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PT SAINT: <u>**Outcomes and outlook for multi-layer snow modelling in COSMO**</u>

Varun Sharma[2,3], Sascha Bellaire[1], Louise Braud[1], Michael Lehning[2,3], Jean-Marie Bettems[1]

[1]MeteoSwiss, Zurich, Switzerland

[2]WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland

[3]CRYOS, School of Architecture, Civil and Environmental Engineering, EPFL, Lausanne, Switzerland
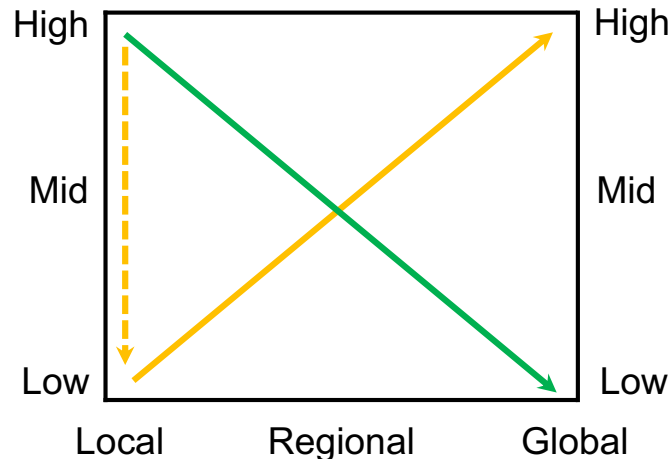
1

Snow modelling across scales
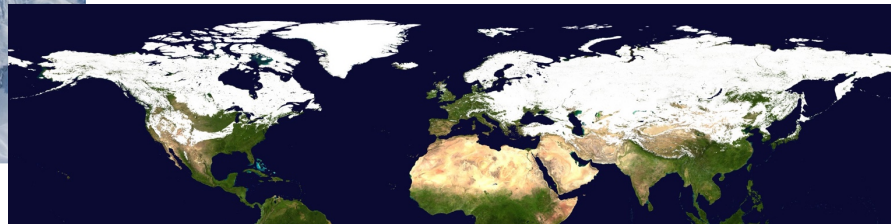

Point Scale:
- Avalanche safety
- Infrastructure health

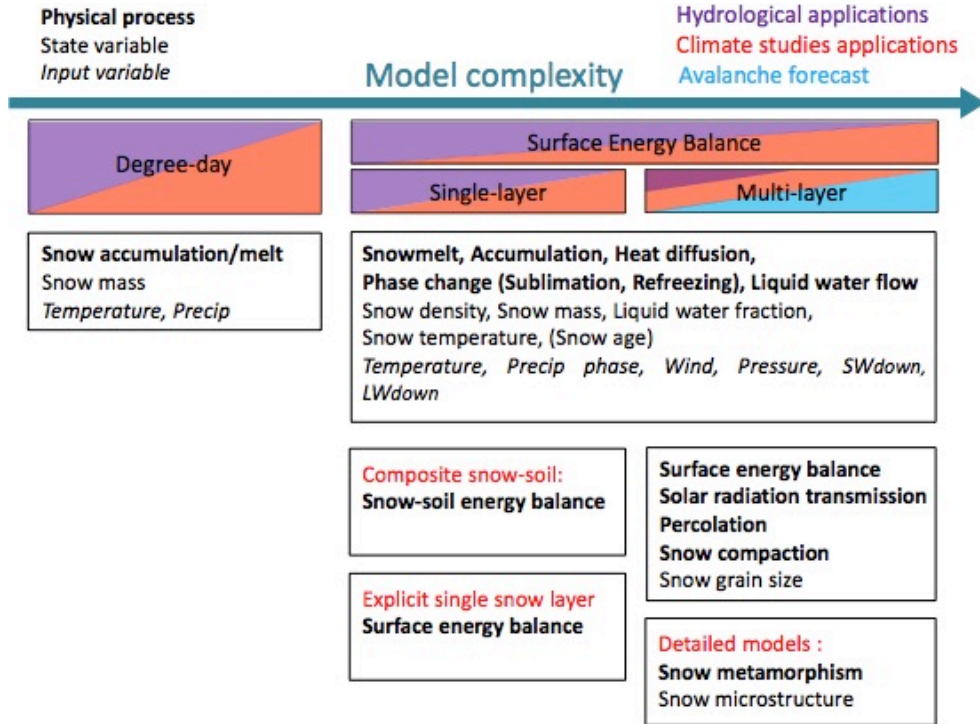Valley Scale:
- hydrology
- agriculture / water resources

Global Scale:
- earth's energy budget
- sea level rise

Model complexity

Comp. costs

High

Mid

Low

High

Mid

Low

Local

Regional

Global

Scale

Snow model complexity

Physical process
State variable
Input variable

Hydrological applications
Climate studies applications
Avalanche forecast

Model complexity

Degree-day

Surface Energy Balance

Single-layer | Multi-layer

Snow accumulation/melt
Snow mass
Temperature, Precip

Snowmelt, Accumulation, Heat diffusion,
Phase change (Sublimation, Refreezing), Liquid water flow
Snow density, Snow mass, Liquid water fraction,
Snow temperature, (Snow age)
Temperature, Precip phase, Wind, Pressure, SWdown, LWdown

Composite snow-soil:
Snow-soil energy balance

Surface energy balance
Solar radiation transmission
Percolation
Snow compaction
Snow grain size

Explicit single snow layer
Surface energy balance

Detailed models :
Snow metamorphism
Snow microstructure

SNOWPACK   **CROCUS**

- **'Good' models must include …**
  - **multiple layers**
  - **new snow density**
  - **surface energy balance (albedo, transfer coefficients)**
  - **heat conduction/equation**
  - **phase changes**
  - **water transport**
  - **compaction/settlement**

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Snow modelling is hard

BAMS Article

Scientific and Human Errors in a Snow Model Intercomparison

Cecile B. Menard, Richard Essery, Gerhard Krinner, Gabriele Arduini, Paul Bartlett, Aaron Boone, Claire Brutel-Vuilmet, Eleanor Burke, Matthias Cuntz, Yongjiu Dai, Bertrand Decharme, Emanuel Dutra, Xing Fang, Charles Fierz, Yeugeniy Gusev, Stefan Hagemann, Vanessa Haverd, Hyungjun Kim, Matthieu Lafaysse, Thomas Marke, Olga Nasonova, Tomoko Nitta, Masashi Niwano, John Pomeroy, Gerd Schädler, Vladimir A. Semenov, Tatiana Smirnova, Ulrich Strasser, Sean Swenson, Dmitry Turkov, Nander Wever, and Hua Yuan

" In fact, the same modeling issues identified by previous snow MIPs arose: albedo is a major source of uncertainty, surface exchange parameterizations are problematic, and individual model performance is inconsistent. This lack of progress is attributed partly to the large number of human errors that led to anomalous model behavior and to numerous resubmissions.
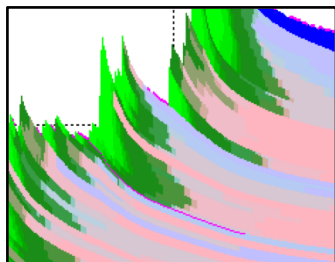
Snowpack gives birth to Snowpolino !

SNOWPACK

- one of the most advanced snow models
- developed by SLF – primarily for avalanche studies
- multi-layer / multiphase
- grain-scale derived parametrizations
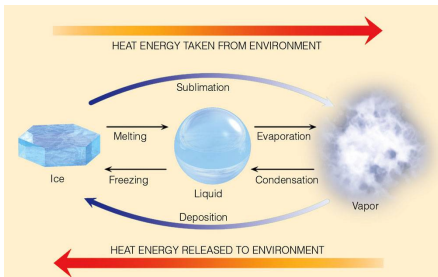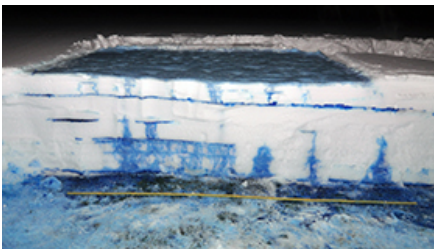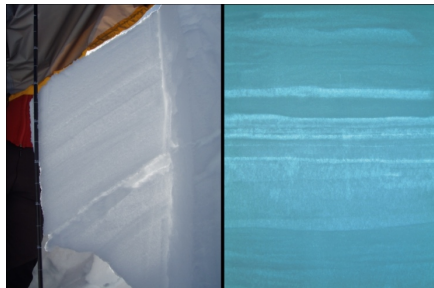
SNOWPOLINO

- From SLF to MCH
- bulk (layer-scale) derived parametrizations

$$\theta_i + \theta_w + \theta_a = 1$$

$$\rho_s = \rho_i\theta_i + \rho_w\theta_w + \rho_a\theta_a$$

$$\rho_s c_p \frac{\partial T_s}{\partial t} - \frac{\partial}{\partial z}(k_{eff}\frac{\partial T_s}{\partial z}) = [Q_{pc}] + [Q_{mm}] + Q_{sw} \ ;$$

$$[Q] = Wm^{-3} \ \text{Volumetric Heat Source}$$

$$\rho_s c_p = \rho_i c_i \theta_i + \rho_w c_w \theta_w + \rho_a c_a \theta_a$$

Snowpolino in Terra StandAlone (TSA) !

o Snowpolino implemented in Terra-Standalone for proper 'Soil-Snow' coupling.

o Testbed for year-long / climate scale simulations.

o Terra-Standalone updated for Snowpolino variables I/O (finalization of GRIB codes for COSMO implementation as well).

o Perfect for debugging – Terra-Standalone very similar to COSMO for land-surface coupling

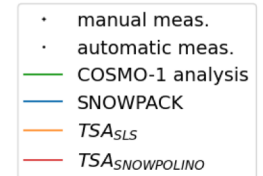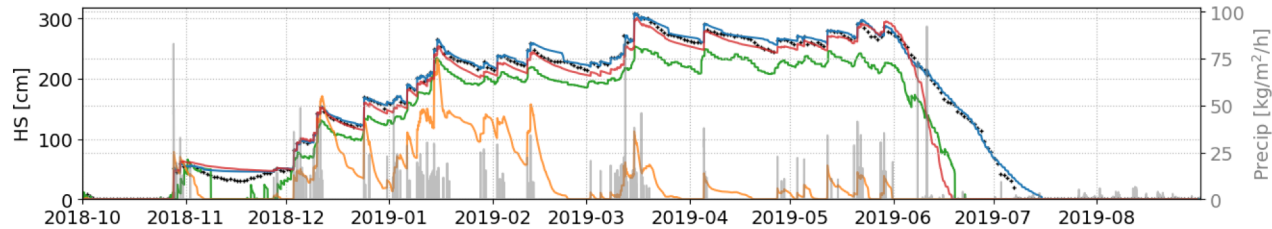o Ability to force Terra-Standalone with COSMO analyses or station data.

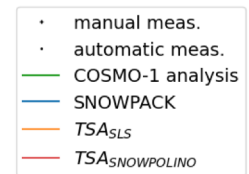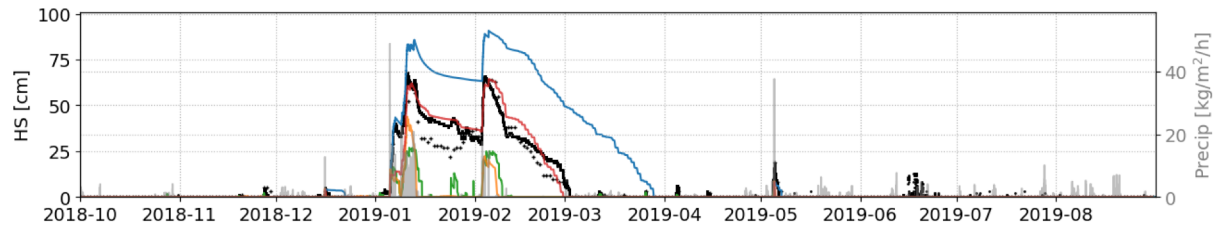# Results : Forcing with Station measurements

GRH - Grimsel Hospiz - (lat, lon, alt)=(46.572, 8.333, 1980.0)
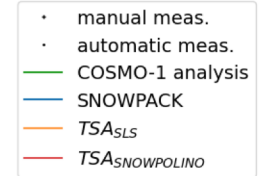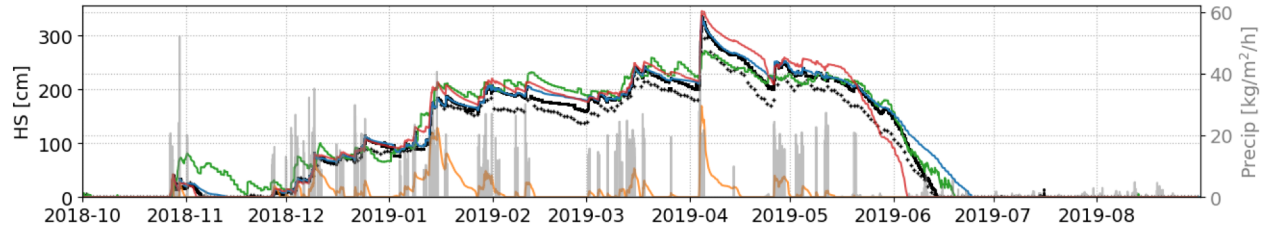
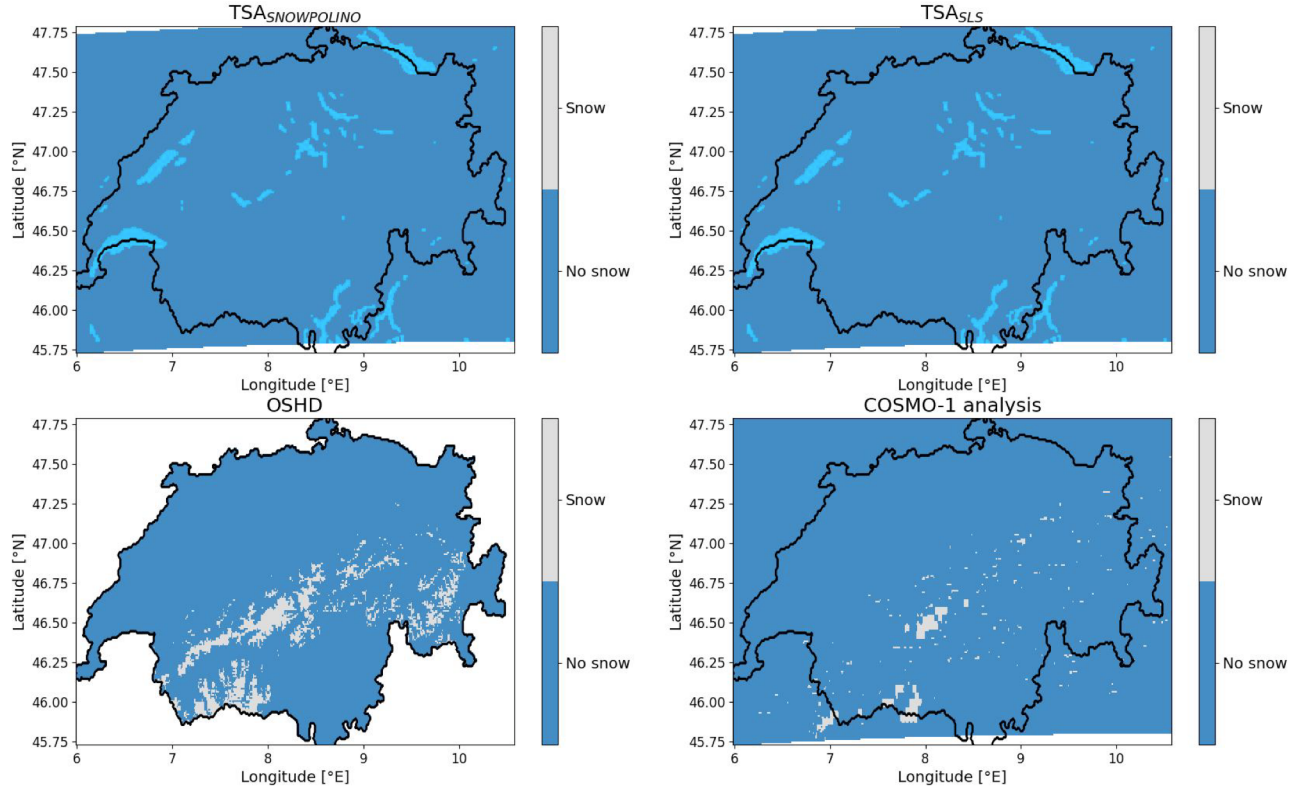WFJ - Weissfluhjoch - (lat, lon, alt)=(46.833, 9.806, 2691.0)

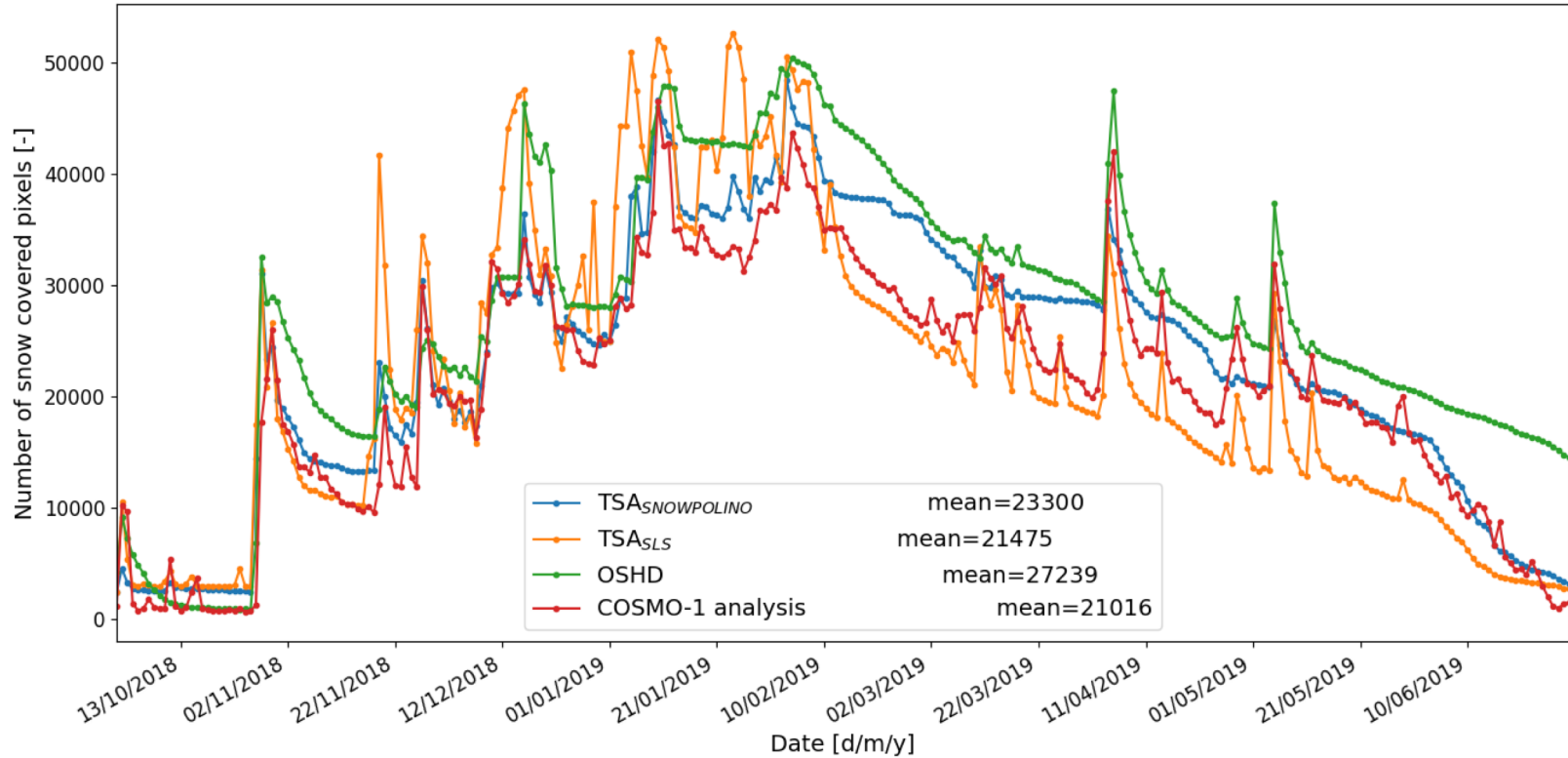STG - St. Gallen - (lat, lon, alt)=(47.425, 9.399, 776.0)

Results: TSA + Snowpolino driven by COSMO-1 analyses
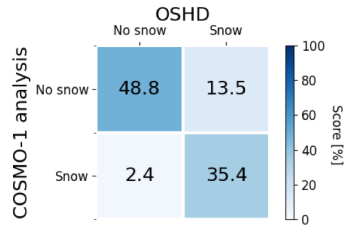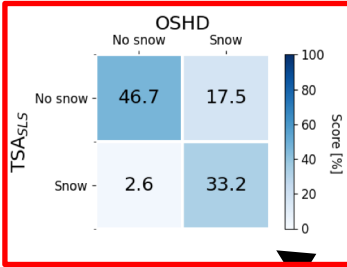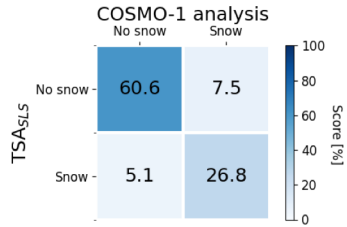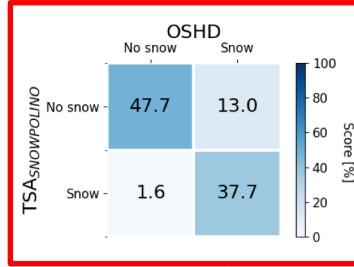
2018-10-01

Results: TSA + Snowpolino

Results: TSA + Snowpolino

Contingency tables - average
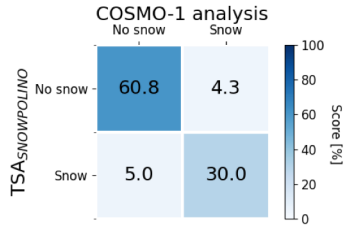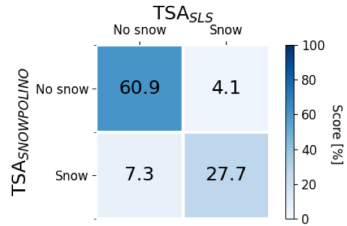
Meas. vs analysis ?

Snow cover vs SWE
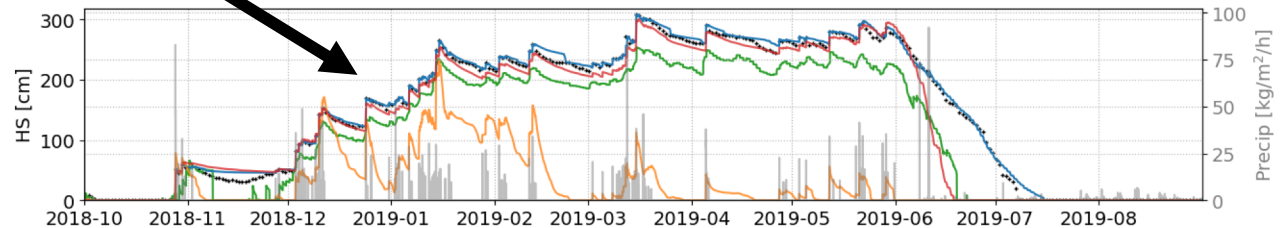
Snowpolino in COSMO !

- o Snowpolino implemented in COSMO (COSMO 6.0)

- o I/O (GRIB), other technical details sorted

- o CPU / GPU both implemented

- o Extensive testing to commence for scores (un-tuning ?)

500 x 500 COSMO-1 setup on GPUs (1 node TSA / SP)

%
increase
in memory

%
increase
in runtime
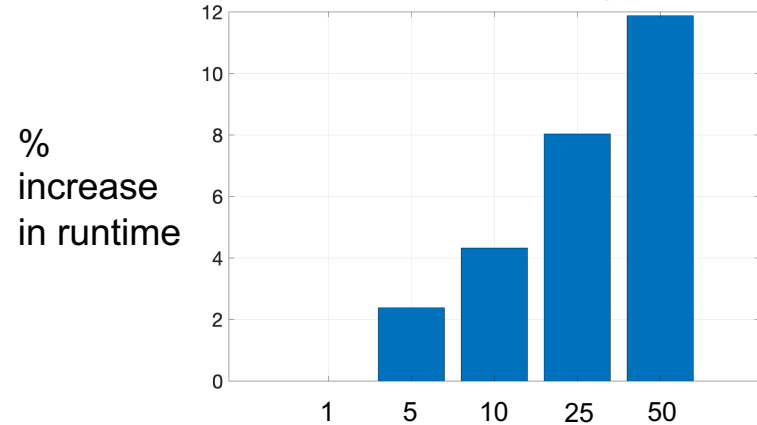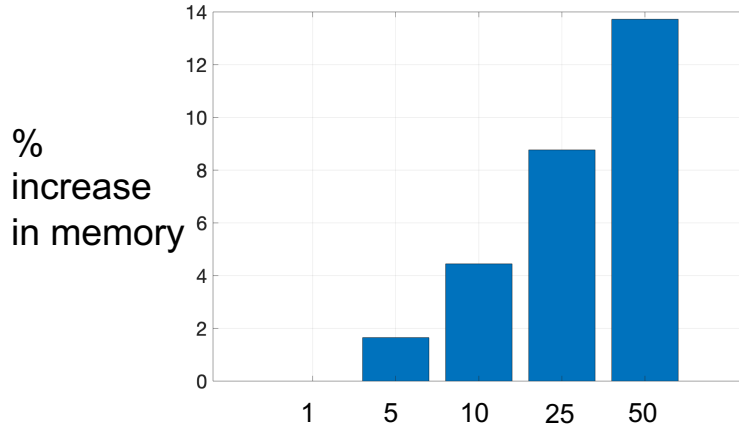
PT Saint : Outlook (immediate term)

o Snowpolino part of COSMO 6.0 release

o COSMO + Snowpolino to be operational beginning Fall 2021 @ MCH

o TSA + Snowpolino to potentially replace snow analysis @ MCH

PT Saint : Outlook (2021-2022/2023)

Bringing SNOWPOLINO to ICON's 'tiled' approach

- Implementation within TERRA should bring all of Snowpolino's improvements and benefits to ICON (including for operational use)

- Testing for the 'tiled' approach in ICON critical

- Updates to surface-atmosphere coupling methodolgy in ICON ? Implications for 'Snowpolino / TERRA'

regrouping into homogeneous tiles

blending height

$\rho^R, \vec{v}_h^R, q_v^R, \theta^R$

$Q_i \; F_i^L \; F_i^S$

G_i
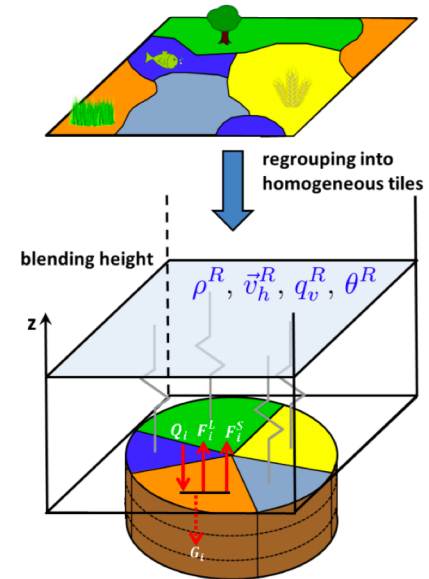
PT Saint : Outlook (2021-2022/2023)

Additional physics: Snow on forest canopies

Geosci. Model Dev., 8, 2379–2398, 2015
www.geosci-model-dev.net/8/2379/2015/
doi:10.5194/gmd-8-2379-2015
© Author(s) 2015. CC Attribution 3.0 License.

Geoscientific
Model Development

A two-layer canopy model with thermal inertia for an improved snowpack energy balance below needleleaf forest (model SNOWPACK, version 3.2.1, revision 741)

- Trunk and leaf spaces seperated

- Simple radiative transfer through canopy including effect of snow accumulation in the leaf space

- Consistent energy and mass balance in the two-layer canopy

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Additional physics: Aerosols and their impact on snow albedo

- Need for multi-layer snow modelling is clearly motivated by this problem

- Snowpolino is equiped by design to easily be expanded to tackle this issue.

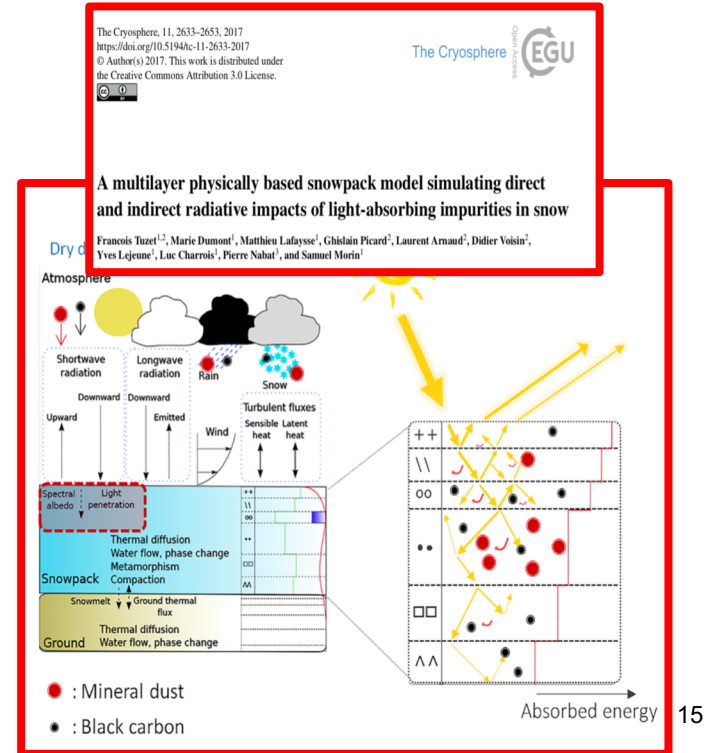- Guidance from recent work at KIT (Rohde et al.) as well as recent implementations in CROCUS

The Cryosphere, 11, 2633–2653, 2017
https://doi.org/10.5194/tc-11-2633-2017
© Author(s) 2017. This work is distributed under the Creative Commons Attribution 3.0 License.

The Cryosphere

A multilayer physically based snowpack model simulating direct and indirect radiative impacts of light-absorbing impurities in snow

Francois Tuzet[1,2], Marie Dumont[1], Matthieu Lafaysse[1], Ghislain Picard[2], Laurent Arnaud[2], Didier Voisin[2], Yves Lejeune[1], Luc Charrois[1], Pierre Nabat[1], and Samuel Morin[1]

● : Mineral dust

• : Black carbon

Summary and Discussion

- PT-SAINT coming to a wrap: multilayer snow model becomes operational in Fall 2021
- TSA + Snowpolino to be tested for potentially replacing the snow analysis at MCH
- COSMO 6.0 to include Snowpolino
- Operational Weather Prediction vs Climate Simulations
  - Current snow treatment in TERRA is of no use WITHOUT analysis
  - CMIP5 snow results !? (most models used single layer snow treatment)
  - What are the analyses / tuning hiding ?
- Snowpolino is agnostic to soil models – i.e., can be quickly coupled to JSBACH for example.

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Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss

Thank you!
Questions or Comments?

Varun Sharma, Sascha Bellaire, Louise Braud, Michael Lehning, Jean-Marie Bettems

Contact: varun.sharma@slf.ch