Airborne retrievals of snow properties

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Jet Propulsion Laboratory / California Institute of Technology

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Pasadena, July 25. 2013
Introduction: Airborne Snow Observatory
Relevance / Impacts / Objectives

Society:
- Water resources and Hydropower
- Natural disasters
- Tourism

Science:
- Climate: Energy balance, precipitation, validation of models, etc.
- Hydrology: improvement of run off models
- Remote sensing: improvement and validation of algorithms, towards orbital appl.

Agency:
- Programs: cryospheric science, terrestrial hydrology, climate change/variability, and applied sciences
- Missions: decadal survey mission HyspIRI, other (to-be) proposed missions
Airborne Observations

**How much snow?**
Using laser radar, known as Lidar, researchers measure the depth of snowpack in California.

1. Laser pulse sent from plane
2. Laser reflects back from the ground.
3. The time it takes the laser to return to the plane is proportional to the elevation. The difference between summer elevation and snow elevation is the snow depth.

**How will it melt?**
With an advanced light sensor, scientists measure snow’s reflectivity—an indicator of how it will melt.

- Light sensor
- Old snow doesn’t reflect as much light, which causes it to melt faster.
- Debris like dust and plants can make snow reflect less.
- New snow is most reflective.
- As snow absorbs sunlight, it warms up. This results in more melting and even more light absorption.

Sources: Thomas Painter, Frank Gehrke, Optech Inc.

Maxwell Henderson / The Register

From: Orange County Register, May 31 2013
Airborne Observations

LiDAR Scanner:
1. Snow Depth
2. Snow Water Equivalent

Hyperspectral Imager:
1. Snow Cover
2. Snow Albedo
3. Grain Size
4. Radiative Forcing
Study Site: Tuolumne River Basin, CA
Ground Team (Calibration/Validation)
Impact on Water Resources Management

Hetch Hetchy inflow forecasting, Spring 2013

- Obs. HH Inflow (cfs)
- Raw PRMS basin_cfs
- ASO PRMS basin_cfs
- Forecast without ASO
- Forecast with ASO
- Actual measured

Adapted from: Tom Painter, et al.
# Main Part: Overview

## Snow Cover Area
- **Product**

## Albedo
- **Method & Theory**
- **Product**
- **Analysis**

## Snow Grain Size
- **Method & Theory**
- **Product**
- **Analysis**

## Radiative Forcing
- **Method & Theory**
- **Product**

## Snow Depth
- **Product**

## Snow Water Equivalent
- **Product**

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Details on the retrieval methods:

Main Part: Snow Cover Area

Snow Cover Area
- Product

Albedo
- Method & Theory
- Product
- Analysis

Snow Grain Size
- Method & Theory
- Product
- Analysis

Radiative Forcing
- Method & Theory
- Product

Snow Depth
- Product

Snow Water Equivalent
- Product
May 03 2013

Missing line.
May 11 2013

3. May is biased (missing flight line)
May 20 2013

3. May is biased (missing flight line)
May 25 2013

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### Albedo

- **Method & Theory**
- **Product**
- **Analysis**

### Snow Grain Size

- **Method & Theory**
- **Product**
- **Analysis**

### Snow Depth

- **Product**

### Snow Water Equivalent

- **Product**

**Details on the retrieval methods:**
Radiance vs. Directional Reflectance

HDRF = Hemispherical Directional Reflectance Function

Data: AVIRIS June 2011, Rocky Mountains.
Radiance => Directional Surface Reflectance

Atmospheric Correction using **ATCOR4 (MODTRAN5)**

=> Hemispheric Directional Reflectance Factor

\[
HDFR_{obs}^{sfc} = \frac{R_{obs}^{sensor} - R_{atm}^{mdl}}{T_{\$,mdl} + S_{sfc}^{mdl} (R_{obs}^{sensor} - R_{atm}^{mdl})}
\]
HDRF = Hemispherical Directional Reflectance Function

\[ \frac{A_{snow}^{mdl}(r, \lambda)}{HDRF_{snow}^{mdl}(\ldots)} \]

anisotropy factor

Difference between reflectance in fwd. vs. nadir direction for the spectral range of the CASI1500 instrument.

Painter, 2011
Directional Reflectance & Atmospheric Scattering
Directional Reflectance
Reflectance $\Rightarrow$ Spectral Albedo

Atmos Corr. using ATCOR4 (MODTRAN5)

$$ HIDRF_{sfc}^{obs} = \frac{R_{sensor}^{obs} - R_{atm}^{mdl}}{T_{\uparrow,mdl}^{\uparrow} + S_{sfc}^{mdl} (R_{sensor}^{obs} - R_{atm}^{mdl})} $$

Correction for dir. Effects $\Rightarrow$ Spectral Albedo

$$ A_{snow}^{obs} (r, \lambda) = HIDRF_{snow}^{obs} (\theta_0, \theta_v, \phi_0 - \phi_v; r; \lambda) \cdot \frac{A_{snow}^{mdl} (r, \lambda)}{HIDRF_{snow}^{mdl} (...) \text{ anisotropy factor}} $$

DISORT – RT model
Spectral Albedo => (Broadband) Albedo

Atmos Corr. using ATCOR4 (MODTRAN5)

$$HDRF_{sfc}^{obs} = \frac{R_{sensor}^{obs} - R_{atm}^{mdl}}{T_{\lambda,mdl}^{\downarrow} + S_{sfc}^{mdl} (R_{sensor}^{obs} - R_{atm}^{mdl})}$$

Correction for dir. effects

$$A_{snow, obs}^{obs} (r, \lambda) = HDRF_{snow, obs}^{obs} (\theta_0, \theta_v, \phi_0 - \phi_v; r; \lambda) \cdot \frac{A_{snow, mdl}^{mdl} (r, \lambda)}{HDRF_{snow, mdl}^{mdl} (\ldots)}$$

anisotropy factor

Irradiance at each terrain cell

$$E_{sfc}^{mdl} (\lambda, \theta_0) = \int_{\lambda=0.36 \mu m}^{1.05 \mu m} (E_{sfc, dir}^{mdl, \lambda} (\lambda, \theta_0) + E_{sfc, dif}^{mdl, \lambda} (\lambda, \theta_0)) \Delta \lambda$$

Broadband Albedo

$$A_{snow, obs}^{obs} (r) = \frac{\int_{\lambda=0.36 \mu m}^{1.05 \mu m} E_{sfc}^{mdl} (\lambda, \theta_0) \cdot A_{snow, obs}^{obs} (r, \lambda) \Delta \lambda}{\int_{\lambda=0.36 \mu m}^{1.05 \mu m} E_{0}^{mdl} (\lambda, \theta_0) \Delta \lambda}$$
Main Part: Albedo

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Albedo: April 10 2013
Albedo: May 11 2013

11. May. 2013

0.0 0.2 0.4 0.6 0.8 1.0

Snow Albedo

0.4 0.6 0.8 1.0

Broadband Albedo

1.0 × 10^6

1.5 × 10^7

2.0 × 10^7
Main Part: Albedo

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Time Series (preliminary results)

April 10 2013
800 km²

May 11 2013
450 km²

June 01 2013
250 km²

Note: biased by data coverage outside of study area.
Main Part: Snow Grain Size

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Details on the retrieval methods:
Snow Grain Size

CASI1500 spectral range

ice absorption coefficient
fine to coarse snow

Dozier, 2009
Snow Grain Size

Painter, 2009
Snow Grain Size

\[ \text{HDRF}_{\text{sfc}}^{\text{obs}} = \frac{R_{\text{sensor}}^{\text{obs}} - R_{\text{atm}}^{\text{mdl}}}{T^{\downarrow, \text{mdl}}_{\text{sfc}} + S_{\text{sfc}}^{\text{mdl}} (R_{\text{sensor}}^{\text{obs}} - R_{\text{atm}}^{\text{mdl}})} \]

Inverse Procedure with Least Absolute Deviation (cost funct. to find best fit)

\[
r : \left( \min \sum_{i=1.02 \mu m}^{1.04 \mu m} \text{HDRF}_{\text{snow}}^{\text{mdl}} (\theta_0, \theta_v, \phi_0 - \phi_v; r; \lambda_i) - \text{HDRF}_{\text{snow}}^{\text{obs}} (\theta_0, \theta_v, \phi_0 - \phi_v; r; \lambda_i) \right)
\]
Main Part: Snow Grain Size

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Snow Grain Size: April 10 2013

Snow Grain Size at 1.03μm [μm]
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Time Series (preliminary results)

- April 10 2013: 800 km²
- May 11 2013: 450 km²
- June 01 2013: 250 km²

**Broadband Albedo**

- April 10: 0.8
- May 11: 0.6
- June 01: 0.4

**Mean Snow Grain Size**

- April 10: 200 μm
- May 11: 150 μm
- June 01: 100 μm

**Snow Cover Area**

- April 10: 800 km²
- May 11: 450 km²
- June 01: 250 km²

3. May is biased (missing flight line)

Note: biased by data coverage outside of study area.
### Main Part: Radiative Forcing

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**Details on the retrieval methods:**

Radiative Forcing

Irradiance at each terrain cell

\[
E_{sfc}^{mdl} (\lambda, \theta_0) = \int_{\lambda=0.36 \, \mu m}^{1.05 \, \mu m} \left( E_{sfc}^{mdl, dir} (\lambda, \theta_0) + E_{sfc}^{mdl, dif} (\lambda, \theta_0) \right) \Delta \lambda
\]

Broadband Albedo

\[
A_{snow}^{obs} (r) = \frac{\int_{\lambda=0.36 \, \mu m}^{1.05 \, \mu m} E_{sfc}^{mdl} (\lambda, \theta_0) \cdot A_{snow}^{obs} (r, \lambda) \Delta \lambda}{\int_{\lambda=0.36 \, \mu m}^{1.05 \, \mu m} E_{sfc}^{mdl} (\lambda, \theta_0) \Delta \lambda}
\]

Radiative Forcing of Snow Impurities

\[
RF_{snow} = \int_{\lambda=0.36 \, \mu m}^{1.05 \, \mu m} E_{sfc}^{mdl} (\lambda, \theta_0) \cdot \left( A_{snow}^{mdl} (r, \lambda) - A_{snow}^{obs} (r, \lambda) \right) \left( \frac{A_{snow}^{mdl} (r, 1.05 \, \mu m)}{A_{snow}^{obs} (r, 1.05 \, \mu m)} \right) \Delta \lambda
\]
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Main Part: Snow Depth

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Snow Depth: April 02 2013
Snow Depth: May 05 2013
Main Part: Snow Water Equivalent

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- **Snow Depth**
  - Product

- **Snow Water Equivalent**
  - Product
Snow Water Equivalent: April 02 2013
Snow Water Equivalent: May 05 2013
Snow Water Equivalent
To Do

2013
- Masking
- Validation against in-situ data
- Re-calibration of CASI NIR radiances
- Updating products

2014+
- Improve atmospheric correction and retrievals
- Upscale to much larger areas worldwide
- New instruments
- Add observations for atmospheric retrievals (aerosols)
First Public AirMSPI data

2013-Jan-18 17:49:53 UTC, Hanford, view 000N, run 174510-12, version 001
Thank you for your attention!

Felix Seidel,
Thomas Painter,
ASO Team

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More in: