Snow melt enhancement by deposition of black carbon and dust: Insight from a new global-scale land surface model

Enrico Zorzetto[1,2], Paul Ginoux[3], Sergey Malyshev[3], Elena Shevliakova[3]

(1) New Mexico Tech, EES & Hantush-Deju Center for Hydrologic Innovation

(2) Princeton University, Oceanic and Atmospheric Science program

(3) NOAA Geophysical Fluid Dynamics Laboratory

NASA's High Mountain Asia Team 2
Collaborative research to study water and cryosphere changes in High Mountain Asia.

NOAA AOR GFDL
3D land-energy exchanges

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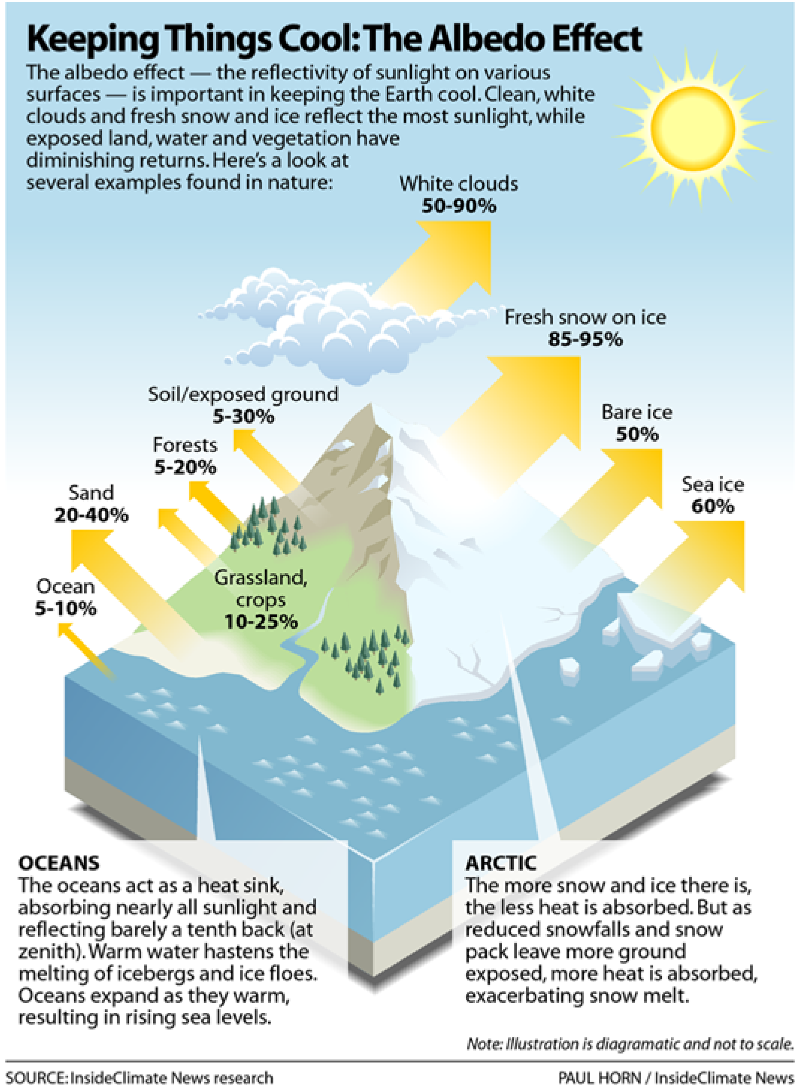
Cryosphere plays a primary role in climate and hydrology



Source: insideclimatenews.org/infographics

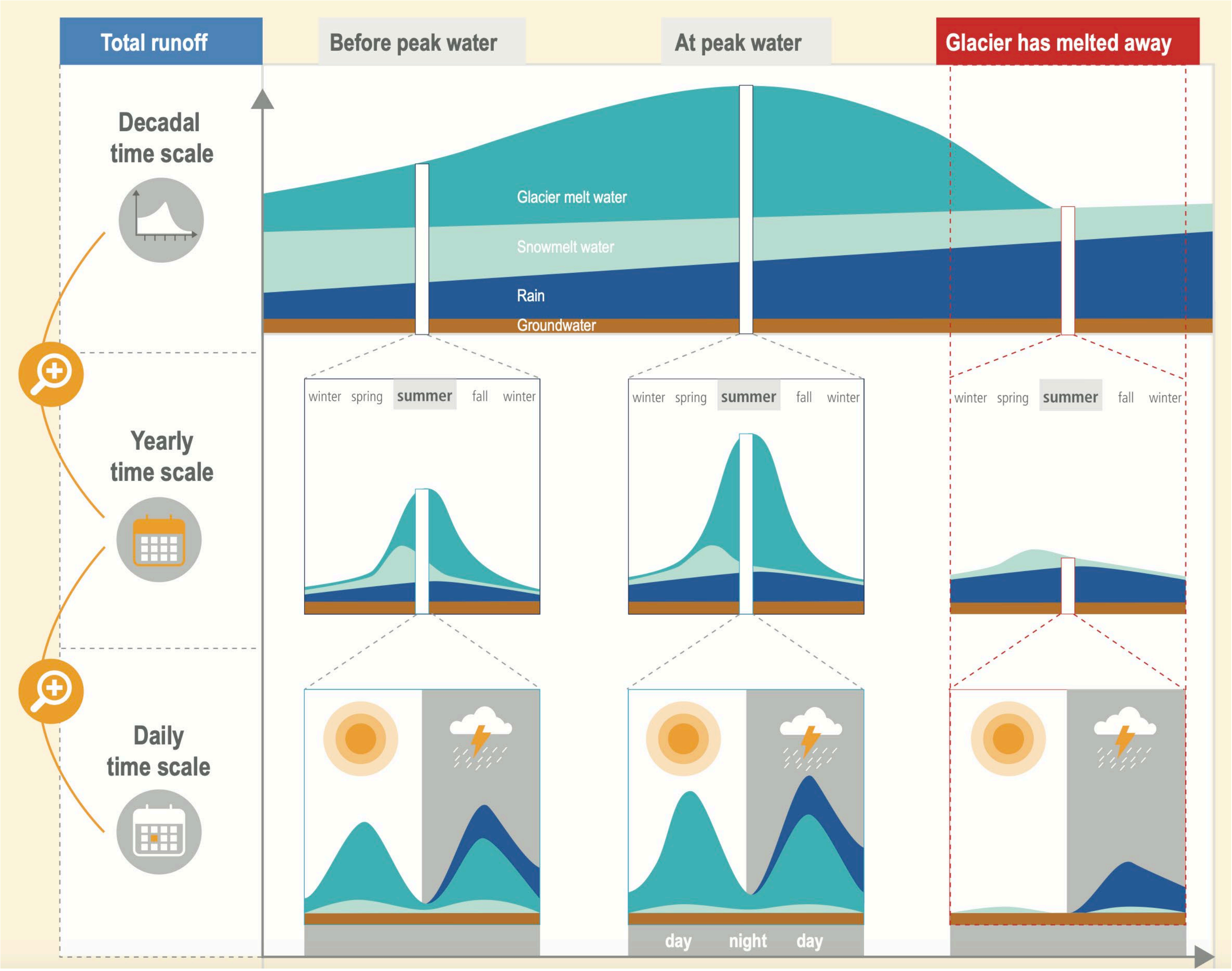
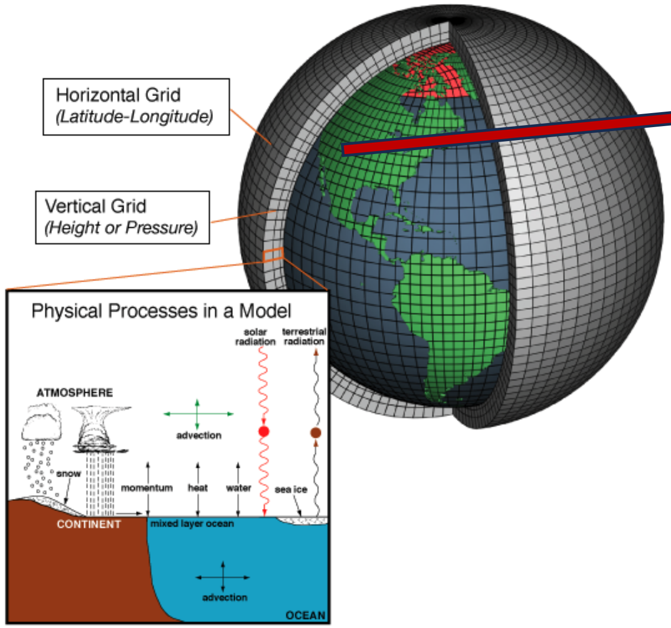


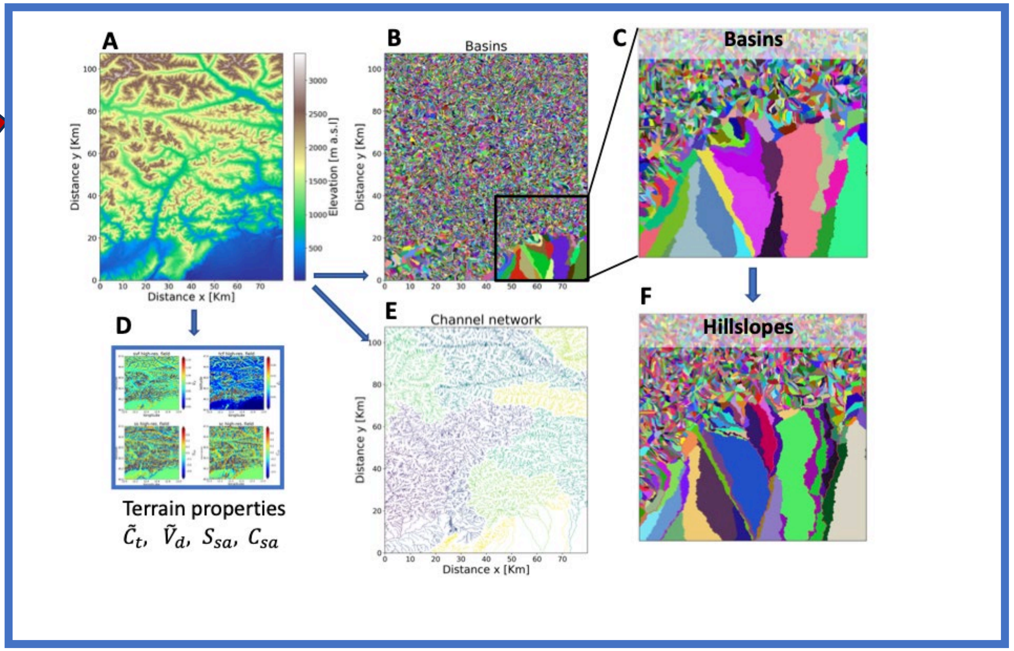
Figure source: IPCC AR6 special report on High Mountain Areas

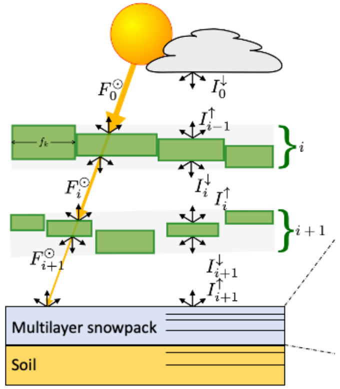
Snow is uniquely reflective and insulating

Images from NASA SVS:MODIS Snow Cover over North America and Europe (https://svs.gsfc.nasa.gov)

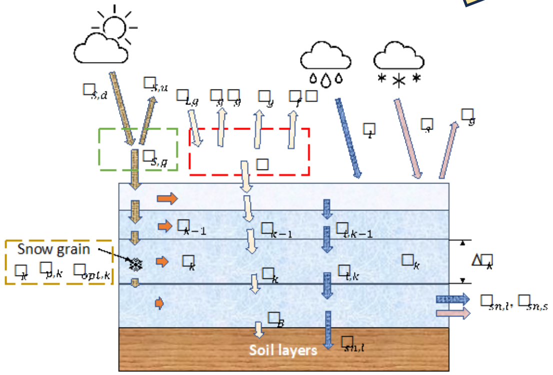
Snow and land processes in climate models



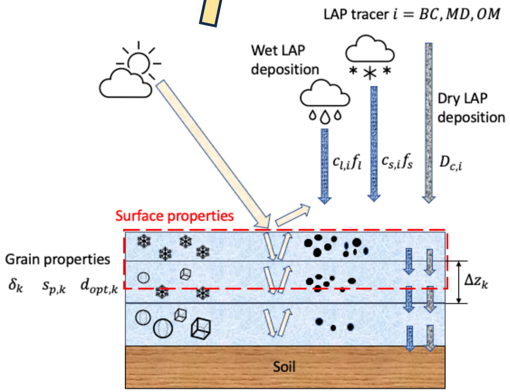




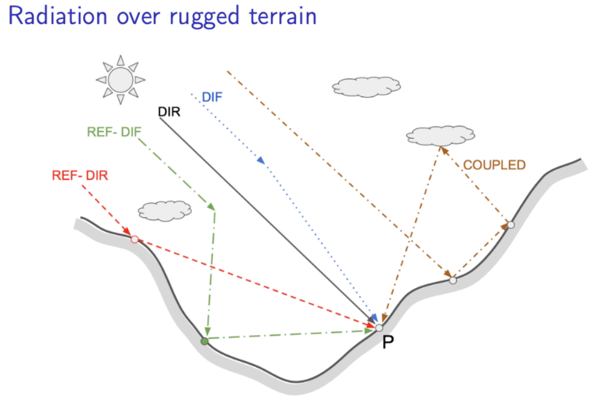
Dynamic vegetation



Improved snow physics

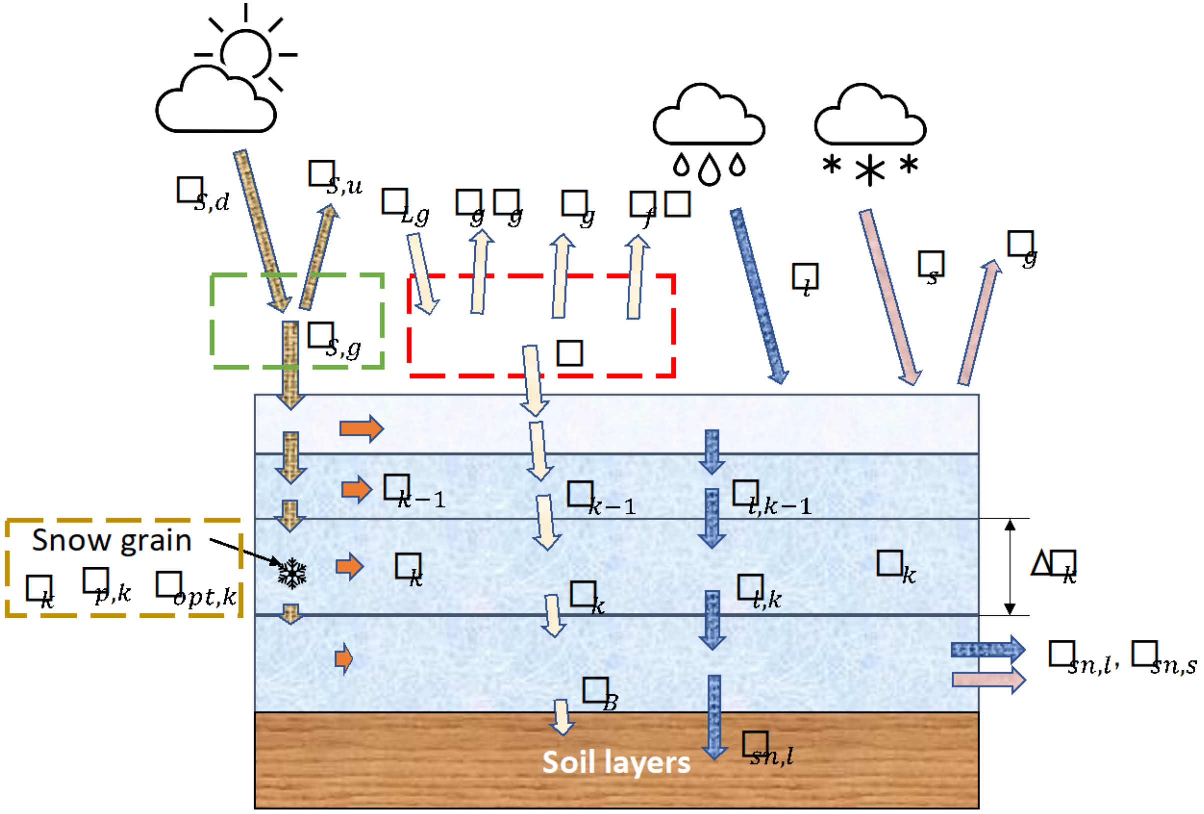


Effect of Impurities on snow



Radiation over complex terrain

New Global Land Snow Scheme (GLASS) for the GFDL ESM



- Prognostic size and shape of snow grain
- Detailed vertical structure aware of each layer's properties (trade-off)
- Fully coupled to soil, multi-layer canopy, atmosphere
- Implicit numeric solver -> Nonlinear solution for melt/freeze

Overview of GLASS in GFDL ESM framework

Snow step 1

heat diffusion through Snowpack

Estimate ice, water, surface T

Soil step 1: heat diffusion

Implicit surface energy balance: Tendencies $\Delta T_g, \Delta\psi, \Delta q_c$

-Canopy water, snow and energy balance
-Turbulent latent and sensible heat fluxes
-Longwave rad. balance

Snow step 2

- **Update snowpack T profile**
- **Snow sublimation and 'explicit' melt/freeze**
- **'Implicit' melt/freeze**
- **Snow solid balance**
- **Snow liquid balance**
- **Snow Compaction + Metamorphism + Wind Drift**
- **Snowpack re-layering**

Soil step 2: Update T profile; Water and heat soil balance

Shortwave radiative balance

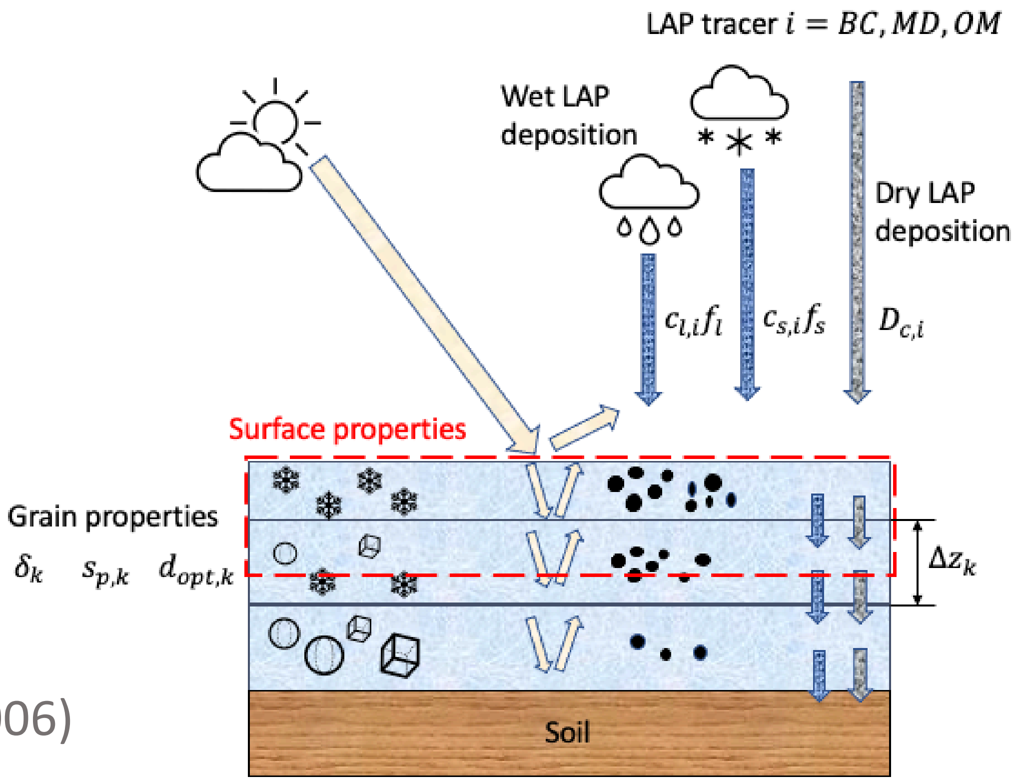
Update snow properties (snow grain, impurities)

Compute surface albedo

Typical model resolution: 1-100 km, 3 – 30 min
Implicit time stepping -> Nonlinearity due to melt/freeze

Effect of light-absorbing particles on snow

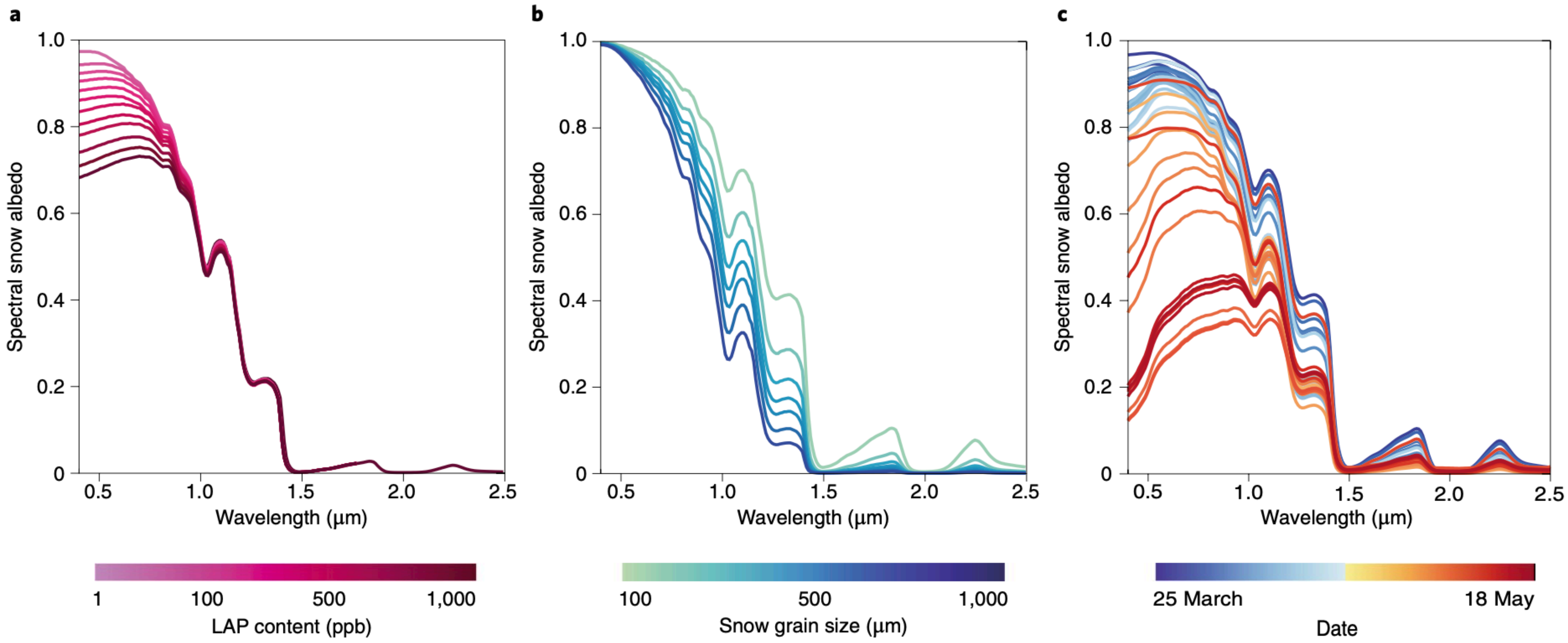
Image credit: NASA



New LM-GLASS snow model:

- Dynamic snowpack layers
- Metamorphism:
  Brun et al. (1992) + Flanner (2006)
- Deposition of impurities (LAPs):
  Ginoux et al., (2015)
- Optical effects of impurities:
  Dang (2015) + He et al., (2018)

Effect of light-absorbing particles on snow



Reduced surface albedo

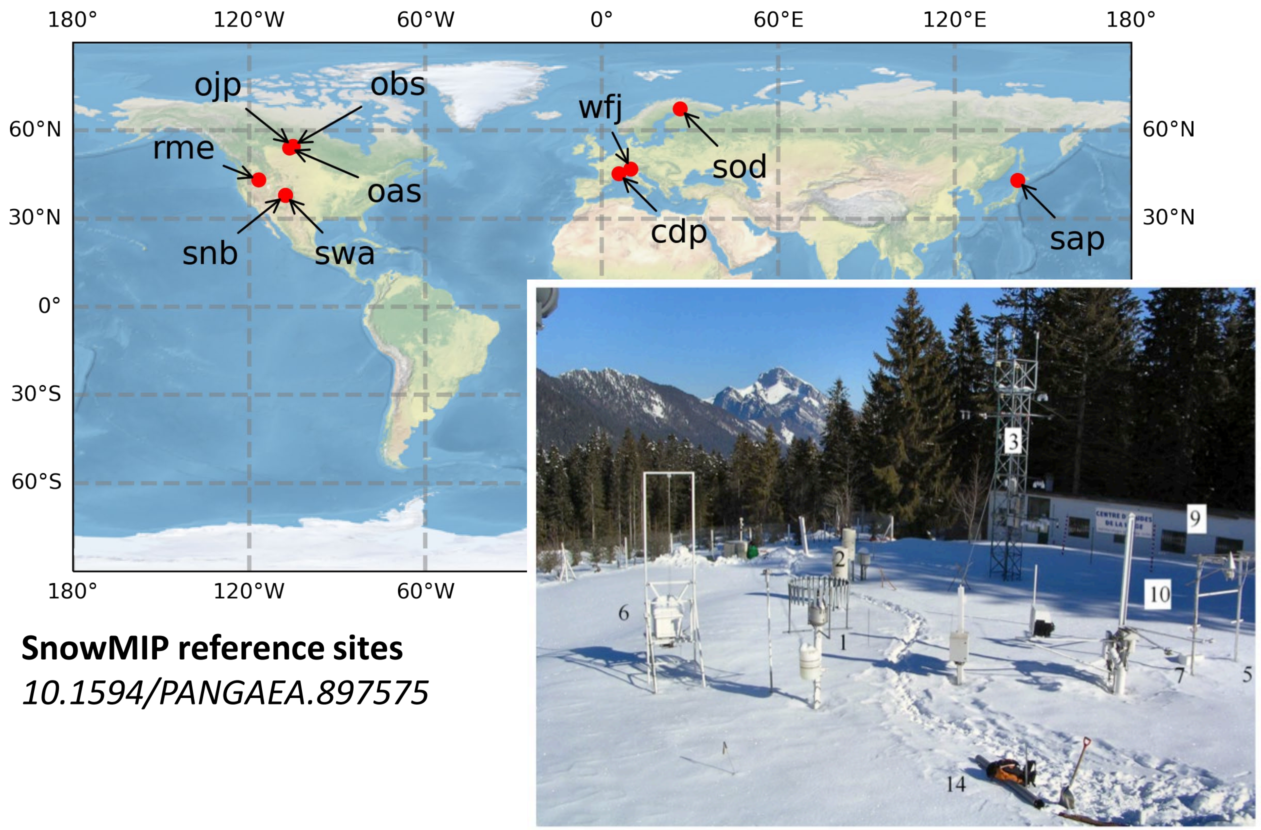
Enhanced snow metamorphism

More snow melt

Fig. 2 | Variation in snow albedo across the range of snow reflectance for changing LAP content and snow grain size. a, Modelled snow albedo showing the decrease in visible albedo as LAP content increases. **b**, Modelled clean snow albedo showing decreasing snow albedo in the longer wavelengths as snow grain size increases. **c**, Daily time series of snow albedo decline during snowmelt, showing the combined impacts LAP surface darkening and snow grain growth. Panel **c** adapted with permission from ref. [5], IGS.

From Skiles et al., 2018

How many snow-days do we lose Because of impurities on snow?



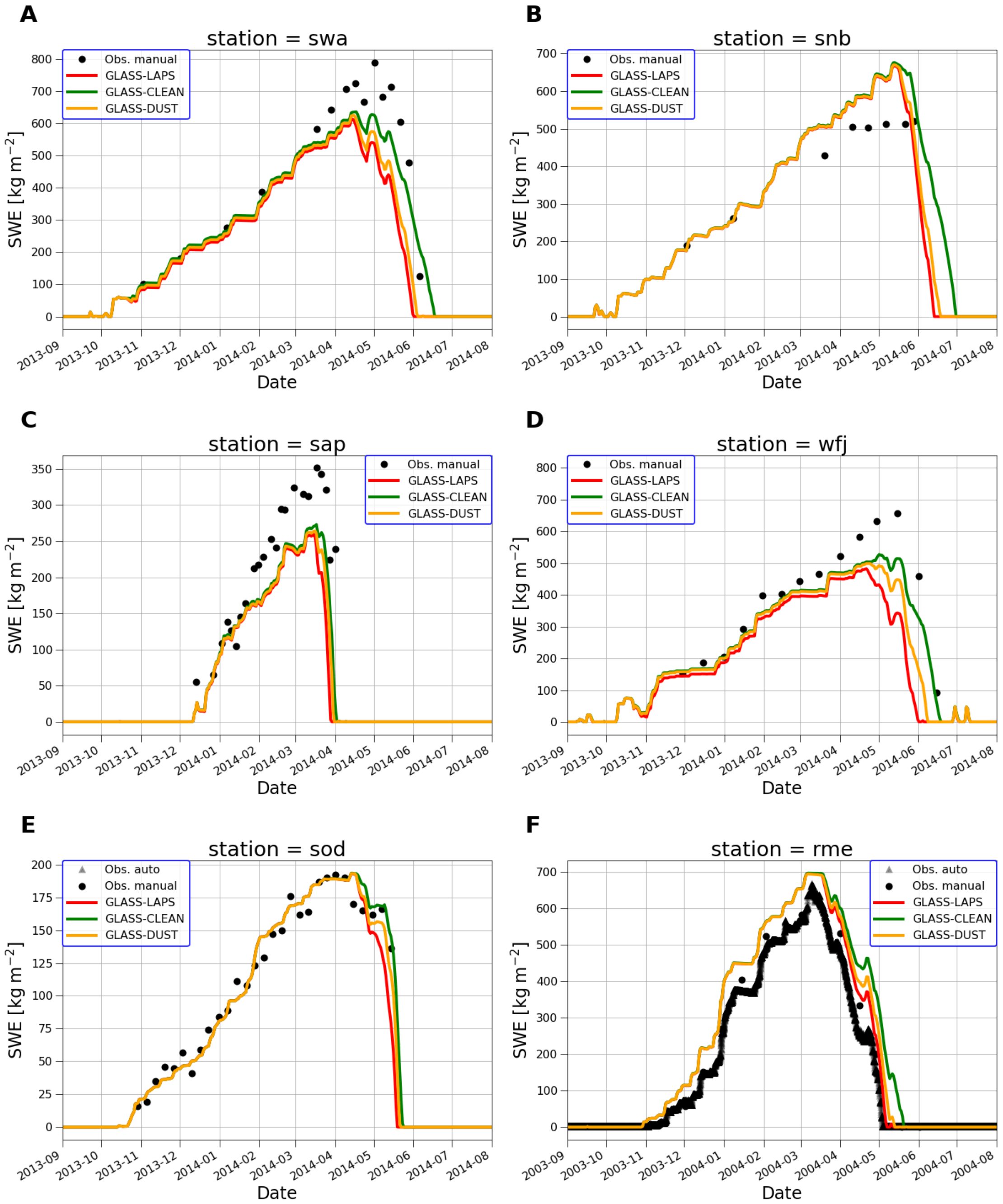
SnowMIP reference sites
10.1594/PANGAEA.897575

Figure from Morin et al., 2012

		swa	snb	sap	wfj	sod	rme	cdp
CLEAN - LAPS	μ_t	25.3	19.4	7.9	24.3	4.9	8.4	10.7
	σ_t	5.4	3.3	3.9	5.8	1.5	3.3	5.0
CLEAN - DUST	μ_t	20.2	15.3	4.2	16.9	3.0	4.8	5.8
	σ_t	4.6	3.5	3.0	6.1	1.1	2.3	3.4

Number of snow days lost due to all LAPs

ALL LAPs vs DUST ONLY vs CLEAN SNOW



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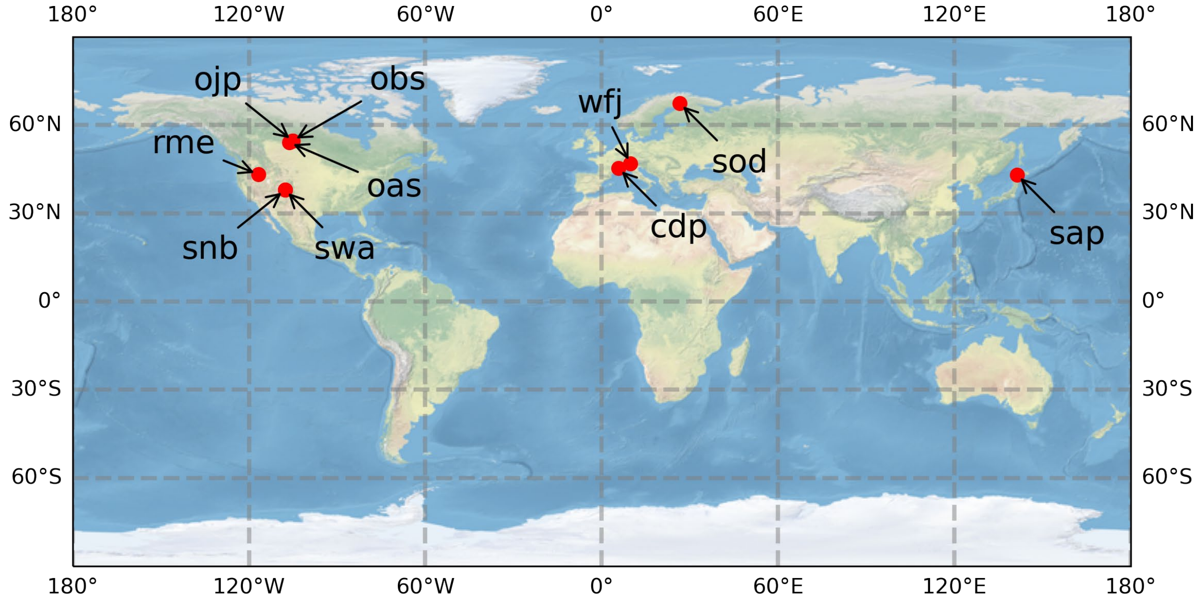

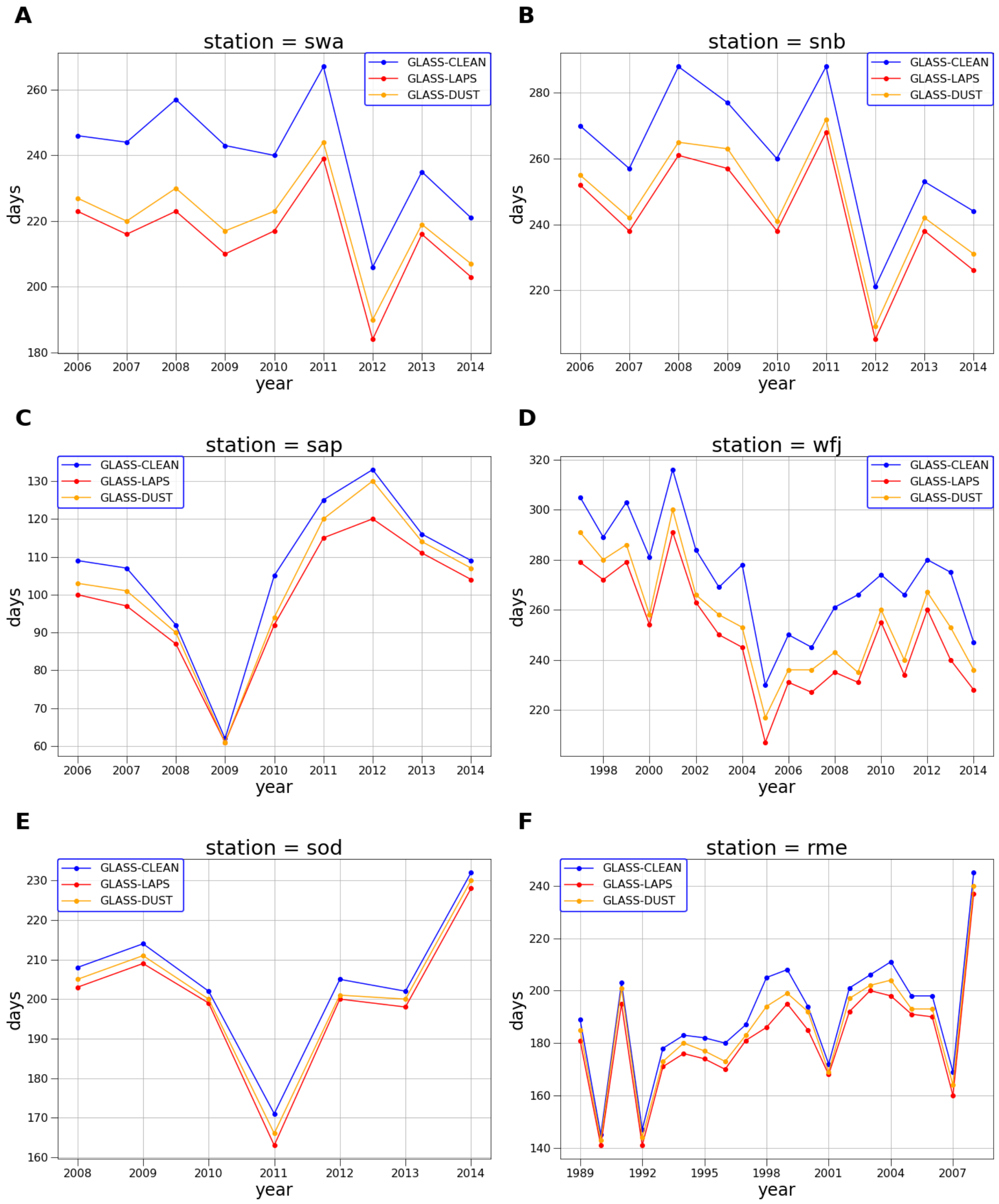

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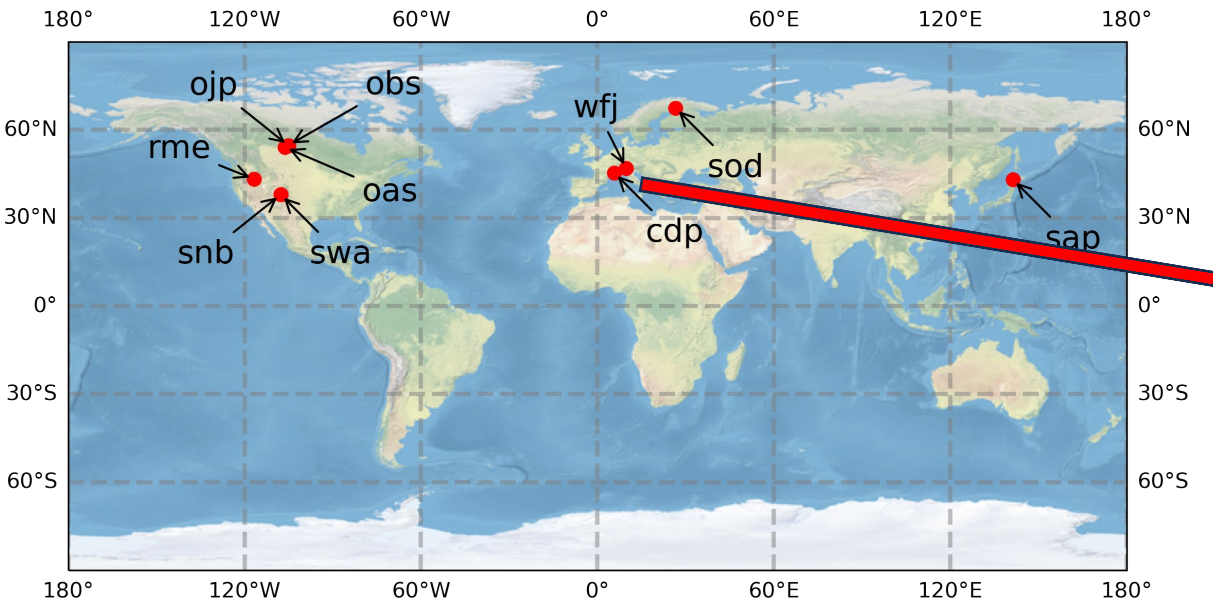
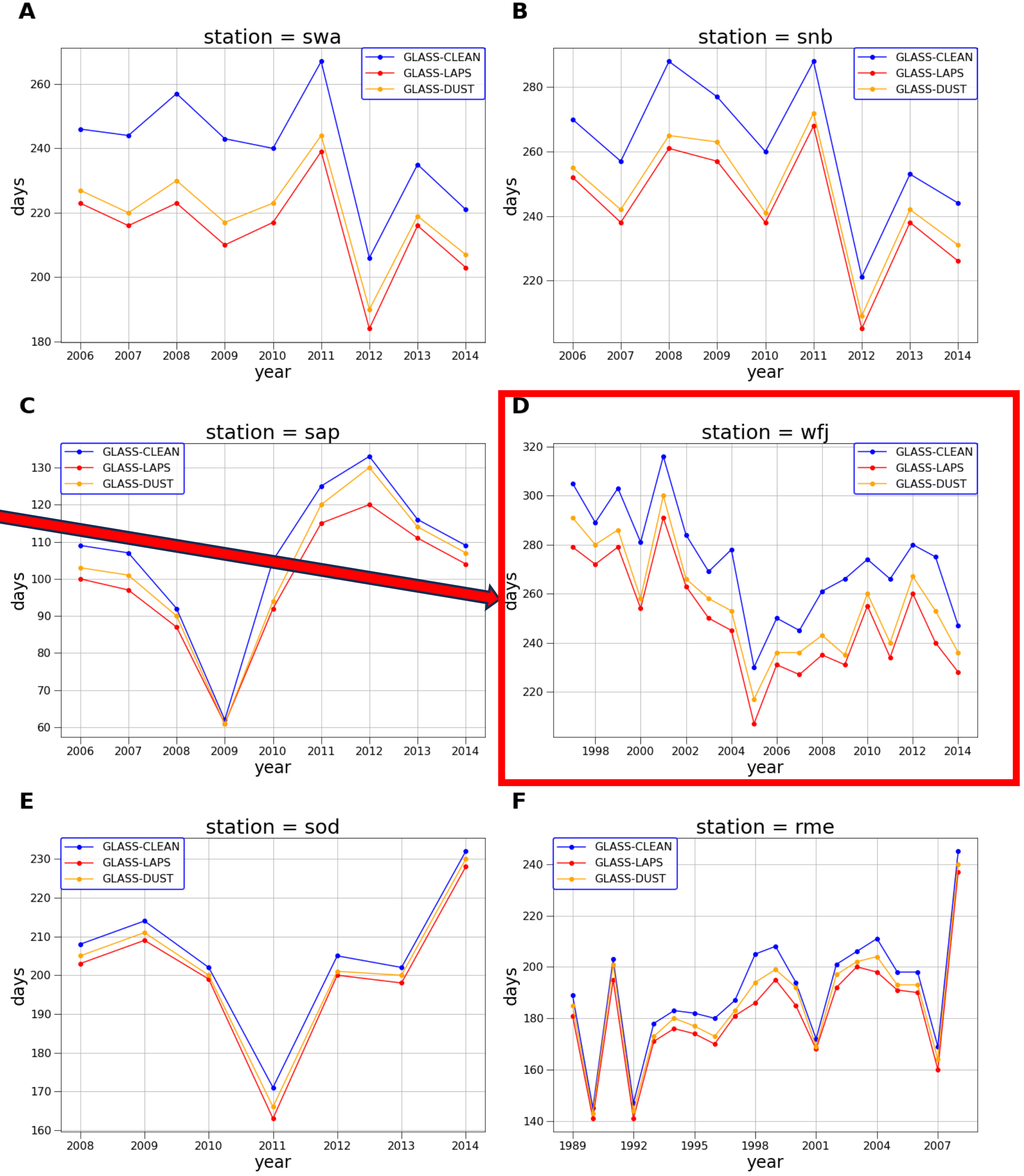
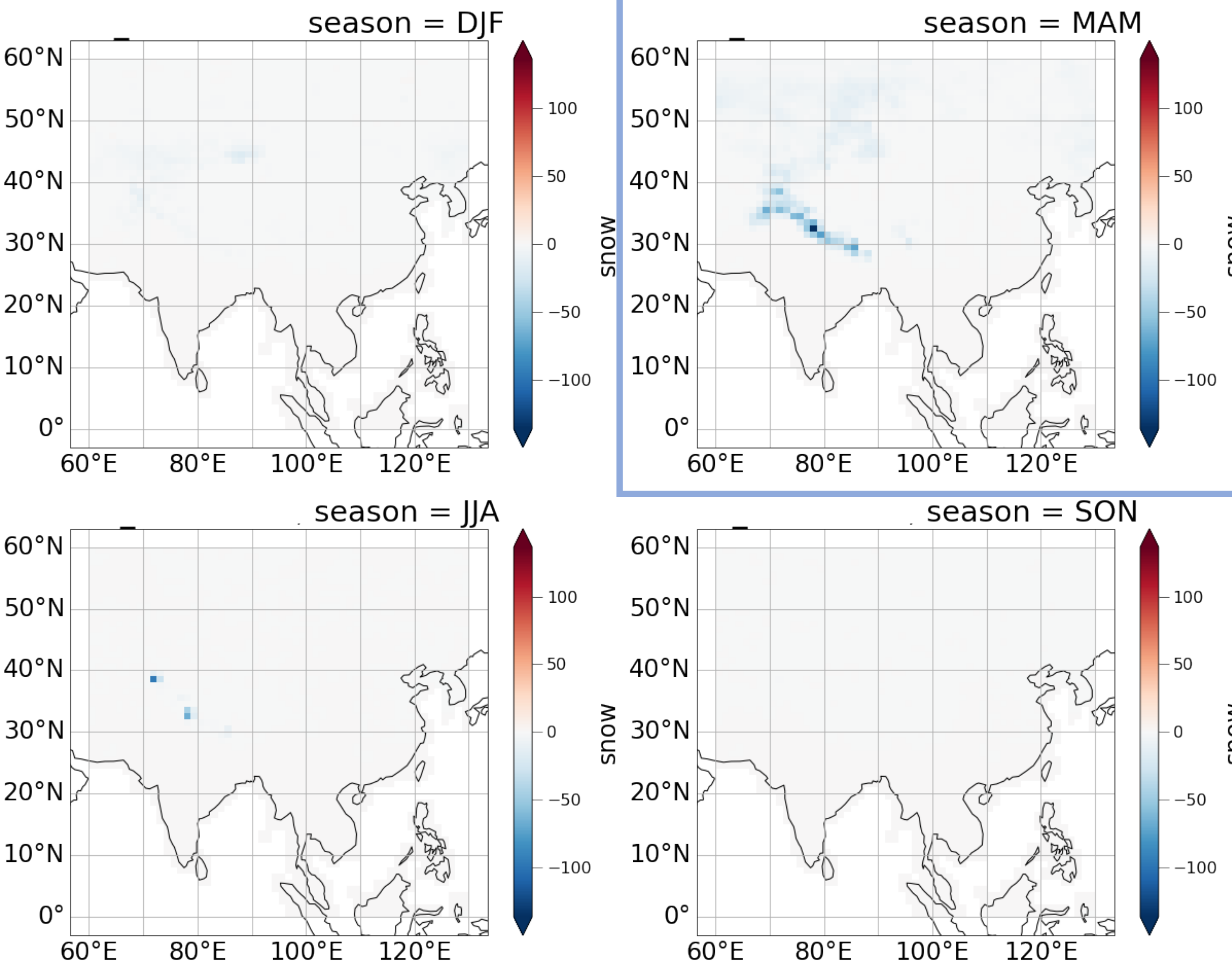
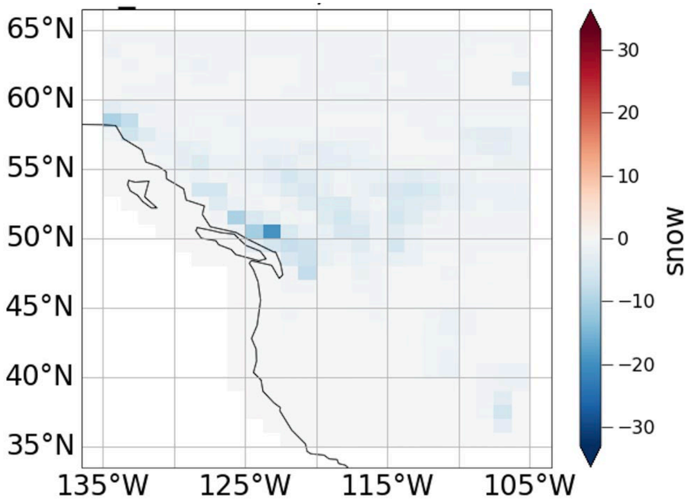




Effect of LAPs on snow high mountain Asia

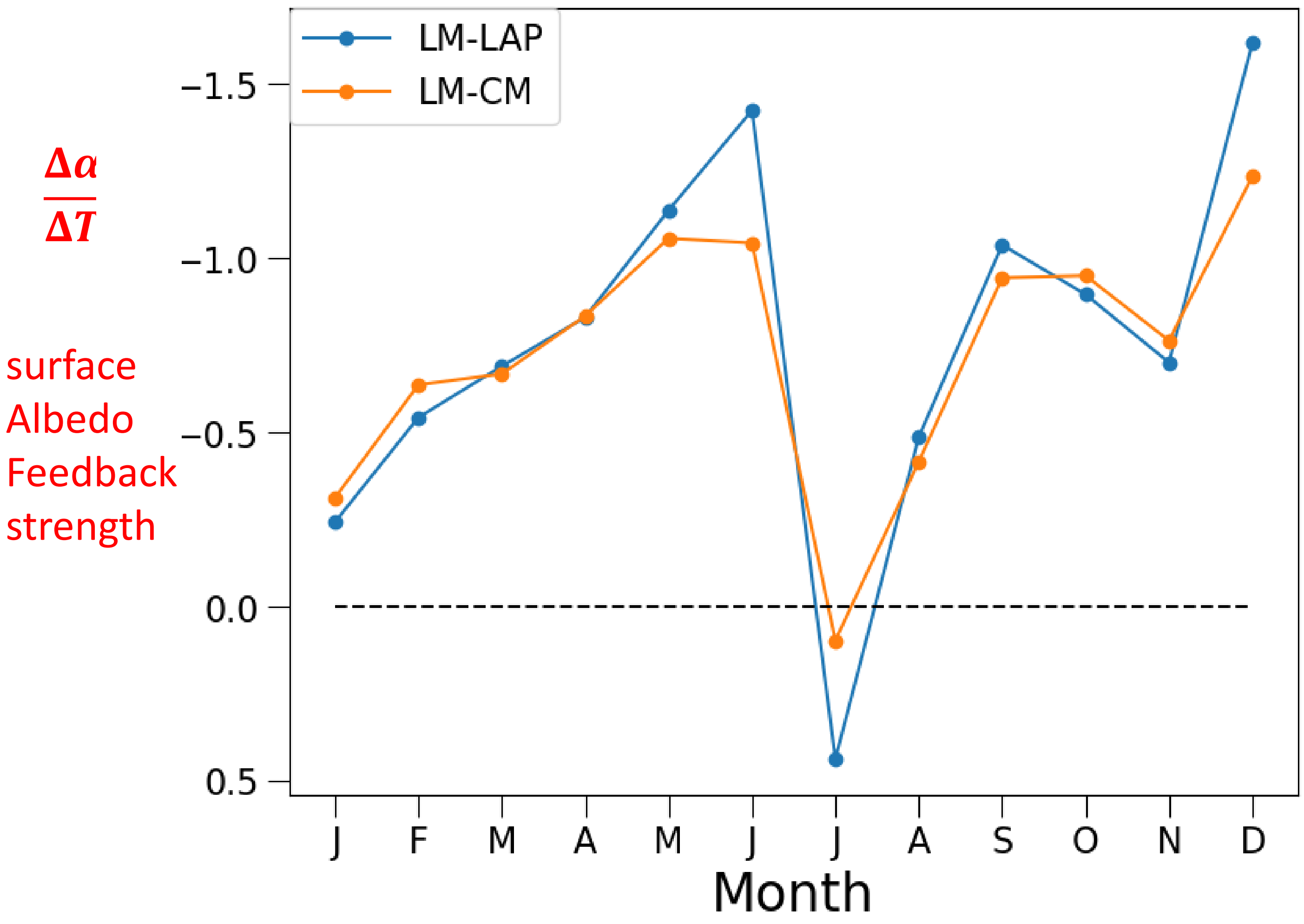
LAP - CLEAN, snow difference [Kg/m2]

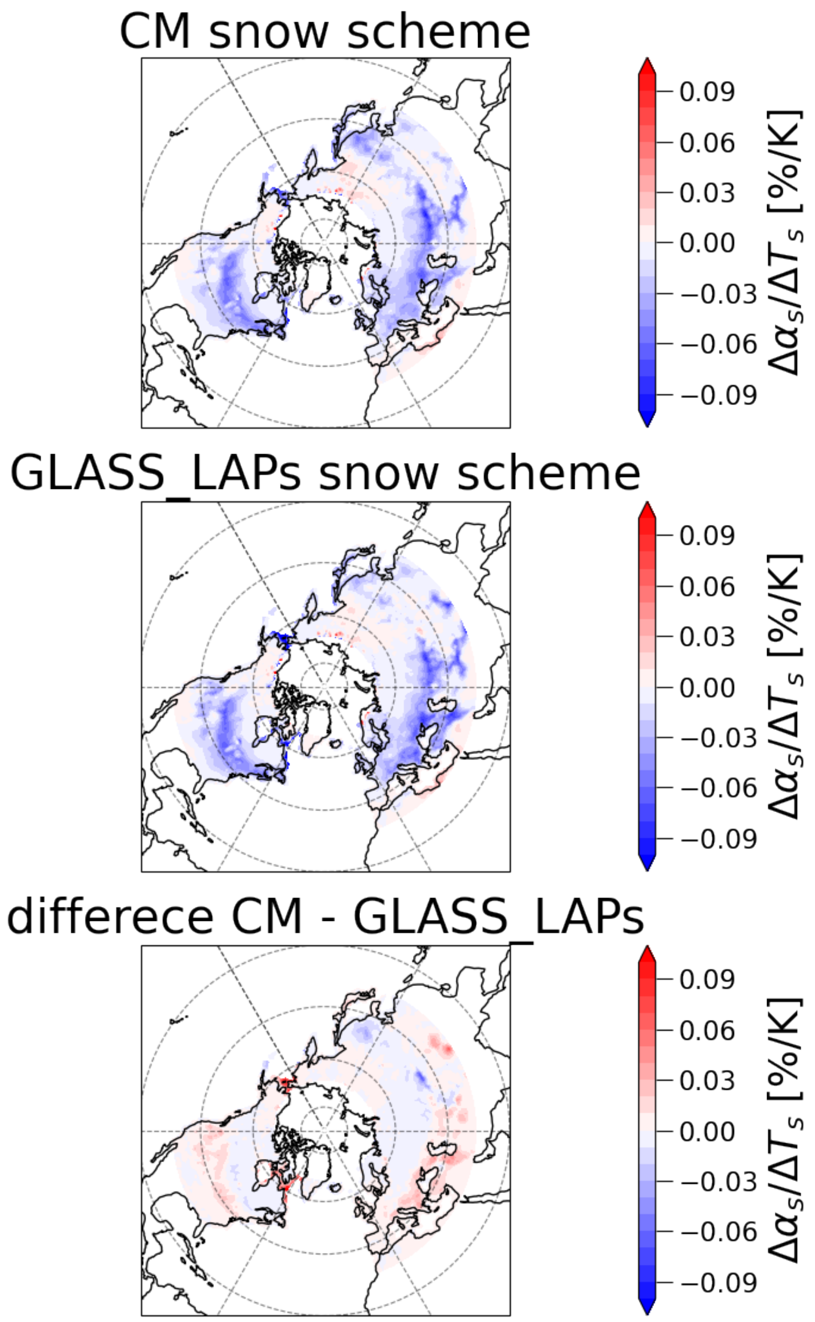




Western US, Effect of LAPs on spring SWE

Effect on new snow scheme on snow albedo feedback estimates

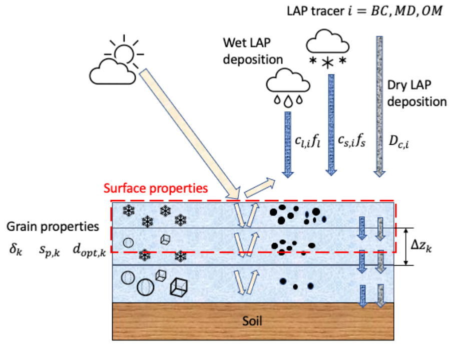




Take away message and future directions

Existing limitations of global coupled climate models in representing snow / cryosphere due to simplified physics.

1. We presented a new snow model (LM-GLASS) includes snow microphysics, improved snow layering structure and light absorbing particles (dust, black carbon)



2. We found the model has good performance and can be used to quantify the effect of LAPs on snow melt and their implication for the surface albedo feedback.