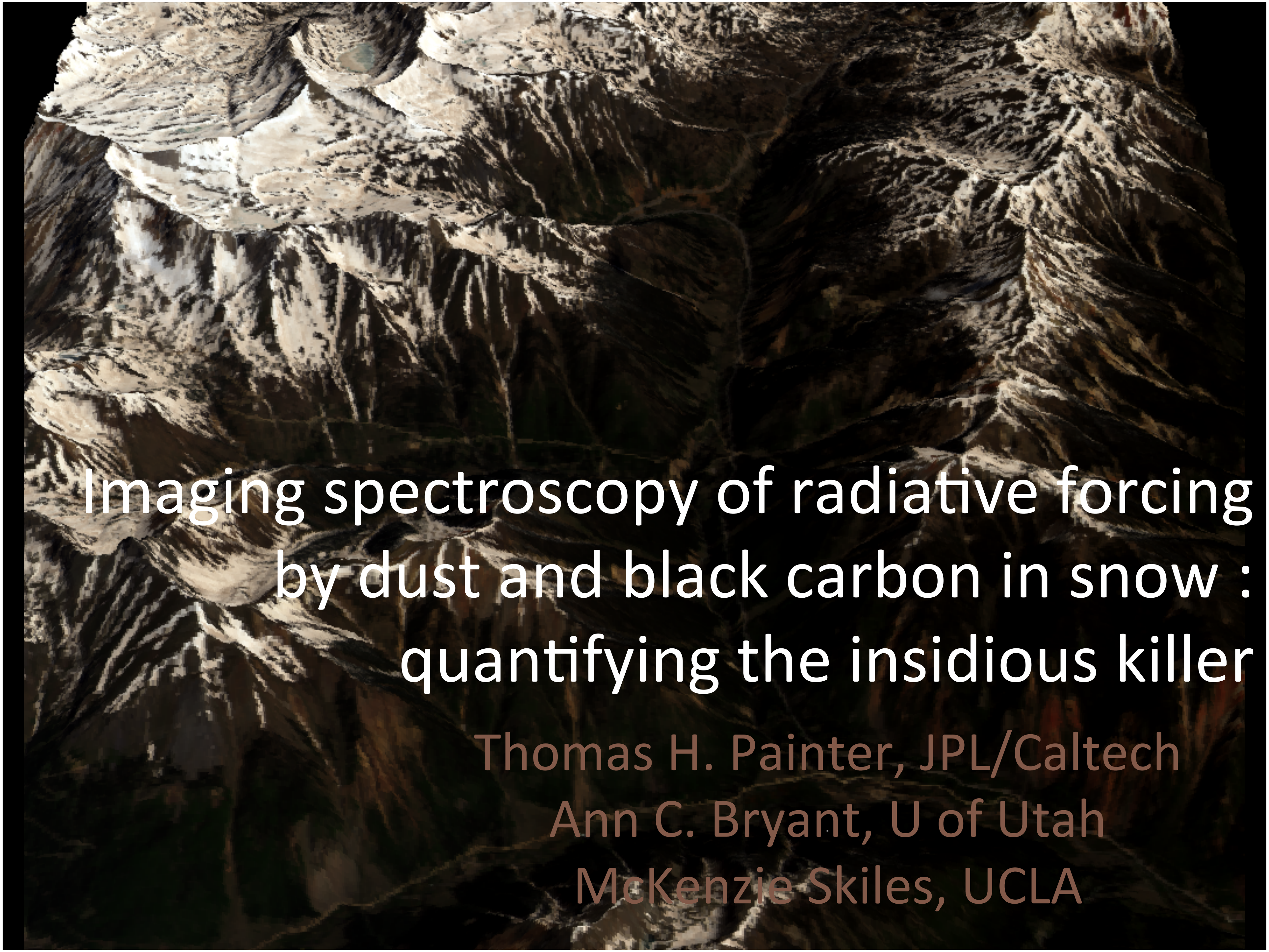


Imaging spectroscopy of radiative forcing by dust and black carbon in snow : quantifying the insidious killer

Thomas H. Painter, JPL/Caltech
Ann C. Bryant, U of Utah
McKenzie Skiles, UCLA

Snow Pit Speech

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

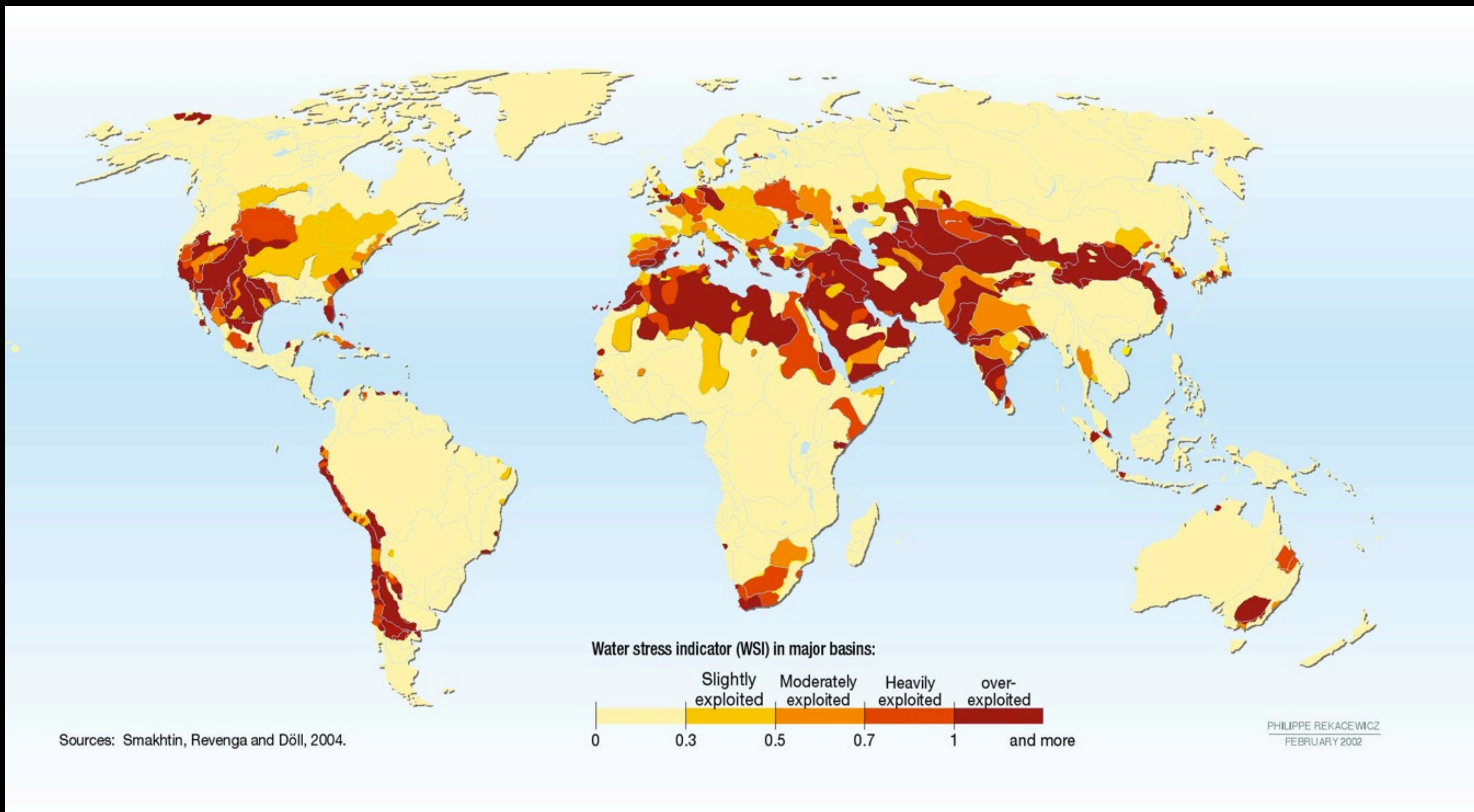
- Perspective on snow and ice melt
- Impacts of changes in albedo
- Global changes in dust and BC loading
- Global need for HyspIRI (USGCRP goals 1&2, Advance Science and Inform Decisions)
- Imaging spectroscopy of radiative forcing
- Upper Colorado River Basin, Spring 2011

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

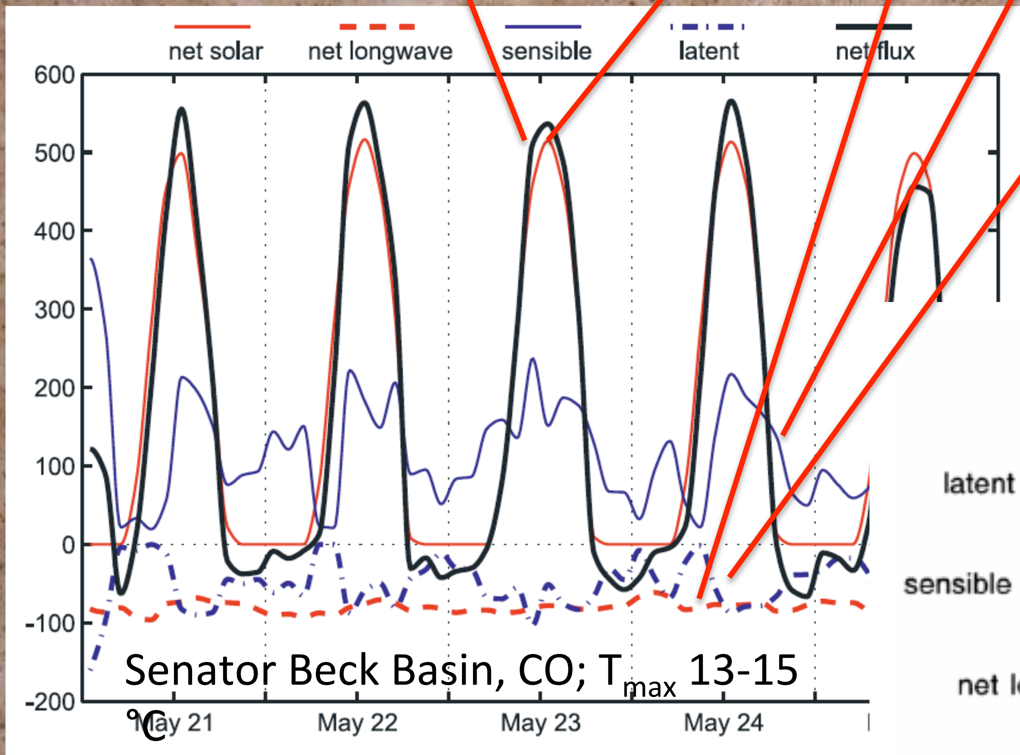
Global Water Stress



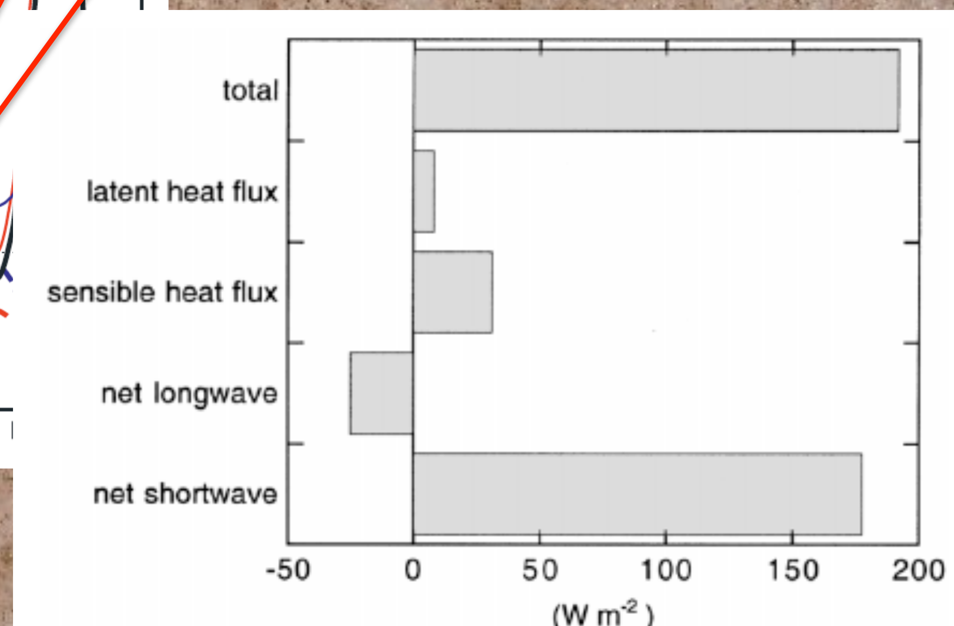
Source: http://www.unep.org/

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

What controls snowmelt?



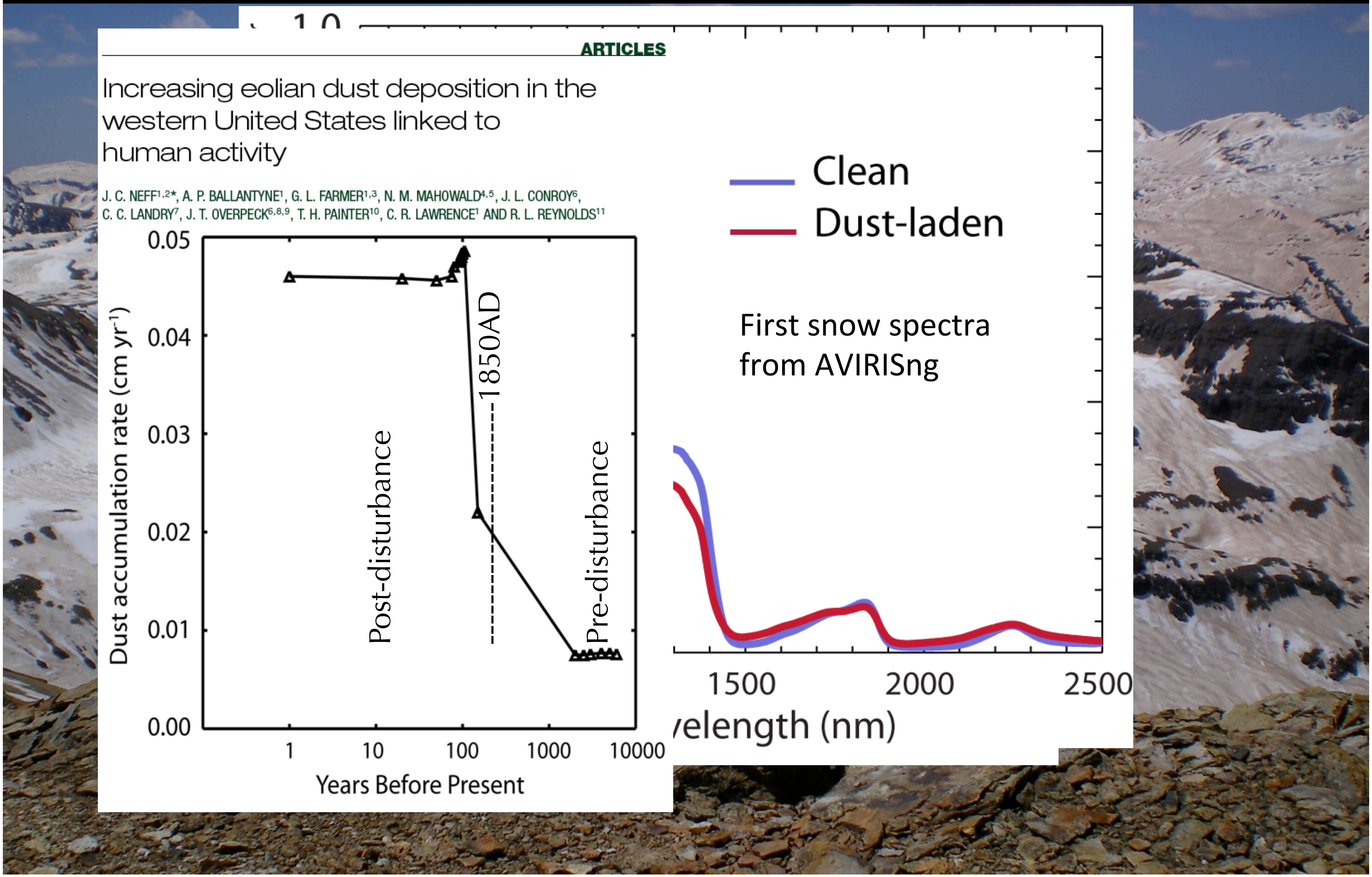
Senator Beck Basin, CO; T_{max} 13-15 °C



Morteratschgletscher (*Oerlemans, 2000*)

Elk Range, Colorado River Basin, April 2009

Upper Colorado River Basin



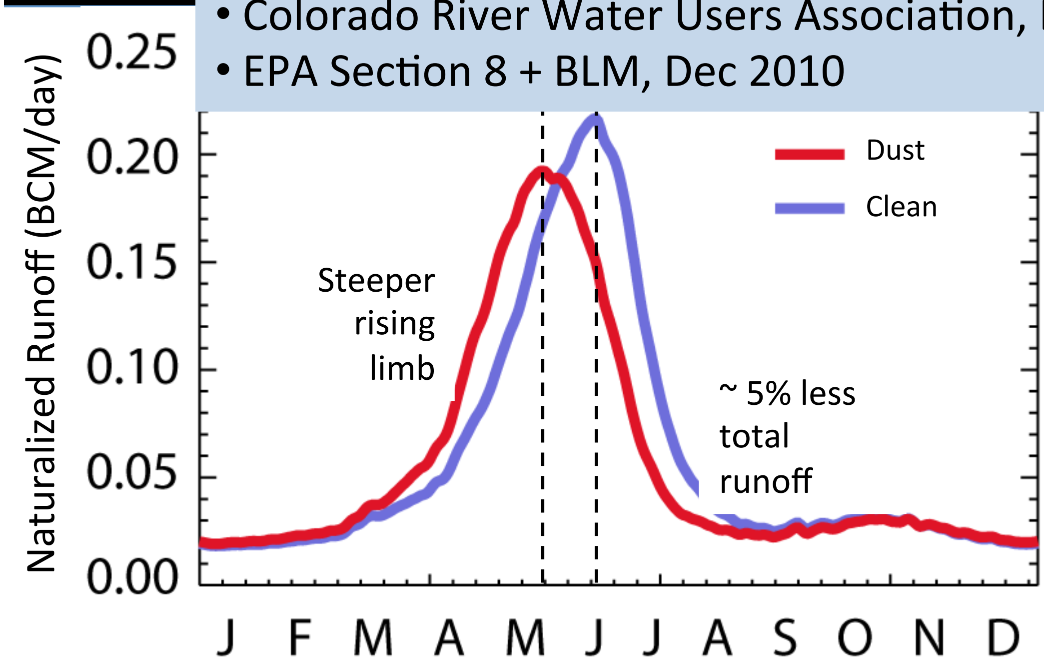
Response of Colorado River runoff to dust radiative forcing in snow

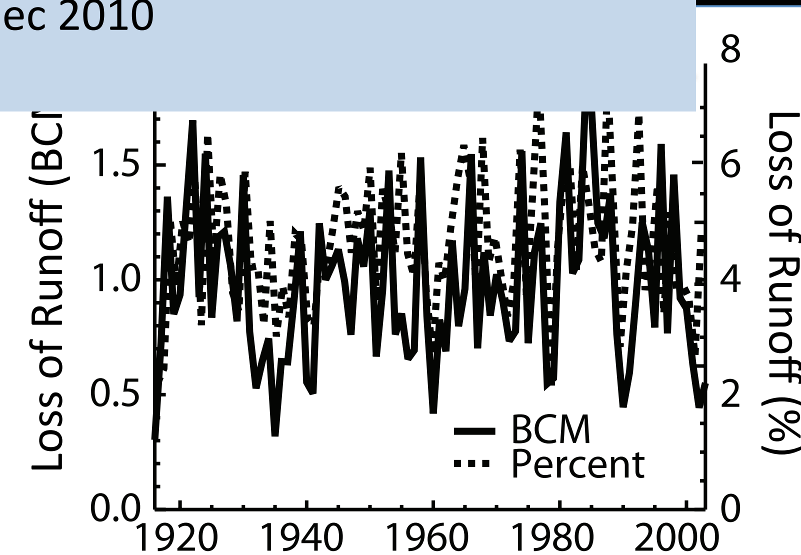
Thomas H. Painter[a,b,1], Jeffrey S. Deems[c,d], Jayne Belnap[e], Alan F. Hamlet[f], Christopher C. Landry[g], and Bradley Udall[d]

[a]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109; [b]Joint Institute for Regional Earth System Science and Engineering, University of California, Los Angeles, CA 90095; [c]National Snow and Ice Data Center, Boulder, CO 80309; [d]National Oceanic and Atmospheric Administration Western Water Assessment, Boulder, CO 80309; [e]United States Geological Survey, Southwest Biological Center, Moab, UT 84532; [f]University of Washington, Department of Civil and Environmental Engineering, Seattle, WA 98195; and [g]Center for Snow and Avalanche Studies, Silverton, CO 81433

Government and Manager Briefings:

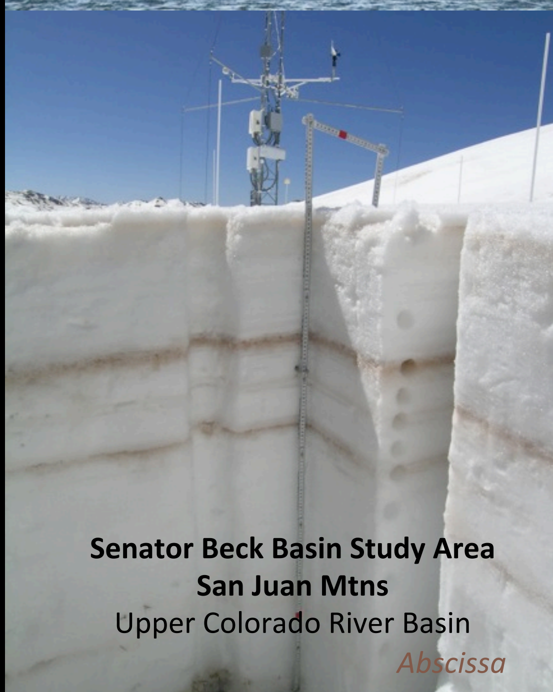
- Anne Castle, Asst Secretary of Interior for Water and Science, Nov 2010
- US Global Change Research Program, Nov 2010
- NOAA HQ, Nov 2010
- Colorado River Water Users Association, Dec 2010
- EPA Section 8 + BLM, Dec 2010

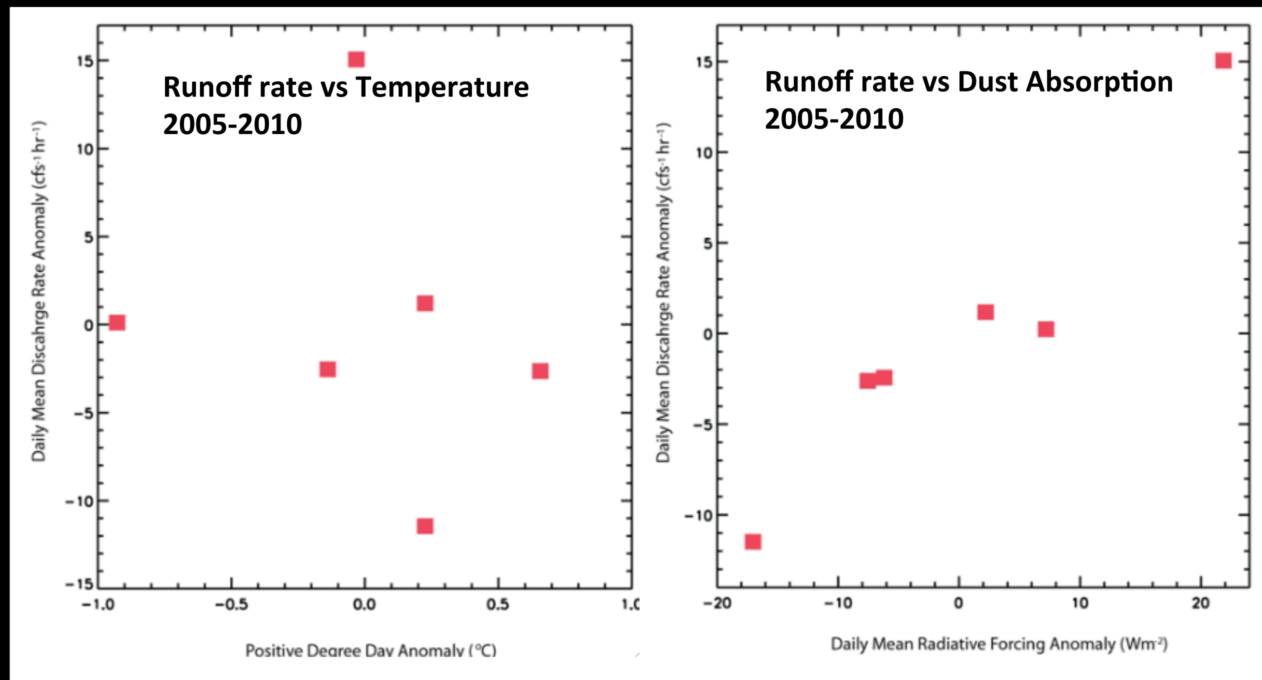




ıst radiative forcing in snow in the Upper Colorado River Basin duces annual runoff by ~5% or more than half of Mexico's annual otment under treaty. **Painter et al 2010, *PNAS***

Snowmelt Runoff and Dust Forcing

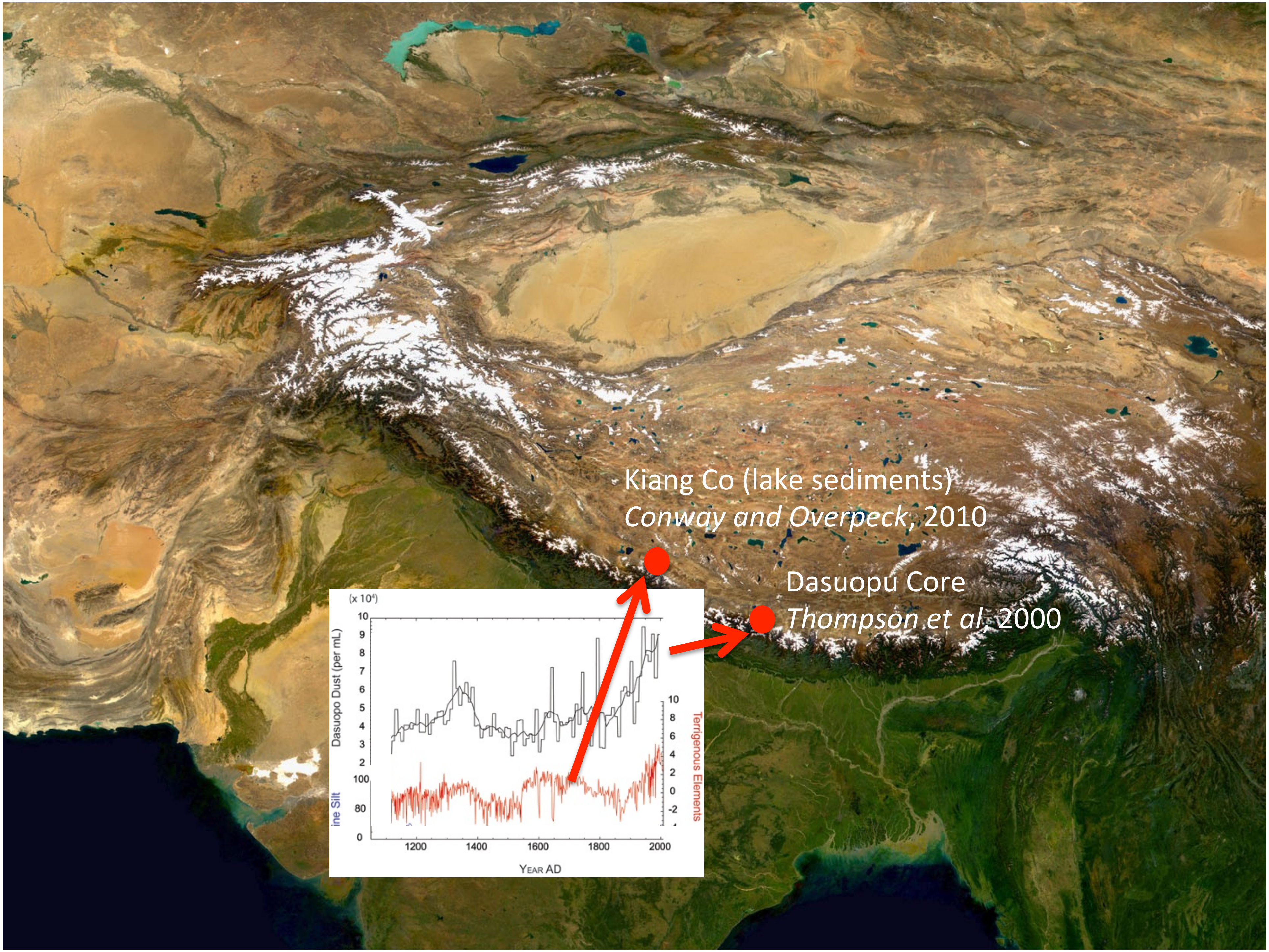




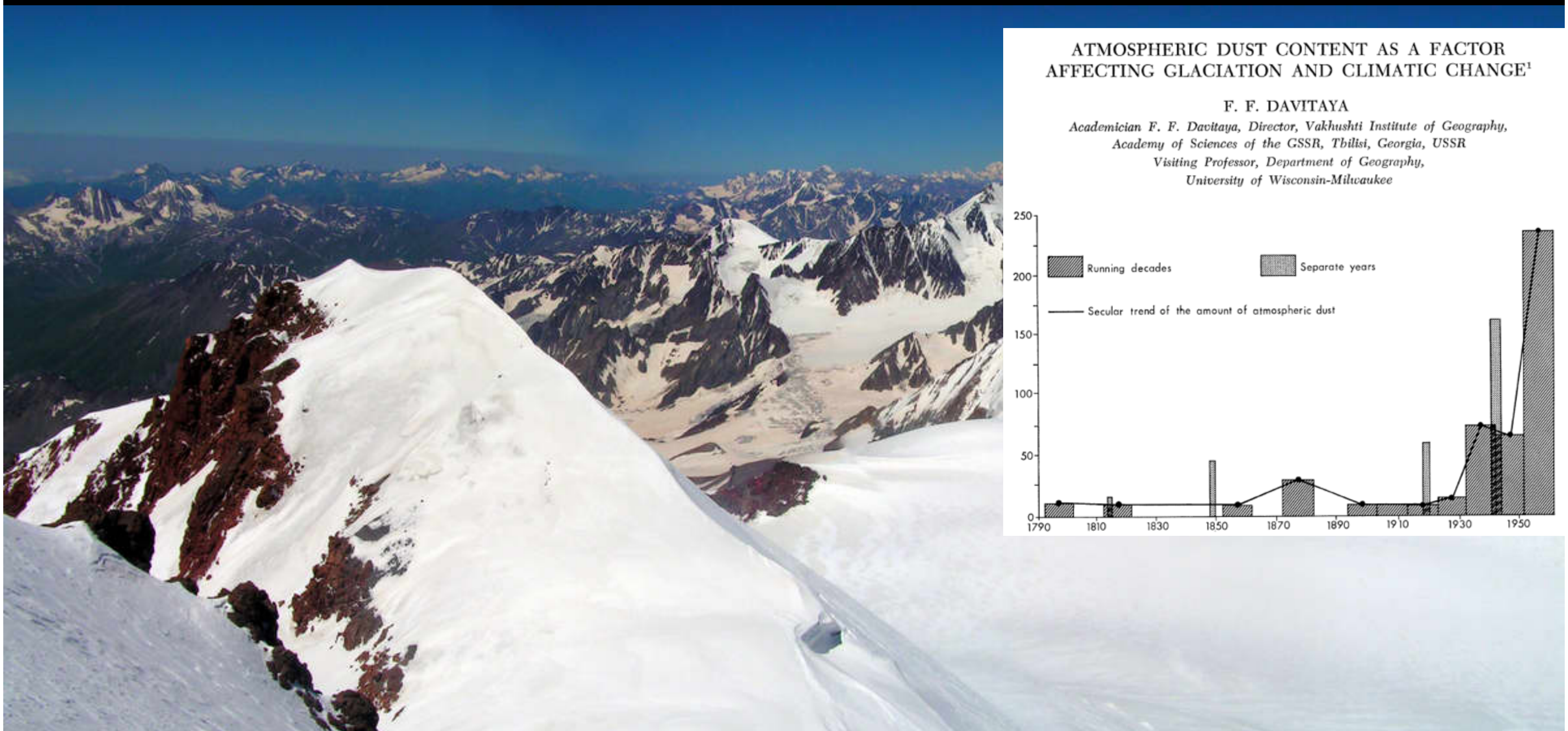
Take Home: Albedo and radiative forcing drive

Painter et al (in preparation)

Funding: *NASA Interdisciplinary Science*


Kiang Co (lake sediments)
Conway and Overpeck, 2010
Dasuopu Core
Thompson et al, 2000
(x 10⁴)
Dasuopo Dust (per mL)
Terrigenous Elements
Year AD

Caucasus Mountains

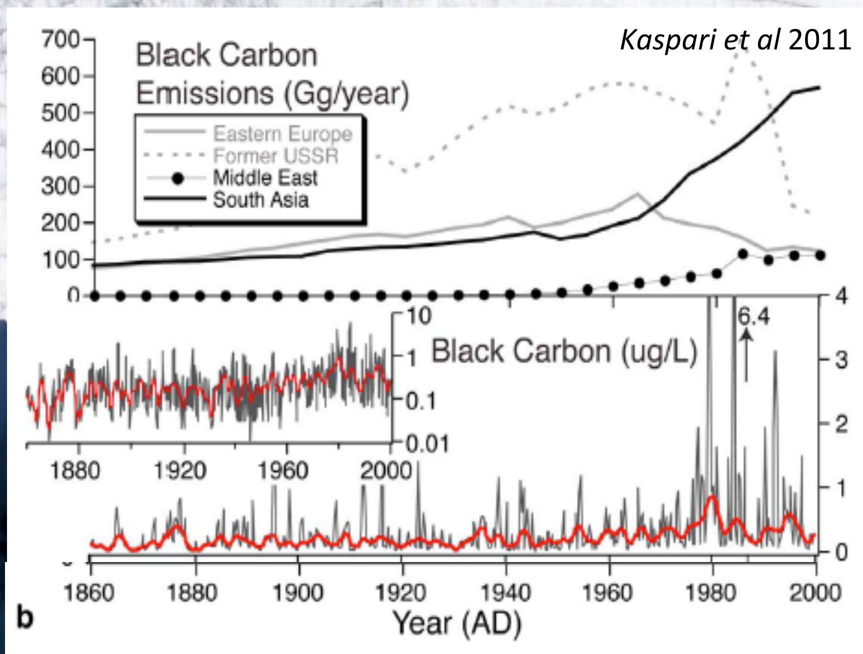


ATMOSPHERIC DUST CONTENT AS A FACTOR AFFECTING GLACIATION AND CLIMATIC CHANGE[1]

F. F. DAVITAYA

Academician F. F. Davitaya, Director, Vakhushti Institute of Geography, Academy of Sciences of the GSSR, Tbilisi, Georgia, USSR
Visiting Professor, Department of Geography, University of Wisconsin-Milwaukee

Black Carbon



PNAS

Black soot and the survival of Tibetan glaciers

Baiqing Xu[a,b], Junji Cao[b], James Hansen[c,1], Tandong Yao[a], Daniel R. Joswia[a], Ninglian Wang[d], Guangjian Wu[a], Mo Wang[a], Huabiao Zhao[a], Wei Yang[a], Xianqin Liu[e], and Jianqiao He[d]

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, D03108, doi:10.1029/2008JD011039, 2009

Click Here for Full Article

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

PNAS

Soot climate forcing via snow and ice albedos

James Hansen*[†‡] and Larissa Nazarenko*[†]

Atmospheric Research 92 (2009) 114–123

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/atmos

ELSEVIER

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

Jing Ming[a,b,c,d,e,*], Cunde Xiao[b,c], Helene Cachier[f], Dahe Qin[a,c], Xiang Qin[c], Zhongqi Li[c], Jianchen Pu[c]

Vol 448|2 August 2007|doi:10.1038/nature06019 nature

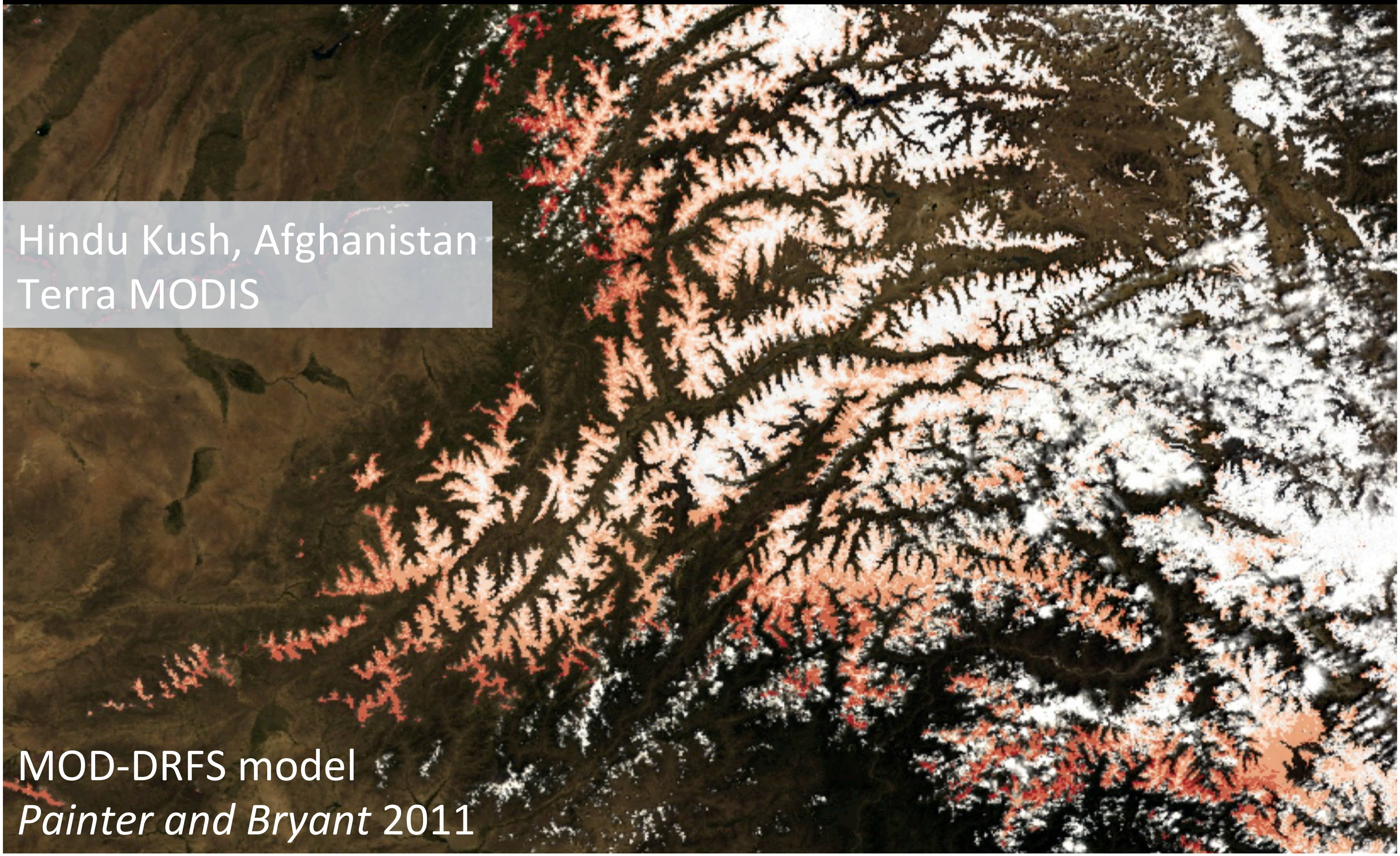
LETTERS

Warming trends in Asia amplified by brown cloud solar absorption

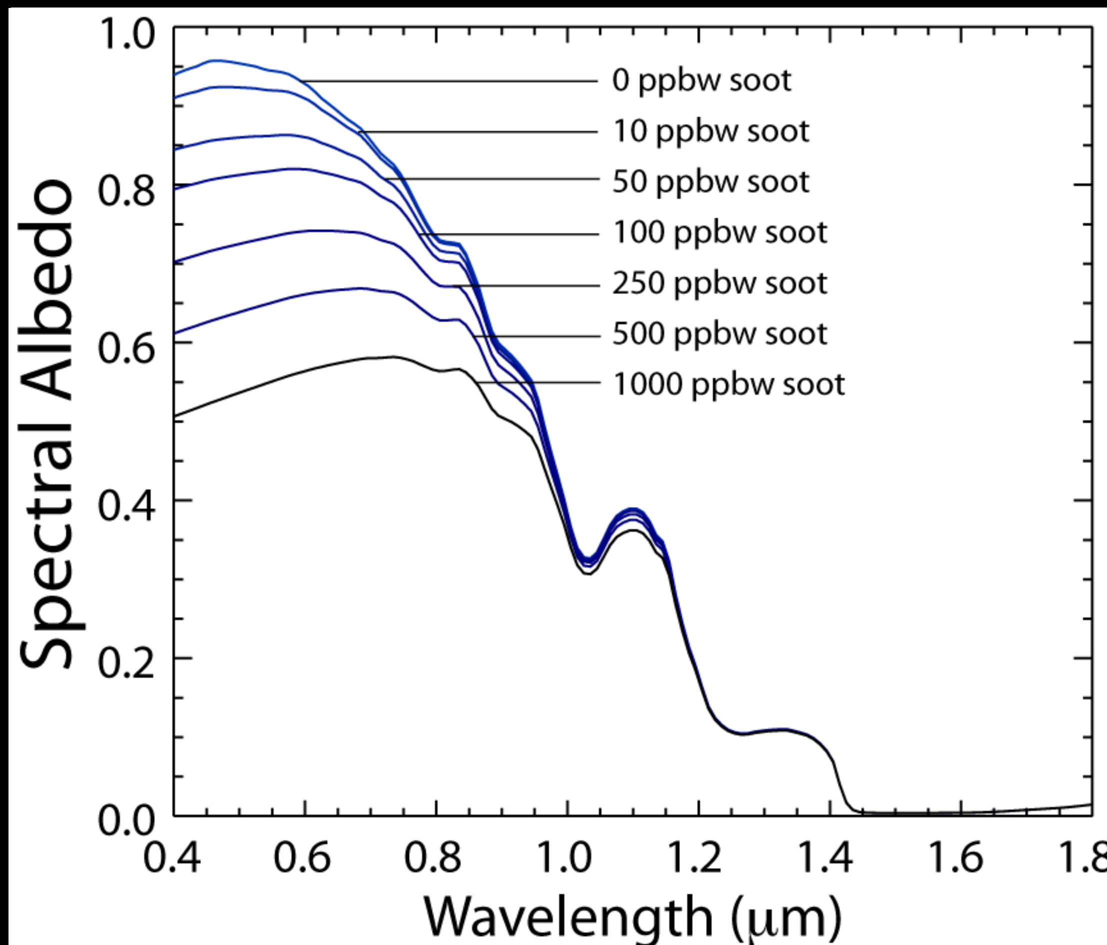
Veerabhadran Ramanathan[1], Muvva V. Ramana[1], Gregory Roberts[1], Dohyeong Kim[1], Craig Corrigan[1], Chul Chung[1] & David Winker[2]

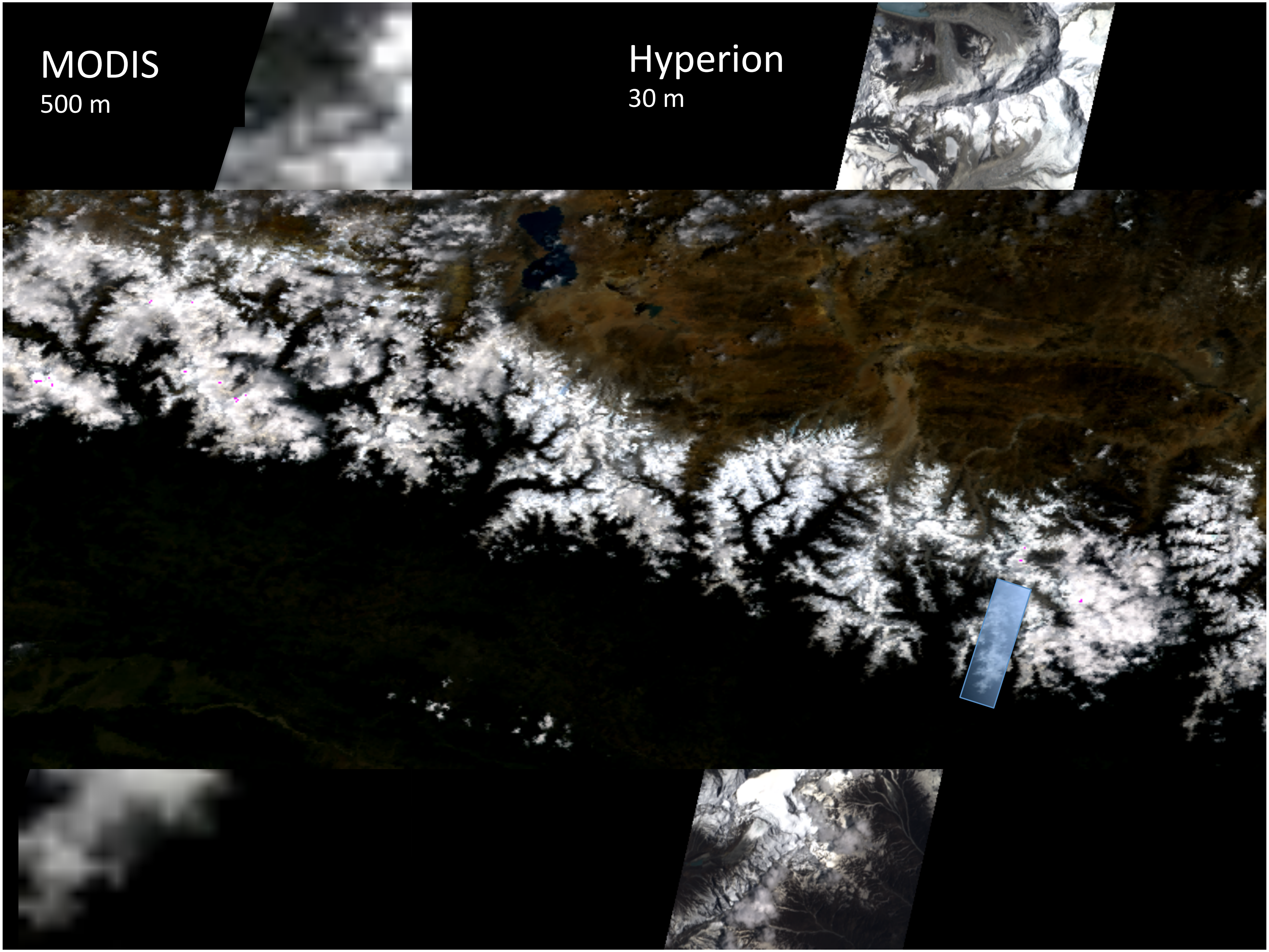
We propose that the combined warming trend of 0.25 K per decade may be sufficient to account for the observed retreat of the Himalayan glaciers[4–6].

What about MODIS and VIIRS?

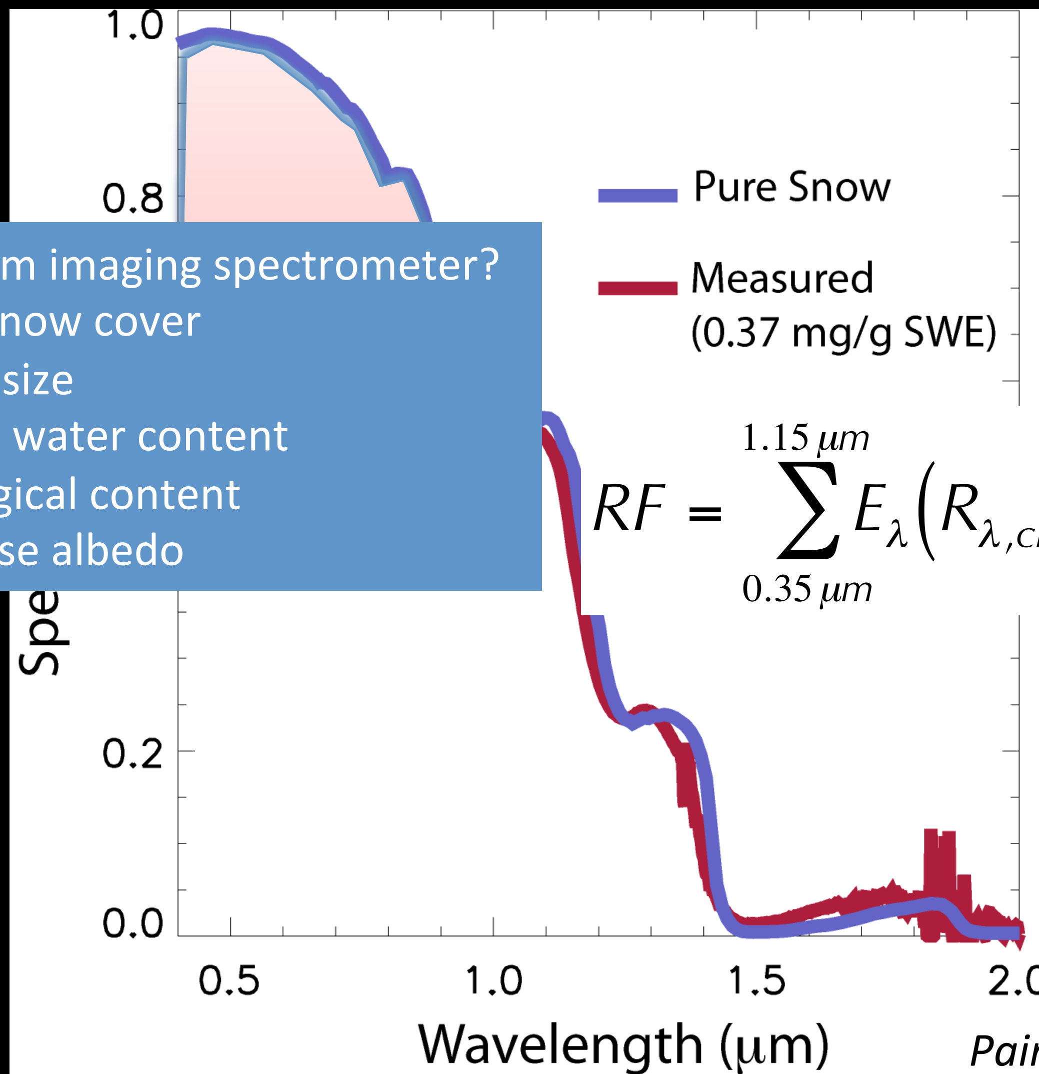


Spectrometer vs MODIS




MODIS
500 m
Hyperion
30 m

Radiative Forcing in Snow

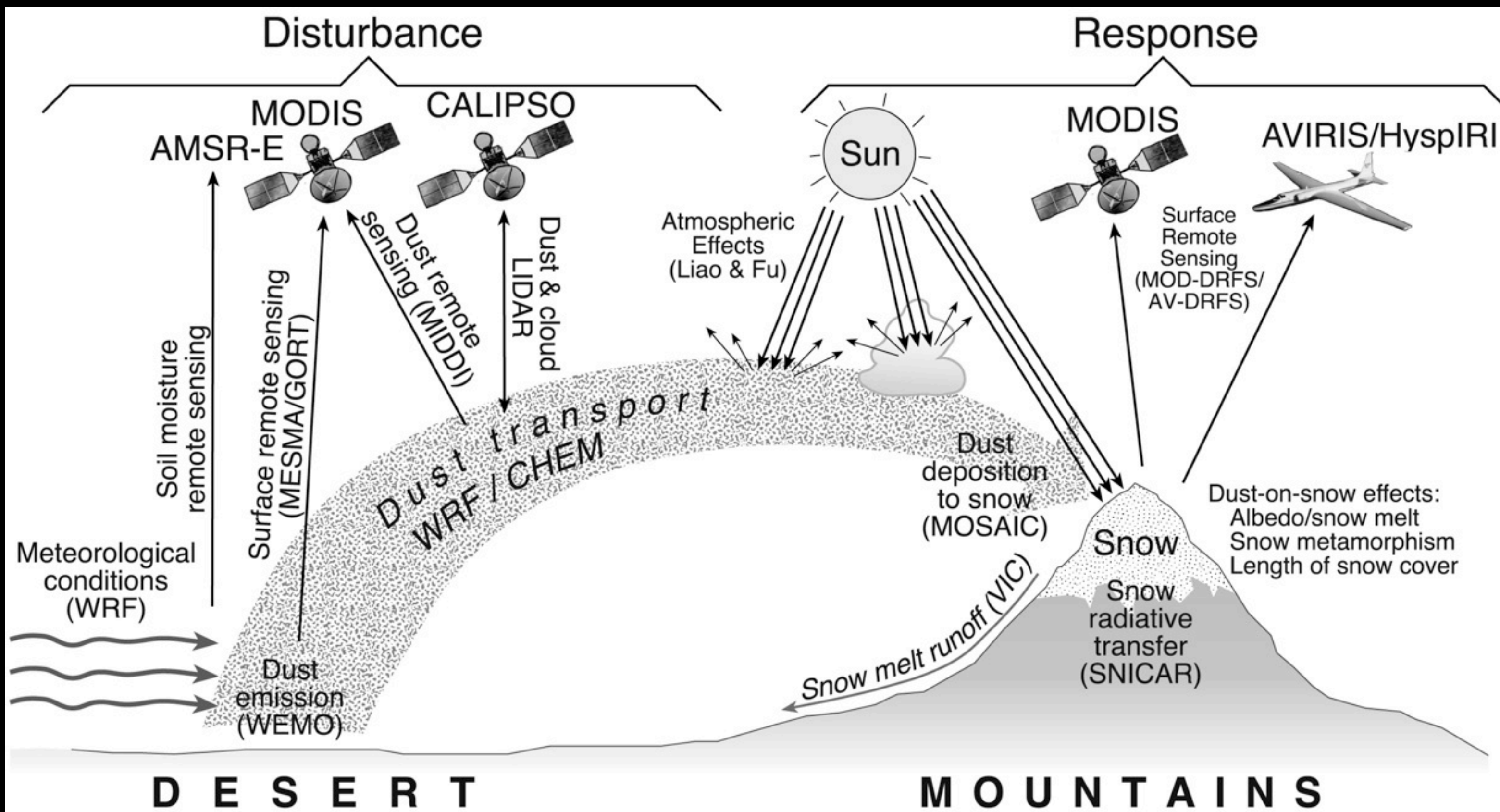


What else from imaging spectrometer?

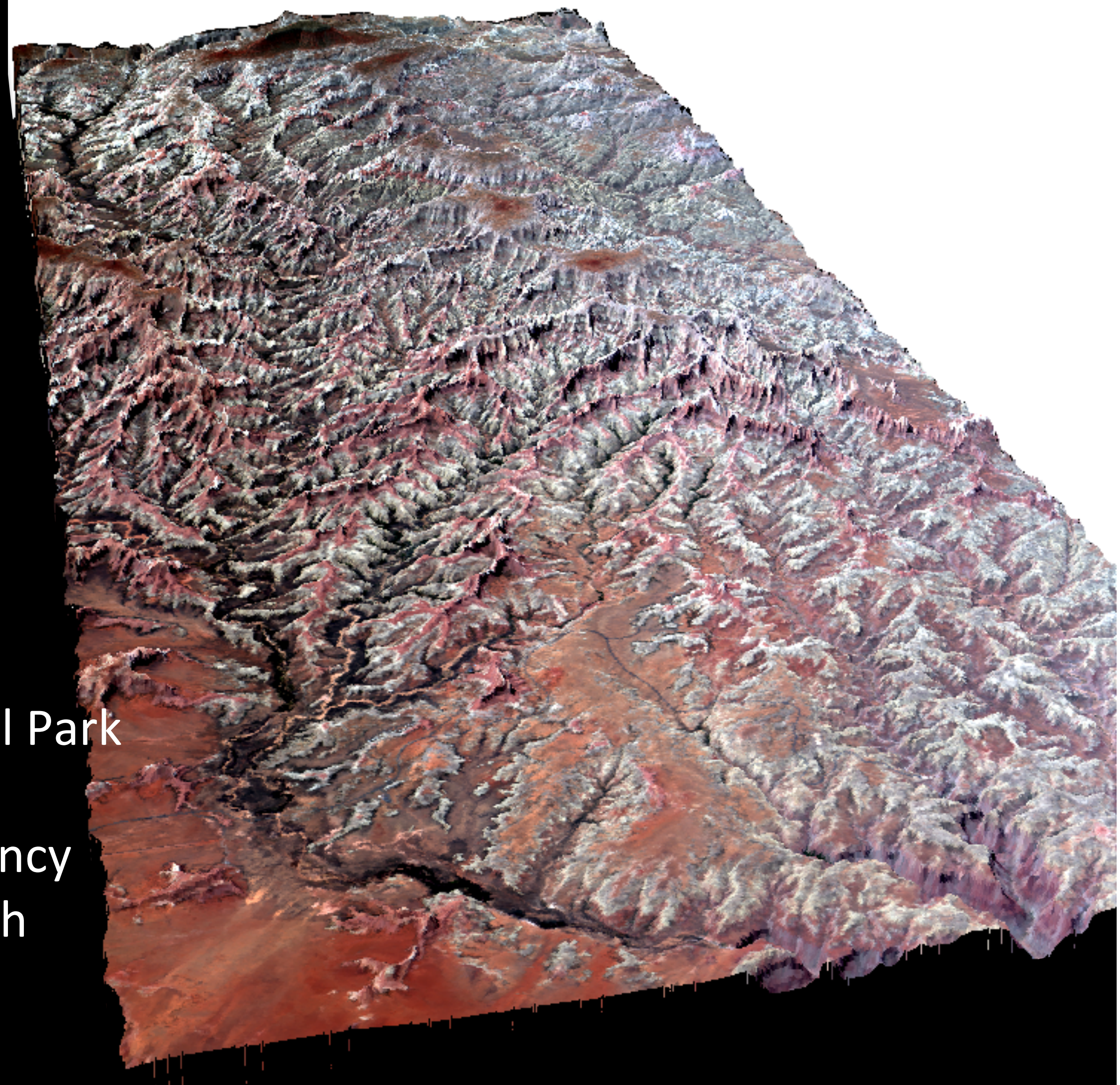
- Fractional snow cover
- Snow grain size
- Snow liquid water content
- Snow biological content
- and of course albedo

$$RF = \sum_{0.35\ \mu m}^{1.15\ \mu m} E_{\lambda} \left(R_{\lambda,clean} - R_{\lambda,dust} \right) d\lambda$$

NASA IDS *Integrated hydrologic response to extreme dust deposition to mountain snowcover of the Colorado River Basin*



AVIRISclassic
6/23/2011

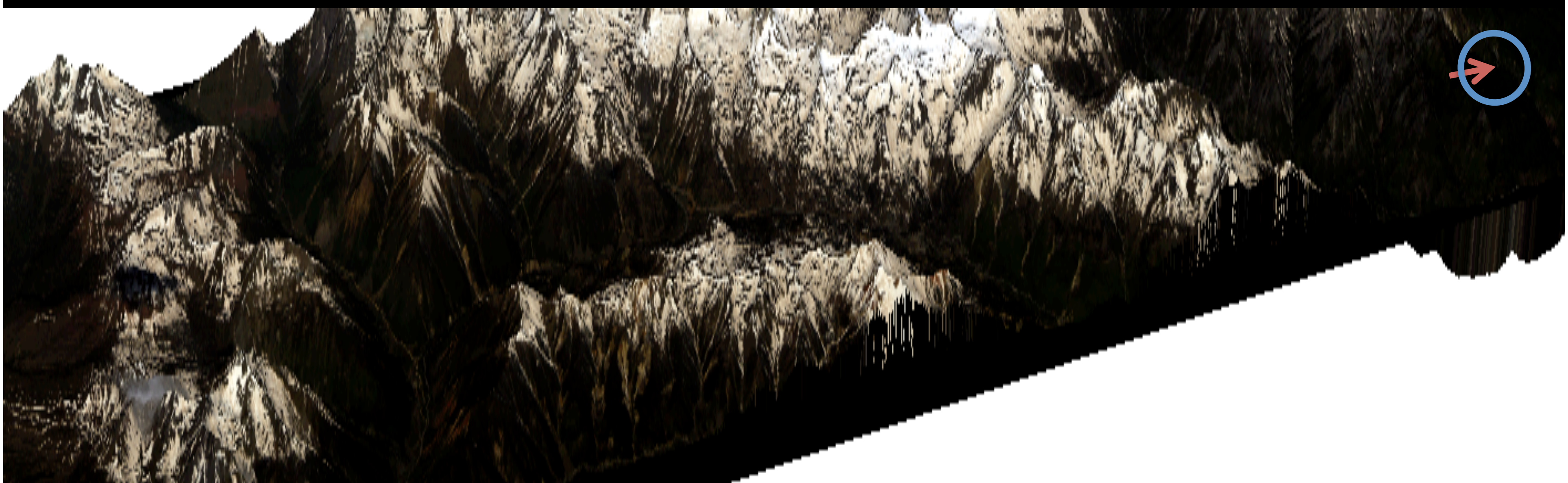


Canyonlands National Park
and
The Nature Conservancy
Canyonlands Research
Center

Upper Colorado River Basin

San Juan Mountains, CO

15 June 2011

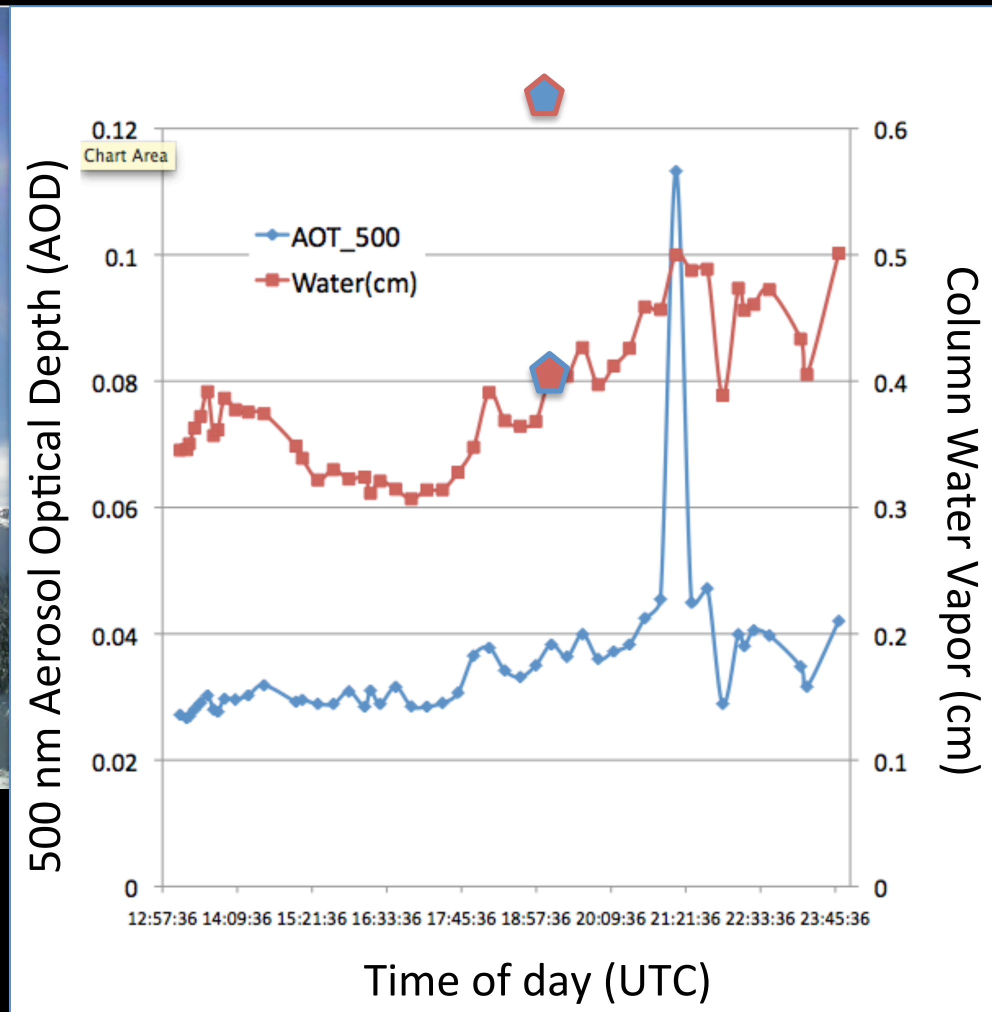


Atmospheric Correction in Rough Terrain

- 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

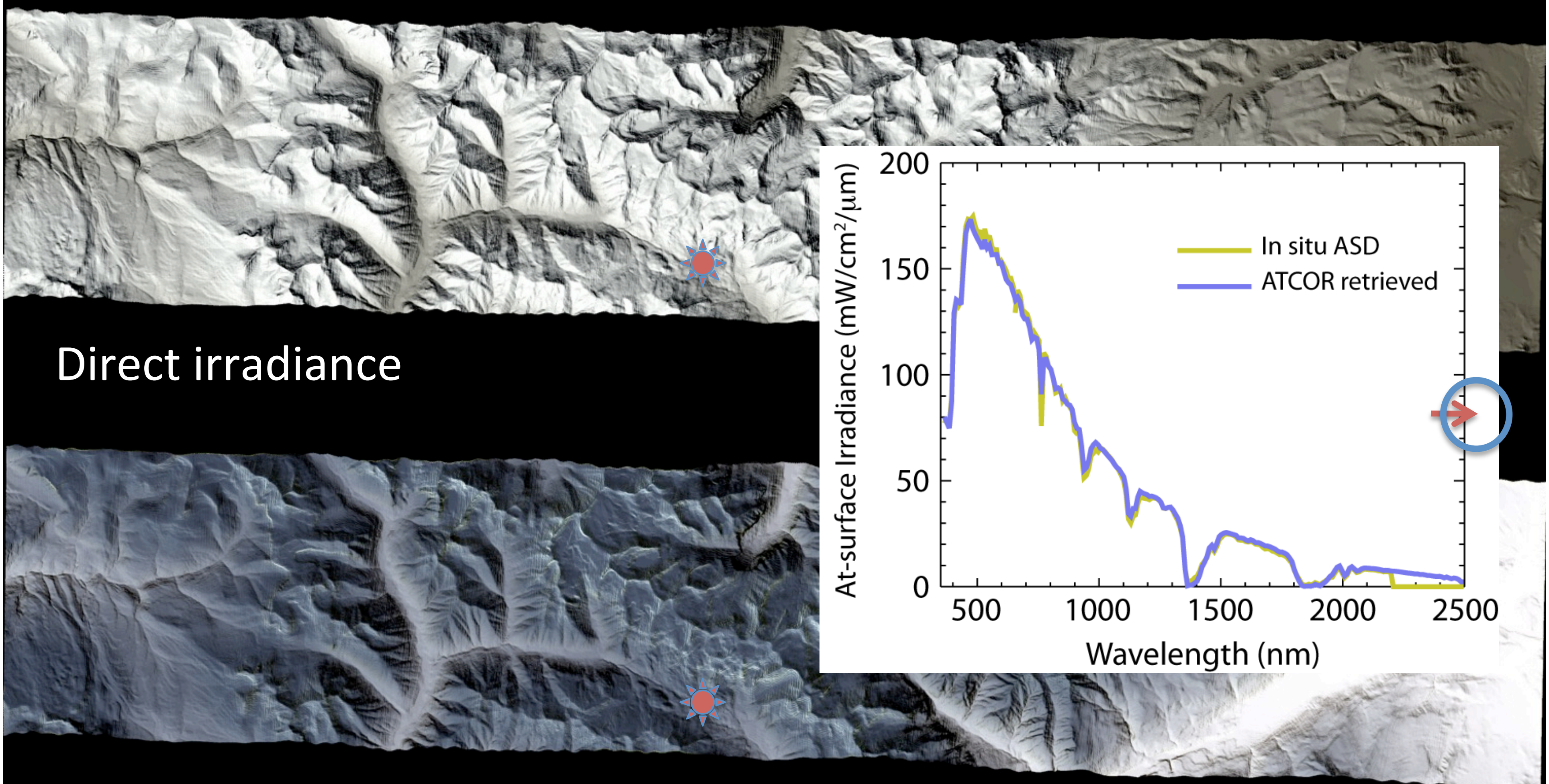
Constrained by sunphotometer

Red Mountain Pass AERONET site
Swamp Angel Study Plot



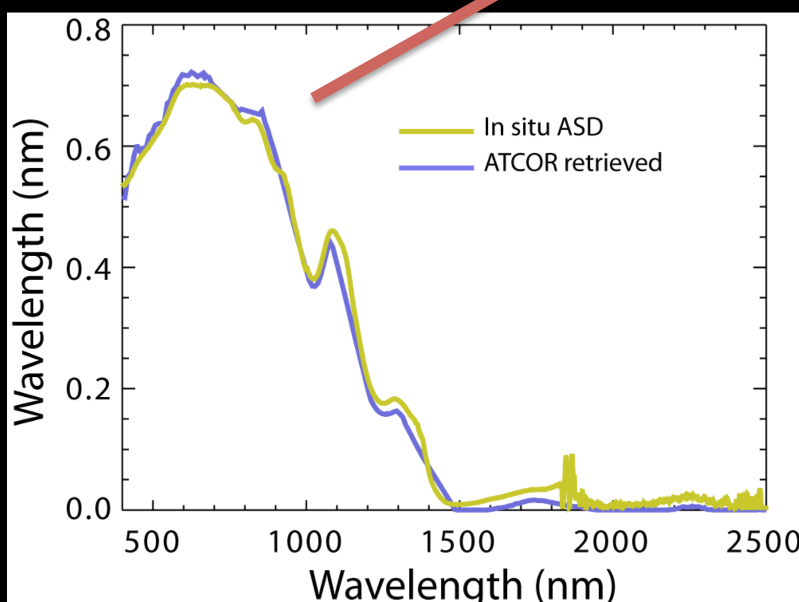
15 June 2011

Irradiances

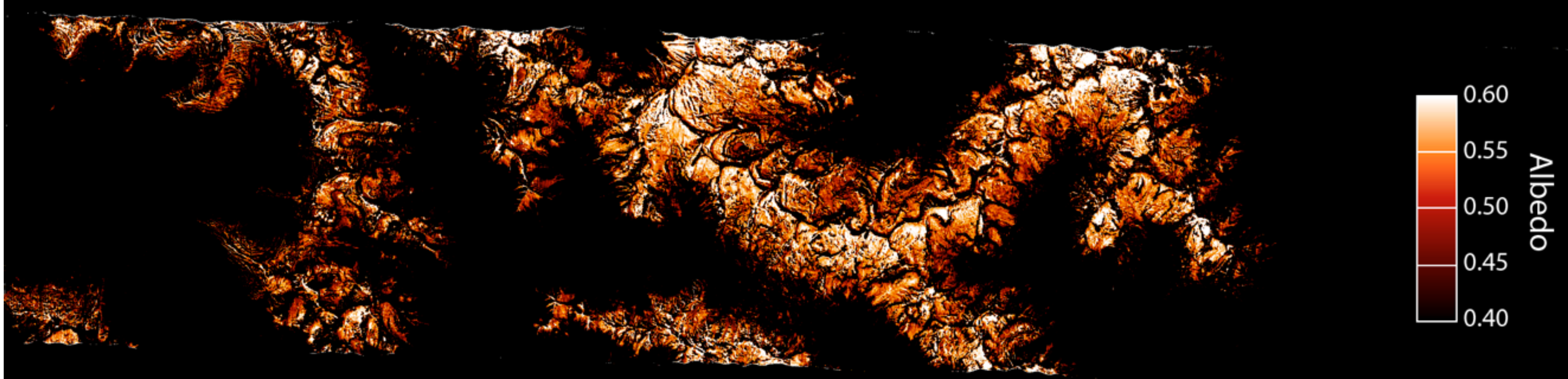


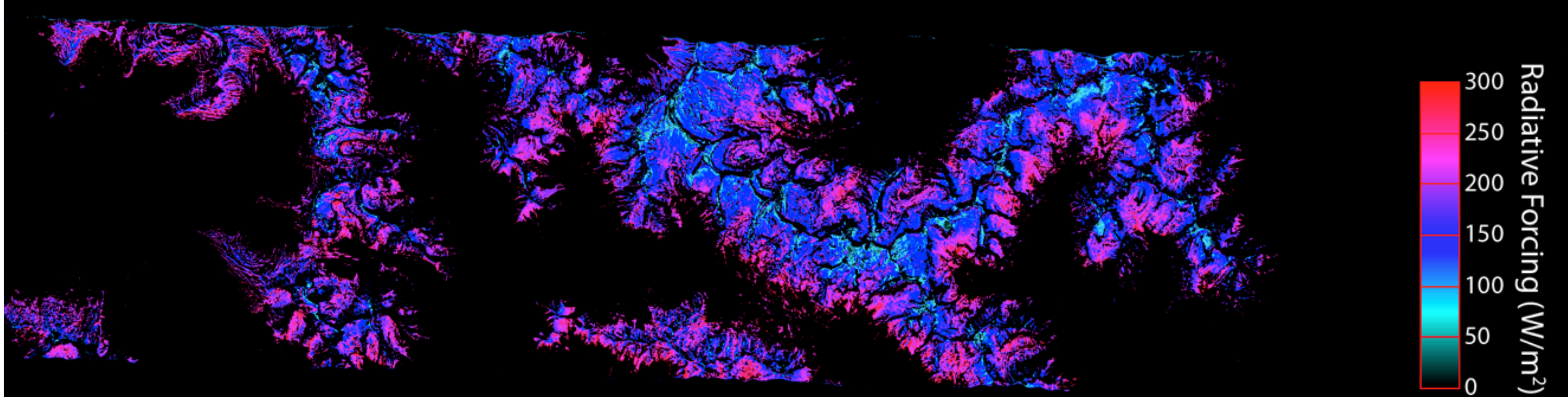
15 June 2011, San Juan Mtns

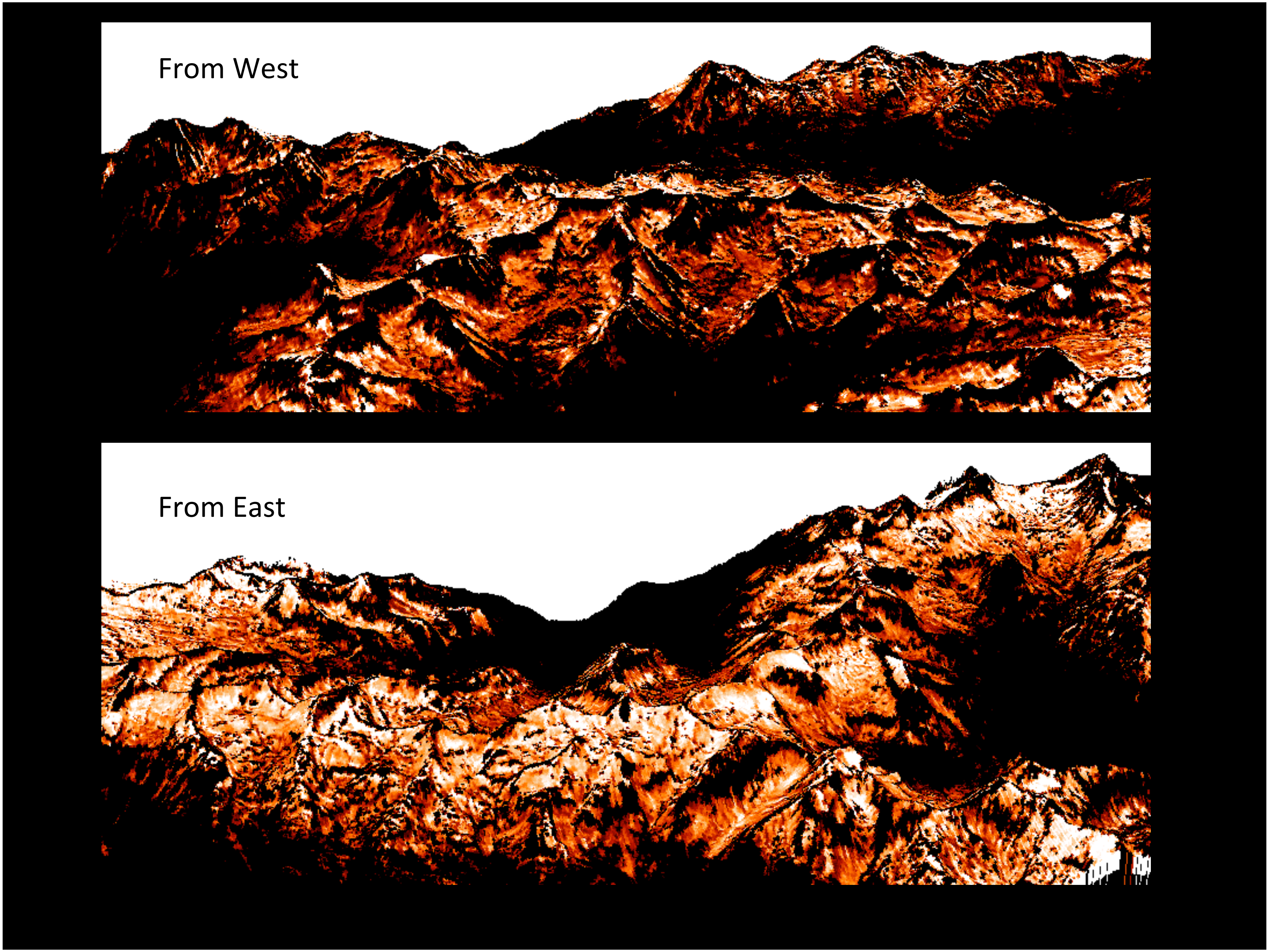
Reflectance



Albedo and radiative forcing





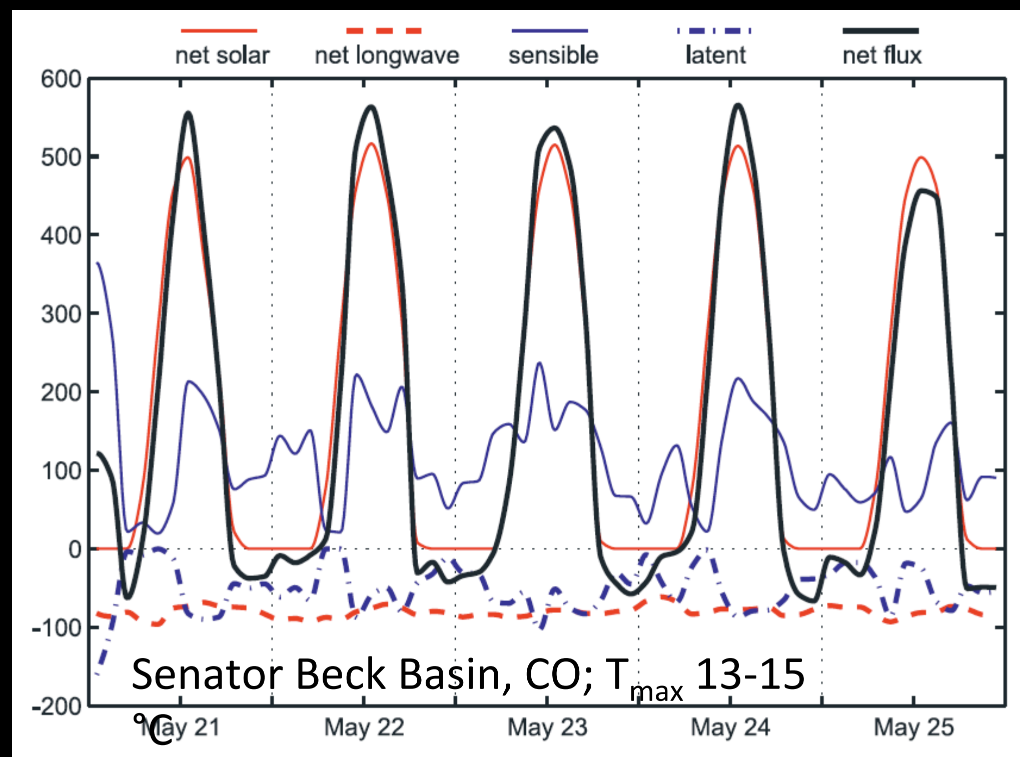

From West
From East

What about the thermal bands?

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

Snow Temp < 0 °C

Snow Temp = 0 °C



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