Imaging spectroscopy of radiative forcing by dust and black carbon in snow: quantifying the insidious killer

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Snow Pit Speech

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May 2011
Guiding Science Questions

How does variation in snow albedo modulate river runoff and glacier mass balance?

How has radiative forcing by increases in dust and black carbon loading in the Anthropocene changed river runoff and glacier mass balance?
Outline

• Perspective on snow and ice melt
• Impacts of changes in albedo
• Global changes in dust and BC loading
• Global need for HyspIRI (USGCRP goals 1&2, Advance Science and Inform Decisions)
• Imaging spectroscopy of radiative forcing
• Upper Colorado River Basin, Spring 2011
Mountain Snow and Ice

- In the Western US, ~75% of freshwater comes from mountain snowmelt.
- Mountain snow and ice of the globe provides freshwater to nearly 2 billion people.
Global Glacier Retreat

Morteratsch Glacier, Switzerland
Global Water Stress

Source: http://www.unep.org/
\[
\frac{dU}{dt} + Q_m = (1 - \alpha)S + L^* + Q_s + Q_v + Q_g + Q_r
\]

What controls snowmelt?

Senator Beck Basin, CO; \(T_{max} 13-15\)

Elk Range, Colorado River Basin, April 2009

Morteratschgletscher (Oerlemans, 2000)
Increasing eolian dust deposition in the western United States linked to human activity
Response of Colorado River runoff to dust radiative forcing in snow

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Government and Manager Briefings:
- Anne Castle, Asst Secretary of Interior for Water and Science, Nov 2010
- US Global Change Research Program, Nov 2010
- NOAA HQ, Nov 2010
- Colorado River Water Users Association, Dec 2010
- EPA Section 8 + BLM, Dec 2010

Insert radiative forcing in snow in the Upper Colorado River Basin reduces annual runoff by ~5% or more than half of Mexico’s annual otment under treaty. Painter et al 2010, PNAS
Snowmelt Runoff and Dust Forcing

Uncompahgre River, Colorado
Upper Colorado River Basin

Senator Beck Basin Study Area
San Juan Mtns
Upper Colorado River Basin

Runoff rate vs Temperature
2005-2010

Runoff rate vs Dust Absorption
2005-2010

Take Home: Albedo and radiative forcing drive

*Pointer et al* (in preparation)
Funding: NASA Interdisciplinary Science
Caucasus Mountains

ATMOSPHERIC DUST CONTENT AS A FACTOR AFFECTING GLACIATION AND CLIMATIC CHANGE

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Black Carbon

Black soot and the survival of Tibetan glaciers

Effects of soot-induced snow albedo change on snowpack and hydrological cycle in western United States based on Weather Research and Forecasting chemistry and regional climate simulations

Soot climate forcing via snow and ice albedos

Black Carbon (BC) in the snow of glaciers in west China and its potential effects on albedos

Warming trends in Asia amplified by brown cloud solar absorption

We propose that the combined warming trend of 0.25 K per decade may be sufficient to account for the observed retreat of the Himalayan glaciers.
What about MODIS and VIIRS?

Hindu Kush, Afghanistan
Terra MODIS

MOD-DRFS model
Painter and Bryant 2011
Spectrometer vs MODIS

![Graph showing spectral albedo vs. wavelength (μm) for different concentrations of soot.](image)
Radiative Forcing in Snow

What else from imaging spectrometer?
- Fractional snow cover
- Snow grain size
- Snow liquid water content
- Snow biological content
- and of course albedo

\[ RF = \sum_{\lambda} E_{\lambda} \left( R_{\lambda,\text{clean}} - R_{\lambda,\text{dust}} \right) d\lambda \]

\[ 0.35 \mu m \quad \text{to} \quad 1.15 \mu m \]
NASA IDS Integrated hydrologic response to extreme dust deposition to mountain snowcover of the Colorado River Basin
Atmospheric Correction in Rough Terrain

- AVIRISclassic acquisitions over spring 2011 (only 15 June presented here)
- ReSe Applications ATCOR4.0
- Rugged terrain model
- Variable visibility calculation
- Full spatial/spectral irradiance (direct & diffuse) reportage
Constrained by sunphotometer

Red Mountain Pass AERONET site
Swamp Angel Study Plot

Time of day (UTC)

500 nm Aerosol Optical Depth (AOD)

Column Water Vapor (cm)

15 June 2011
Irradiances

Direct irradiance

Diffuse irradiance

15 June 2011, San Juan Mtns
Reflectance
Albedo and radiative forcing
What about the thermal bands?

\[
\frac{dU}{dt} + Q_m = \left(1 - \alpha\right)S + L^* + Q_s + Q_v + Q_g + Q_r
\]

Snow Temp < 0 °C

Snow Temp = 0 °C

Senator Beck Basin, CO; \( T_{\text{max}} 13-15 \)
Summary

• Changes in global snow and ice drive powerful positive feedbacks in the Earth system and
• HyspIRI will provide global direct access to snow albedo, radiative forcing by dust and BC, and the snow thermal response
• HyspIRI will also provide a baseline against which reductions in dust loading and BC may be assessed
• Aerosol model remains the powerful challenge for reflectance retrievals, particularly in rough mountain terrain
• Thanks to Diane Wickland, Jared Entin, Rob Green, Ian McCubbin, Michael Eastwood, Sarah Lundeen