Constraining next generation physically-based mesoscale and global scale climate modeling
Snow albedo and its physical controls from SBG

Thomas H. Painter, K. Bormann, L. Carey, Jeff Dozier, Y. Qian, S. McKenzie Skiles
The thaw was beginning, a slow cold thaw which stained the snow without melting it.

- Émile Zola, Germinal
Thriving on Our Changing Planet
A Decadal Strategy for Earth Observation from Space
H-1c. Quantify rates of snow accumulation, snowmelt, ice melt, and sublimation from snow and ice worldwide at scales driven by topographic variability
Science questions

QESO: Determine the controls on absorbed solar radiation in snow and ice by grain size variation and radiative forcing by dust and black carbon to within daily mean of 3 W m$^{-2}$.

1. What is the contribution of regional warming (including its influence on snow grain size growth) and radiative forcing by dust and black carbon to present day snow and ice melt?

2. How will climate-driven and population-driven increases in desertification and forest fires lead to accelerated snow and ice melt and perturbation of the global water cycle and regional water supplies?

3. How will perturbations of snow and ice albedo impact mountain and ice sheet glacier mass balance?

4. For how long would reduction of radiative forcing by dust and BC mitigate against increased melt and sea level rise from climate warming?
To understand the time and space variation in the snow’s energy and mass balances along with the extensive feedbacks with the Earth’s climate, water cycle, and carbon cycle, it is critical to accurately measure snow. Indeed, the most recent Earth Science Decadal Survey (ESDS) recommended the Surface Biology and Geology (SBG) as an imperative “Designated measurement”. SBG would include a visible through shortwave infrared imaging spectrometer and spectral thermal imager for understanding snow spectral albedo, the controls on snow albedo, and snow surface temperature.

SnowEx 2019: Sierra Nevada, leveraging the ASO program with CA DWR

SnowEx 2020: Most likely heading to the Arctic for partnership with ABOVE.
Shortwave dominates melt

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

Global climatological annual snow cover days (in weeks) for the period 1972-2017 from NOAA-SCE

Bormann, et al, NCC, in review
Changes in grain size and RF on $\alpha$

\[
\frac{d\alpha}{dt} = \frac{\partial \alpha}{\partial GS} \frac{\partial GS}{\partial t} + \frac{\partial \alpha}{\partial RF} \frac{\partial RF}{\partial t}
\]

for a fixed solar zenith angle and spectral irradiance
Clean snow

Present day Dirty snow

Photos courtesy Jeffrey Deems/University of Colorado, James Balog/Extreme Ice Survey, and NASA IDS project Integrated Hydro Response

Skiles et al, 2012
Uncertain controls on $\alpha$ and melt

Model Melt Uncertainty due to Uncertainty in GS and RF

NCAR CESM + SNICAR, Flanner pers. comm
High Mountain Asia

WRF-Chem/CLM/SNICAR comparisons with MODSCAG and MODDRFS (Painter et al 2009; 2012)
In the context of our NASA High Mountain Asia team project.

Sarangi et al, in review
Understand the physical controls on snow and ice albedo across Earth’s cryosphere and their contribution to melting.

Also:
- Liquid water
- Snow algae

### Uncertainties

2.1 ± 5.1 W m⁻²

0.4 ± 0.1%
<table>
<thead>
<tr>
<th>NASA Science Goals</th>
<th>SIRFA Science Goals</th>
<th>SIRFA Science Objectives</th>
<th>Scientific Measurement Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1. Quantify the net effect of time and space variation of light-absorbing impurities on the solar absorption by snow and ice</td>
<td>Snow and ice spectral albedo in 400–2350 nm spectral range with 30-nm spectral resolution by 0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Quantify the net effect of time and space variation of snow grain size on the solar absorption by snow and ice</td>
<td>Spectrally-integrated snow albedo in the range 0.3–0.9 unitless, by 0.015</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Constrain regional and global climate models to understand the relative importance of contributions to melt of light-absorbing impurities, changing grain size, and the remainder of the energy balance</td>
<td>Snow grain radius: 50–2000 μm, by 20 μm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Solar at-surface radiative forcing by dust/BC/organics by 3 W m⁻²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>In representative areas from Polar ice sheets, tundra/taiga snow, Mid-latitude glaciers and snow, Equatorial glaciers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>At least one seasonal transition over a variety of environmental conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Visible/shortwave infrared (VSWIR) radiance spectra, 400–2350 nm:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20-nm precision at 400–900 nm for radiative forcing due to dust and BC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30-nm precision at 980–1070 nm for snow grain size</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10-nm precision at 740–780 nm for oxygen A-band atmospheric correction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10-nm precision at 860–1020 nm and 1050–1250 nm for water vapor corrections</td>
</tr>
</tbody>
</table>
Measurement Needs
ASO time series

Total SWE = 1897.6 TAF

Radiative Forcing (Wm^-2)

Day of Year

2013
2014
2015
2016

SWE Value (Meters)
10
0

Kings (USCAKC) 388 TAF
Colorado Rocky Mountains
AVIRIS Classic
June 11, 2011

Painter et al 2013
Refining modeling
Path Forward

• Contributions to SBG SATM
• Evaluation of directional reflectance measurements (Gatebe/GSFC)
• Assessment of EMIT retrievals
• Implementation of cryosphere products in EnMAP chain
• SnowEx campaigns