{\phi} = 1 - \frac{u_*}{u_0^{\phi}} \frac{S_{neut}^{\phi}}{S_{neut}^{M}}$ in general

- Hypothesis:
  - Mainly because the lowest model layer is still too large, the stability-dependency of the transfer-resistances is damped in cases of strong gradients and MO-similarity is not well represented, even if it is valid
    - Too large transfer-coefficients (and surface fluxes) for stable stratification
  - The introduction of the scheme had (nevertheless) gained one of the largest increase of skill
    - partly due to its larger generality
    - partly due to the compensation of still missing effects by the constructed stratification damping

Testing our hypothesis:

by Ines Cerenzia

- Application of component testing using CSMO-SC with the common TURBDIFF-code and tower measurements:
  - Reducing the numerical security limits in the turbulence model and the specific SAT-code (based on the common code)
    - ➢ Only marginal effect
  - Comparison with a modification by substituting the dimensionless P-Layer-resistance by the MO-stability function

$$\kappa u_0^\phi \cdot r_{0A}^\phi = \ln\left(\frac{z_A}{z_0}\right) - \underset{\uparrow}{\psi}\left(\frac{z_A}{L_{MO}}\right) \qquad L_{MO} := -\rho \frac{c_p}{g} \frac{u_*^3 \hat{\theta}_v}{S_{hfl}}$$

MO-stability-length

MO- semi-empirical integral-stability-function

- ➢ Considerably larger sensitivity of transfer-coefficients at stable stratification
  - Lower magnitude of surface fluxes
  - Stronger decrease of nocturnal T2m

Fluxes: sensitivity to observed stability

Friction velocity

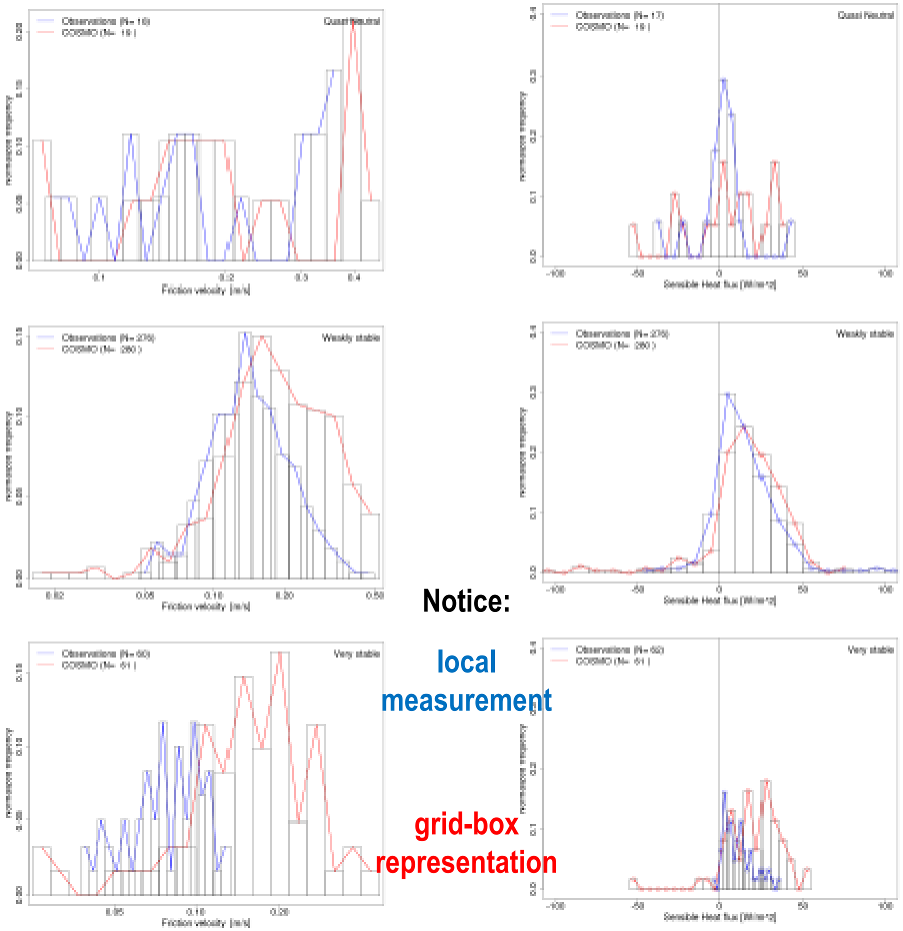
Sensible heat flux

Observations
COSMO

Quasi Neutral

Weakly Stable

Very Stable



Notice:

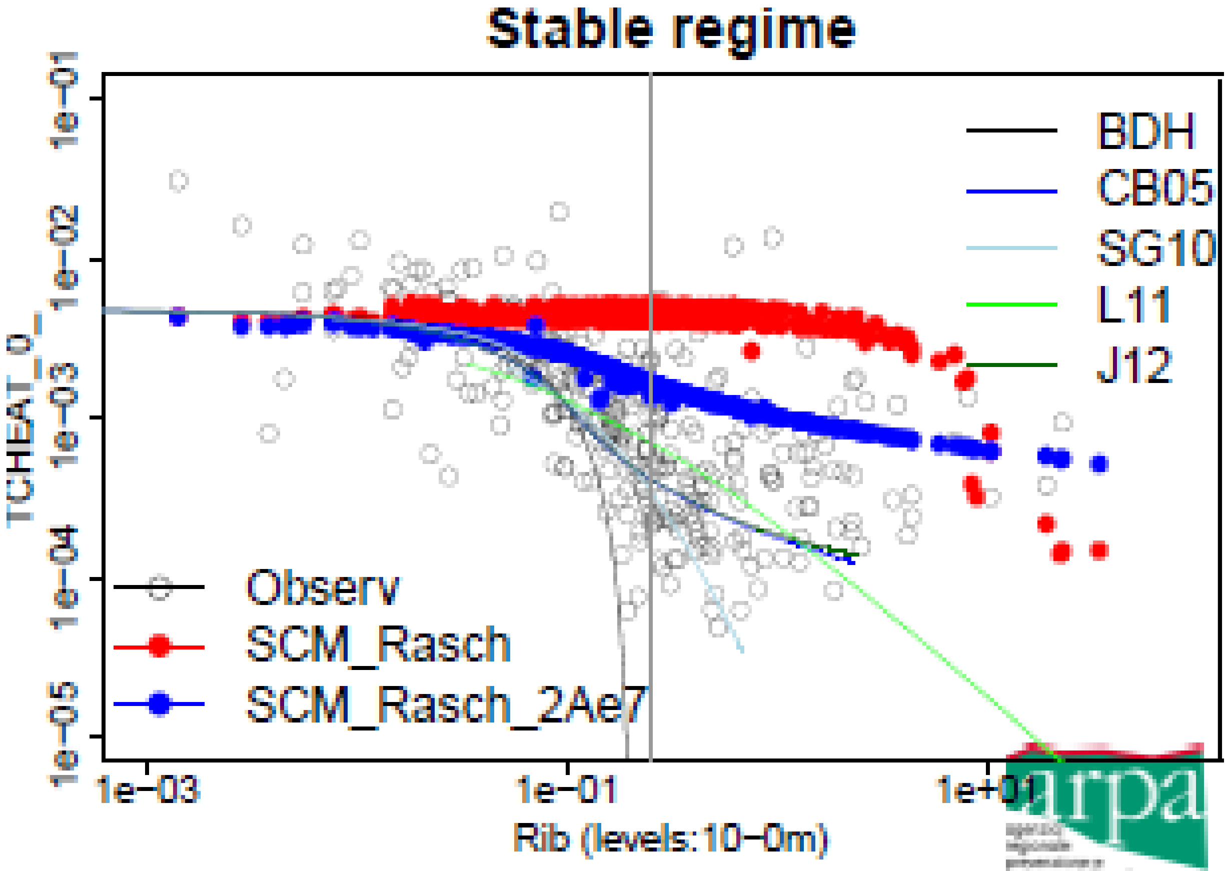
local measurement

grid-box representation

The more the regime is stable, the more COSMO tends towards higher values of fluxes!

Transfer-coefficients:

- Simulated in a SC-run forced by measured T2m, Td2m V10m and Ts
- and derived directly form measurements



- A first test-case based verification over Italy was rather indifferent, even though pointing in the right direction

Next steps

- Testing and further developing the recently implemented P-layer-resistance without the upper turbulent node in comparison with the MO-test-implementation
- Investigation of the direct Iteration of z0 and the stability parameter over sea-surfaces
- Implementing and testing a developed fully closed resistance formulation without a special treatment of neither the R- nor a L-layer.

The new TURBDIFF-version for COSMO and ICON

Part 1:

- general features
- implementation in COSMO
- modification in the atmospheric part

Matthias Raschendorfer

DWD

Generalized numerical vertical diffusion:

$$K^{\phi} = \begin{cases} \mathrm{MAX}\left\{k^{M}, '\mathrm{tkm\,min}', \ell S^{M} q\right\} & \phi \quad \text{is a horizontal wind component} \\ \mathrm{MAX}\left\{k^{\phi}, '\mathrm{tkh\,min}', \ell S^{H} q\right\} & \phi \quad \text{is a scalar variable} \\ \ell S^{TKE} q, \quad S^{TKE} = \mathrm{const} & \phi = \mathrm{TKE} \end{cases}$$

$$\partial_t \phi\big|_{VDif} = \partial_z \left[K^{\phi} \partial_z \phi + F^{\phi}_{NGrd}\right] =: \underbrace{\partial_z \left[K^{\phi} \partial_z \tilde{\phi}\right] = \partial_t \tilde{\phi}\big|_{VDif}}_{\text{solved } \textbf{semi-implicitly} \text{ (tri-diagonal linear solver)}}$$

non-gradient flux corrections

- Can be applied to halve- and full-level variables
- Can be looped over all variables to be diffused; common calculations are done only once
- Non-gradient flux corrections may be due to
  - flux conversion into non conserved variables scalar variables due to SGS phase changes of water
  - current representation of the “circulation term” (to be revised) for TKE
- Explicit tendencies can be considered in the implicit equations as well
- Lower boundary conditions selectable for each diffused variable

The additional shear terms:

- Additional shear terms are marked by F_C^M in the **total shear term** $F_T^M := (\partial_z \hat{u})^2 + (\partial_z \hat{v})^2 + F_C^M$
- 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

$$P_C^{SKE}(q_C, L_C, \cdots) \approx \frac{q_c^3}{\alpha_c^{MM} L_C}$$

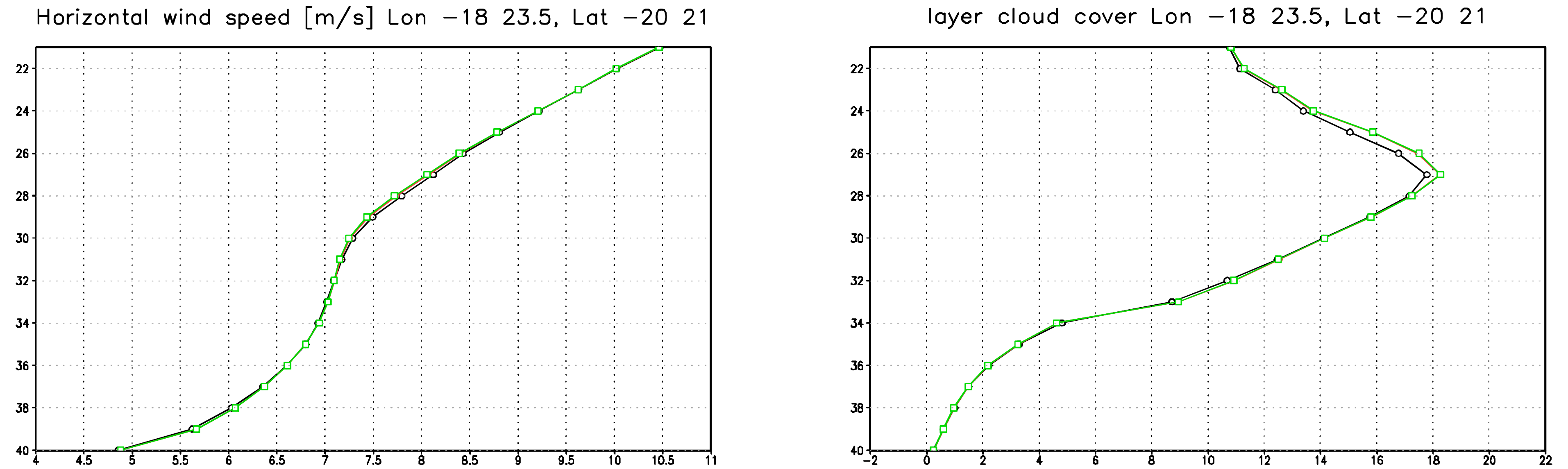
  - (laminar shear)
- They are positive definite and neither dependent on ℓ nor on q
- They prevent turbulence from "dying" in the absence of vertical shear and negative buoyancy (stable stratification)
- They make the turbulent scheme realizable, if turbulent closure assumptions are not valid for the 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**

The new TURBDIFF-version for COSMO and ICON

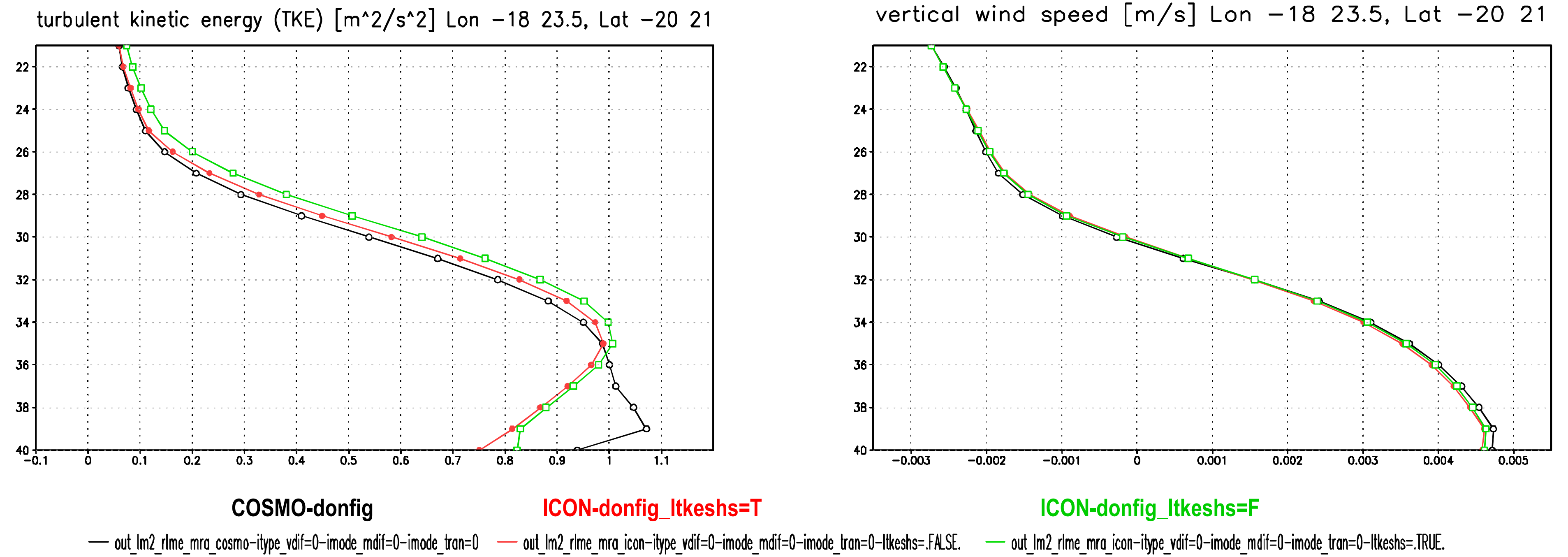
Part 2:
- modification in the SAT-part
- first results and next steps

Matthias Raschendorfer

DWD



COSMO-EU: common TURBDIFF



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Next steps

turbtran:

- Testing and further developing the P-layer-resistance without the upper turbulent node
- Implementing and testing the fully closed resistance formulation without a special treatment of neither the R- nor the L-layer.

turbdiff (diffusion part):

- Introducing metric corrections for vertical diffusion in case of 3D-diffusion (in ConSAT)

turbdiff (turbulence part):

- Testing not yet activated (new and even older) development
  - positive-definite TKE-solution, less restrictive relaxation of singularities in stb.funct.
  - Deardorff-restriction of turbulent master-scale for stable stratification, …
- Further development of STIC
  - Circulation-term” as “thermal SSO-scheme
  - Statistical saturation adjustment including contributions from all SGS processes (also related to T2(RC)2)
  - Substituting the so far rather crude ICON-fixes
  - Complete transport including contributions from all SGS processes
- Implementing further extensions
  - Prognostic equations for scalar variances