Constraining next generation physically-based mesoscale and global scale climate modeling

Snow albedo and its physical controls from SBG

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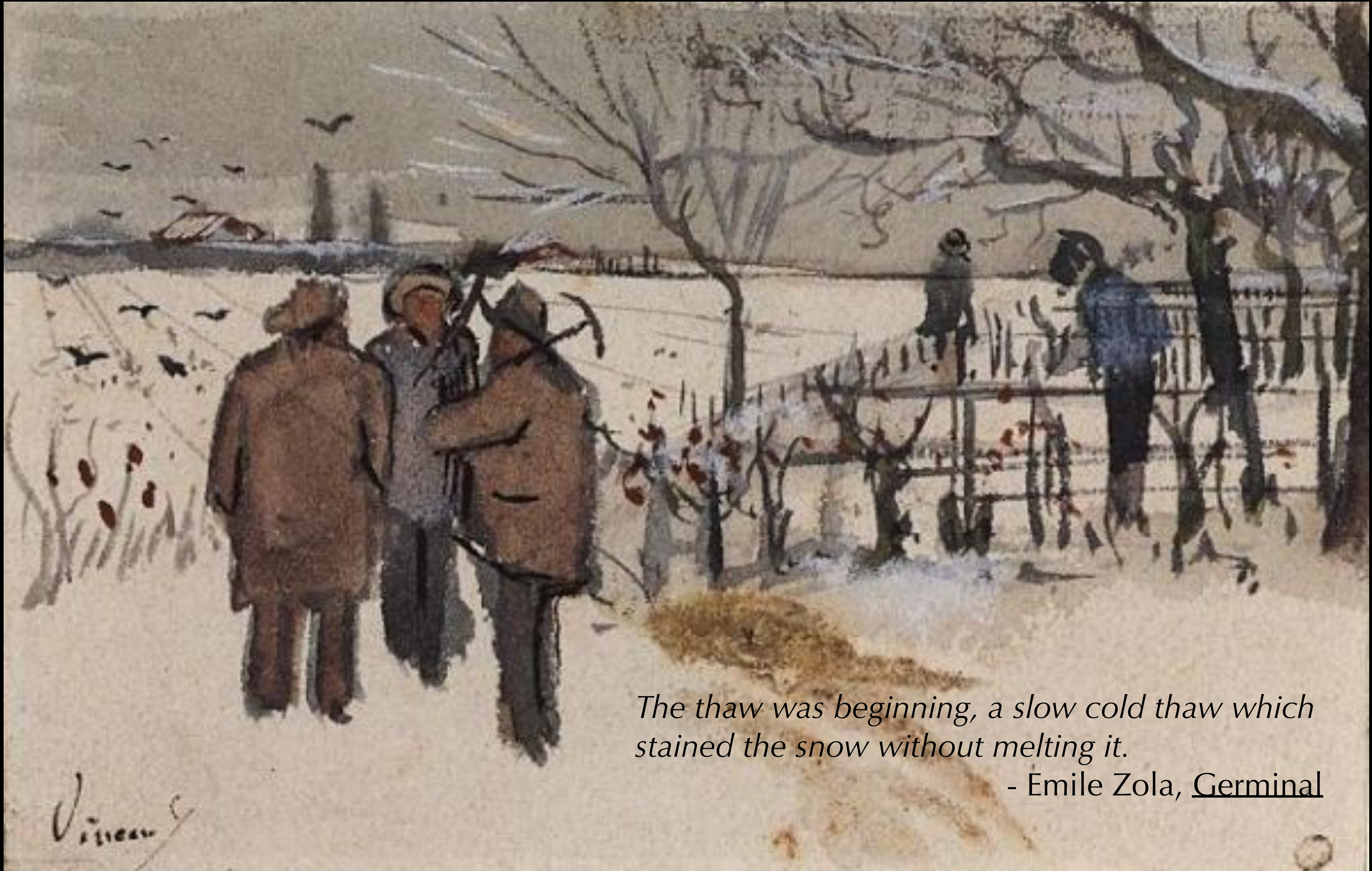


The thaw was beginning, a slow cold thaw which stained the snow without melting it.

- Emile Zola, Germinal

Thriving on Our Changing Planet

A Decadal Strategy for Earth Observation from Space

Recommended NASA Priorities: Designated

TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their direct and indirect effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform	X		

Surface Biology and Geology	CATE Cap $650M	Key to understanding active surface changes (eruptions, landslides and evolving landscapes); snow and ice accumulation, melting, and albedo; hazard risks in rugged topography; effects of changing land-use on surface energy, water, momentum and carbon fluxes; physiology of primary

H-1c. *Quantify rates of snow accumulation, snowmelt, ice melt, and sublimation from snow and ice worldwide at scales driven by topographic variability*

DESIGNATED—***Targeted Observable:*** **Surface Biology and Geology** [**H-1c**, 2a, 2b, 3a, 3b, 3c, 4a, 4c, 4d; W-3a; **S-1a**, 1c, 2b, 4b, 4c, 7a; E-1a, **1c**, 1d, **2a**, **3a**, 5a, 5b, 5c; C-3a, 3c, 3d, 6b, 7e, 8f]

& Change	and permafrost	ionospheric correction

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?


National Aeronautics and Space Administration

NASA SnowEx Science Plan:
Assessing Approaches for Measuring Water in Earth's Seasonal Snow

Science Plan Committee: Mike Durand, Charles Gatebe, Ed Kim, Noah Molotch, Thomas H. Painter, Mark Raleigh, Melody Sandells, and Carrie Vuyovich

"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

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

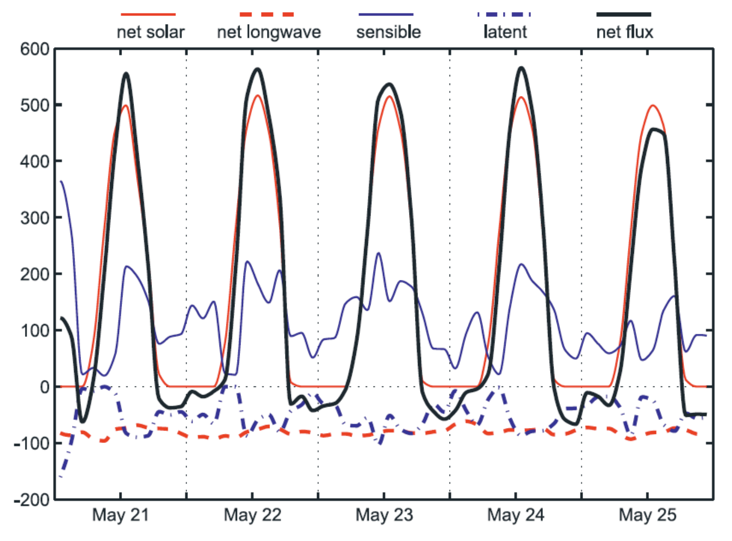
SnowEx 2020: Most likely heading to the Arctic for partnership with ABOVE.

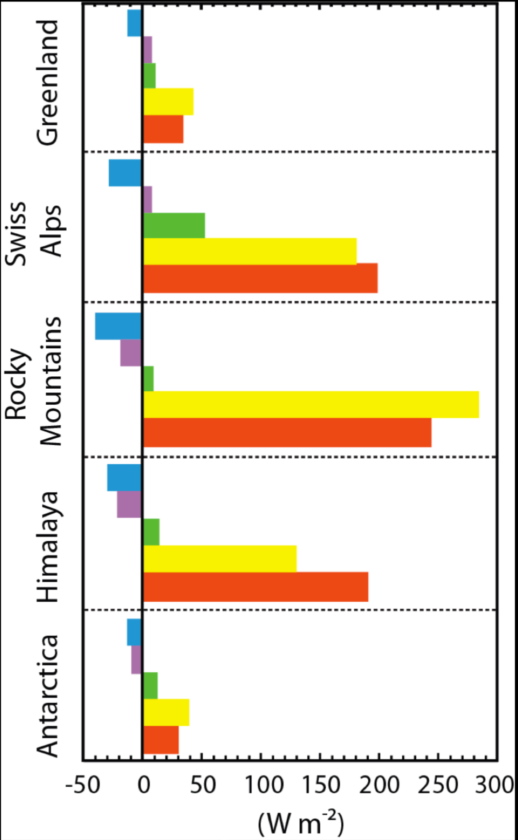
infrared imaging spectrometer and spectral thermal imager for understanding snow spectral albedo, the controls on snow albedo, and snow surface temperature. "

Shortwave dominates melt

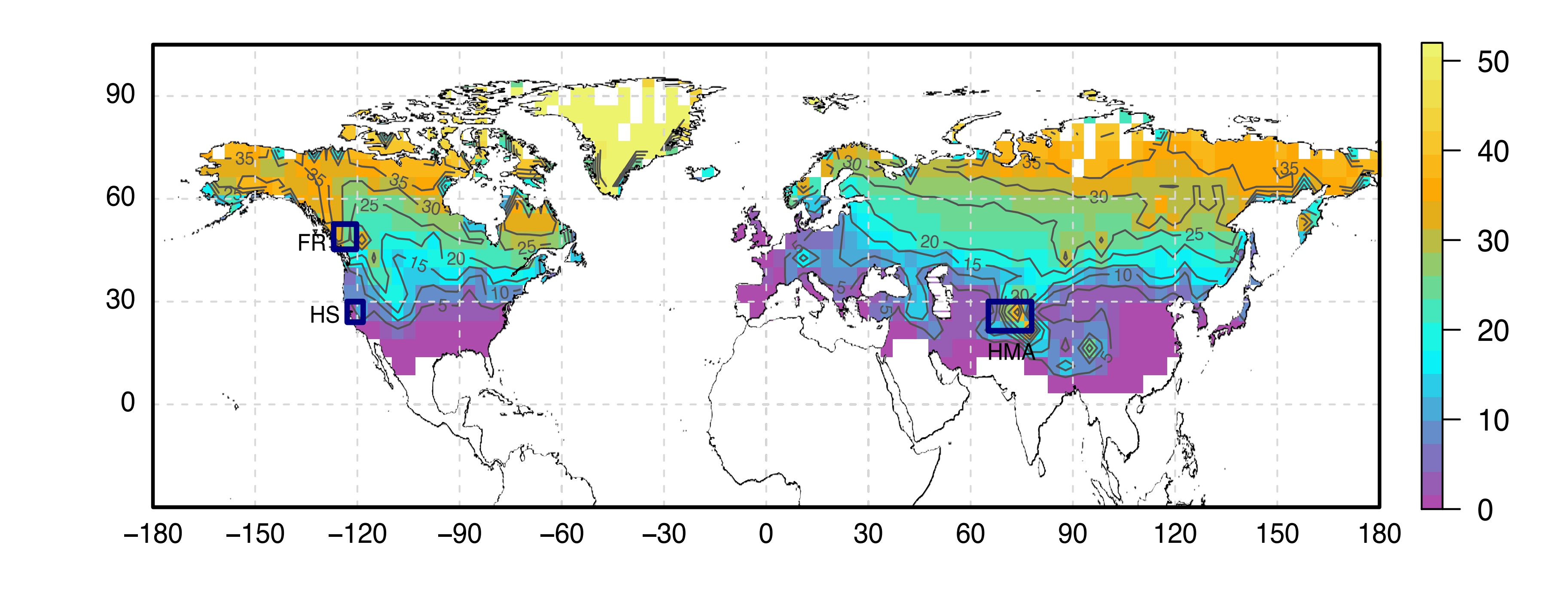
Net Flux | Net Solar | Net Longwave | Sensible | Latent

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





Terrestrial Impact



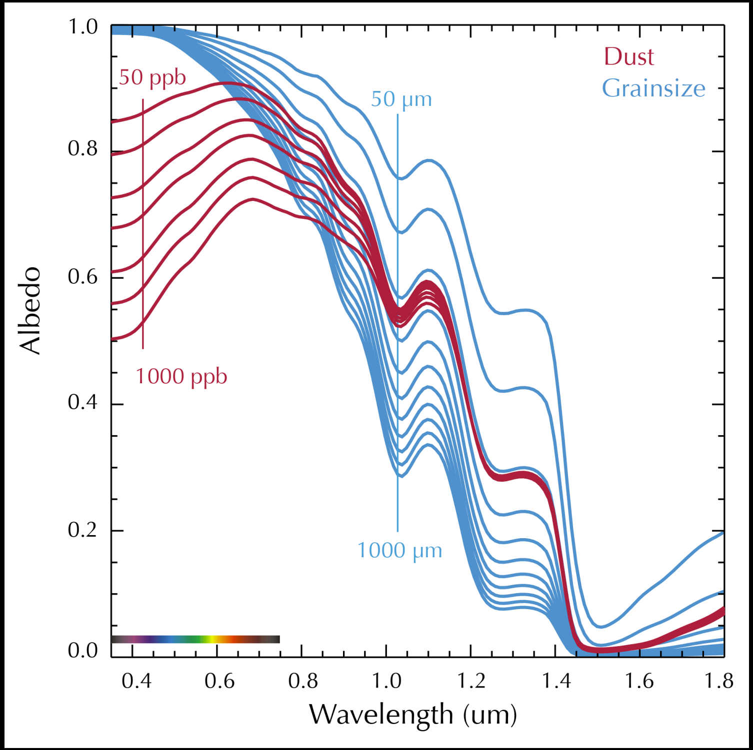
Global climatological annual snow cover days (in weeks) for the period 1972-2017 from NOAA-SCE

Bormann, et al, *NCC*, in review

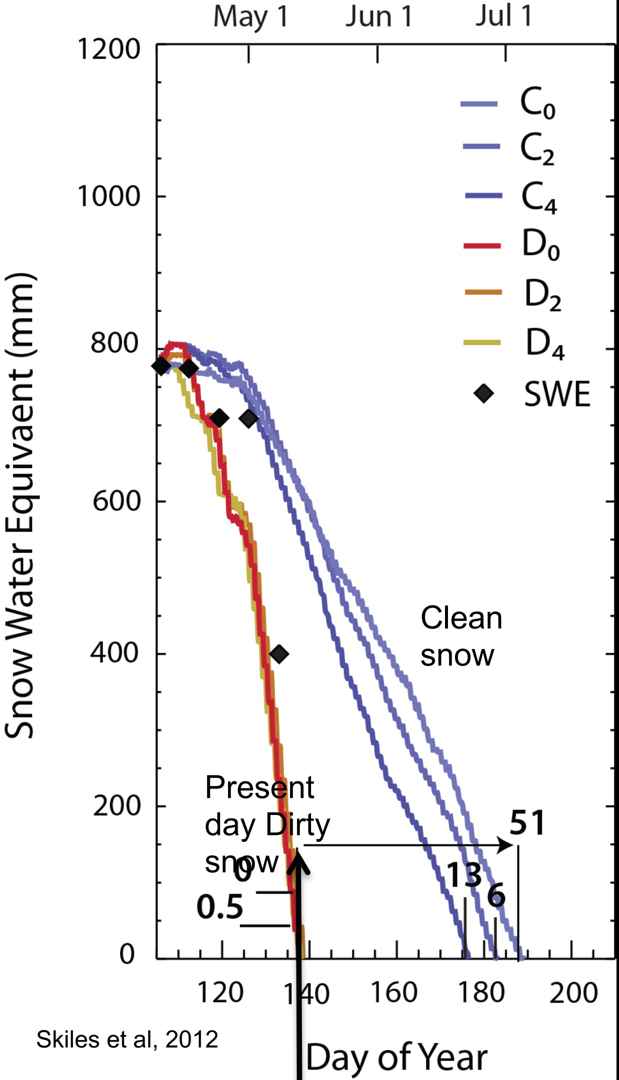
Changes in grain size and RF on α

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

for a fixed solar zenith angle and spectral irradiance

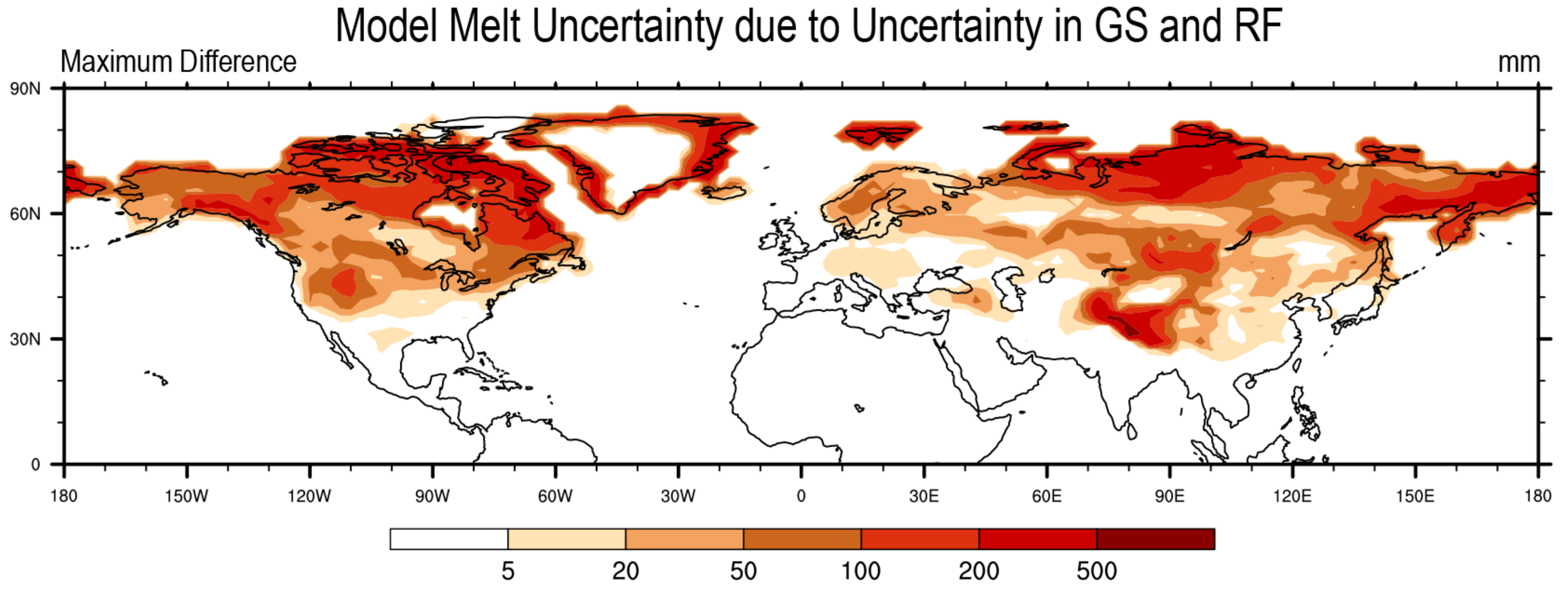


Photos courtesy Jeffrey Deems/University of Colorado, James Balog/Extreme Ice Survey, and NASA IDS project *Integrated Hydro Response*



Skiles et al, 2012

Uncertain controls on α and melt



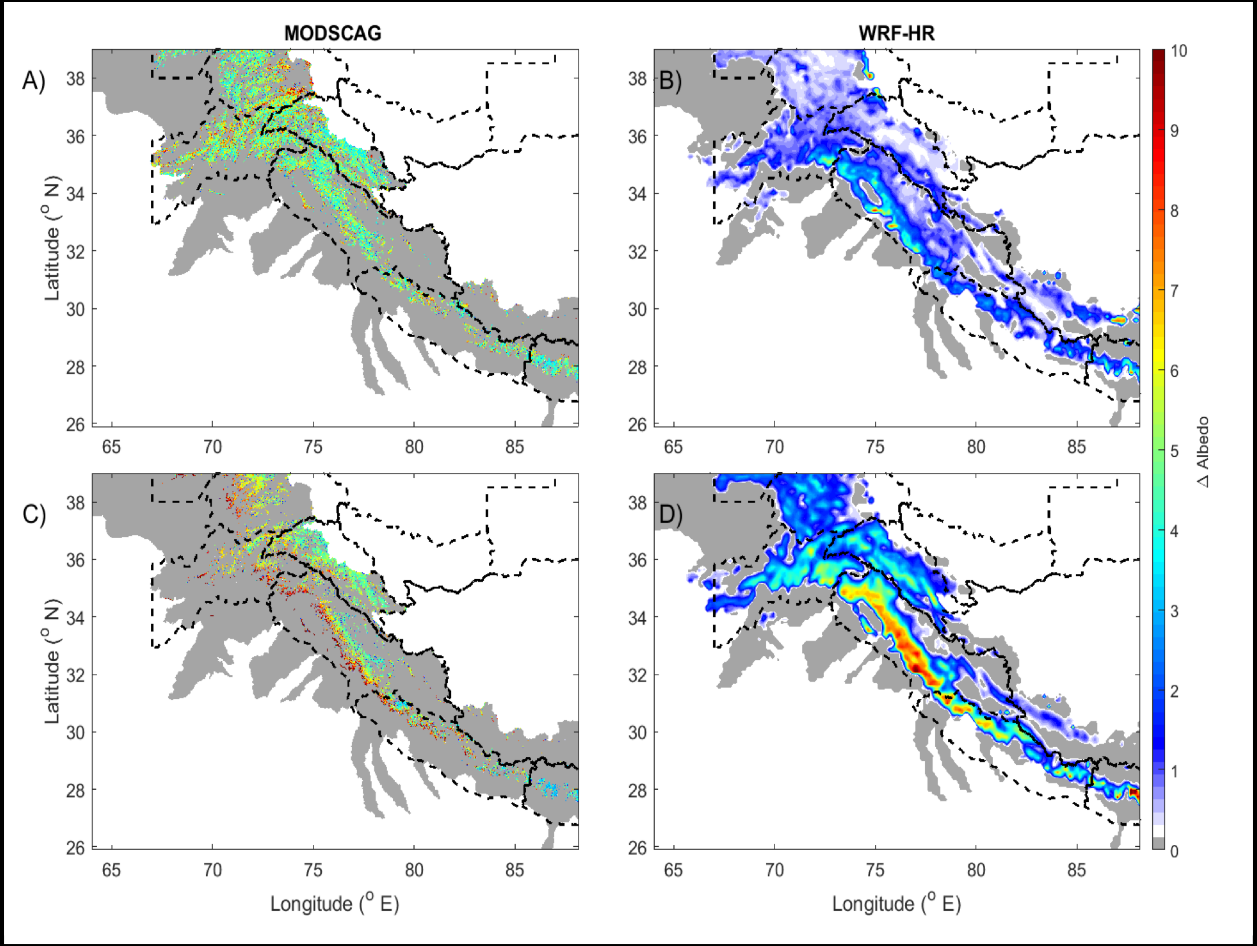
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 112, D11202, doi:10.1029/2006JD008003, 2007

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*



SATM

NASA Science Goals	SIRFA Science Goals	SIRFA Science Objectives	Scientific Measurer
			Physical Parameters
Climate Change and Variability: Understand the roles of ocean, atmosphere, land, and ice in the climate system and improve predictive capability for future evolution.	Understand the physical controls on snow and ice albedo across Earth´s cryosphere and their contribution to melting.	1. Quantify the net effect of time and space variation of light-absorbing impurities on the solar absorption by snow and ice	Snow and ice spectral albedo in 400–2350 nm spectral range with 30-nm spectral resolution by 0.03 Spectrally-integrated snow albedo in the range 0.3–0.9 unitless, by 0.015
		2. Quantify the net effect of time and space variation of snow grain size on the solar absorption by snow and ice	Snow grain radius: 50–2000 µm, by 20 µm Solar at-surface radiative forcing by dust/BC/organics by 3 W m^{-2}
		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	In representative areas from Polar ice sheets, tundra/taiga snow, Mid-latitude glaciers and snow, Equatorial glaciers At least one seasonal transition over a variety of environmental condi-tions

Uncertainties

-0.4±0.1%

0.2±0.1%

±20µm

2.1±5.1 W m^{-2}

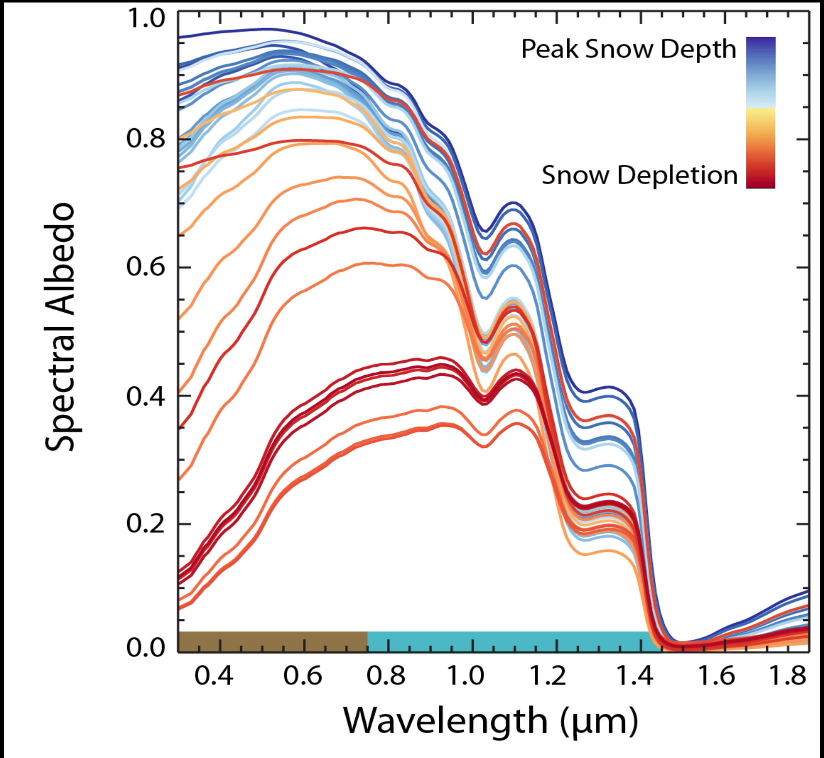
Also:

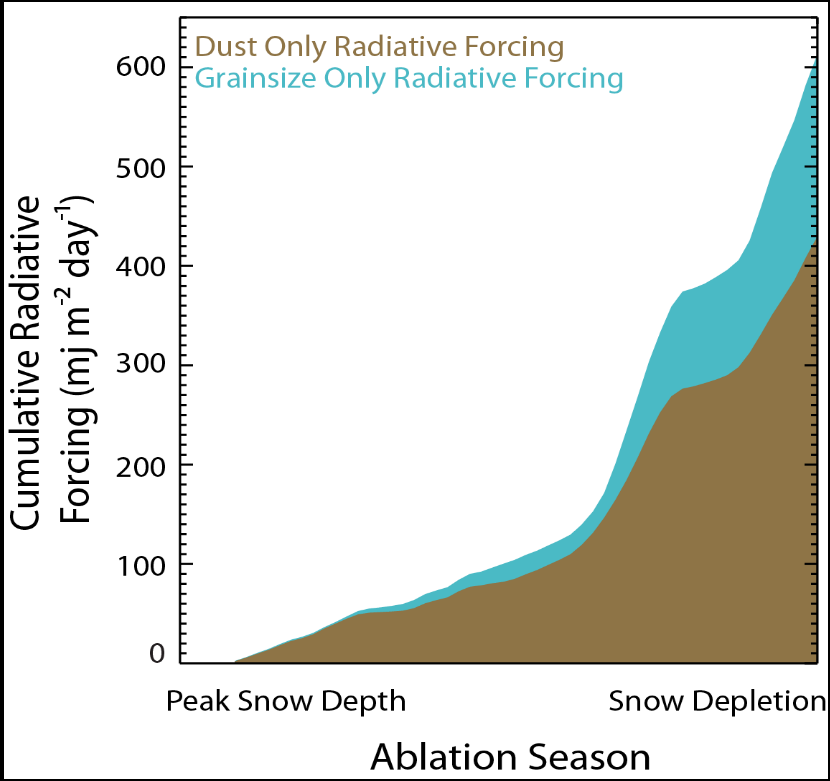
- Liquid water
- Snow algae

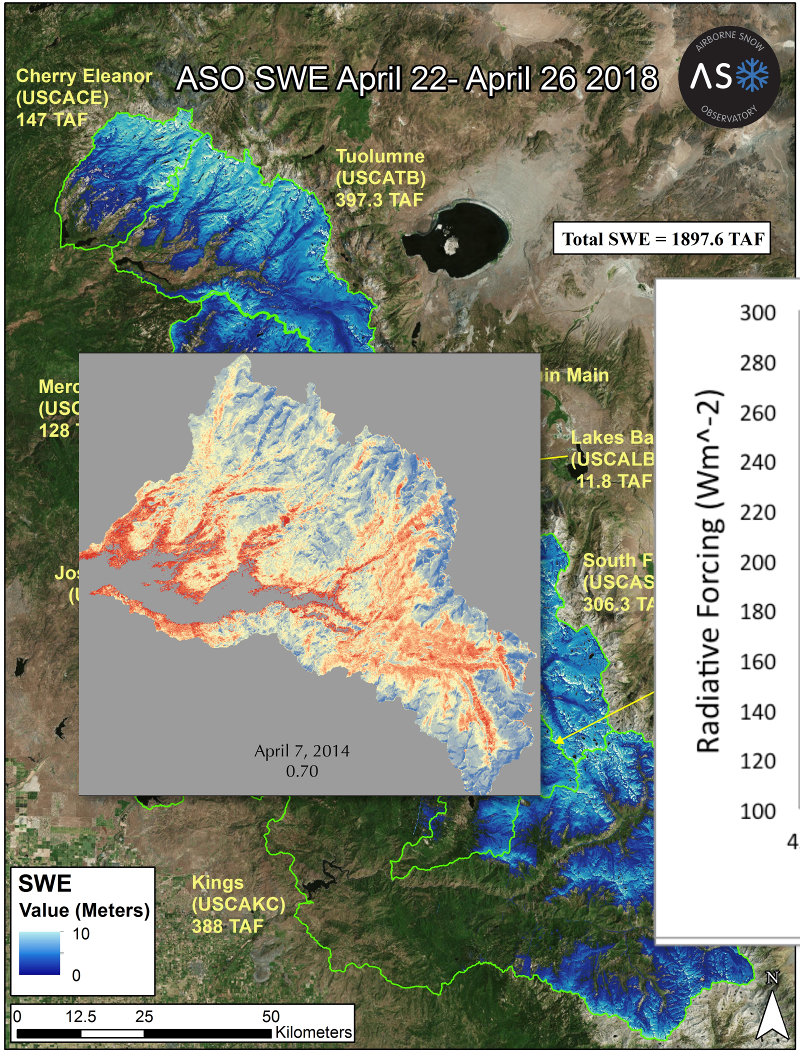
SATM

NASA Science Goals	SIRFA Science Goals	SIRFA Science Objectives	Scientific Measurement Requirements	
			Physical Parameters	Observable
Climate Change and Variability: Understand the roles of ocean, atmosphere, land, and ice in the climate system and improve predictive capability for future evolution.	Understand the physical controls on snow and ice albedo across Earth´s cryosphere and their contribution to melting.	1. Quantify the net effect of time and space variation of light-absorbing impurities on the solar absorption by snow and ice 2. Quantify the net effect of time and space variation of snow grain size on the solar absorption by snow and ice 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	Snow and ice spectral albedo in 400–2350 nm spectral range with 30-nm spectral resolution by 0.03 Spectrally-integrated snow albedo in the range 0.3–0.9 unitless, by 0.015 Snow grain radius: 50–2000 µm, by 20 µm Solar at-surface radiative forcing by dust/BC/organics by 3 W m^{-2} In representative areas from Polar ice sheets, tundra/taiga snow, Mid-latitude glaciers and snow, Equatorial glaciers At least one seasonal transition over a variety of environmental conditions	Visible/shortwave infrared (VSWIR) radiance spectra, 400–2350 nm: 20-nm precision at 400–900 nm for radiative forcing due to dust and BC 30-nm precision at 980–1070 nm for snow grain size 10-nm precision at 740–780 nm for oxygen A-band atmospheric correction 10-nm precision at 860–1020 nm and 1050–1250 nm for water vapor corrections

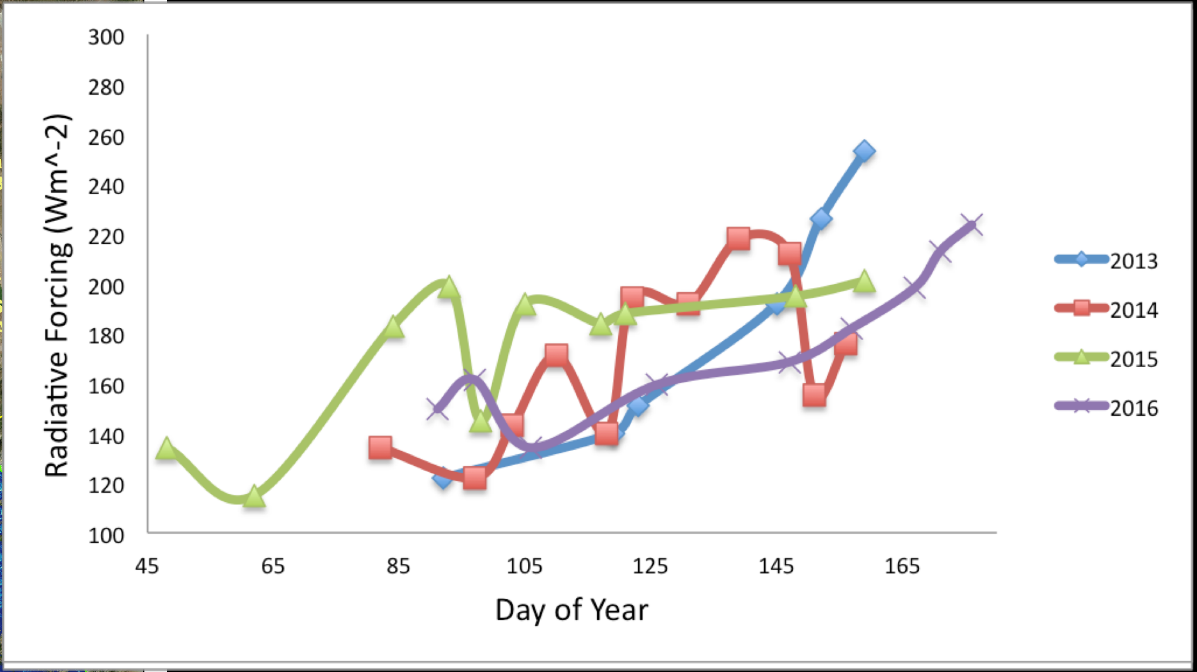
Measurement Needs



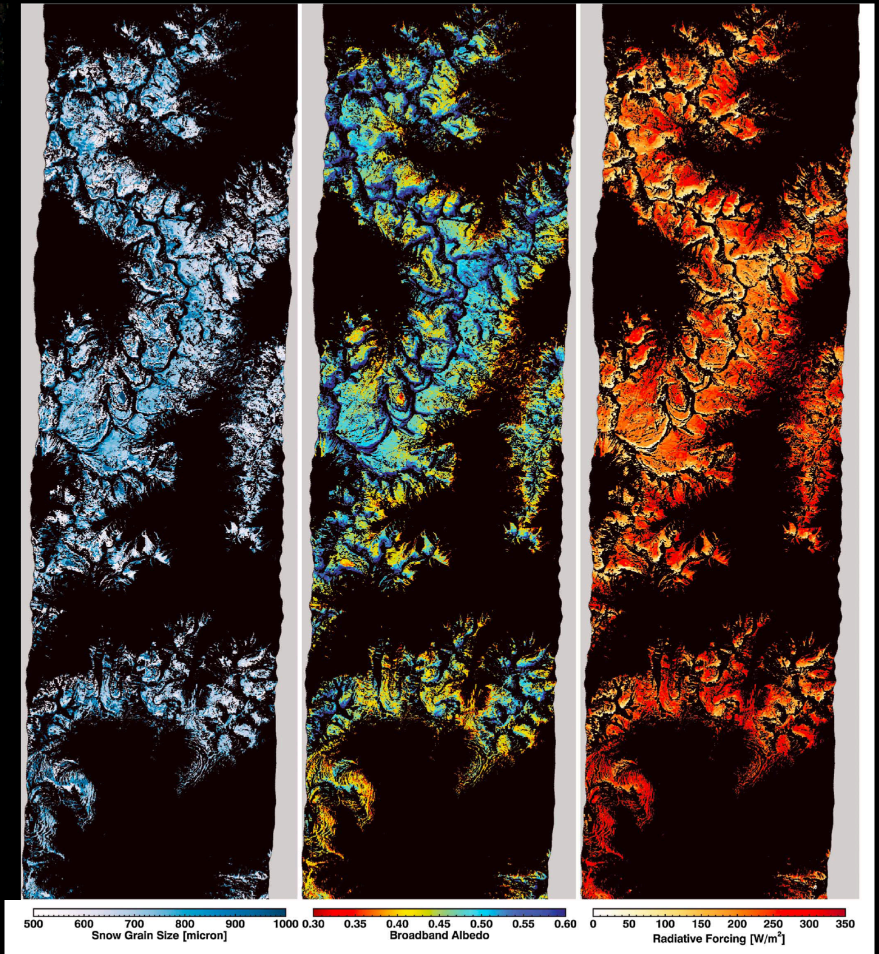




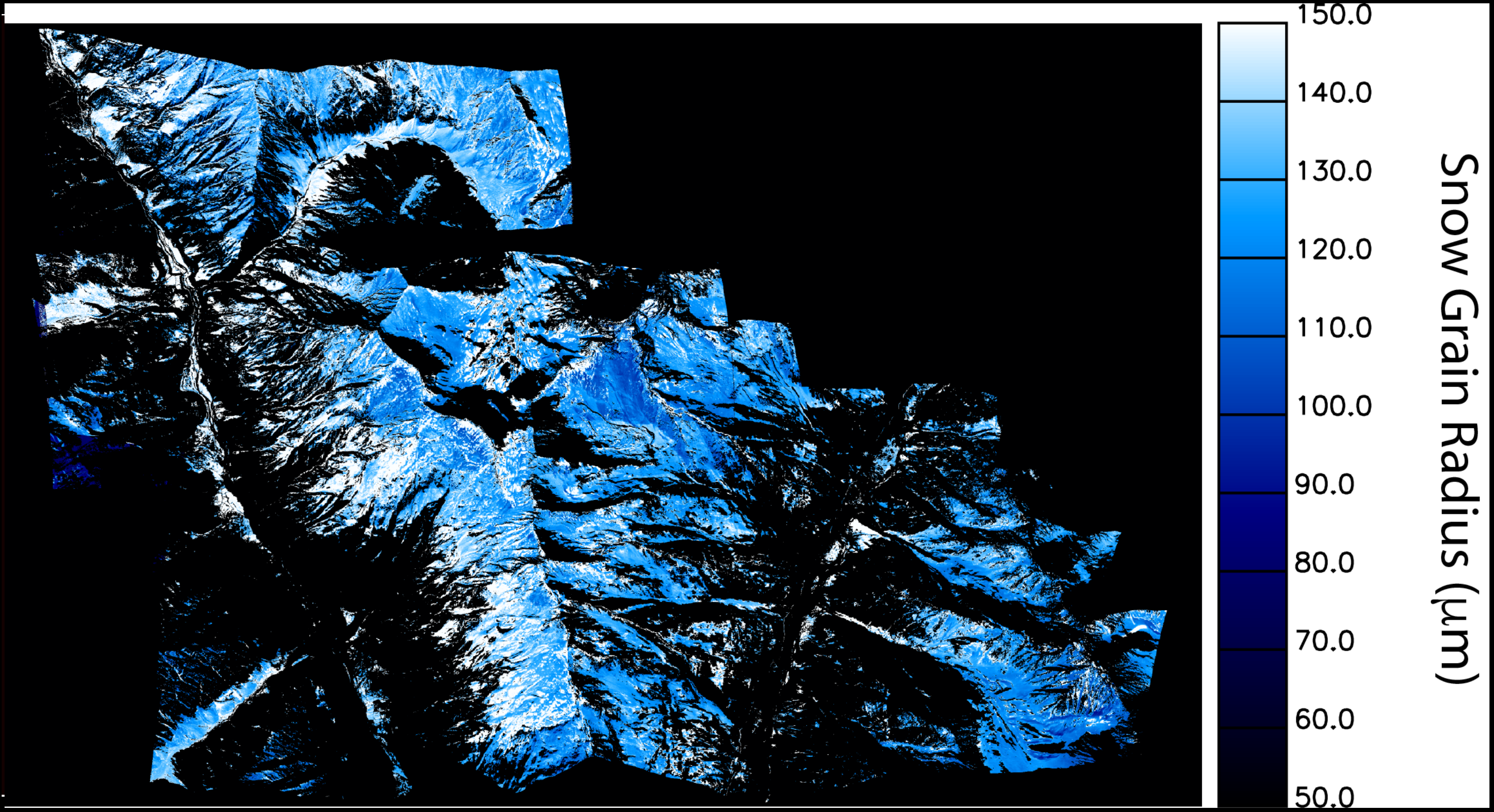
ASO time series

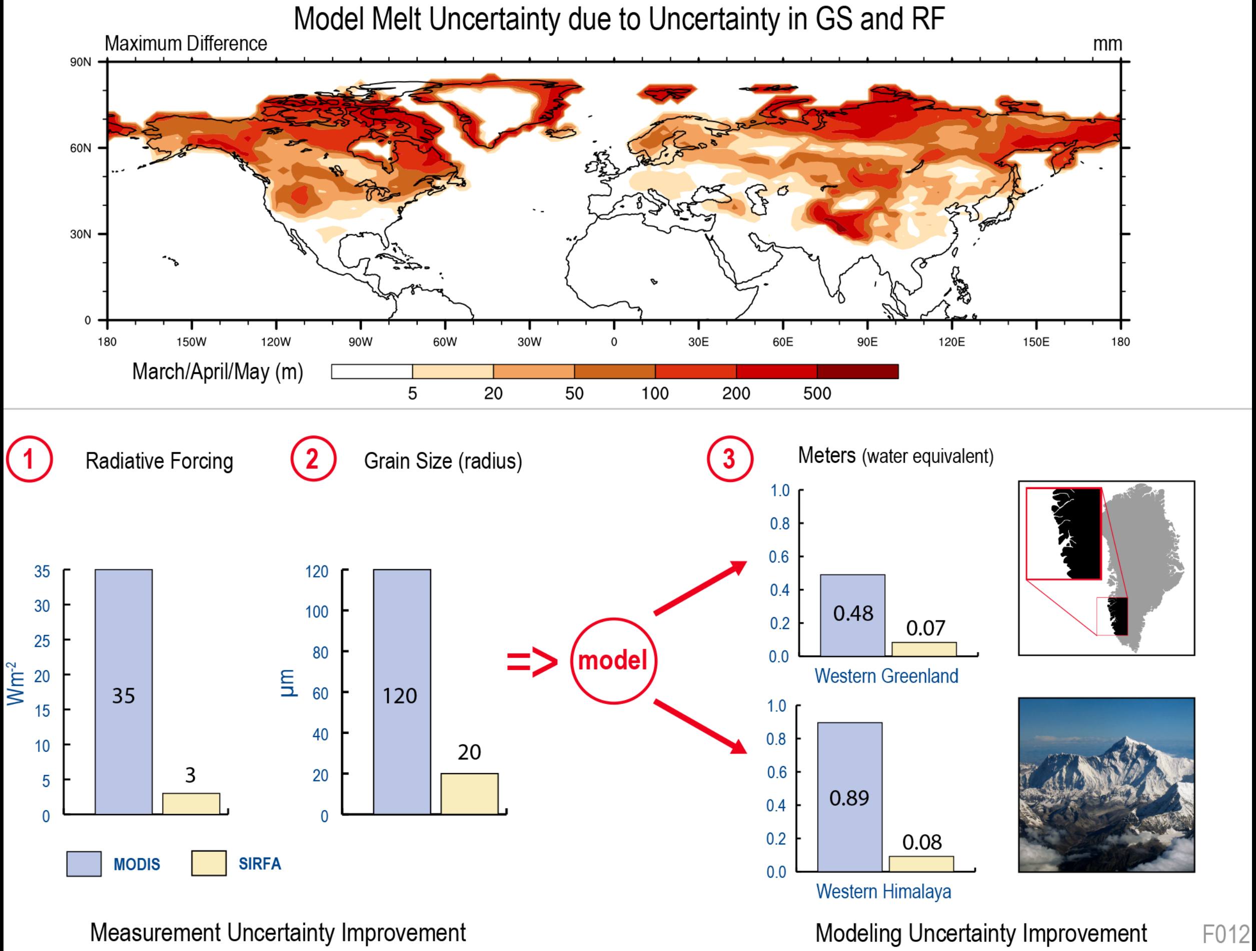


Colorado Rocky Mountains
AVIRIS Classic
June 11, 2011



Painter et al 2013


150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
Snow Grain Radius (μm)


Model Melt Uncertainty due to Uncertainty in GS and RF
Maximum Difference
mm
90N
60N
30N
0
180
150W
120W
90W
60W
30W
0
30E
60E
90E
120E
150E
180
March/April/May (m)
5
20
50
100
200
500
1
Radiative Forcing
2
Grain Size (radius)
3
Meters (water equivalent)
35
30
25
20
15
10
5
0
Wm-2
35
3
120
100
80
60
40
20
0
μm
120
20
=> model
1.0
0.8
0.6
0.4
0.2
0.0
0.48
0.07
Western Greenland
0.89
0.08
Western Himalaya
MODIS
SIRFA
Measurement Uncertainty Improvement
Modeling Uncertainty Improvement
F012

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

Jet Propulsion Laboratory
California Institute of Technology

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