Global observations of snow albedo and radiative forcing by light absorbing impurities in snow from HyspIRI

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?
What controls snowmelt?

Energy for melting

Absorbed sunlight

Elk Range, Colorado River Basin, April 2009

Senator Beck Basin, CO; $T_{max}$ 13-15 °C
SWE

Albedo
Dust radiative forcing in snow of the Upper Colorado River Basin:
1. A 6 year record of energy balance, radiation, and dust concentrations

Thomas H. Painter,¹,²,³ S. McKenzie Skiles,²,³ Jeffrey S. Deems,⁴,⁵ Ann C. Bryant,⁶ and Christopher C. Landry⁷

Dust radiative forcing in snow of the Upper Colorado River Basin:
2. Interannual variability in radiative forcing and snowmelt rates

S. McKenzie Skiles,¹,² Thomas H. Painter,¹,²,³ Jeffrey S. Deems,⁴,⁵ Ann C. Bryant,⁶ and Christopher C. Landry⁷
Response of Colorado River runoff to dust radiative forcing in snow

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The waters of the Colorado River serve 27 million people in seven states and two countries but are overallocated by more than 10% through dust’s direct absorption and accelerated snow metamorphism.
What controls the interannual variability of the snowmelt runoff hydrograph?
Explain steepness of rising limb

TEMPERATURE 2005-2010

ALBEDO 2005-2010

Painter et al (in preparation)
Causasus Mountains

ATMOSPHERIC DUST CONTENT AS A FACTOR AFFECTING GLACIATION AND CLIMATIC CHANGE

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[Bar graph showing atmospheric dust content from 1790 to 1950 with running decades and separate years]
Irradiiances

Direct irradiance

Diffuse irradiance

ATCOR4.0 - 15 June 2011, San Juan Mtns
Reflectance Validation

ATCOR4.0 - 15 June 2011, San Juan Mtns
Radia+ve Forcing in Snow

$R_F = \sum_{\lambda=0.35 \mu m}^{1.10 \mu m} E(\theta, \lambda) \cdot \left( \alpha^{\text{clean}}(\lambda; r) - \alpha^{\text{obs}}(\lambda; r) \cdot \frac{\alpha^{\text{clean}}_{1.10 \mu m}}{\alpha^{\text{obs}}_{1.10 \mu m}} \right) \Delta \lambda$

$I_{1.26} = \sum_{\lambda=1.12 \mu m}^{1.31 \mu m} \left( \frac{\text{HDRF}_{\text{sfc, cont}}^{\text{obs}}(\theta_0, \theta_r, \phi_r, \lambda) - \text{HDRF}_{\text{sfc}}^{\text{obs}}(\theta_0, \theta_r, \phi_r, \lambda)}{\text{HDRF}_{\text{sfc, cont}}^{\text{obs}}(\theta_0, \theta_r, \phi_r, \lambda)} \right) \Delta \lambda$

Spectral Albedo

Wavelength (\mu m)
Albedo retrieval

Spectral albedo

\[
\begin{align*}
a_{sfc}^{obs} (r; \lambda) &= \text{HDFR}_{sfc}^{obs} (\theta_0; \theta_r, \phi_r; r; \lambda) \cdot \frac{a_{sfc}^{mdl} (r; \lambda)}{\text{HDFR}_{sfc}^{mdl} (\theta_0; \theta_r, \phi_r; r; \lambda)} \\
&= \text{HDFR}_{sfc}^{obs} (\theta_0; \theta_r, \phi_r; r; \lambda) \cdot c_{\lambda; \theta_r, \phi_r; r; \lambda}
\end{align*}
\]

Spectrally-integrated albedo

\[
\alpha_{sfc} (r) = \sum_{\lambda=0.35 \mu m}^{2.50 \mu m} E(\lambda; \theta_0) \cdot \alpha_{sfc} (\lambda; r) \Delta \lambda
\]
Uncertainties from AVIRIS spectral NEΔL
Water vapor uncertainty: ±0.0007 cm.
Grain size from 1.03 & 1.26 μm, ±5.4 μm & ±7.1 μm.
Albedo: ±0.006
Instantaneous radiative forcing: ±1.8 W m⁻².
Airborne Snow Observatory

Snow water equivalent
San Juan Mountains
11 May 2012

AVIRISng color composite
San Juan Mountains
11 May 2012

Snow Depth (m)
Summary

• Critical void in knowledge of the impacts of dust/BC on snowmelt and glacier melt
• New multispectral algorithms provide qualitative retrievals
• The imaging spectrometer provides the quantitative retrieval needed to understand this impact
• HyspIRI will give us the global access to that knowledge
• MODIS/VIIRS and the Airborne Snow Observatory will anchor HyspIRI at the temporal and spatial ends