Physical Process in COSMO		Method	Name	Authors
Local Parameterizations of atmospheric source terms	Radiation Transport	δ two-stream; revised optical cloud properties		Ritter and Geleyn (1992) Blahak (->)
	Microphysics	1-moment; 3 prognostic ice phases; prognostic rain and snow		Doms (2004) Seiffert (2010)
		optionally 2-moment version		
Grid-scale Parameterizations of sub-grid scale atmospheric processes (dependent on horizontal resolution)	any other not yet (completely) considered process (e.g. SSO driven thermal circulations or horizontally propagating GW)			
	Convection (deep, shallow)	2-class (updraft-downdraft) mass-flux equations with moisture convergence closure and simplified microphysics		Tiedke (1989), update by Bechthold et al. (2008) optionally
	Sub-grid Scale Orography (SSO) effects	orographic blocking and breaking of vertically propagating Gravity Waves (GW)		Lott and Miller (1997)
	Quasi-Isotropic Turbulence	2-nd order closure; progn. TKE with addit. scale-interaction terms (STIC); horizont. BL-approx. with opt. 3D-extensions: turb. sat.- adjustm.	TURBDIFF	
	Surface-to-Atmosphere Transfer and Roughness Layer effects	transfer resistances based on vertically constant **turbulent/laminar** near-surface fluxes normal to roughness-covering surfaces; separate heat budget of roughness elements (shading)	TURBTRAN	Raschendorfer (2001,->)
Modelling the non-atmospheric part below the surface	**Vertical Heat and Water Transport of the Soil including Vegetation and a Snow-cover**	1- layer snow; m.- layer soil; freezing of soil water; resistances for vapor from stomata of leaves and soil pores; moisture and root mass dep. conduct.; coupled with roughness-layer concept	TERRA (CLM and Veg3D can be coupled via OASIS-coupler)	Heise and Schrodin (2002), Schulz (2016, ->), Helmert (->), Raschendorfer (->)
		optional m.-layer snow		Maschulskaya (->)
	Heat Transport and Phase Change of Lakes	1-layer with an assumed shape function of temperature profiles; including freezing of lake water and a possible snow-cover	FLAKE	Mironov (2008)
	Heat Transport and Amount of Sea Ice			

tiled only in ICON

Main topics:

- ✓ **Improved formulation of surface-to-atmosphere coupling:**
  - **reformulation and implicit coupling of near surface heat-budget equations**

    for the snow-free skin (or roughness layer),
    snow-cover and
    rigid soil below
  - **testing the shading effect of a (so far) mass-less roughness cover (skin-layer)**
  - **consistent integration of an improved multi-layer snow-model**
  - **an effective adaptation to urban surfaces**
- ✓ ***More advanced soil-physics and relevant plant-physiology***
  - ***testing different plant-phenology models***
  - ***build-up of groundwater table; slop-dependent runoff***
  - ***usage of harmonized Word Soil Database***

    (improved soil-texture information including vertical structure)
- ✓ ***Objective Calibration of Model-Parameters (CALMO)***
  - **the problem of poorly confined model parameters**

Current state of the TERRA-development in ICON:

Result of a history of "migration"

- COSMO (original version) -> **ICON : further development (partly merged from parallel COSMO-development)**
  -> COSMO : adaptations (interfaces, parameter-generation, etc.)

Additional TERRA-development in ICON:

Last year and older

- ➔ **surface tiles** (is a matter of technical organization of the model, **not foreseen for COSMO so far**)
- ➔ some **special tuning** (desert, Geenland-ice): G. Zängl
- ➔ **tuned GlobCover 2009 look-up table** for land-use parameters: G. Zängl
- ➔ **exponential root density profile** and **impact of roots on thermal and hydraulic conductivity:** J. Helmert
- ➔ **reformulated resistance based bare soil evaporation**: J.-P. Schulz
- ➔ more **advanced treatment of snow-fraction** (including effect of vegetation and SSO) and **revision of interception store):** G. Zängl
- ➔ Introduction a **resistance based treatment of a vegetation canopy** similar to the treatment in HIRLAM (not yet consistently integrated into surrounding physics): ICON-test-version by J. Helmert

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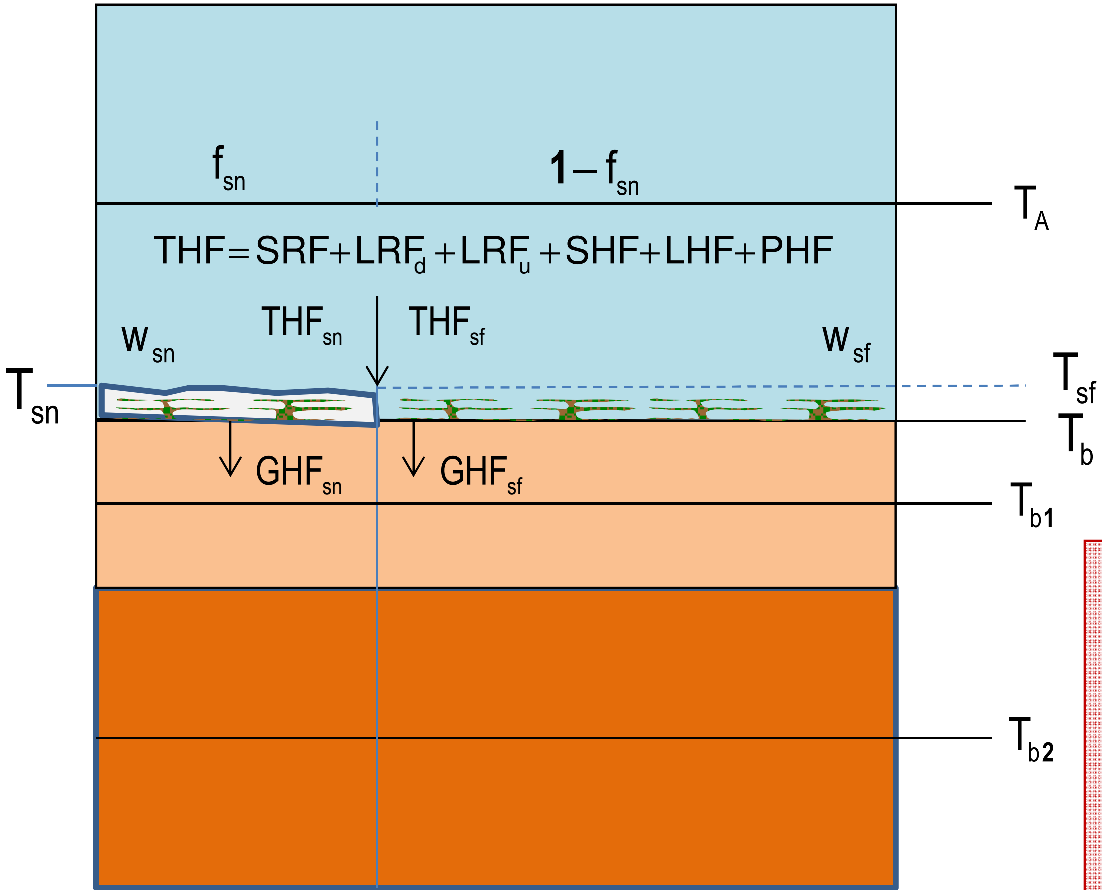
This year

- ➔ Introduction of a **preliminary skin-layer extension** for testing the shading-effect of plants (according to Viterbo and Beljaars 1995: ICON-version by J.-P. Schulz
- ➔ Major **reformulation of surface heat budgets** (including **1-layer snow-cover), of snow-fraction calculation, as well as evaporation of snow and interception water** in terms of **implicitness** (and associated **removal of detrimental artificial limits)** for **numerical stabilization, already including the above skin-layer extension**: recent development; ICON-version by M. Raschendorfer

New Surface-to-atmosphere coupling in TERRA:

M. Raschendorfer, DWD



(not yet used) mean cover-temp.

$$THF_{sf} - GHF_{sf} = [\rho_c c_c]^0 \frac{T_{cm} - T_{cm}^0}{\Delta t} \rightarrow 0$$

mean snow-temp.

$$THF_{sn} - GHF_{sn} = [\rho_{sn} c_{sn}]^0 \frac{T_{sm} - T_{sm}^0}{\Delta t} \xrightarrow[h_{sn \to 0}]{} 0$$

Current state:

- Thermal forcing of the soil by **explici**t THF_sf:

  T_sf = T_b = T_b1
- Heat-budget for snow-cov. is **only partly implicit** and has **singularity** for vanishing snow-depth
- Evaporation of w_sn and w_sf is **explici**t with **artificial restrictions** to avoid negative water levels.

- **Artificial flux limiter necessary to prevent from model crashes**
- **Strong 2dt-oscillations at large time steps used in ICON (dt = 6 min)**
- **Even a few crashes in EPS-runs for some ensemble members**
- **Problems mainly at grid-points with:**
  - **strong rad. forcing (tropics)**
  - **a thin snow-cover**
  - **fractional snow-cover**
  - **freezing or melting of soil-water**
  - **phase-changes of precipitation at surface**

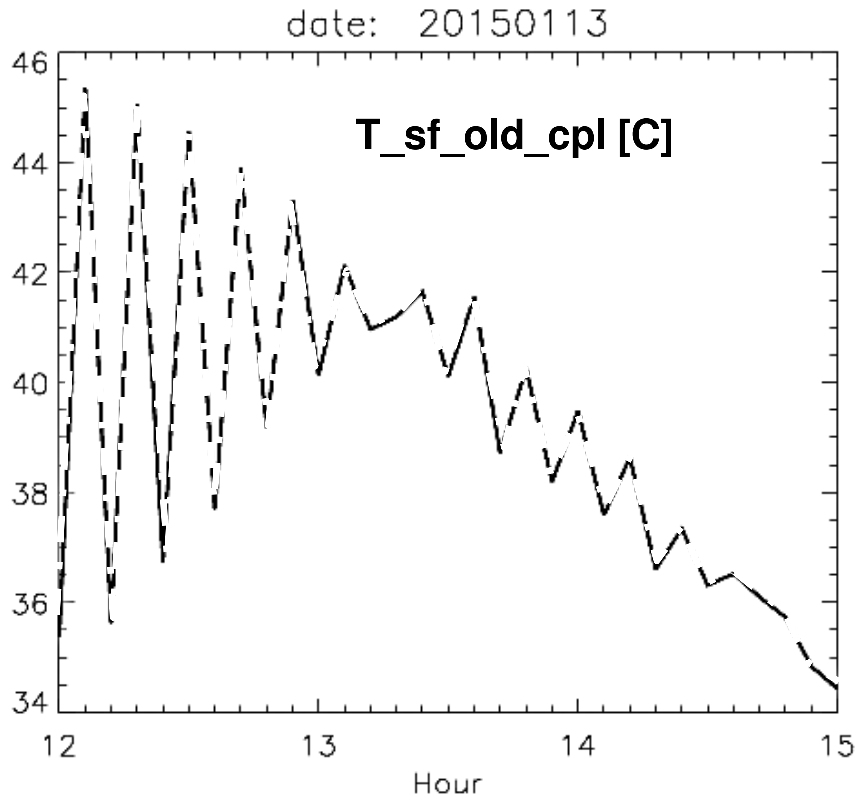
Test-grid-point Kenia (+33.71_+7.89) :

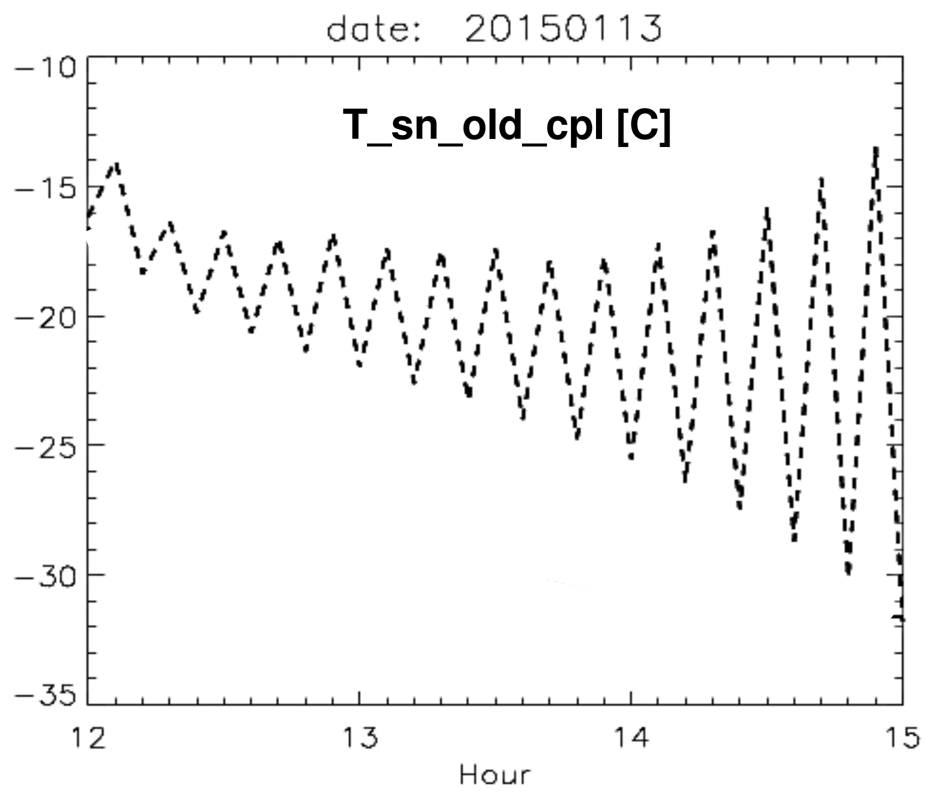
after-noon situation; tropical hot; strong radiation forcing

Test-grid-point North-India (+58.51_+28.33) :

evening situation; tropical hot; frozen soil; snow-fall with thin snow-cover

- **3 hour ICON-global test-runs (R2B6, dt = 6 min) with OLD surface-coupling in TERRA**

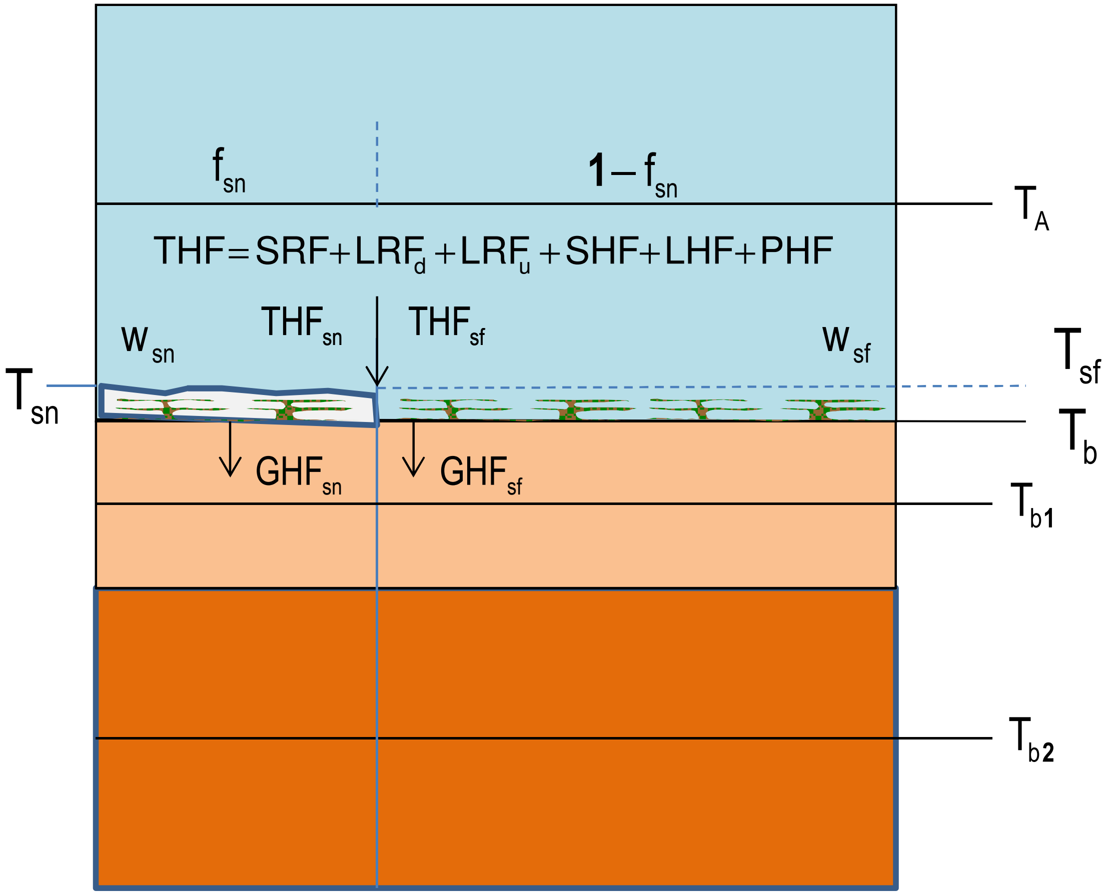




!! Strong oscillations in T_sf or T_sn (although artificial flux-limiter is activated) !!

New Surface-to-atmosphere coupling in TERRA:

M. Raschendorfer, DWD



New treatment:

- Linearization of all contributions to THF_sx in terms of T_sx
- Extra heat-budget for snow-free roughness-elements:

substantial, loosely coupled, semi-transparent C-layer → **idealized, infinite-thin S-layer (skin)** $T_b \rightarrow T_{sf}$

$$GHF_{sf} = -\alpha_{b1}^{b} \cdot (T_{sf} - T_{b1})$$

$$GHF_{sn} = -\frac{\alpha_b^{sn}}{\underbrace{\alpha_b^{sn} + \alpha_{b1}^{b}}} \cdot (T_{sn} - T_{b1})$$

concatenation of resistances avoids singularity for vanishing snow-depth

- For **n=8 soil layers**, there are always **n+2 linearly coupled heat-budget equations** for the temperatures T_sn, T_sf, T_b1, …, T_bn , which can easily be **tri-diagonalized**.
- For the time being, **only the S-layer approximation** is implemented into ICON

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

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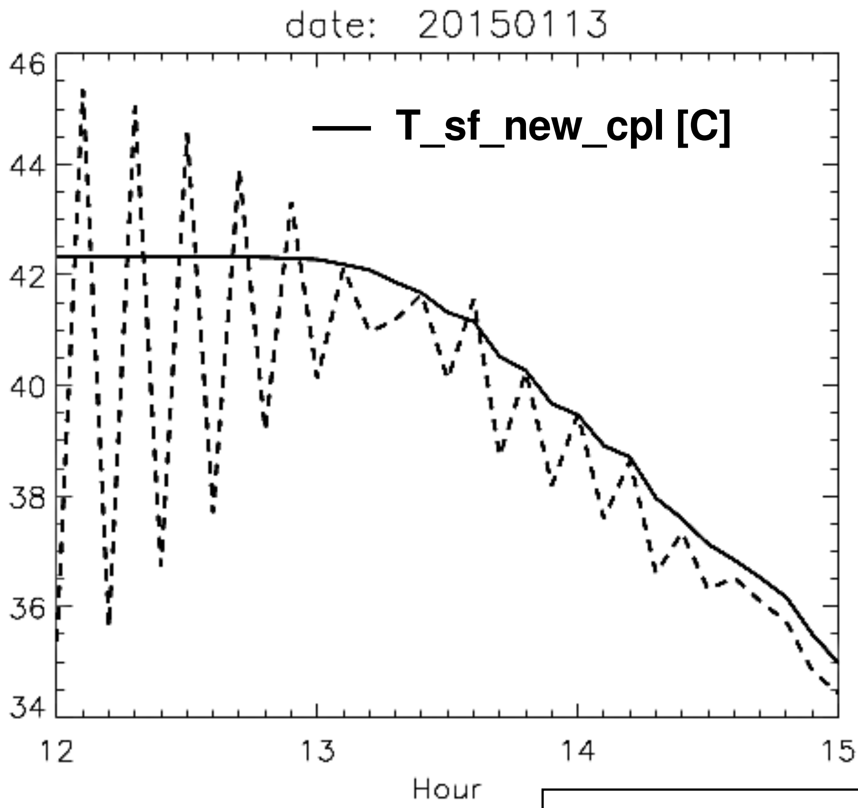
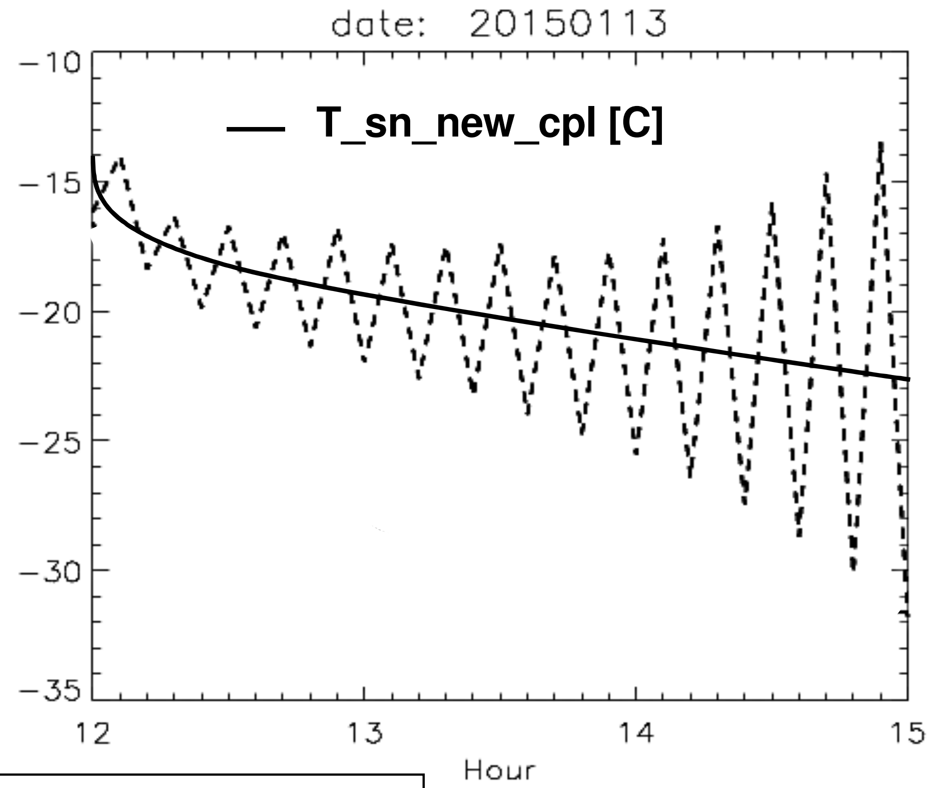
Test-grid-point North-India (+58.51_+28.33) :

evening situation; tropical hot; frozen soil; snow-fall with thin snow-cover

- **3 hour ICON-global test-runs (R2B6, dt = 6 min) with NEW surface-coupling in TERRA**





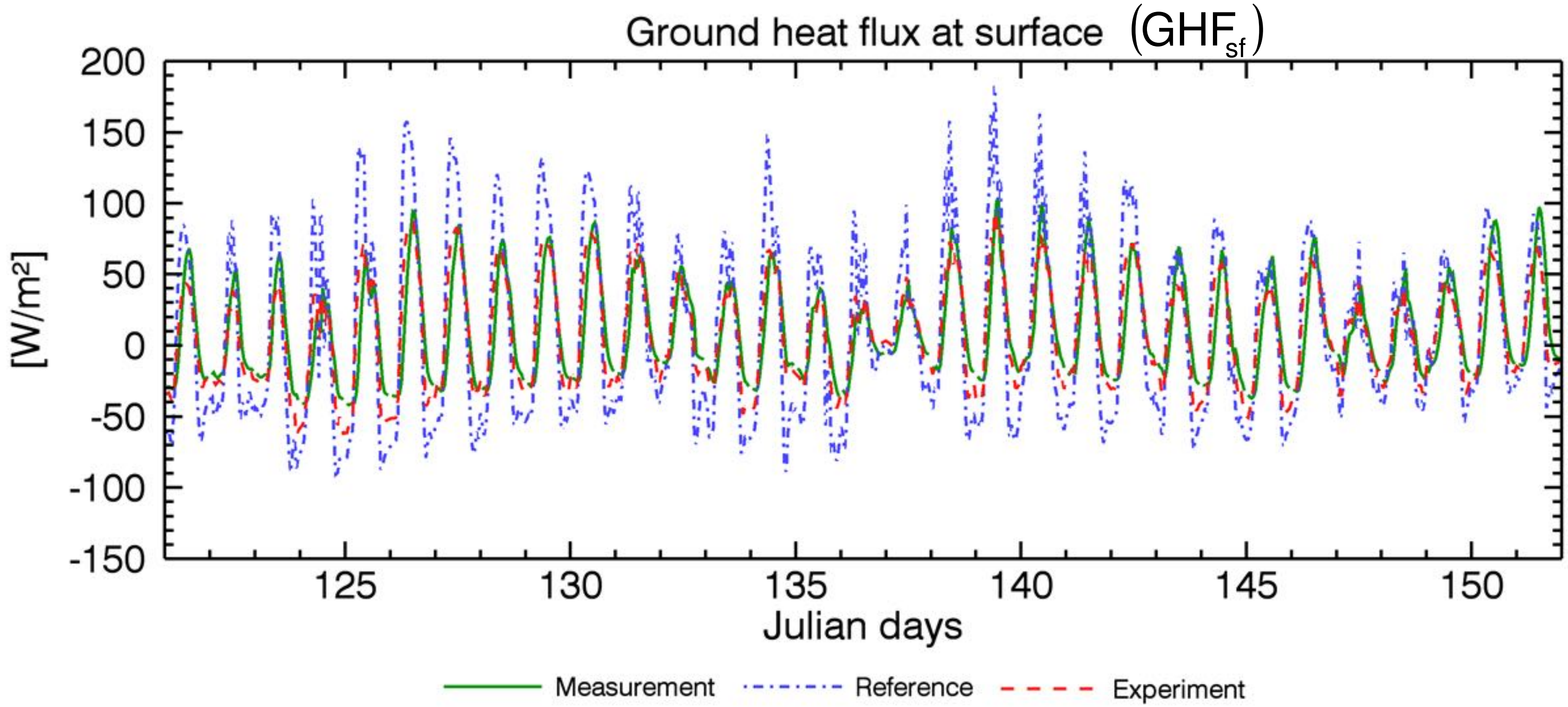
!! Almost no oscillations in T_sf or T_sn, (even without any flux-limiter) !!

Physical advantages of the new coupling:

- **Shading** of a (**semi-transparent**) **roughness cover** with an **rather loose thermal coupling** to the rigid soil can be considered:
  - **Smaller diurnal-cycle amplitudes of GHF and T_bx**
  - **Larger diurnal-cycle amplitudes of SHF, LHF and T_2m, Td_2m**

a welcome behaviour for COSMO/ICON!

1) Experiment with a preliminary **skin-layer-extension** added to the current TERRA-equations (before the major reformulation; only a few lines of code) using a **tuned fixed effective heat-conductivity between level b1 and the skin-surface-level sf** (according to scheme in IFS, adapted by J.-P. Schulz):



Observations from Lindenberg-Observatory (Gerd Vogel, DWD) compared with results from TERRA test-version in offline-mode

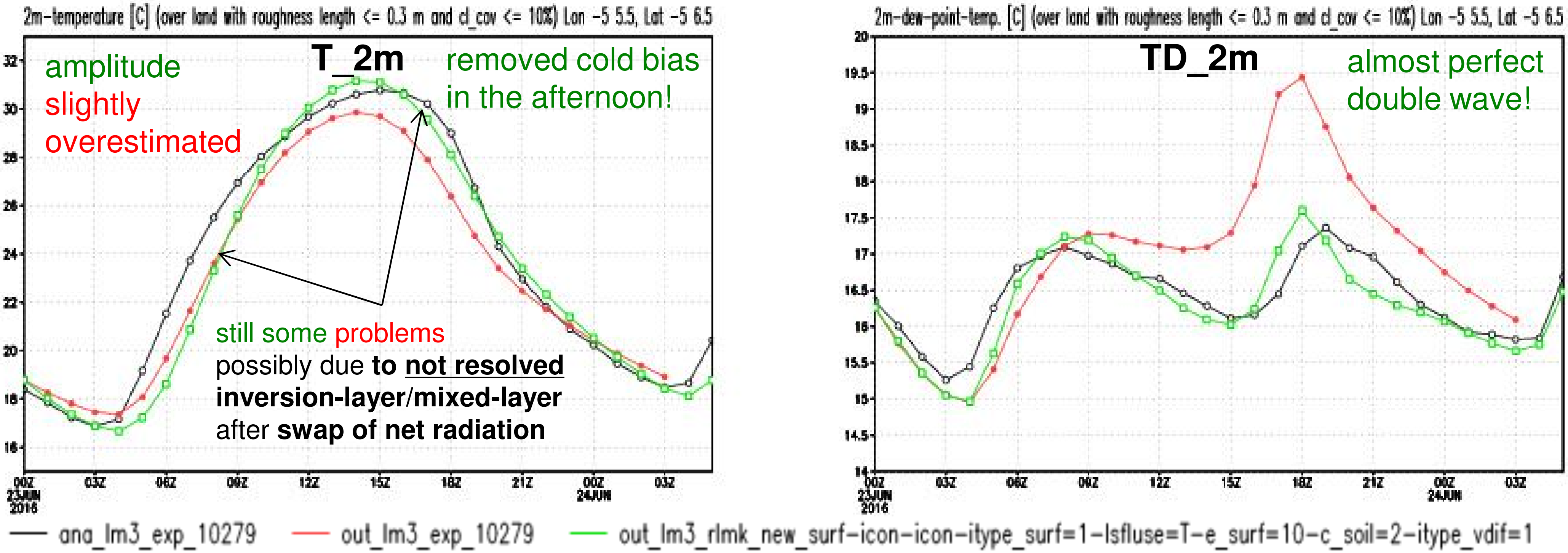
- A more advanced **semi-transparent C-layer extension** (by M. Raschendorfer) with **parameterized heat-conduction** and **heat storage** of the **full roughness cover** (e.g. plant canopy) is **being adapted** from an existing test-version prepared last year within COSMO.
  - The **final combination** with the **reformulated budgets** will **include all related partial development!**

2) Experiment with **the existing test-version in COSMO:**

already shown last year

- **COSMO-DE with lateral boundaries from ICON-EU**
- **domain averaged daily cycles of near-surface variables**
- **almost saturated soil due to long standing rain period before**
- **only for rather smooth surfaces: applied filter**
- **almost no clouds due to high pressure situation + applied filter**

conditional diagnostic



direct analysis of T_2m and TD_2m

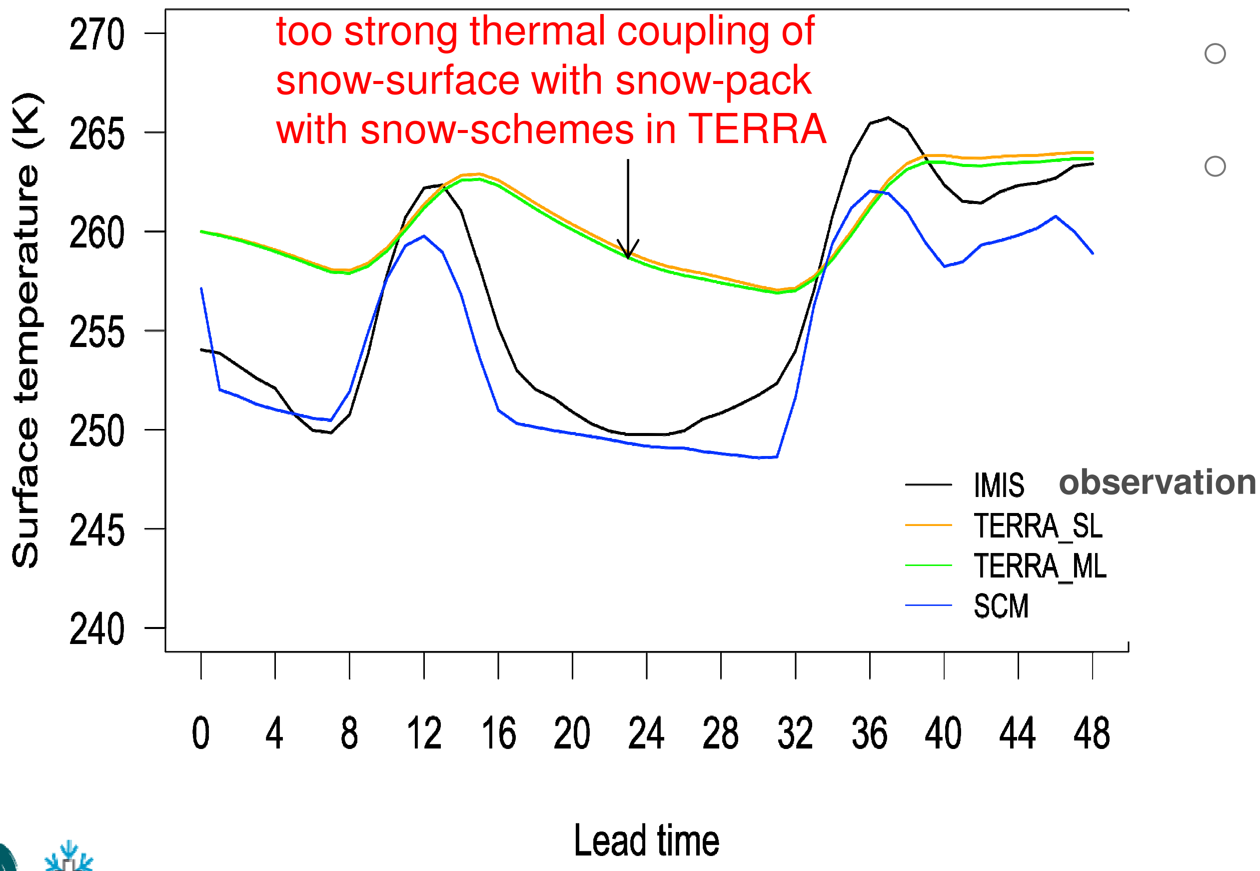
revised TURBDIFF imported from ICON

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

More advanced treatment of the snow-covered surface:

- Special treatment of a **roughness C-layer** only prepared for the snow-free (sf) surface.
    - **Snow-cover** is treated as a substitute of the roughness C-layer.
- A **sophisticated multi-layer snow-model** may describe its own roughness C-layer:

Diurnal cycle of Snow-Surface Temperature: COSMO standard versus advanced snow model (SCM)



- developed at SLF/Davos
- being implemented into TERRA

Testing different plant-phenology models:

J.-P. Schulz et al., DWD

- ***Catch inter-annual variability of vegetation cycle***

→ currently LAI *climatology* is used in COSMO (‘sine curve’)

→ over Europe, inter-annual variability of vegetation cycle is important

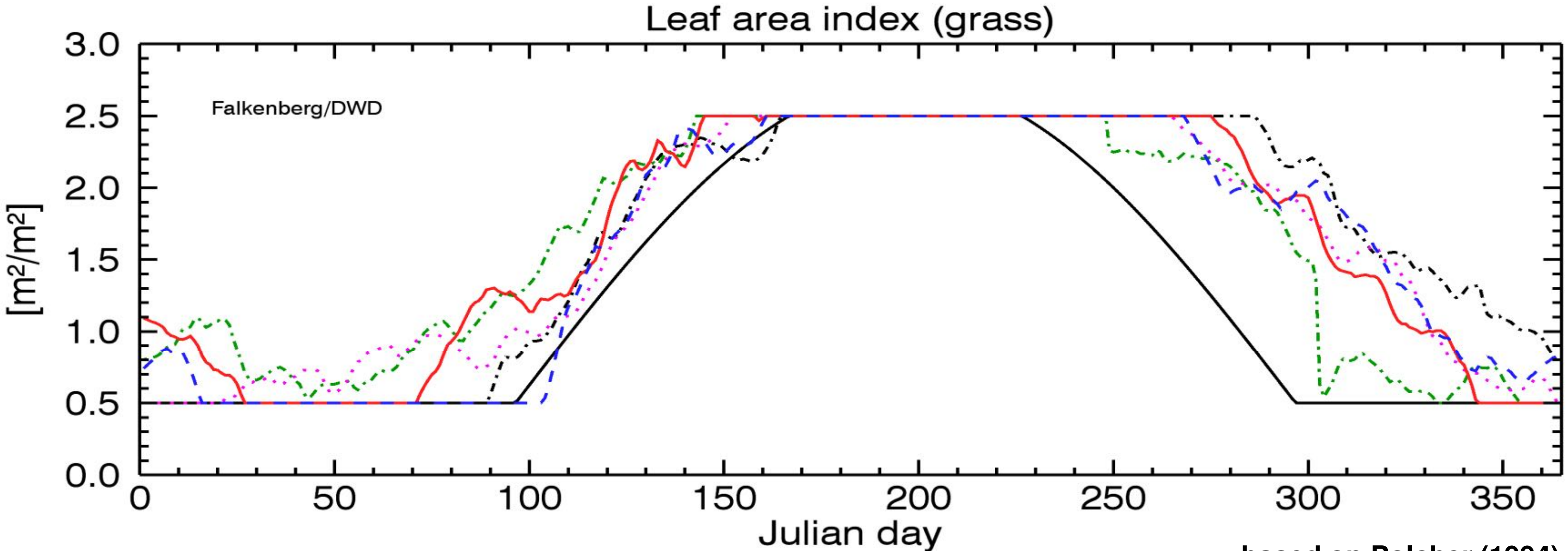
→ trying different phenology models to capture this inter-annual variability

→ **phenology model by Stöckli et al. (2011)** provides daily LAI maps (based on MODIS data calibrated with Ensemble Kalman Filter)

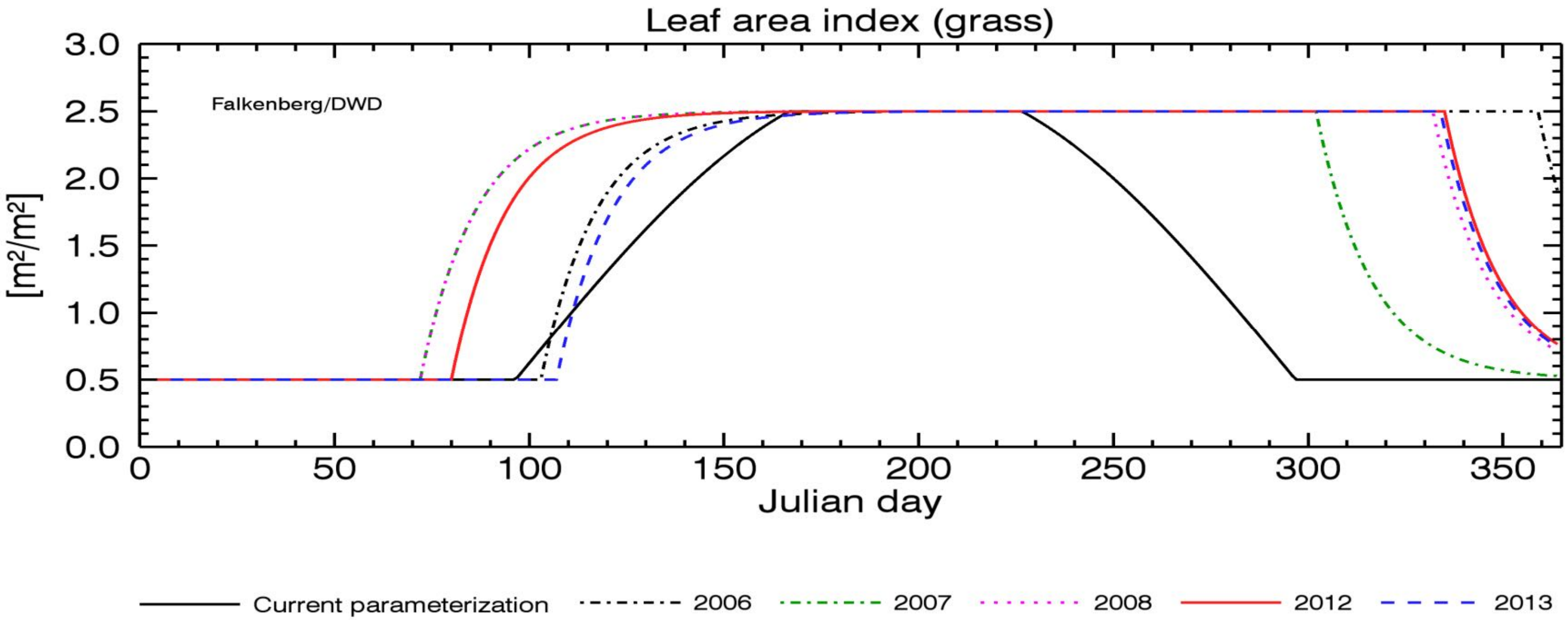
→ significant impact on T2m on large region in spring and summer (typically 1K per 2 LAI in April)

→ mixed impact on T2m *score*… model re-calibration required

Annual cycle for different Phenology-models :

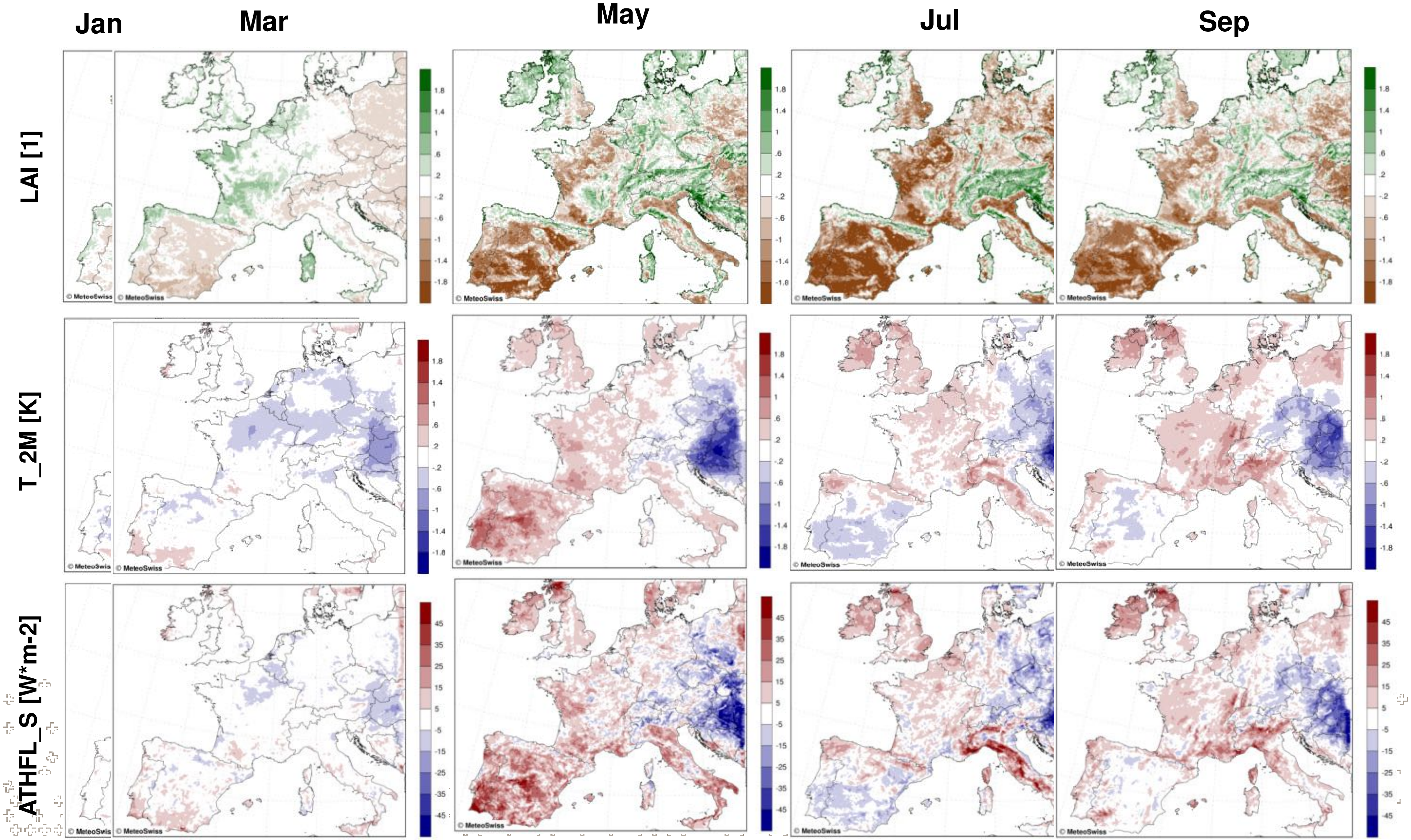


based on Polcher (1994)



based on Knorr et al. (2010)

Pheno model by Stöckli et al. minus climatology: (monthly means of daily 15h UTC values, year 2011)



External parameters

- **Usage of Harmonized World Soil Database**
  → improved information on soil texture, incl. vertical structure
  → work in progress

TERRA-URB *(Wouters, H., KU Leuven)*

- Goal: *add cheap but realistic bulk parameterization of urban effects mainly by adapted/**new*** **urban external parameters (Impervious Surface Area, Antrop. Heat-Flux)**
- Benefit: *variability of urban heat island well reproduced*
- Status: ***addit. framework to derive optimal bulk parameters for any specific city***

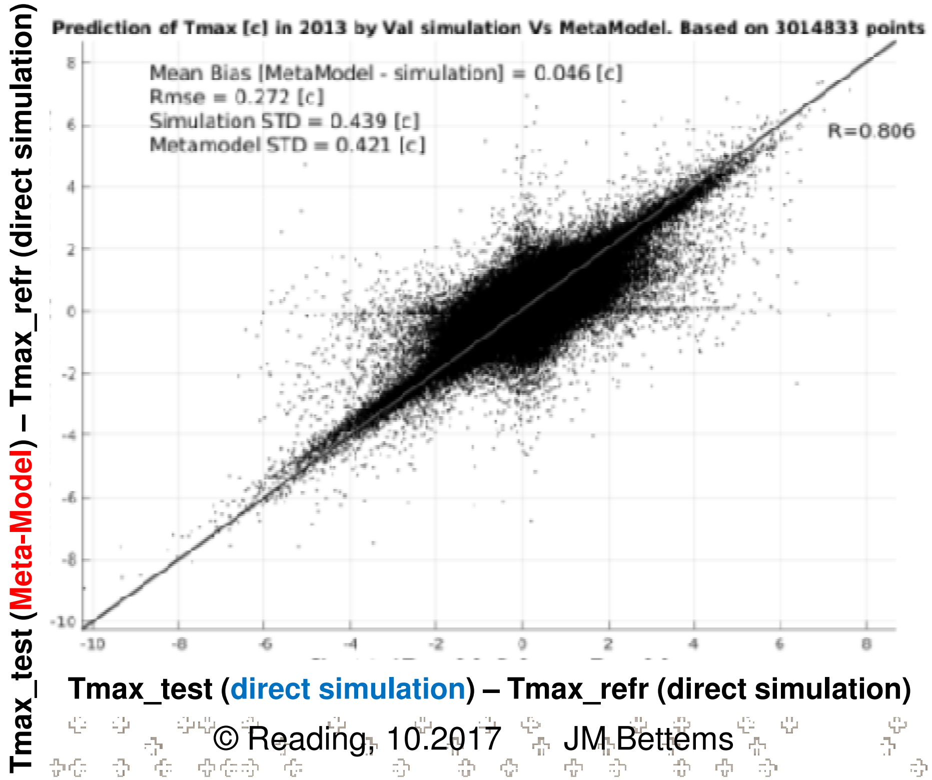
  already good results obtained
  operational introduction planned for 09.2018

Objective Calibration of COSMO Model (CALMO)

Method : Omar Bellprat, ETH

- Describing the dependency of a (user oriented) **model performance metric** (that can be represented by **observations**) as a function of **unsecure and sensitive model parameters** by a **cheap** **Meta-Model** based on **quadratic forms**
- Searching for the **global maximum** (**optimal parameter tuple**) of the performance metric for the given **parameter space** (bounded by the valid range of each parameter) **by means of the Meta-Model**

Meta-Model for Tmax-prediction vs. direct COSMO-simulation (with a tested parameter configuration) →



CALMO: current state

- The method developed at ETHZ has been adapted to NWP, and was applied to calibrate 6 parameters of COSMO-2
- The **Meta-Model** is able to reasonably reproduce the dependency of the model on the unconfined parameters using a **performance function** based on **Client Oriented Scale of Improvement (COSI)** using:
  - *T2m daily min/max, 24h precipitation*
  - *total column water*
  - *wind, temperature, humidity at 3 standard pressure levels*
- **Calibration of COSMO-2, daily 36h forecast, full year 2013**

  ➢ **Improvement of 4% of COSI score**

- Main desired application:
  - **Retuning** after introducing more advanced physics, particularly in order to *beat* prior **compensating errors**

CALMO: problems and inherent chances

- **Optimal values** of some parameters show significant dependency on:
  - **annual season**
  - **climatological regime**

→ **functions of specific model-state variables**

non-confident **model parameters** going to be estimated:

- treated as a constant
- turns out to be a function of the model state (including gradients and external parameters)

derived variable of a specific SGS process

$$\psi = f_{\underline{p}}(\underline{\phi}) = g_{\underline{\pi}}(\underline{\phi})$$

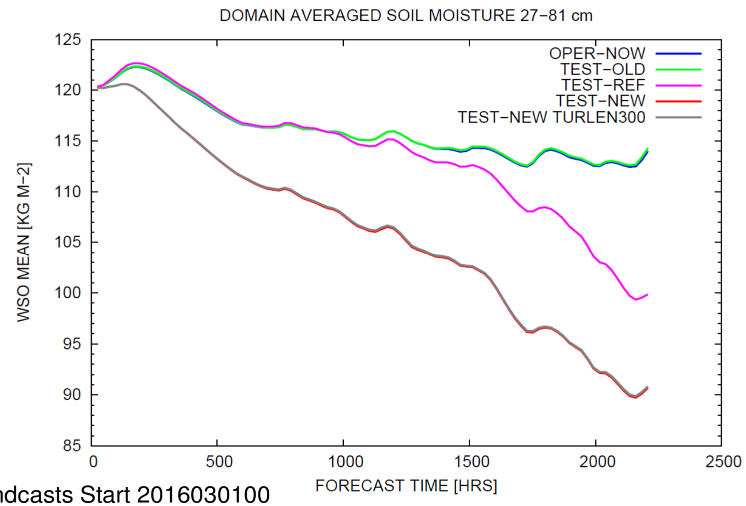
Idea (M. Raschendorfer):

- **New (regression) parameters** $\underline{\pi}$ of a possible **Statistical Hyper-Parameterization**,
  - where $\underline{\pi}$ should be **less dependent on the model state** (more confident)
- It removes a remaining **systematic error** **(complement of Physical Parameterization)**,
  - whereas a Stochastic Parameterization tries to remove a remaining stochastic error

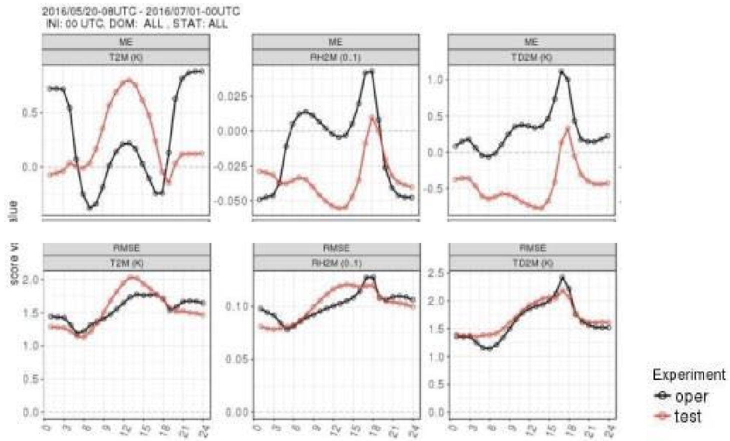
TERRA news

- **New unified COSMO / ICON TERRA with COSMO v5.05**
  To support the COSMO community & avoid duplication of effort

  → significant delay due to unexpected bad results from NWP test suite
  → bad scores due to soil drying in summer in some regions
  → hidden effect in ICON-EU due to active soil moisture analysis
  → requires new minimal stomatal resistance map… but issue not fully settled



Hindcasts Start 2016030100



Towards a new prognostic equilibrium surface temperature in combination with SAT and the soil model:

- ✓ Completion of the roughness layer model (TERRA-part)
- ✓ Thermal decoupling of a Cover built by roughness elements(canopy) above the dense soil (shading effect)
- ✓ Representation of the thermal energy storage of the roughness layer

Matthias Raschendorfer

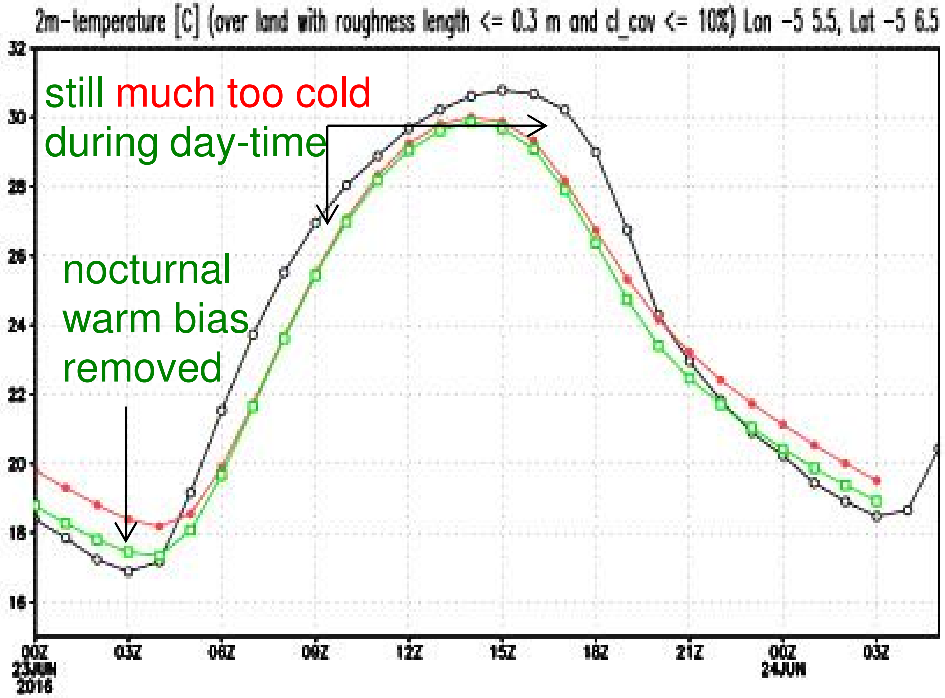
Case study: 23.06.2016

COSMO-DE with lateral boundaries from ICON-EU

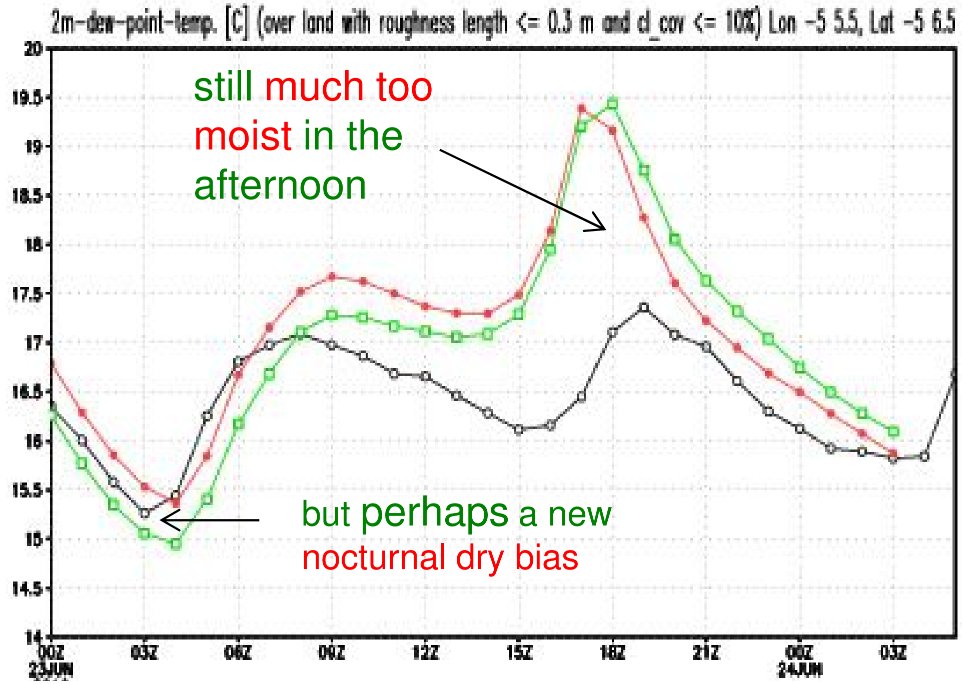
- ✓ only for rather smooth surfaces; applied filter
- ✓ almost saturated soil due to long standing rain period before
- ✓ almost no clouds due to high pressure situation; + applied filter

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

- **n cover layers** including the **surface of the dense soil** (n=0) are connected by long-wave radiation interaction and sensible heat exchange

→ **thermally decoupled roughness elements (shading)**

- Only **a part of the inner surfaces is connected to A** by the resistance chain, the **other part is for the inter- surface exchange**

→ strongly effects the **LAI-impact of transpiration**!

$$r_{SA}^H = r_{S0}^H + r_{0A}^H$$

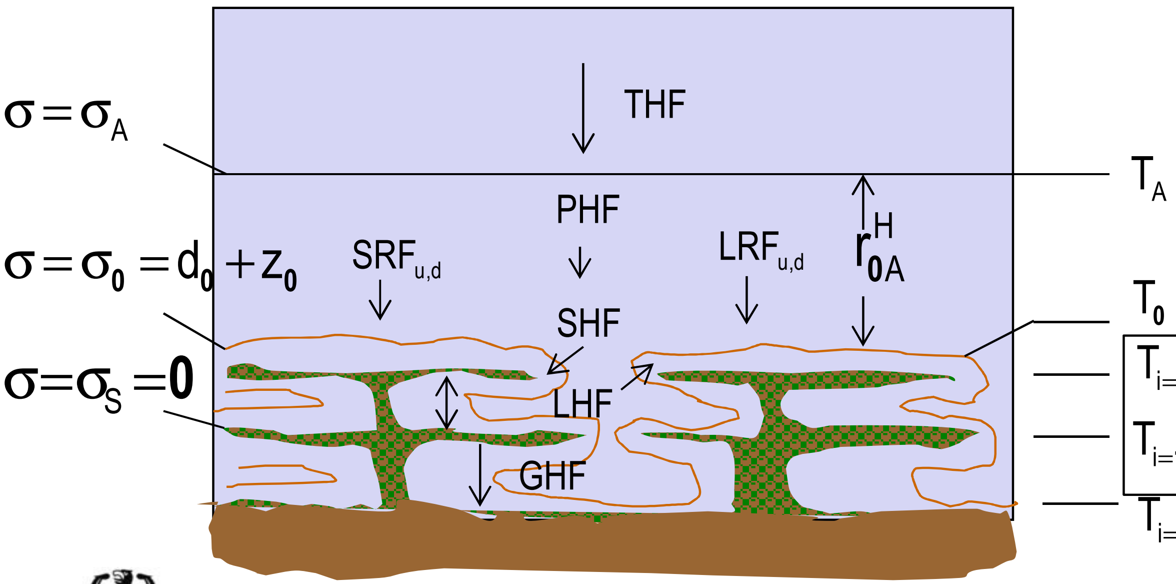
$$r_{S0}^H = \frac{1}{\kappa S_0 \cdot u_0^H} \cdot \left(\lambda^H + \ln \frac{\kappa z_0 u_0^H}{k^H} \right) = \frac{1}{\kappa u_0^H} \cdot \ln \left[\frac{z_0}{z_0^H} \right]$$

$$SAI = 2n + 1 = 2 \cdot LAI + c\_lnd$$

$$S_0 = \frac{(SAI-1)\cdot(SAI_\infty - 1)}{(SAI-1)+(SAI_\infty-1)} + 1 \quad \begin{cases} = 1 & , SAI = 1 \\ \rightarrow SAI_\infty & , SAI \rightarrow \infty \end{cases}$$

$$a_B + a_C = 1 = a_B^R + a_C^R$$

functions of SAI only



$$T_{i=n} = T_R = a_B^R T_B + a_C^R T_C$$

$$T_{i=1} = T_B + \frac{i}{n} \cdot (T_R - T_B)$$

$$T_{i=0} = T_B$$

T_C

T_B

$$T_S = a_B T_B + a_C T_C$$

TURBTRAN: $T_A, q_{v_A}, p_A, (u_m, v_m)_A \rightarrow \boxed{r^H_{S0}, r^H_{0A}}$

$S \quad v_{S*} \quad S$

TERRA: $T_A, q_{v_A}, r^H_{S0}, r^H_{0A} \rightarrow$

S

T_S valid for **next** time level may be **out of equilibrium**

q_{vS} valid for **this** time level,
associated to **current evapotranspiration**

$\parallel$

q^*_{vS} used for **next** time level

- **Diagnostic of surface temperature:**

$$THF^0 = \left(SRF^0_{u,d} + LRF^0_d + PHF^0\right) + LRF^0_u + \partial_T\left[LRF^0_u\right] \cdot \left(T^0_R - T^0_S\right) + SHF^0 + LHF^0 \rightarrow \boxed{T_B}$$

itype_surf=0

$$\boxed{T_S} = T_B$$

itype_surf=1

$$T_C = T_B + \left(T_S - T_B\right)/a_C \qquad T_R = T_B + \left(T_C - T_B\right) \cdot a^R_C$$

$$\frac{(MC)_C}{\Delta t} \cdot \left(T_C - T^0_C\right) = THF^0 + \partial_{T_B}\left[LRF^0_u + SHF^0 + LHF^0\right] \cdot \left(T_B - T^0_B\right) + \partial_{T_C}\left[SHF^0 + LHF^0\right] \cdot \left(T_C - T^0_C\right) - \partial_{\Delta T}\left[GHF^0\right] \cdot \left(T_C - T_B\right)$$

$$\boxed{T_S} = a_B T_B + a_C T_C$$

Case study: 23.06.2016

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- ✓ almost saturated soil due to long standing rain period before
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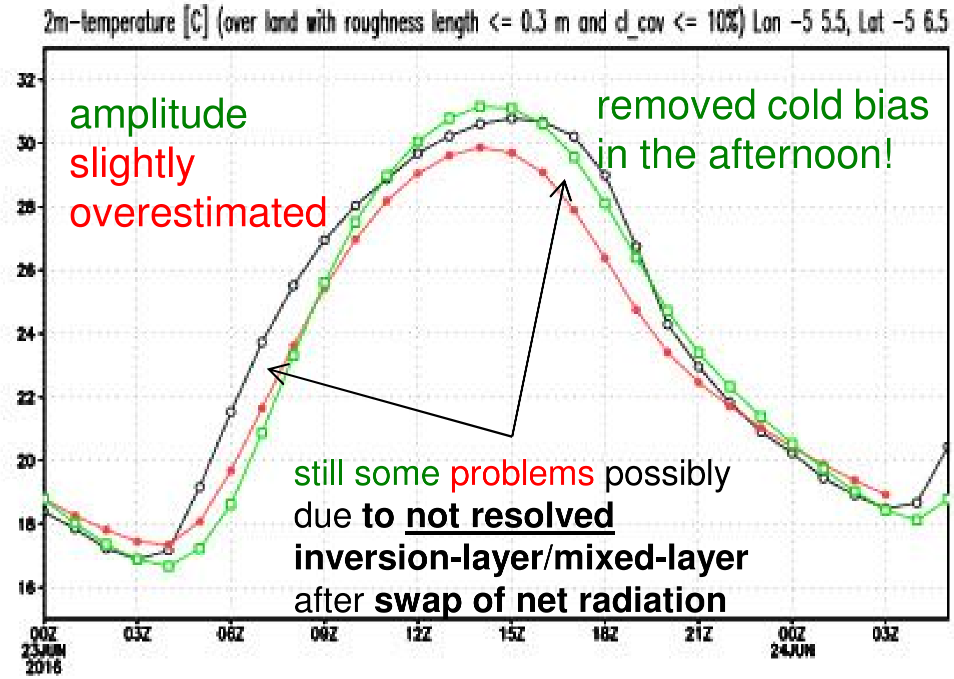
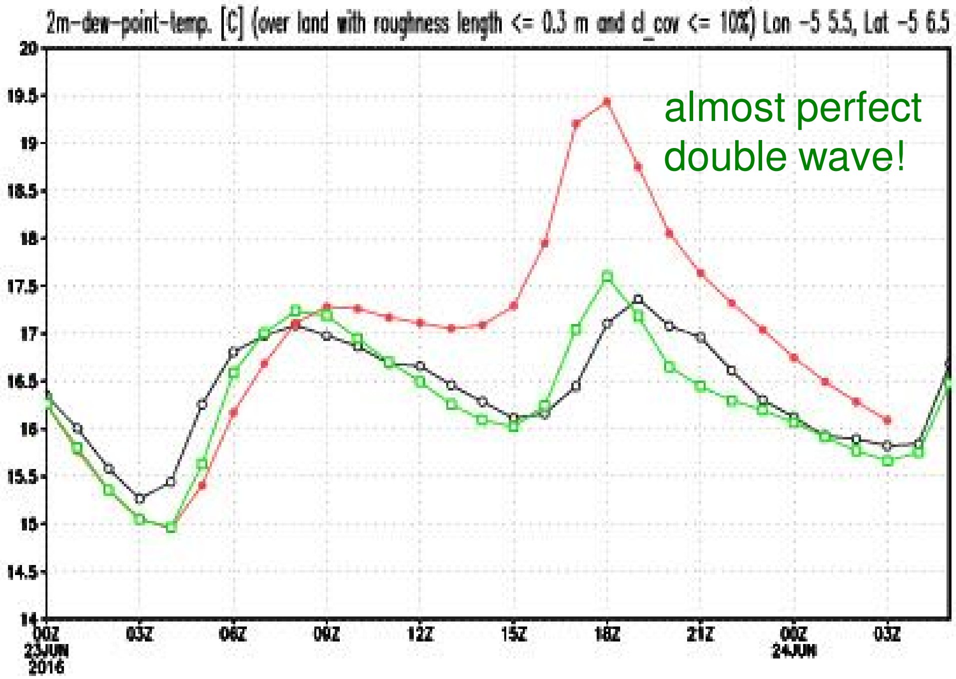


TD_2m



— 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

revised TURBDIFF imported from ICON + new decoupled surface cover: $SAI_{\infty} = 10$