Improving Snow and Aerosol Physics in CLM and CCSM with SNICAR

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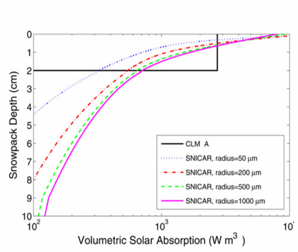
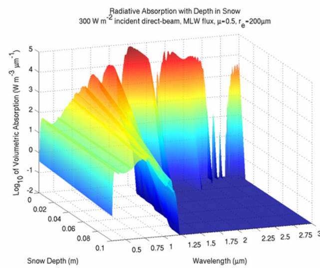
1. Vertically-Resolved Radiative Absorption

CLM prescribes all solar absorption to occur in the top-most snow layer. However, our SNow, ICe, and Aerosol Radiative model (SNICAR) predicts that 20-40 % of the total absorption occurs more than 2 cm beneath the surface, depending on snow grain size (left) [*Flanner and Zender*, 2005]. All near-infrared radiation is absorbed in the top few millimeters, but visible radiation penetrates deeper (right). Daytime snow temperature maxima exist a few centimeters beneath the surface due to radiative cooling at the surface and strong thermal insulation by the snow. Thus energy deposition beneath the surface layer can induce sub-surface snowmelt. This effect is significant in mid- and low- latitude snowpack (i.e., Tibetan Plateau), where there is intense winter insolation.





Summary

Snow-albedo feedback is a critical process in the climate system. It is triggered by temperature changes (i.e. greenhouse gas forcing) or by alterations to snow optical properties (i.e. darkening from aerosols). Only proper treatment of snow physical processes, such as radiative absorption and grain growth, will allow realistic assessment of climate sensitivity to such forcings.

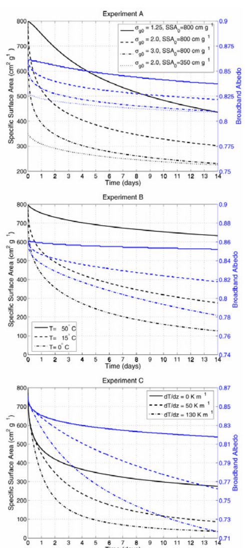
Key Results:

- Subsurface radiative absorption can induce snowmelt during periods of intense insolation.
- Temperature gradient in the snow is a significant source of grain growth (albedo decay).
- Surface radiative forcing by soot is small globally, but significant near industrial sources and boreal fires.
- Radiative changes in CCSM due to improved snow aging are much greater than snowpack aerosol forcings.
- Darkening of snow on sea-ice must be considered to assess the global forcing and feedback of soot.

2. Snow Aging

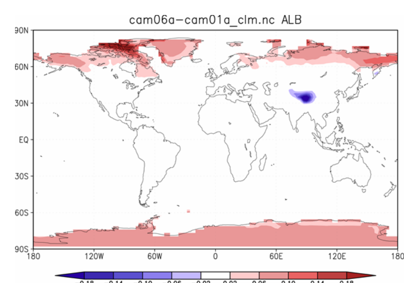
Snow reflectance decreases following snowfall as snow grains grow. GCMs represent snow aging with empirical functions. We incorporate vapor-diffusion theory into SNICAR to estimate snow grain growth in dry snow as a function of time since snowfall, snow temperature, and temperature gradient [*Flanner and Zender*, submitted]. Temperature gradient can induce large vertical vapor fluxes in the snowpack, but is not considered in any GCM parameterization. Grain growth is linked to radiative transfer with aspherical particle theory [*Grenfell et al*., 1999; *Neshyba et al*., 2003].

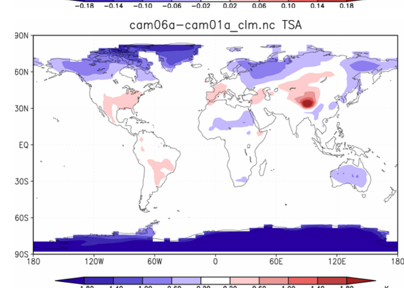
SNICAR-predictions of snow specific surface area (inversely related to effective radius) evolution following snowfall are depicted with different initial size distributions (top), temperatures (middle), and temperature gradients (bottom). Corresponding broadband snow albedo is plotted in blue on the right axes. The bottom figure shows that 14 days after snowfall, albedo can vary by more than 0.10 depending on the vertical temperature gradient.



3. Snow Aging Results with CAM/CLM

The effects of vertically-resolved absorption and physically-based snow aging on annual-mean surface reflectance (top) and 2-meter air temperature (bottom) relative to vanilla CAM/CLM3 are depicted. Albedo decrease over the Tibetan Plateau indicates less snow cover, caused by sub-surface melt and ice-albedo feedback. These changes reduce model-measurement discrepancy [*Flanner and Zender*, 2005]. Albedo increase at high-latitudes indicates greater snow albedo, caused primarily by initial size distribution. Changes in mean air temperature track these albedo changes. This sensitivity indicates a strong need for more accurate remotely-sensed surface reflectance over snow-covered regions, and shows that snow parameters may be tuned to address some temperature biases in CLM.

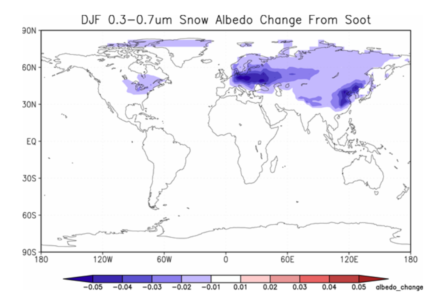


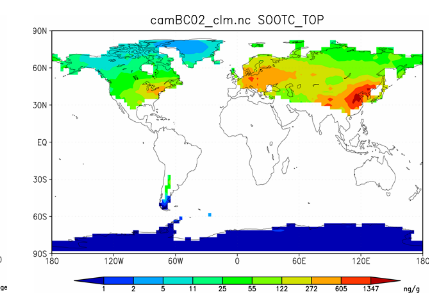


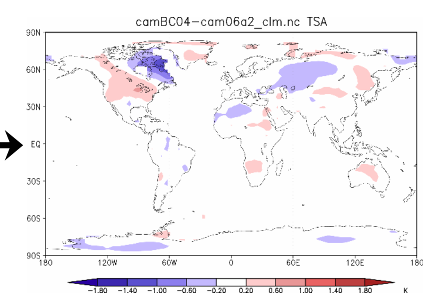
4. Snow Darkening by Soot

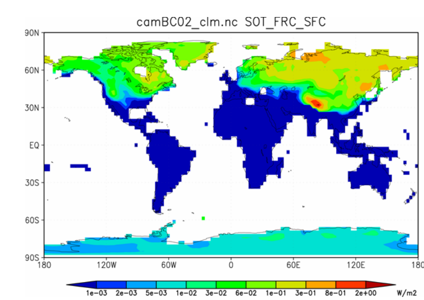
Black carbon (soot) enhances radiative absorption by snow and accelerates the rate of grain growth through heating. Thus it amplifies snow-albedo feedback through two separate mechanisms. We incorporate soot transport and deposition [*Rasch et al.,* 2001] to the snow in CLM/CAM using emissions inventory from Cooke and Penner.

Annual-mean soot concentration in the top-most snow layer (top-right), and mean surface energy forcing (bottom-right) without radiative feedback are depicted. Soot concentrations are highest near the industrial centers of east-Asia and Europe. The change in winter visible snow reflectance (assuming a completely snow covered viewing area) predicted from soot is largest in these regions (top-left). Finally, mean annual 2-meter air temperature with radiative feedback from soot (bottom-left) indicates a possible regime change in atmospheric circulation. The arrow indicates that these changes are smaller than those resulting from more realistic snow aging









References

Flanner, M. G., and C. S. Zender (2005), Snowpack radiative heating: Influence on Tibetan Plateau climate, *Geophys. Res. Lett., 32*, doi:10.1029/2004GL022076.

Flanner, M. G., and C. S. Zender (2005), Linking snowpack microphysics and albedo evolution, submitted to *J. Geophys. Res.*

Neshyba, S., T. Grenfell, and S. Warren (2003), Representation of a nonspherical ice particle by a collection of independent spheres for scattering and absorption of radiation: 2. hexagonal columns and plates, *J. Geophys. Res., 108 (D15),*10.1029/2002JD003302.

Rasch, P. J., W. D. Collins, and B. E. Eaton (2001), Understanding the Indian Ocean Experiment (INDOEX) aerosol distributions with an aerosol assimilation, *J. Geophys. Res., 106 (D7),* 7337-7355.