

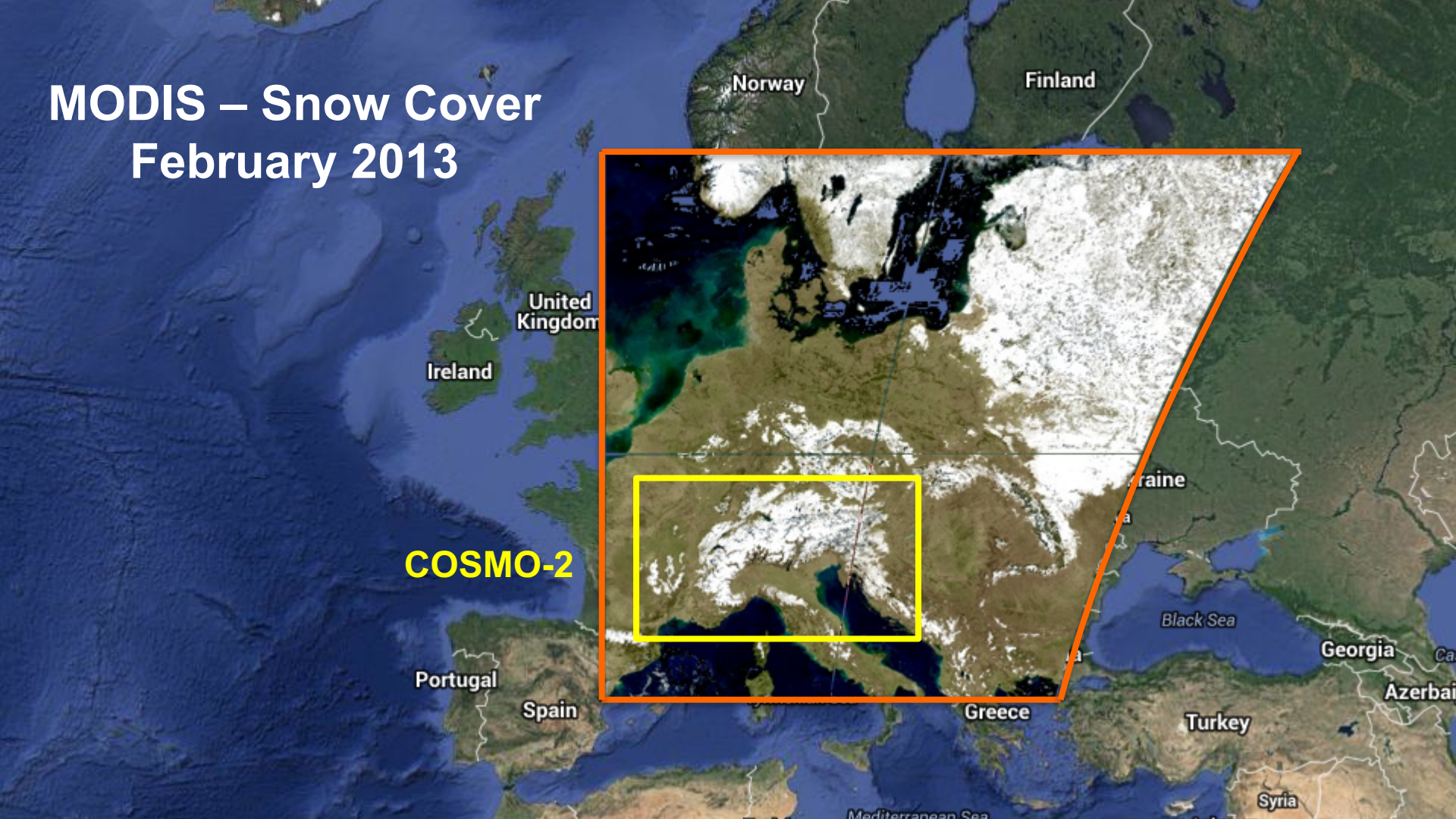
Project SAINT
Snow-cover Atmosphere INTeractions

Sascha Bellaire, Michael Lehning, Jean-Marie Bettems

Jerusalem, 11.09.2017

MODIS – Snow Cover
August 2013

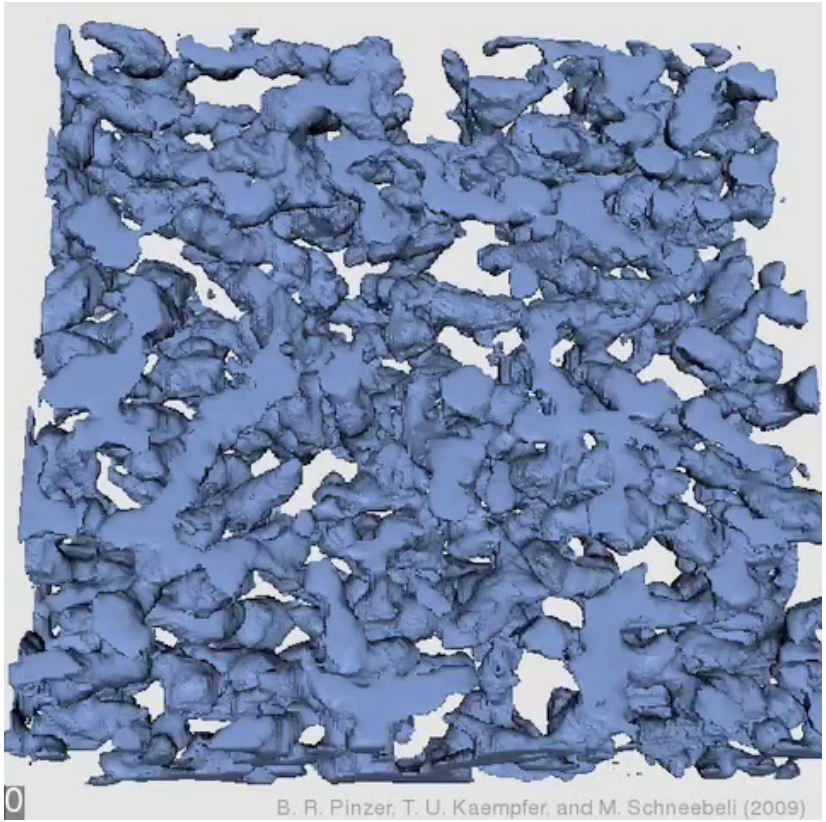
MODIS – Snow Cover February 2013



WSL Institute for Snow and Avalanche Research SLF

- Hosts Swiss Avalanche Warning Service and Hydrological Warning Service
- 100+ people

Snow metamorphism …

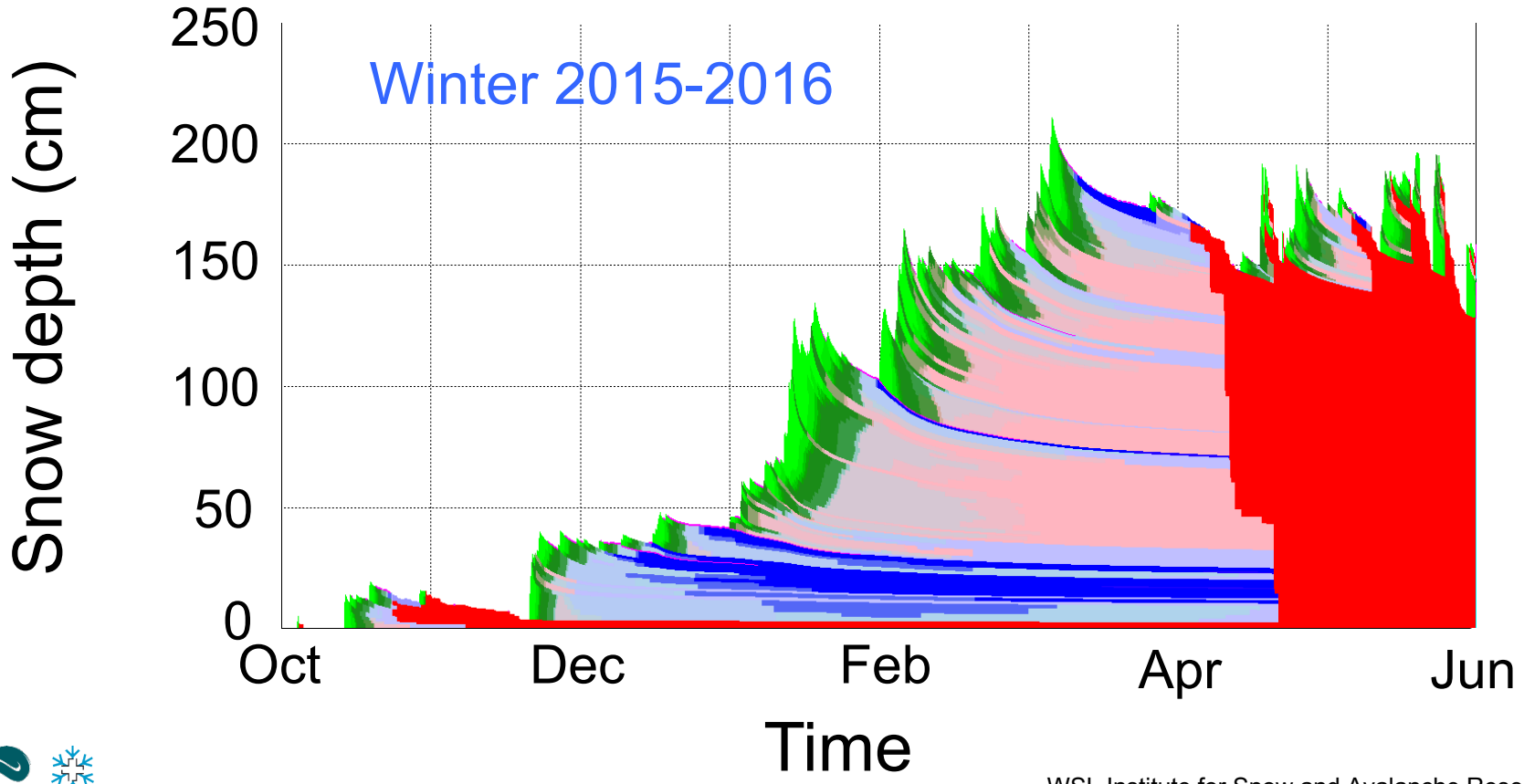


- … is controlled by temperature gradient.
- Temperature gradient defined by temperature at the soil/snow interface and surface temperature.
- Mass and energy balance at the surface controls formation and evolution of the snow cover – which can be modelled (SNOWPACK).

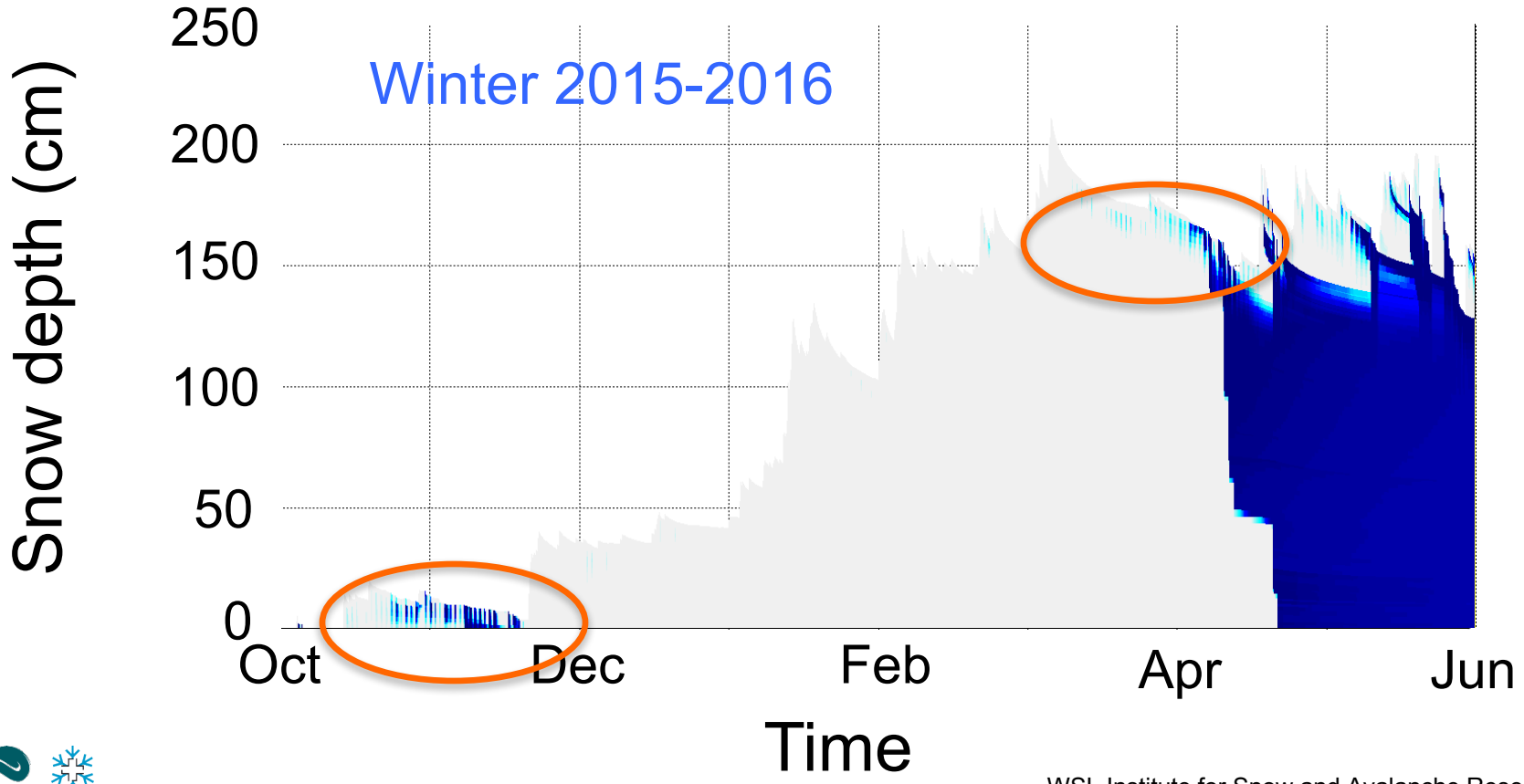
Depth hoar formation from micro-CT

Intercantonal Measurement and Information System (IMIS)

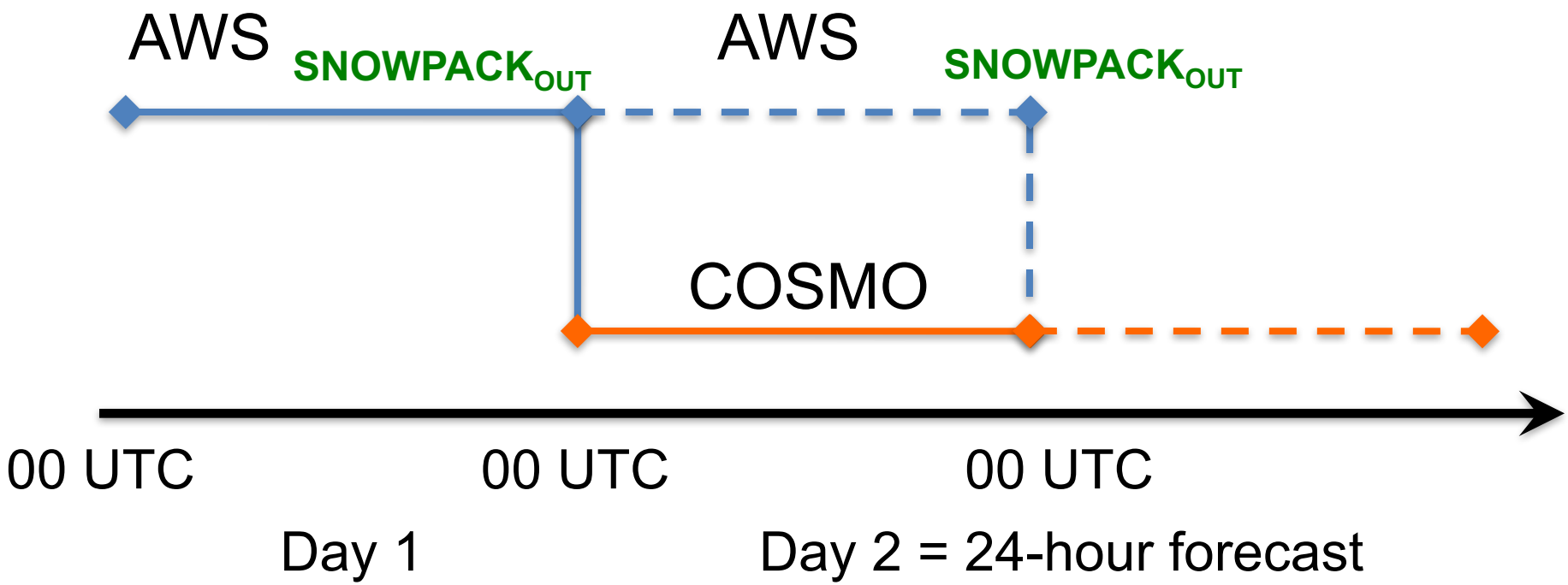
Snow cover modeling – SNOWPACK (Flat field)



Snow cover modeling – Liquid Water Content (LWC)

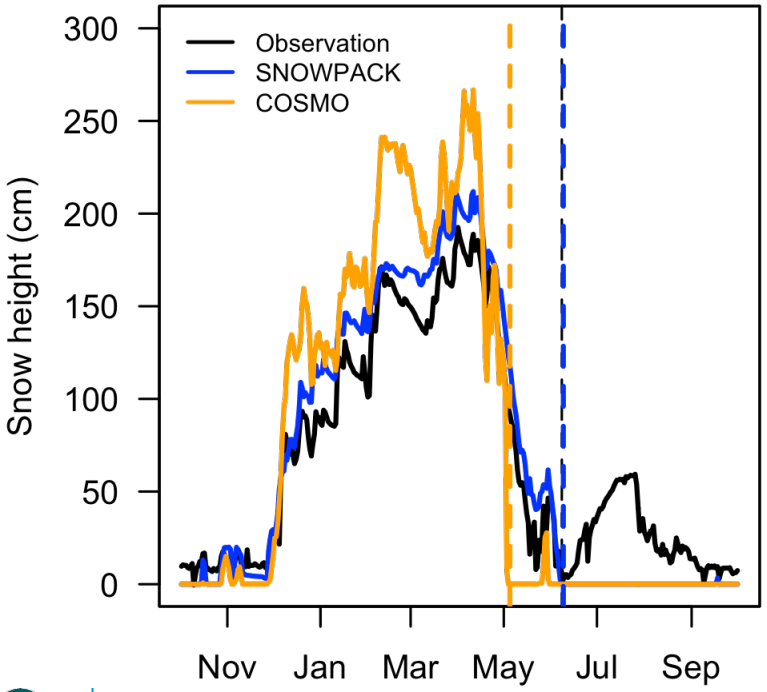


Predicting wet-snow avalanche cycles

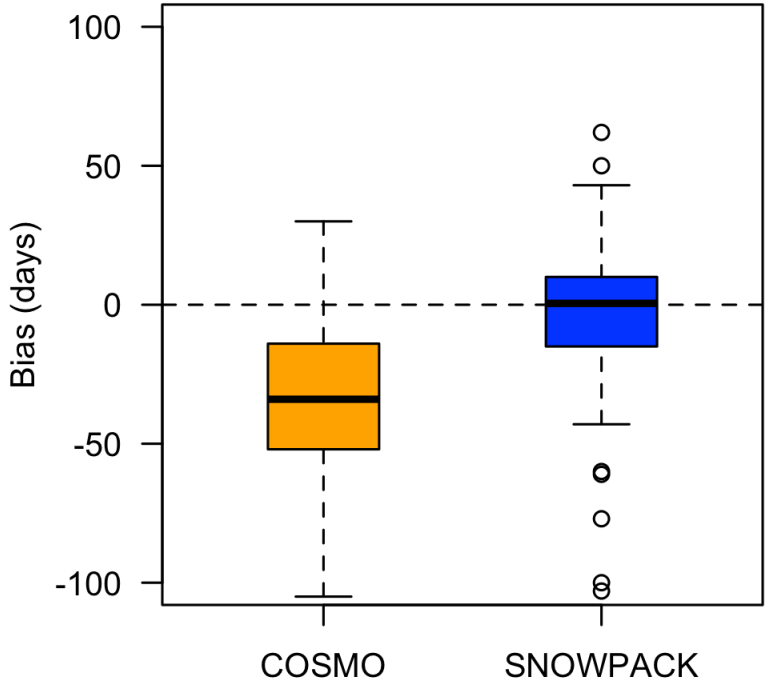


Snow height comparison – Local vs. regional

Weissfluhjoch

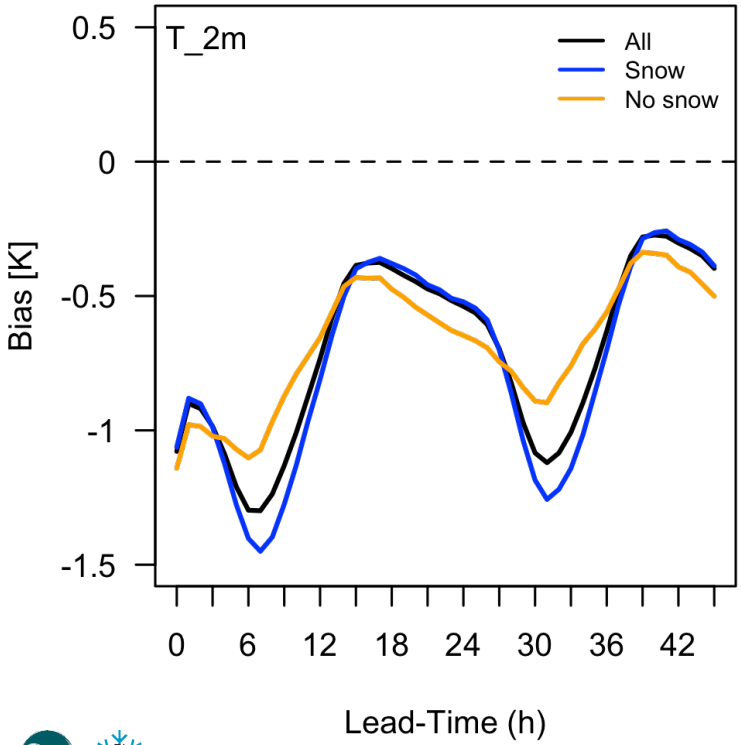


IMIS

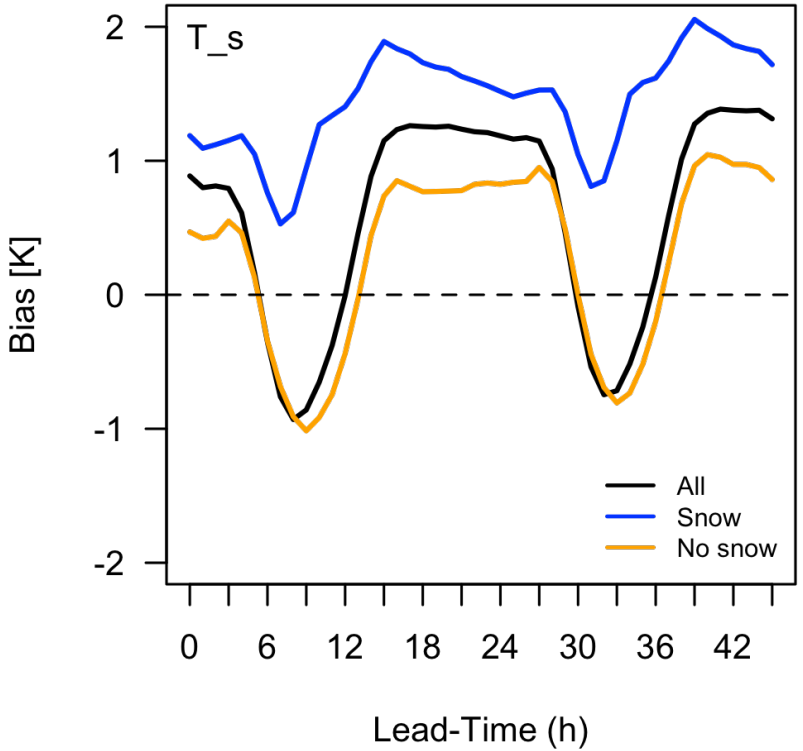


Temperature Bias – Regional (IMIS)

Air



Surface



Single layer snow module – Force response model

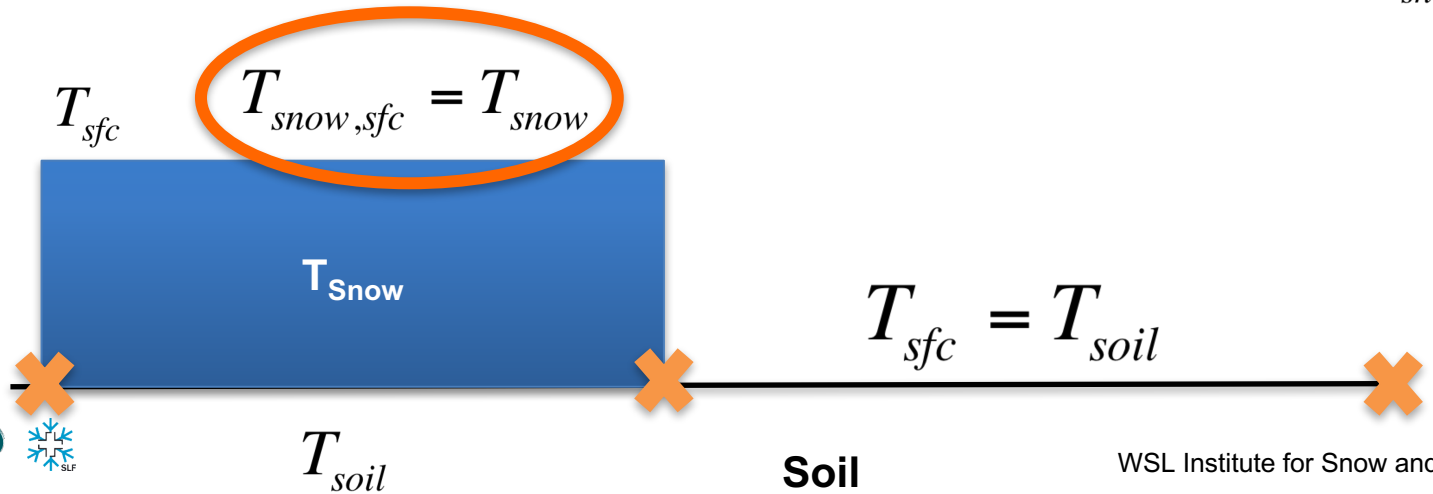
$$\frac{\partial T_{snow}}{\partial t} = \frac{1}{(\rho c \Delta z)_{snow}} \left(Q_F - Q_G + Q_M \right)$$

Atmospheric Forcing:

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

Ground heat Flux:

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



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

SEB - Surface Energy Balance (Fluxes)

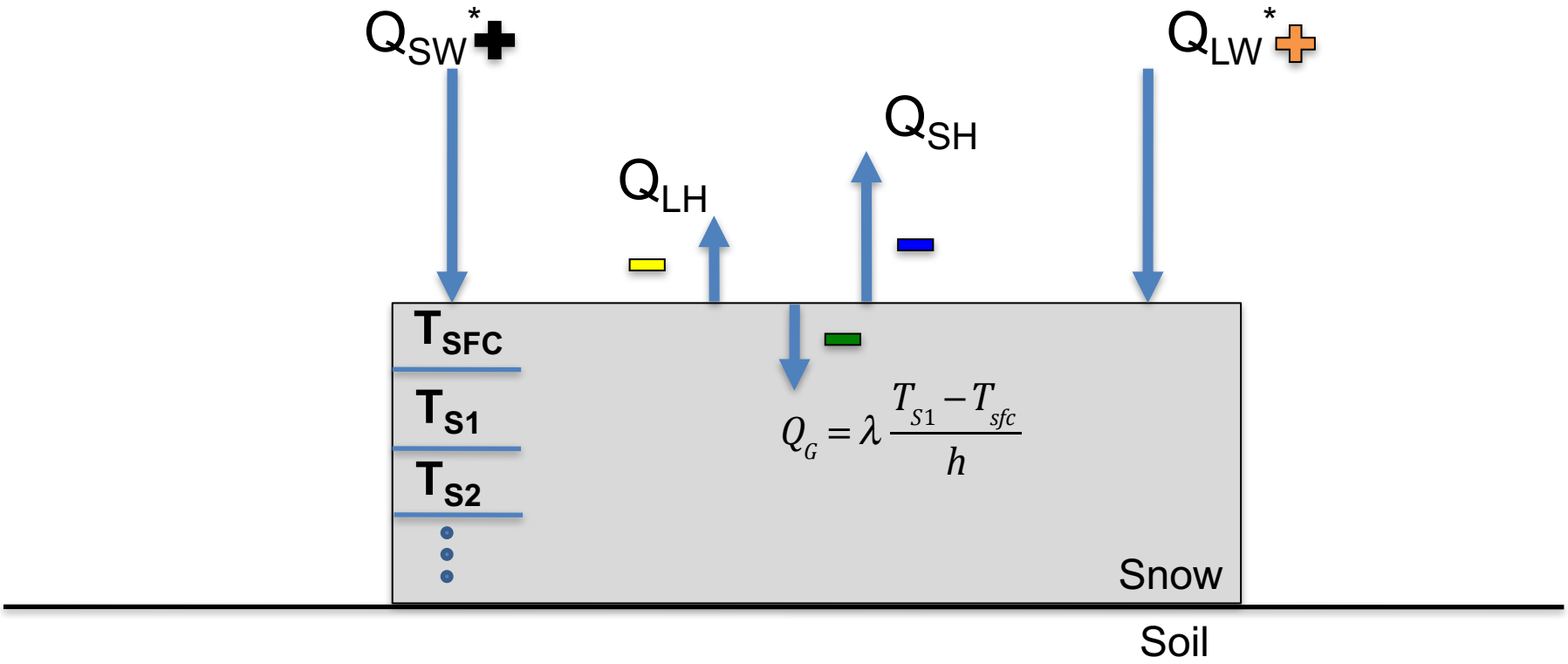
Radiation **Turbulence** **Ground = Snow**

$$Q^*_{SW} = -Q^*_{LW} - Q_{LH} - Q_{SH} + Q_G$$

SW = short-wave
LW = long-wave

LH = latent heat
SH = sensible heat

SEB based, multi-Layer snow cover model (SCM)



Solving Heat Equation

One dimensional heat-equation:

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

$$\alpha = \frac{\lambda}{\rho c_p}$$

Forward Time, Centered Space:

$$T_i^{m+1} = rT_{i+1}^m + (1-2r)T_i^m + rT_{i-1}^m$$

$$r = \frac{\alpha \Delta t}{\Delta x^2}$$

Thermal conductivity

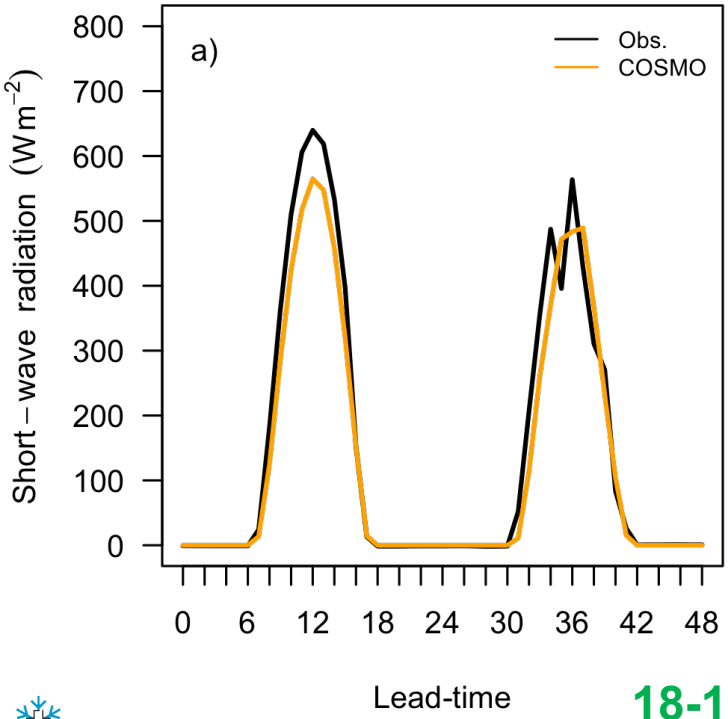
$$\lambda = 2.0 \times 10^{-2} + \left(2.5 \times 10^{-6} \times \rho^2\right)$$

layer index = i
time index = m

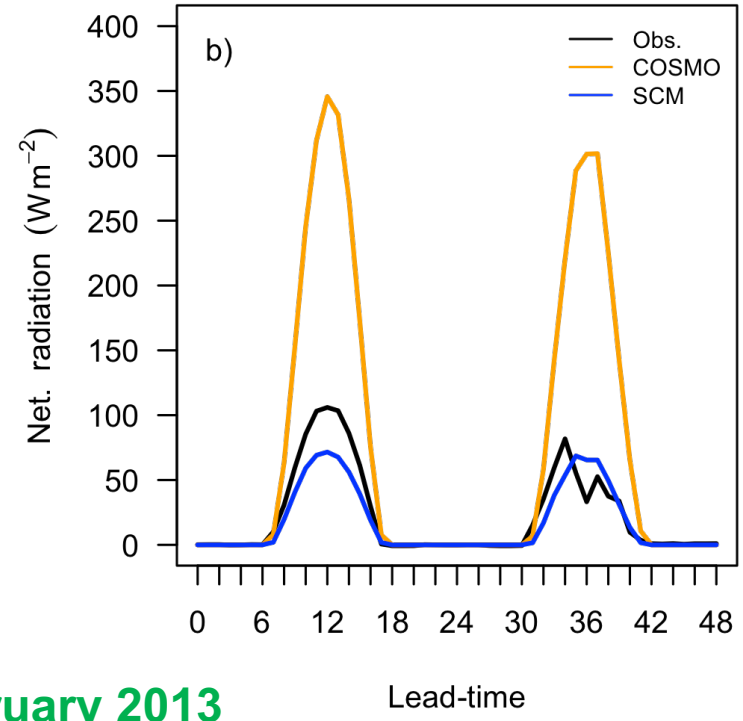
density ρ
Specific heat of ice; c_p = 2105 J kg^{-1} K^{-1}

Short-wave radiation (WFJ)

Incoming



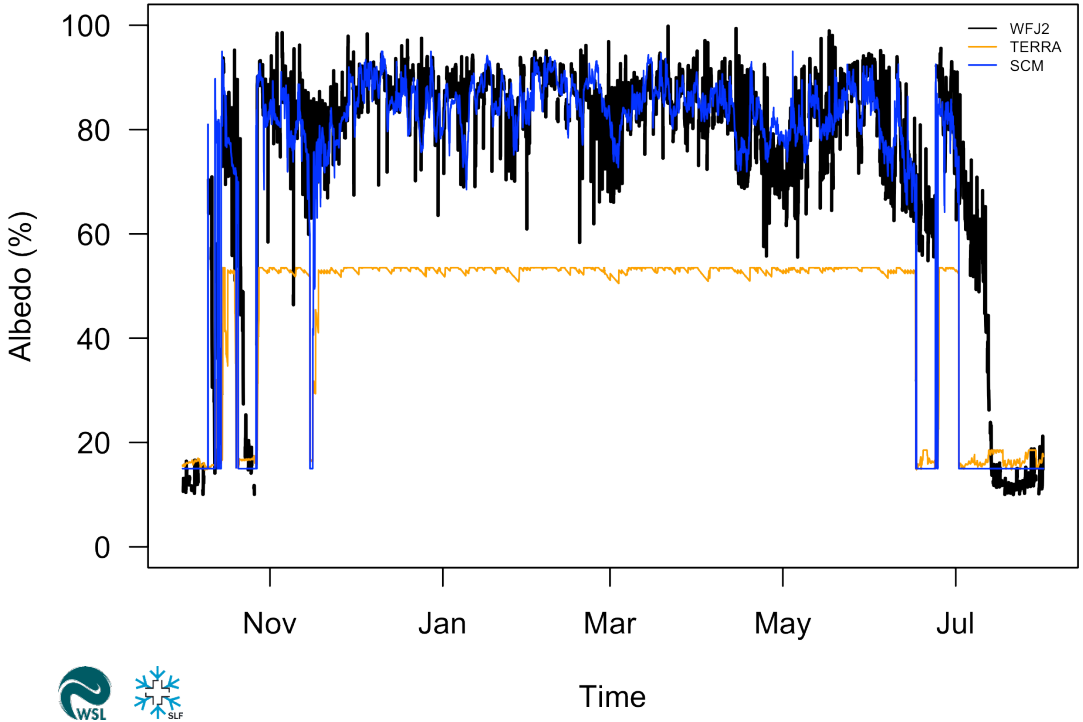
Net.



18-19 February 2013

Albedo model (WFJ)

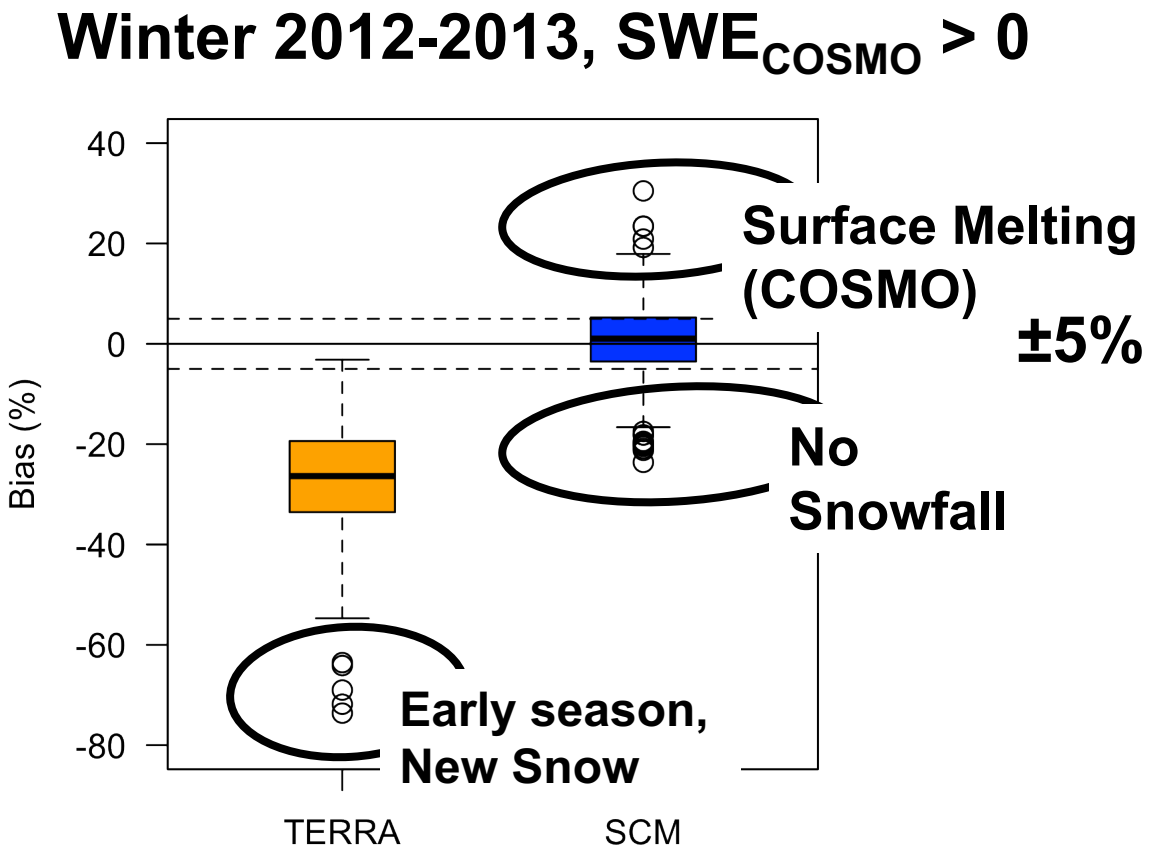
$$\alpha_{SCM} = a + b \times P_{rate} + c \times T_{SFC} - d \times T_{10m}$$



P_{rate} = Precipitation Rate
T_{SFC} = Snow Surface Temperature

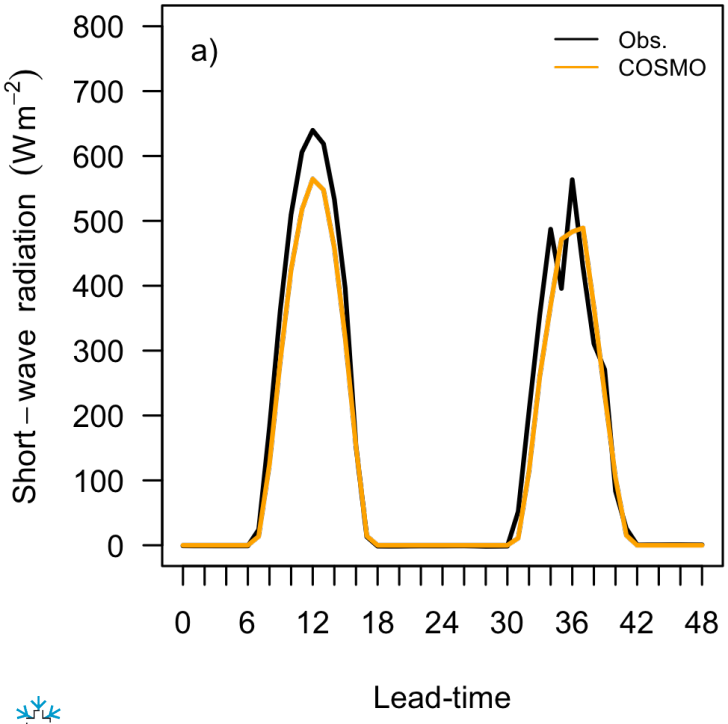
T_{10m} = Air Temperature 10 m

Albedo model (WFJ)



Short-wave radiation (WFJ)

Incoming



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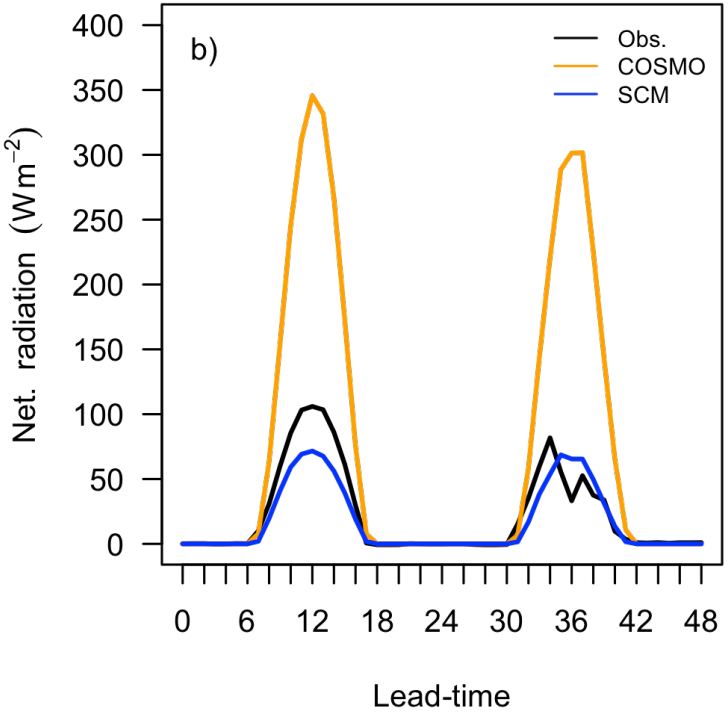
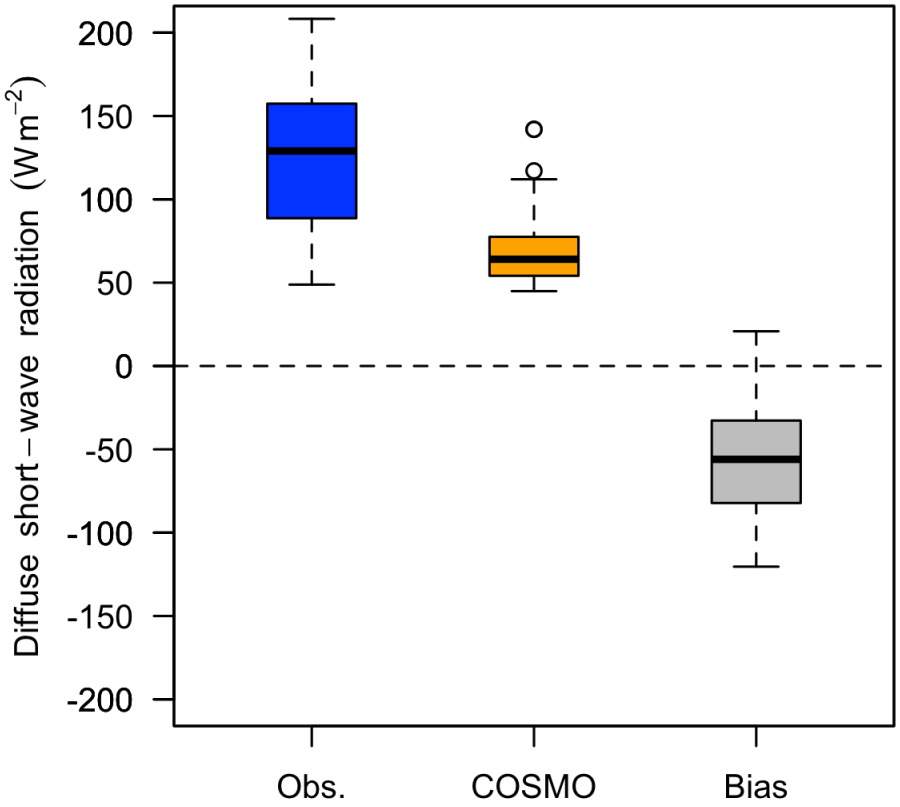
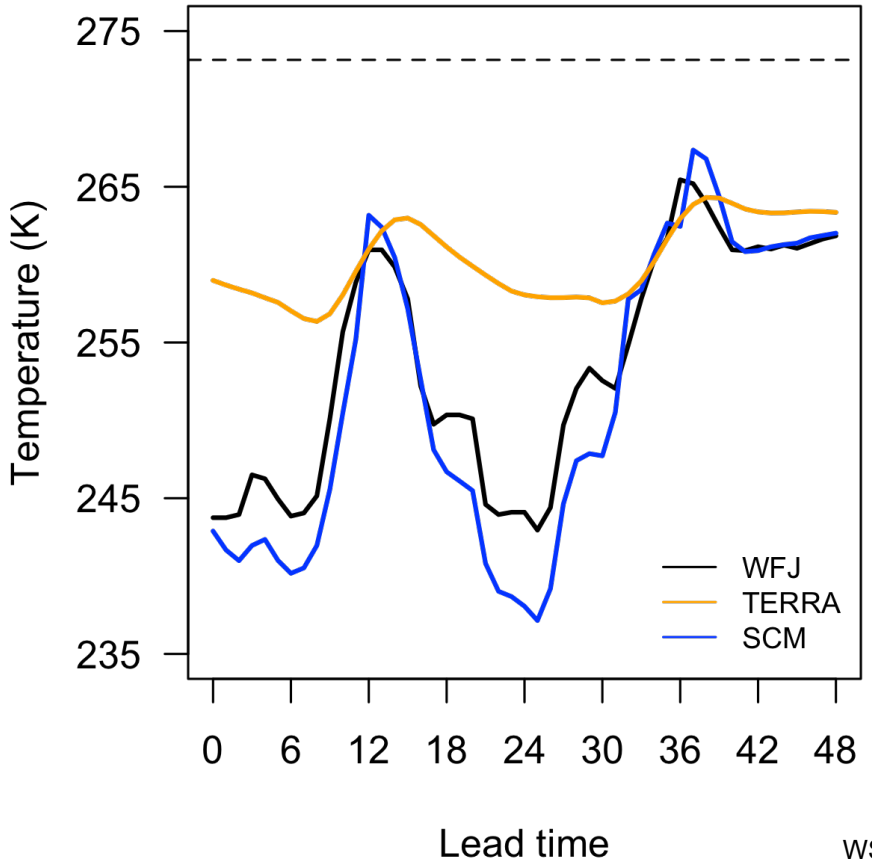


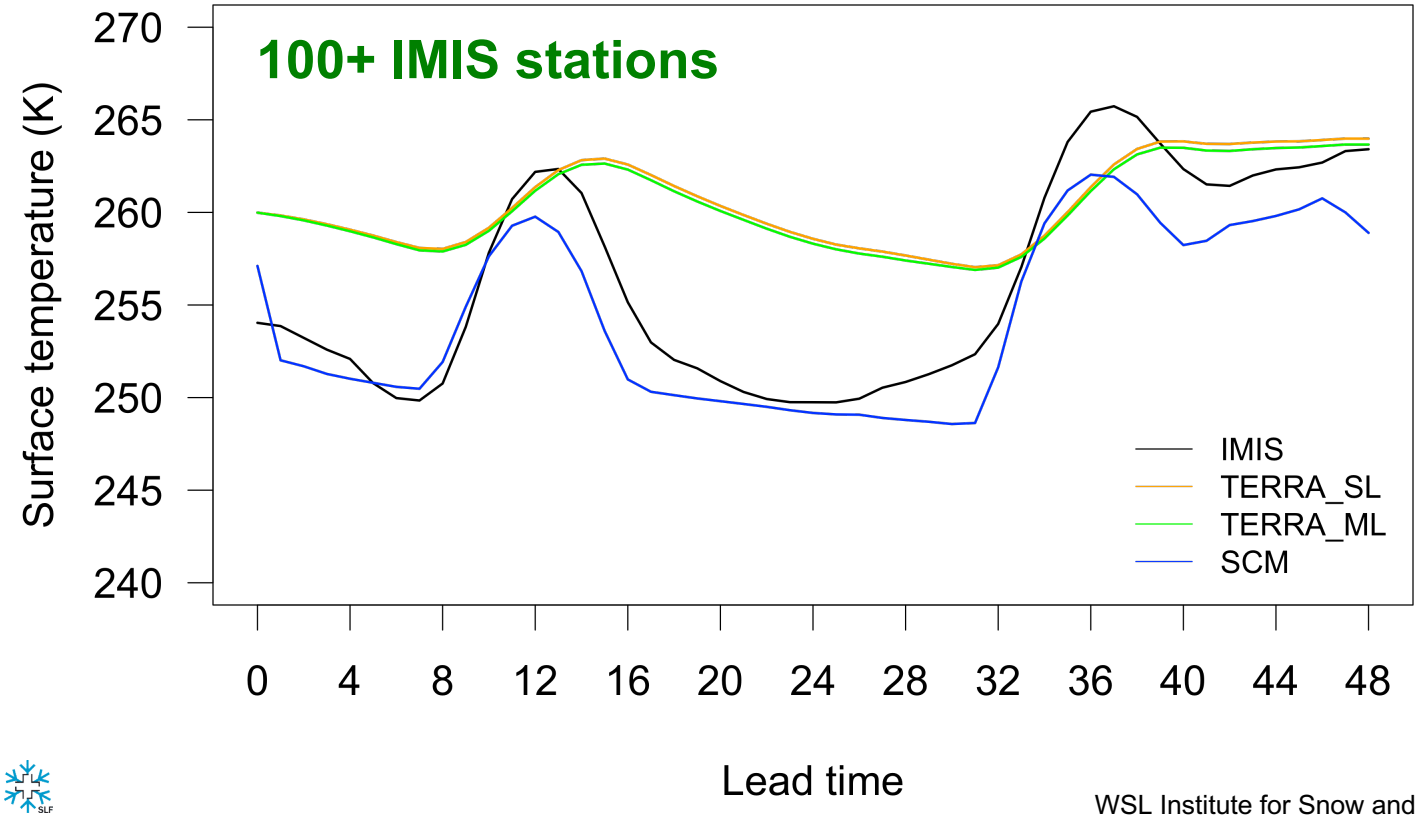
Diffuse radiation (WFJ)



Surface Temperature (WFJ-SCM$_{offline}$)



Surface Temperature (SCM_{online})



Turbulence (bulk approach)

Sensible Heat:

$$Q_{SH} = k_H \, u_z \, \rho_{air} \, c_p \left(\Theta_{air} - \Theta_{sfc} \right)$$

Latent Heat:

$$Q_{LH} = k_H \, u_z \, \rho_{air} \, L_H \left(q_1 - q_{sfc} \right)$$

Transfer coefficient (heat):

$$k_H = \frac{\kappa^2}{\left(\log\left(\frac{z}{z_0} \right) \right)^2} \times k_s$$

$$k_S = MAX\left(k_{H.MIN}, \frac{1}{1+15 \times Ri_b} \times \left(\left(1+5 \times Ri_b \right) \right)^{0.5} \right)$$

$k_{H,MIN}$ = min. transfer coefficient

Multi-layer snow scheme: Formulation

Snow Temperature T_{sn}

$$\rho_{sn}\frac{\partial T_{sn}}{\partial t}=\frac{\partial}{\partial z}\lambda_{sn}\frac{\partial T_{sn}}{\partial z}+L_f\left(F-M\right)-\frac{\partial R}{\partial z}$$

Liquid Water W_{liq}

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

Total Water (SWE) W_{tot}

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

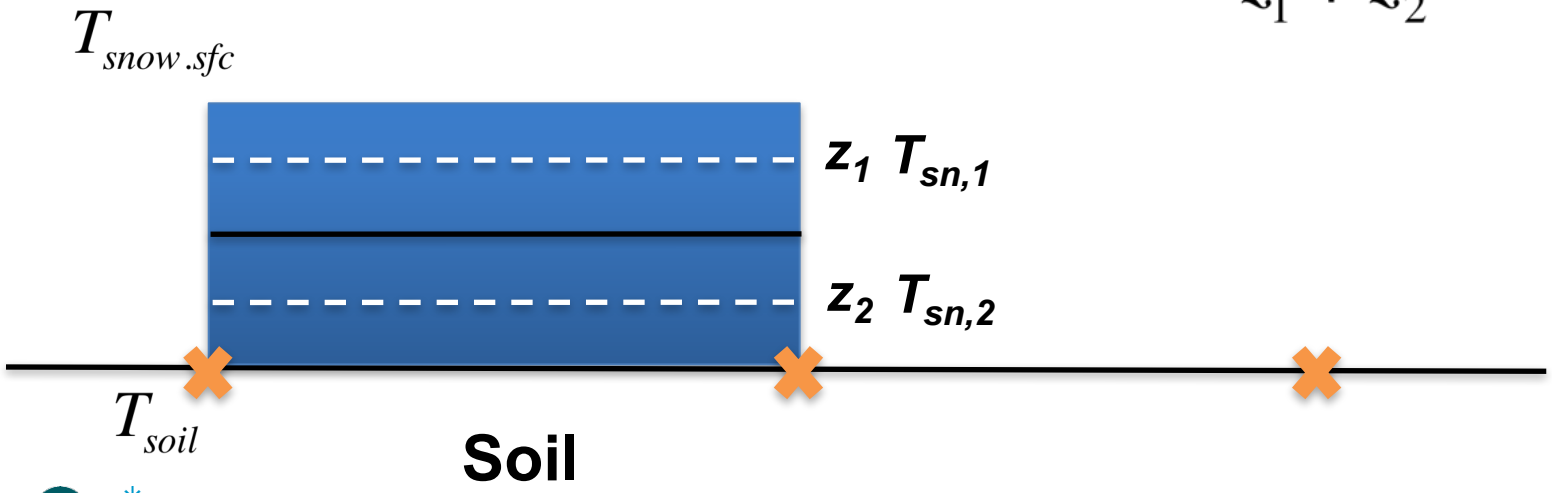
Snow density ρ_{sn}

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

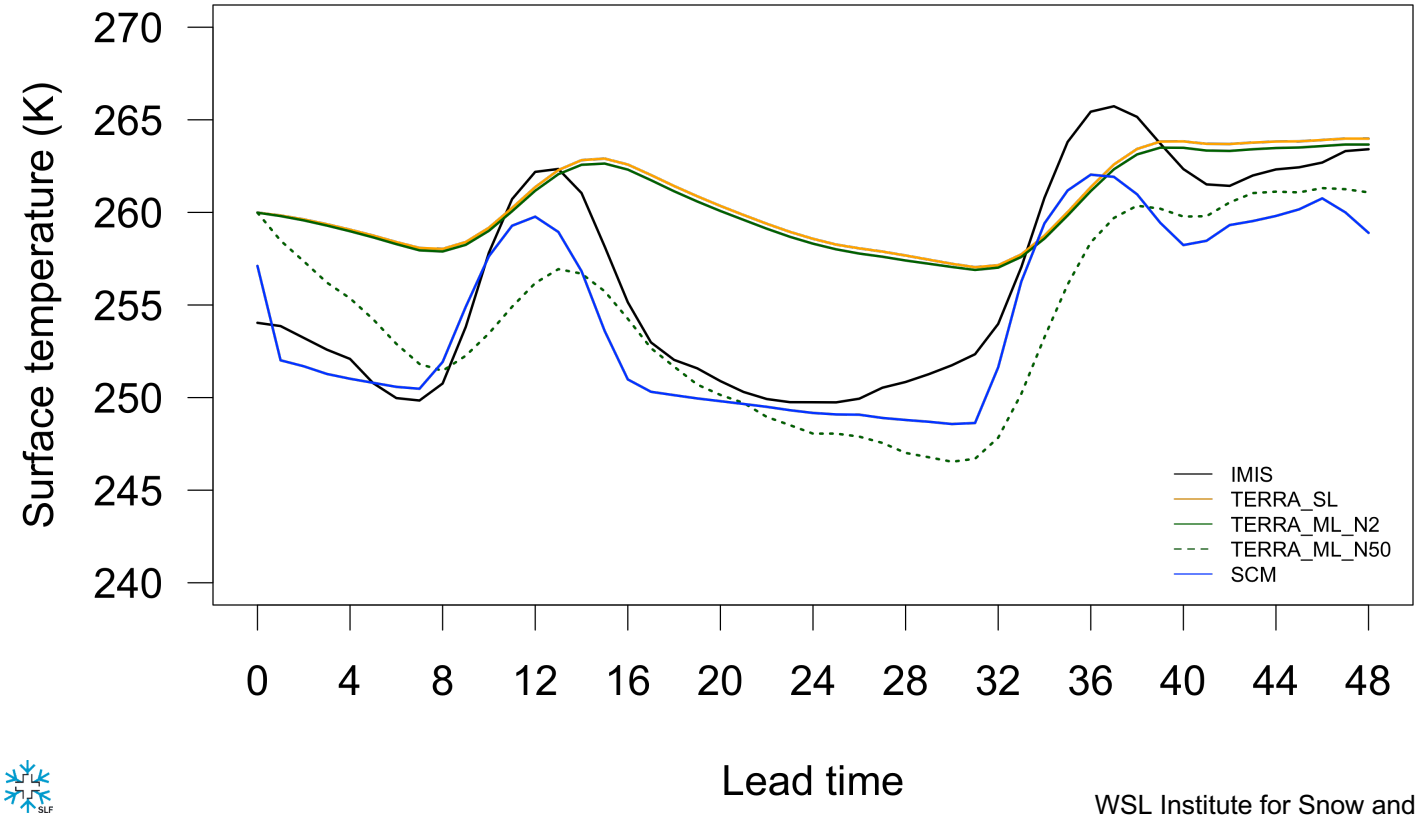
Multi-layer snow scheme: Surface Temperature

Snow surface temperature by linear extrapolation:

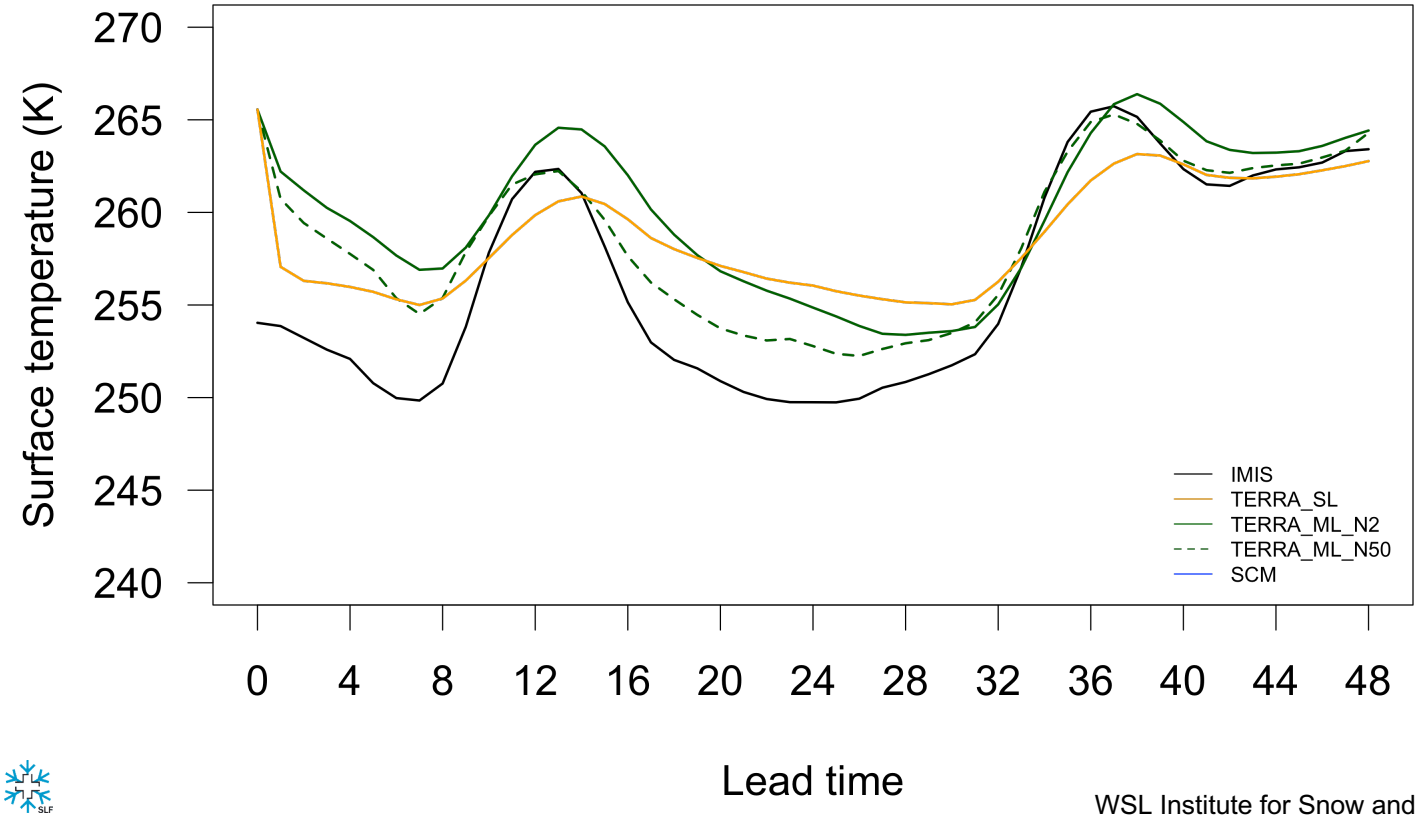
$$T_{snow,sfc} = \frac{T_1 \cdot (2z_1 + z_2) - T_2 \cdot z_2}{z_1 + z_2}$$



Sensitivity to number of layers



Snow Surface Temperature – COSMO-1(km)



Proposed COSMO Priority Task Project – SAINT

- **Phase I:** validation of current multi-layer scheme – update as needed
- **Phase II:** implementation – adjustment of currently implemented parametrizations ; radiation (albedo), turbulence , tile approach …
- **Phase III:** validation of implementation especially diagnostic parameters (e.g. T_2m)
- **Phase IV:** documentation
- **Duration: 2 years (50%), Start July 2017, End June 2019**

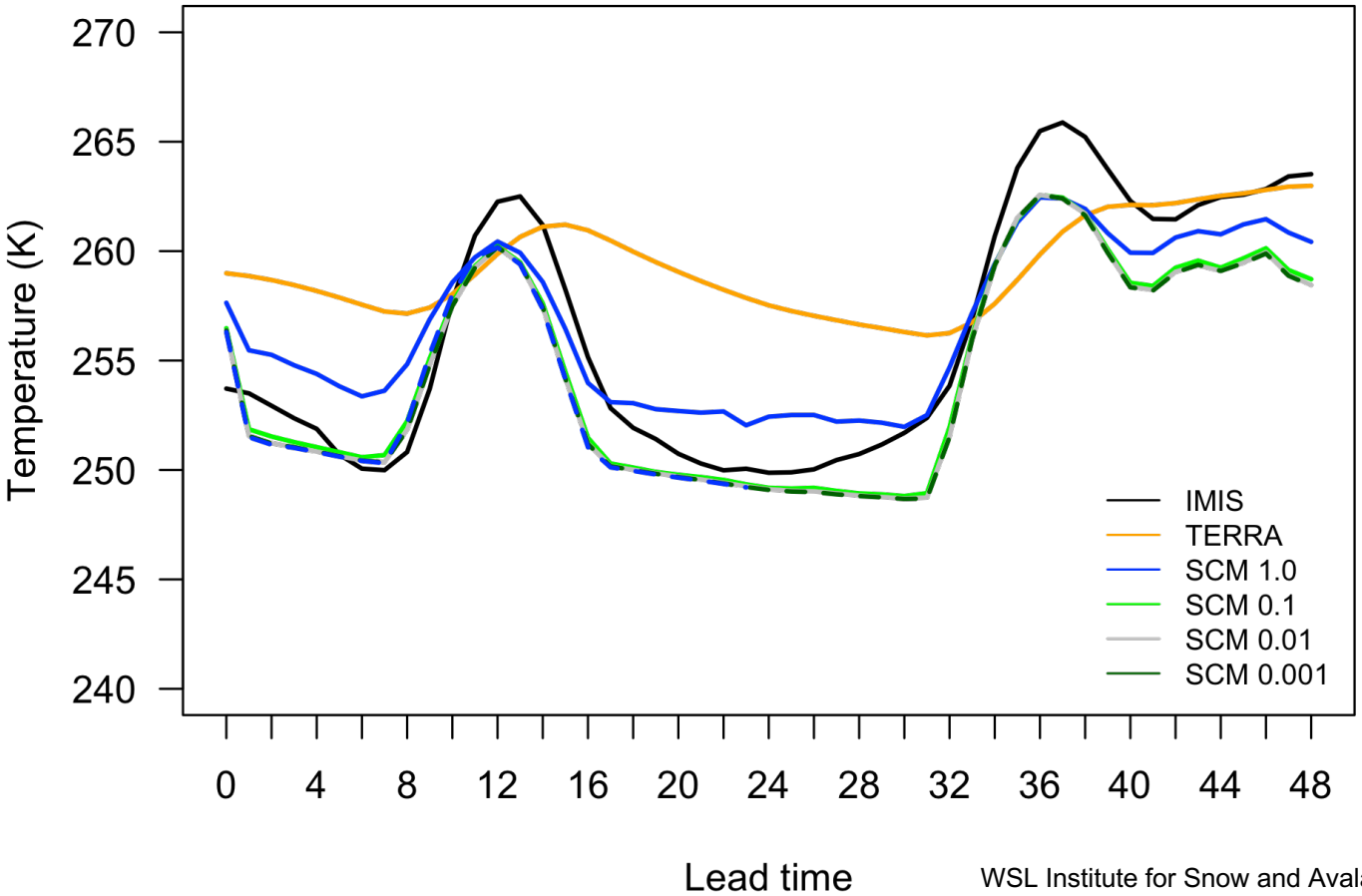


Thoughts, comments?

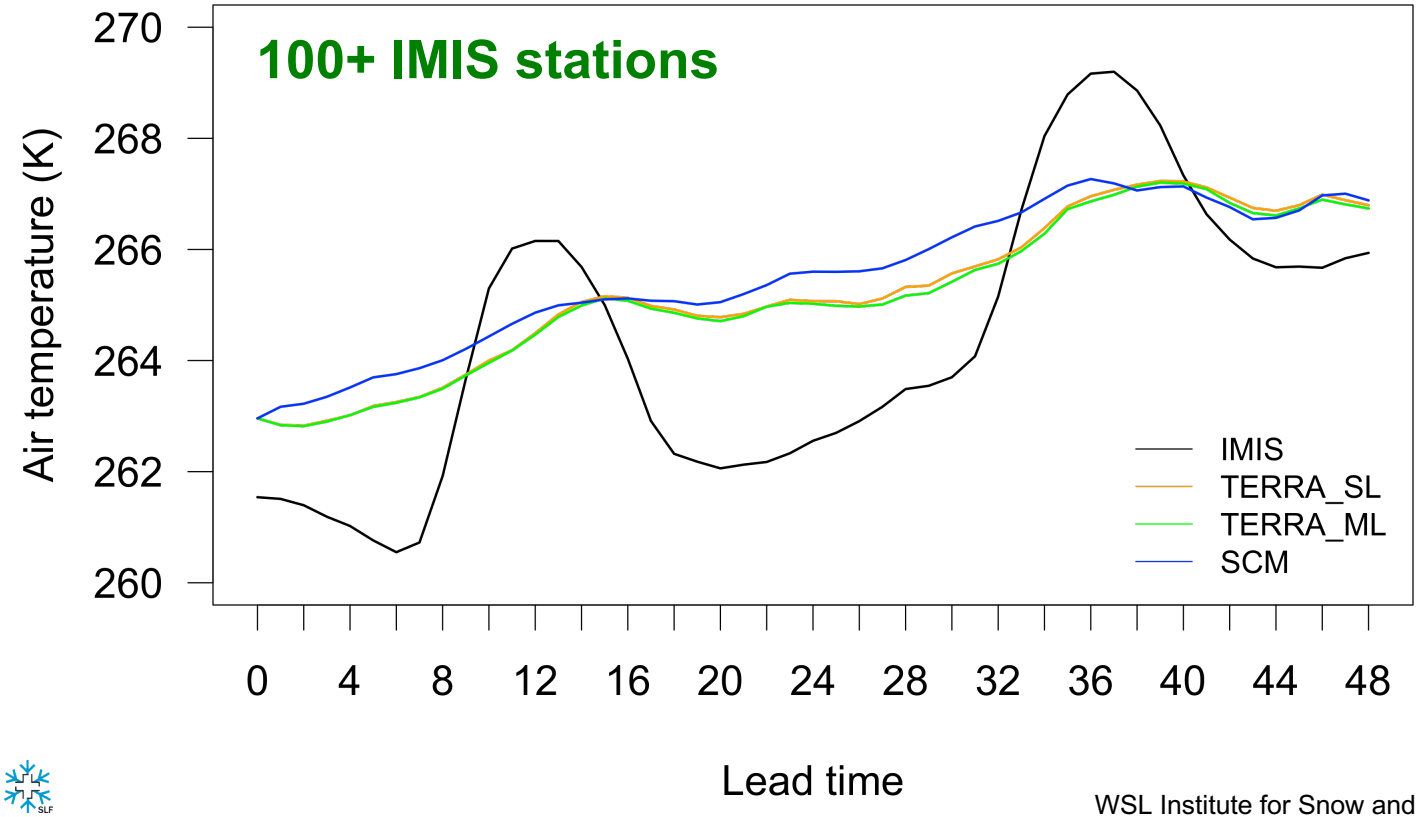
Sascha Bellaire

Jerusalem, 11.09.2017

Surface Temperature



10m air temperature



2m air temperature