Aerosols and their impact on snow albedo

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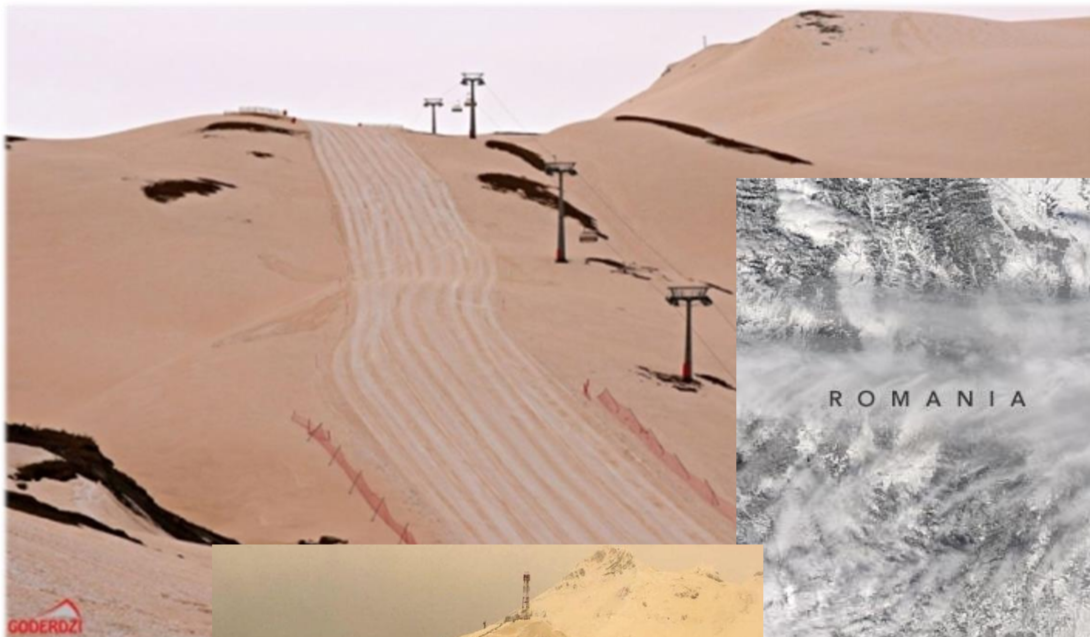
The Colors of Snow

Karlsruhe Institute of Technology



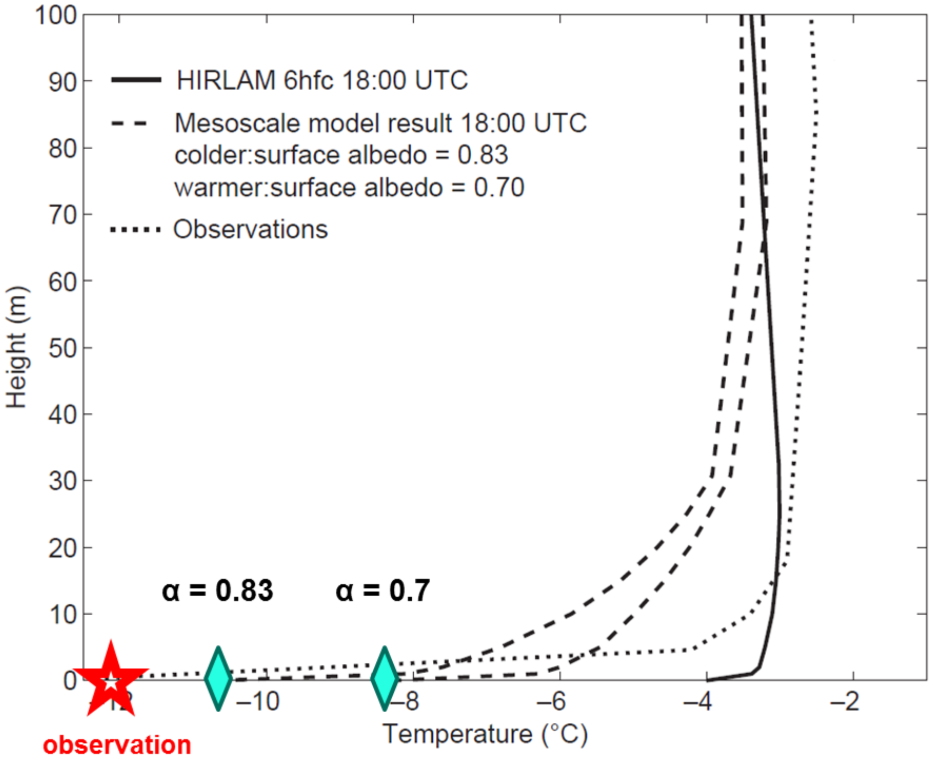
Credits: Goderdzi Resorts

Saharan Dust

Credits: NASA

Credits: BBC

High Model Sensitivity to Surface Albedo



Pirazzini et al., 2002

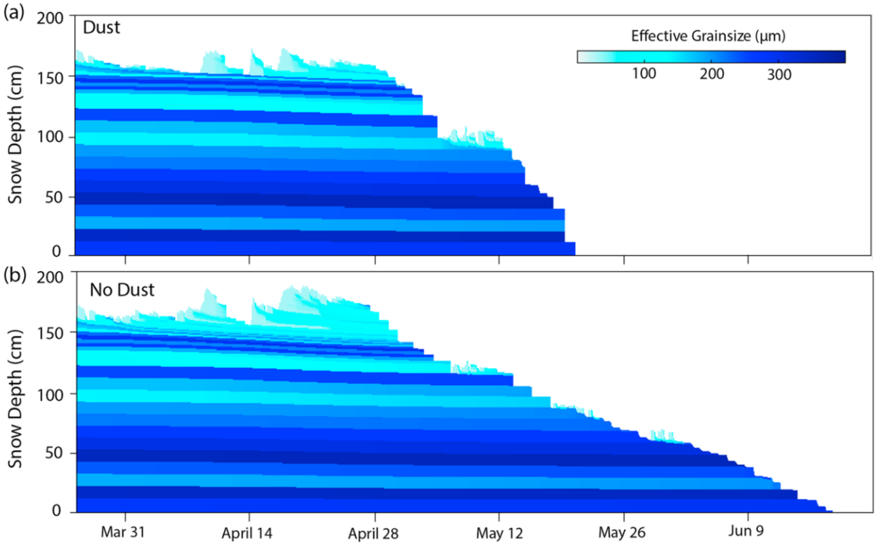
feedbacks to changes in snow albedo

→surface temperature

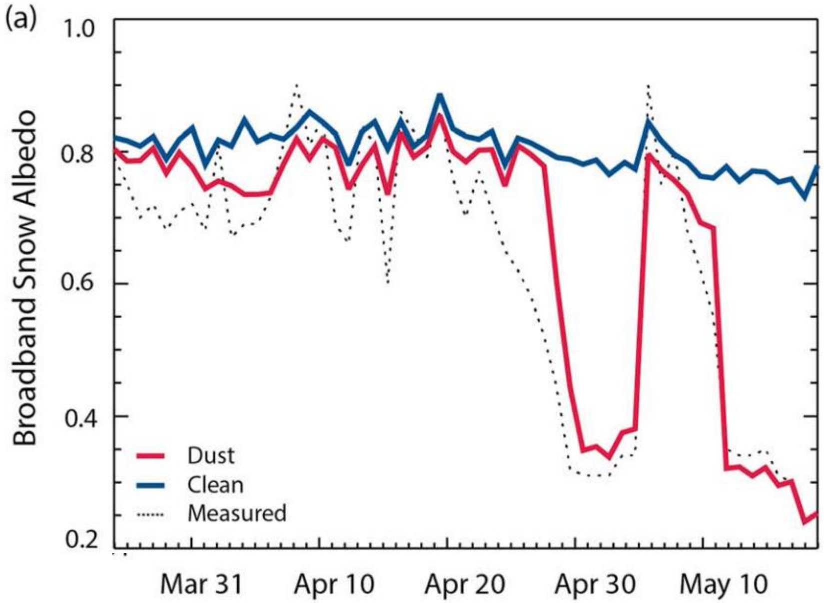
→air temperature

→snow melting / runoff

High Model Sensitivity to Surface Albedo



Painter et al., 2012



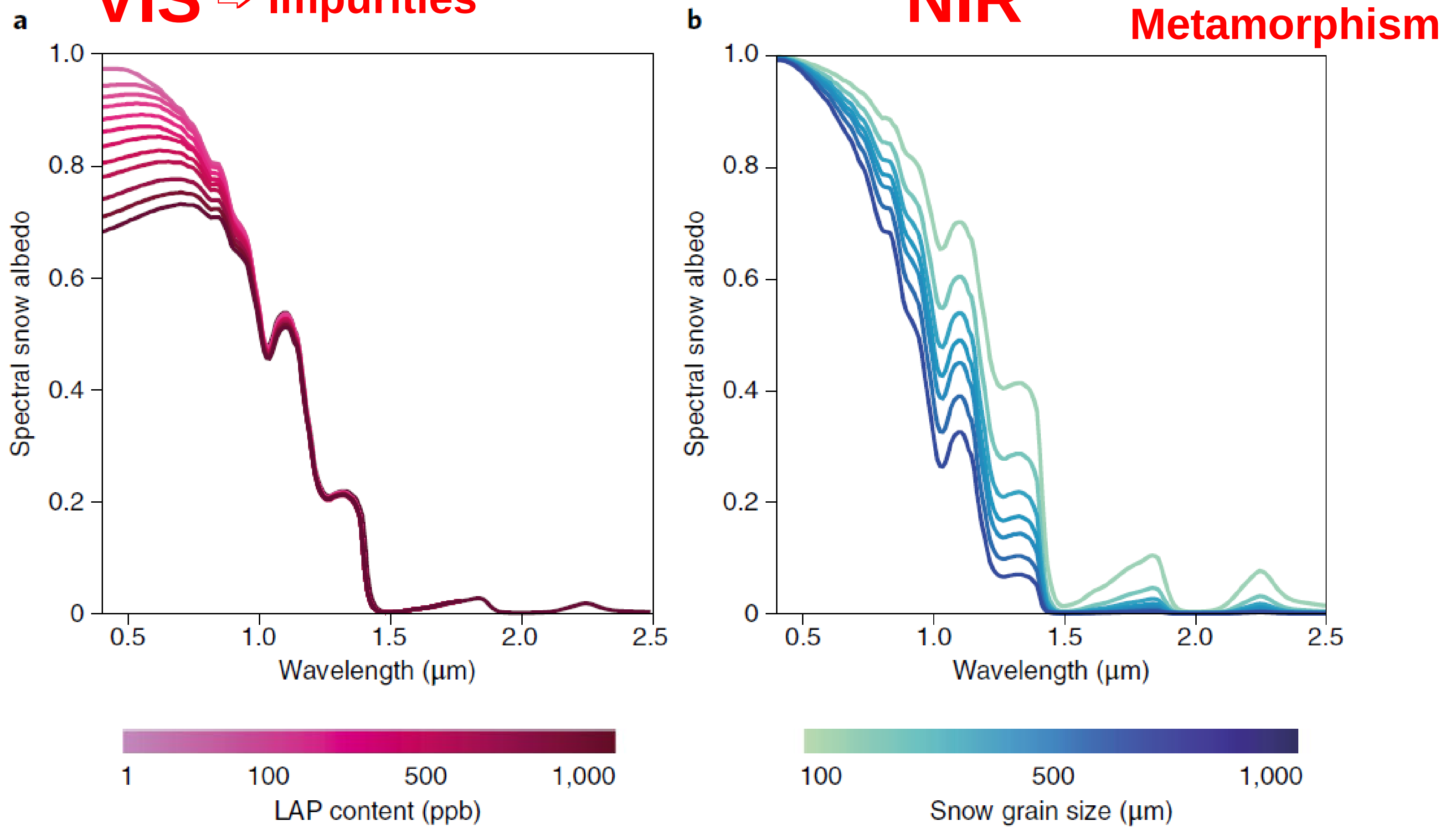
Skiles & Painter, 2019:

advanced snowmelt by 30 days!

The Snow Albedo

VIS ⇨ Impurities

NIR ⇨ Snow Metamorphism



Skiles et al., 2018

Framework: ICON-ART

The Aerosols:

- optical properties of dust (Mie coefficients)
- emission & transport
- acc. deposition

The Snow Model:

- experimental multi-layer snow model by Ekaterina Machulskaya (DWD)
- snow height, density, temperature
- simple time-dependent broadband snow albedo

Missing Features:

- **spectral information of snow albedo**
  → optical snow grain size & Mie coefficients
- **aerosol concentration in snow layers**

New Developments: Optical Grain Radius

Snow Aging (Metamorphism)

relates the scatter properties of a complex snow grain to those of a sphere of ice

$$r(t+\Delta t) = \left[r(t)^2 + \frac{G_r}{\pi}\Delta t \right]^{1/2}$$

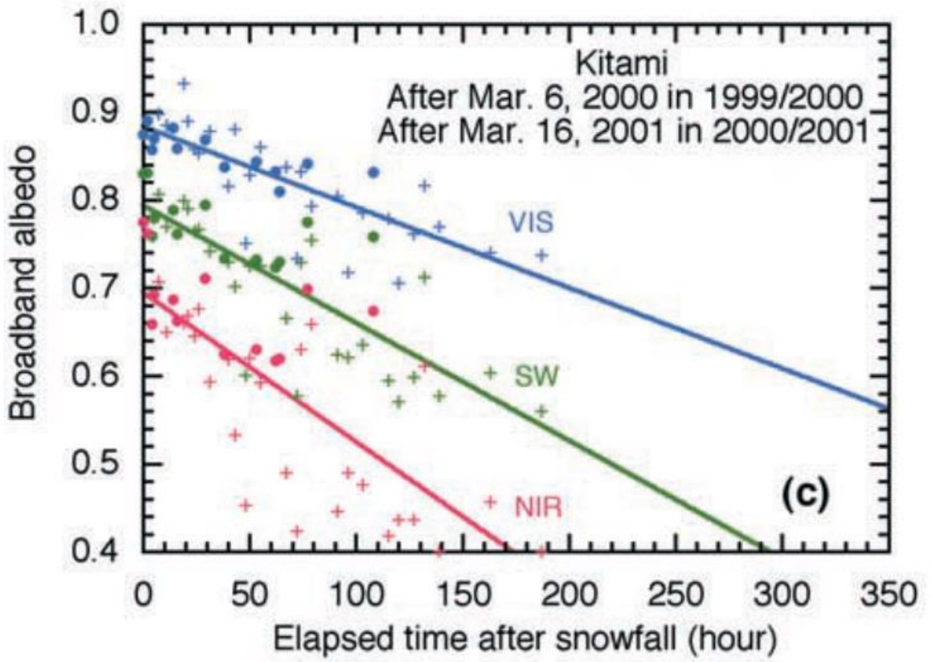
$$-[r(t) - r_0]\frac{S_f \Delta t}{d_0}$$

$$+[r_{max} - r(t)]\frac{z_{rain}\Delta t}{z_{rain,max}}$$

- growth factor
- snow fall
- rain fall

based on Essery et al., 2001

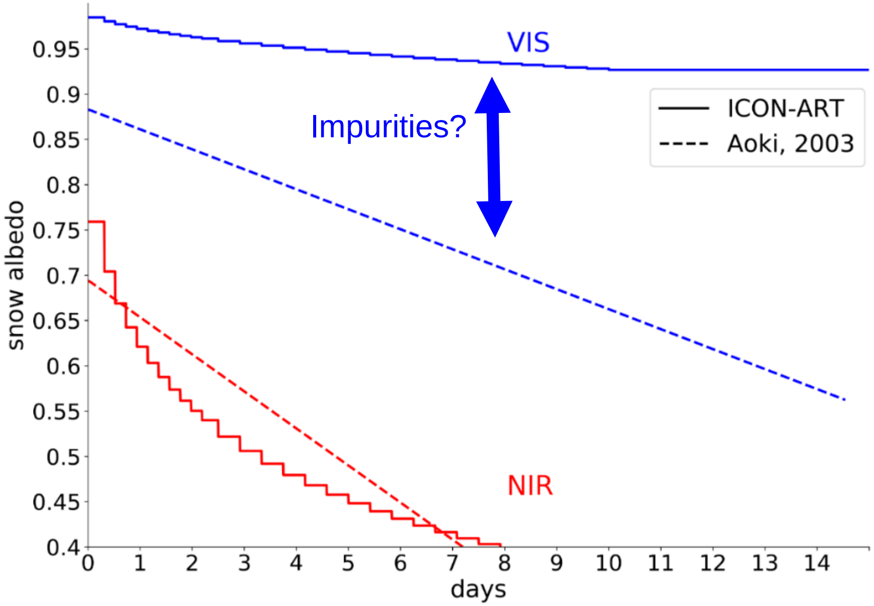
Comparison with Measurements



Aoki, 2003

Comparison with new Parametrization

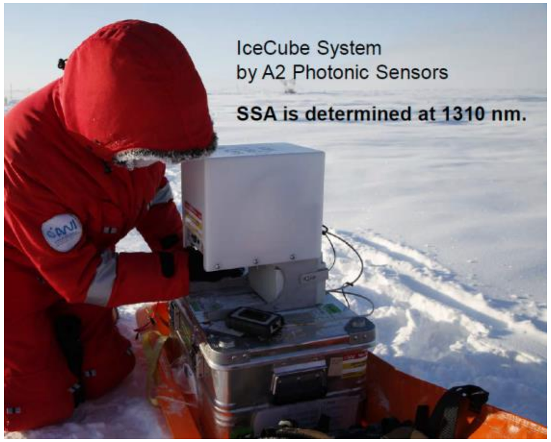
assumptions: melting snow
r_0 = 150 µm

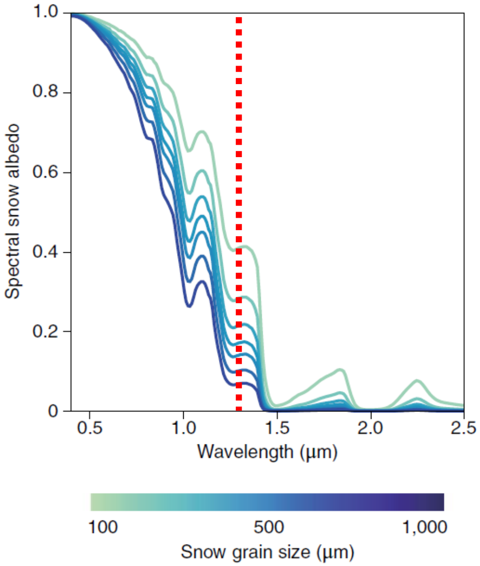


Comparison with Measurements in Greenland

PAMARCMiP campaign:

- ground measurements
- airborne measurements
- satellite data

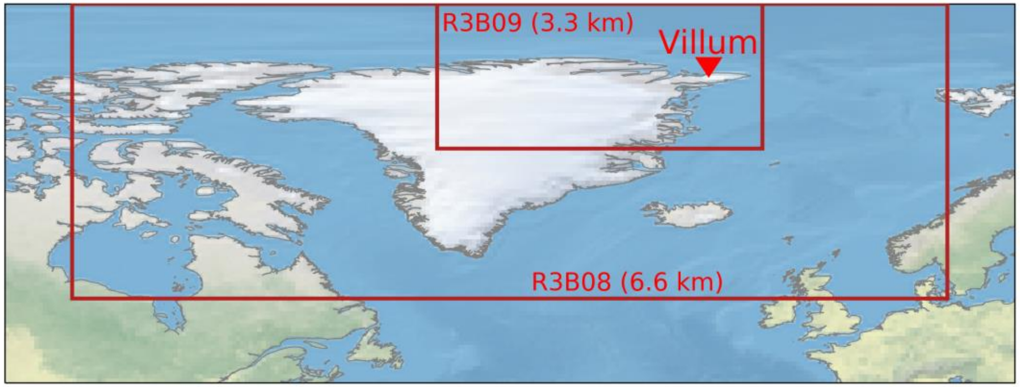




ICON-LAM Simulation

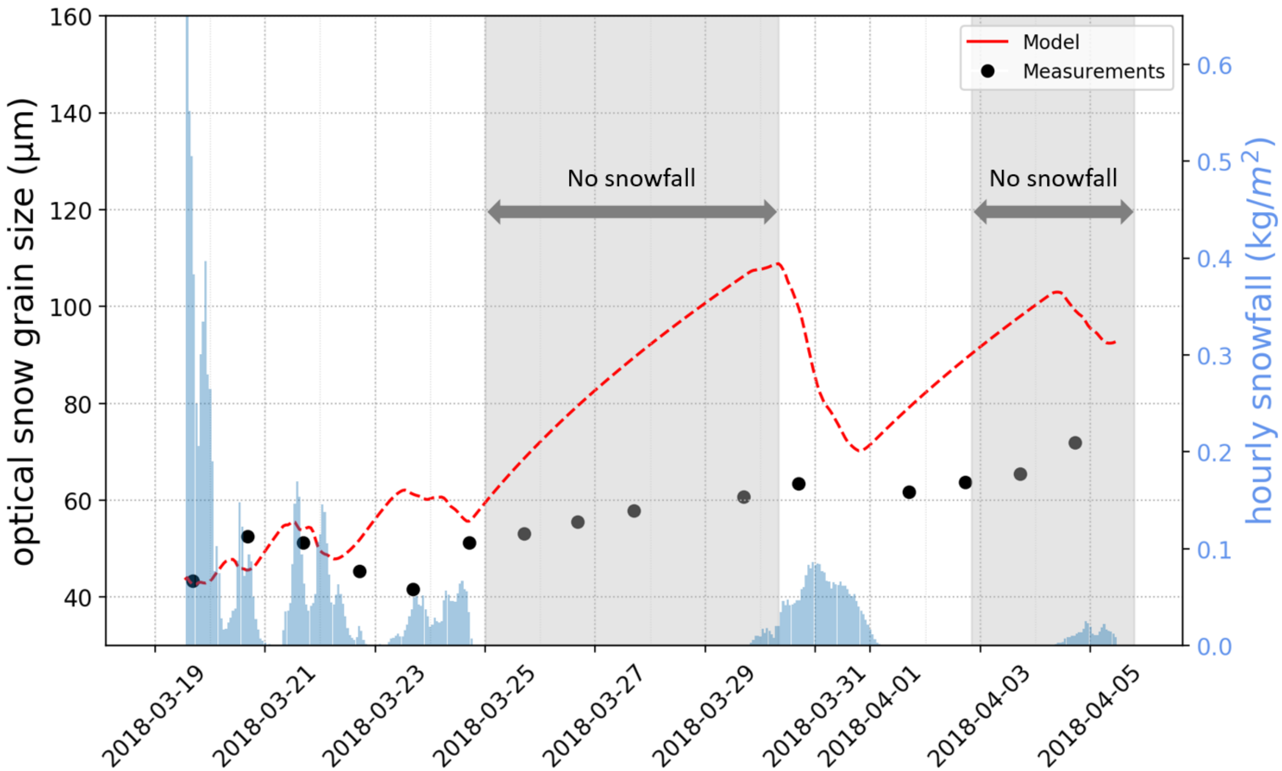
19.03.2018 – 05.04.2018

- clean snow
- boundary data: 6h IFS



Special thanks to E. Jäkel, G. Birnbaum from University of Leipzig and AWI!

New Developments: Optical Grain Radius



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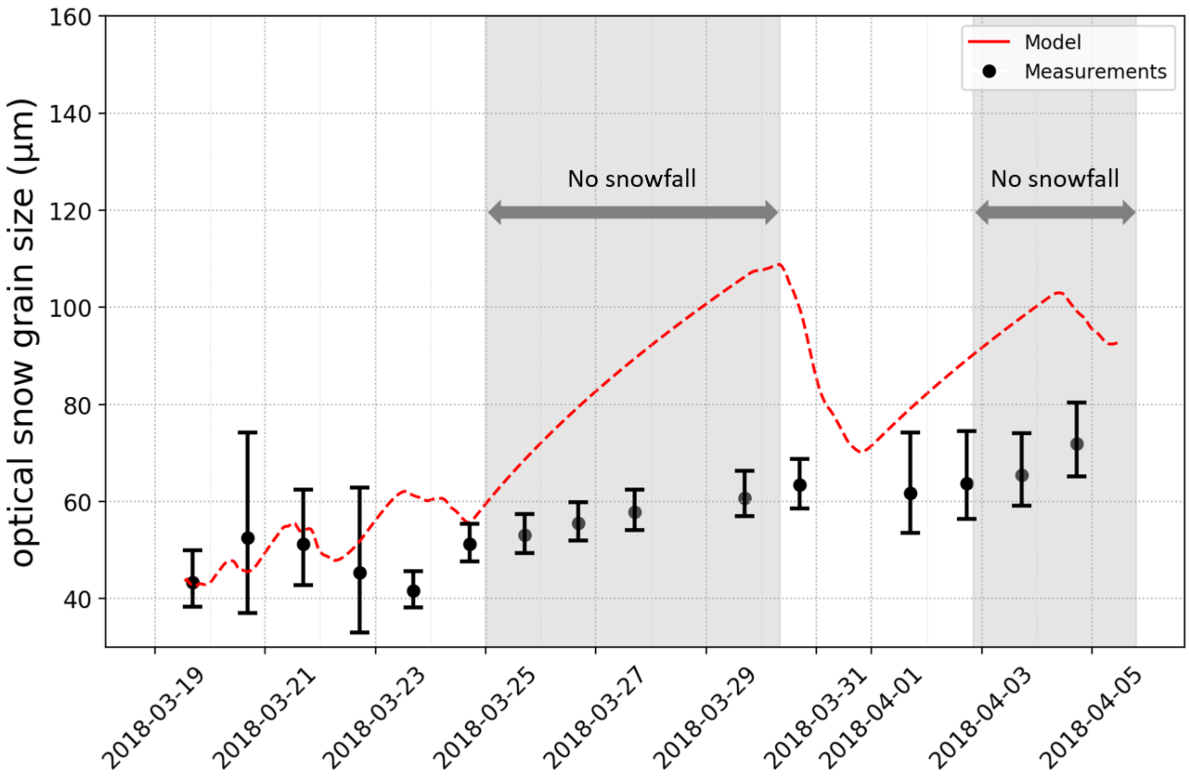

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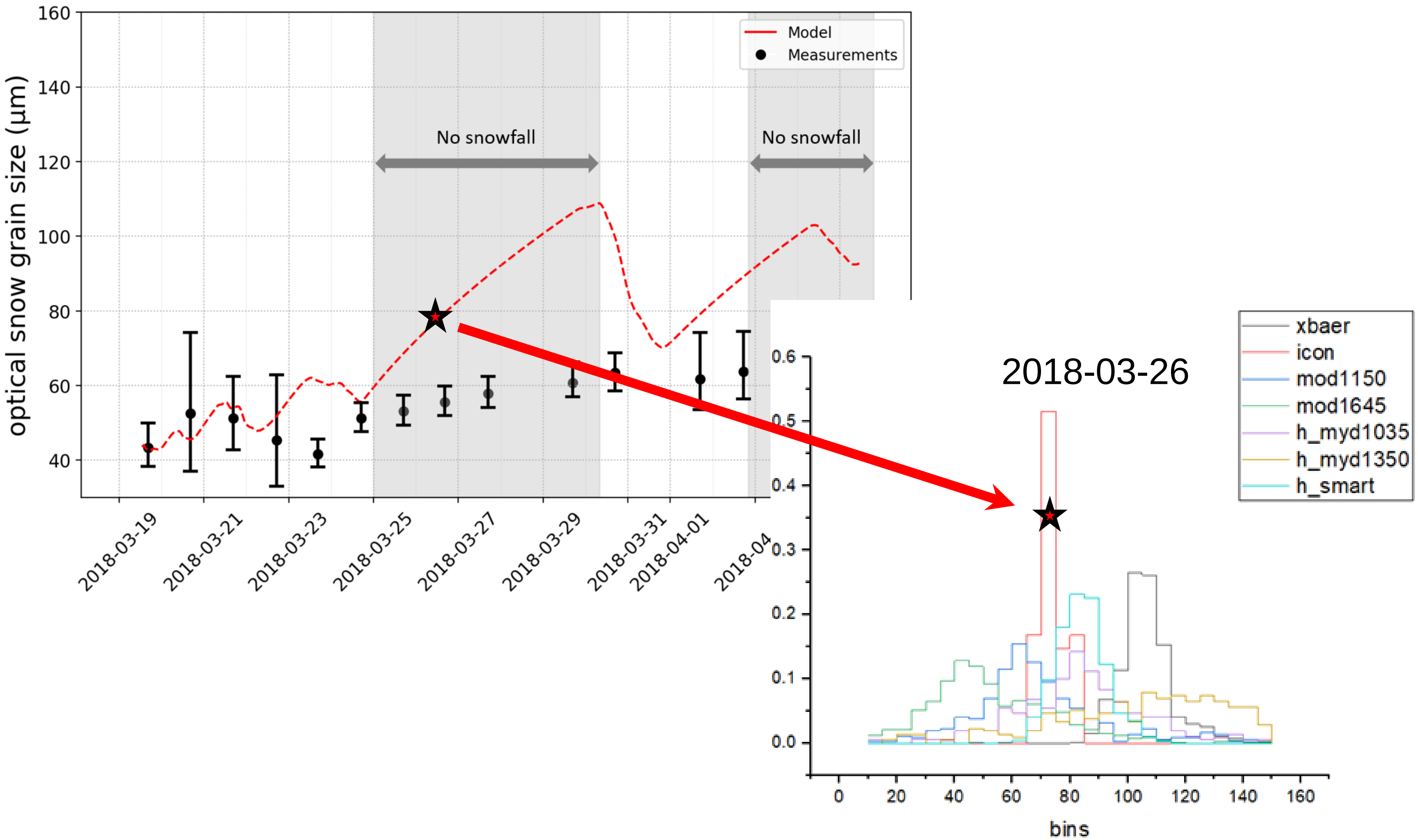

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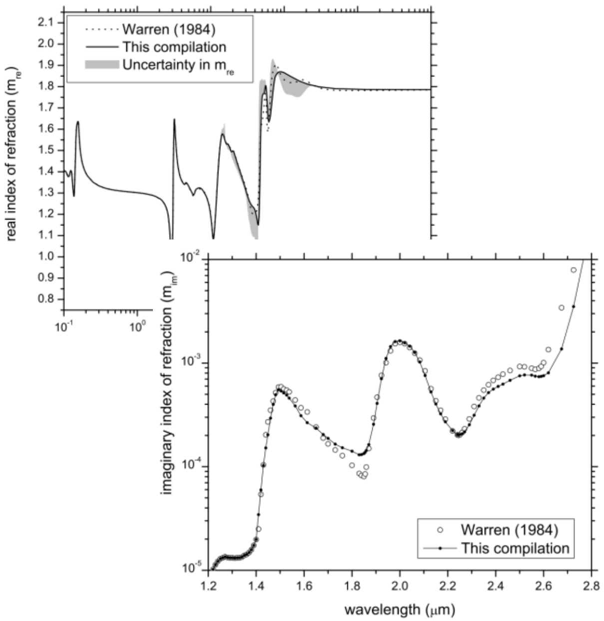
New Developments: Mie Coefficients of Ice

Refractive Index of Ice

\+ Optical Snow Grain Radius



Mie Calculations

ICON LUT:
Mie Coefficients

Warren et al., 2008

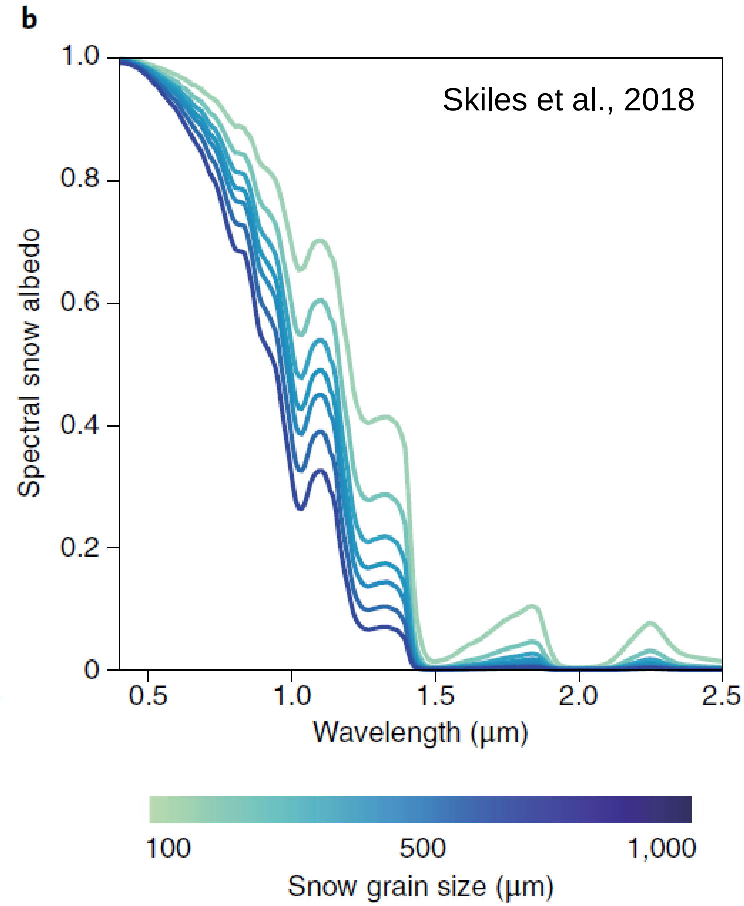
New Developments: Spectral Snow Albedo

Spectral Snow Albedo (diffuse, semi-infinite)
Wiscombe & Warren, 1980:

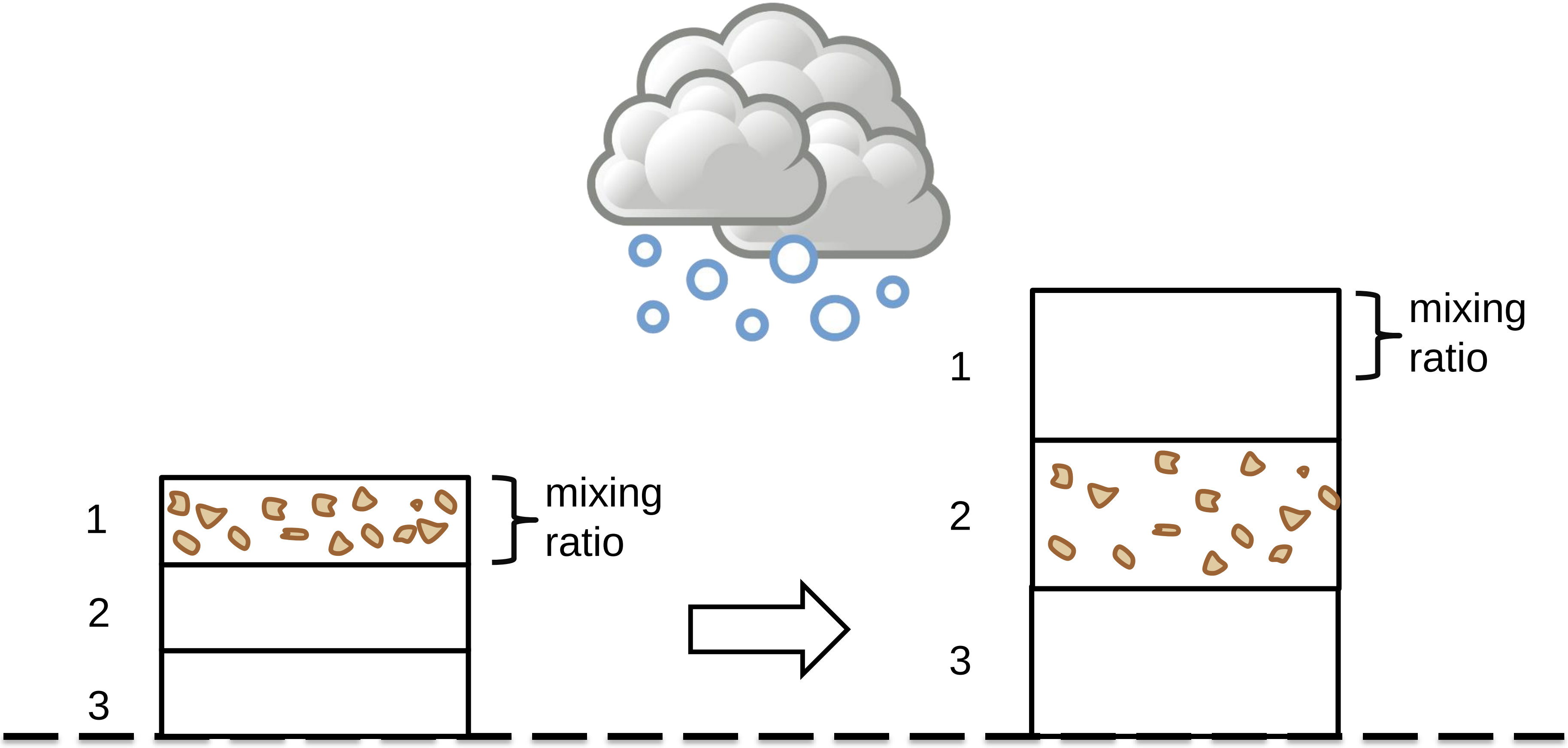
$$a_d^\infty = \frac{2\,\tilde{\omega}^*}{1+P}\left\{\frac{1+b^*}{\xi^2}\left[\xi - \ln(1+\xi)\right] - {b^*}/{2}\right\}$$

Spectral Albedo (optically thin)

$$Qa_d = 2P\left[(1-\gamma+\bar{\omega}^*b^*)(1-\tau_0^*) - \frac{\gamma\bar{\omega}^*(1+b^*)}{1-\bar{\omega}^*}\right]\exp(-\tau_0^*) - 2P\left[\bar{\omega}^*(1+b^*)\left(\frac{2}{\xi^2}+\frac{\gamma\tau_0^*}{1-\bar{\omega}^*}\right)\right.$$
$$\left. + (1-\gamma+\bar{\omega}^*b^*)\tau_0^{*2}\right]\mathrm{Ei}(-\tau_0^*) + \frac{2\bar{\omega}^*(1+b^*)}{\xi^2}\left[Q^+\{\mathrm{Ei}[-(1+\xi)\tau_0^*] + \xi - \ln(1+\xi)\}\right.$$
$$\left. - Q^-\{\mathrm{Ei}[-(1-\xi)\tau_0^*] - \xi - \ln|1-\xi|\}\right] - \bar{\omega}^*b^*(Q^+ - Q^-),$$



New Developments:
Shifting of Aerosols in Snow



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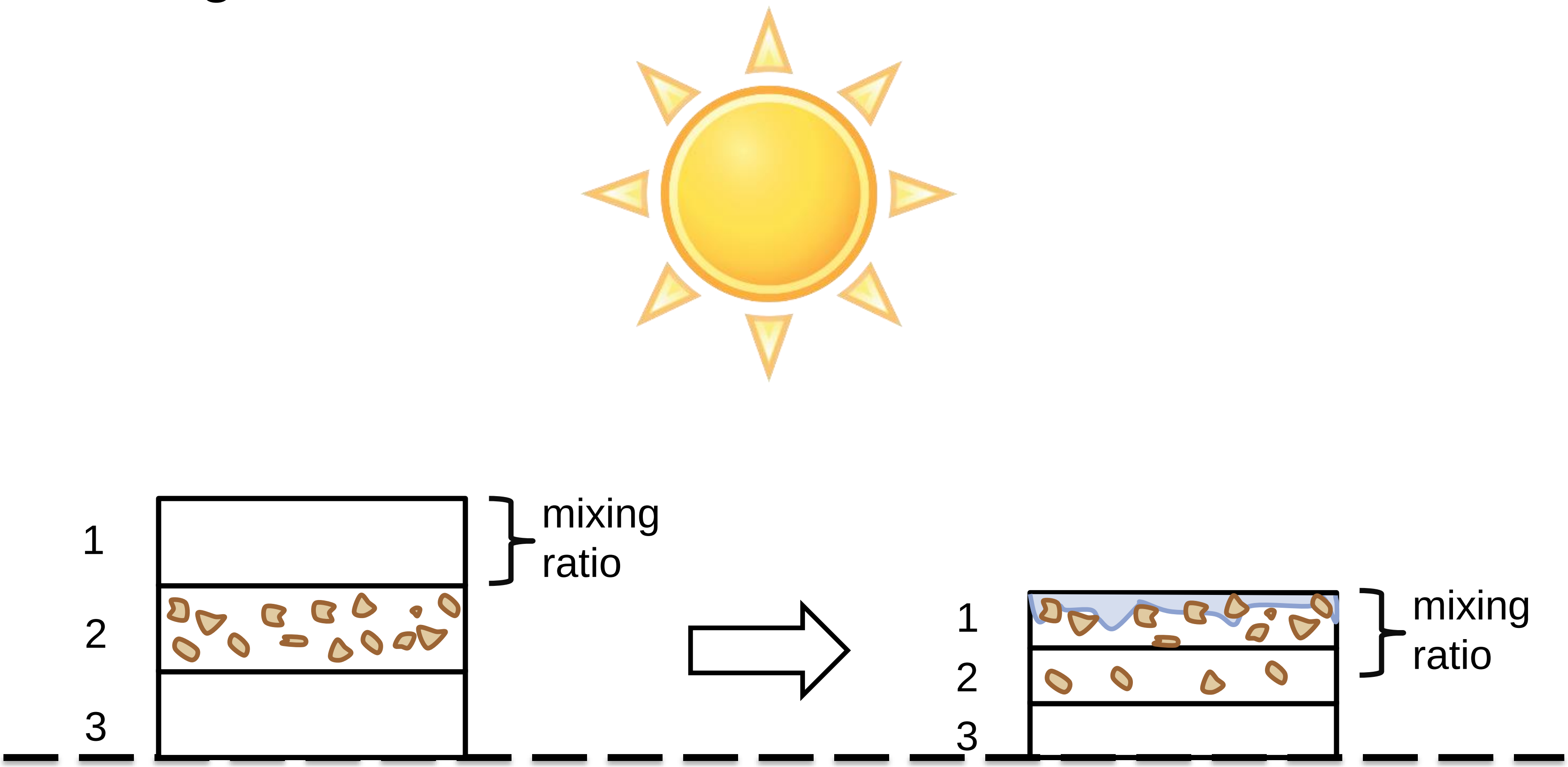

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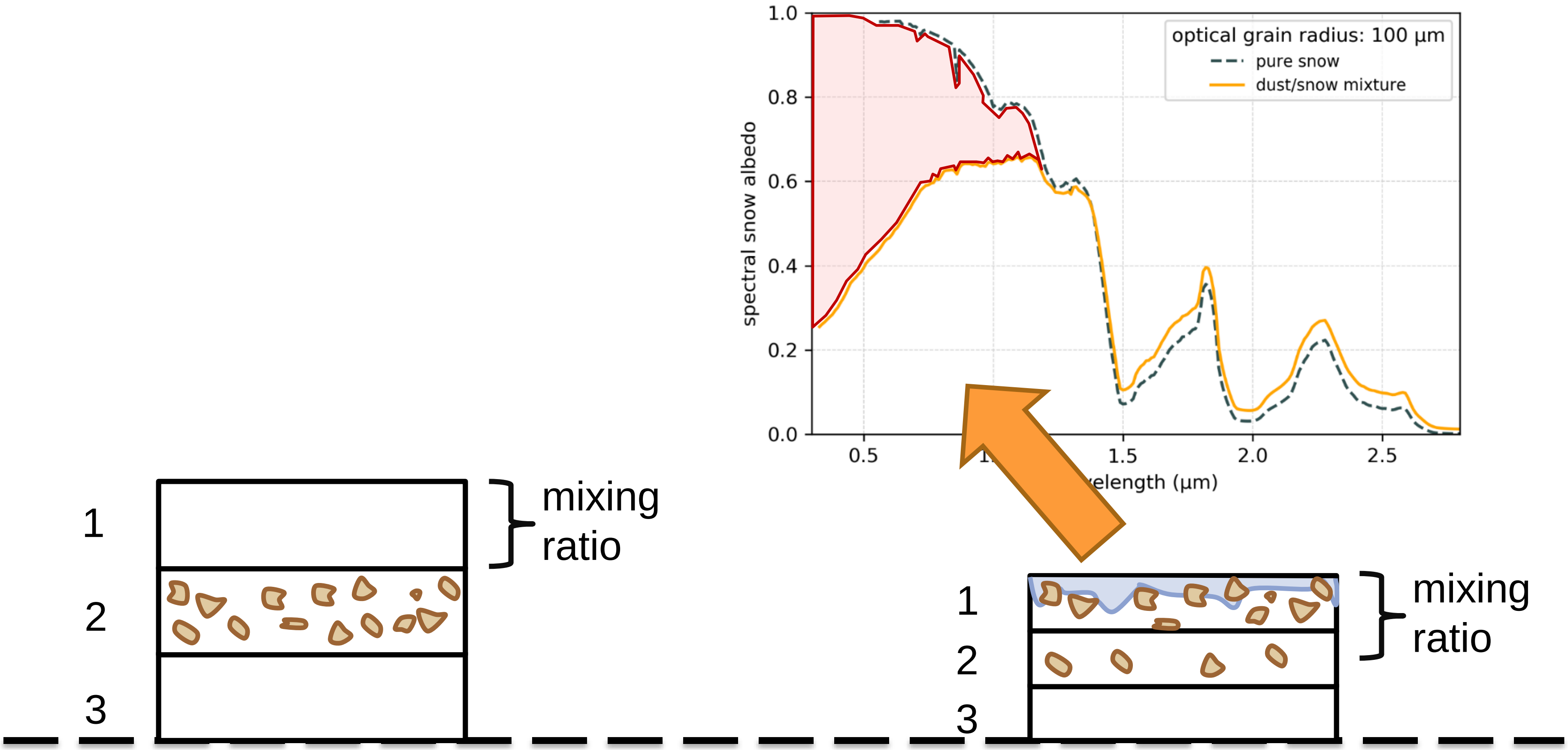
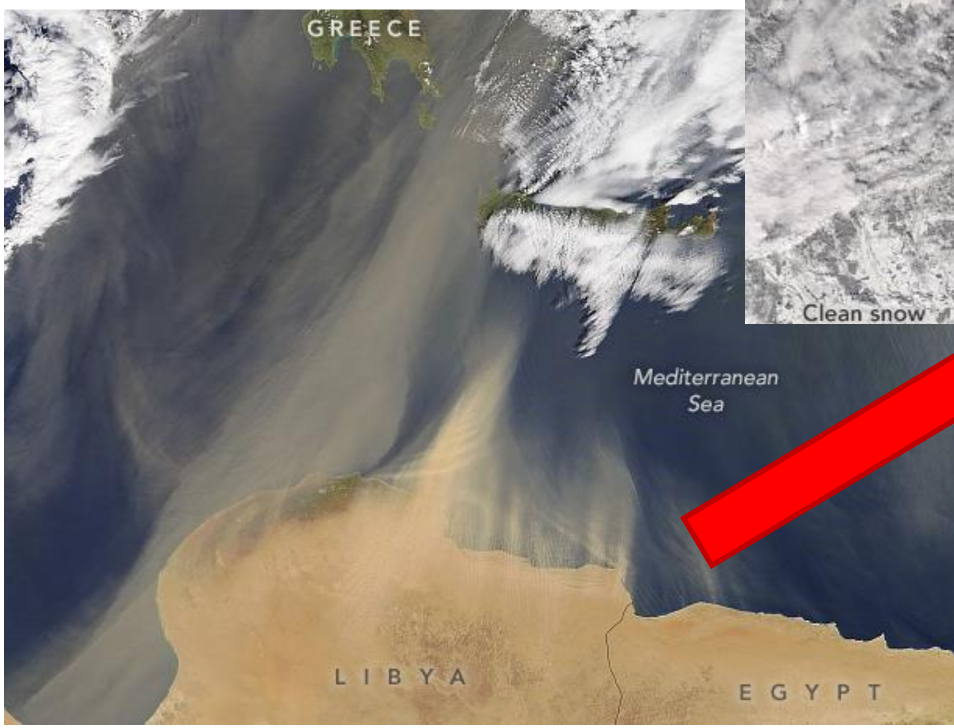


average of Mie coefficients: cross-sectional areas per unit volume as weight factors

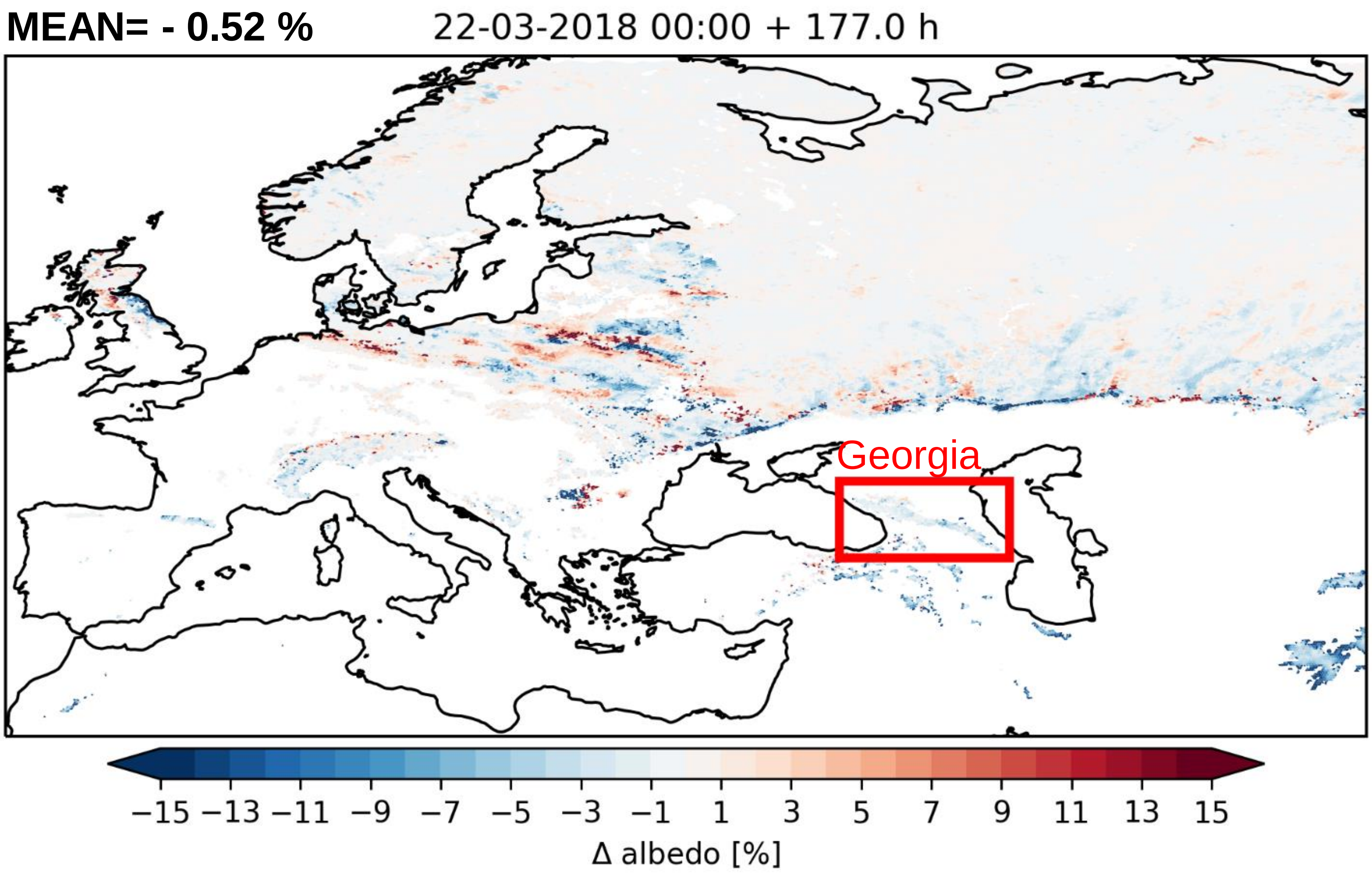
Dust Event March 2018

ICON LAM Simulation
- R2B08: ~ 10 km
- 15 days

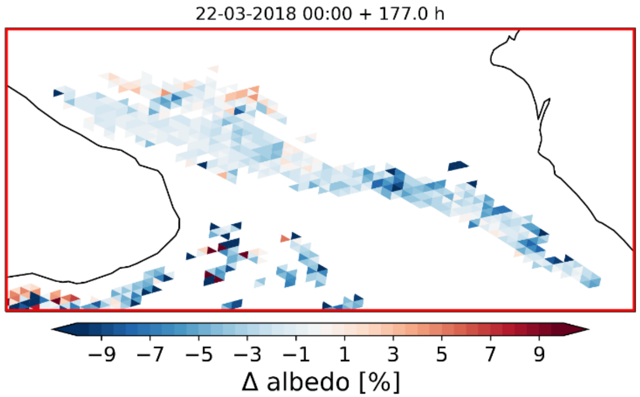


Initial state: IFS data
Boundary: R2B06 ICON data

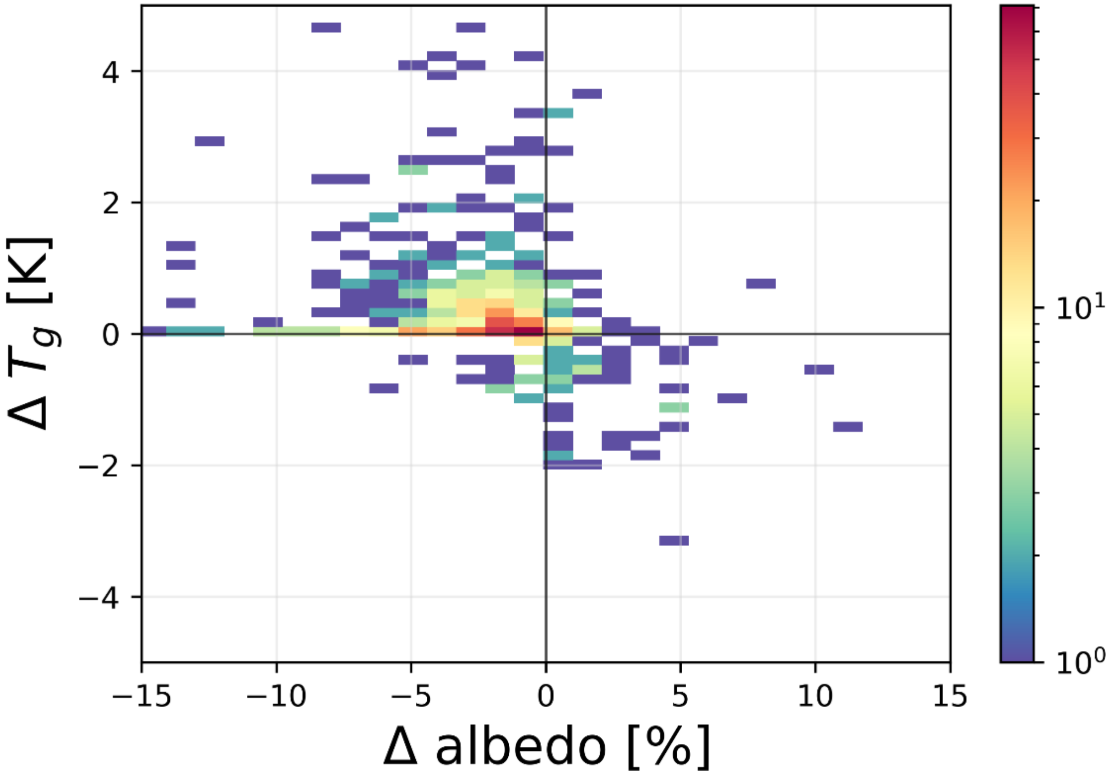
Dust Event March 2018



Dust Event March 2018



Georgia



Δ albedo

Mean = - 2.57 %

Min = - 60.38 %
Max = 47.30 %

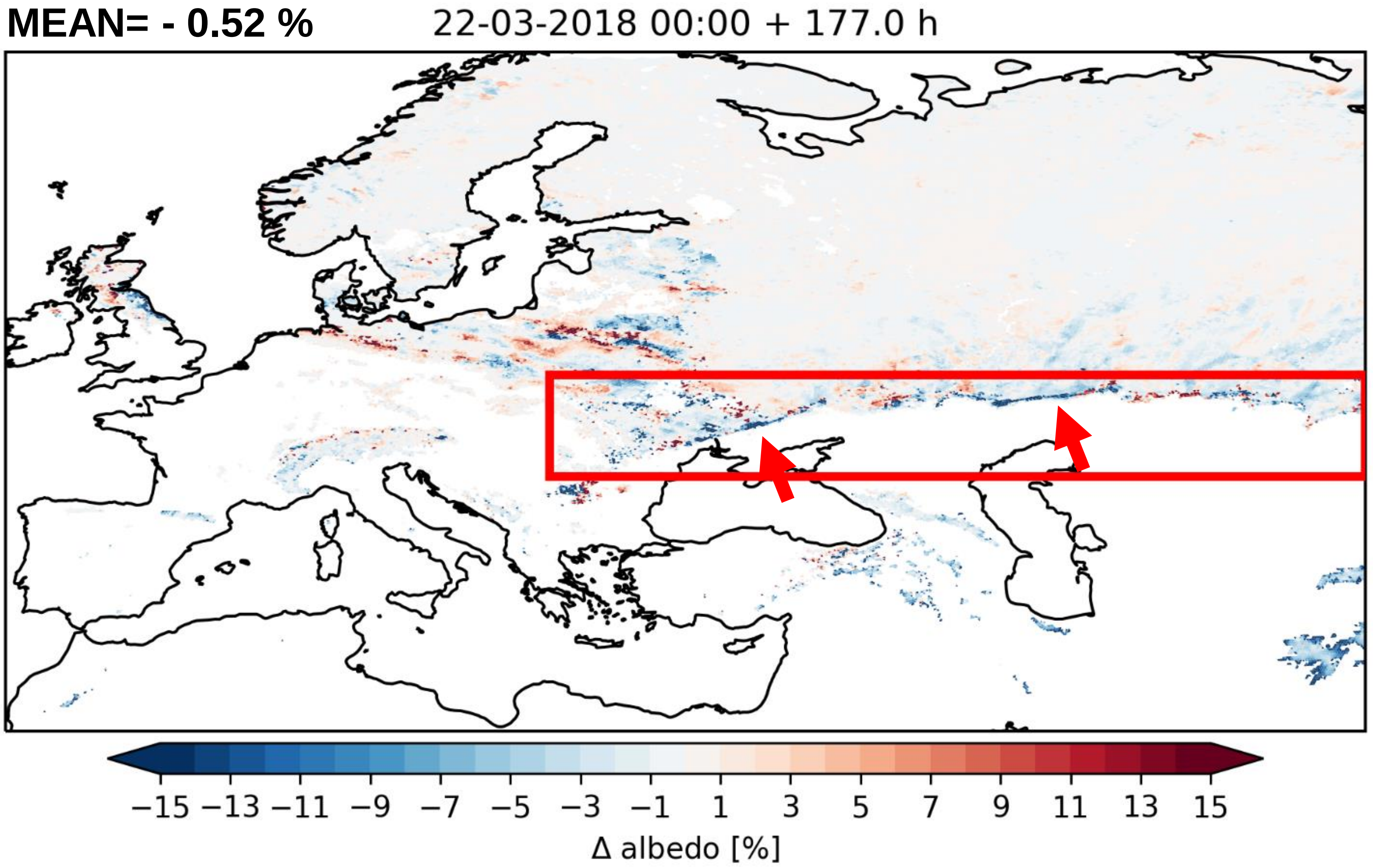
Δ T_g

Mean = 0.37 K

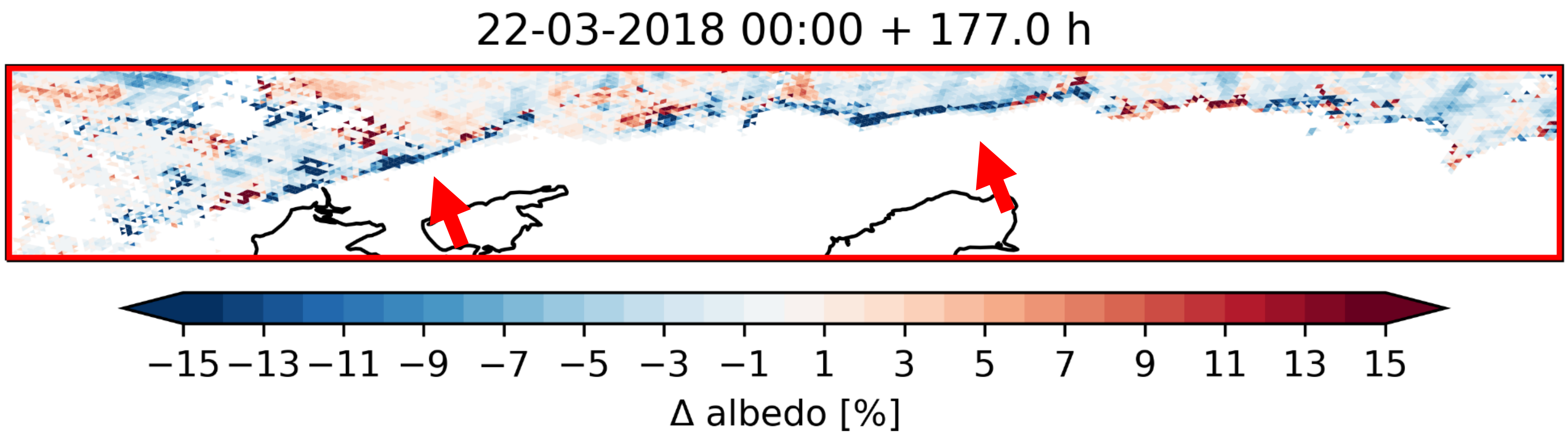
Min = - 6.26 K
Max = 8.21 K

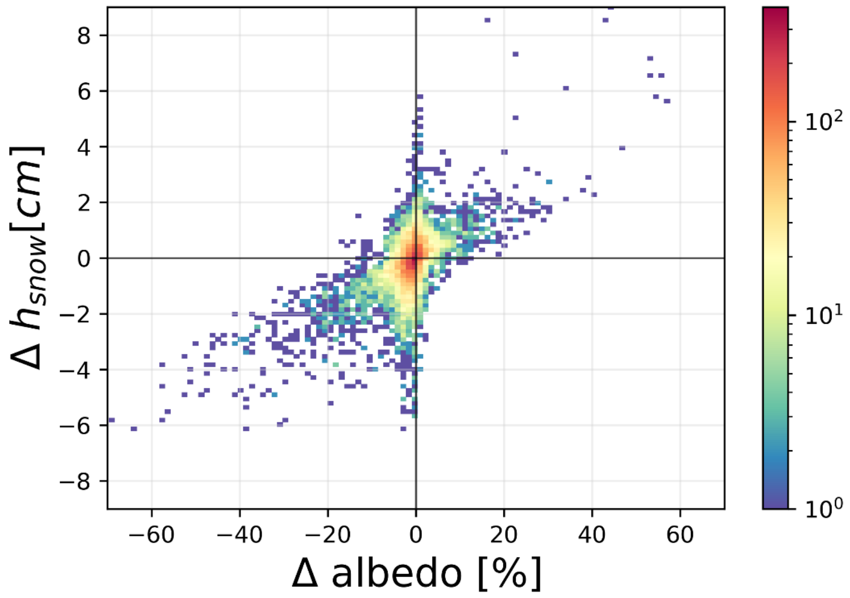
Dust Event March 2018

MEAN= - 0.52 %



Dust Event March 2018



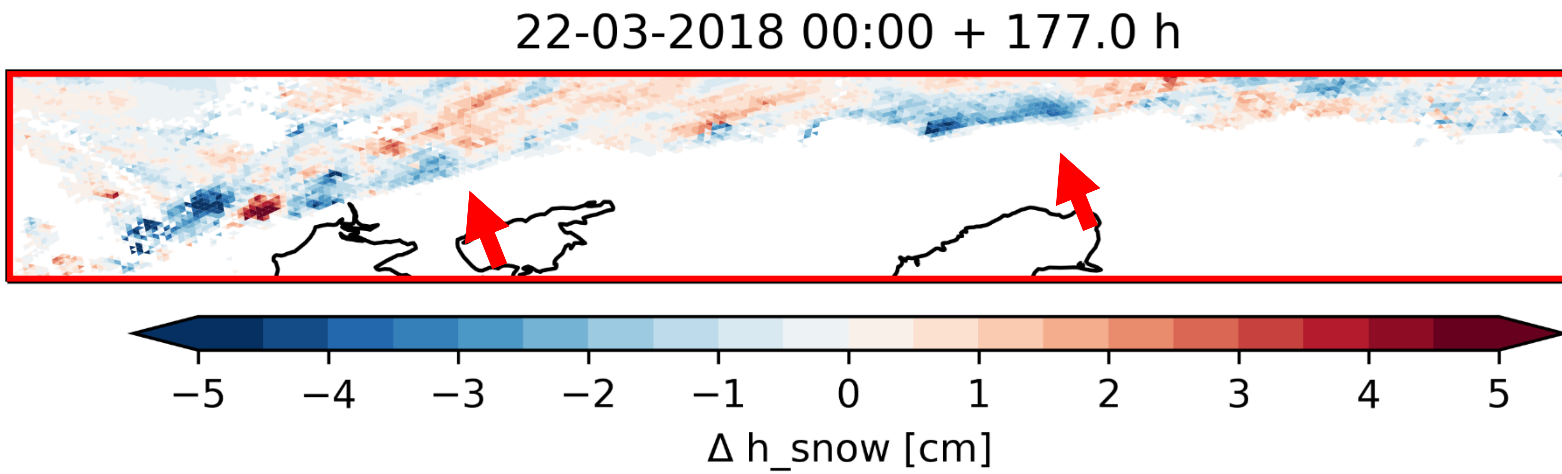


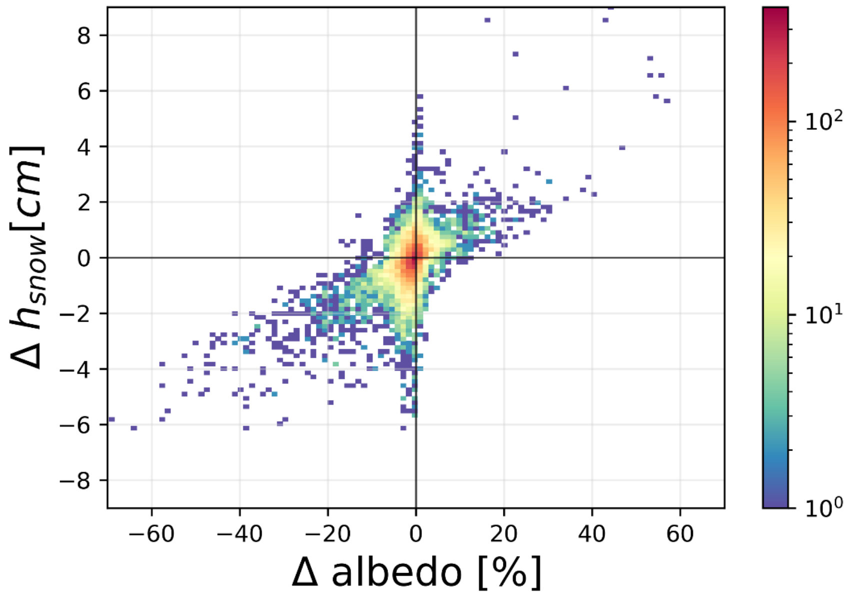
Δ albedo

Mean = - 1.45 %

Min = - 69.68 %
Max = 57.65 %

Dust Event March 2018





Δ albedo

Mean = - 1.45 %

Min = - 69.68 %
Max = 57.65 %

Δ h_snow

Mean = - 2.13 mm

Min = - 62.00 mm
Max = 90.72 mm

Summary

New Developments

- optical equivalent snow grain size & aging
- new spectral snow albedo
  → thick & thin snow layer
- shifting of aerosol between snow layers
- online aerosol snow interactions (optical properties)

Simulations

Greenland → grain size meets the average of the different measurement techniques

Dust Event 2018 (after 7 days)

Greater Caucasus Mountain: → $\Delta\alpha$ = - 2.57 %

at snow line: → $\Delta\alpha$ = - 1.45 %
→ Δh_{snow} = - 2.13 mm