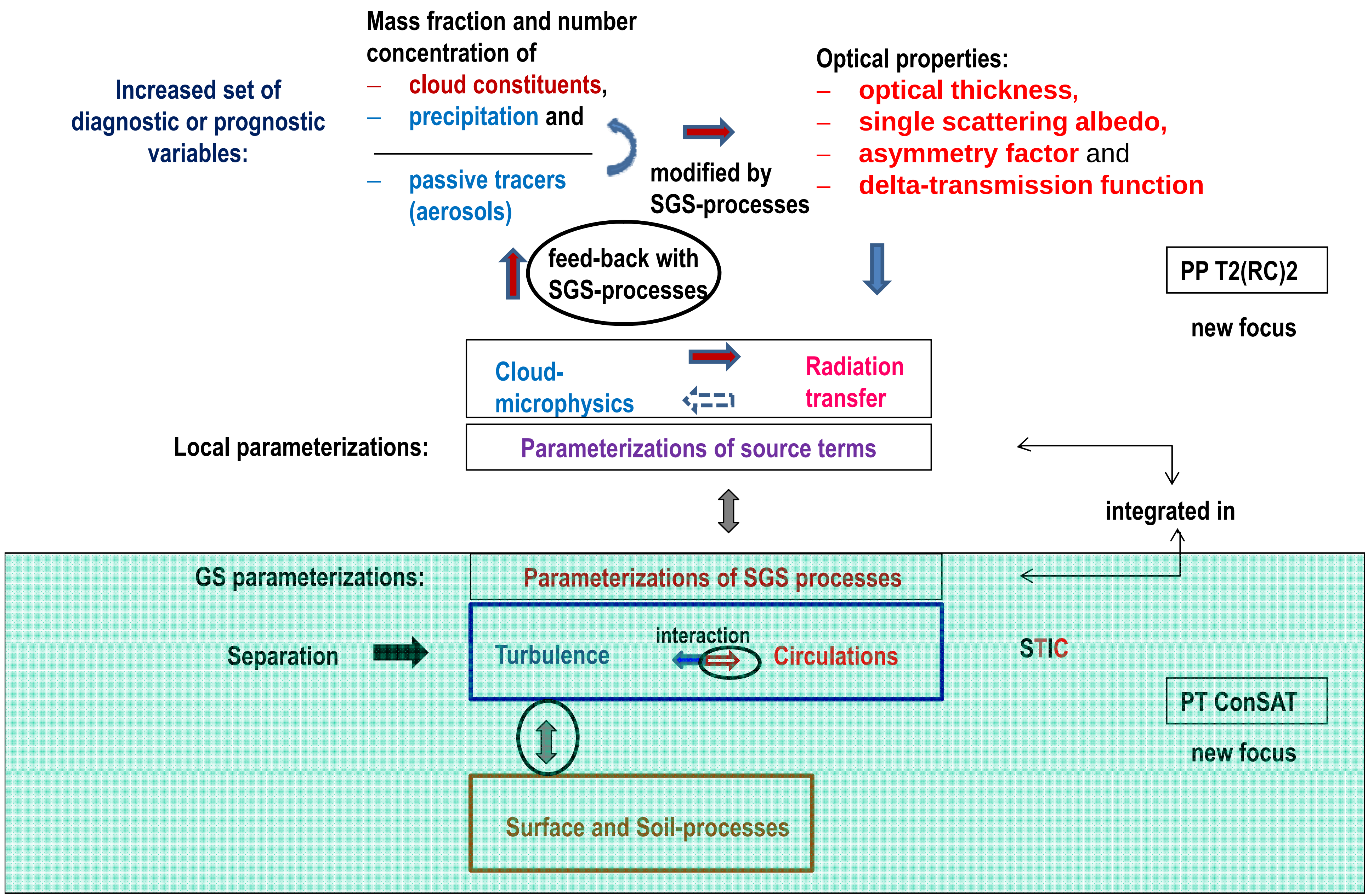
# Along the aim of COSMO-SP to consider missing interactions:



# Status about scale-separation and the impact of surface-inhomogeneity on SAT:

# The fundamental problem of missing scale separation:

- We usually apply parameterizations of effects on 1-st order budgets due to flow-patterns on different sub-grid scales (turbulence, $\underbrace{\text{convection, SSO wakes, gravity waves. ...}}_{\text{sub-grid “circulations”}}$)
  without using a clear scale-separation procedure.
  - ➢ Each scheme for a specific SGS pattern would ONLY be valid, if ALL the other sub grid scale processes were IN ACCORDANCE WITH ITS SPECIFIC CLOSURE ASSUMPTIONS, what is in CONTRADICTION to the need of DIFFERENT SGS schemes!!
- This missing separation causes serious problems:
  - ➢ Non-realizability due to the application of not valid assumptions
  - ➢ Double-counting of effects from different scale regimes
  - ➢ Missing feedback between different scale regimes
    - o No amplification of turbulence due to the action of circulations especially at stable stratification
      - ❖ Turbulence forecast for aviation can’t be based on EDR from turbulence scheme!
    - o No decrease of Circulation Kinetic Energy (CKE) by turbulent friction
    - o No trigger of convective circulations by turbulent eddies or shallow surface-layer circulations
    - o No consistent parameterization for sub-grid cloud generation from different scales

## Problem of the NOT-separated TKE-scheme (including empirical extensions by Günther Z.):

- TKE vanishes at stable stratification without vertical shear
  - Unrealistic decouple of surface and boundary layer and missing stratospheric turbulence
    - Artificial limitations and empirical extensions are necessary
    - A turbulence index for aviation can't be based on

EDR

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

restrictions for very stable stratification

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

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

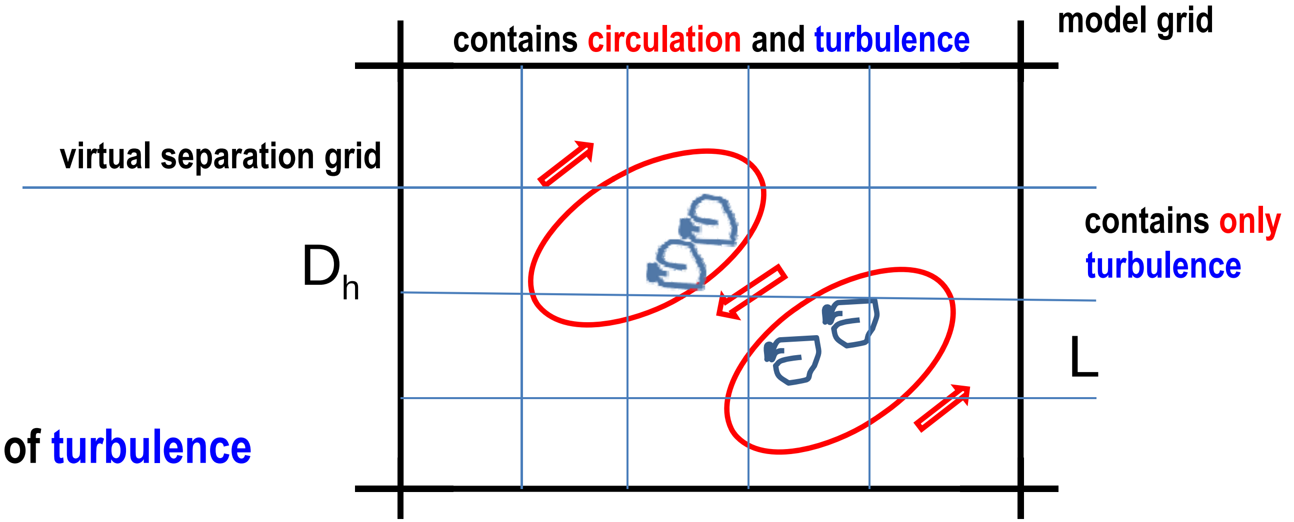
artificial treatment of possible singularities

- **diagnostic (linear) system** dependent on **TKE=$q^2/2$**
  and **mean vert. gradients** $F_T^M \quad F^H$
  (for all other 2-nd order moments) => **stability functions**: $S^M \quad S^H$

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

Ri.number dependent minimal diffusion coefficients Kmin

# Separated Turbulence Interacting with non-turbulent Circulations (STIC):




- 3D-shear production of turbulence
  - But also from non-turbulent sub-grid flow patterns (circulations) -> SI-terms
    - Connected with coherent structures being NOT IN ACCORDANCE with turbulence closure
    - Would be expressed by grid-scale 3D shear, if the patterns were resolved by a smaller grid
    - Extracts kinetic energy from the circulation flow and feeds turbulence
- SI-terms appear automatically in separated 2$^{nd}$-order equations for pure turbulence
  - Built with respect to the separation scale L and additionally filtered by the grid scale $D_h$
- 1-st order budgets with SGS contributions from turbulence and circulations

$$\overline{\rho\phi\psi} = \bar{\rho}\hat{\phi}\hat{\psi} + \overline{\rho\phi''\psi''}\Big|_L + \overline{\bar{\rho}\big|_L \hat{\phi}\big|_L{}'' \hat{\psi}\big|_L{}''}$$

$|_L$ : with respect to the separation scale L

# Separated TKE equation contains additional shear term:

- **Semi-parameterized (neglecting laminar transport and roughness layer modification of transport)**

$$2\cdot \mathrm{TKE} := q^2 := \frac{\overline{\overline{\rho}|_L\, q|_L{}^{2}}}{\overline{\rho}} \qquad 2\cdot \mathrm{CKE} = q_C^2 := q|_L{}^{2} := \frac{1}{\overline{\rho}|_L}\sum_{i=1}^{3}\overline{\rho v_i''^{2}}|_L$$

$|_L$ : with respect to the separation scale L

not yet considered

$$\partial_t\left(\frac{1}{2}\overline{\rho}\cdot q^2\right) = \frac{1}{2}\overline{\nabla}\cdot\left(\overline{\rho}\, q^2\,\hat{\mathbf{v}} \boxed{+\hat{\rho}|_L\,\overline{q|_L^{2}\,\hat{\mathbf{v}}|_L''}} + \sum_{i=1}^{3}\overline{\left(\rho v_i''^{2}\mathbf{v}''\right)|_L}\right) + \frac{g}{\hat{\theta}_v}\overline{\overline{\rho\theta_v''w''}|_L} + \left[-\sum_{i=1}^{3}\overline{\overline{\rho v_i''\mathbf{v}''}|_L}\cdot\overline{\nabla}\hat{v}_i\right] + \overset{Q_C^{TKE}}{\left[-\sum_{i=1}^{3}\overline{\overline{\rho v_i''\mathbf{v}''}|_L{}'\cdot\left(\overline{\nabla}\hat{v}_i\right)|_L{}'}\right]} + \left[-\overline{\rho}\frac{q^3}{\alpha^{MM}\ell}\right]$$

time tendency

transport:
(advection
**+ circ. diffusion**
+ turb. diffusion)

buoyancy production

labil: $>0$
neutral: $=0$
stabil: $<0$

shear production by the mean flow

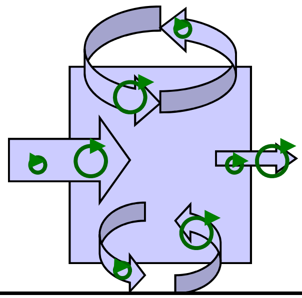
$\boxed{\geq 0}$

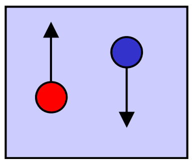
**shear production by sub grid scale circulations**

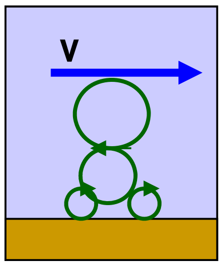
$\boxed{\geq 0}$

eddy-dissipation rate (**EDR**)

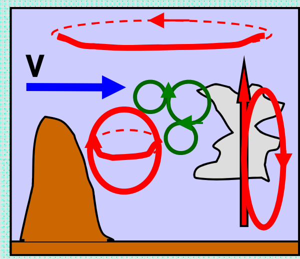
$\boxed{<0}$



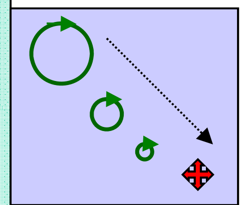




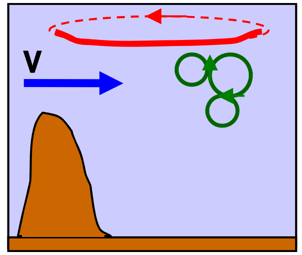




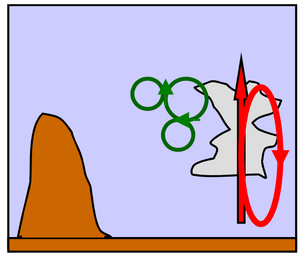




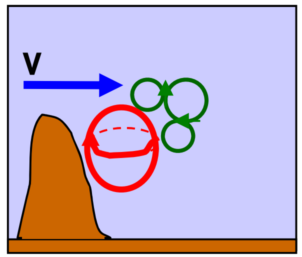
# Current status of STIC in ICON:




- dTKEshs → "due to separated horizontal shear currents"
  - ✓ switched on in TKE-equation and stored for EDR post-processing
  - ✓ main contributor in the stratosphere and in frontal zones
  - ✓ empirical reduction near the ground and for strong stable stratif. ✓ Introduced by Günther Z.
    - ➢ formulation SI-sink in CKE-budget of SHS-circulation also dependent on turbulent velocity scale. ✓ related extension in preparation



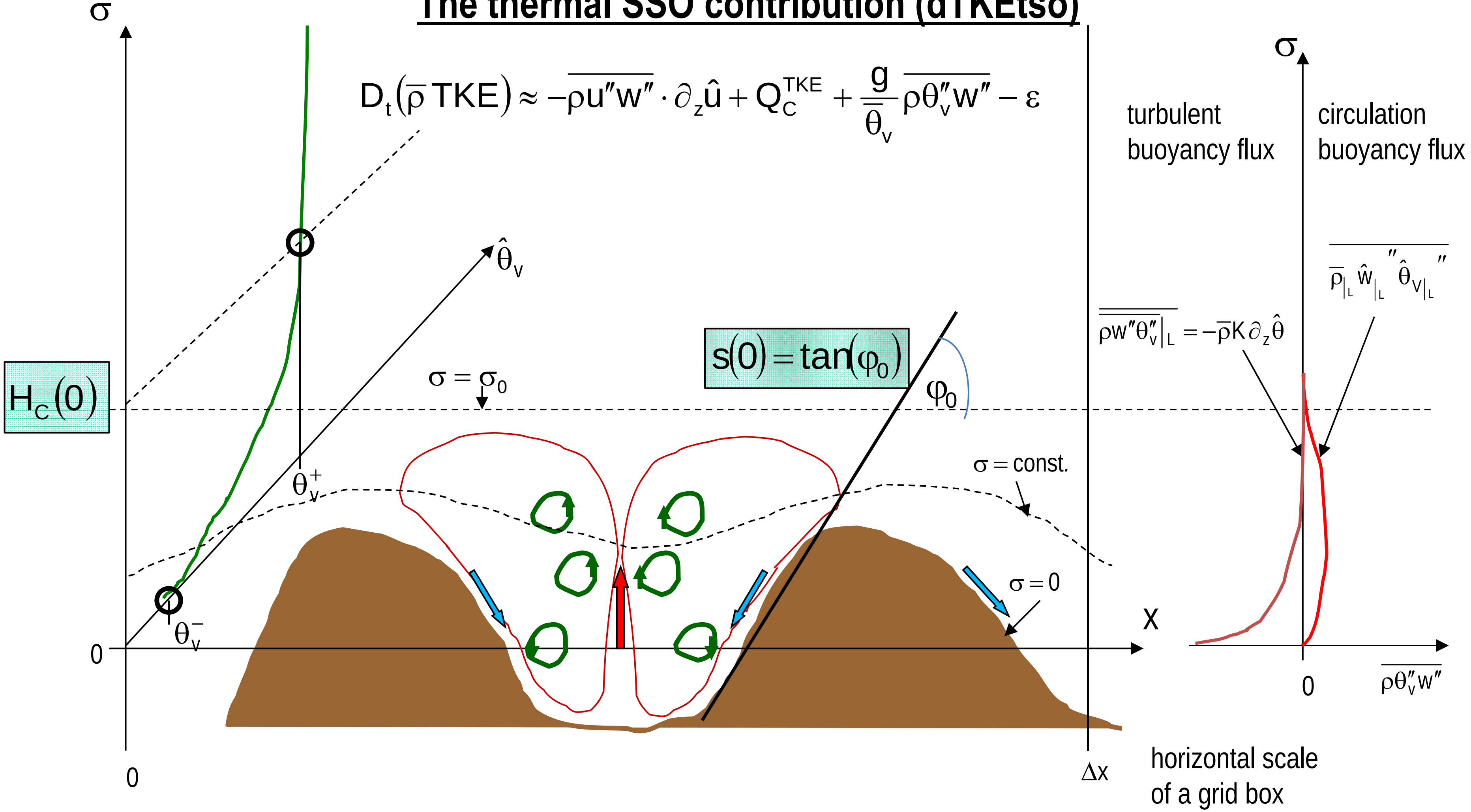
- dTKEcnv → "due to action of parameterized convection"
  - ✓ so far only calculated for EDR post-processing
  - ✓ Important EDP-contributor within the troposphere
  - • Not yet used in prognostic TKE-equation
    - ➢ removing sources of detrimental jumps in space and time
    - ➢ introducing turbulence-feedback into convection-scheme ✓ not planned for near future
    - ➢ formulating detrainment/entrainment also dependent on turbulent velocity scale
    - ➢ triggering SGS convective plumes by turbulent vertical velocity




- dTKEsso → "due to action of parameterized SSO-blocking and and braking of vertically propagating gravity waves"
  - ✓ Switched on in TKE-equation and stored for EDR post-processing
  - ✓ important contributor above mountains and at top of stratosphere
  - ✓ empirical reduction for strong stable stratification ✓ Introduced by Günther Z.
    - ➢ formulation of SI-sink in CKE-budget of mechanical SSO-circulation dependent on turbulent velocity scale ✓ related extension in preparation

# Implementation of a new STIC-contribution due to sub-grid kata- (or ana-)batic circulation induced by SSO:

## The thermal SSO contribution (dTKEtso)




Even for **vanishing mean wind** and **negative turbulent buoyancy** there remains a **positive definite source term**

➡ TKE will **not** vanish ➡ Solution even for **strong stability**

# TKE-production by sub-grid circulations:

- **Equilibrium of production and spectral transfer towards turbulence:**

$$g\frac{\Delta\overline{\theta}_v}{\overline{\theta}_v}\sin(\varphi)\cdot q_C \approx Q_C^{TKE} \propto \frac{q_C^3}{L_C}$$

is going to substitute current "circulation term", which had already been restricted to grid-points with strong SSO amplitudes by G. Zängl

$$H_C(\sigma) \approx \max\{0, H_C(0) - \sigma\}$$

mean height-amplitude of a $\sigma$ -surface

$$s(\sigma) = \tan[\varphi(\sigma)] \approx s(0)\cdot\frac{H_C(\sigma)}{H_C(0)}$$

mean slope of a $\sigma$ -surface

$$L_C = \frac{H_C}{\sin(\varphi)}$$

coherence-length along the $\sigma$ -slope

$$\Delta\overline{\theta}_v \approx \left|\partial_z\overline{\theta}_v\right|\cdot H_C$$

effective temperature difference

$$\boxed{Q_C^{TKE} \approx \alpha_C\frac{(s\cdot H_C)^2}{1+s^2}\left|F^H\right|^{\frac{3}{2}}}$$

resulting TKE-production

$q_C$ may trigger convection

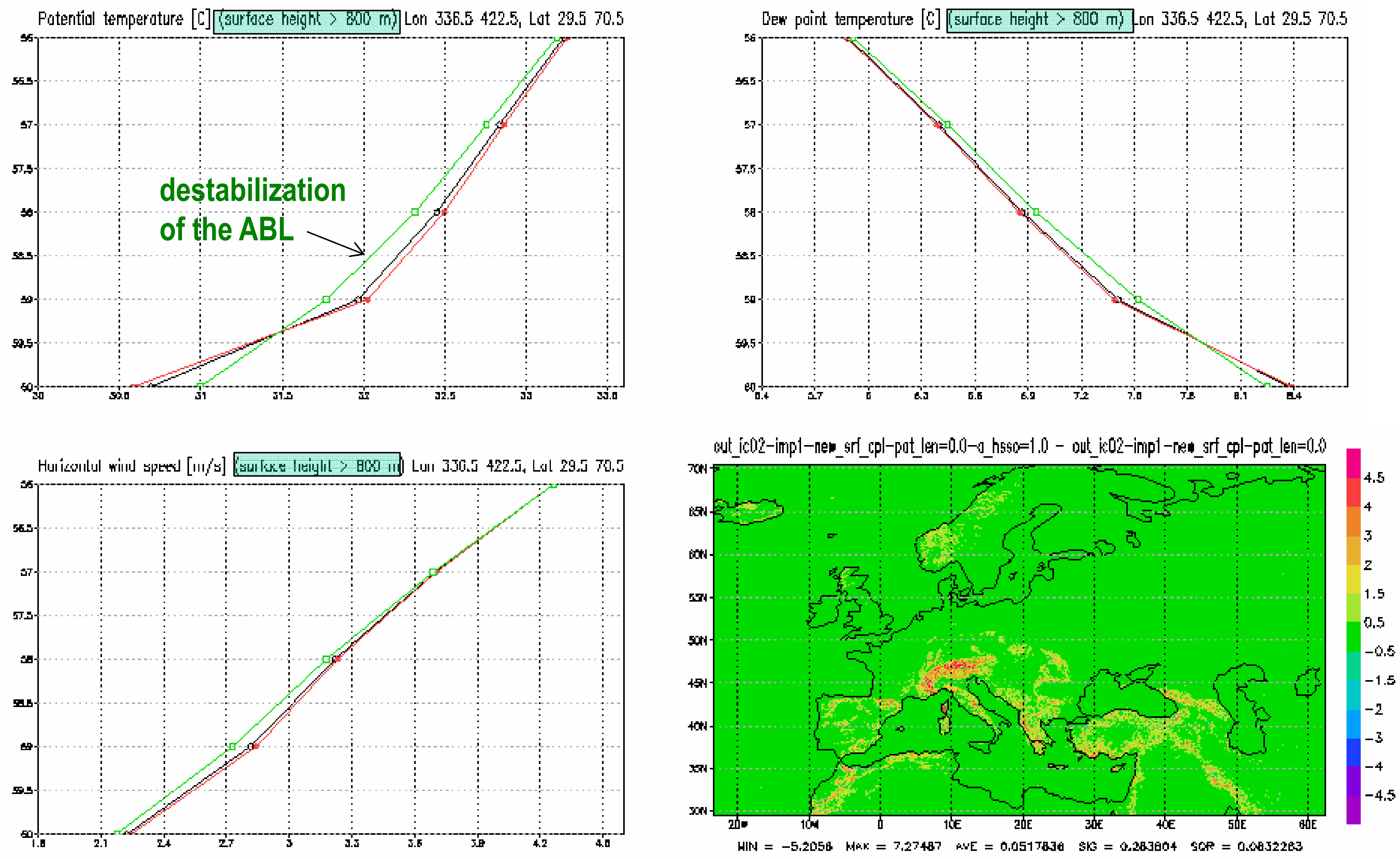
$$F^H = \frac{g}{\overline{\theta}_v}\partial_z\overline{\theta}_v \begin{cases} <0: \text{anabatic} \\ >0: \text{katabatic} \end{cases}$$

$q_C$ ventilates the SBL

$$\left.\begin{array}{l} H_C(0) \\ s(0) \end{array}\right\}$$ external 2D SSO-parameters

$\alpha_C$ effective scaling parameter

# Nocturnal effect of new SI-term from thermal SSO




current circ.-term with strong SSO-limitation — out_ic02-imp1-new_srf_cpl

no thermal circulation term at all — out_ic02-imp1-new_srf_cpl-pat_len=0.0

new therm. SSO term with $\alpha_c$ = 1 — out_ic02-imp1-new_srf_cpl-pat_len=0.0-a_hsso=1.0

pr time=03Z23JUN2016 pr hour=3hr

## General Remarks to the STIC-Impact:

- **Increased shear lowers Ri-number at stable stratification within the ABL and also enters the calculation of stability functions**
  - **Avoids singularities of the solution**
  - **Substitutes the introduction of artificial "long-tale" stability functions**
- **Has a direct impact on transfer-velocities due to the adapted construction of the transfer scheme:**
  - **Two TKE-equations: at the roughness-layer top and the next higher half-level**
  - **At least the latter can receive an impact by STIC-terms**
- **Generates additional physically based turbulent mixing at heterogeneous surfaces and stable stratification**
  - **avoids unrealistic decoupling of a heterogeneous surface from the atmosphere**
  - **Substitutes (at least partly) the introduction of artificial minimal diffusion coefficients**
- **Vertical transport by the Circulations needs to be expressed independent form turbulent diffusion!**

# Another aspect of surface heterogeneity at stable stratification

# along the idea of the current “circulation-term”:

## Employing the TKESV-scheme for expressiong the effect of

## patterns with different surface-temperature:

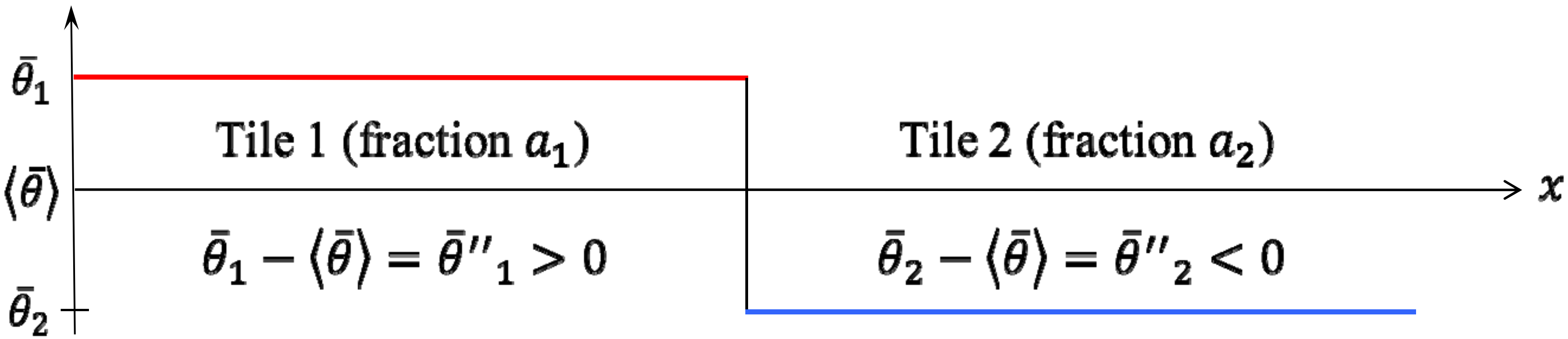
# Coupling of TKESV and Tile approach

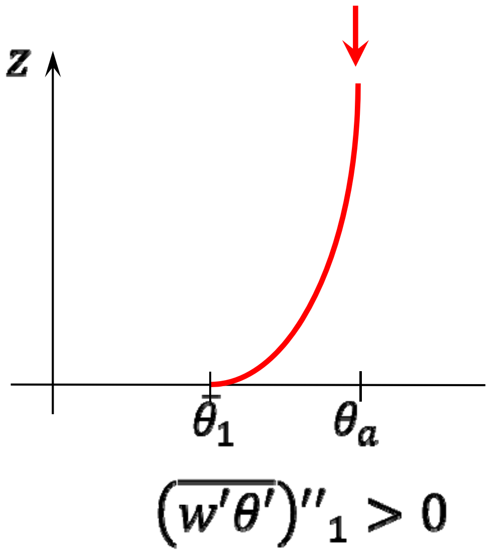


- **TKESV scheme** for **turbulent diffusion** carries prognostic transport equations not only for TKE, but also for scalar variances
- **Tile approach** in ICON (considering different surface types with individual mean Ts,  qvs and respetcive turbulent surface fluxes
- This information could be used to define a LB flux-condition for the scalar variances
- The related flux-aggregation of variances is similar to the flux-aggregation of 1-st order variables and is for the TKESV-approach a gain in consistency

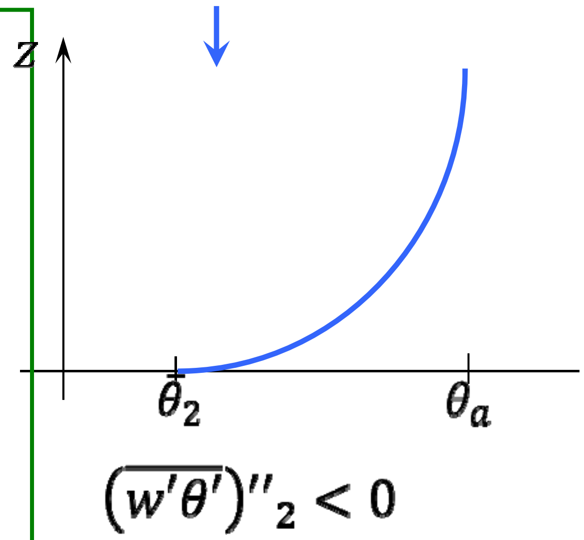
# Flux-Aggregation for temperature variance





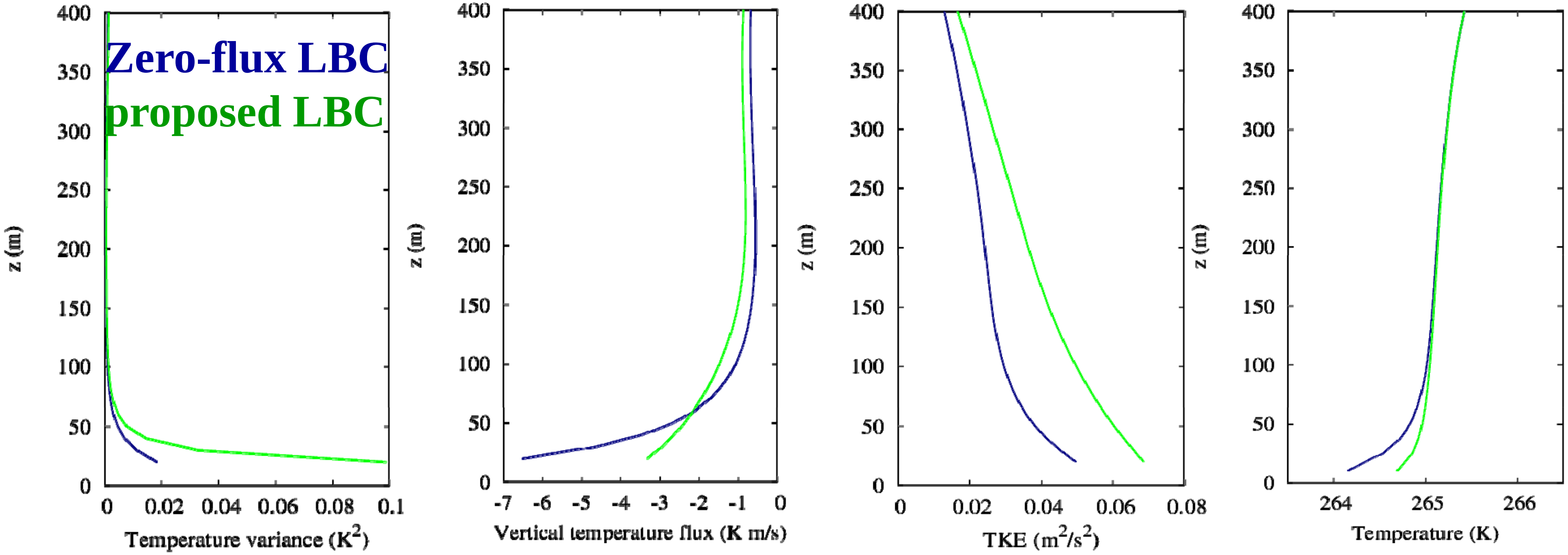

Surface temperature variations modulate local static stability and hence the surface heat flux
→ not vanishing surface-flux of temperature variance!




$$\boxed{\langle w'\theta'^2\rangle = a_1\bar{\theta}''_1(\overline{w'\theta'})''_1 + a_2\bar{\theta}''_2(\overline{w'\theta'})''_2 > 0}$$

# Numerical experiment: results

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



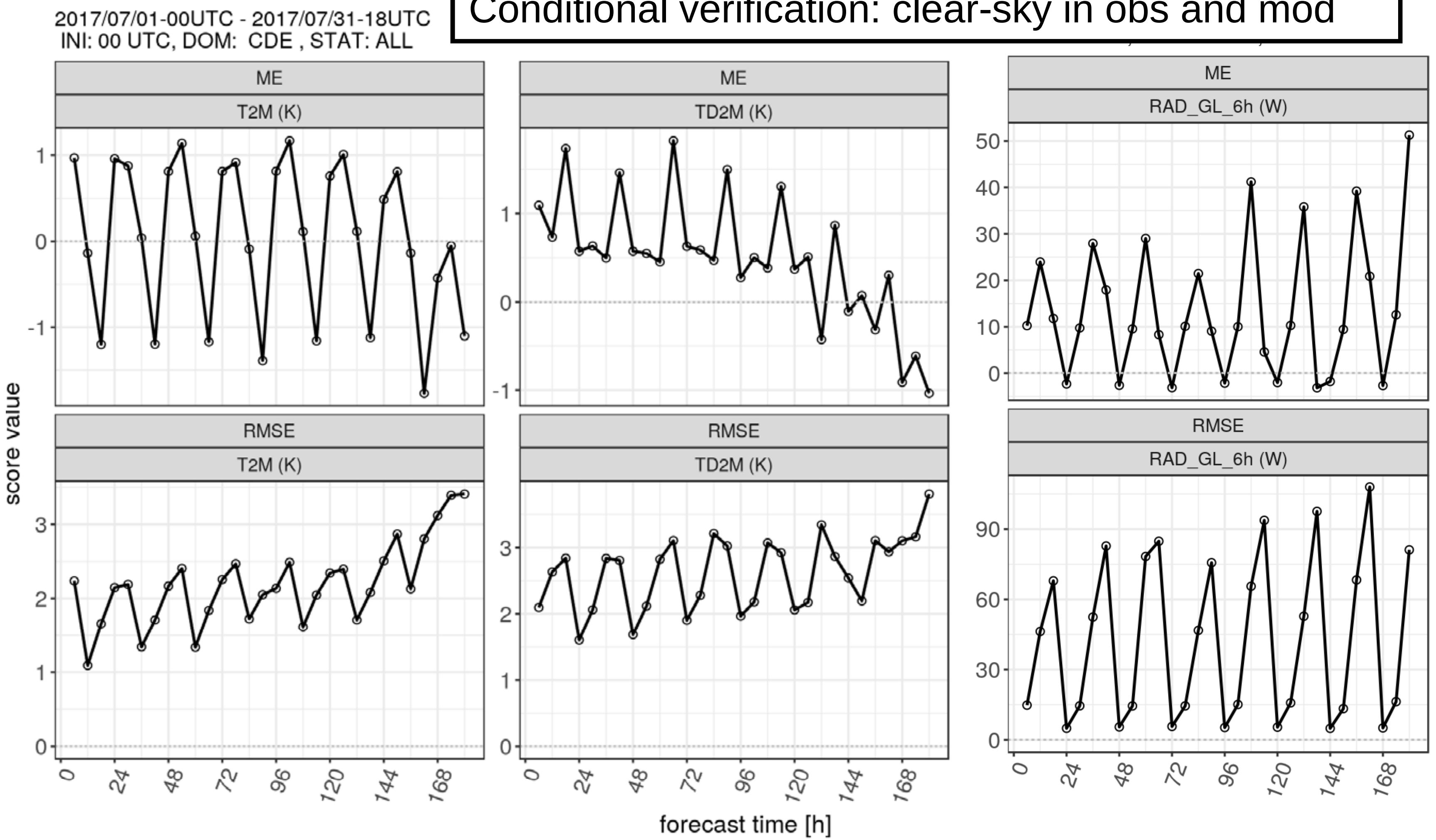

increased $\langle \theta'^2 \rangle$ near the surface → reduced magnitude of downward heat flux → less work against gravity → increased TKE → stronger mixing

- Near surface **turbulent** mixing contains the total effect of patterns with different surface temperature **without** a scale separation or even a specification of **additional scales**.
- It needs to be clarified, if in this special case the scale and the coherent and non-turbulent nature of the induced circulation can really be neglected effectively.

# Status about the improvement of direct SAT:

# ICON: Central Europe, July 2017, 00 UTC

Conditional verification: clear-sky in obs and mod




Surface warm bias at night (about 1 K), strange cold and moist bias at 18 UTC. Global radiation overestimated (about 30 W/m$^2$) during day-time.

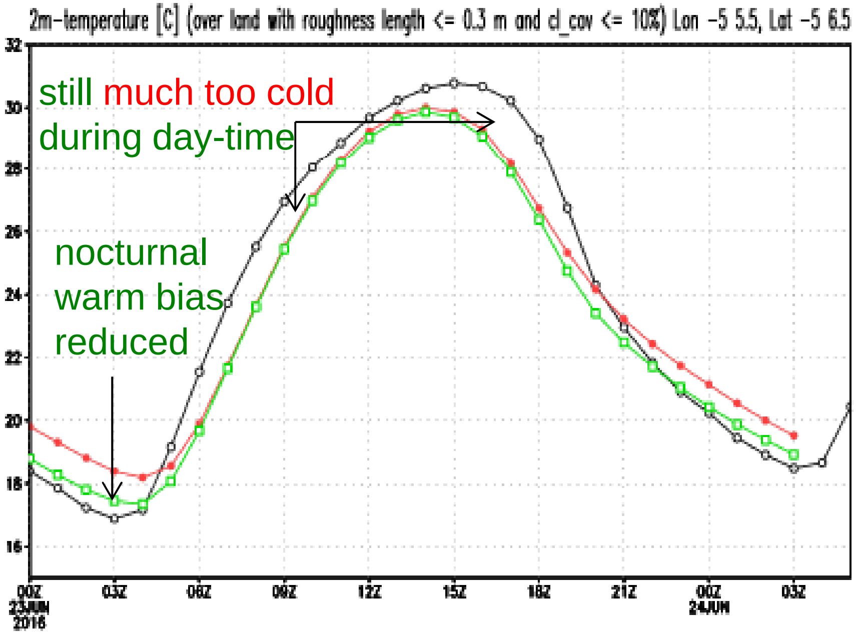
# Case study: 23.06.2016

**COSMO-DE with lateral boundaries from ICON-EU**

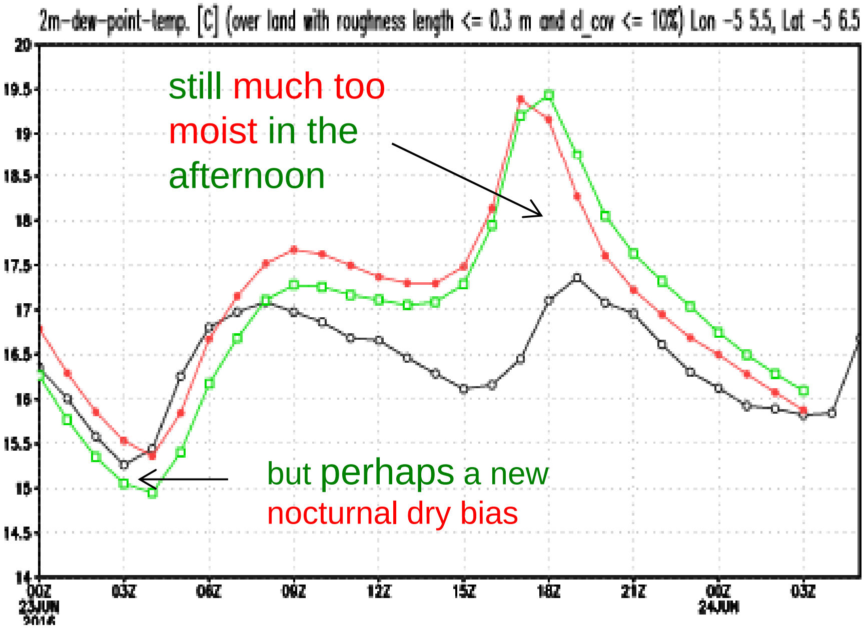
- ✓ **only for rather smooth surfaces; applied filter**
- ✓ **almost saturated soil due to long standing rain period before**
- ✓ **almost no clouds due to high pressure situation; + applied filter**

## domain averaged daily cycles of near-surface variables

**T_2m**



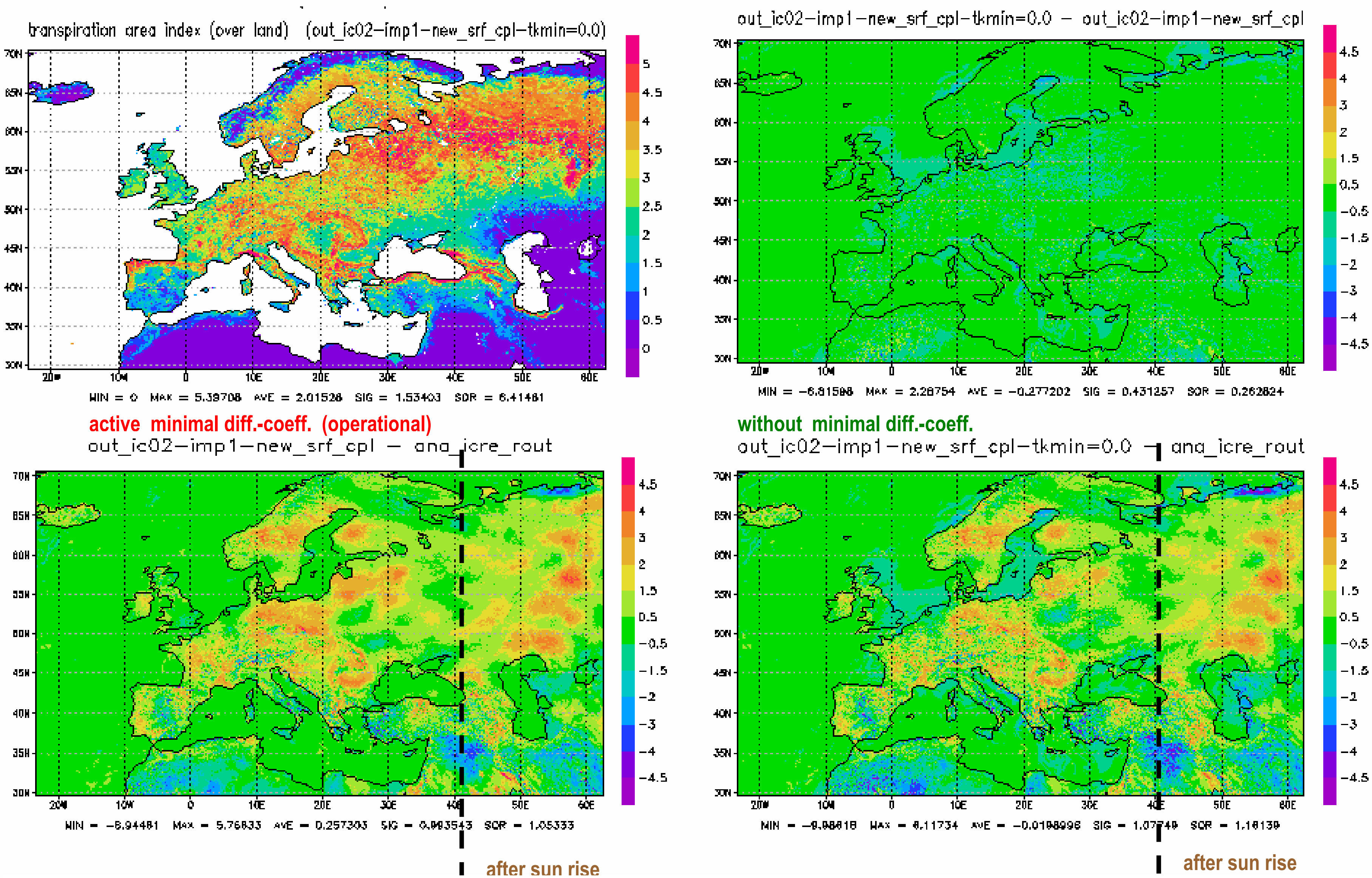

**TD_2m**




| ana_lm3_exp_10279 | out_lm3_rout | out_lm3_exp_10279 |
|---|---|---|
| direct analysis of T_2m and TD_2m | operational configuration | revised TURBDIFF imported from ICON |

# 2m−temperature [C] at 3:00 UTC

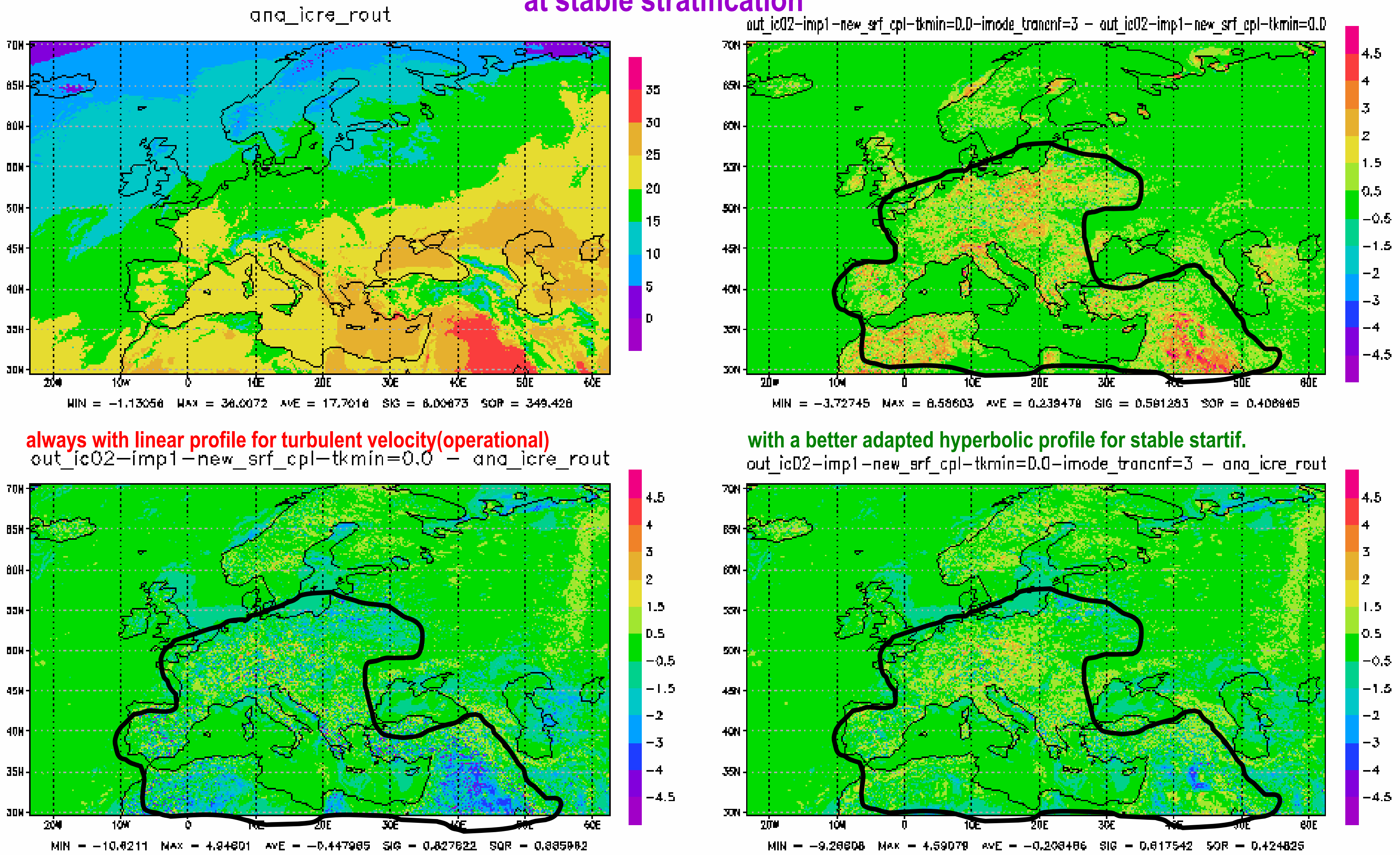
## Nocturnal effect of minimal diffusion coefficients in ICON




Positive nocturnal T2m-bias is mainly present at vegetated areas and can be slightly decreased **without** an artificial background diffusion.

# temperature [C] at 3:00 UTC

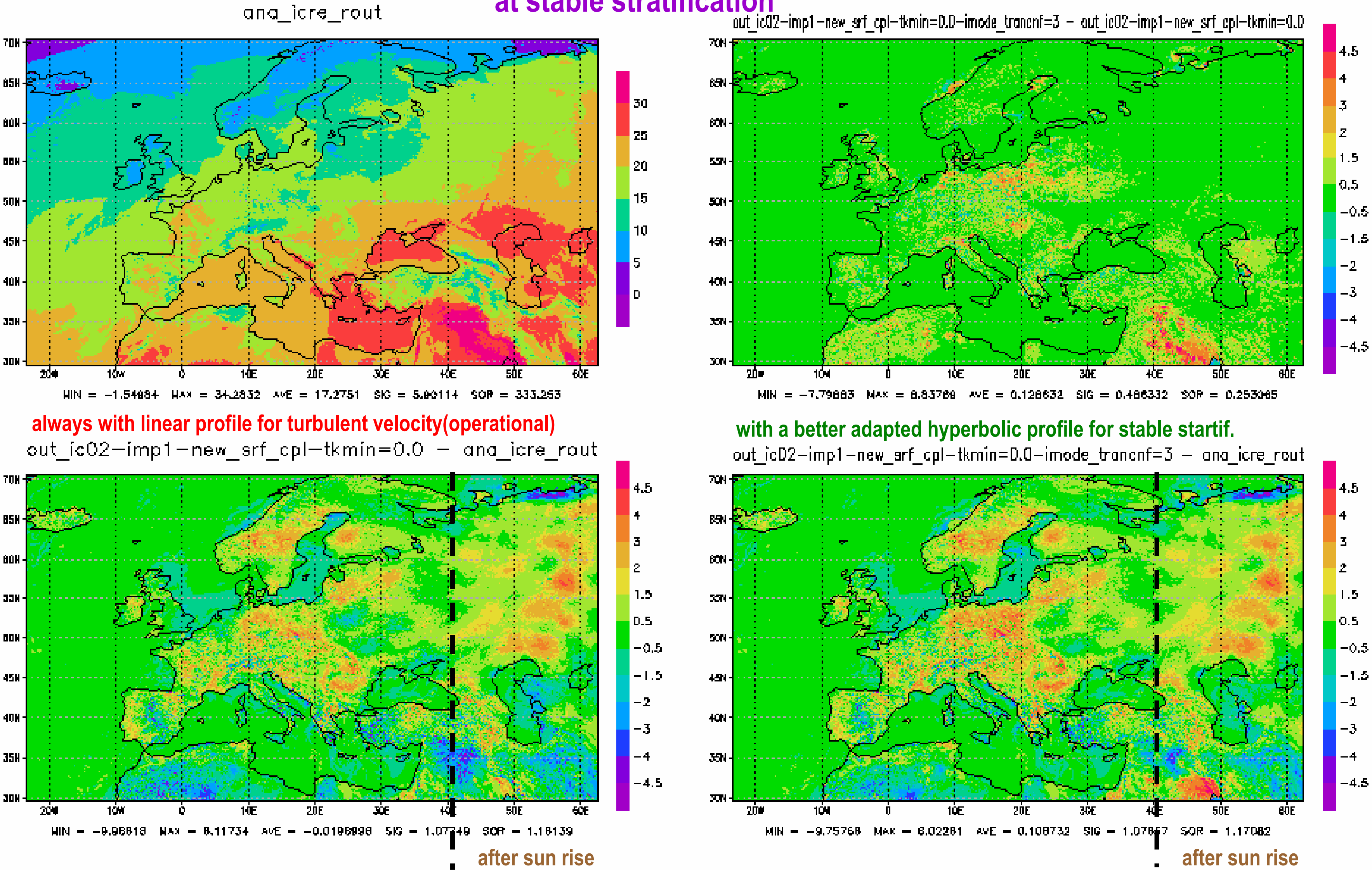
## Nocturnal effect of an specific interpolation function for turbulent velocity within the transfer-layer at stable stratification




The adapted profile-function reduces the surface coupling at stable stratification and keeps the BL above the surface warmer. This seems to be proper correction.

# 2m–temperature [C]

## Nocturnal effect of an specific interpolation function for turbulent velocity within the transfer-layer at stable stratification




But the reduced heat-flux towards the surface can't cool it down sufficiently
and T2m becomes even larger than smaller; possibly due to heat-transport from the soil!

- **<u>The lessen from these investigations:</u>**

> – **Pure modifications in the description of the turbulent Prandtl-layer can <u>hardly correct</u> the main sources of current model-errors of the diurnal cycle of near surface variables!**
>
> – **The main reason for the reduced amplitude of T2m seems to be a too strong coupling of the surface with the compact soil!**

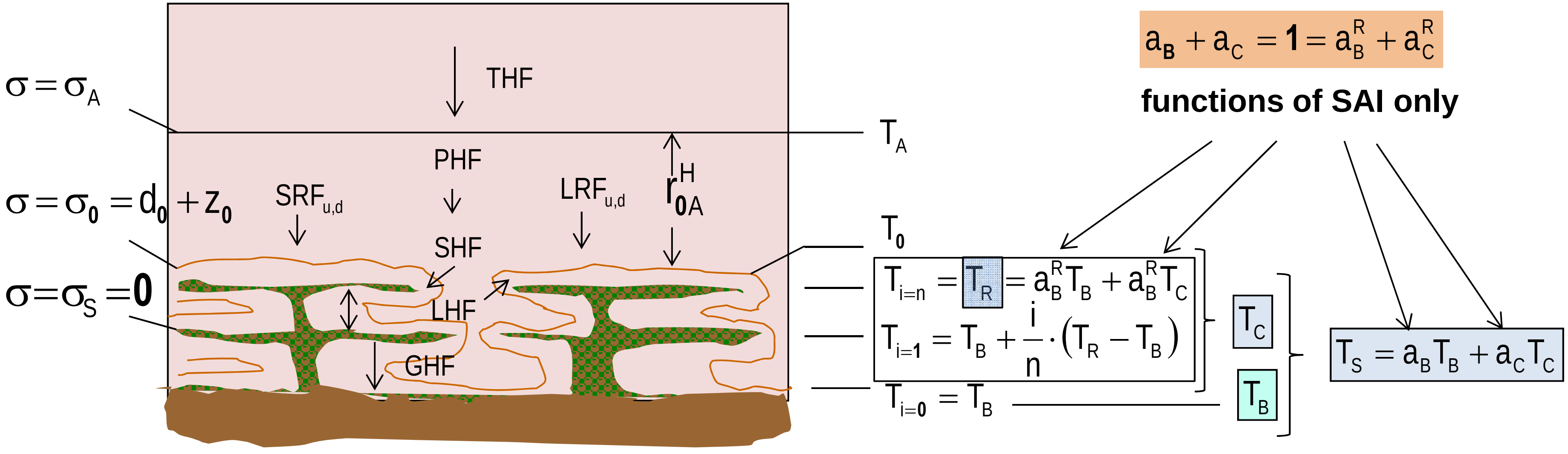
⇩

**Efforts towards a substantial, semi-transparent cover-layer (canopy) thermally loosely coupled to the dense soil:**

❖ A canopy-extension of TERRA has been developed already 2 years ago in COSMO-TERRA:

**Sequence of connected semi-transparent and substantial cover layers**

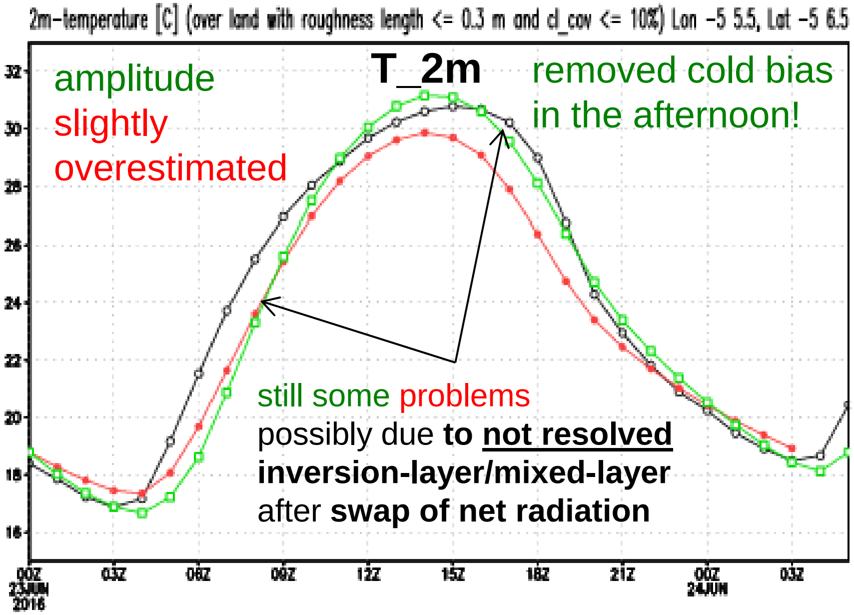
- **Coupled by long-wave radiation and atmospheric heat-transfer**
- **Linear cover-layer T-profile**
- **Common heat-budget of the cover-layers with implicit surface temperature**
- **Decreased direct coupling of surfaces with the atmosph. from top to bottom**
- **Controlled by present external parameters and 2 tuning parameters**

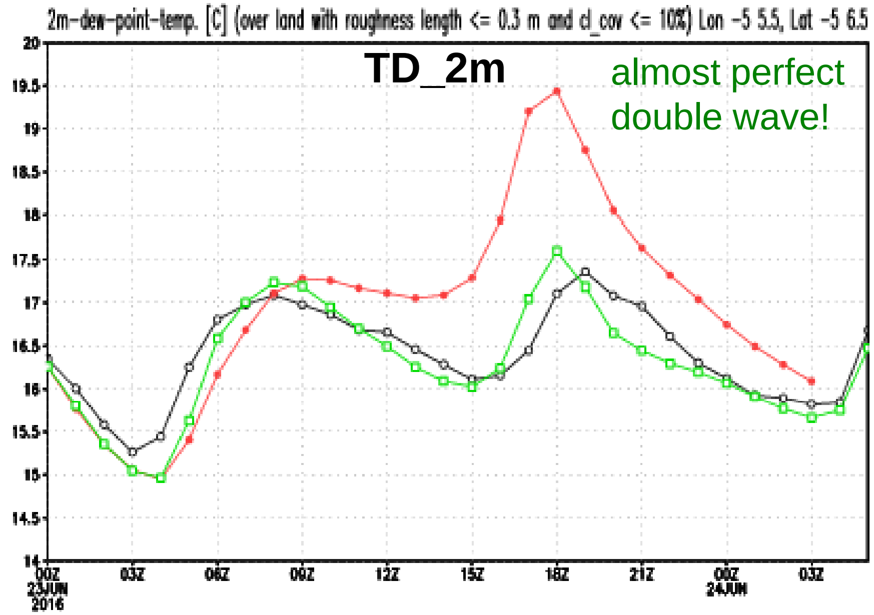


# Case study: 23.06.2016

**COSMO-DE with lateral boundaries from ICON-EU**

- ✓ **only for rather smooth surfaces; applied filter**
- ✓ **almost saturated soil due to long standing rain period before**
- ✓ **almost no clouds due to high pressure situation; + applied filter**




— ana_lm3_exp_10279 — out_lm3_exp_10279 — out_lm3_rlmk_new_surf-icon-icon-itype_surf=1-lsfluse=T-e_surf=10-c_soil=2-itype_vdif=1

**direct analysis of T_2m and TD_2m**

**revised TURBDIFF imported from ICON**

**full C-layer treatment : semi-transparent + loosely coupled + heat-storage + adapted evapo-transpiration**

- **Implementation strategy for ICON:**

**Cover layer as an extension of revised TERRA and TURBTRAN with implicit treatment of sn and sf surface temperature.**

- **Removes striking oscillations of Tsf and Tsn at large timesteps**
- **No flux limiter needed anymore**
- **Separation of formal modifications from physical extensions**

1. **Additional thermal equation for snow-free skin and corrected heat-budget for single-layer snow.**
2. **Linearization of surface processes**
3. **Thermal equations for skin, snow and soil coupled through implicit temperatures => extended linear system of equations**
4. **Related adaptations for snow-cover diagnostic, dynamic tiles, initialization (of nested domains) and organization of model-restart**
5. **Cleaning the code from detrimental limitations**
6. **Necessary restructuring of code**
7. **Correction of various inconsistencies with respect to the treatment of water interception and phase transitions of surface water**
8. **Adaptation of surface roughness at a the presence of snow**
9. **Merge with various work-arounds and extensions also present at interfaces**
10. **Passing a technical test-suite for ICON with various iterations**

**a very large effort!**

**Official ICON-release hopefully within 2018**

# Resulting matrix of the extended linear system:

altered

created

- All 2 + k_soil budgets are always present (even for f_sn=0 or f_sn=1)
- They are linearly coupled in the temperatures:

| | Sn | Sf | B1 | B2 | B3 | ... | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| isc | $a^{Sn}_{Sn}$ | | $a^{B1}_{Sn}$ | | | | $T_{Sn}$ | | | $d_{Sn}$ |
| fes | | $a^{Sf}_{Sf}$ | $a^{b1}_{sf}$ | | | | $T_{Sf}$ | | | $d_{Sf}$ |
| ifb | $a^{Sn}_{B1}$ | $a^{Sf}_{B1}$ | $a^{B1}_{B1}$ | $a^{B2}_{B1}$ | | | $T_{B1}$ | $\bullet$ | $=$ | $d_{B1}$ |
| | | | $a^{B1}_{B2}$ | $a^{B2}_{B2}$ | $a^{B1}_{B2}$ | | $T_{B2}$ | | | $d_{B2}$ |
| | $\vdots$ | | | $a^{b2}_{B3}$ | $a^{B3}_{B3}$ | $a^{B4}_{B3}$ | $\vdots$ | | | $\vdots$ |

- Can easily be tri-diagonalized by matrix-operations and solved by the standard solver
- The new features are partly reducible by parameters:

**isc:** degree of corrected implicit coupling of $T_{Sn}$ to the soil- and atm. temperatures

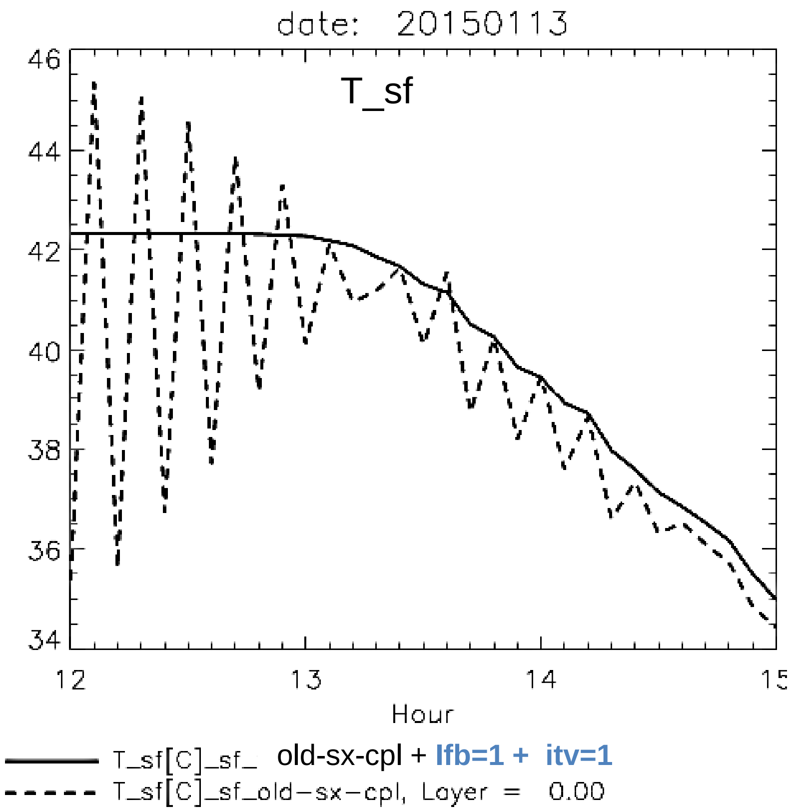
**fes:** degree of considered flux-equilibrium in diagnostics of $T_{Sf}$

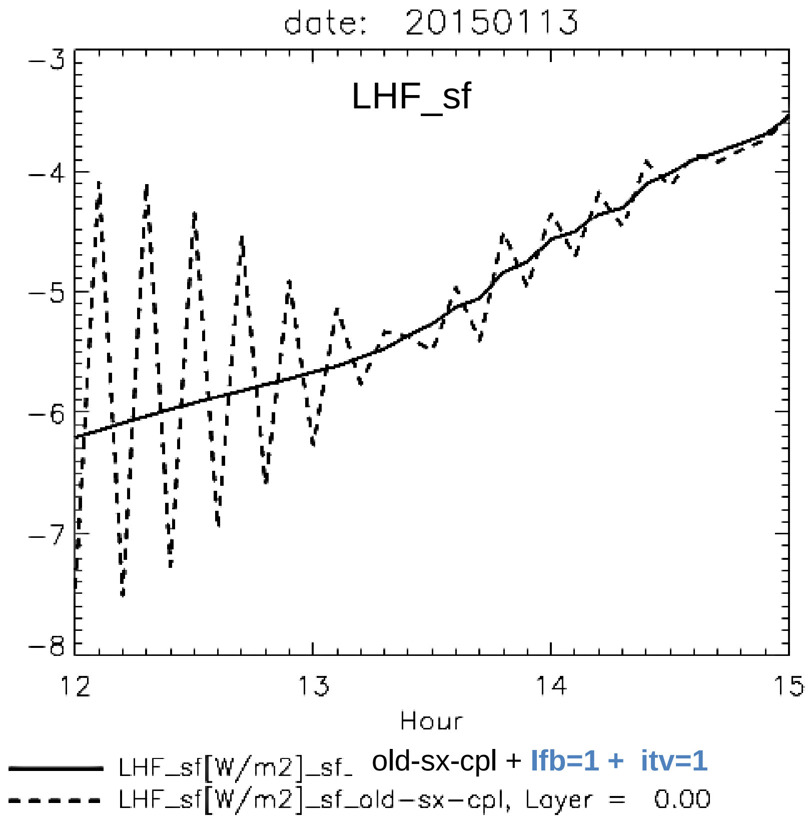
**ifb:** degree of implicitness for effective surface fluxes used in the heat budgets

Default for test: isc=1; fes=1; ifb=1 (full implicit solution active) - modified for diagnostic points

# Test-grid-point Kenia (+33.71_+7.89) :

- After-noon situation; tropical hot with strong radiation forcing
- 3 hour ICON-global test-run (R2B6, dt=6min) with
- implicit defaults of the new development version of SAT-formulation (mainly TERRA)
- Emulation of so far operational explicit surface coupling only for a special grid-point




- Oscillations almost completely eliminated by ifb=1 + itv=1
- Similar result but a bit larger daily amplitudes ifb=1 + itv=1 + fes=1 (not shown)

itv=1: full consideration of implicit T_sx-dependency in atmospheric transfer velocity

fes=1: full consideration of flux-equilibrium at the sf surface

- **Next steps:**

11. **Including phase-transitions of precipitation (as well as soil water including melting of snow) into the implicit treatment** **already prepared!**
12. **Merge with canopy-extension, prepared 2 years ago in COSMO-TERRA**
13. **Discrimination between intercepted snow and snow below the canopy, which would resolve lots of present workarounds in the current ICON-TERRA**

# Prospects for improved sea-surface coupling

Martin Köhler



- **Consideration the diurnal cycle of SST**
- **Through a heat-budget of a shallow well-mixed water layer at the sea surface**
- **Depth of the mixed layer dependent on vertical mixing of water**
  - o **Influenced by surface drag from wind**
  - o **Stability of vertical density stratification dependent on salinity-profile**

## OSTIA foundation SST from UK Met Office

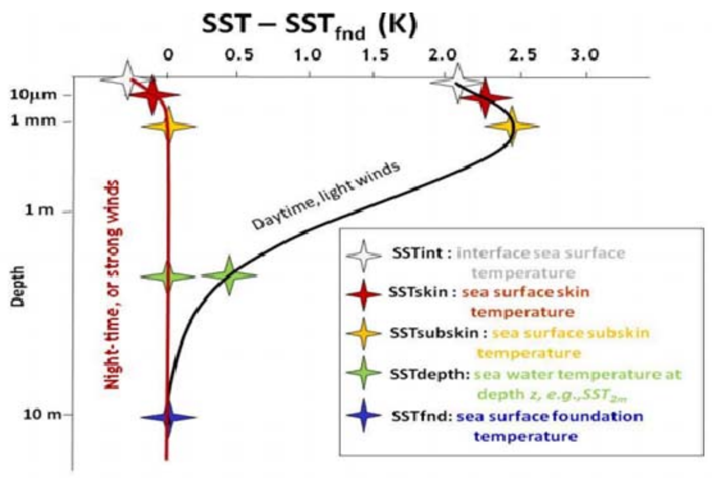
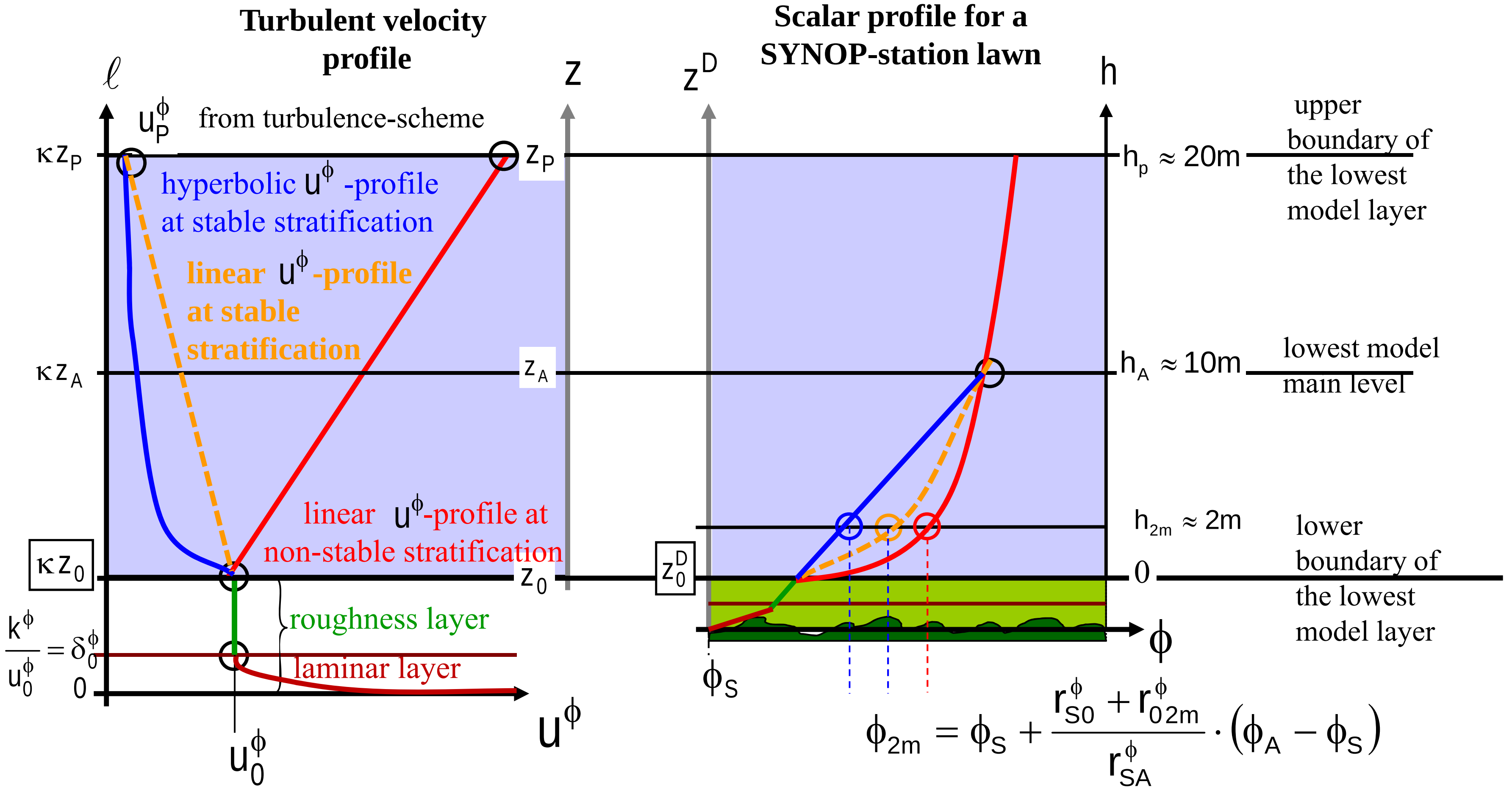



Figure 1. Cartoon of near-surface temperature gradients. The numbers on the axes are for guidance only and to not represent rigorously derived scales. Variability exists in both the temperature and depth scales.

- **Description could be according to Zeng and Beljaars (2005)**
- **Or by employing FLAKE with some extensions, such as**
  - o **Consideration of salinity**
  - o **Adapted depth of the thermocline**

# STIC-effect on the Profile-Function on near-surface values:




$$\phi_{2m} = \phi_S + \frac{r_{S0}^\phi + r_{02m}^\phi}{r_{SA}^\phi} \cdot (\phi_A - \phi_S)$$

$$\boxed{r_{SA}^\phi = \frac{1}{u_{SA}^\phi} = \frac{1}{\kappa}\int_0^{\ell_A} \frac{d\ell}{\ell \cdot u^\phi}}$$

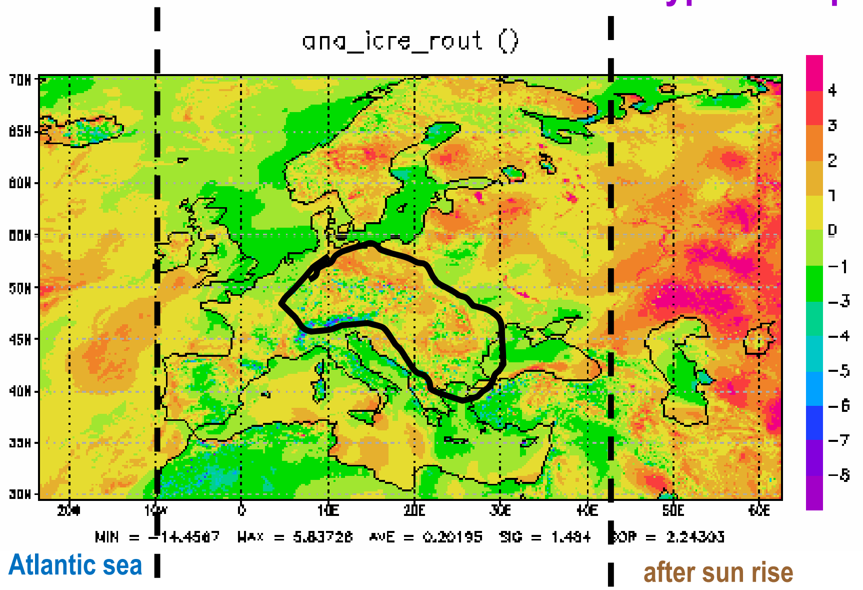
$$SHF_S = \bar{\rho}_S u_{SA}^H \cdot c_{p_d}\left(\hat{\theta}_A - \hat{T}_S\right)$$

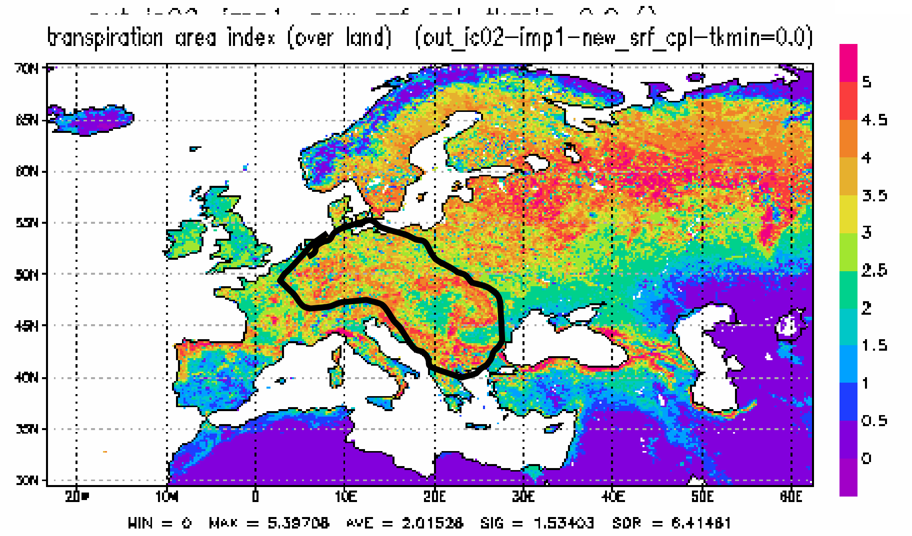
$$LHF_S = \bar{\rho}_S u_{SA}^H \cdot L_{ev}\left(\hat{q}_{vA} - \hat{q}_{vS}\right)$$

- **Effect of SI-terms (or Kmin):**
  - **Increased transfer-velocity**
  - **Non-stable profile shape**

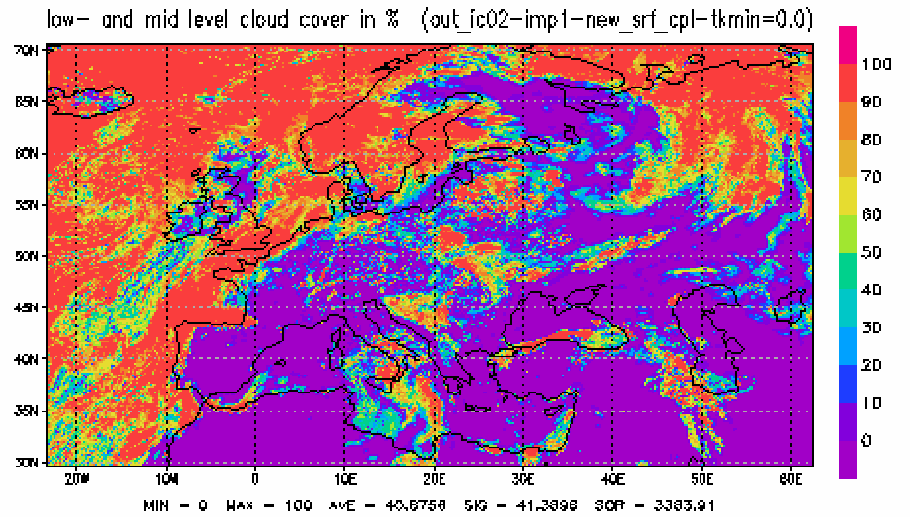
# t_g – t_2m [C]

## Nocturnal effect of hyperbolic profile for stable turbulent velocity scale




- **Attention:**
  - **Nocturnal surface-temperature during the assimilation run is warmer than measured T2m!**
  - **Not only below some sheltering clouds**
  - **But correlated with the amount of leaves**
    - ➢ **Missing decoupling of plant-surfaces with the still warm soil mass!?**
    - ➢ **Radiative cooling is almost compensated by heat form the soil**
    - ➢ **Warmer nocturnal BL with hyperbolic profiles causes (although this is an improvement) an even increased positive T2m-bials.**




➢ **Semi-transparent and decoupled cover-layer in TERRA -> is being done**

pr time=03Z23JUN2016 pr hour=3hr

# Coupling of TKESV and Tile approach



**TKESV scheme**: carries prognostic transport equations not only for TKE (SGS kinetic energy), but also for scalar variances (where SGS potential energy)

→ The scalar-variance equations require boundary conditions at the surface

**Tile approach**: considers different surface types within a grid box
→ grid-box mean fluxes of $T$ and $q$ are computed as the sum of the tile-specific fluxes
(= second-order aggregated moments are used as LBC for the first-order equations – for mean temperature and humidity)

Similarly: in the TKESV scheme, the aggregated third-order moments (scalar-variance fluxes) are proposed to be used as LBC for the second-order moments (scalar variances)

The use of the same type of information provided by the tile approach for the boundary condition for the second-order moments makes the entire model more physically consistent

# Outlook:

- Implementing a semi-transparent substantial cover-layer built from R-elements being thermally decoupled from the rigid soil
  - Larger amplitude of diurnal cycle
  - Reduction of evaporating surface
  - Treatment of snow below a plant canopy

- Expressing missing transport by parameterized sub-grid circulations
  - Additional vertical and horizontal diffusion at circulation scales

- Expressing the effect of turbulence on circulations
  - Substitution of dissipation-like scale-transfer expressing the related shear term directly
  - Automatically introduces turbulent feedback:
    - Dependency of SI-terms on turbulent length scale and thermal stratification

- Describing near surface thermal circulations caused by land use roughness
  - Kata- and anabatic circulations at buildings and vegetation
    - Nocturnal labialization and daytime stabilization of transfer between soil and canopy