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Component Validation for Surface: ideas and first steps

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Motivation

- ISBA-DIF(+MEB) is a target scheme for a new surface physics in Harmonie-Arome. It is being tested starting from 2020.
- Hope was that we get a ready-made well established scheme and can run it operationaly quite soon, but …
- ISBA-DIF was developed mainly for scientific purposes (process studies, projects). Scores were of secondary interest. Scientific conclusions may be obtained without them, consireding model errors.
- For NWP, we need both: good scores, with good scientific basis

Known problems of ISBA-DIF:

- Too large duirnal/annual cycle within the soil
- Drying
- Too much evaporation (also in ISBA-FR)
- Reduced wind speed (comparing to ISBA-FR)

Current status

- In Météo-France, the MASCOT project: global off-line runs, comparison with soil observations over France
- In HIRLAM: test ISBA-DIF with 3 patches and different options (MULCH, SOC, DSL, LITTER) (Patrick)
- Hope now is to find a suitable confuguration. But it is not easy: takes much time, result might be compensating errors.

How can we help ourself? Let us look backward!

Philosophy

From Strategy:

”Unfortunately, one can say, multi-layer physics is not suitable to be activated stepwise since all of its components are deeply integrated”

- But at least, it can be validated stepvise!

ISBA-DIF is a large enough model to be divided into components and validated component-vise!

Philosophy: what is our model?

- Model assumptions

  Horizontal exchange in the soil in negligebly small

- Model variables and model equations

  Eq. for soil moisture diffusion with upper and low boundary conditions

- Numerical schemes

  Crank-Nicolson implicit scheme to solve the diffusion equation

- Model parameters

  Fraction of sand and clay

- The code

  SURFEX modules and subroutines

Where problems can come from?

- Model assumptions – may be wrong! We try to add more details, but ...
  Horizontal exchange in the soil in negligebly small
- Model variables and model equations – may contain errors!
  Eq. for soil moisture diffusion with upper and low boundary conditions
- Numerical schemes – may have low accuracy, be unstable, etc.!
  Crank-Nicolson implicit scheme to solve the diffusion equation
- Model parameters – huge source of uncertainty!
  Fraction of sand and clay
- The code – may contain bugs!
  SURFEX modules and subroutines

Our routine verification ...

- Is performed against in-situ T2m, Q2m and V10m
- Standard scores

Shows problems, but give only a little hint how to adress them!
No answer: where to look?

Tuning:

- Model assumptions
- Model variables and model equations
- Numerical schemes
- Model parameters
- The code

Can address only this:

How to address other problems?

Component validation

- Use more observations (not only SYNOP)
- Academic tests, sensitivity tests
- Adress different types of problems more systematically

Steps towards component validation:

- ACCORD Physics WW in Madrid, November 2024
- HIRLAM Physics WW in Oslo, March 2025

Analytical solution of the heat diffution equation

~ example of component validation test

In the most simple case
(soil parameters are constant in vertical):

$$\frac{\partial T(z,t)}{\partial t} = a \frac{\partial^2 T(z,t)}{\partial z^2}$$

T - temperature, K (or ^{o}C)

t - time, sec

z - depth, m

a - temperature conductivity, m^2/sec

This is a ”dynamical core” for ISBA-DIF. We solve it numerically in SURFEX.

However, it has analytical solutions in some cases.

Analytical solution of the heat diffusion equation:

In the specific case: $\left(0 \leq z < \infty\right)$ $\left(\infty < t\right)$ - domain

$T\left(0, t\right) = A \cdot \cos\left(\omega t\right)$ - upper boundary condition , oscillations

A - amplitude, K or ^{o}C $\omega = \frac{2\pi}{P}$ - frequency, sec^{-1} P - period , sec

= 86400 for duirnal cycle

Analytical solution*:

$$T\left(z, t\right) = A \cdot \exp\left(-\sqrt{\frac{\omega}{2 \cdot a}} z\right) \cdot \cos\left(\sqrt{\frac{\omega}{2 \cdot a}} z - \omega t\right)$$

* - Tikhonov, Samarski, 1951

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How we can use the analytical solution?

$$\boldsymbol{T}(\boldsymbol{z},\boldsymbol{t}) = \boldsymbol{A} \cdot \exp\left(-\sqrt{\frac{\omega}{2 \cdot \boldsymbol{a}}}\,\boldsymbol{z}\right) \cdot \cos\left(\sqrt{\frac{\omega}{2 \cdot \boldsymbol{a}}}\,\boldsymbol{z} - \omega \boldsymbol{t}\right)$$

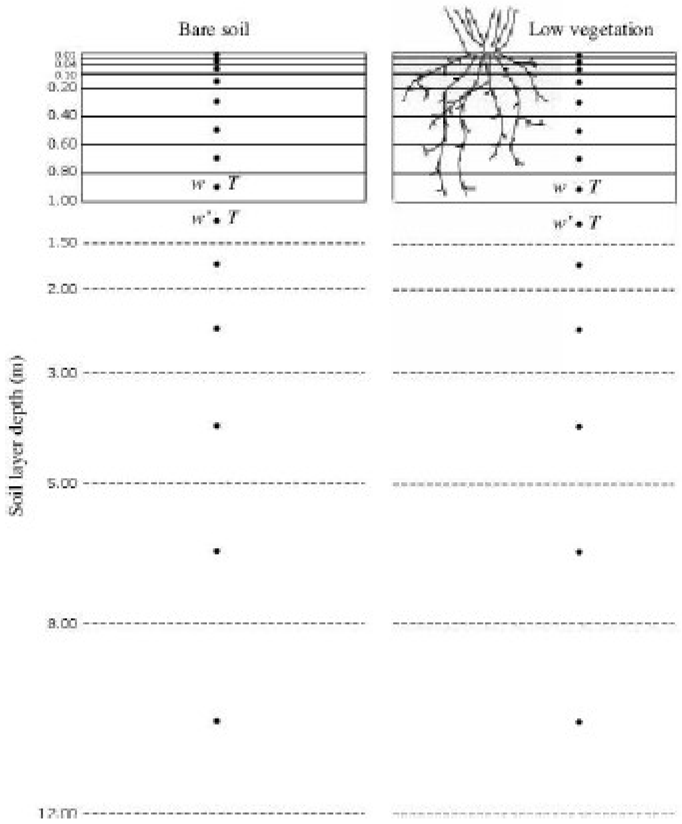
- To provide the initial condition to the numerical solution for testing
- To compare with the numerical solution with the same upper boundary condition. Will allow to estimate the accuracy of the numerical solution; to assess the grid
- From observations within the soil, to estimate roughly ***A*** and ***a*** and compare them with values from SURFEX

Comparison with numerical solution from SURFEX: how?

Numerical solution of the soil temperature equation Neglecting the phase transformation term, Eq. (4.75a) can be written using an implicit time scheme as

$$T_j{}^n = T_j{}^{n-1} + \frac{\Delta t}{c_{g\,j}\,\Delta z_j}\left[(1-\varphi)\left(G_{j-1}{}^{n-1} - G_j{}^{n-1}\right) + \varphi\left(G_{j-1}{}^{n} - G_j{}^{n}\right)\right] \qquad (4.87)$$

where $\varphi = 1$ (backward difference) is currently used for the soil temperature profile ($\varphi = 1/2$ corresponds to the Crank-Nicolson scheme). Using either scheme, the linear set of diffusion equations can be cast in tridiagonal form and solved with relative ease. Although the Crank-Nicolson scheme is more accurate (second order), the surface energy budget equation is solved in ISBA using the backward difference scheme, so for consistency this scheme is used to evaluate the diffusion term in Eq. (4.75a).



- Numerical scheme and vertical grid from SURFEX (14 levels, zero-flux lower boundary condition)
- Upper boundary condition with oscillations
- Initial conditions from the analytical solution
- Coded outside SURFEX

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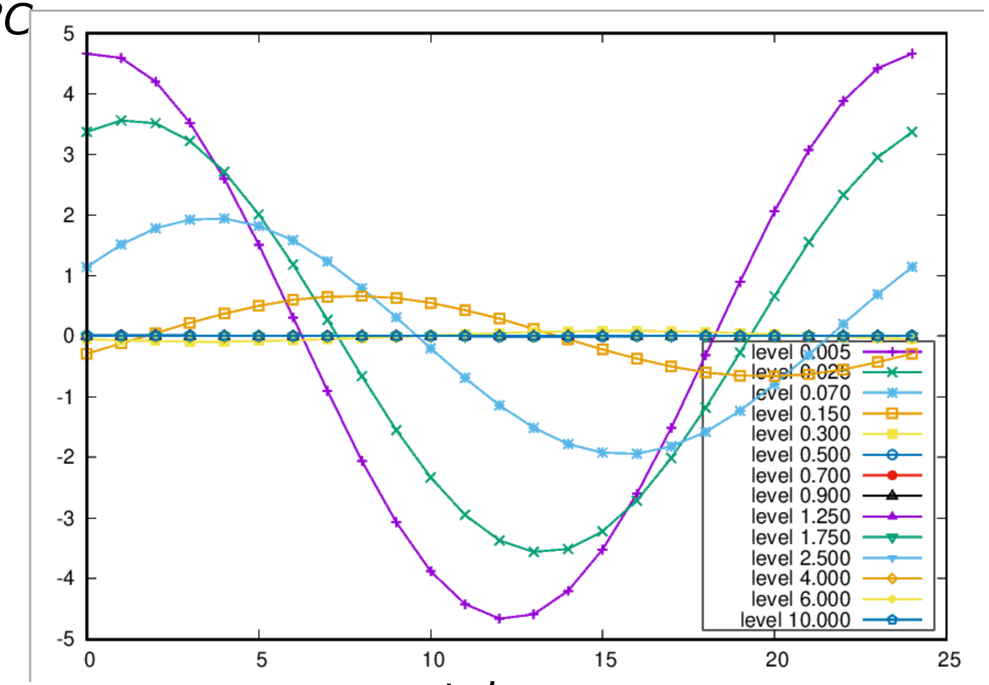
Comparison with numerical solution from SURFEX: results

Analytical solution

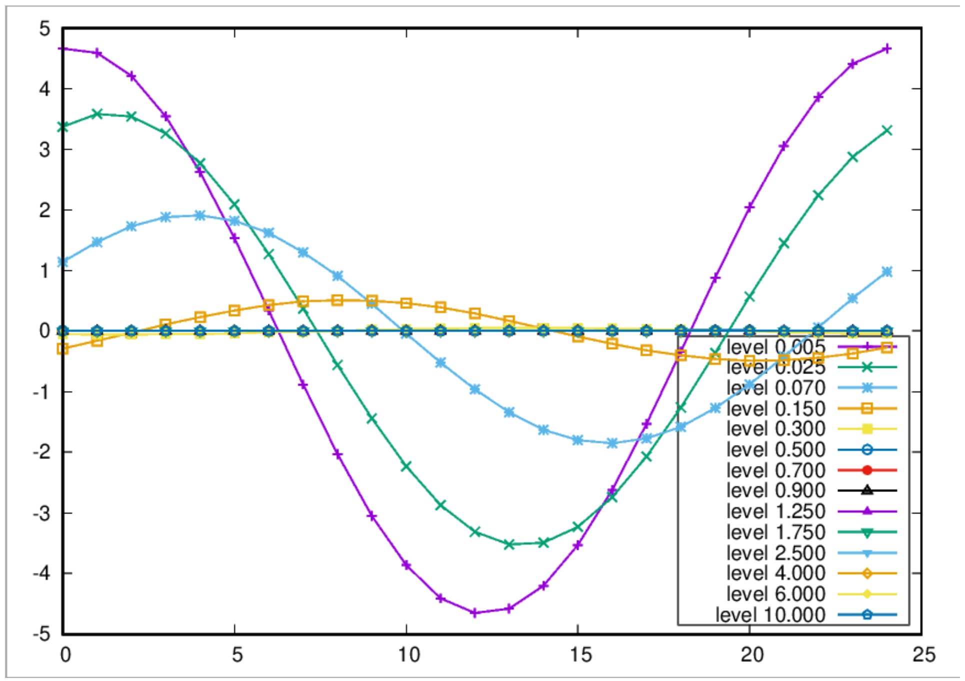
Numerical solution

T, °C



t, hours

T, °C



t, hours

$\boldsymbol{A}$ = 5°C, $\boldsymbol{a}$ = 2 $*10^{-7}m^2/sec$

Excellent agreement!

ideal "bubble" test

Estimating of A and a from the observed temperature evolution within the soil: how?

$$T(z,t) = A \cdot \exp\left(-\sqrt{\frac{\omega}{2 \cdot a}}\, z\right) \cdot \cos\left(\sqrt{\frac{\omega}{2 \cdot a}}\, z - \omega t\right)$$

Observations on level z_1: A_1

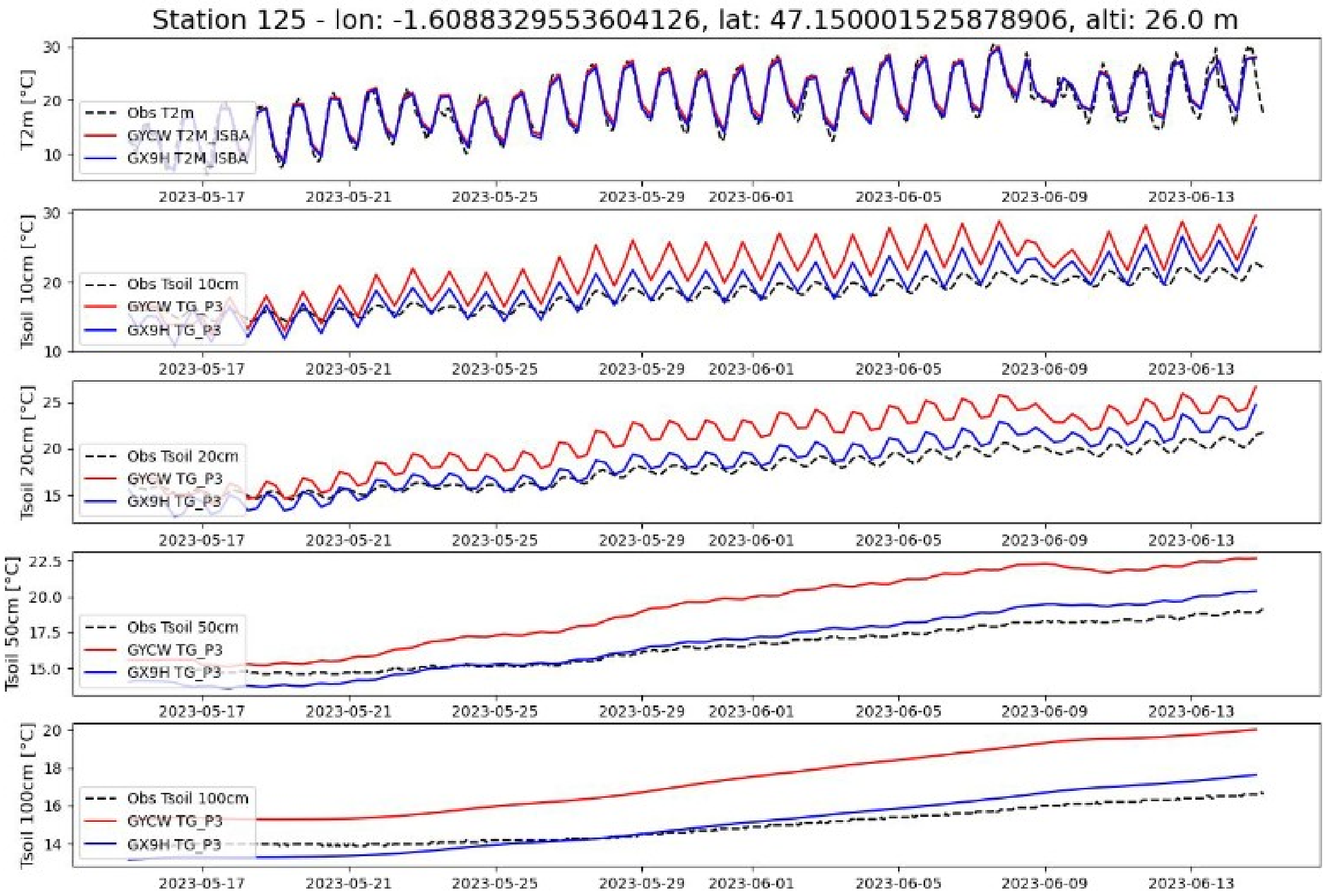
Observations on level z_2: A_2

$$A = \exp\left(\frac{z_2 \ln(A_1) - z_1 \ln(A_2)}{z_2 - z_1}\right)$$

$$a = \frac{\pi}{P} \frac{(z_2 - z_1)^2}{\ln^2 \frac{A_1}{A_2}}$$

Examples of estimating of ***A*** and ***a*** from soil observations

- Results presented by Adrien, 2024
- Nantes airport
- May-June 2023
- With MULCH option



Examples of estimating of ***A*** and ***a*** from soil observations

<u>From observations:</u>

$\boldsymbol{Z_1} = 0.1$ m : $\boldsymbol{A_1} = 1.5\ ^{o}C$ → $\boldsymbol{A} = 4.5\ ^{o}C$ a = $3*10^{-7}$ m^2/sec

$\boldsymbol{Z_2} = 0.2$ m : $\boldsymbol{A_2} = 0.5\ ^{o}C$

<u>From SURFEX perofmance:</u>

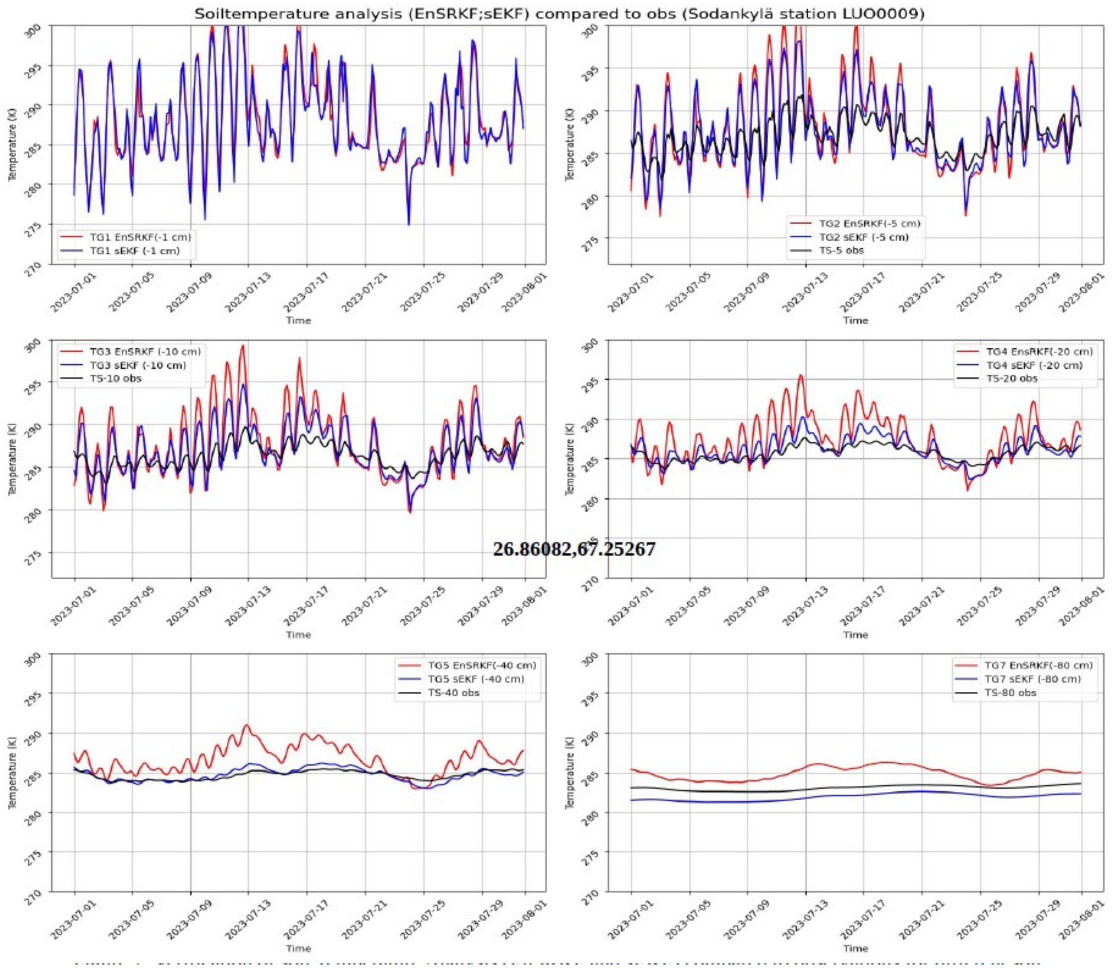
$\boldsymbol{Z_1} = 0.1$ m : $\boldsymbol{A_1} = 3.5\ ^{o}C$ → $\boldsymbol{A} = 8.1\ ^{o}C$ a = $5*10^{-7}$ m^2/sec

$\boldsymbol{Z_2} = 0.2$ m : $\boldsymbol{A_2} = 1.5\ ^{o}C$

Errors both in upper boundary condition and soil parameters

Examples of estimating of ***A*** and ***a*** from soil observations

- Results by Adhishek (and Mikael), 2024
- Sodankylä
- July 2023
- MULCH option - ?



Examples of estimating of ***A*** and ***a*** from soil observations

<u>From observations:</u>

$\boldsymbol{Z_1}$ = 0.05 m : $\boldsymbol{A_1}$ = 1.0 °C

→ $\boldsymbol{A}$ = 2.0 °C a = 1.9*10^{-7} m^2/sec

$\boldsymbol{Z_2}$ = 0.1 m : $\boldsymbol{A_2}$ = 0.5 °C

<u>From SURFEX perofmance:</u>

$\boldsymbol{Z_1}$ = 0.05 m : $\boldsymbol{A_1}$ = 4.0 °C

→ $\boldsymbol{A}$ = 16.0 °C a = 0.5*10^{-7} m^2/sec

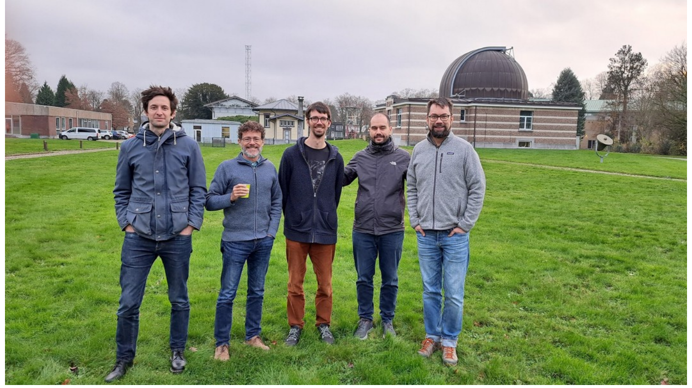
$\boldsymbol{Z_2}$ = 0.1 m : $\boldsymbol{A_2}$ = 1.0 °C

Errors both in upper boundary condition and soil parameters

Lessons from exps. with analytical solution

- Analytical solution of the heat transfer equation is useful for the component validation of SURFEX. It allows Academic tests, such as the ”bubble test” in dynamical core.
- Numerical scheme of SURFEX, on the SURFEX grid, coded outside SURFEX, reproduces the analytical solution with very high accuracy (almost perfectly). Problems appear somewhere else.
- Duirnal amplitide and soil parameters estimated from analytical solution equation using soil observations and SURFEX output differ a lot. Errors in SURFEX come both from problems in upper boundary condition and soil parameters.
- <u>Next steps:</u>
  - to check pedotransfer functions in SURFEX
  - to implement the analytical solution into SURFEX, to exclude coding errors in the numerical scheme.

OSWAS tool: a step towards component validation



- OSVAS will be a set of scripts and namelists developed within the ACCORD community to provide a systematic approach for testing NWP-like SURFEX settings over stations from the ICOS project (flux observations).
- The tool (under construction) is hosted on GitHub: https://github.com/svianaj/OSVAS
- Tested successfully on ATOS machine, for forcing generation & all steps of an offline surfex run.
- Currently, OSVAS allows testing forcing generation in 3 sites:
  - Meteopole (FR)
  - Majadas_south (ES)
  - Loobos (NL)

Existing tools for component validation for Surface

...	Samuel et. al (OSVAS)	Mikael and Abhishek	Marvin	Carl	Katya
General/Component	general	general	surface layer	heat balance	heat diffusion
Experimens	1D	3D	3D and archives	archives	1D
Forcing (for 1D)	obs., model	-	-	-	analytical solution
Testing	performance	performance	sensitivity	performance	sensitivity
For the performance testing, obs. used	fluxes, T2m and Q2m	soil temp. and soil moist.	-	fluxes, low-level parameters	-
For the performance testing, sites	Meteopole, Majadas	Sodankylä	-	Lindenberg, Cabauw, Sodankylä	-
Implementation by ...	python	python/Epigram	python	python, R	fortran

Conclusions

- Surface model is large enough to be validated component-vise
- Component validation for Surface is needed to localize errors and to address different types of errors more systematically
- Component validation will allow good forecast scores with good scientific basis
- We already have several tools for general and component validation. Work will continue in this direction. On ACCORD level?

Thank you for your attention!