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

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Cryosphere plays a primary role in climate and hydrology.

Keeping Things Cool: The Albedo Effect

The albedo effect — the reflectivity of sunlight on various surfaces — is important in keeping the Earth cool. Clean, white clouds and fresh snow and ice reflect the most sunlight, while exposed land, water and vegetation have diminishing returns. Here’s a look at several examples found in nature:

- **White clouds:** 50-99%
- **Fresh snow on ice:** 85-95%
- **Bare ice:** 50%
- **Sea ice:** 60%
- **Oceans act as a heat sink, absorbing nearly all sunlight and reflecting barely a tenth back (at zenith).** Warm water hastens the melting of icebergs and ice floes. Oceans expand as they warm, resulting in rising sea levels.

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

- Improved snow physics
- Effect of Impurities on snow
- Radiation over complex terrain
- Dynamic vegetation
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

**Shortwave radiative balance**
- Update snow properties (snow grain, impurities)
- Compute surface albedo

**Snow step 2**
- 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

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

**Snow sublimation and ‘explicit’ melt/freeze**

‘Implicit’ melt/freeze

Snow solid balance

Snow liquid balance

Snow Compaction + Metamorphism + Wind Drift

Snowpack re-layering

Typical model resolution: 1-100 km, 3 – 30 min
Implicit time stepping -> Nonlinearity due to melt/freezer
Effect of light-absorbing particles on snow

New LM-GLASS snow model:
- Dynamic snowpack layers
- Metamorphism:  
- Deposition of impurities (LAPs):  
  Ginoux et al., (2015)
- Optical effects of impurities:  
Effect of light-absorbing particles on snow

From Skiles et al., 2018

**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. 3, IGS.
How many snow-days do we lose because of impurities on snow?

Figure from Morin et al., 2012

**SnowMIP reference sites**

10.1594/PANGAEA.897575

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Number of snow days lost due to all LAPS
How many snow-days do we lose because of impurities on snow?
How many snow-days do we lose because of impurities on snow?
How many snow-days do we lose
Because of impurities on snow?
Effect of LAPs on snow high mountain Asia

Western US, Effect of LAPs on spring SWE
Effect on new snow scheme on snow albedo feedback estimates

$\frac{\Delta a}{\Delta T}$

Surface Albedo Feedback strength

CM snow scheme
GLASS LAPs snow scheme
difference CM - GLASS LAPs
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.