Climate response in the western United States to dust-shortened snow cover duration since late 1800s soil disturbance

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Outline

• Dust in mountain snowcover
• Radiative effects of dust in snow
• Reconstruction of deposition
• SNICAR + CAM3
• Results (temperature anomaly, net shortwave forcing)
• Summary
Efficacy of Dust in Snow

Dust decreases snow albedo

Dust deposition comes generally in the spring (Neff et al, 2005)

- solar irradiance is increasing
- snowpack is warming

Dust generally accumulates in surface layers and is not entrained in melt - therefore, the surface continues to darken
Surface Shortwave Radiative Forcing

The perturbation of net shortwave radiation due to the deposition of dust to snow cover \((W \, m^{-2})\).

\[
F_{dust} = \int_{\lambda=0.28 \, \mu m}^{\lambda=3.0 \, \mu m} E_{\lambda, tot} \left( \alpha_{\lambda, dustfree} - \alpha_{\lambda, dust} \right) d\lambda + F_{dust, indirect}
\]

\begin{align*}
\text{Net solar radiation} & \quad \text{without dust} \\
\text{Net solar radiation} & \quad \text{with dust}
\end{align*}

Spectral Albedo

\[
F_{dust} = - F_{dust, ind2}
\]
SNOBAL

Marks et al (1998)

Driven by complete energy balance measurements at SBBSA

Radiative effects of dust removed on hourly basis: spring radiative forcing = 30±14 W m⁻²

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Measured

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$F_{dust,min}$

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$F_{dust,max}$

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Niwot Ridge, Colorado, Dust scrape experiment, 2006
(unpublished data)

10 days, 35 cm differential melt

30 days, 1.05 m differential melt
Mean $F_{dust}$ during period:
144 W m$^{-2}$

Based on snowmelt modeling
SNOBAL model
(Marks et al., 1998)
Soil Disturbance in the West

Widespread soil disturbance across the western US

- Grazing, agriculture, mining, and recreational activities coupled with drying have accelerated dust emission from the Colorado Plateau. 
  *Reynolds et al. (2001)*
- Disturbance of biological crusts is critical and soil erosion is dramatically increased - dust emission *Belnap and Gillette (1997)*

Increased dust emission since disturbance of western US in late-1800s and increased deposition to the mountains *(Neff et al., in review)*

In turn, mountain snow cover has shorter duration than prior to disturbance.
Lake Sediments

Neff et al (2008), *in review*
SNICAR + CCSM

Snow Ice and Aerosols Radiative Transfer model (Flanner et al., 2006)

Community Atmosphere Model (CAM3), NCAR

Experiment

– Dust and soot in snow (~2.8° x 2.8° resolution)
  • Single scattering albedo 0.842-0.977
  • Extinction coefficient: 0.2-2.7 m²/g
– Control: dust and soot active in atmosphere, not snow
– Experiment: dust and soot active in atmosphere and snow
– Zender et al. (2008), in preparation
SNICAR + CAM3

Zender et al. (2008), in prep.
SNICAR + CAM3

Zender et al. (2008), in prep.
SNICAR + CAM3

Zender et al. (2008), in prep.
Summary

• Present day (Senator Beck basin):
  – spring radiative forcing = $30 \pm 14 \text{ W m}^{-2}$
  – $\Delta$ duration = $-28 \pm 6$ days

• Present dust mass accumulation rate x5 of that of pre-disturbance

• SNICAR+CAM3 Western regional forcings
  – Net shortwave forcing 3-27 W m$^{-2}$
  – Temperature anomaly 0.2 - 1.8 K
  – Implications for soil moisture, monsoon

• Future
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