

Towards a new snow cover scheme for COSMO and ICON

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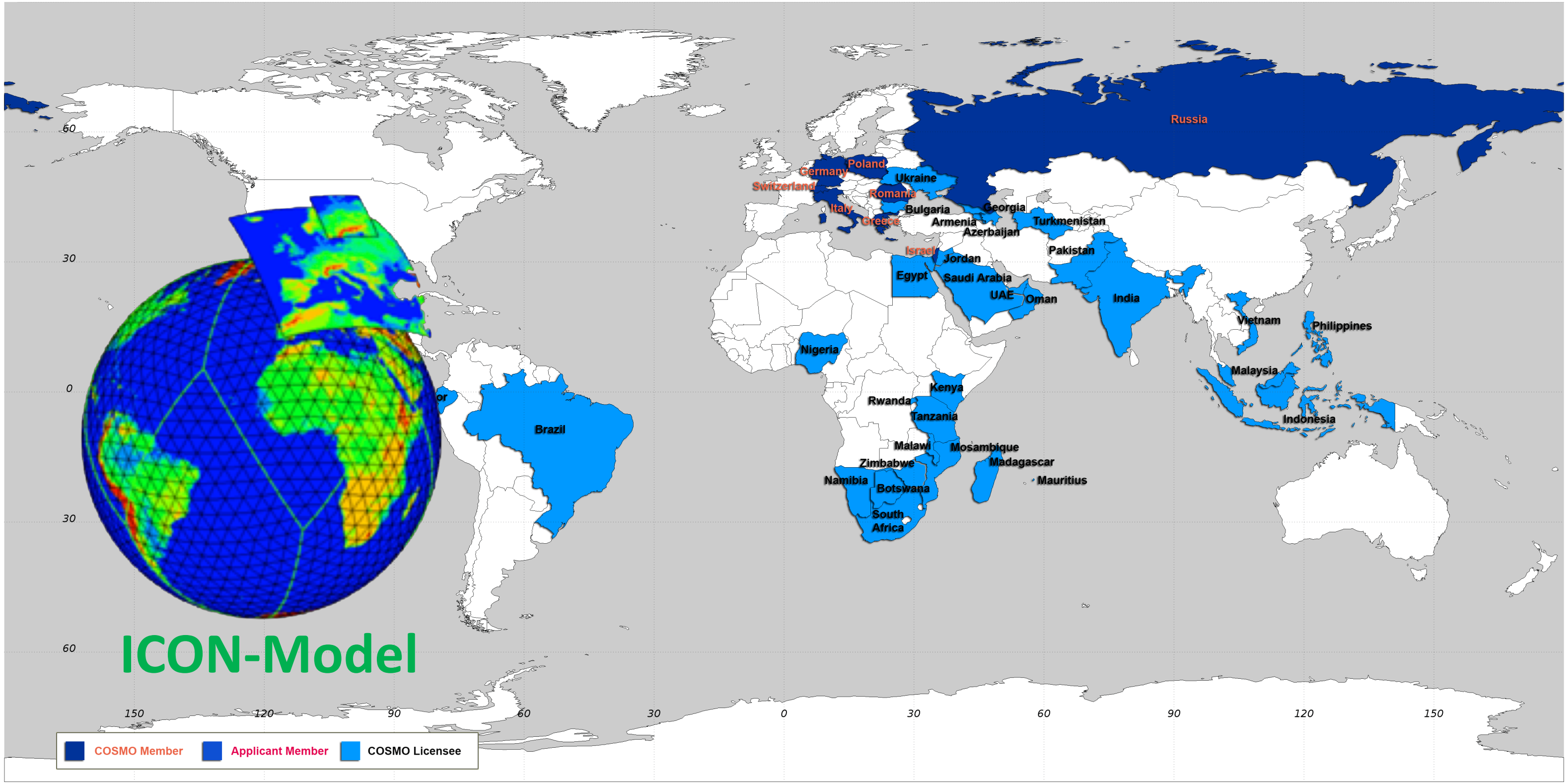
Davos, 05.03.2019

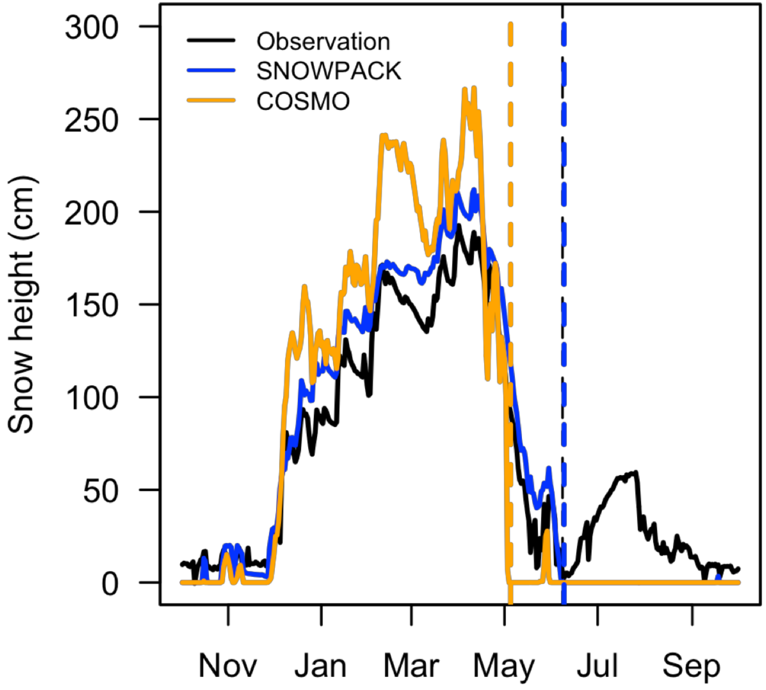
COSMO (Global usage) & ICON$_{\text{Global, LAM, LES}}$



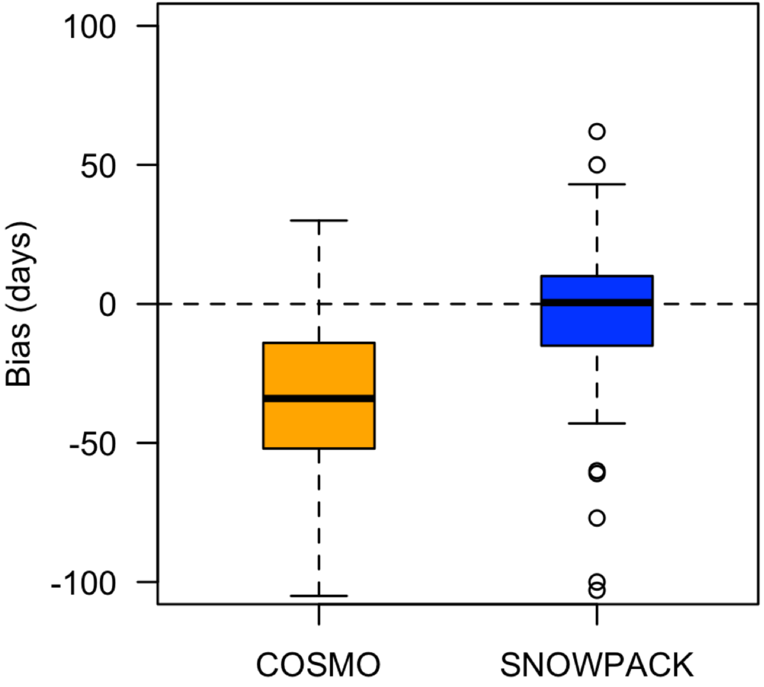
COSMO & ICON used in climate mode

COSMO-2 validation (Snow depth)

Weissfluhjoch



IMIS



Single layer snow cover scheme – COSMO

$$\frac{\partial T_{snow}}{\partial t} = \frac{1}{(\rho c \Delta z)_{snow}} \left(Q_F - Q_G + Q_M \right)$$

Atmospheric Forcing:

$$Q_F = Q_S^* + Q_L^* + Q_{HE} + Q_{SE}$$

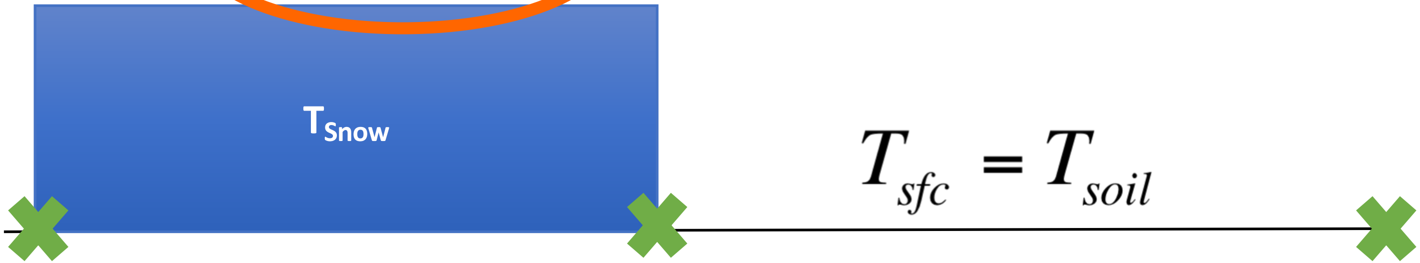
Ground heat Flux:

$$Q_G = \lambda_{snow} \frac{T_{snow,sfc} - T_{soil}}{z_{snow}}$$

$$\lambda_{snow} = \lambda_{ice} \left(\frac{\rho_s}{\rho_w} \right)^{1.88}$$

T_{sfc}

$$T_{snow,sfc} = T_{snow}$$



$$T_{sfc} = T_{soil}$$

T_{soil}

Soil

Single layer snow cover scheme – SnowMIP project

Annals of Glaciology 38 2004

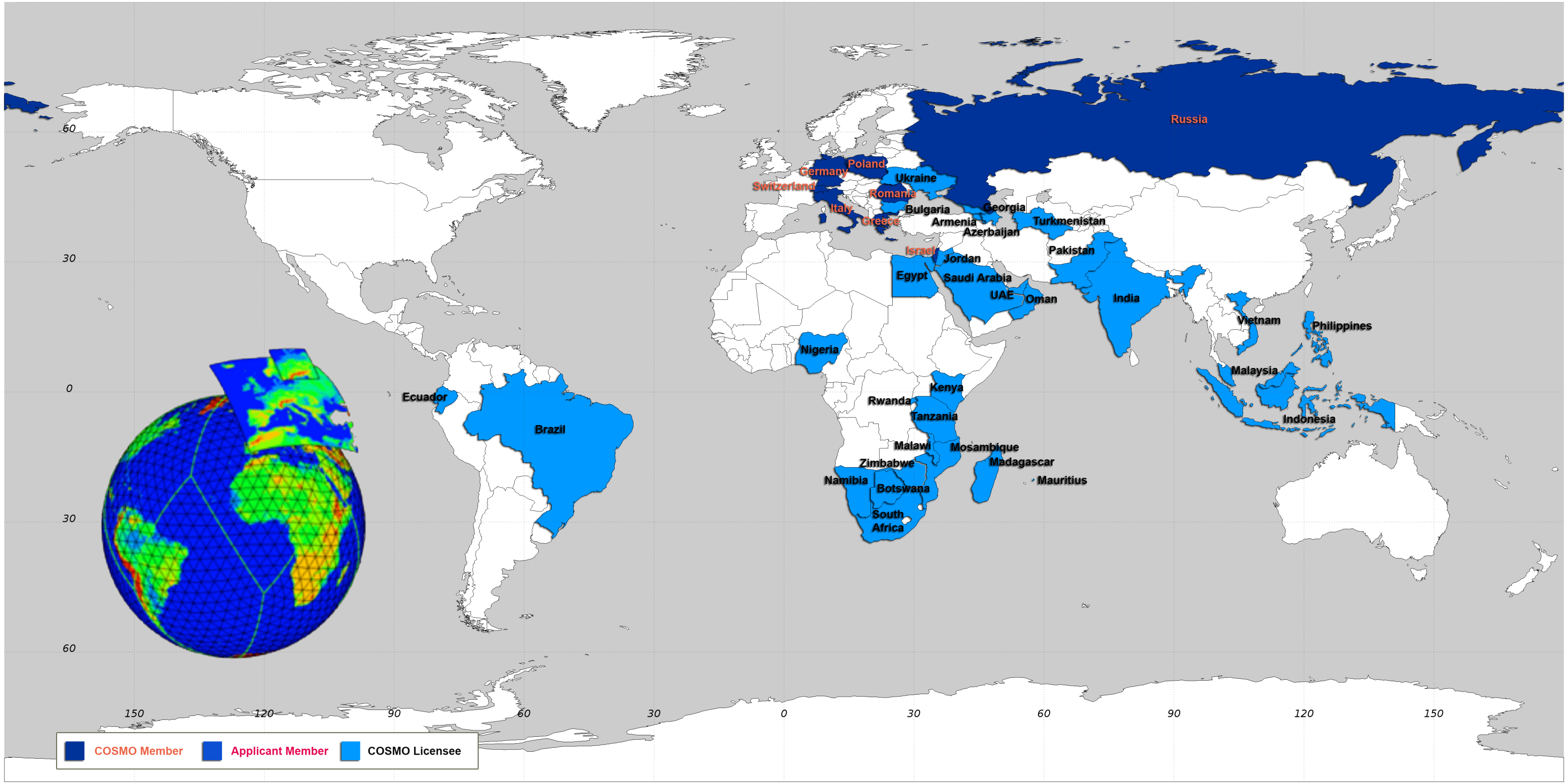
Validation of the energy budget of an alpine snowpack simulated by several snow models (SnowMIP project)

Pierre ETCHEVERS,[1] Eric MARTIN,[1] Ross BROWN,[2] Charles FIERZ,[3] Yves LEJEUNE,[1] Eric BAZILE,[4] Aaron BOONE,[4] Yong-Jiu DAI,[5] Richard ESSERY,[6] Alberto FERNANDEZ,[7]

From Conclusions:

simulated amount of melting that is too small. Finally, the model complexity appears to have a strong impact on the net longwave radiation simulation. Indeed, snow surface temperature is the result of a complex equilibrium in the snowpack, and the models which explicitly simulate internal snow processes simulate the snow surface temperature best. In contrast, model complexity has relatively little

COSMO & ICON$_{\text{Global, LAM, LES}}$ – Global usage



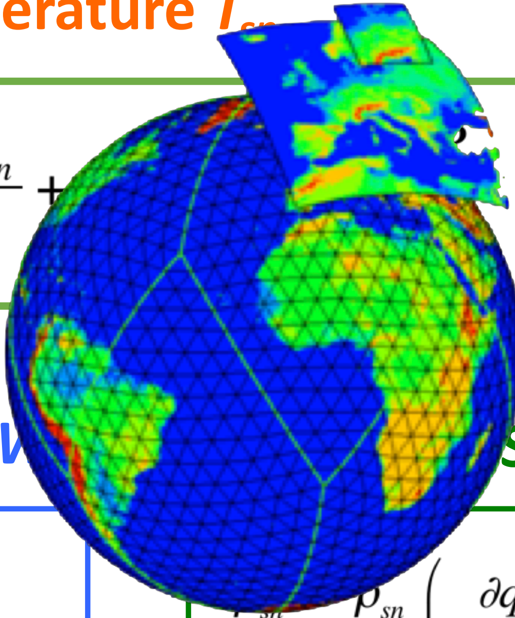
Multi-layer snow cover scheme – COSMO

Snow Temperature T_{sn}

$$\rho_{sn}\frac{\partial T_{sn}}{\partial t} = \frac{\partial}{\partial z}\lambda_{sn}\frac{\partial T_{sn}}{\partial z} + \ldots$$

Liquid Water W_{liq}

$$\frac{\partial W_{liq}}{\partial t} = M - F - \frac{\partial q}{\partial z}$$



Total Water (SWE) W

$$\frac{\partial W_{tot}}{\partial t} = -\frac{\partial q}{\partial z}$$

Snow density ρ_{sn}

$$\frac{\partial \rho_{sn}}{\partial t} = \frac{\rho_{sn}}{W_{tot}}\left(-\frac{\partial q}{\partial z}\left(1-\frac{\rho_{sn}}{\rho_w}\right)+\rho_{sn}\frac{\rho_w-\rho_i}{\rho_w\rho_i}\left(M-F\right)\right)+\sigma(t)$$

Proposed COSMO Priority Task (PT) Project – SAINT

CONSORTIUM FOR SMALL SCALE MODELING

COSMO

COSMO Priority Task: Snow cover Atmosphere INTeractions (SAINT)

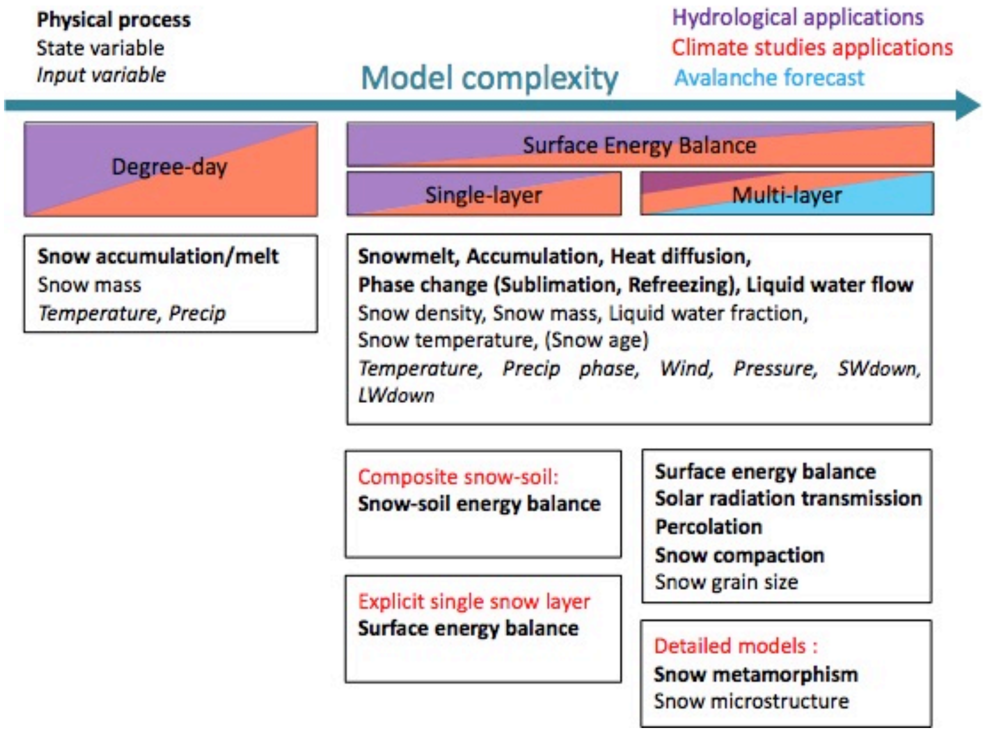
Version 1.0, 13.10.2017

Task Leader: Sascha Bellaire (WSL Institute for Snow and Avalanche Research SLF)

Main goal

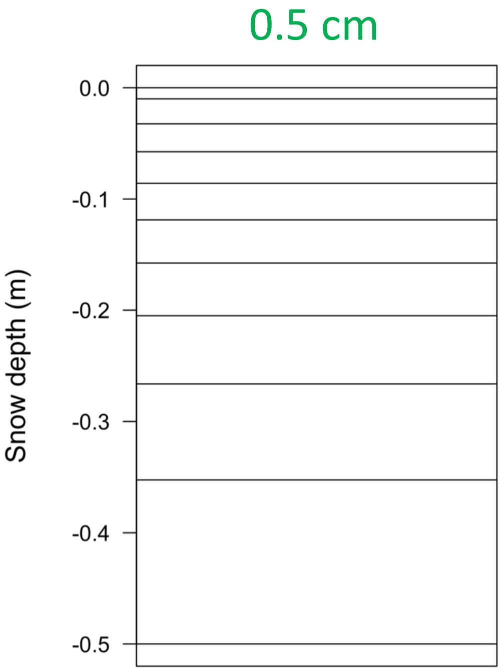
Improving the current multi-layer snow cover scheme

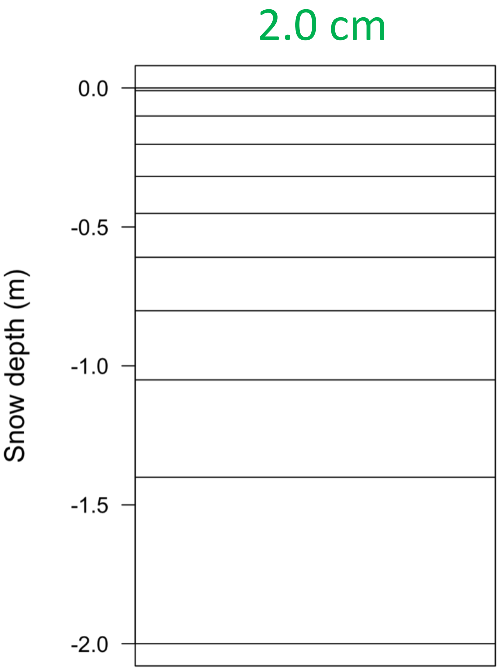
Proposed COSMO Priority Task (PT) Project – SAINT



- **'Good' models must include …**
  - **new snow density,**
  - **albedo parameterization (SEB),**
  - **heat conduction/equation,**
  - **phase changes,**
  - **water transport.**
  - **compaction/settlement.**

The Scheme: Multi-layer snow cover scheme (MLS; Layering)





General Structure:

- Maximum 10 snow layers
- fixed first layer thickness 0.01 m
- Logarithmic increase of layer thickness with depth

Limitations:

- no layer smaller than 0.01 m
- minimum snow depth 0.01 m

Snow cover scheme (MLS) – Implementation

```
!!==========================
 
MODULE sfc_terra
 
!==================
```

```
 
!SB <
USE sfc_snow
USE snow_utilities
!SB >
 
!--------------------------------------------
```

New snow model called in TERRA ...

... consists of 2 (or 3) subroutines called ...

CALL snow_forcing(...)

- snow specific atmospheric forcing

CALL snow_on_soil(...)

- layering/new snow
- heat conduction
- phase changes
- water transport
- settling
- re-meshing
- ...

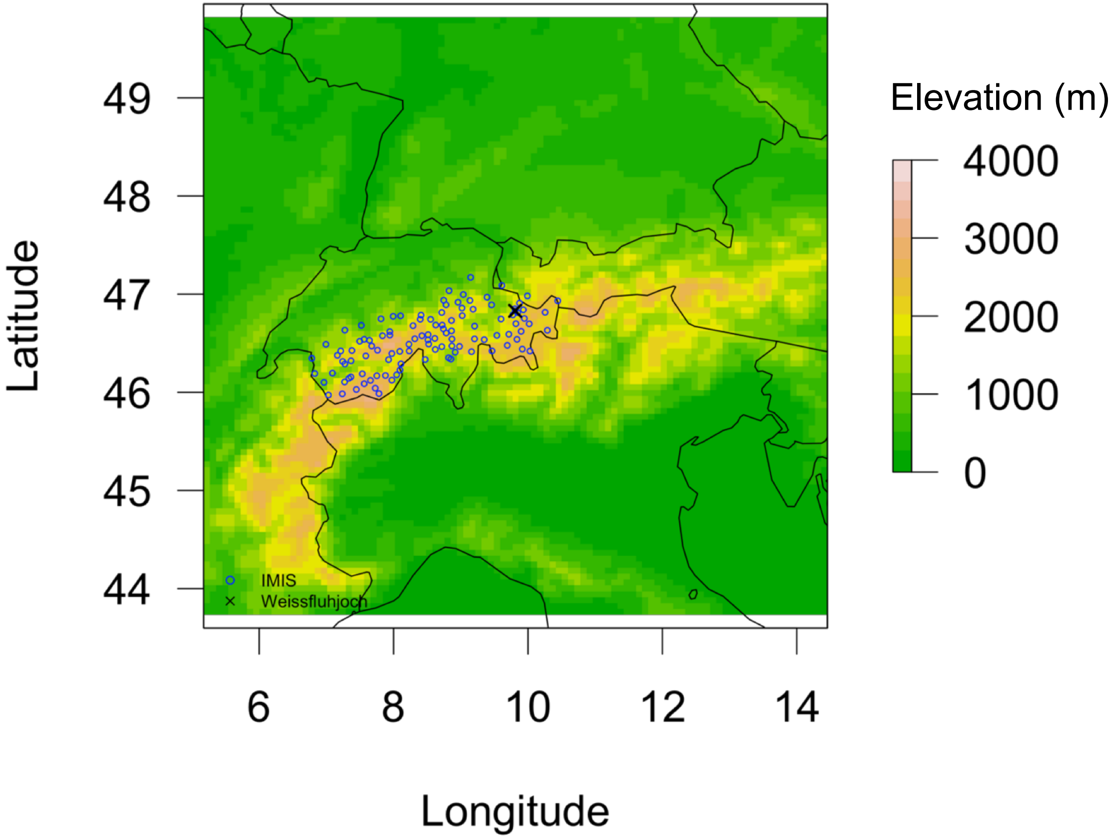
CALL interface_snow(...)

- preparation of required input (# layers, layering, heat conductivity etc.) for solving heat equation in TERRA

... before solving the heat equation in TERRA

```
 
    END DO
  END DO         ! soil layers
 
!MR: 05.05.2017 and later: heat-budget for inner soil layers substituted by a slightly different notation: >
!----------------------------------------------------------------------------------------------
 
!**********************************************************************************************
!MR: 05.05.2017: modified heat-budget for boundary soil layers including a single-layer snow-cover: <
!**********************************************************************************************
 
```

The Method: Validation (COSMO-7)



- … ~ 700 km x 700 km domain centered around Davos …
- … covering most of the Alpine ridge …
- … computationally inexpensive …
- .. boundary conditions from COSMO-7 analysis …
- … 72-hour forecast/hindcast

Heat Equation – Implementation

1D heat equation:

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2}; \quad 0 \leq x \leq L; \quad t \geq 0$$

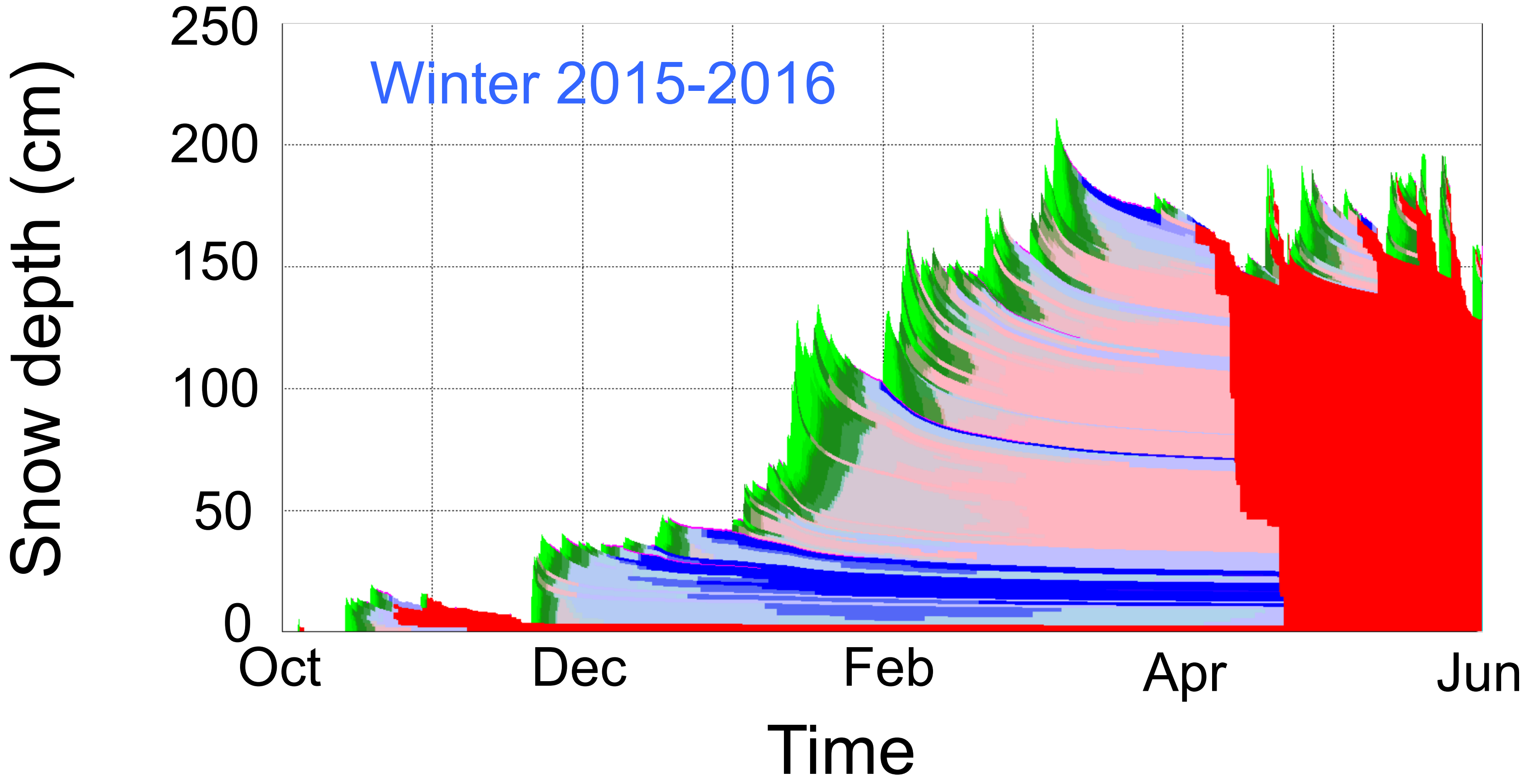
- Solve the one-dimensional heat equation.
- Setup a tridiagonal matrix for set of linear equations for each layer.
- Solved using the Thomas-Algorithm

```
! ---------------------------------------------------------------
! Setup tridiagonal matrix for set of linear equations for each layer ...
! ---------------------------------------------------------------

! ... TOP LAYER
dz_low = zm_sn(top_sn+1)

a(top_sn) = 0.0_wp
b(top_sn) = 1 + (1 - cn) * alpha(top_sn) * hcon_sn_now(top_sn)/dz_low - alpha(top_sn)*dlw_u_sn
c(top_sn) = -   (1 - cn) * alpha(top_sn) * hcon_sn_now(top_sn)/dz_low

d(top_sn) = t_sn(top_sn) + alpha(top_sn) * (for_sn - dlw_u_sn*t_sn(top_sn) + cn*hdif_sn(top_sn))


  ! ... INNER LAYERS
  DO i = top_sn+1,  bot-1, 1

    dz_up  = zm_sn(i)   - zm_sn(i-1)
    dz_low = zm_sn(i+1) - zm_sn(i)

    a(i) = - (1 - cn)   * alpha(i) *  hcon_sn_now(i-1)/dz_up
    b(i) = 1 + (1 - cn) * alpha(i) * (hcon_sn_now(i)  /dz_low + hcon_sn_now(i-1)/dz_up)
    c(i) = - (1 - cn)   * alpha(i) *  hcon_sn_now(i)  /dz_low

    d(i) = t_sn(i) + cn*alpha(i) * (hdif_sn(i) - hdif_sn(i-1))


  ENDDO


 ! ... BOTTOM LAYER

 dz_up = zm_sn(bot)   - zm_sn(bot-1)

 a(bot) = - (1 - cn)   * alpha(bot) * hcon_sn_now(bot-1)/dz_up
 b(bot) = 1 + (1 - cn) * alpha(bot) * hcon_sn_now(bot-1)/dz_up
 c(bot) = 0.0_wp

 d(bot) = t_sn(bot) - cn*alpha(bot-1) + alpha(bot)*hdif_sn(bot)

! ---------------------------------------------------------------
! Solve the system - Thomas Algorithm
! ---------------------------------------------------------------

! NOTE: The following can be put in a subroutine

 DO i = 1, bot, 1

  e(i) = t_sn(i)

 ENDDO


  beta = b(top_sn)

   ! Forward substitution
   DO j = 1, bot, 1

       IF(j == 1) THEN

         e(j) = d(j) / beta

       ELSE

         gama(j) = c(j-1) / beta
         beta    = b(j) - a(j) * gama(j)
         e(j)    = (d(j) - a(j) * e(j-1)) / beta

       ENDIF

   END DO ! end of j


    ! Backward substitution
    DO j = bot-1 , 1, -1

      e(j) = e(j) - gama(j+1) * e(j+1)

    ENDDO
```

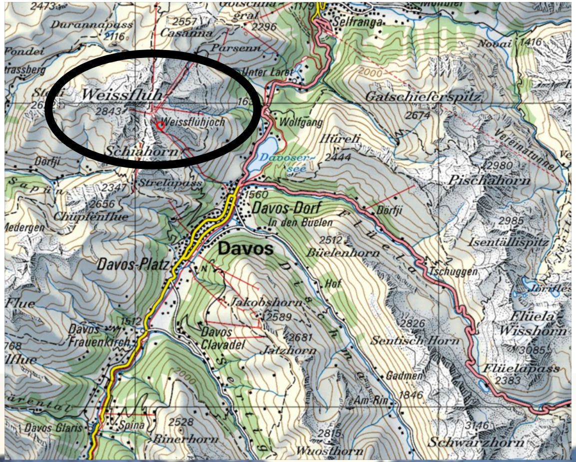
Top layer

for_sn = forcing = SEB

Heat Equation – Benchmarking (SNOWPACK vs. MLS)



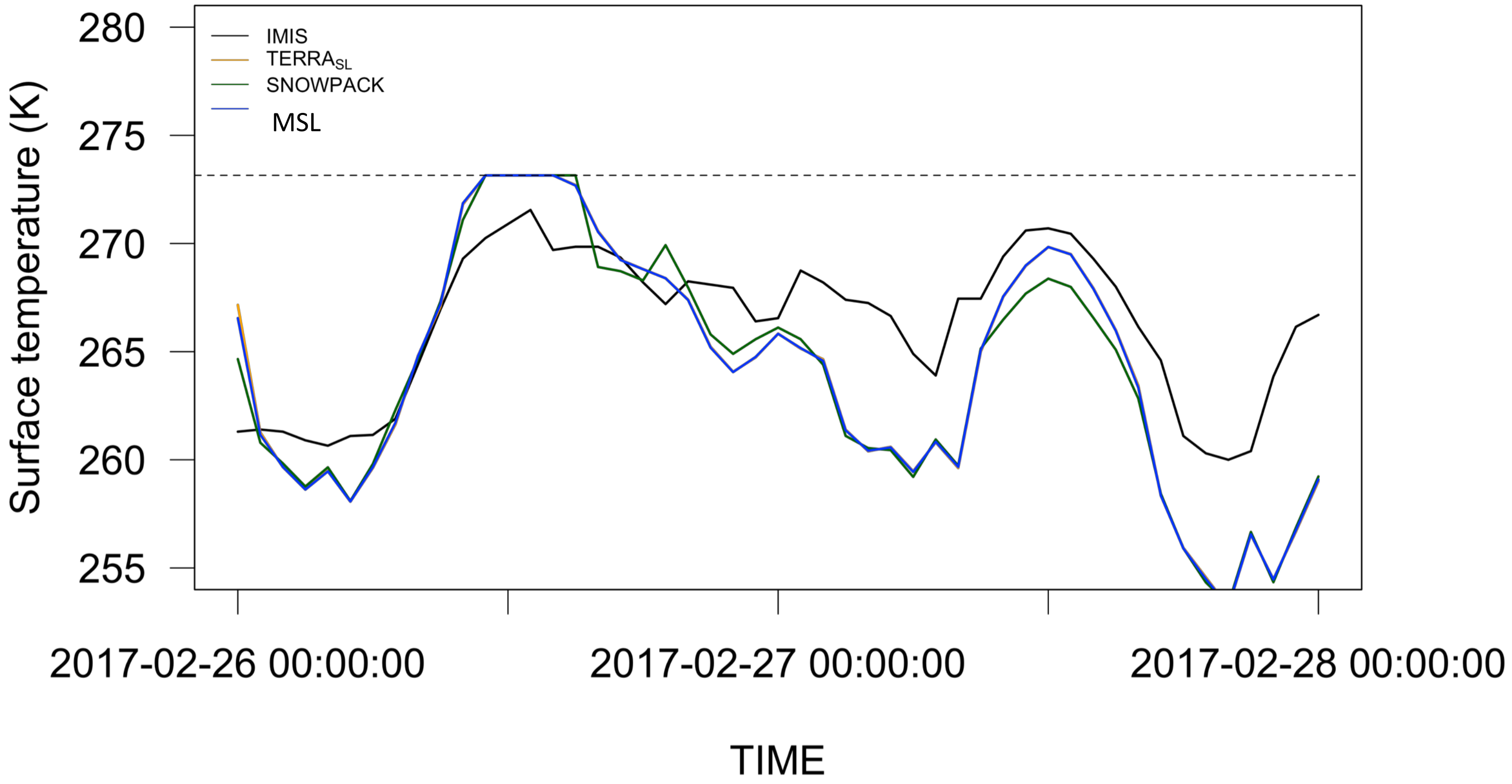
Heat Equation – Benchmarking (Observations)



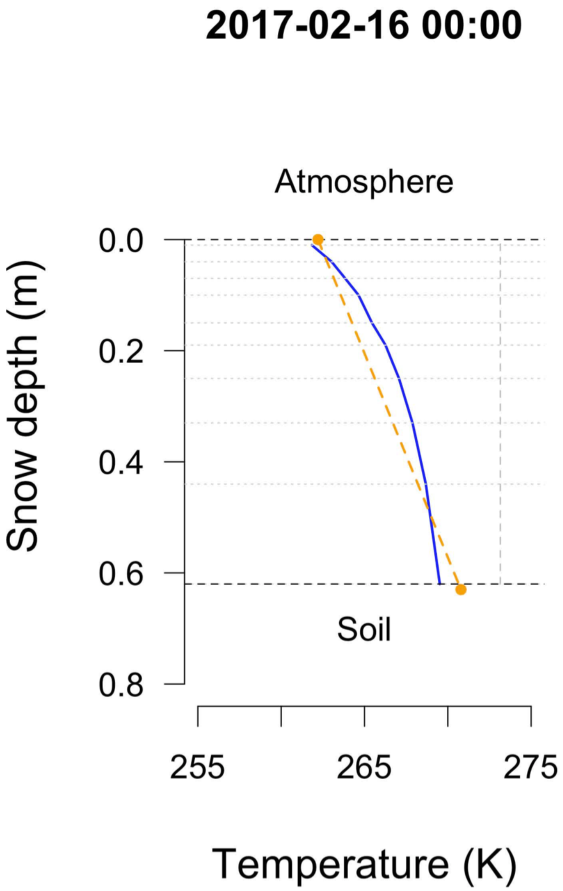
Experimental Site Weissfluhjoch, Davos, Switzerland

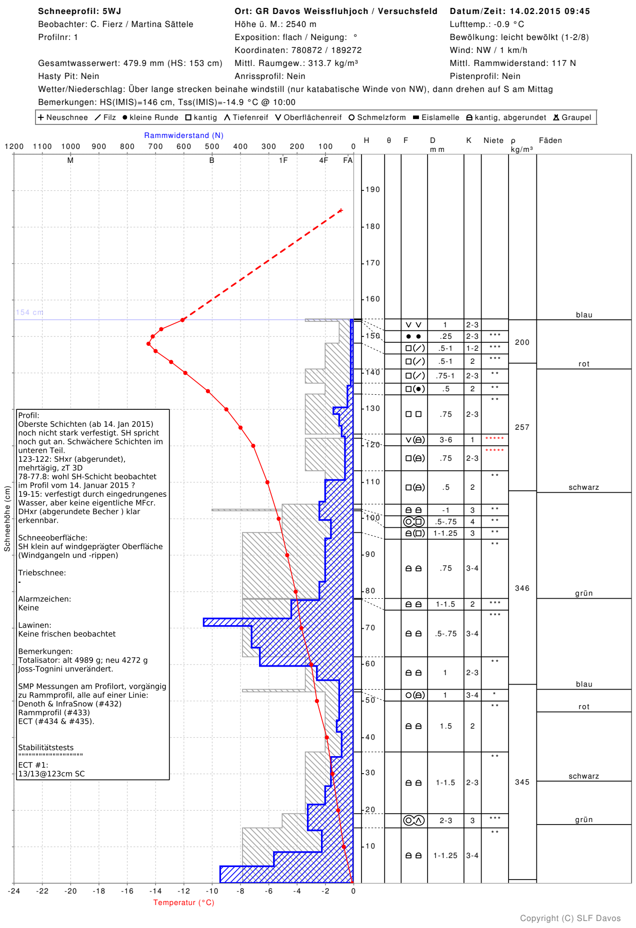
Heat Equation – Benchmarking (SNOWPACK vs. MLS)

Weissfluhjoch



Heat Equation – Snow temperature profile



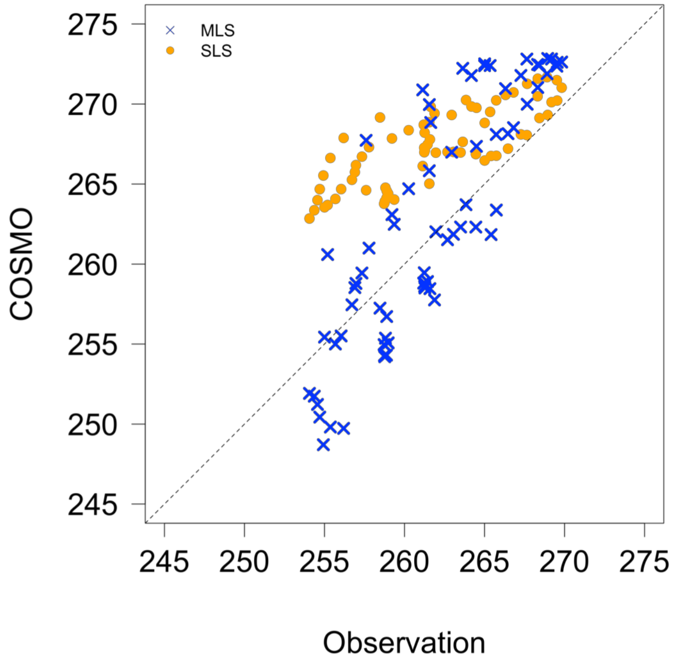


Intercantonal Measurement and Information System (IMIS)

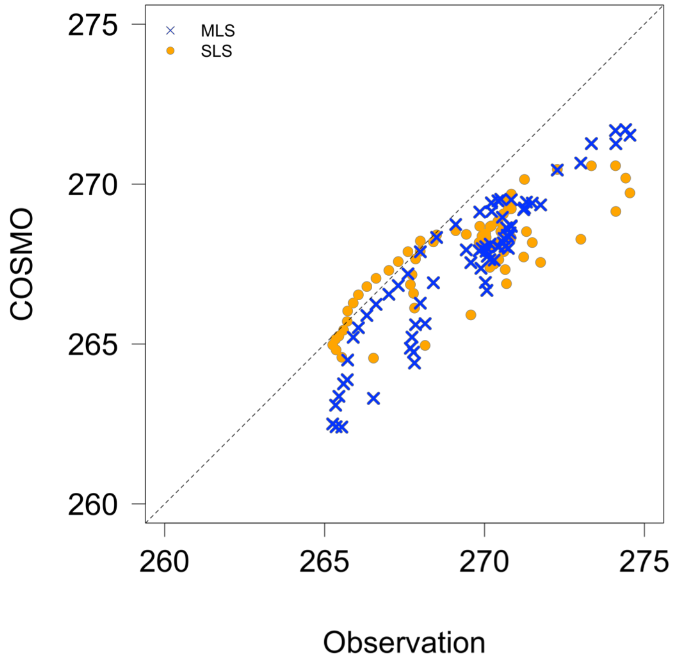
Heat Equation – Initial Results (Surface Temperature)

All IMIS (N = 112)

T_SNOW

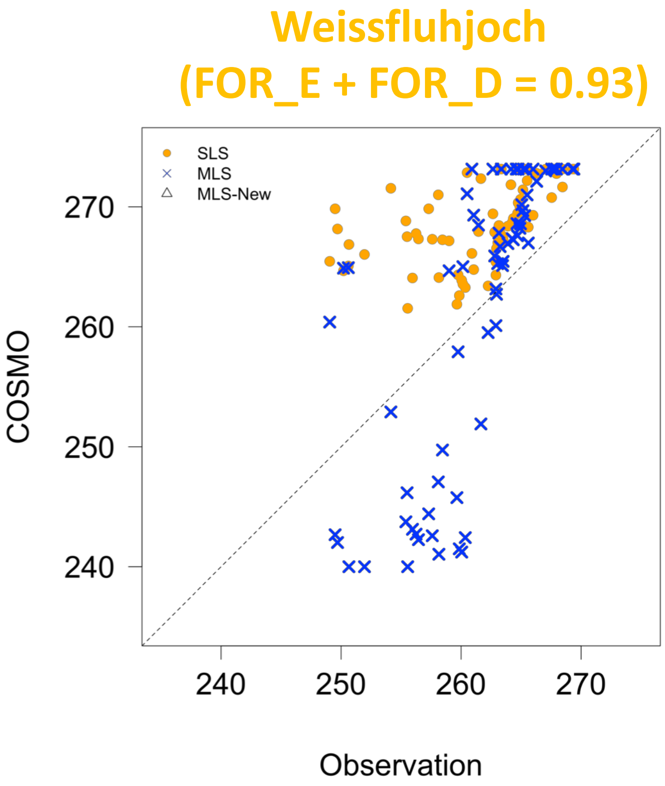


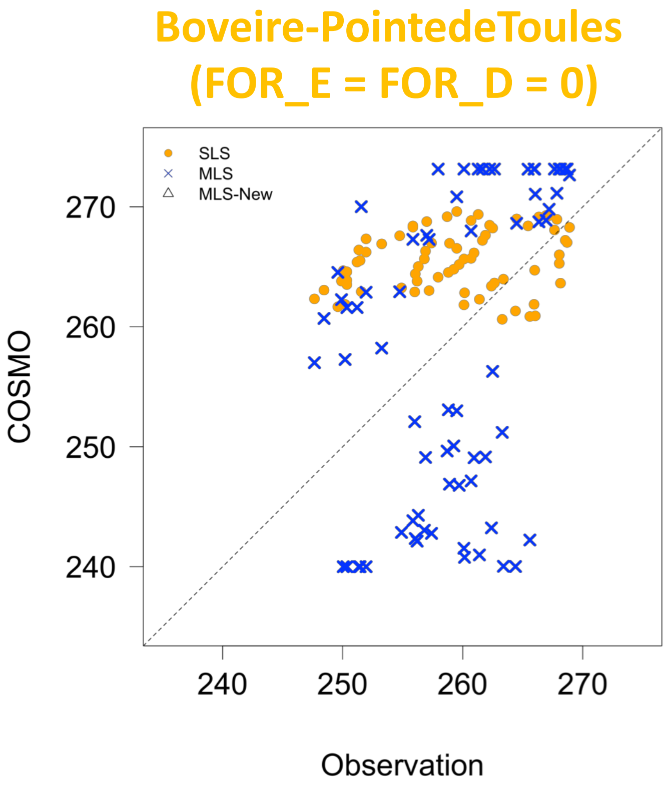
T (1st level)



= Single layer snow cover scheme (SLS)   X = Multi-layer snow cover scheme (MLS)

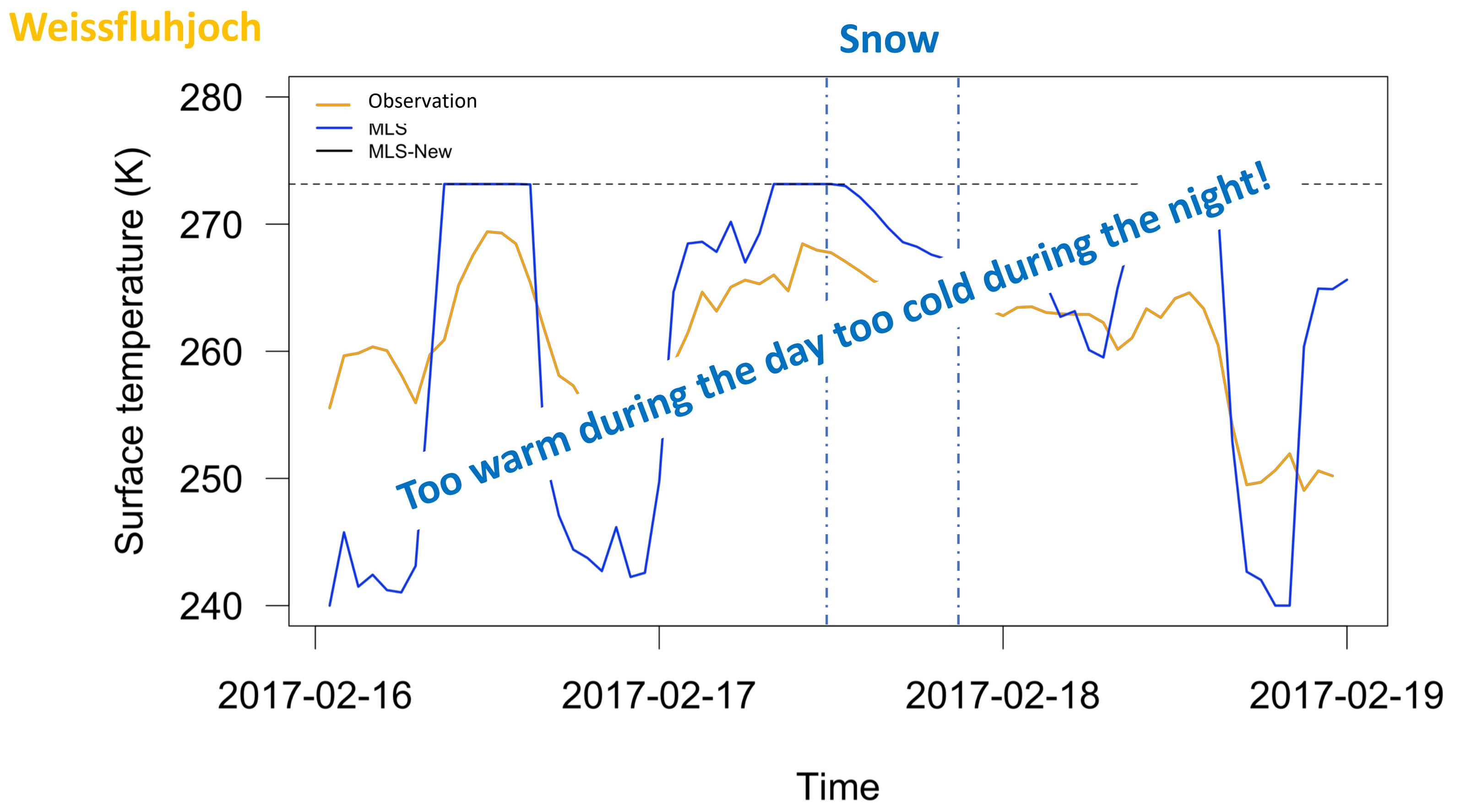
Heat Equation – Initial Results (Surface Temperature)



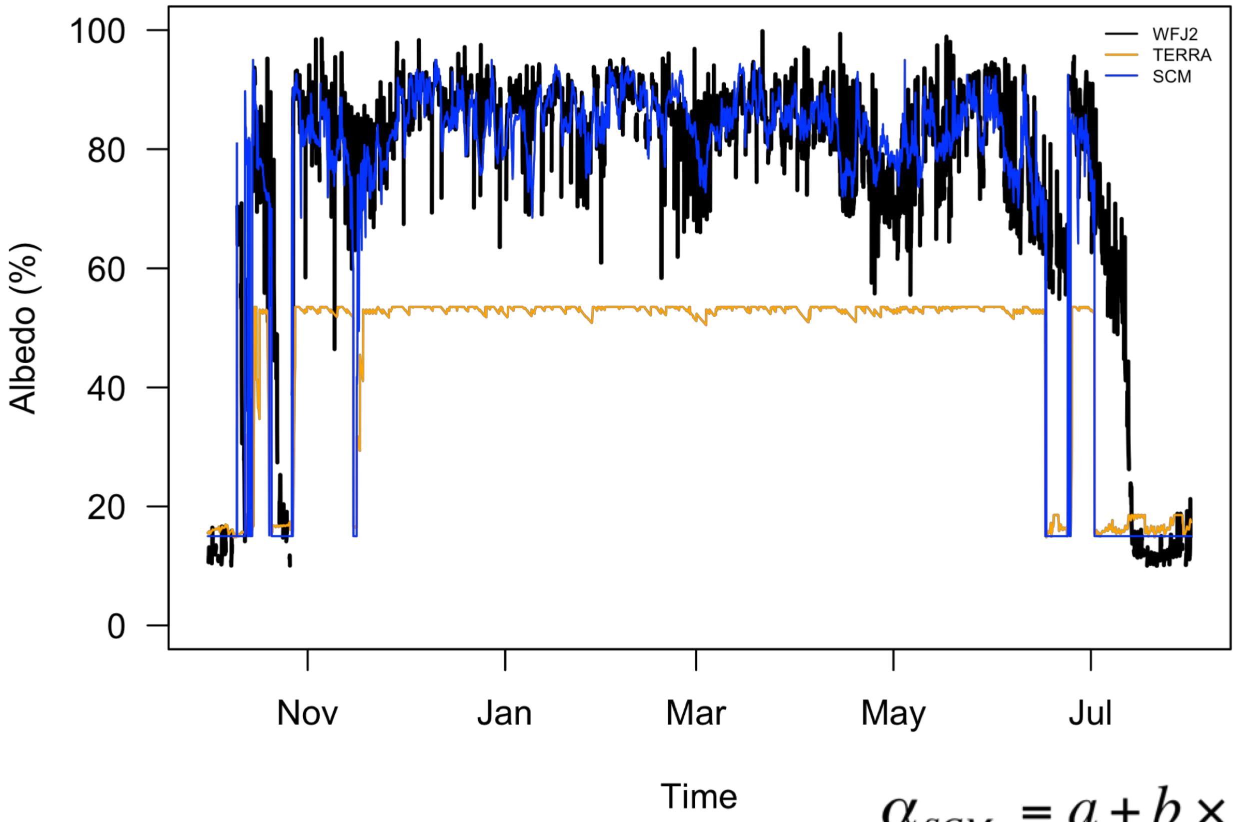


● = Single layer snow cover scheme (SLS) X = Multi-layer snow cover scheme (MLS)

Heat Equation – Forcing?



Heat Equation – Forcing (Albedo)



P_{rate} = Precipitation rate

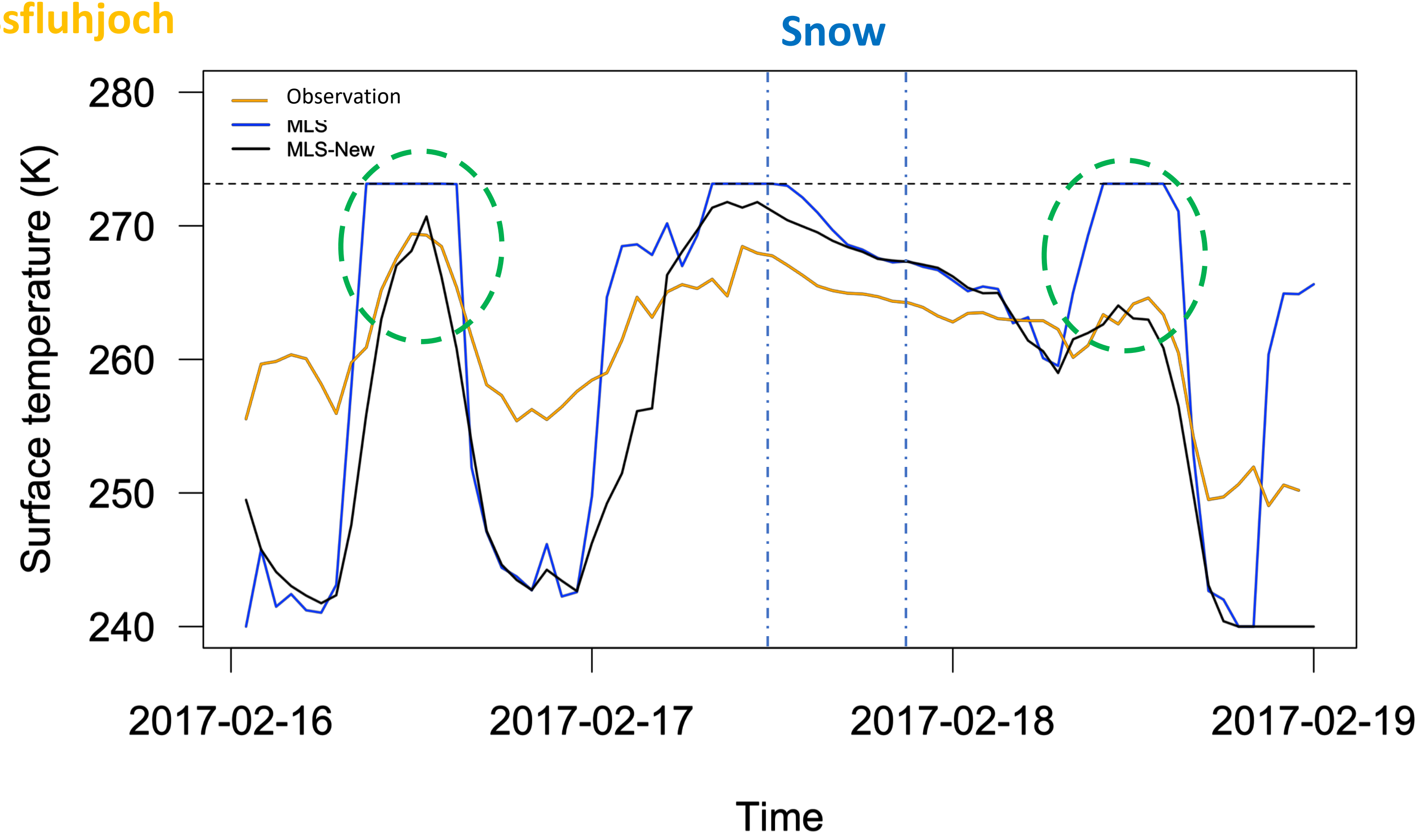
T_{SFC} = Snow surface temperature

T_{10m} = Air Temperature 10 m

$$\alpha_{SCM} = a + b \times P_{rate} + c \times T_{SFC} - d \times T_{10m}$$

Heat Equation – Forcing (Albedo)

Weissfluhjoch



Heat Equation – Forcing (Transfer Coefficient)

Boundary-Layer Meteorology
October 2017, Volume 165, Issue 1, pp 161–180 | Cite as

How do Stability Corrections Perform in the Stable Boundary Layer Over Snow?

Authors | Authors and affiliations

Sebastian Schlögl, Michael Lehning, Kouichi Nishimura, Hendrik Huwald, Nicolas J. Cullen, Rebecca Mott

Sensible heat flux:

$$H = \rho c_p C_H \bar{U} \Delta\theta,$$

Transfer Coefficient:

$$C_H = \frac{k^2}{\left[\ln\left(\frac{z_{\mathrm{ref}}}{z_{0M}}\right) - \psi_m(\zeta)\right]\left[\ln\left(\frac{z_{\mathrm{ref}}}{z_{0M}}\right) - \psi_s(\zeta)\right]},$$

where $k = 0.4$ is the von Kármán constant, $\zeta = (-k\, z_{\mathrm{ref}}\, g T_*)/(\theta_s u_*^2)$ is the modelled stability parameter (stability parameter henceforth), $u_* = k\bar{U}\left(\ln(z_{\mathrm{ref}}/z_{0M}) - \psi_m\right)^{-1}$ is the modelled friction velocity, $T_* = k\left(\theta_s - \theta_{z_{\mathrm{ref}}}\right)\left(\ln(z_{\mathrm{ref}}/z_{0M}) - \psi_s\right)^{-1}$ is the modelled temperature scale, z_{0M} is the aerodynamic roughness length and ψ_m and ψ_s are the stability corrections for momentum and scalars. In our analysis, we used the simple approach that the roughness

Stability Corrections:

$$\psi_m\left(T, T_{sn}, \bar{U}\right) = a_1 B + b_1 S,$$

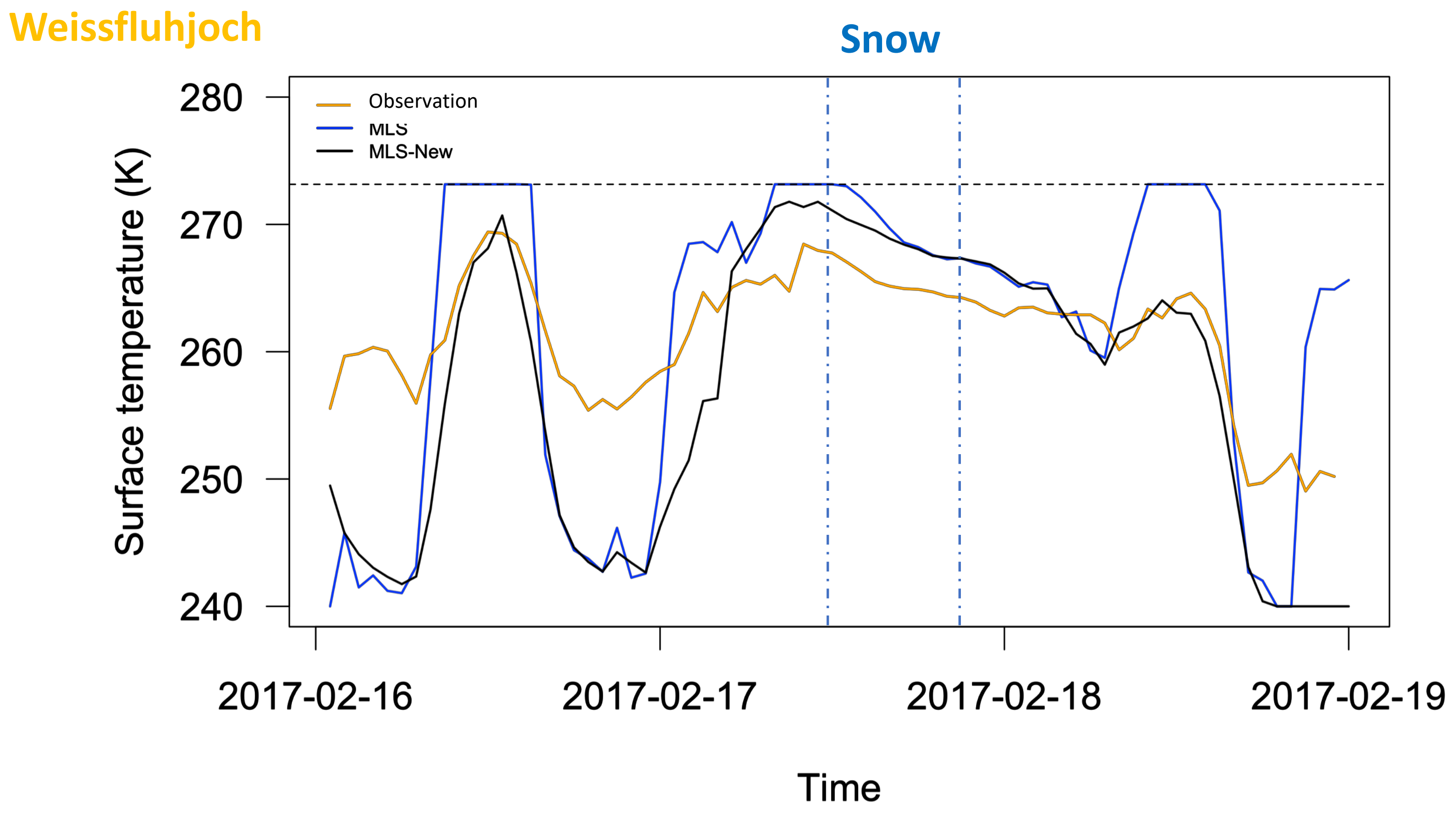
$$\psi_s\left(T, T_{sn}, \bar{U}\right) = a_2 B + b_2 S,$$

test site	a_1	b_1	test site	a_2	b_2
WFJ07 (3 m)	3.227	0.0043	WFJ07 (3 m)	−982.90	−0.0005
WFJ07 (5 m)	−4.441	0.0025	WFJ07 (5 m)	−642.51	0.0009
WFJ11	−30.74	0.0008	WFJ11	−1135.4	−0.0015
PM07 NWW	−191.93	0.0008	PM07 NWW	−751.73	−0.0005
PM07 SEE	−29.55	0.0090	PM07 SEE	−692.74	−0.0123
GR00 (1 m)	−145.41	−0.0914	GR00 (1 m)	−378.92	−2.0489
GR00 (2 m)	−179.56	−0.0369	GR00 (2 m)	−243.93	−0.7448
Universal	−65.35	0.0017	Universal	−813.21	−0.0014

$$B = \Delta T/\bar{T}$$

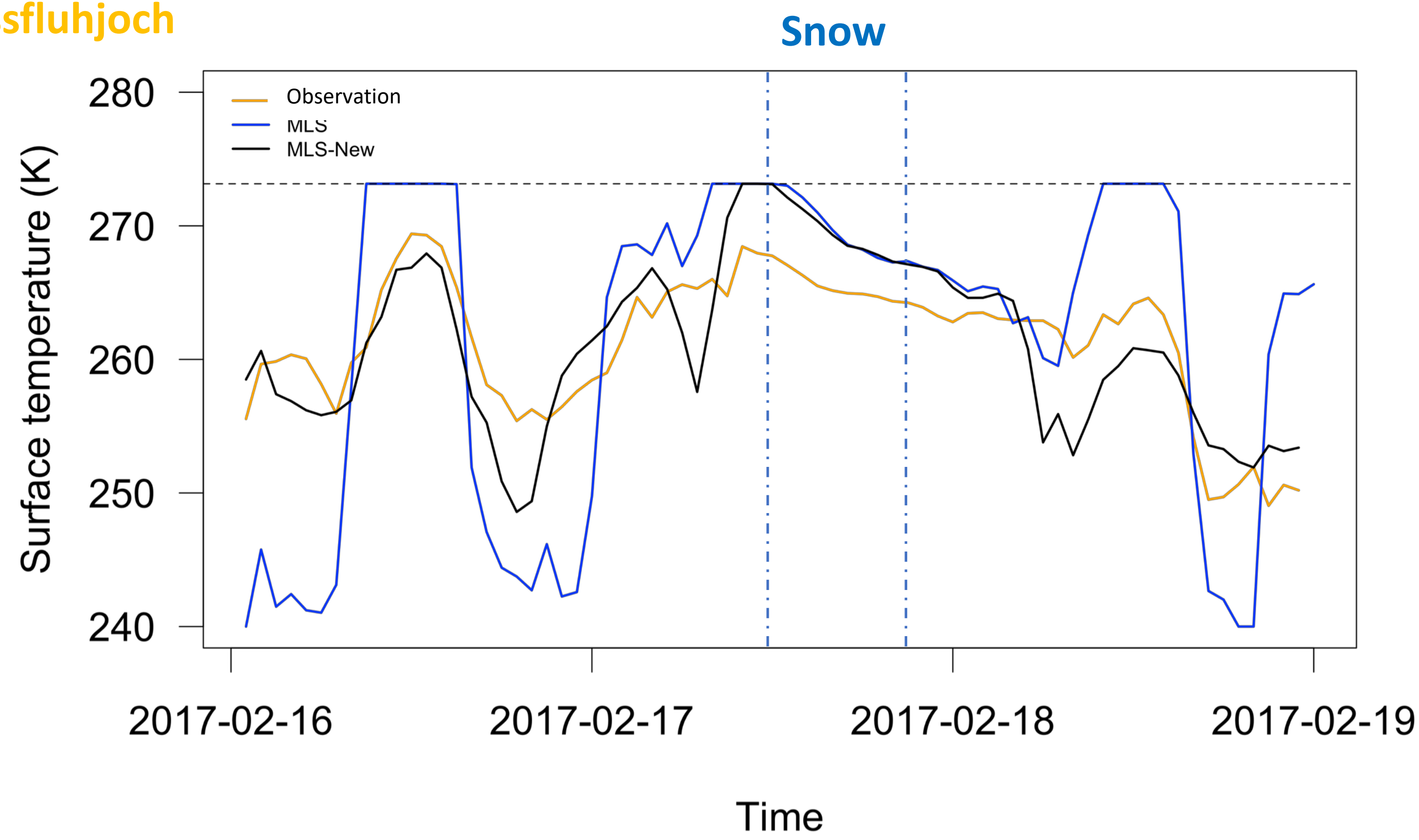
$$S = z_{\mathrm{ref}}\, g/\bar{U}^2$$

Heat Equation – Forcing (Transfer Coefficient)



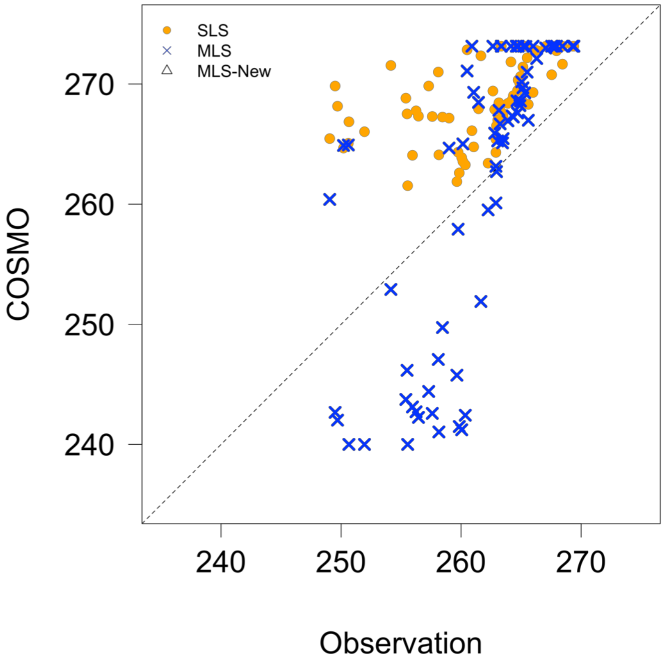
Heat Equation – Forcing (Transfer Coefficient)

Weissfluhjoch

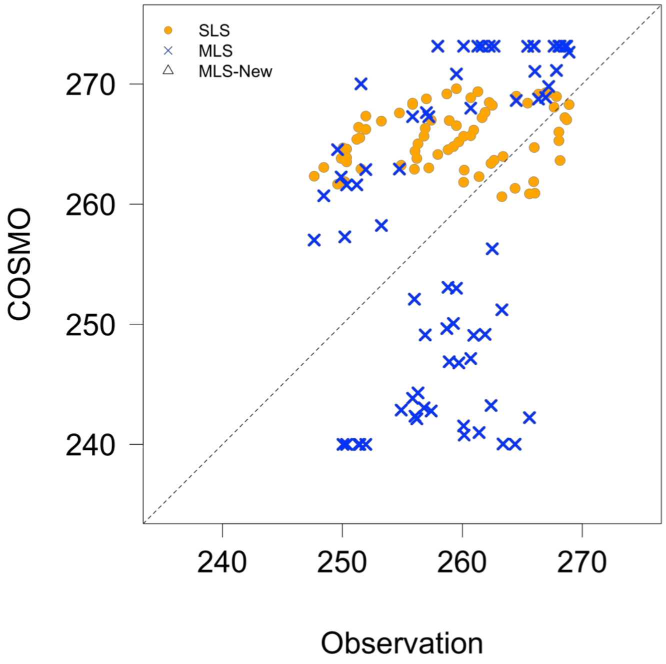


Heat Equation – Initial Results

Weissfluhjoch
(FOR_E + FOR_D = 0.93)



Boveire-PointedeToules
(FOR_E = FOR_D = 0)



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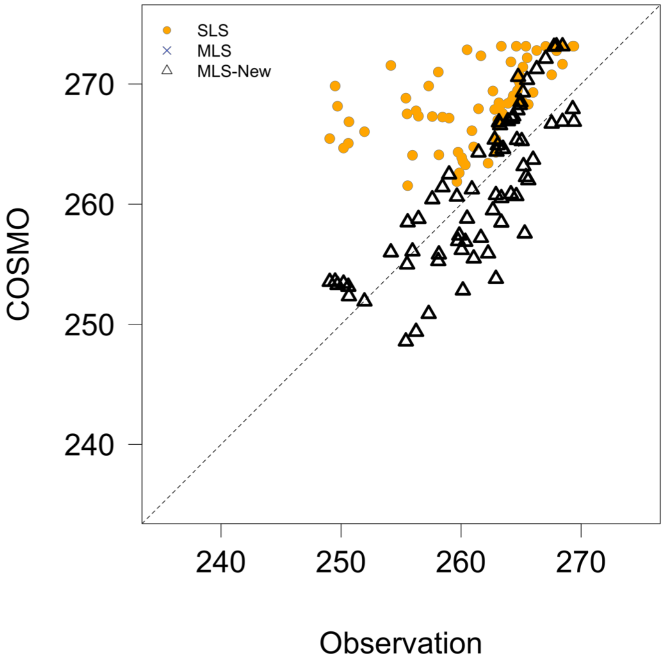
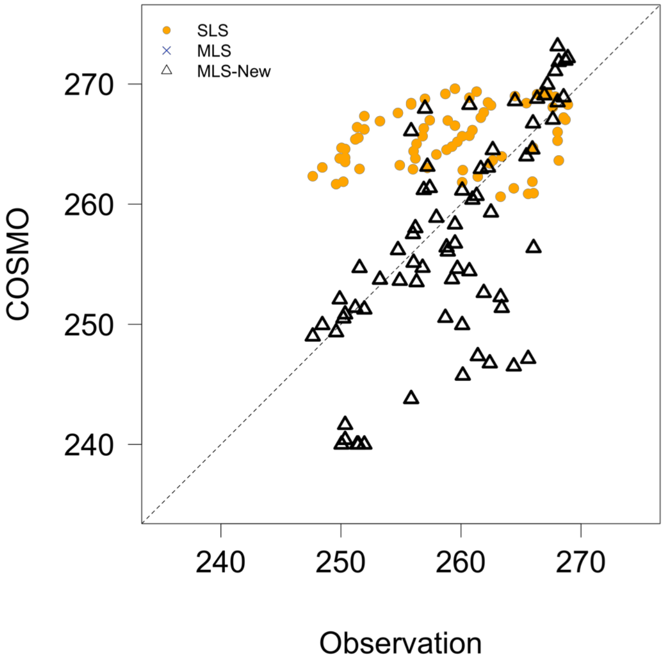
Heat Equation – Initial Results

Weissfluhjoch (FOR_E + FOR_D = 0.93)



Boveire-PointedeToules (FOR_E = FOR_D = 0)



△ = Multi-layer snow cover scheme (MLS) with new flux parameterizations

Snow cover scheme (MLS) – Implementation

```
!!==========================

MODULE sfc_terra

!==================
```

```
!SB <
USE sfc_snow
USE snow_utilities
!SB >

!-------------------------------------------
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New snow model called in TERRA …

… consists of 2 (or 3) subroutines called …

CALL snow_forcing(…)

- snow specific atmospheric forcing

CALL snow_on_soil(…)

- layering/new snow
- heat conduction
- phase changes
- water transport
- settling
- re-meshing
- …

CALL interface_snow(…)

- preparation of required input (# layers, layering, heat conductivity etc.) for solving heat equation in TERRA

… before solving the heat equation in TERRA

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    END DO
  END DO          ! soil layers

!MR: 05.05.2017 and later: heat-budget for inner soil layers substituted by a slightly different notation: >
!------------------------------------------------------------------------------------------------------

!*****************************************************************************************************
!MR: 05.05.2017: modified heat-budget for boundary soil layers including a single-layer snow-cover: <
!*****************************************************************************************************

```
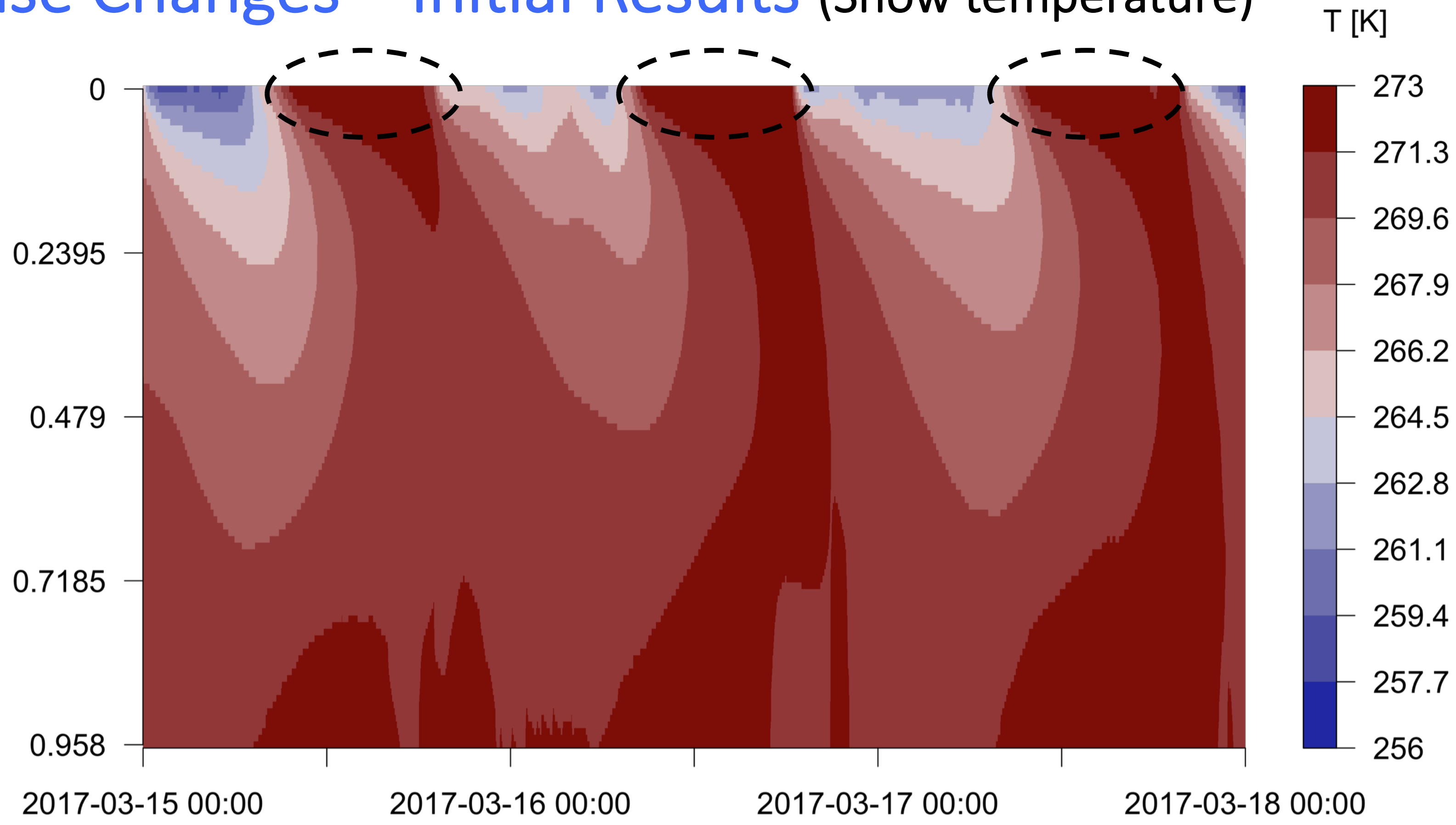
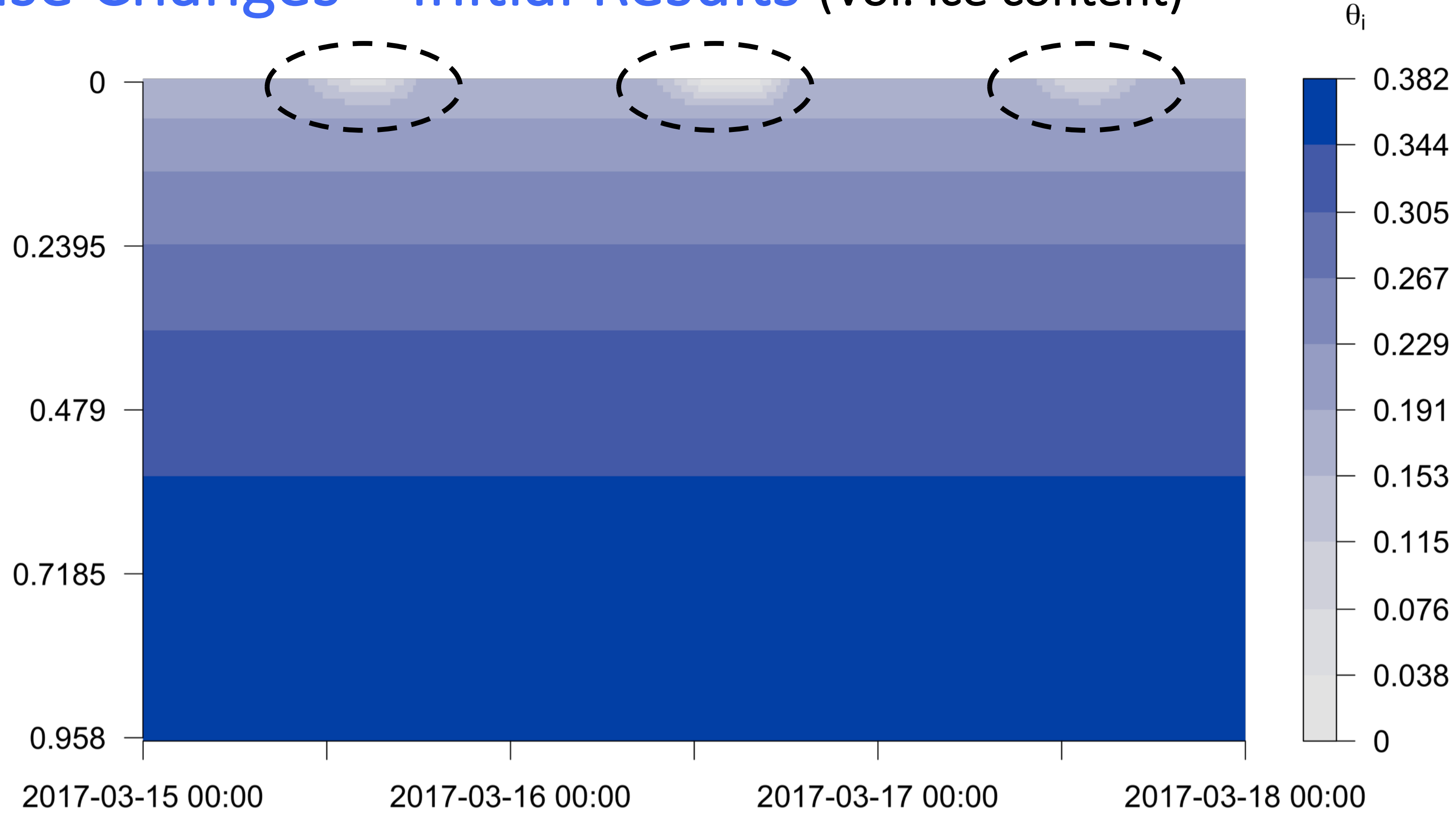
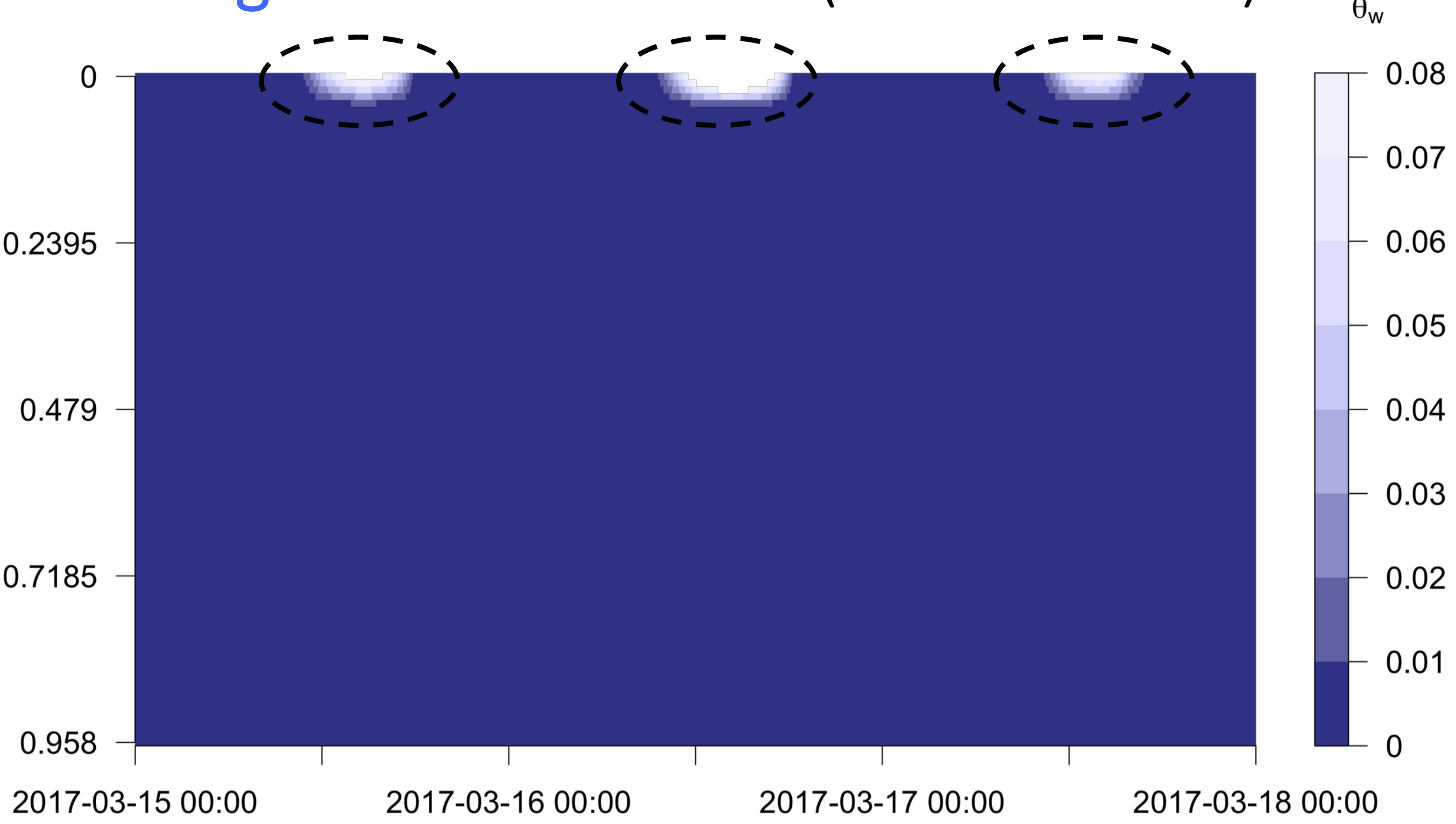

Phase Changes – Initial Results (Snow temperature)



Phase Changes – Initial Results (Vol. ice content)



Phase Changes – Initial Results (Vol. water content)



Water Transport – Initial Results (Vol. water content)

Snow cover scheme (MLS) – Implementation

```
!!========================

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!==================
```

```
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!------------------------------------------------------------------------------------------

!******************************************************************************************
!MR: 05.05.2017: modified heat-budget for boundary soil layers including a single-layer snow-cover: <
!******************************************************************************************

```
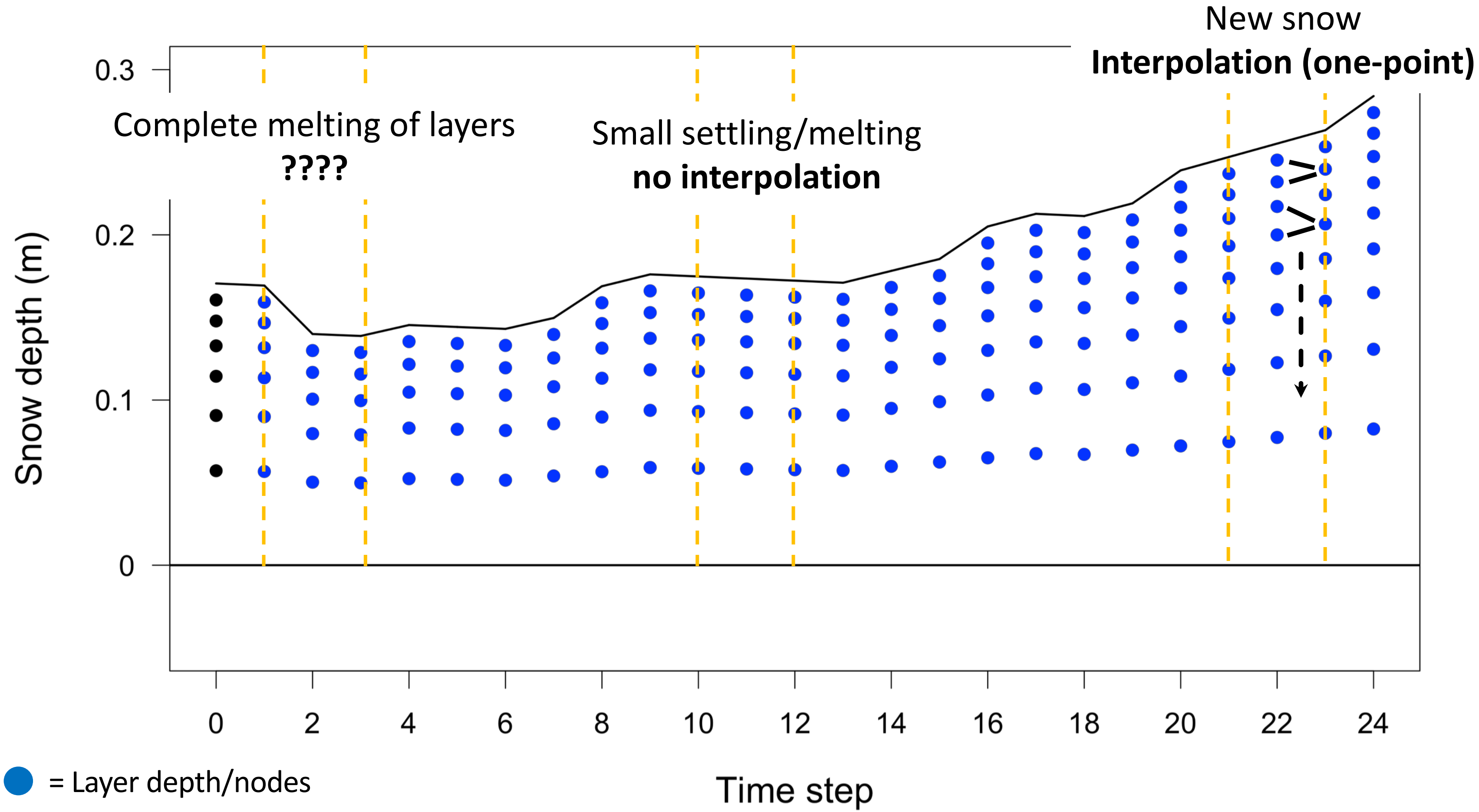
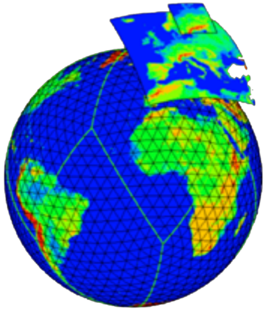

Settling & Re-meshing – Implementation



Outlook & Future work

- Version 0 'ready' by mid April
- Validation of snow cover scheme (fully coupled; interface routine), further adaptations of the scheme (e.g. absorption of solar energy)
- First runs with ICON (global, LAM) fall 2019



ICON-Model

- Adaptation of snow analysis and data assimilation (meeting today 13-16 p.m.; B125)
- Standalone version of the snow cover scheme to be able to force it externally (e.g. INCA, AWS etc.)
- Find a cool name !!!!



Thanks!
Questions and/or comments?

Sascha Bellaire[1], Michael Lehning[1,2], Jean-Marie Bettems[3], Oliver Fuhrer[3]

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Email: bellaire@slf.ch

Priority Task (PT) project - SAINT

Summary:

- PT SAINT: Joined project of MeteoSwiss and SLF (Project leader: S. Bellaire)
- Start: July 2017 ; Ends June 2020
- Goal: New 'operational' multi-layer snow cover scheme for NWP models COSMO and ICON.
- 'Limited' SNOWPACK version:
  - Max. 10 Layers
  - Heat conduction
  - Phase changes
  - Water transport
  - Settling/Compaction
  - …

Outcome/Outlook:

- Better representation of **snow cover** in **NWP models** on **different scales** local, regional to global, **e.g. snow height/ water equivalent, albedo and new snow amounts**. **Direct** production of **HN and HS maps** on any horizontal resolution
- Fully coupled, i.e. **S**now cover **A**tmosphere **INT**eraction (i.e. SAINT) fulfilled, integral approach. SNOWPACK forced with COSMO or any other forecasted data is only a one-way coupling.
- Possible standalone version allows integration into Nowcasting Systems (e.g. INCA).

Snow related activities at MeteoSwiss

Current situation:

- COSMO PT SAINT
- Snow analysis for COSMO-1 / COSMO-E requires update
- Possible new COSMO PP about snow analysis
- New collaborator at DWD starting in April 2019, will work on snow analysis (2D Var …)
- Observation driven snow model used at LOM
    - 24h accumulated height of new snow: use 10 min INCA snow output feeding a simple snow model (compaction, calibration)
    - forecaster would like to have 3 days accumulated new snow, Matteo judges that his current model is too simple for that purpose
    - Matteo asks if it could be possible to use the new snow model developed by Sascha (in standalone mode)

Snow related activities at MeteoSwiss

Topics:

- New snow model (PT SAINT) – Interface routines by Matthias R.
- New snow model (PT SAINT) – First complete implementation, planned for mid April
- New snow model (PT SAINT) – How to proceed to transfer this development in an official COSMO release, in an official ICON-LAM release?
- New snow model – Standalone version: what is required? where to implement (SNOWE, TSA)? what about the SAT scheme (e.g. Louis scheme in TSA)? which meteorological fields required to drive the model (COSMO, INCA)?
  New snow model – Standalone version: which quality to expect running the model with perfect forcing on a full winter season? What is the importance of snow transport by wind (not modeled)?
- New snow model – Standalone version: which plans for ICON-LAM?
- Snow analysis for the COSMO system – Adapt for new multi-layers snow model
- Snow analysis for the COSMO system – Correct MSG SEVIRI derived snow mask (bogus HR product, work on-going at Locarno) or use different snow mask
- Snow analysis for the COSMO system, CH domain – Use of SLF analysis? Share with nowcasting group the development of an observation driven standalone snow model over CH?
- Snow analysis for the COSMO system – New COSMO PP , 09.2019 – 09.2021, with RHM? Which goals (1D SAINT based snow model…)? Shall one also invest in the lateral interpolation? ICON-LAM compatibility? Which resources?