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A 'new' snow cover scheme for numerical weather prediction models (e.g. COSMO & ICON)

(PT-SAINT: Status Report)

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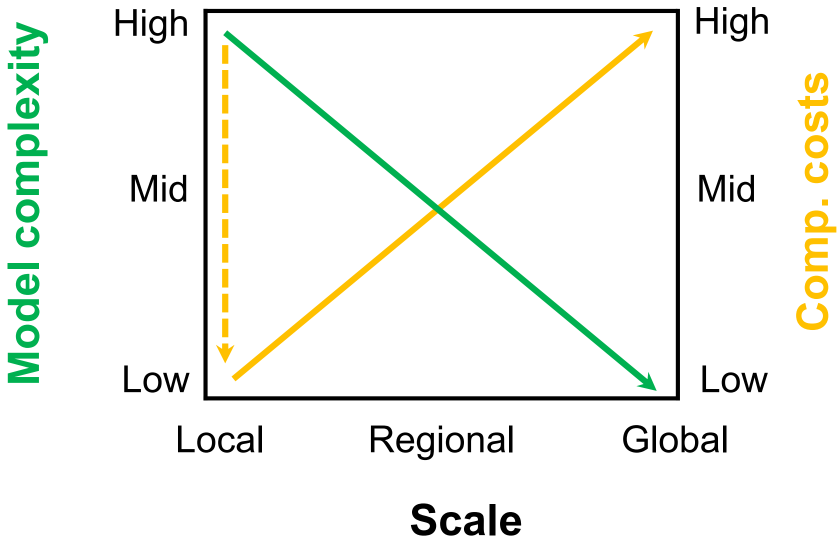
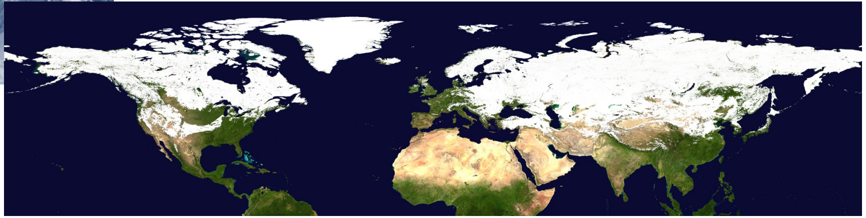
Snow modelling (earth system; scales)

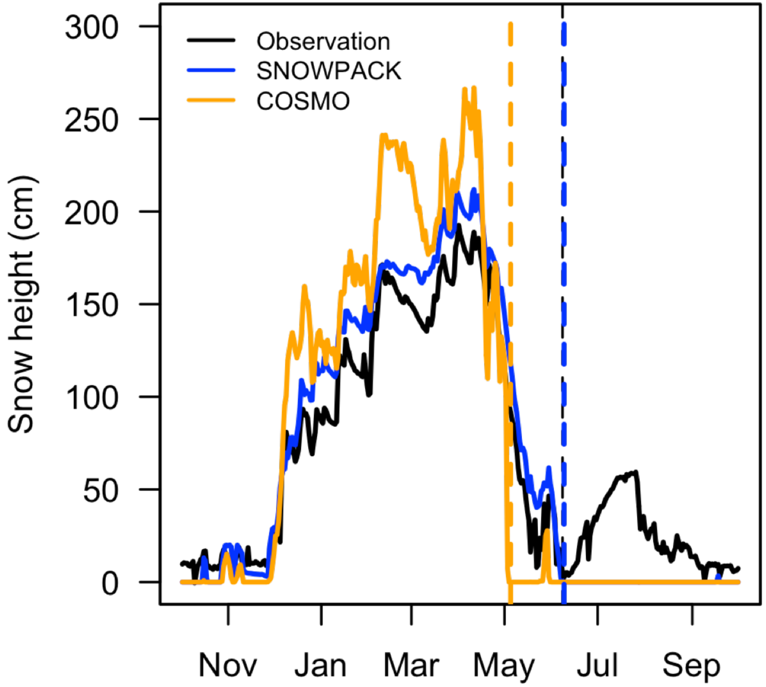




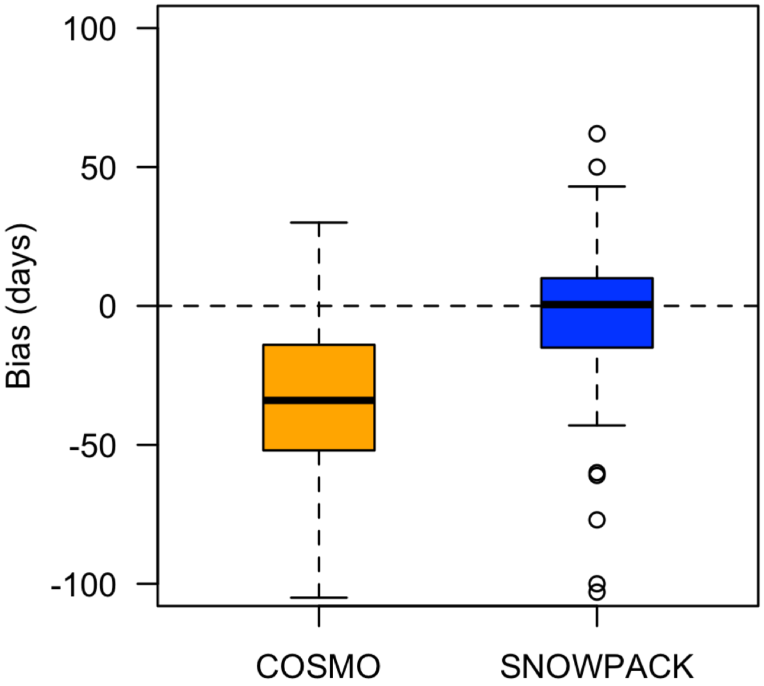
https://svs.gsfc.nasa.gov/2899

Snow height$_{(COSMO-2)}$

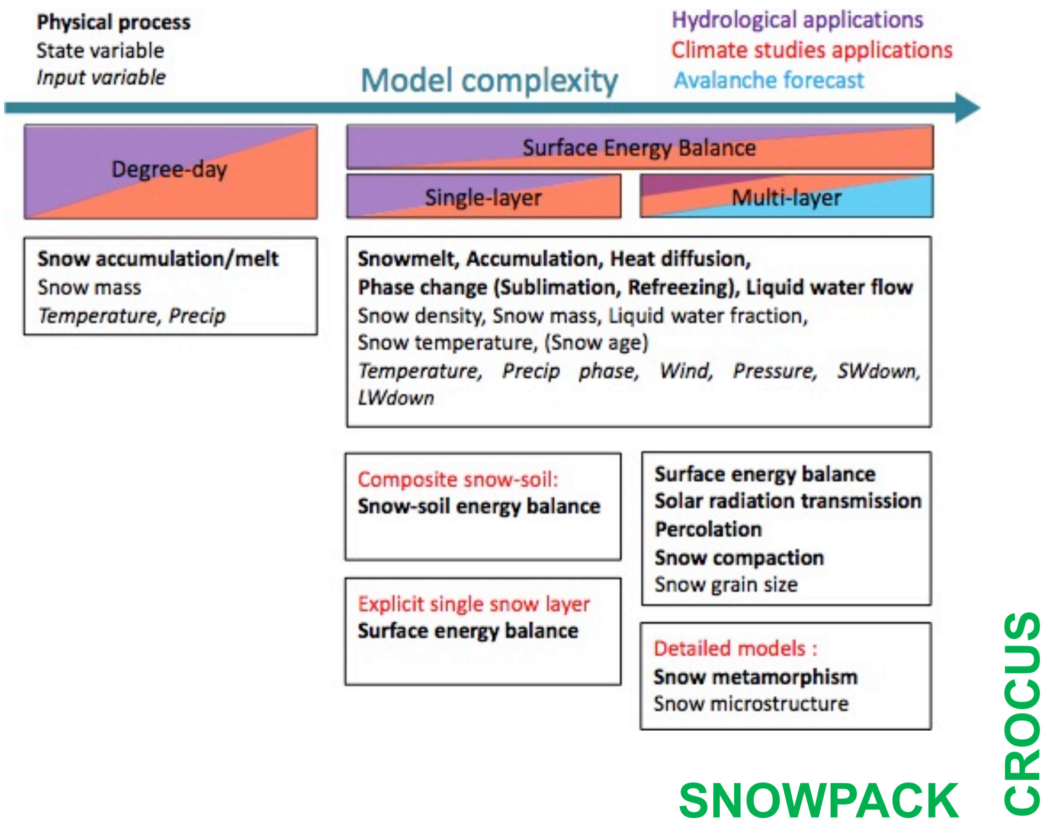
Weissfluhjoch



IMIS



Snow model complexity

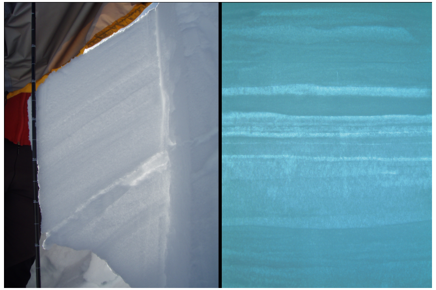


- ‘Good’ models must include …
  - multiple layers
  - new snow densit…
  - surface en… …ce (albed… … coefficients)
  - … …uction/equation
  - …se changes
  - water transport
  - compaction/settlement

SNOWPOLINO

Physical processes - Layering

SNOWPACK



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

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

θ : Volumetric Fraction (-)

ρ : Density (kg m^{-3});

s, i, w, a, v: subscripts for Snow, Ice, Water, Air, Vapor

Bulk Temperature Equation:

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

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

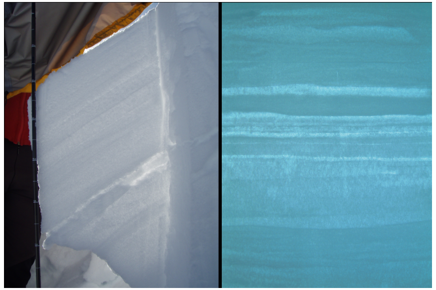
$$\rho_s c_p = \rho_i c_i \theta_i + \rho_w c_w \theta_w + \rho_a c_a \theta_a$$

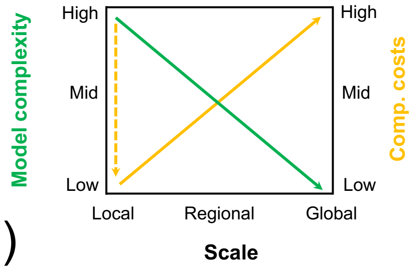
T_S: Temperature of Snow (K)

c_p : Heat Capacity (J kg^{-1} K^{-1})

k_{eff}: Effective Thermal Conductivity (W m^{-1} K^{-1})

Physical processes - Layering





- Multi-layer scheme
- Number of layers pre-defined ('default' 25)
- Max. thickness new layer 0.02 m min. 0.0025 m

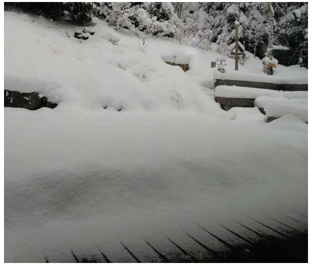
Snowfall:

- New snow amounts ≥ 0.02 m new layer added …
- … until max. number of snow layers is reached …
- … second layer from bottom, i.e. above soil, merged with bottom layer …
- … layers are 'shifted' downward accordingly.

Melt:

- If layers thickness ≤ 0.0025 m, layer gets merged with bottom layer.
- If number of layers smaller then pre-defined value, bottom layer gets split $dz_{(1)} = dz_{(1)} - 0.02$ m ; $\theta(1)_{i,w,a} = \theta(2)_{i,w,a}$
- Layer boundaries are 'shifted' upwards and levels adjusted accordingly.

Physical processes – New snow density (SNOWPACK)



$$\rho_s = 10^x$$

RH = relative humidity = 0.8
T_a = air temperature (℃)
UV = wind speed (m/s) ; max. 2.0

If T_a < -14 ℃

$$\boldsymbol{x} = a + b * \boldsymbol{T_a} + c * (ASIN(SQRT(\boldsymbol{RH})) + d * LOG_{10}(\boldsymbol{UV})$$

Else

$$\boldsymbol{x} = a + b * \boldsymbol{T_a} + c * (ASIN(SQRT(\boldsymbol{RH})) + d * LOG_{10}(\boldsymbol{UV}) + e$$

Coefficients: a = 3.28 ; b = 0.03; c = -0.75 ; d = 0.3; e = -0.36

Physical processes – Heat Equation

1D heat equation:

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

- Implicitly: Crank-Nicholson
- 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 ...
! -----------------------------------------------------------

DO ksn = -top+1, n_substrate

  IF(ksn .EQ. -top+1) THEN ! ... TOP LAYER

  dz_low = zm(ksn+1) - zm(ksn)

    a(ksn)      = 0.0_wp
    b(ksn)      = 1 + (1.0_wp - cn) * alpha(ksn) * hcon(ksn)/dz_low - alpha(ksn) * dlw_u_sn
    c(ksn)      = -   (1.0_wp - cn) * alpha(ksn) * hcon(ksn)/dz_low

    d(ksn)      = t(ksn) + alpha(ksn) * (for_sn - dl

  ELSEIF (ksn .LE. n_substrate-1) THEN ! ... INNER

   dz_up  = zm(ksn)   - zm(ksn-1)
   dz_low = zm(ksn+1) - zm(ksn)

      a(ksn) = -         (1.0_wp - cn)   * alpha(ksn) *  hcon(ksn-1)/dz_up
      b(ksn) = 1.0_wp + (1.0_wp - cn)   * alpha(ksn) * (hcon(ksn)  /dz_low + hcon(ksn-1)/dz_up)
      c(ksn) = -         (1.0_wp - cn)   * alpha(ksn) *  hcon(ksn)  /dz_low

      d(ksn) = t(ksn) + cn*alpha(ksn) * (hdif(ksn) - hdif(ksn-1))


  ELSEIF (ksn .EQ. n_substrate) THEN ! BOTTOM LAYERS

   dz_up = zm(ksn)   - zm(ksn-1)

     a(ksn) = -         (1.0_wp - cn) * alpha(ksn) * hcon(ksn-1)/dz_up
     b(ksn) = 1.0_wp + (1.0_wp - cn) * alpha(ksn) * hcon(ksn-1)/dz_up
     c(ksn) = 0.0_wp

     !d(bot_idx) = t(bot_idx) - cn*alpha(bot_idx-1) + alpha(bot_idx)*hdif(bot_idx)
     d(ksn)      = t(ksn) - cn*alpha(ksn)*hdif(ksn-1) + alpha(ksn)*hdif(ksn)

  ENDIF


ENDDO
```

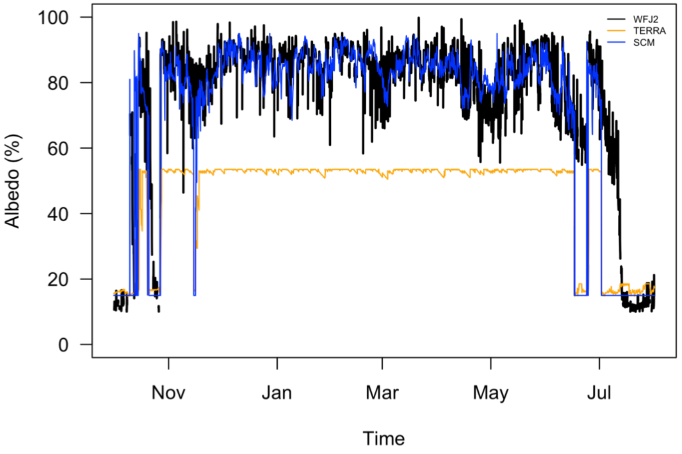
Atmospheric forcing

Physical processes – Atmospheric forcing(Albedo)

```
REAL (KIND=vpp), PARAMETER            :: &

  a1 = 0.9_vpp          , &    ! coefficients for the albedo parameterization
  a0 = 0.6_vpp
```

```
! ------------------------
! Calculate albedo
! ------------------------

 ! UKMO GCM
 IF(t_sn_sfc - 273.15_vpp .LE. -2.0_vpp) THEN

   alpha_sn = a1

 ELSE

   alpha_sn  = a1 - 0.15_vpp*(a1-a0)*((MIN(t_sn_sfc, t0_melt) - 273.15_vpp) + 2.0_vpp)

 ENDIF
```

Measured vs. modeled Albedo



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

P_{rate} = Precipitation Rate
T_{SFC} = Snow Surface Temperature
T_{10m} = Air temperature 10m

Physical processes – Atmospheric forcing (Turb. Fluxes)

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

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

Stability Corrections:

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

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

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

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

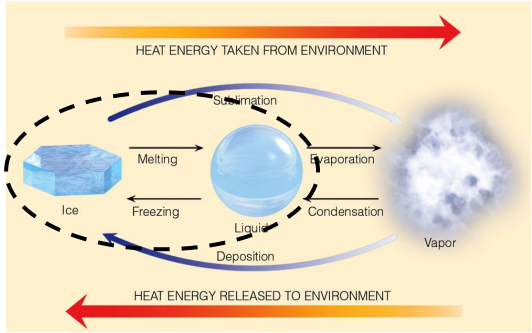
test site	a_1	b_1	test site	a_2	b_2
WFJ07 (3 m)	3.227	0.0043	WFJ07 (3 m)	−982.90	−0.0005
WFJ07 (5 m)	−4.441	0.0025	WFJ07 (5 m)	−642.51	0.0009
WFJ11	−30.74	0.0008	WFJ11	−1135.4	−0.0015
PM07 NWW	−191.93	0.0008	PM07 NWW	−751.73	−0.0005
PM07 SEE	−29.55	0.0090	PM07 SEE	−692.74	−0.0123
GR00 (1 m)	−145.41	−0.0914	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

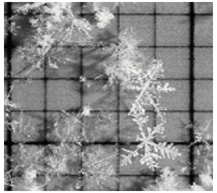
Transfer Coefficient:

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

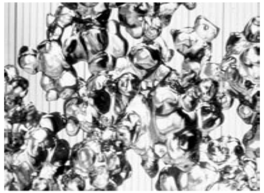
where $k = 0.4$ is the von Kármán constant, $\zeta = (-k\, z_{\text{ref}}\, g T_*) / (\theta_s u_*^2)$ is the modelled stability parameter (stability parameter henceforth), $u_* = k\bar{U}\left(\ln\left(z_{\text{ref}}/z_{0M}\right) - \psi_m\right)^{-1}$ is the modelled friction velocity, $T_* = k\left(\theta_s - \theta_{z_{\text{ref}}}\right)\left(\ln\left(z_{\text{ref}}/z_{0M}\right) - \psi_s\right)^{-1}$ 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

Physical processes – Phase Changes (SNOWPACK)





precipitation particles



melt-forms

$$\Delta T = T_s - T_{melt}$$

$$\Delta \theta_w = \frac{c_s \theta_i \rho_i \Delta T}{L_f \rho_w}$$

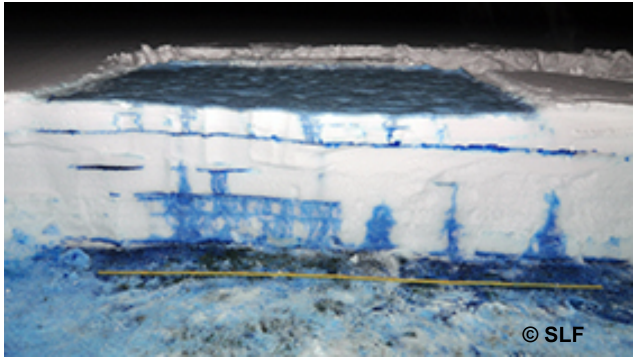
$$\Delta \theta_i = \frac{\rho_w \Delta \theta_w}{\rho_i}$$

$$Q_{pc} = \Delta \theta_i \rho_i L_f$$

$$L_f = 334 \frac{J}{kg}$$

- Calculate ‘hypothetical’ temperature.
- Determine mass changes due to phase change and associated energy.

Physical processes – Water transport(Bucket Model)



- Bucket model (1:1 from SNOWPACK)
- Estimate residual water content (Coleou and Lesaffre,1998)
- Percolate excess water, i.e. water larger than residual water content down the domain (layer to layer; bucket to bucket)
- Layer temperature set to 273.15K
- Excess water at snow/soil interface is stored.

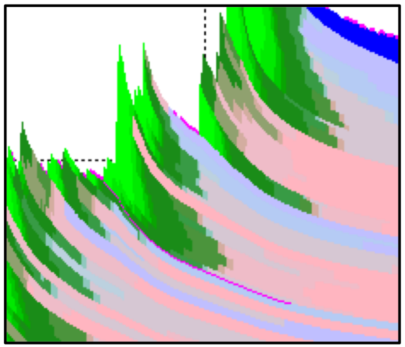
Physical processes – settling/densification

The detailed snowpack scheme Crocus and its implementation in SURFEX v7.2

V. Vionnet, E. Brun, S. Morin, A. Boone, S. Faroux, P. Le Moigne, E. Martin, J.M. Willemet

$$\Delta\theta_i = \frac{\rho_w \Delta\theta_w}{\rho_i}$$ '+' $$\frac{dD}{D} = \frac{-\sigma}{\eta} dt$$

change of layer thickness (melt) + change of layer thickness due to ..



$$\sigma_i = \Sigma_1^{i-1} g \cos(\Theta) \rho(i) D(i)$$

... overburden stress

$$\eta = f_1 f_2 \eta_0 \frac{\rho}{c_\eta} \exp\left(a_\eta (T_{\text{fus}} - T) + b_\eta \rho\right)$$

… snow viscosity

correction factors for …

$$f_1 = \frac{1}{1 + 60 \frac{W_{\text{liq}}}{\rho_w D}}$$

… presence of water

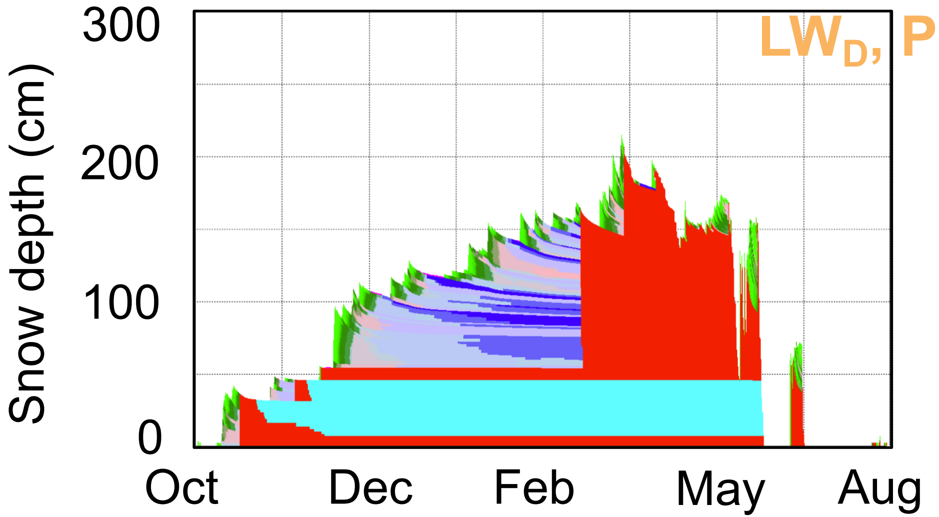
$$f_2 = \min\left[4.0, \exp(\min(g_1, g_s - g_2)/g_3)\right]$$

… microstructure

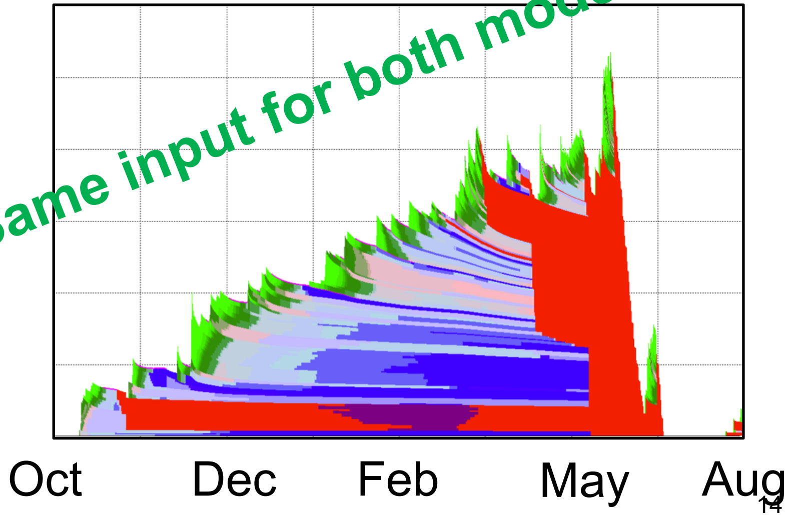
Testing (SNOWPACK vs. SNOWPOLINO)

T_{AIR}, RH, FF,
SW_U, T_{SNOW}, H_{SNOW}

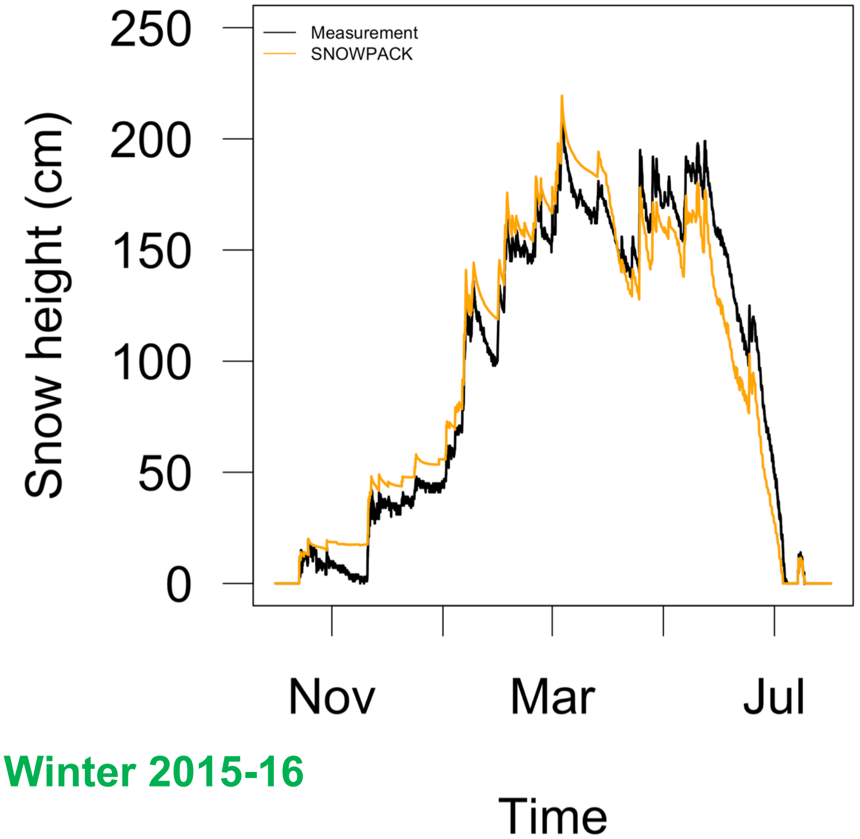
T_{AIR}, RH, FF, SW_D,
LW_D, PP



Same input for both models !!!!

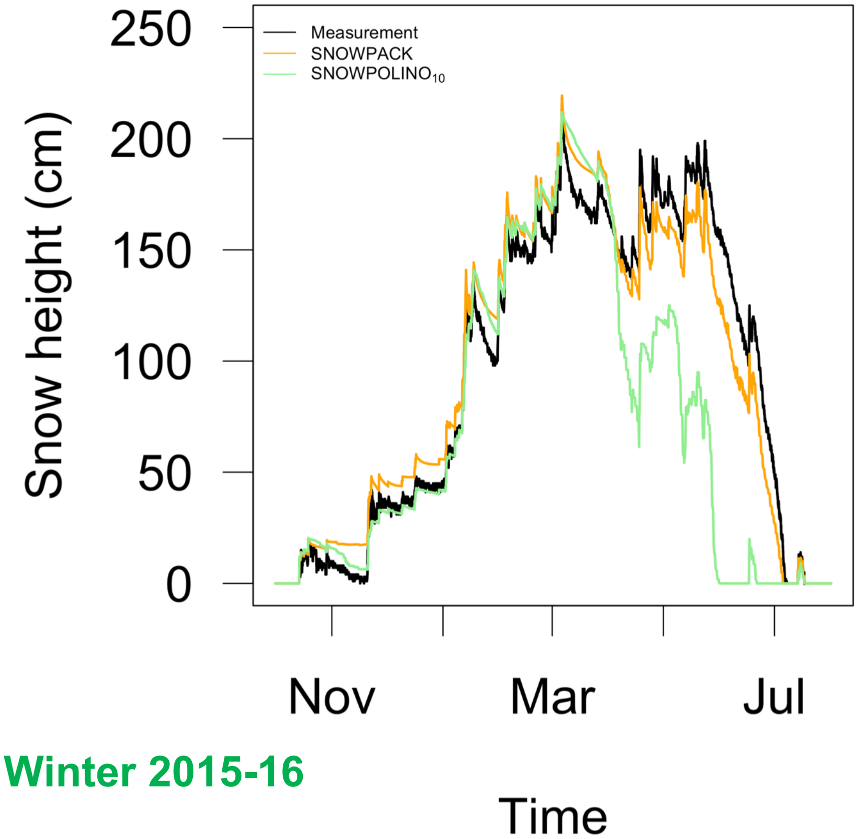


Snow height (local) – Sensitivity (# layers)



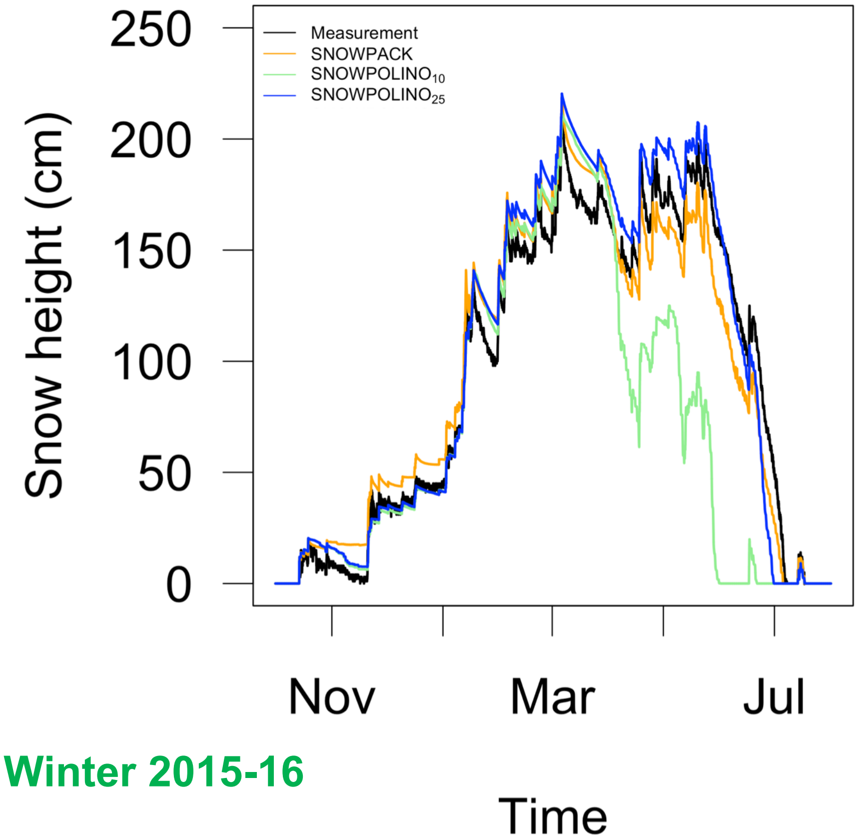
Weissfluhjoch – Winter 2015-16

Snow height (local) – Sensitivity (# layers)



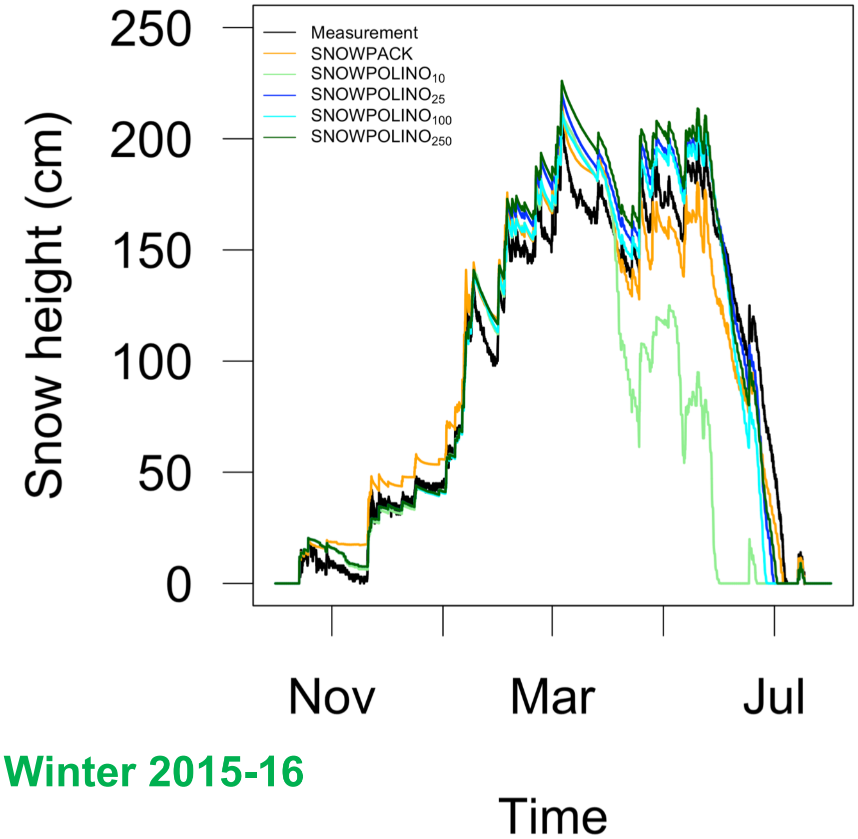
Weissfluhjoch – Winter 2015-16

Snow height (local) – Sensitivity (# layers)



Weissfluhjoch – Winter 2015-16

Snow height (local) – Sensitivity (# layers)

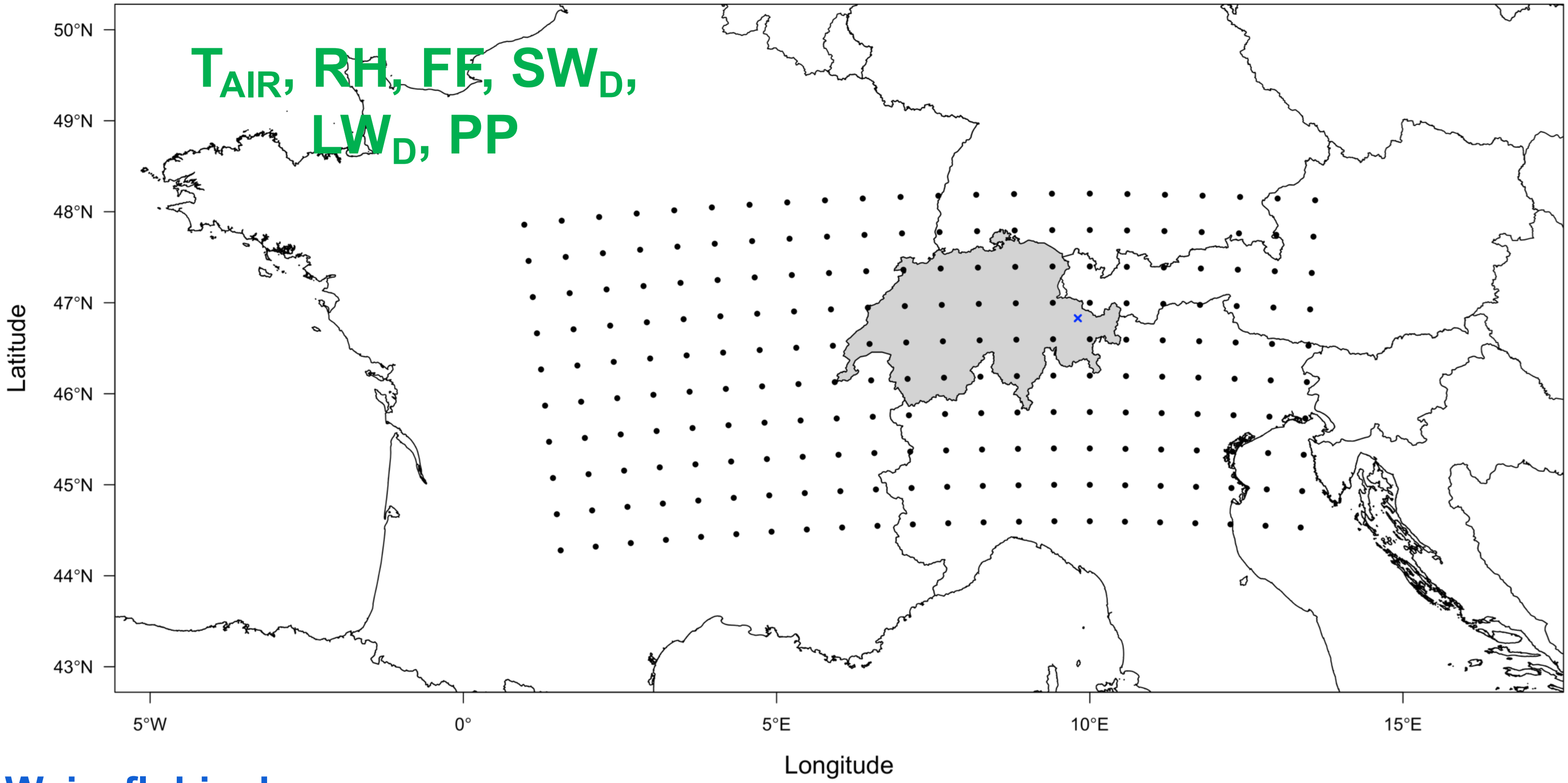


Runtime

# Layers	Time	Percent
-	s	%
10	4.6	69
25	**6.6**	**100**
100	16.9	256
250	43.2	655

Weissfluhjoch – Winter 2015-16

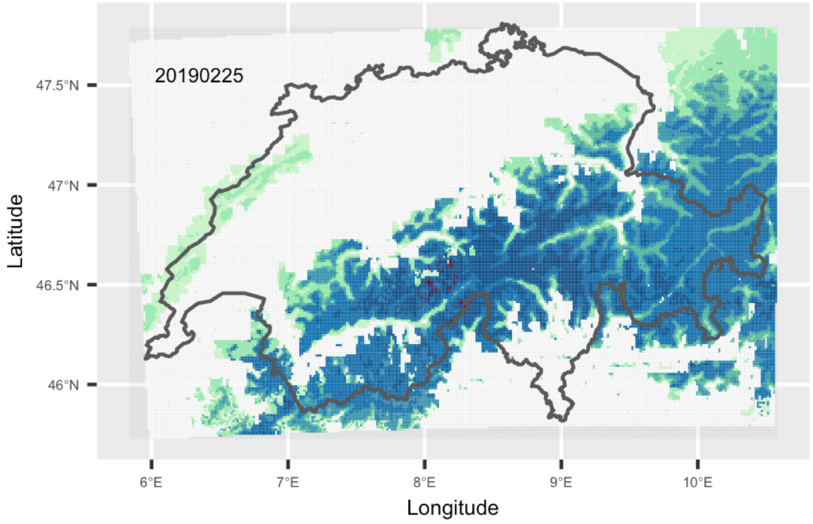
Snow height (regional) - COSMO-1 Analysis/SNOWPOLINO



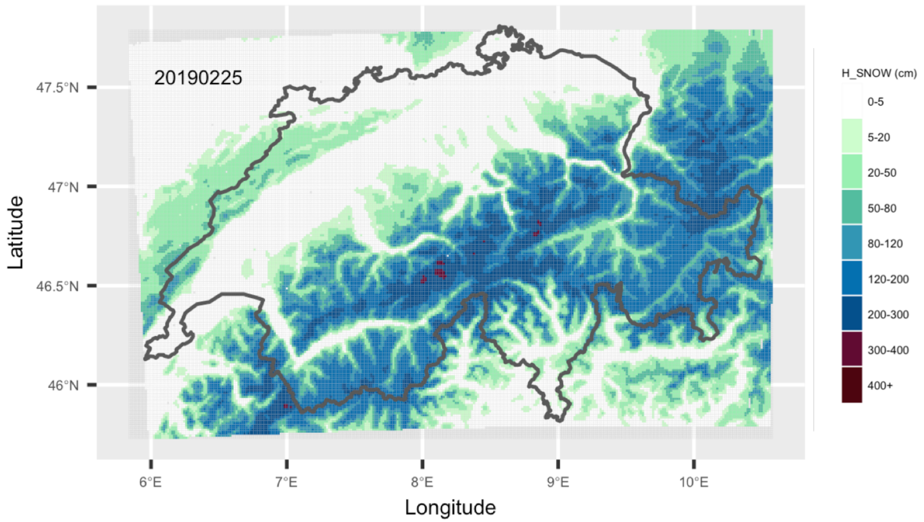
x = Weissfluhjoch

Snow height (regional)

COSMO-1 (Analysis)

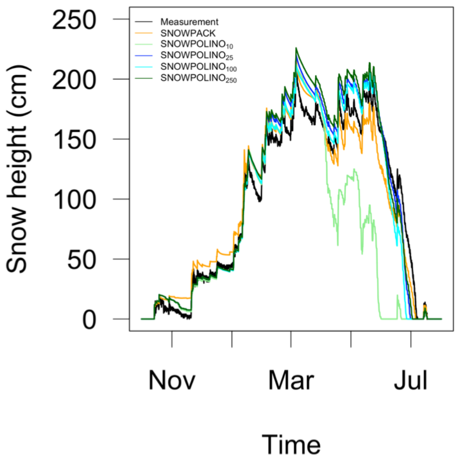


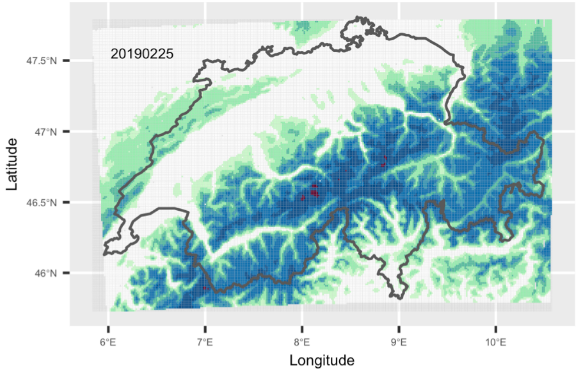
SNOWPOLINO



Summary & Conclusion

- ‘New’ (**GPU capable**) multi-layer snow cover scheme (SNOWPOLINO) was implemented into COSMO - **v6.0 ready**!
- Minor to major adaptations; e.g. implementation, tuning, switches – v6.1
- Main physical parametrizations (i.e. phase change, water transport) were taken or adapted mainly from the sophisticated snow cover model SNOWPACK.
- Scheme is switchable (**namelist option; lsnow**) and no. of layers can be chosen (default currently n=25).
- Local (offline) validations of SNOWPOLINO shows **comparable results to SNOWPACK**.
- Spatial validation (online) shows … **(stay tuned)**
- **Operational implementation (MCH) – Winter 2020/2021**





Thank you!
Questions or Comments?

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

Contact: sascha.bellaire@meteoswiss.ch

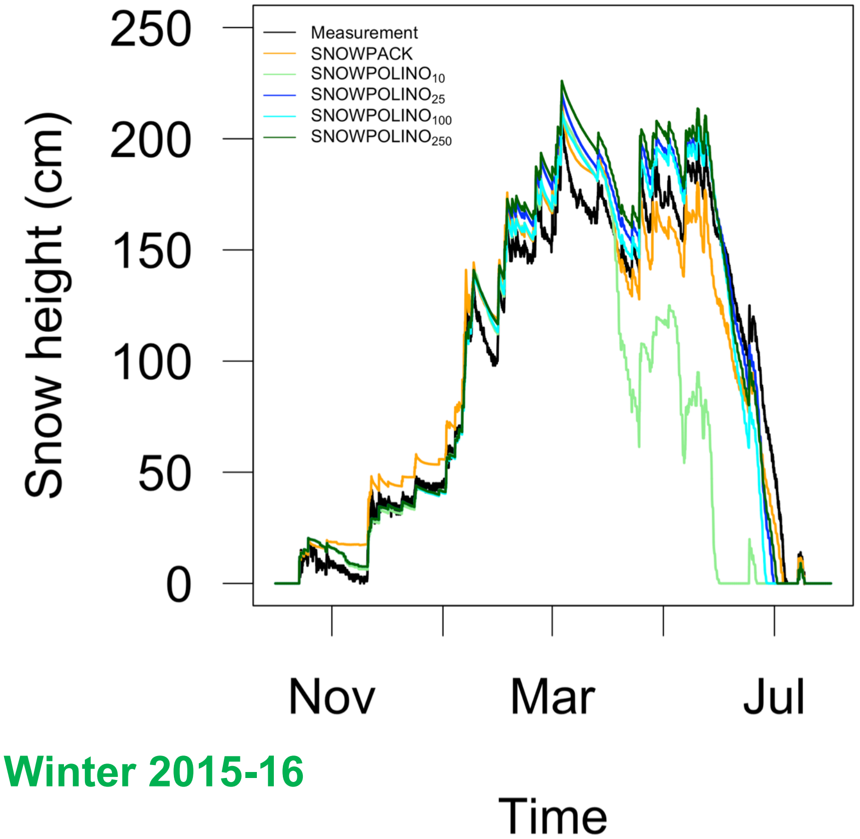
Future snow analysis

(MCH - Tentative plan)

Sascha Bellaire, Louise Braud, Jean-Marie Bettems

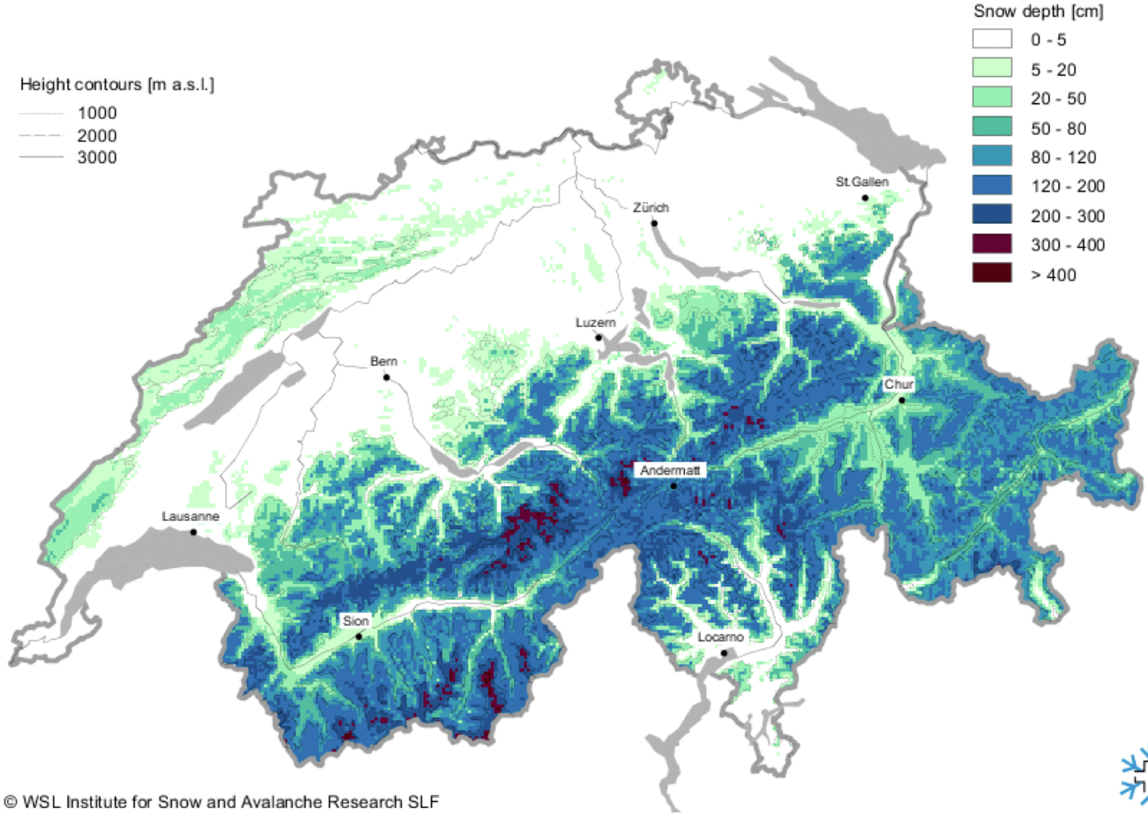
MeteoSwiss, Zurich, Switzerland

Snow height (local) – Sensitivity (# layers)

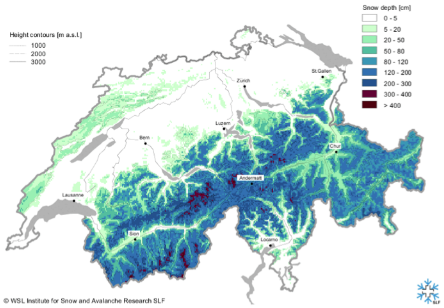


Weissfluhjoch – Winter 2015-16

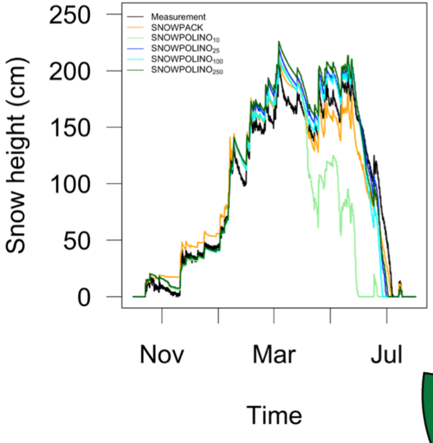
Snow Analysis – What do we need?

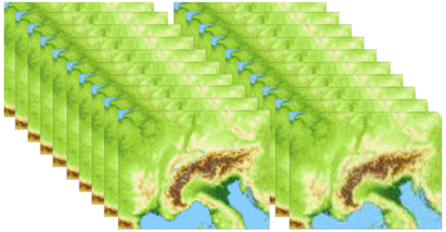


Snow Analysis – SLF$_{(?OSHD?)}$ MCH products



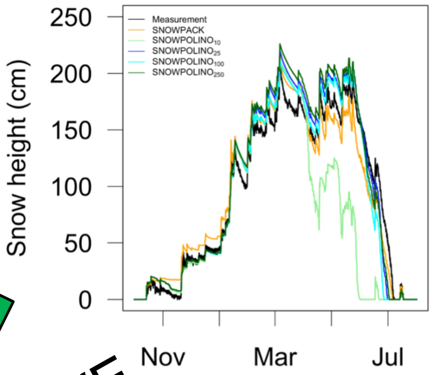
to SNOWPOLINO





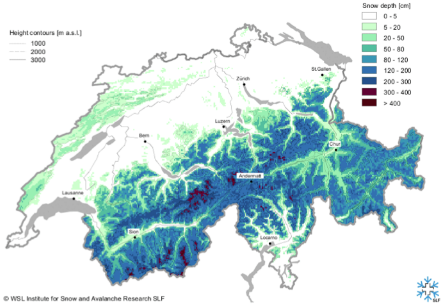
back to COSMO

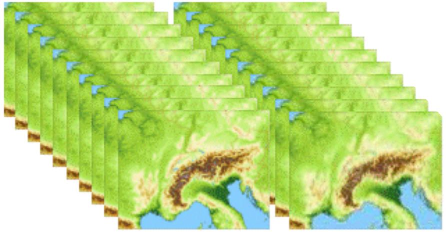
Snow Analysis – What's the alternative?



SNOWE

to generate snow cover mask(s)

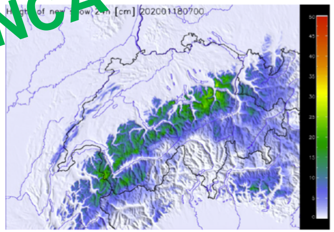




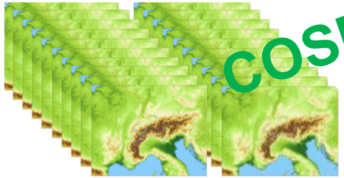
back to COSMO

Snow Analysis – What's the alternative?

INCA



COSMO



Radar

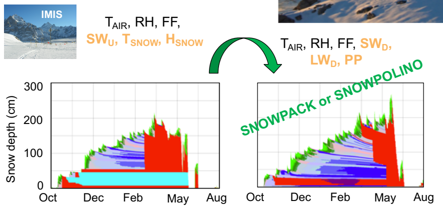
SMRT: an active–passive microwave radiative transfer model for snow with multiple microstructure and scattering formulations (v1.0)

Ghislain Picard[1], Melody Sandells[2], and Henning Löwe[3]
[1]UGA, CNRS, Institut des Géosciences de l'Environnement (IGE), UMR 5001, 38041 Grenoble, France
[2]CORES Science and Engineering Limited, Burnopfield, UK
[3]WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland

Satellite

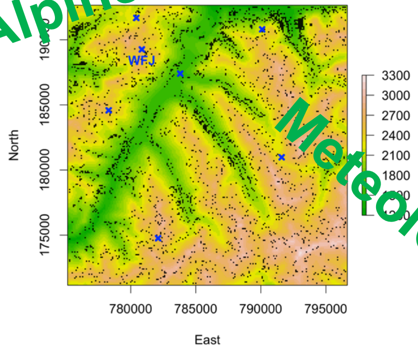
T_{AIR}, RH, FF, SW_D, LW_D, PP

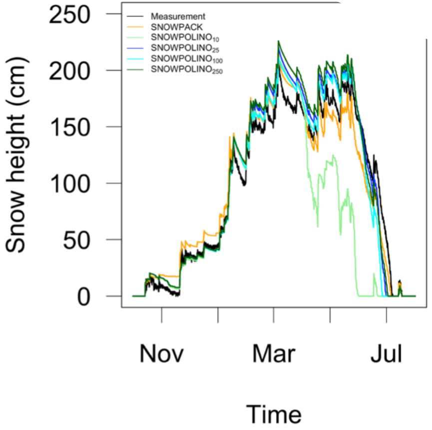
AWS



Alpine3D

MeteoIO





Thank you!
Questions or Comments?

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Introduction: Model complexity vs. Costs