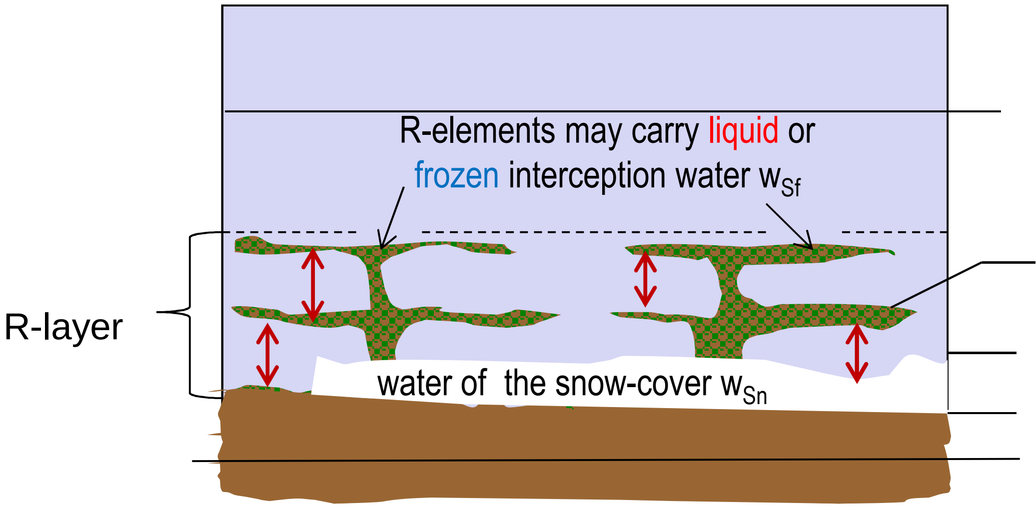
Towards a more sophisticated and implicit formulation of surface layer processes for COSMO and ICON

-

Numerical and conceptual effects of a reformulated SAT

- ✓ **Analysis of the current simplified, explicit and sequential chain of surface-processes in TERRA**
- ✓ **Implicit treatment of surface-temperature including**
  - o **treatment of the snow-temperature (implicitly coupled with soil and its surface)**
  - o **additional feedback of surface temperature via**
    - **thermal stability-effect of atmospheric transfer-velocity**
    - **freezing and melting of interception-water and falling precipitation**
  - o **potential of treating roughness-layer effects (surface-temperature decoupled from compact soil)**

Illustration of a realistic surface concept:



↕ : inter-surface exchange of sensible-heat and (mainly long-wave) radiation

A : indicator of the lowermost full atm. level

$S := B + C$: area and indicator of total surface

C : area and indicator of the cover-surface (surface of all R-elements)

Sn : indicator of the snow-cover surface

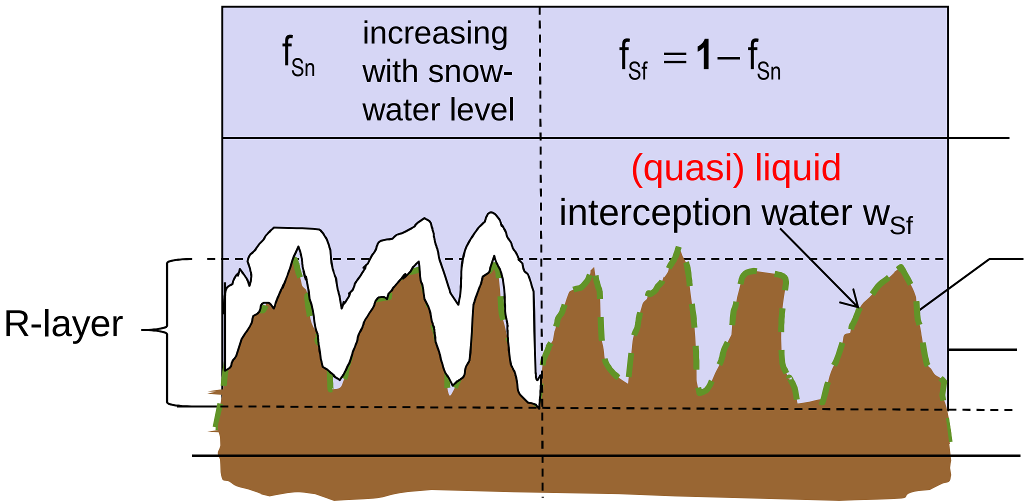
B : area and indicator of the bare-soil surface

B_1 : indicator of the uppermost full soil level

Sf : indicator of all snow-free surfaces

- **Critical properties of the real surface:**
  - **R-elements** are **substantial**, **semi-transparent and thermally loosely coupled to B**.
    - Their **temperature T_C may be different from T_B**, which is **distinctive from T_{B1}**.
    - They can **shade B and Sn from radiation.**
    - They **exchange sensible-heat** and **(long-wave) radiation with B.**
    - They may carry **liquid and frozen interception water w_{Sf} dependent on T_C**.
  - **In case of a present snow-cover, snow-free parts of S are mainly parts of C**.
    - **R-elements vanish within a deep snow-cover**.
    - Distribution of **snow cover alters** aerodynamic **R-length (z_0)** and **short-wave albedo**.
    - **Snow/rime** and **black-ice** have **different short-wave albedo**
  - **Coexistence of liquid and frozen interception-water** is possible.
    - **Smooth transition due to variance of T_{Sf}.**

Idealized and incomplete surface concept of the current implementation:



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- **Current implementation:**
  - **Total land-use surface** is a **topographic enlargement of the horiz. ground** by the factor SAI.
    - **thermally coupled with the soil like the bare-soil surface**
    - with fractions of **distinctive Sf-evaporation**: bare-soil, vegetated, wetted, or sealed)
    - **snow-cover** always **thermally coupled with soil like an additional soil layer**
  - **R-elements do not cover (shade) the bare-soil surface B**, as **they are rather a part of it**!
    - only **one Sf surface-temperature $T_{Sf} = T_C = T_B = T_{B1}$**!!
  - **R-elements** carry **only liquid interception water.**
    - oper. COSMO: **rime** is treated as **part of the snow-cover**
  - Mass (**heat-capacity**) **of R-elements (including w_{Sf}) is neglected**.
    - they are treated like a pure **additional transport-resistance** for sensible and latent heat.
  - **Snow-cover follows surface-structure** (some **snow-effect on z_0** only in ICON).

Some consequences of the incomplete surface-concept:

- **Too strong thermal coupling between surface and compact soil:**
  - **Overestimated heat-flux into or from the ground**:
    - ➢ Artificially **reduced diurnal cycle** of mean surface temperature T_S!
- **Snow-covered B below snow-free C can't be represented:**
  - **No heating of R-layer air above a shaded snow-cover possible:**
    - ❖ Snow is artificially "pushed together" to obtain Sf surfaces with T_{Sf}>Tmelt.
      - Always a **Sf part of B** present, which may
        - ➢ perform **overestimated bare-soil evaporation** at T_{Sf}>Tmelt
          - ❖ that is artificially reduced.
        - ➢ **push** some **heating dedicated for the surrounding air into the soil**.
        - ➢ raise T_{B1} , leading to **overestimated snow-melting from below**:
          - ❖ Introduction of dynamic sub-tiles for Sn and Sf with individual $T_{B1, \ldots}$
      - Large spreading of rime | fresh-snow can't be captured
        - ➢ **Sn (showing potential evaporation) is too small | individual snow-depth is too large**
          - ❖ Introduction of rime as part of w_{Sf} | Snow-depth calculated by a special fresh-snow fraction

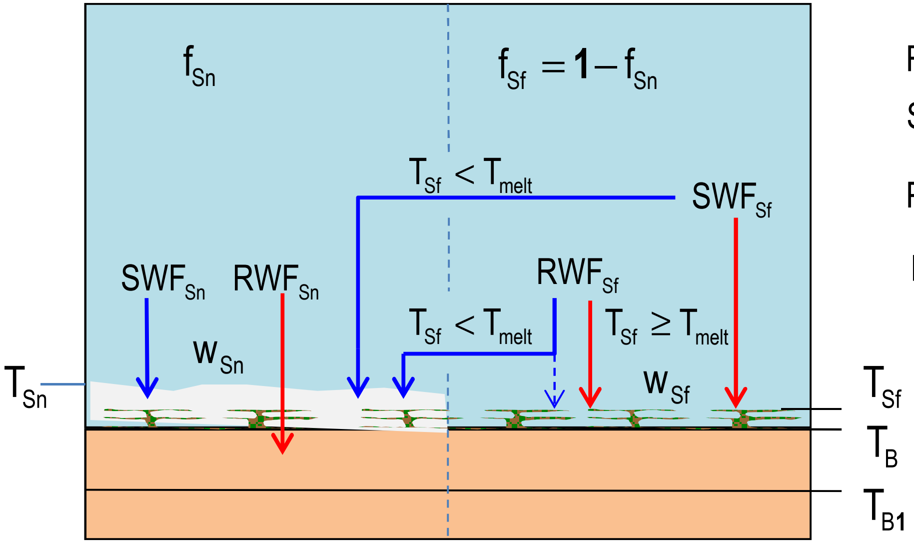
            but: albedo-effect, and heat release for dew<->rime transition is not yet described!
  - **No simulation of snow-albedo reduction by snow-free C above a snow-cover:**
    - ❖ Treatment of "dirty" snow ("polluted" by R-Elements) with reduced albedo, which
      - ➢ **pushes** some **heating dedicated for the surrounding air into the snow-pack**
      - ➢ raises T_{Sn} , leading to **overestimated snow-evaporation**
        - ❖ that is artificially reduced.

❖ : indicator for "dirty" fixes in
current **ICON-version**

⇩

substantial,
semi-transparent
cover-layer (canopy),
being
thermally
loosely coupled
to the compact soil!

Current explicit and sequential treatment of precipitation and interception water:



RWF : rain-water flux-density

SWF : snow-water flux-density (including graupel)

$PWF := RWF + SWF$: precipitation-water flux-density

PHF : latent-heat flux-density (from PWF phase-transit.)

X^0 : any variable valid for the **previous time level**

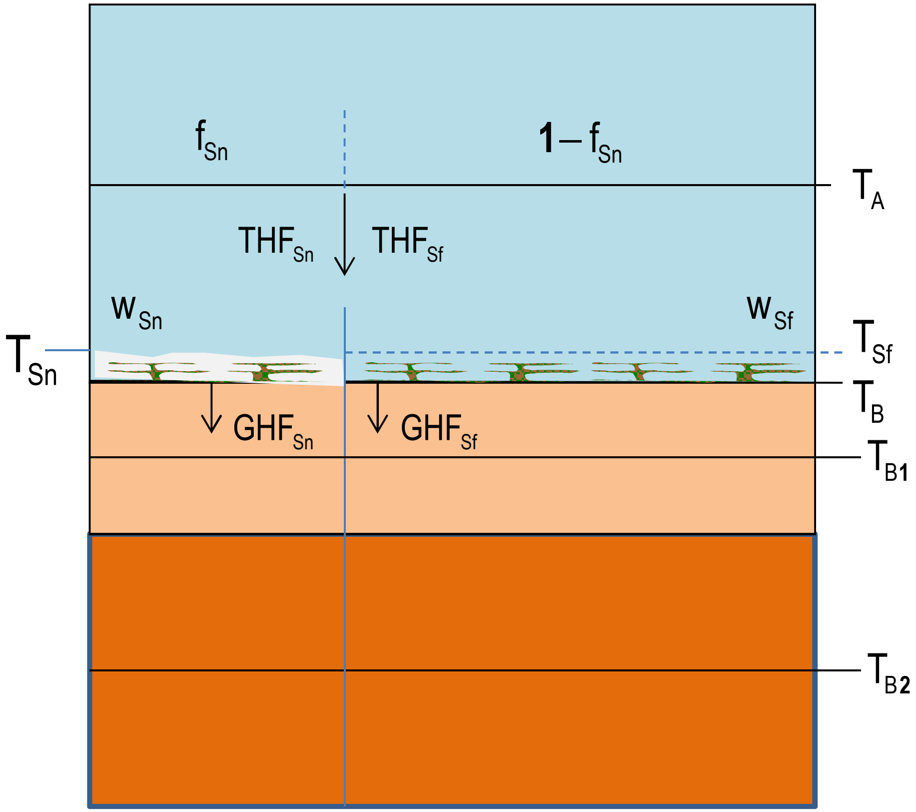
- **Rime**-fall onto **Sn** is a part of $\mathbf{SWF_{Sn}}$.
- **Rime**-fall onto **Sf** either contributes
  - o to $\mathbf{w_{Sn}}$ as well (COSMO) or
  - o to $\mathbf{w_{Sf}}$ as part of a **frozen fraction** (ICON)

- $\mathbf{RWF_{Sn}}$ is offered for **infiltration**.
- **Explicit evaporation**: applied to $\mathbf{w^0_{Sf}}$; **artificially restricted** to avoid negative water levels.
- **Thereafter**, remaining $\mathbf{PWF_{Sf}}$ charges $\mathbf{w_{Sf}}$, and a drip-water rate $\mathbf{DWF_{Sf}}$ reduces it.
- $\mathbf{w_{Sf}}$ is **afterwards limited to remain positive-definite** and **below a maximal capacity**
- **Exceeding water** spills and is offered for **infiltration**.
- **Freezing** $\mathbf{RWF_{Sf}}$ provides a **positive** contribution to $\mathbf{PHF_{Sf}}$ (flux-density of latent **freezing** heat).
- **Melting** $\mathbf{SWF_{Sf}}$ provides a **negative** contribution to $\mathbf{PHF_{Sf}}$ (flux-density of latent **melting** heat).

- ➢ **Explicit** treatment of w_{Sf} with **consecutive processes splitting** in an **arbitrary order**:
  - o **Evaporation** may be **restricted**, **although it is raining**!
  - o **PWF-conversions** may be **too excessive**, since their **implicit effect on** $\mathbf{T_{Sf}}$ is **not considered**!
- ➢ Even if **rime** is **considered as part** of $\mathbf{w_{sf}}$, **freezing or melting of** $\mathbf{w_{sf}}$ has **no caloric effect** so far!

Current explicit treatment of surface-heat flux-densities:

$$THF_{Sx} = [PHF + SRF + LRF_d + LRF_u + SHF + LHF]_{Sx}$$



THF : total-heat flux-density towards the surface

SRF : shortwave-radiation flux-density tow. the surface

LRF : longwave-radiation flux-density tow. the surface

SHF : sensible-heat flux-density tow. the surface

LHF : latent-heat flux-density tow. the surface
related to the water vapour flux-density VWF

GHF : ground-heat flux-density towards the soil

- $\boxed{GHF_{Sf} = THF^0_{Sf}}$

conductivity of the snow-pack

- $\boxed{GHF_{Sn} = GHF^0_{Sn} = -\alpha^{Sn}_B \cdot (T^0_{Sn} - T^0_{B1})}$
- $GHF = f_{Sf} \cdot GHF_{Sf} + f_{Sn} \cdot GHF_{Sn}$ **explicit** flux-density
- solution of **implicit equation** of **soil-heat conduction** $\Longrightarrow$ T_{B1}, T_{B2}, Λ
- $\boxed{T_{Sf} = T_B = T_{B1}}$
- T_{Sn} from almost **explicit snow-heat budget**:

$$\boxed{THF^1_{Sn} - GHF^0_{Sn} = [\rho_{Sn} c_{Sn}]^0 \frac{T_{Sm} - T^0_{Sm}}{\Delta t}} \qquad T_{Sm} = \frac{1}{2} \cdot (T_{Sn} + T_{B1})$$

singularity for vanishing snow-depth!

- **Sensible heat associated with water fluxes** is **never** considered **all over the model**!
- **Soil water distribution** is carried out based on **previous explicit infiltration** with an (incomplete) implicit extension
- **Melting of snow** and **freezing | melting of soil-water** executed **explicitly afterwards**.
  - o **Melted snow-water** and its needed **melting-heat** is **balanced with the uppermost soil-layer**.

Consequences of the explicit surface-coupling:

- Lots of **explicit limitations** to avoid **unrealistic** or even **unphysical** increments
  - **arbitrary**, **artificial** and often **inconsistent manipulations**

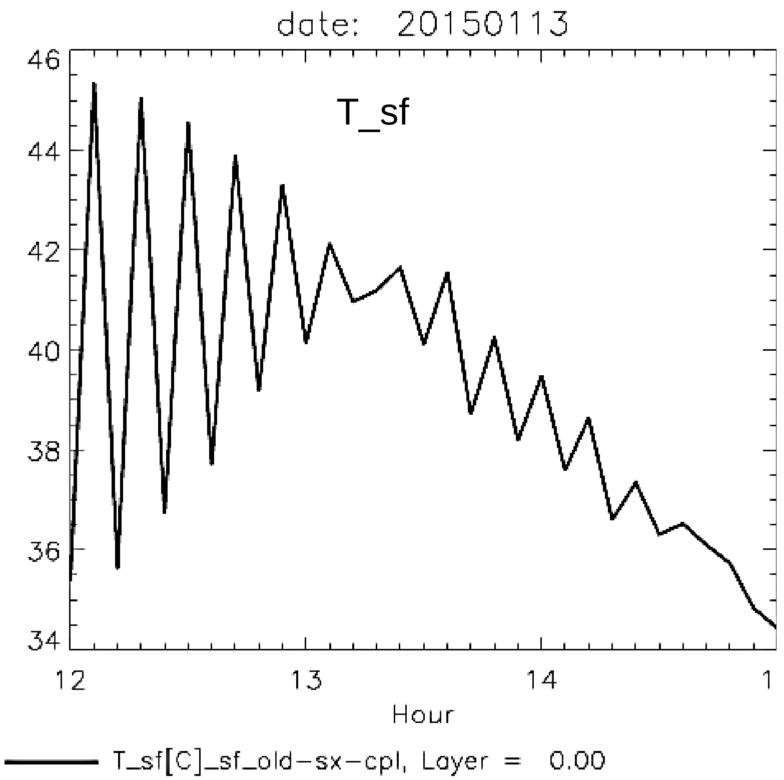
- Potential **numerical instabilities** due **to feedback oscillations**
  - **2dt-oscillations of T_{Sf}** and **T_{Sn}**
    - Could largely be **compensated** by an **artificial flux-limiter** in COSMO
    - With a **large model-time step** of about 6min or more (as used with ICON):
      - **Amplitudes** up to more than **80K** and some **model crashes!**
        (even with an **active flux-limiter**)
    - The **problems** mainly occur at **grid-points** related to the **following properties**:
      - **strong radiation forcing** (tropics)
      - a **thin** (developing or vanishing) **snow-cover**
      - **frozen precipitation** at **warm surface | liquid precipitation** at **frozen surface**
      - **disappearing interception-water or snow-water**
      - **fractional snow cover** (ICON: particularly with **dynamical Sf and Sn sub-tiles**)
      - **freezing/melting of soil water** or **melting of snow**

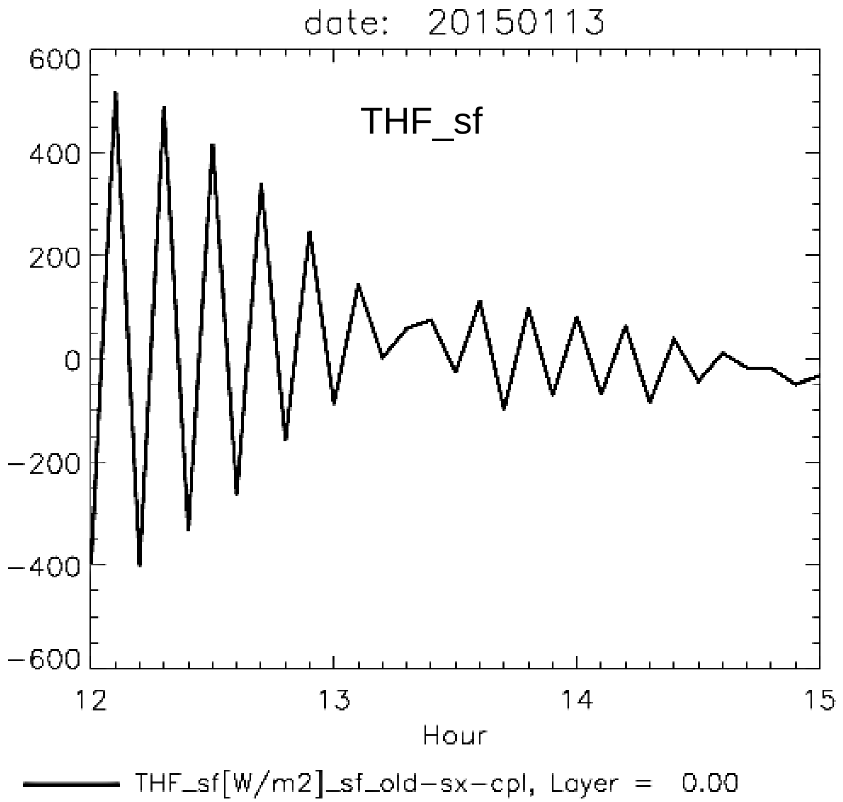
➡

- ❖ **Implicit surface-coupling** with regard to **T_{Sf}** and **T_{Sn}**
- ❖ **Implicit formulation** of **w_{Sf}**-evolution

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





old-sx-coupling: (isc=0; fes=0; ifb=0)

- **Strong 2*dt- oscillations with old coupling around noon and strong radiative forcing!**

New linear-implicitly coupled budget equations at the surface :
(completely implemented)

$$THF_{Sx} = [PHF + SRF + LRF_d + LRF_u + SHF + LHF]_{Sx}$$

total implicit heat flux-density towards the surface

$$= \quad THF^0_{Sx} \quad + \boxed{\partial_{T_{Sx}} [LRF_u + SHF + LHF]^0_{Sx} \cdot (T_{Sx} - T^0_{Sx})}$$

explicit flux-density + implicit extension

total (virtual) conductivity

$$\partial_{T_{Sx}} [LRF_u]^0_{Sx} = -4\sigma\varepsilon_0 \cdot (T^0_{Sx})^3$$

atmospheric transfer-velocity for scalars

specific humidity at saturation

$$\partial_{T_{Sx}} [SHF]^0_{Sx} = -[\rho_s u^H_s]^0 \cdot c_p$$

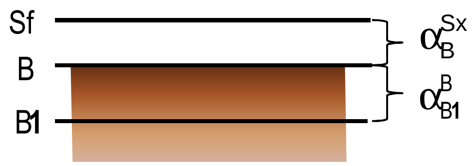
specific latent heat of evaporation

concatenation of resistances

$$\partial_{T_{Sx}} [LHF]^0_{Sx} = - \cdot [\rho_s u^H_s \cdot f^{red}_{Sx} \cdot d_T q^{sat}_v \cdot L_{ev}](T^0_{Sx})$$

specific reduction of actual evaporation

$$GHF_{Sx} = -\boxed{\frac{\alpha^{Sx}_B \cdot \alpha^B_{B1}}{\alpha^{Sx}_B + \alpha^B_{B1}}} \cdot (T_{Sx} - T_{B1})$$



(due to exchange of SH and LR for Sx=Sf)

α^y_x : conductivity between levels x and y

$$THF_{Sn} - GHF_{Sn} = [\rho_{Sn} c_{Sn}]^0 \frac{T_{Sm} - T^0_{Sm}}{\Delta t} \boxed{\xrightarrow[h_{Sn \to 0}]{} 0}$$

reduces to **implicit flux-balance** for vanishing snow-depth

$$T_{Sm} = \frac{1}{2} \cdot (T_{Sn} + T_B)$$

linear vertical T-profile of snow-pack

$$THF_{Sf} - GHF_{Sf} = [\rho_c c_c]^0 \frac{T_{Cm} - T^0_{Cm}}{\Delta t} \boxed{\xrightarrow[C_c \to 0]{} 0}$$

reduces to **implicit flux-balance** for

currently applied skin-layer approximation:

$$\boxed{\begin{array}{l} C_c \to 0 \\ \alpha^{Sf}_B \to \infty \\ T_C \to T_B \end{array}}$$

$$T_{Cm} = \frac{1}{2} \cdot (T_C + T_B)$$

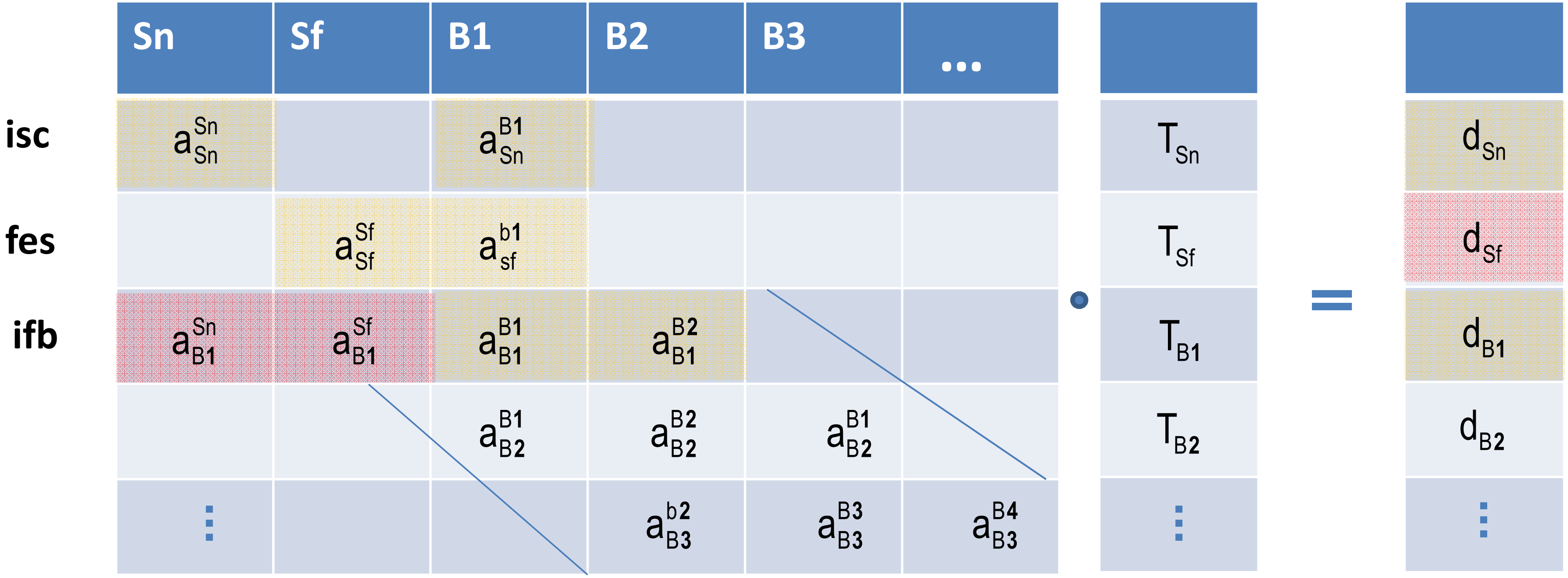
linear vertical T-profile of R-layer

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:



$$\begin{array}{c|cccccc} & Sn & Sf & B1 & B2 & B3 & \dots \\ \hline isc & a^{Sn}_{Sn} & & a^{B1}_{Sn} & & & \\ fes & & a^{Sf}_{Sf} & a^{b1}_{sf} & & & \\ ifb & a^{Sn}_{B1} & a^{Sf}_{B1} & a^{B1}_{B1} & a^{B2}_{B1} & & \\ & & & a^{B1}_{B2} & a^{B2}_{B2} & a^{B1}_{B2} & \\ & \vdots & & & a^{b2}_{B3} & a^{B3}_{B3} & a^{B4}_{B3} \end{array} \bullet \begin{array}{c} \\ \hline T_{Sn} \\ T_{Sf} \\ T_{B1} \\ T_{B2} \\ \vdots \end{array} = \begin{array}{c} \\ \hline d_{Sn} \\ d_{Sf} \\ d_{B1} \\ d_{B2} \\ \vdots \end{array}$$

- Can easily be <u>tri-diagonalized</u> by matrix-operations and solved by the standard solver
- <u>Partly reducible</u> 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

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- **3 hour ICON-global test-run (R2B6, dt=6min) with**
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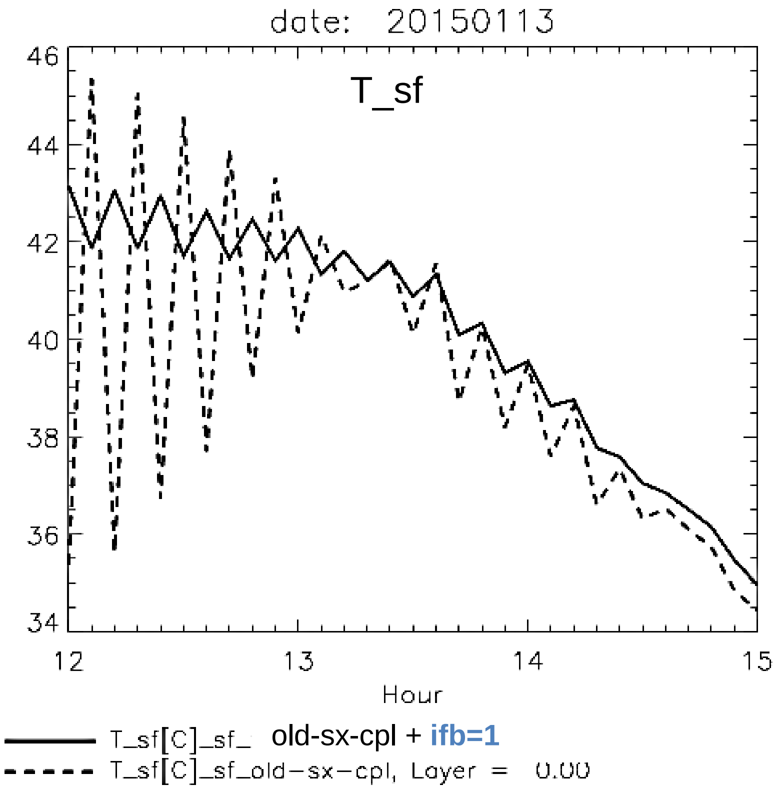

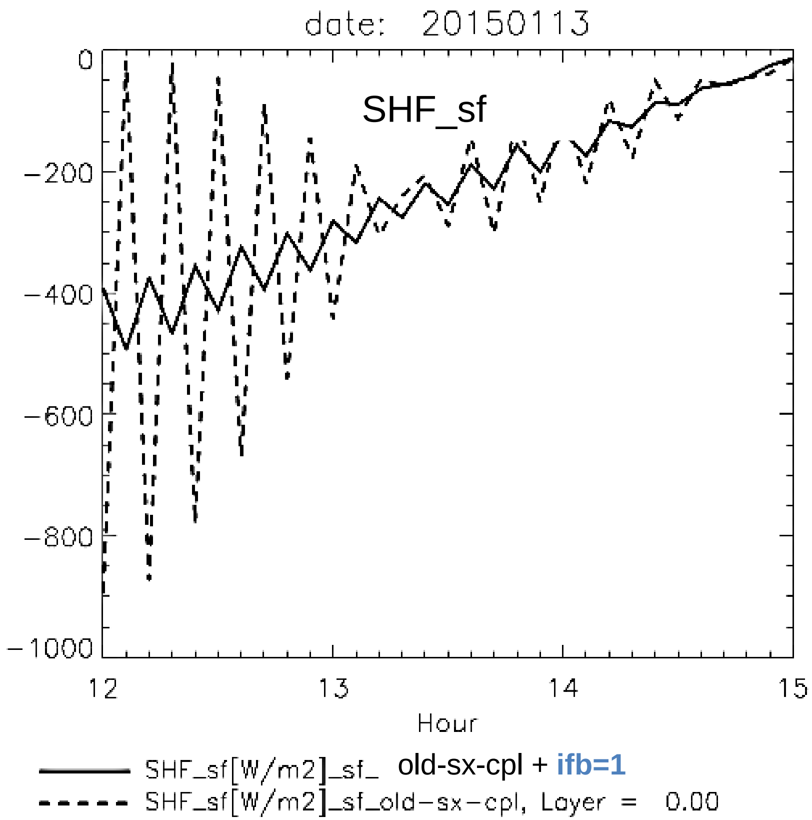

- **Oscillations strongly reduced by ifb=1 (implicit flux increments active for soil forcing)**

Implicit increments of atmospheric transfer velocities:
(already implemented)

- Remaining oscillations may be due a **hidden T_{Sx}-dependency** of the **transfer velocity for heat** u_s^H , which controls the **virtual conductivities** of SHF_{Sx} and LHF_{Sx}:

$$\partial_{T_{Sx}}[SHF]^0_{Sx} = -[\rho_s \boxed{u_s^H}]^0 \cdot c_p \qquad \partial_{T_{Sx}}[LHF]^0_{Sx} = -\cdot[\rho_s \boxed{u_s^H} \cdot f^{red}_{Sx} \cdot d_T q_v^{sat} \cdot L_{ev}](T^0_{Sx})$$

$$\boxed{[u_s^H]^0 \rightarrow u_s^H := [u_s^H]^0 + \partial_{T_{Sx}}[u_s^H]^0 \cdot (T_{Sx} - T^0_{Sx})}$$

- The implicit heat budgets for Sf and Sn become **quadratic** in T_{Sx} :

- From **solutions** T^*_{Sx} of the **decoupled** versions of these **implicit quadratic** equations:

$$[u_s^H]^* = [u_s^H]^0 + \partial_{S_{sx}}[u_s^H]^0 \cdot (T^*_{Sx} - T^0_{Sx})$$

- This **updated transfer velocity** $[u_s^H]^*$ is used in the **subsequent linear system**.

- The factor of the **linear T_{Sx}-dependency of the transfer-velocity** is estimated by **registration**:

$$\partial_{T_{sx}}[u_s^H]^0 \approx \frac{[u_s^H]^0 - [u_s^H]^{-1}}{T_s^0 - T_s^{-1}} \qquad T_s := (1-f_{Sn}) \cdot T_{Sf} + f_{Sn} \cdot T_{Sn}$$

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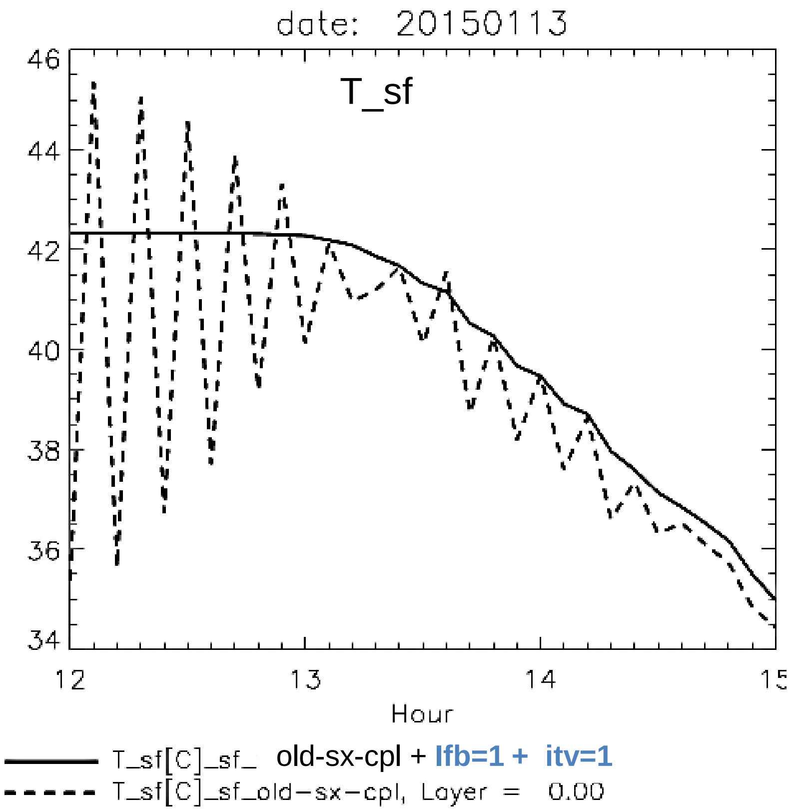
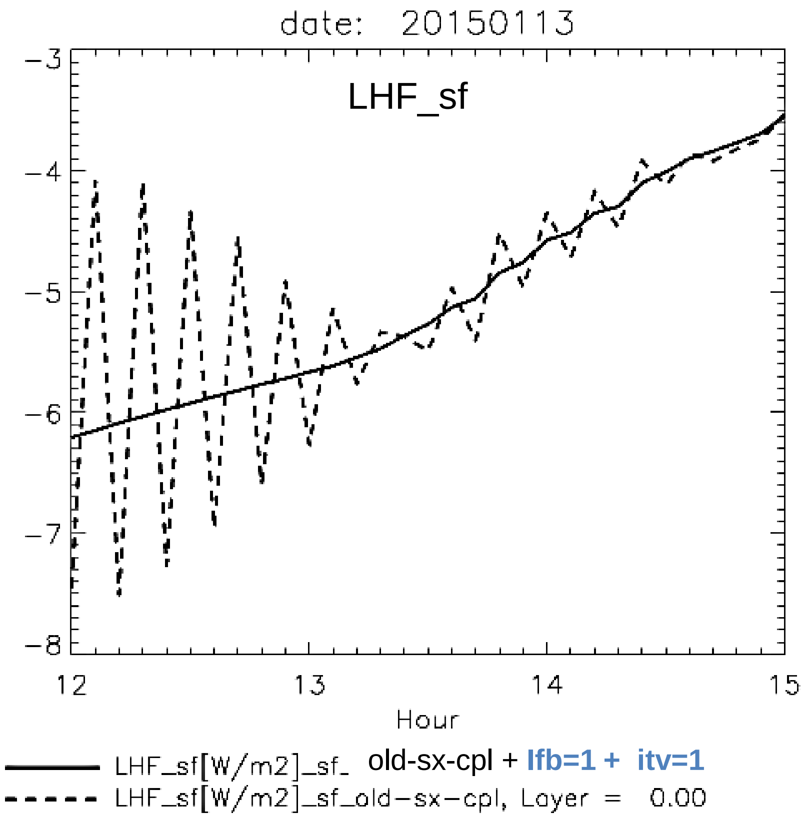




- **Oscillations almost completely eliminated by** **ifb=1 + itv=1**
- **Similar result but a bit larger daily amplitudes** **ifb=1 + itv=1 + fes=1 (not shown)**

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

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

Current state :

- **Major adaptations** in TERRA, TURBTRAN (and related interfaces) introduced into **ICON-branch**:
  - **Restructuring** the sequence of processes
  - **Removal** of various, now detrimental limitations all over the code
  - **Reformulations** related to variable-redistribution for dynamic snow-tiles
  - **Generalization** of snow-cover diagnostics
  - **Substitution** of previous descriptions by new formulations
  - **Implementation** of new features
- **Sanity-checks** performed:
  - **numerically stable** even for **large time steps**
  - some **remaining oscillations** due to phase-transitions of snow or soil-water
  - almost minor differences compared to operational version, **but:**
  - the so far **inconsistent** treatment of **rime as part of w_{sf}** had to be **removed!**
    - **positive effect of this feature no longer present!**

⇒

- ❖ **consistent formulation of a 2-phase interception-store**
- ❖ **together with the so far missing implicit formulation** of w_{sf}-evolution

New implicit and simultaneous incrementation of interception water:
(partly implemented)

$$\frac{w_{Sf}-w_{Sf}^{0}}{\Delta t}=PWF_{Sf}+VWF_{Sf}+DWF_{Sf}$$

PWF : given precipitation-water flux-density

$$VWF_{Sf}=-f_{Sf}^{cov}\left(w_{Sf}\right)\cdot VWF_{Sf}^{pot}\left(T_{Sf}^{0}\right)$$

: current water-vapour flux-density

explicit potential evaporation (negative for dew- or rime-fall, where $f_{Sf}^{cov}\left(w_{Sf}\right)\equiv 1$)

linear cover-function: $f_{Sf}^{cov}\left(0\right)=0$ $\boxed{f_{Sf}^{cov}\left(w_{Sf}^{max}\right)=1}$ (for real evaporation)

$$DWF_{Sf}=-f_{Sf}^{drp}\left(w_{Sf}\right)\cdot DWF_{Sf}^{ref}$$

: current drip-water flux-density

explicit reference value at $f_{Sf}^{dpr}=1$ (parameter of the scheme)

rational drip-function: $f_{Sf}^{dpr}\left(0\right)=0$ $\boxed{f_{Sf}^{dpr}\xrightarrow[w_{Sf}\to w_{Sf}^{max}]{}\infty}$

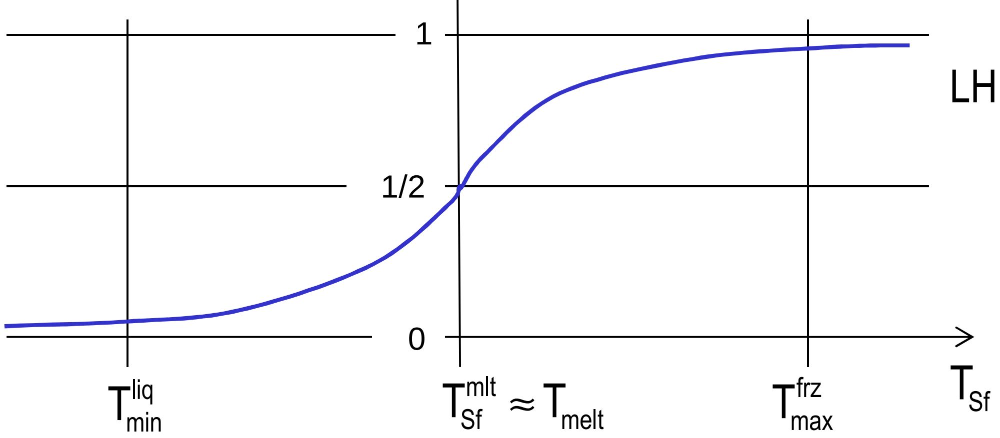
- **Quadratic equation for** $0\le w_{Sf}\le w_{Sf}^{max}$ **; automatically positive-definite and limited**
- **Simultaneous consideration of all sources and sinks**
- VWF_{Sx}^{pot} **still depends on previous surface temperature** T_{Sf}^{0}
  - **No implicit coupling between hydrological and thermal equations yet!**
  - **Lower atmosph. BC**: **explicit** VWF_{Sx}^{0} and **corrected** $SHF_{Sx}=SHF_{Sx}^{0}+\Delta THF_{Sx}$!!

Implicit freezing and melting of interception water and precipitation:
(being implemented)

- At least for $T_{min}^{liq} \leq T_{Sf} \leq T_{max}^{frz}$ **liquid and frozen** interception-water **coexists** with a **smooth transition**.

$$\boxed{f_{Sf}^{liq}\left(T_{Sf}\right) \approx f_{Sf}^{liq}\left(T_{Sf}^{0}\right) + d_T f_{Sf}^{liq}\left(T_{Sf}^{0}\right) \cdot \left(T_{Sf} - T_{Sf}^{0}\right)}$$

: **liquid fraction** of w_{Sf} and its linearization



$$LHF_{Sf} = LHF_{Sf}^{0} + \partial_{T_{Sx}}\left[LHF\right]_{Sx}^{0} \cdot \left(T_{Sx} - T_{Sx}^{0}\right)$$

$$\partial_{T_{Sf}}\left[LHF\right]_{Sf}^{0} = - \cdot \left[\rho_s u_s^H \cdot f_{Sf}^{red} \cdot d_T q_v^{sat} \cdot \boxed{L_{ev}}\right]\left(T_{Sf}^{0}\right)$$

$$\boxed{L_{ev}\left(T_{Sf}^{0}\right) \rightarrow L_{ev}\left(T_{Sf}\right) = L_{lv} \cdot f_{Sf}^{liq}\left(T_{Sf}\right) + L_{fv} \cdot \left[1 - f_{Sf}^{liq}\left(T_{Sf}\right)\right]}$$

generalized latent heat of vaporization

$$PHF_{Sf} = PHF_{Sf}^{0} + \partial_{T_{Sf}}\left[PHF\right]_{Sf}^{0} \cdot \left(T_{Sf} - T_{Sf}^{0}\right)$$

: latent heat flux-density due to rain<->snow transition including implicit extension

$$PHF_{Sf}^{0} = L_{fl} \cdot \left[RWF_{Sf} - \left(RWF_{Sf} + SWF_{Sf}\right) \cdot \boxed{f_{Sf}^{liq}\left(T_{Sf}^{0}\right)}\right]$$

: related explicit part

$$\partial_{T_{Sx}}\left[PHF\right]_{Sx}^{0} = -L_{fl} \cdot \left(RWF_{Sf} + SWF_{Sf} + \frac{w_{Sf}^{0}}{\Delta t}\right) \cdot \boxed{d_T f_{Sf}^{liq}\left(T_{Sf}^{0}\right)}$$

: related virtual conductivity including associated phase transition of present interception water w_{Sf}^{0}

- Introducing **LHF$_{Sf}$** and **PHF$_{Sf}$** in **decoupled** **T$_{Sf}$-equation** and solving this in **quadratic approximation**:
  - **Correct** and **implicit** treatment of **liquid and frozen interception water**
  - Final **T$_{sf}$** is in **dynamical accordance** with **complete turnover of latent heat.**

Next steps:

- **Completion** of running implementations related to interception water
- **Running** chain of test-cases
- **Performing** some code-optimizations in terms of vectorization

➡ ❖ **1-st official ICON-release -> COSMO**

- **Adding** melting of snow and freezing/melting of soil-ice into the implicit heat budgets

➡ ❖ **2-nd official ICON-release -> COSMO**

- **Incorporation** of a multi-layer snow-model
- **Introducing** the extension with a decoupled, substantial and semi-transparent **cover-layer**, including
  - the partitioning of fluxes into those related to B and C
  - expressions for the additional conductivity α_B^C and the additional heat capacity c_c :

$$THF_C - GHF_C = [\rho_c \boxed{c_c}]^0 \frac{T_{Cm} - T^0_{Cm}}{\Delta t}$$

$$T_{Cm} = \frac{1}{2} \cdot (T_C + T_B)$$ linear vertical T-profile of R-layer

$$GHF_C = -\frac{\boxed{\alpha_B^C} \cdot \alpha_{B1}^B}{\boxed{\alpha_B^C} + \alpha_{B1}^B} \cdot (T_C - T_{B1})$$

c_c due mass of R-elements and interception water

α_B^C due to exchange of SH and LR between B and C

➢ based on an **already developed prototype**, present in an **older test-version of COSMO**!

➢ largely **prepared just by the current implementations** into ICON!

➢ **removal of remaining conceptual deficiencies!**

➢ **significant impact on simulated properties!**

- **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**

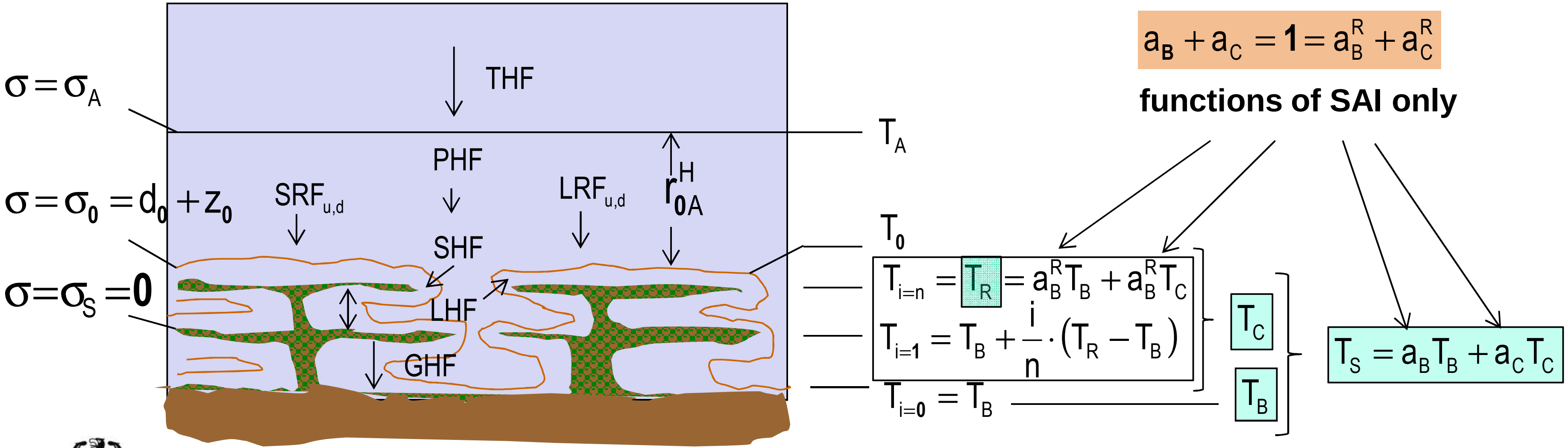
  ➡ strongly effects the **LAI-impact of transpiration**!

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

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

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

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



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

functions of SAI only

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

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

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

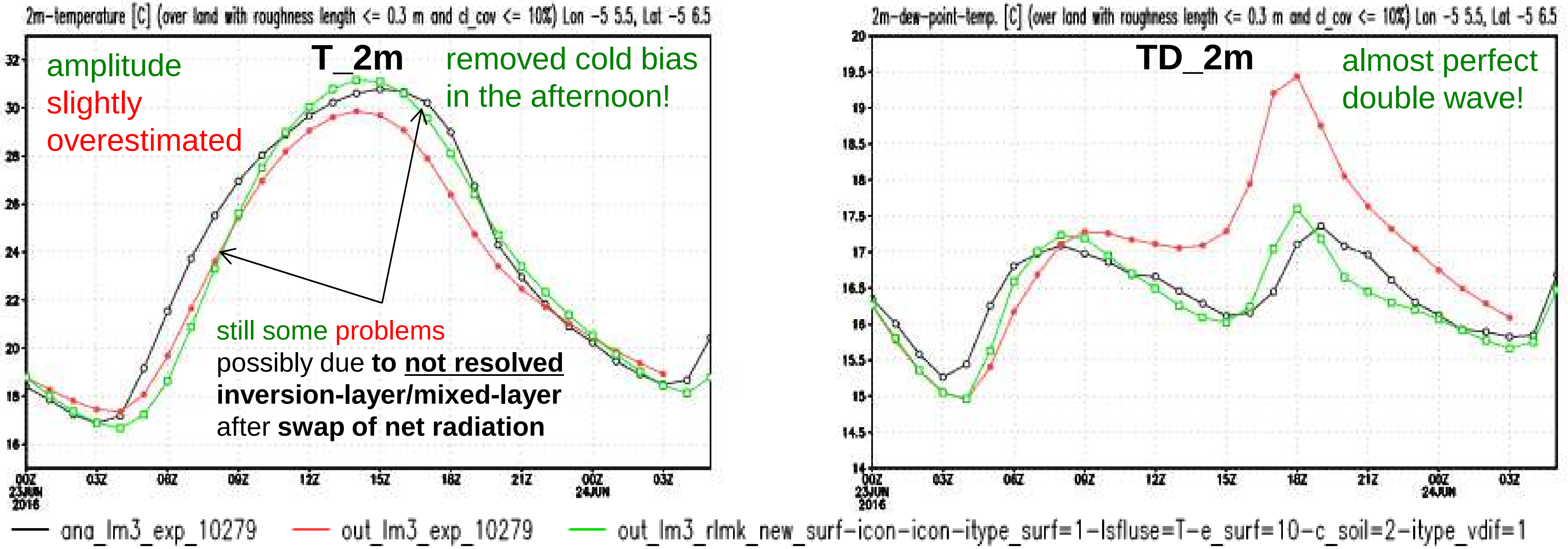
$$\boxed{T_S = a_B T_B + a_C T_C}$$

- 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:**
   - **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**

already shown
last year

conditional
diagnostic



T_2m

amplitude
slightly
overestimated

removed cold bias
in the afternoon!

still some problems
possibly due **to not resolved**
inversion-layer/mixed-layer
after **swap of net radiation**

TD_2m

almost perfect
double wave!

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

Thank you for attention!