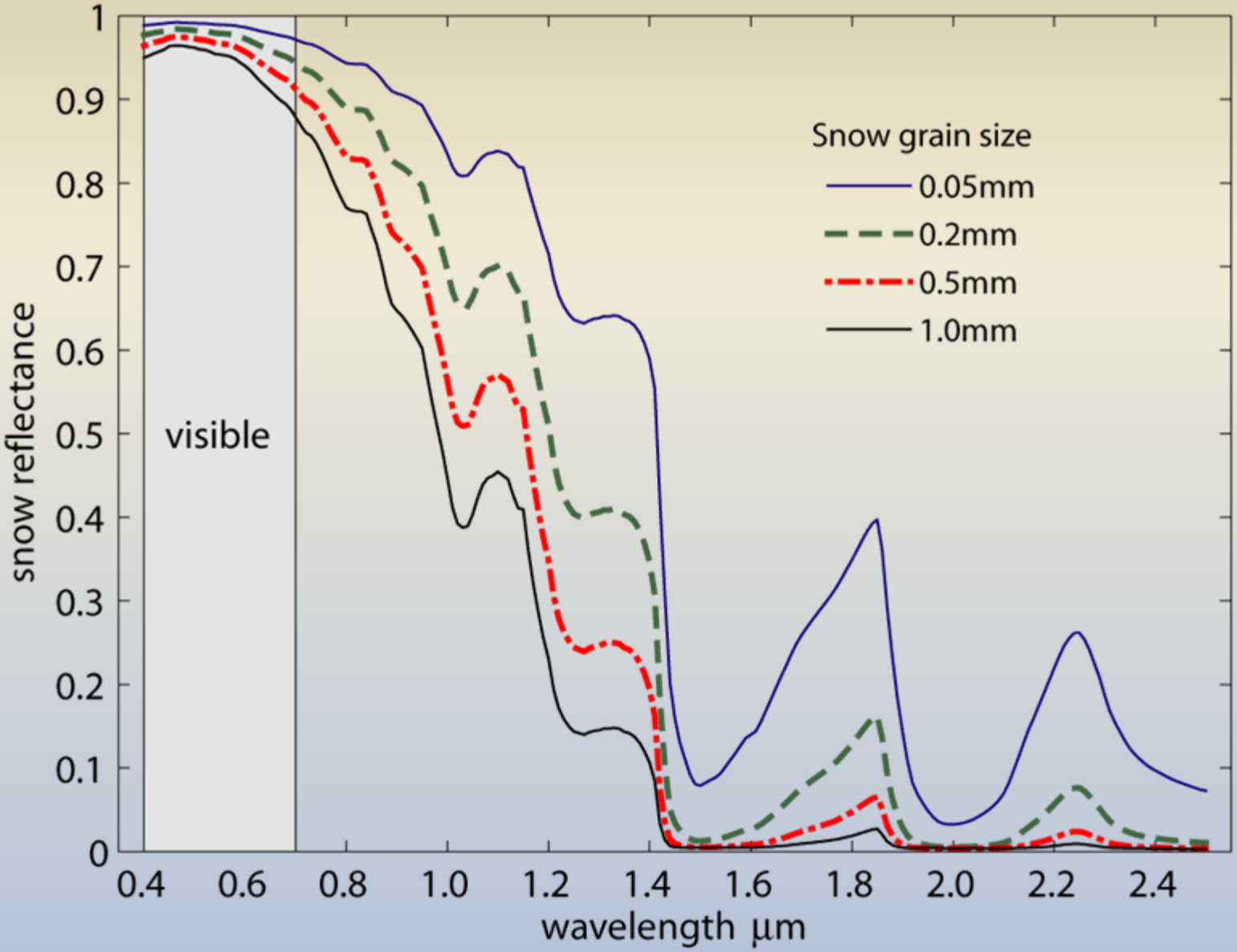
Interpretation of Snow's Color from Imaging Spectrometry

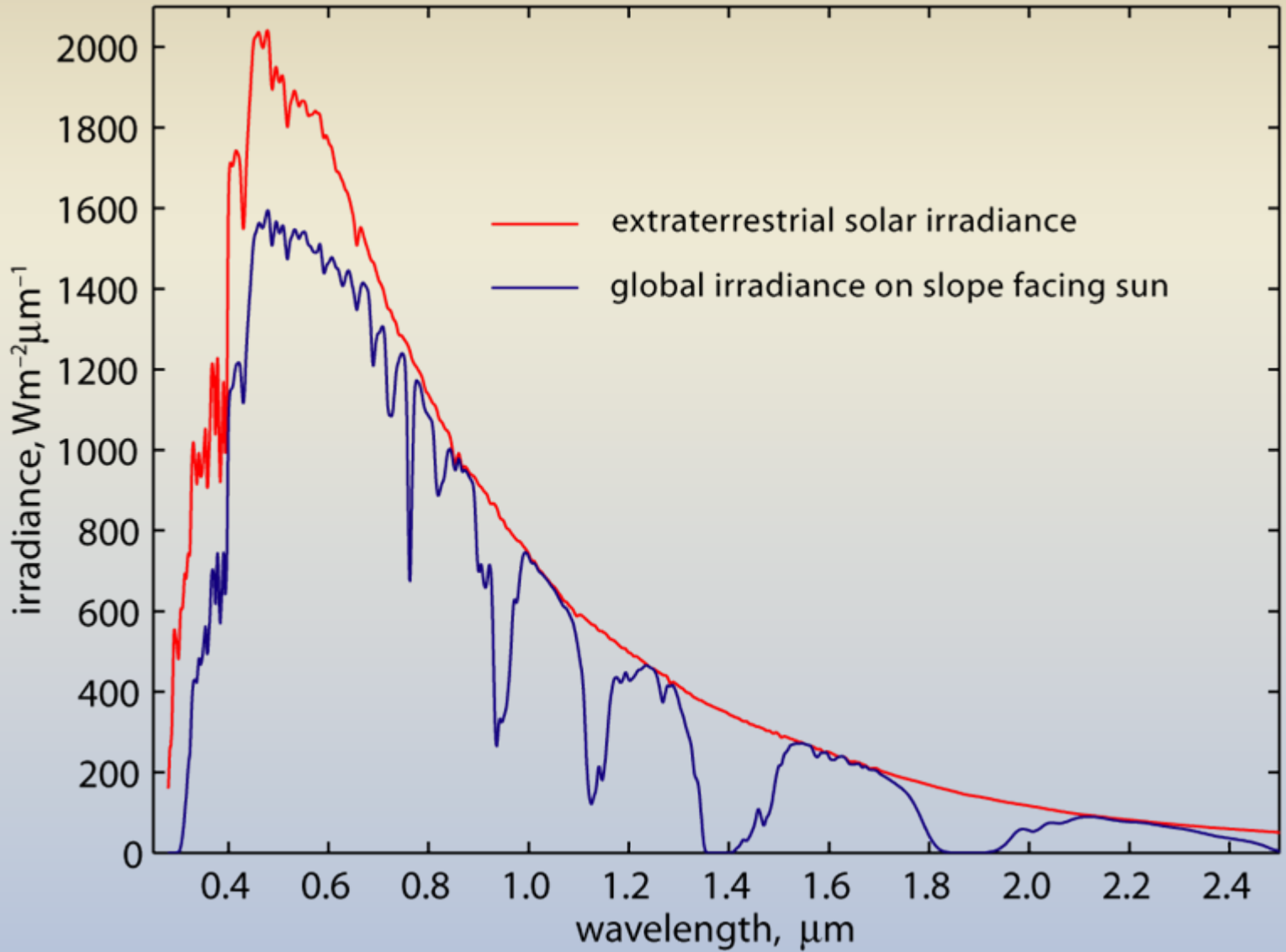
Topics

- Spectral reflectance of snow and its variability
- Why do we care?
  - Implications for energy balance of snowpack
- Reasons: optics of ice
  - Snow is a collection of ice grains
  - Along with dust, algae, and (eventually) liquid water
- Implications for imaging spectrometry
  - What can we measure?
  - How can we use the information in hydrology?
  - How do we integrate spectrometry with multispectral measurements?

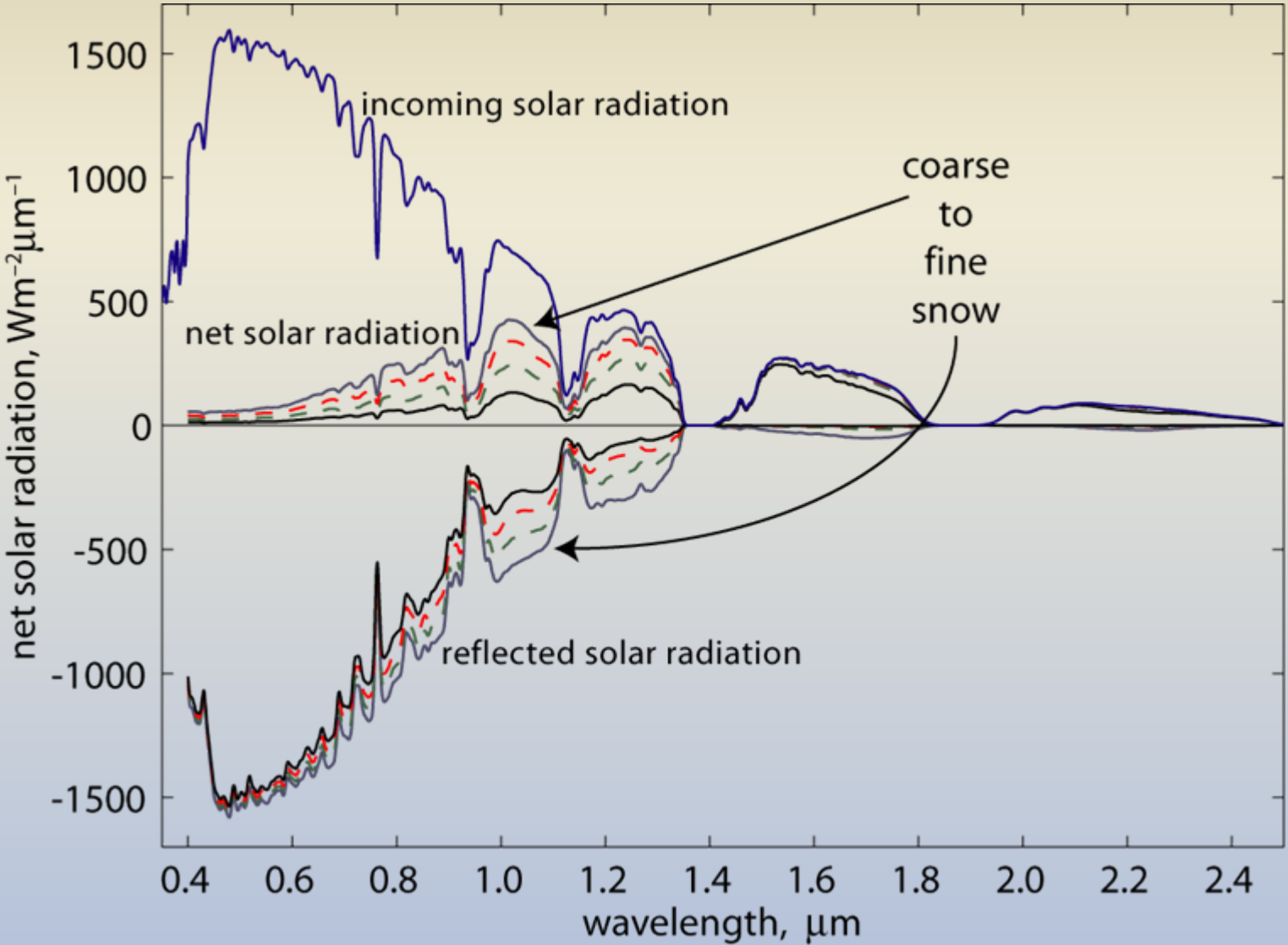
Spectral reflectance of clean snow



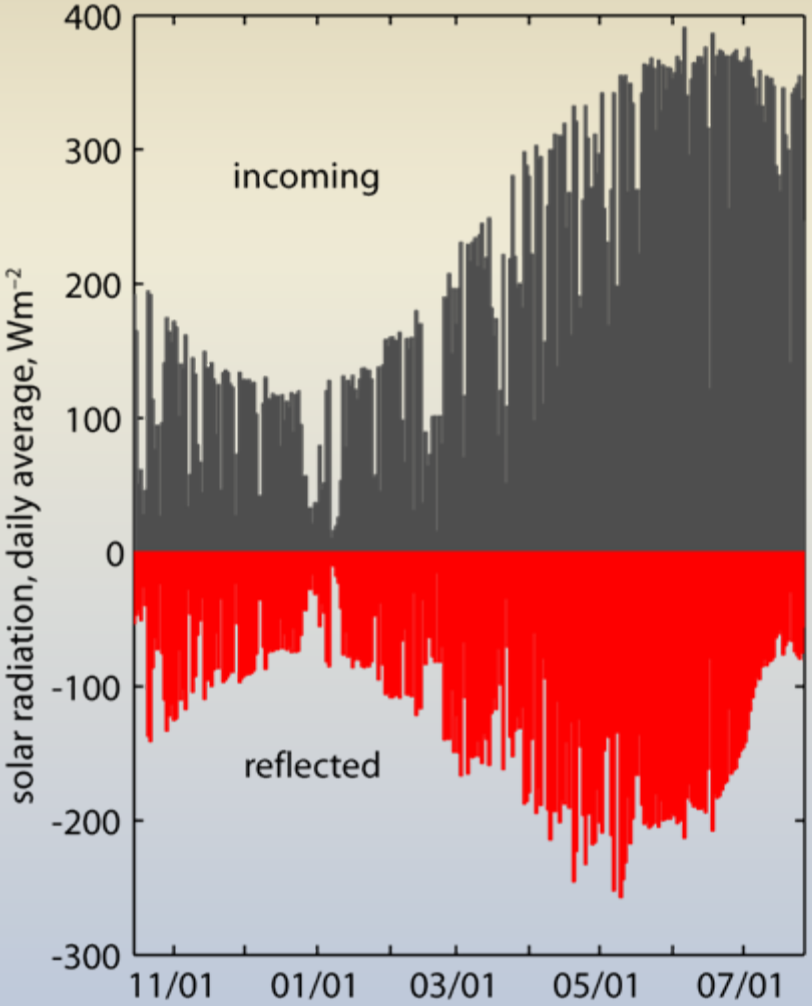
Spectral solar irradiance

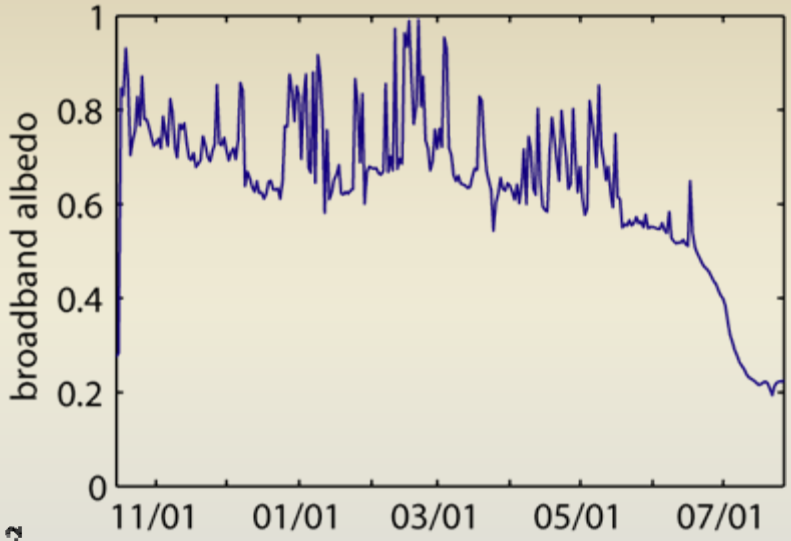


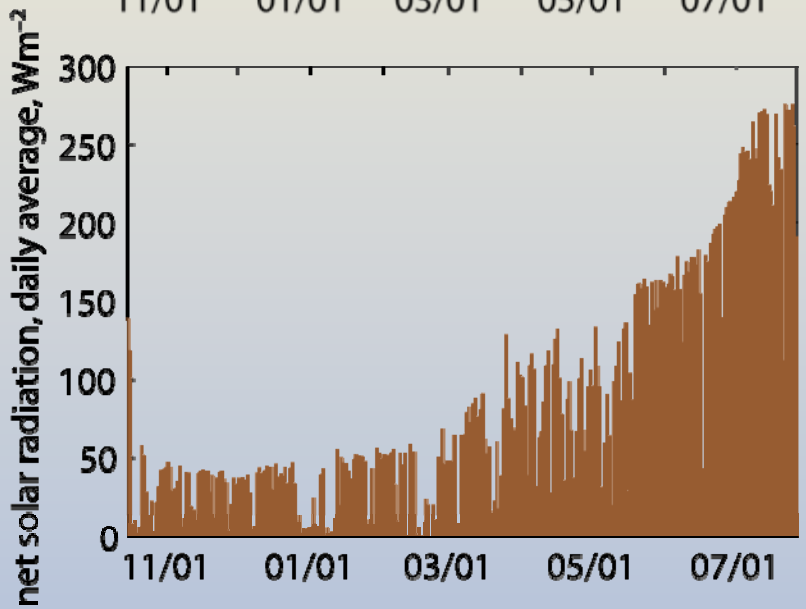
Net solar radiation



Seasonal solar radiation (Mammoth Mtn, 2005)

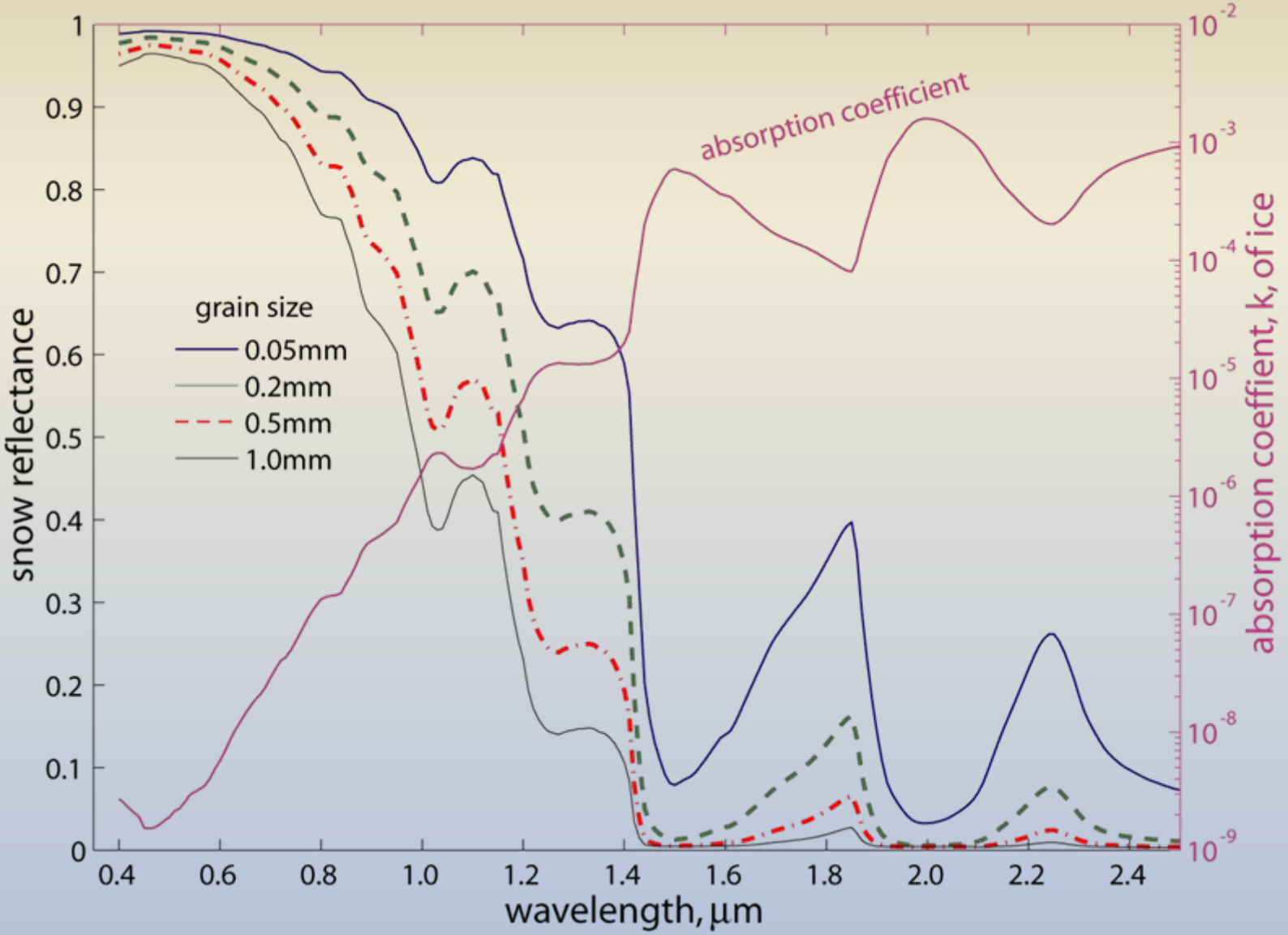






Snow is a collection of scattering grains

Snow spectral reflectance and absorption coefficient of ice



Analyses of snow properties from imaging spectrometry

- Spectral albedo and conversion to broadband albedo
  - [Nolin & Dozier, *Remote Sens. Environ.*, 2000]
- Fractional (subpixel) snow-covered area, along with albedo
  - [Painter et al., *Remote Sens. Environ.*, 2003]
- Liquid water in surface layer
  - [Green et al., *Water Resour. Res.*, 2006]
- Absorbing impurities
  - [Painter et al., *Appl. Environ. Microbiol.*, 2001; work in progress]

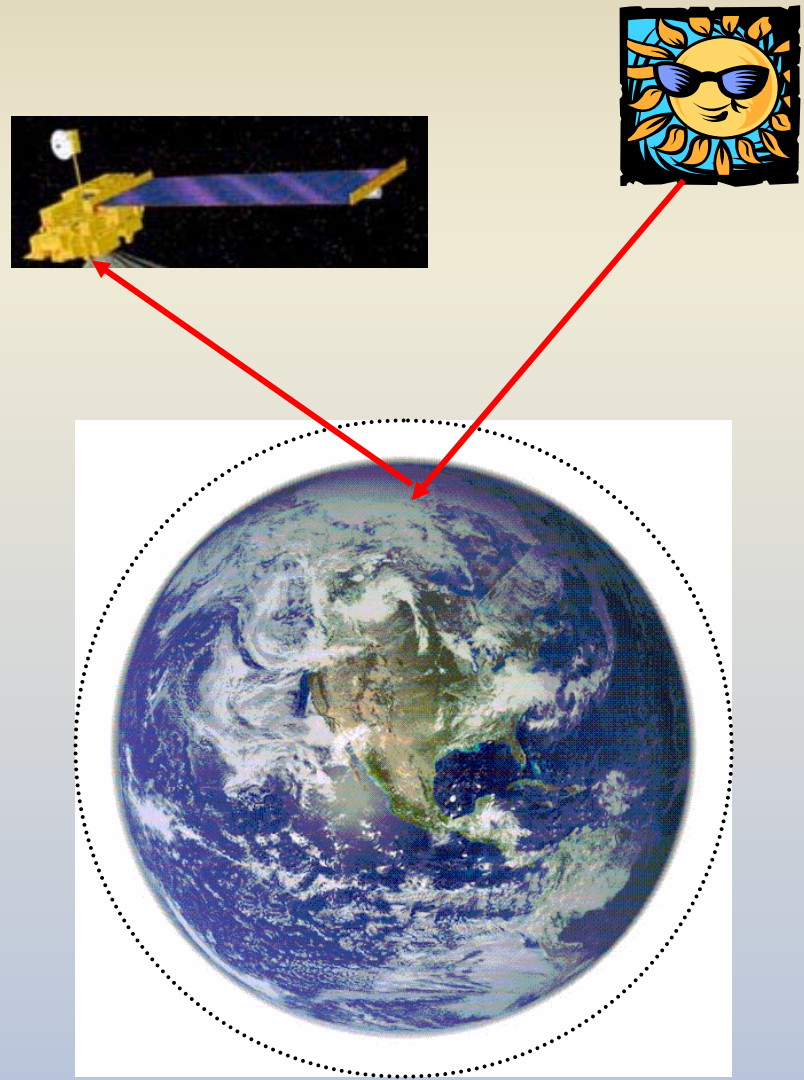
Conventional approach to estimating albedo

Satellite radiance (~5% error)

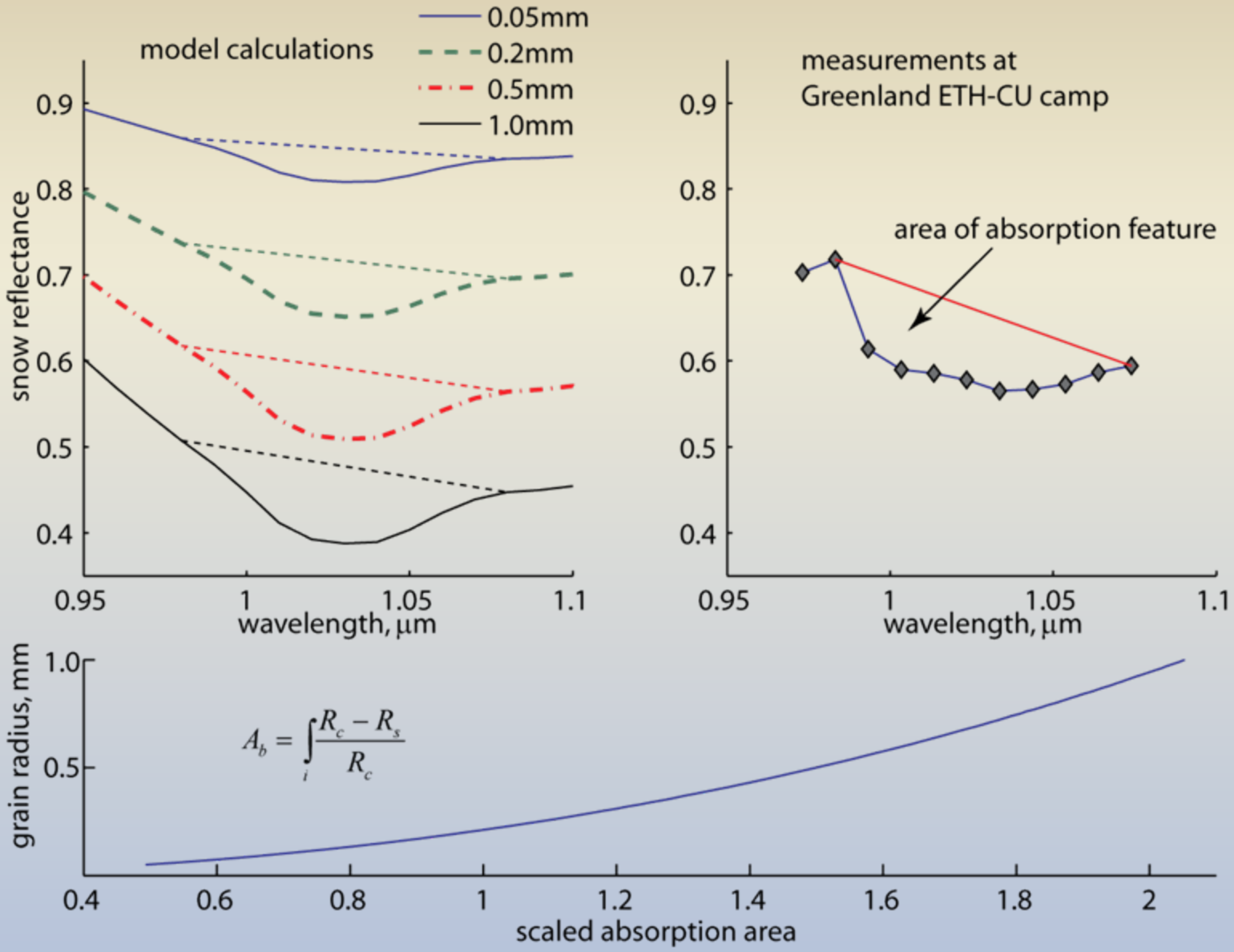
Surface reflectance (>5%)

Narrowband albedo (5-10%)

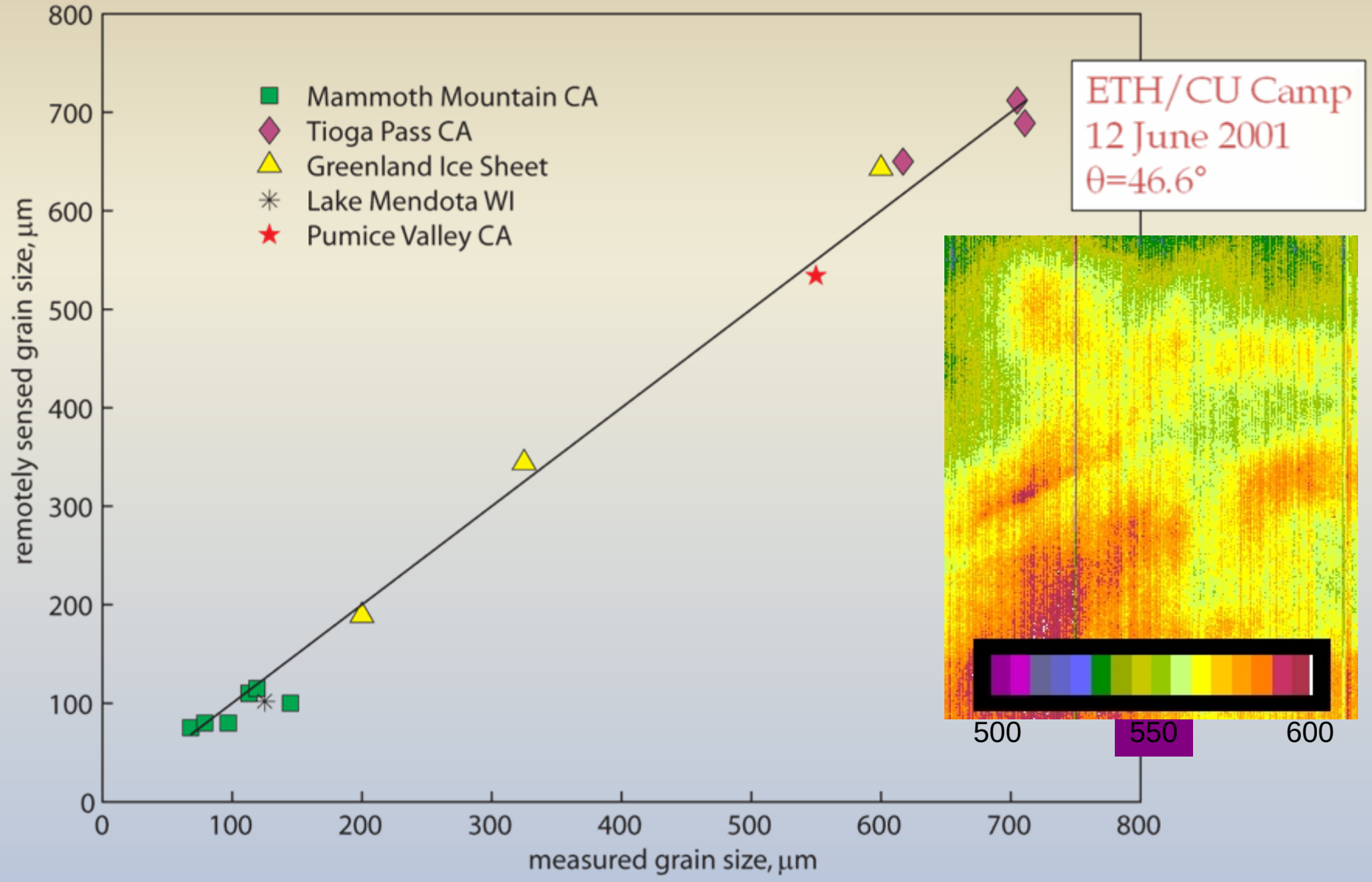
Broadband albedo (5-10%)



Estimate grain size from the 1.03μm absorption feature



Measured vs remotely sensed grain size



Spectral mixture analysis

$$\overline{R_\lambda} = \sum_{i=1}^{N} F_i R_{\lambda i} + \varepsilon_\lambda$$

Spectral mixture equation, per pixel

$$\varepsilon_\lambda = \overline{R_\lambda} - \sum_{i=1}^{N} F_i R_{\lambda i}$$

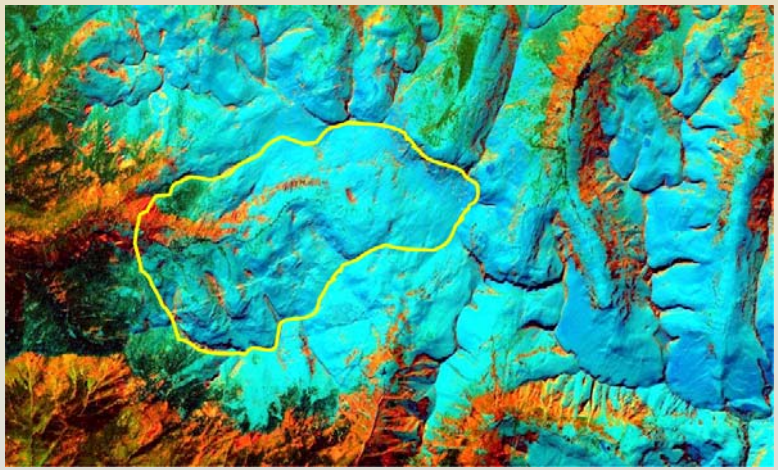
Spectral residuals, per pixel

$$RMSE = \sqrt{\frac{1}{M} \sum_{\lambda=1}^{M} \varepsilon_\lambda^2}$$

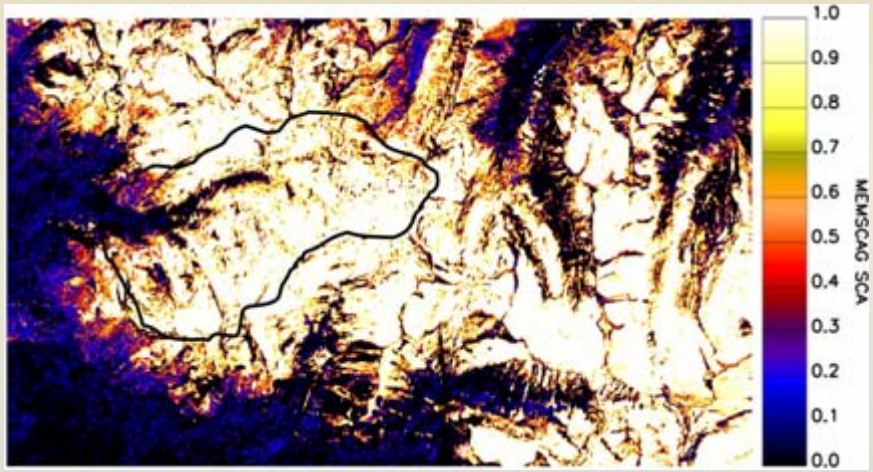
RMS error, per pixel

Snow-covered area in the Tokopah Basin (Kaweah River drainage), Sierra Nevada

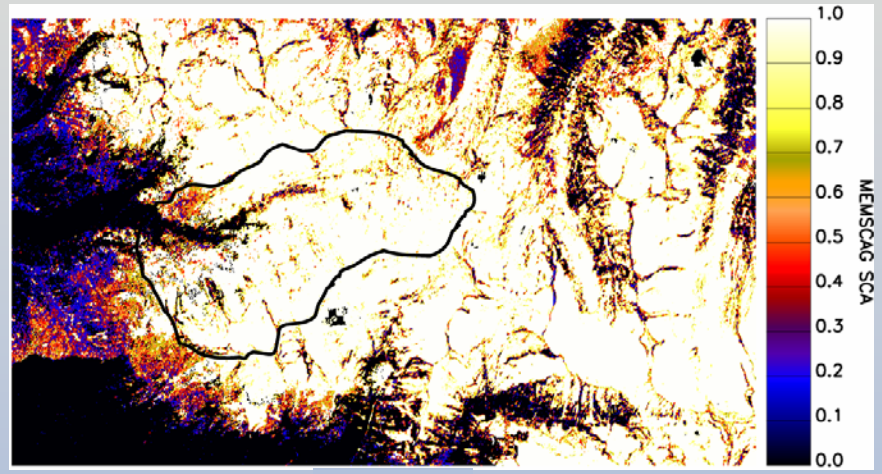
AVIRIS



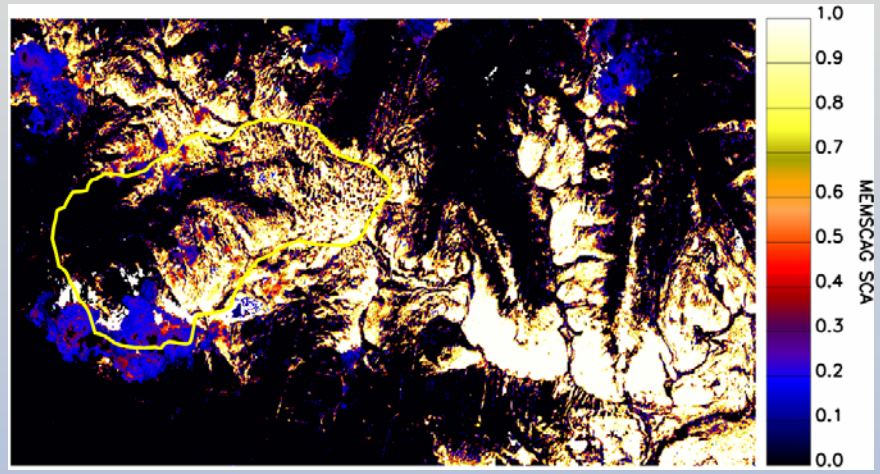
21 May 1997



05 May 1997



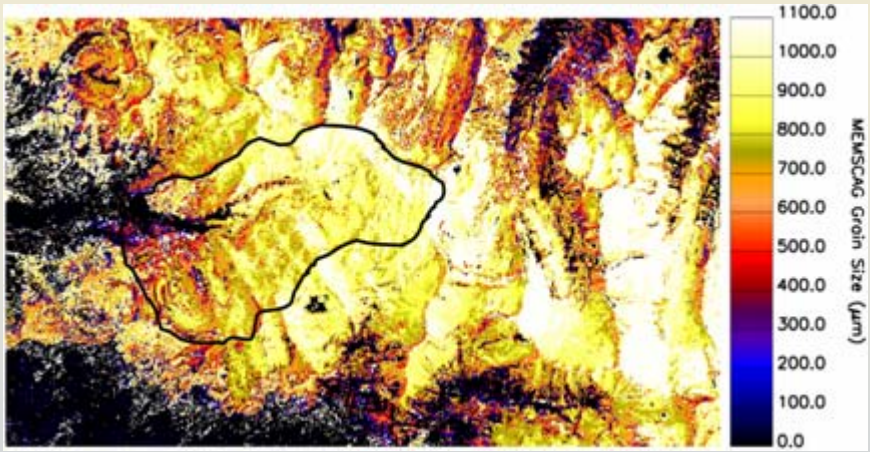
18 June 1997



20 km

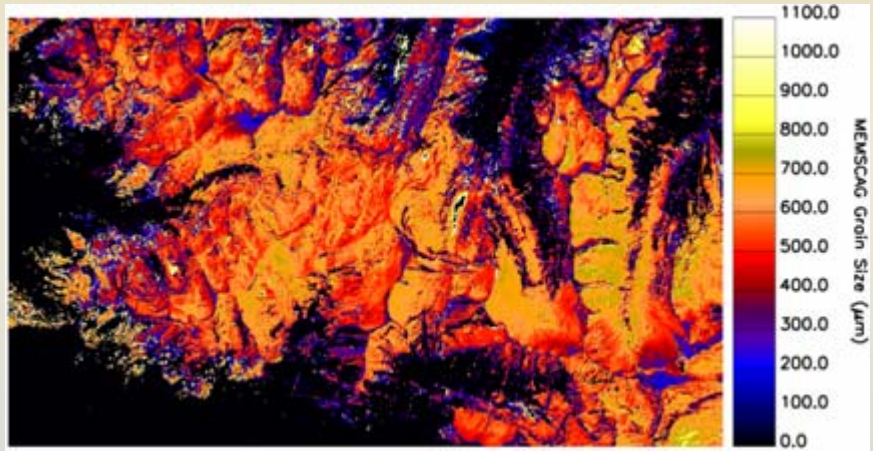
Grain size in the Tokopah Basin (Kaweah River drainage), Sierra Nevada

05 May 1997

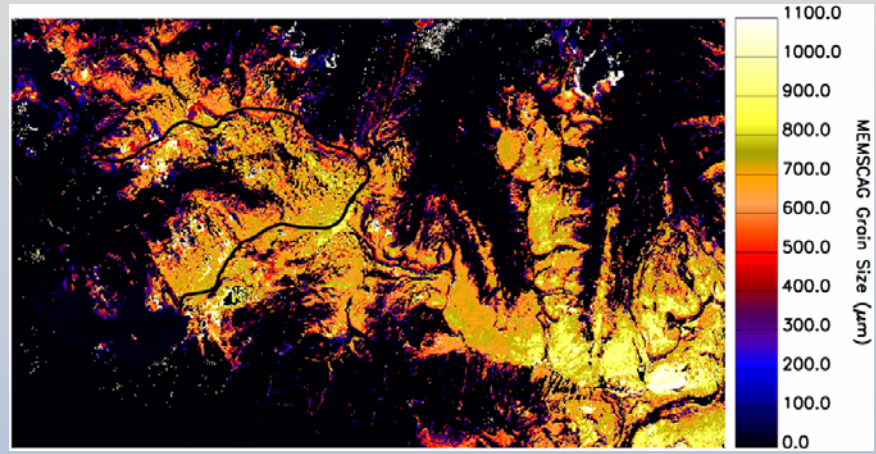


20 km

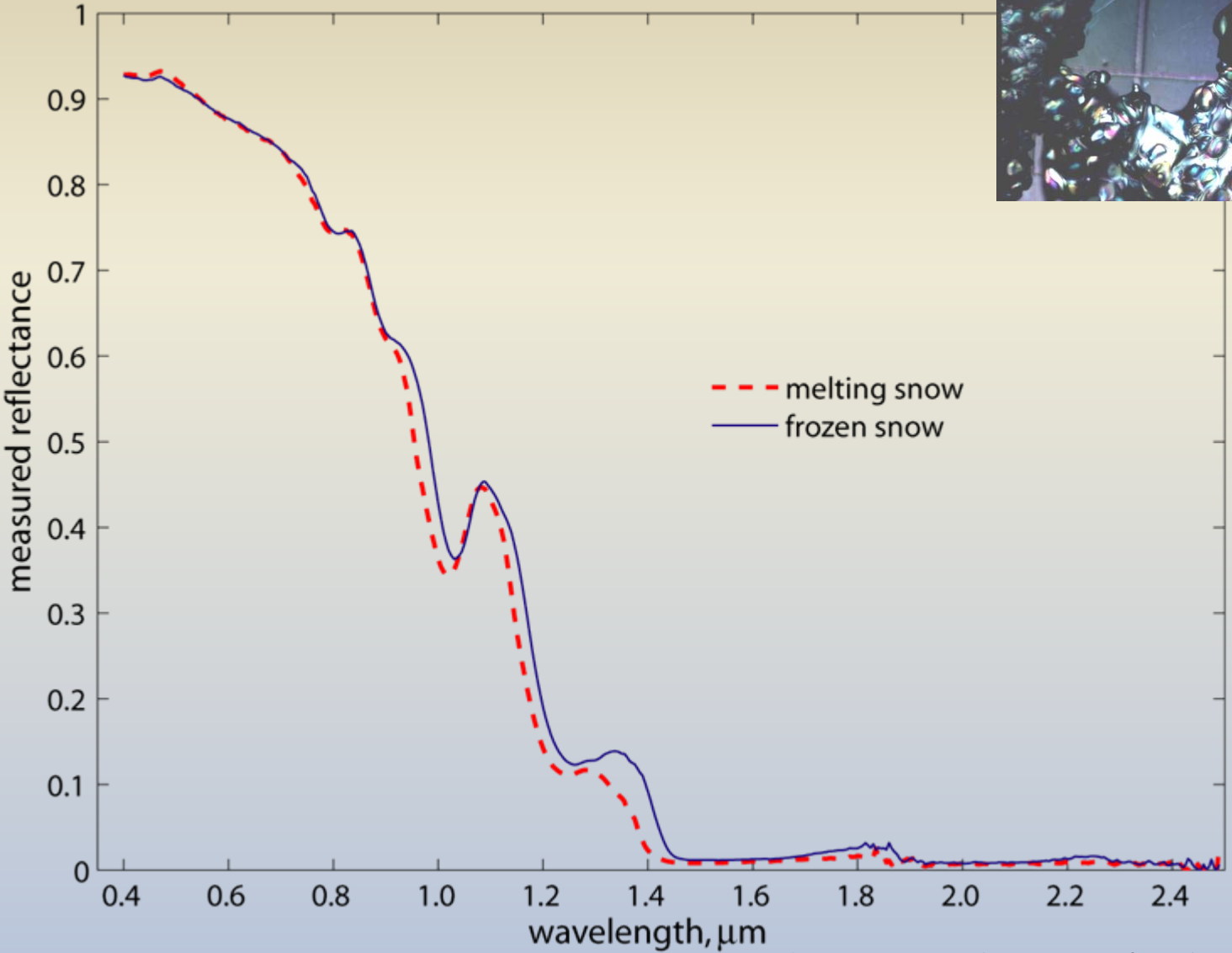
21 May 1997



18 June 1997

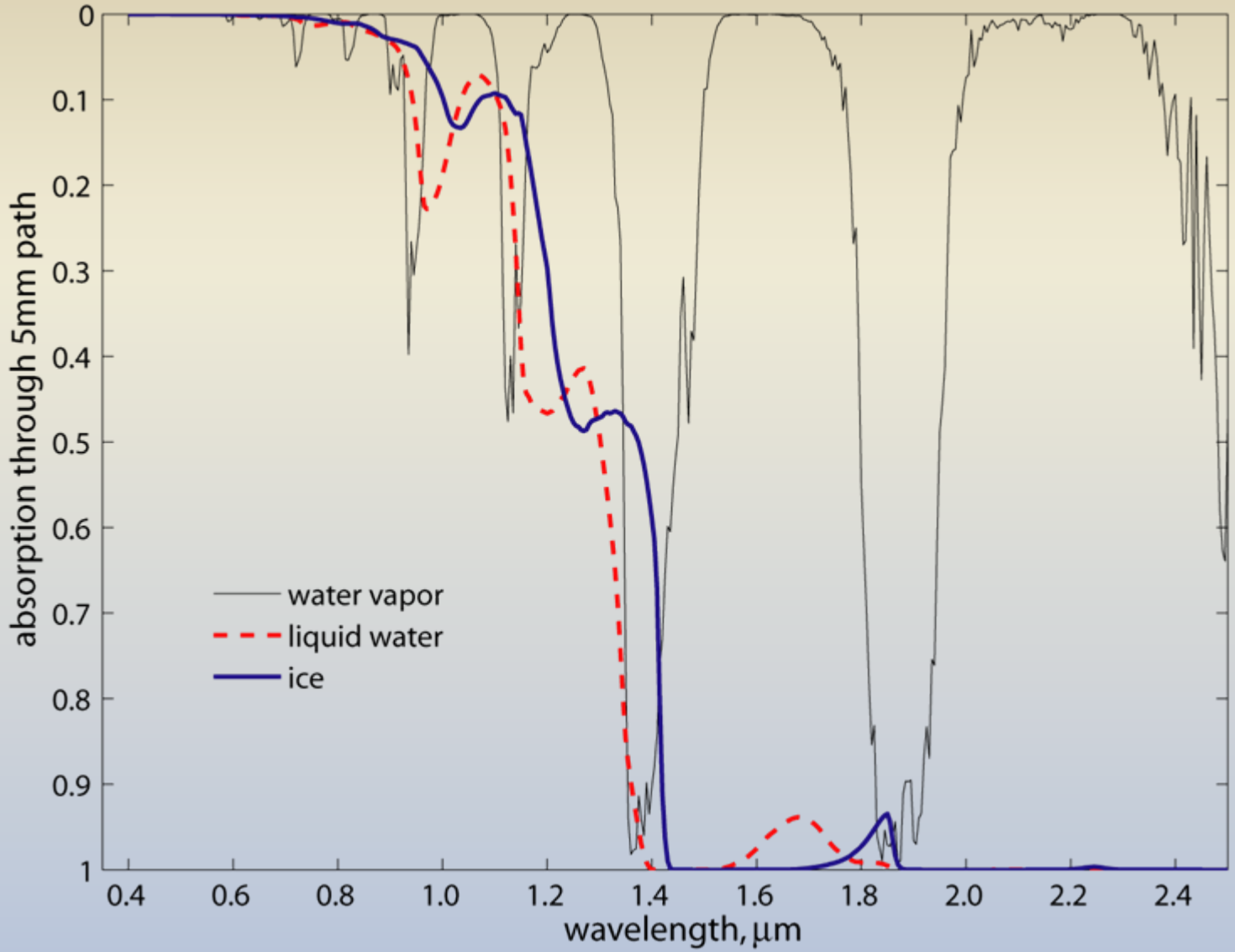


Wet snow

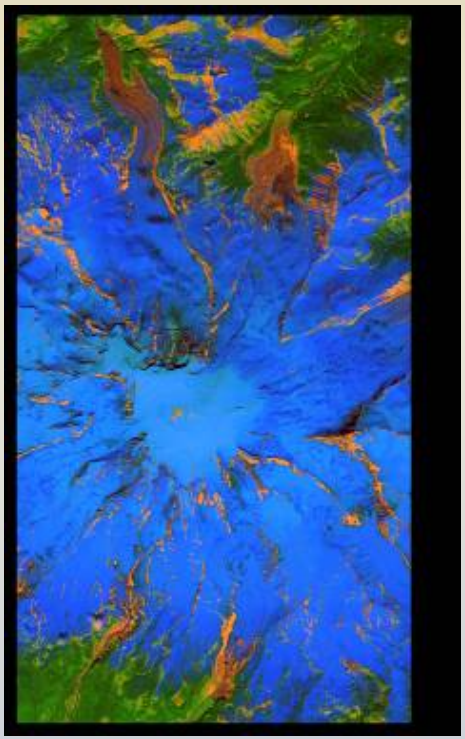


(Green et al, *WRR*, forthcoming)

Absorption by three phases of water

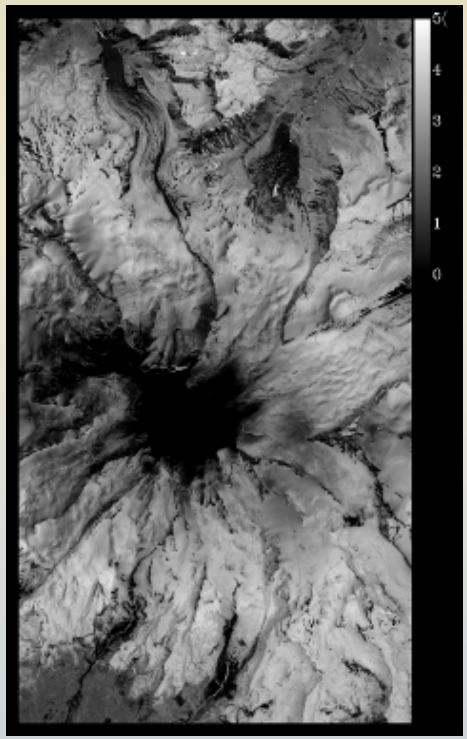


Surface wetness with AVIRIS, Mt. Rainier, 14 June 1996

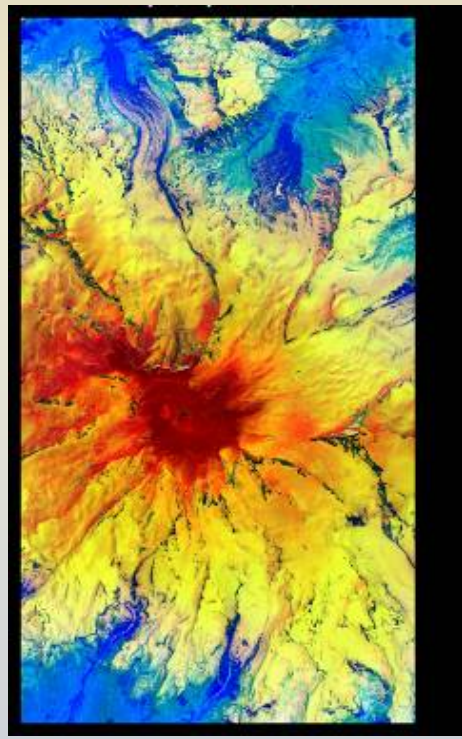


AVIRIS image, 409, 1324, 2269 nm

precipitable water, 1-8 mm



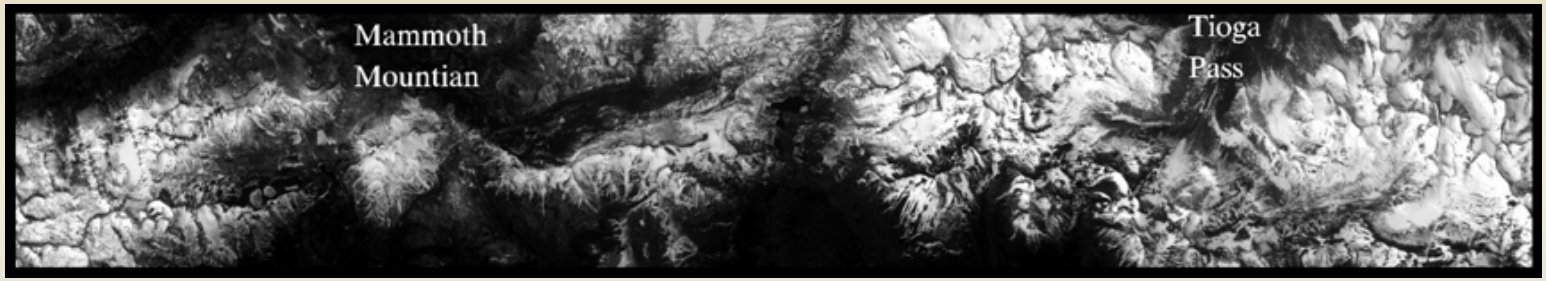
liquid water, 0-5 mm path absorption



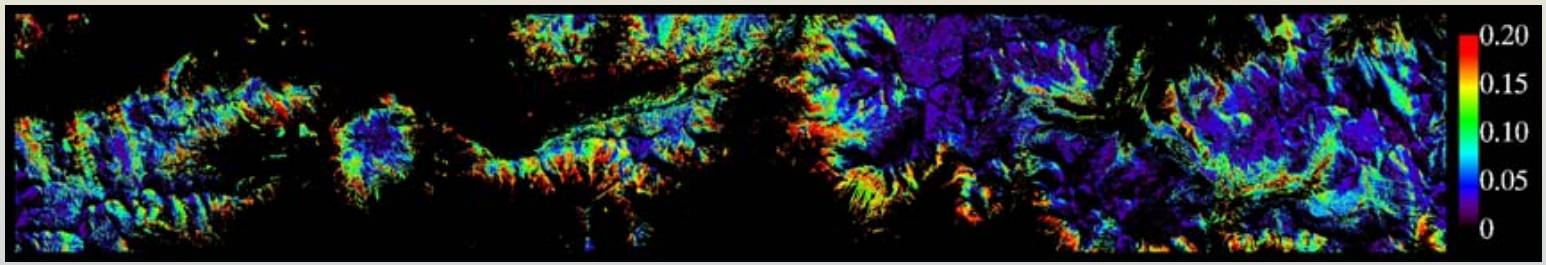
vapor, liquid, ice (BGR)

Progression of snow wetness throughout morning

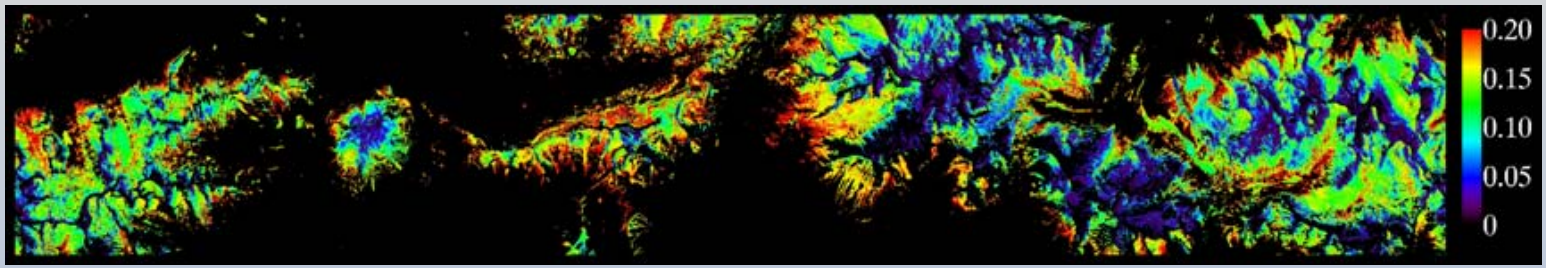
N



AVIRIS
20 May 1996



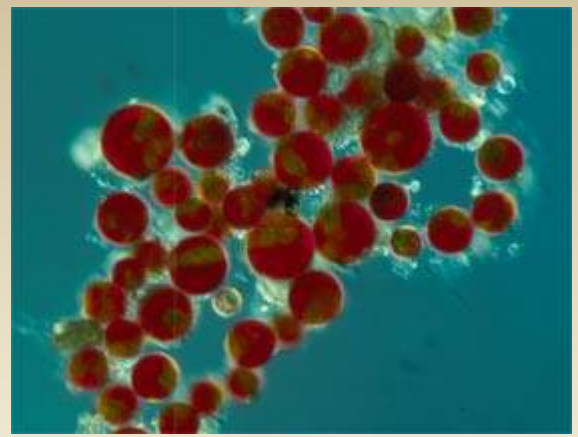
Surface
wetness
09:54 am

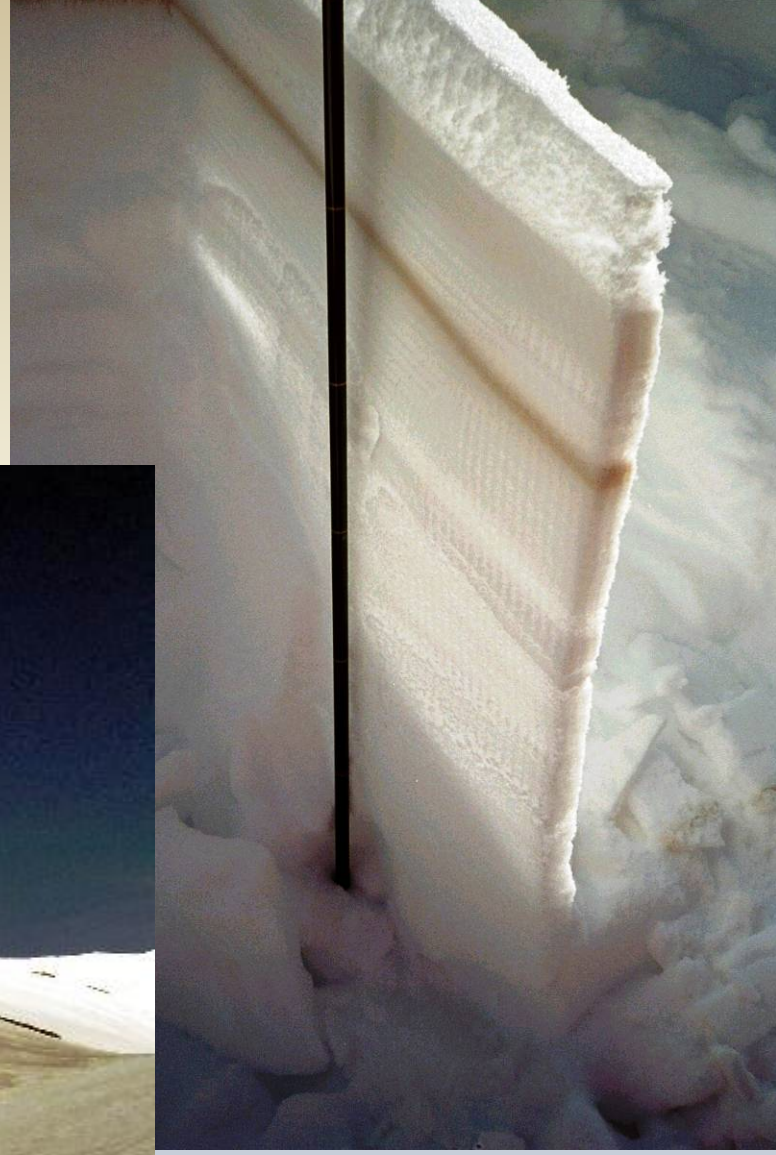


Surface
wetness
11:32 am

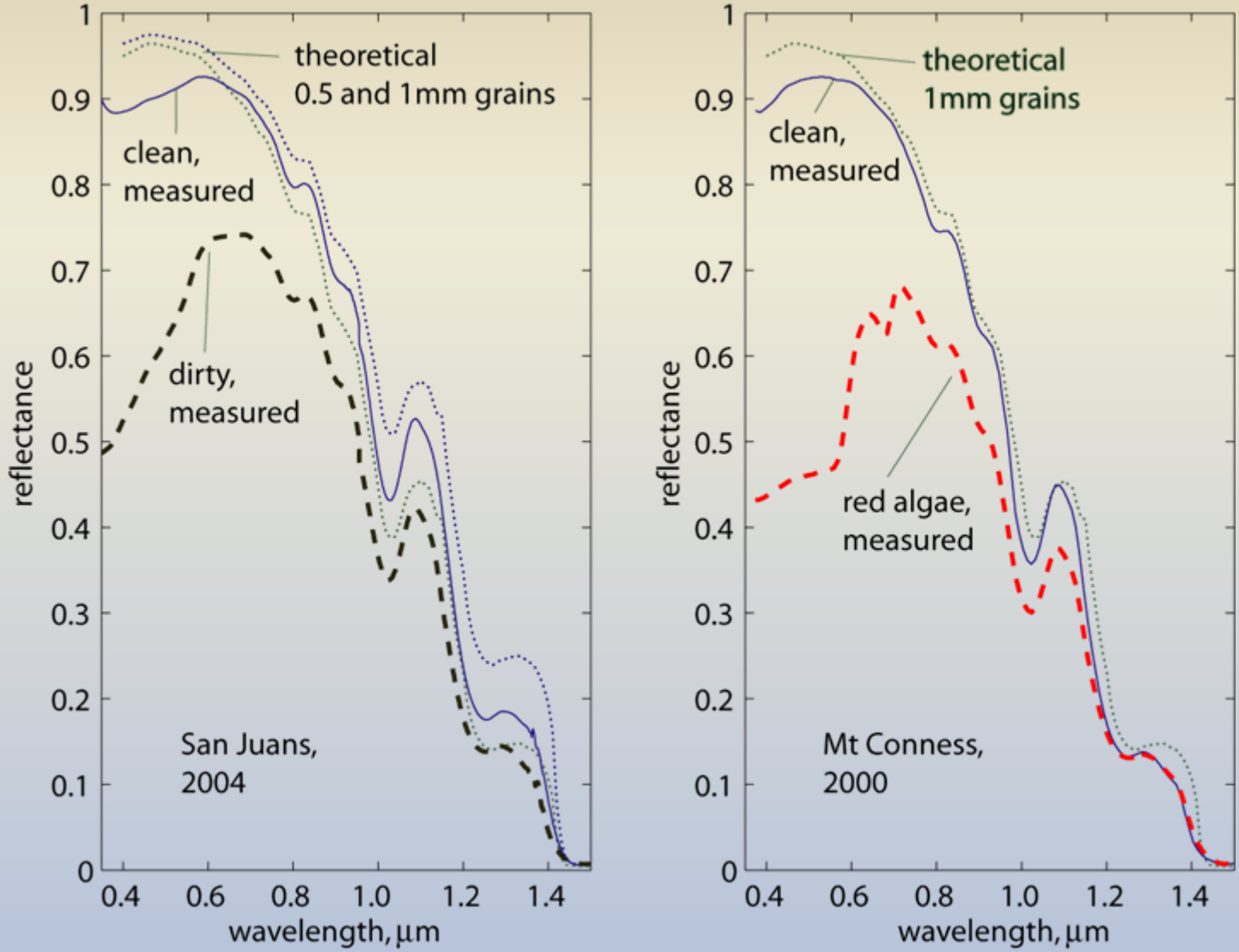
70 km

Dust and algae





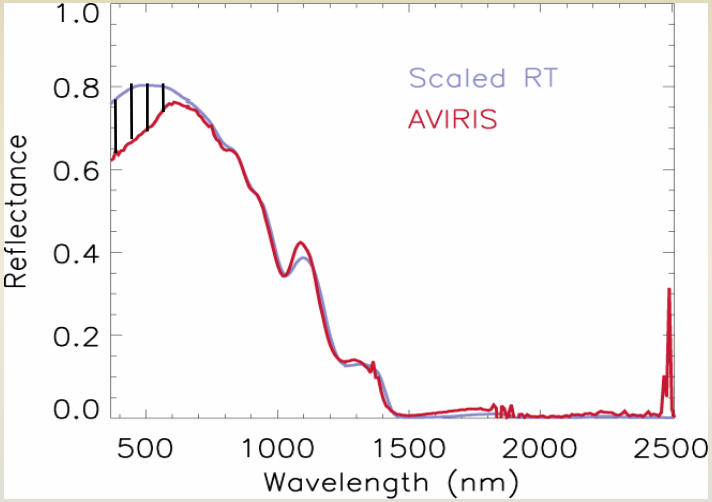
Spectral reflectance of dirty snow and snow with red algae (*Chlamydomonas nivalis*)

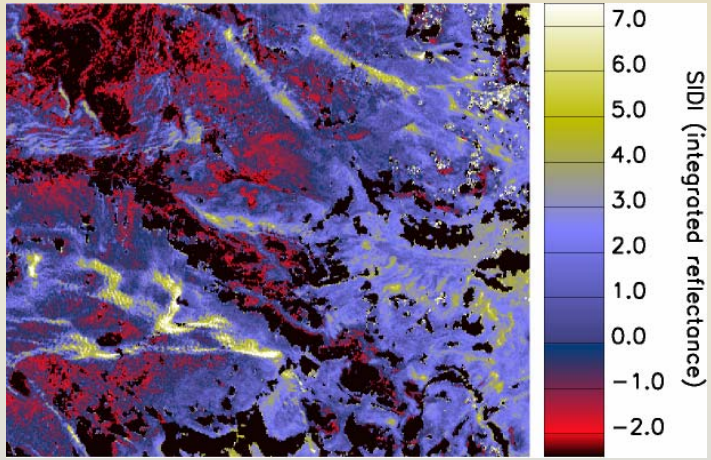


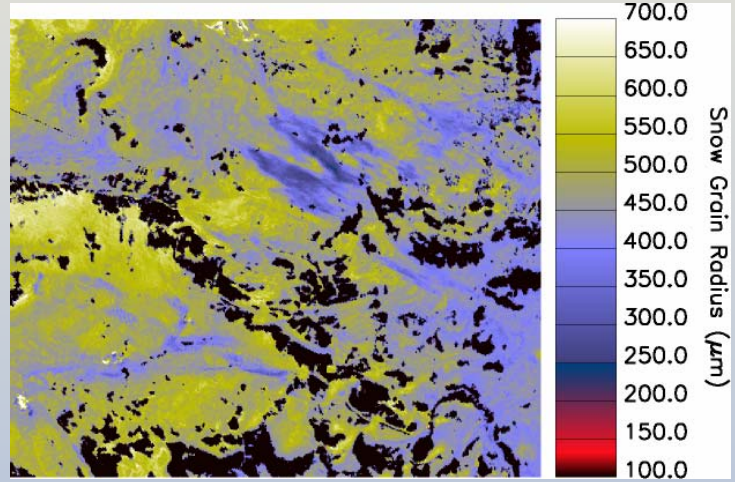
Snow algae concentration

[Painter et al, 2001, *Appl. Environ. Microbiol.*]

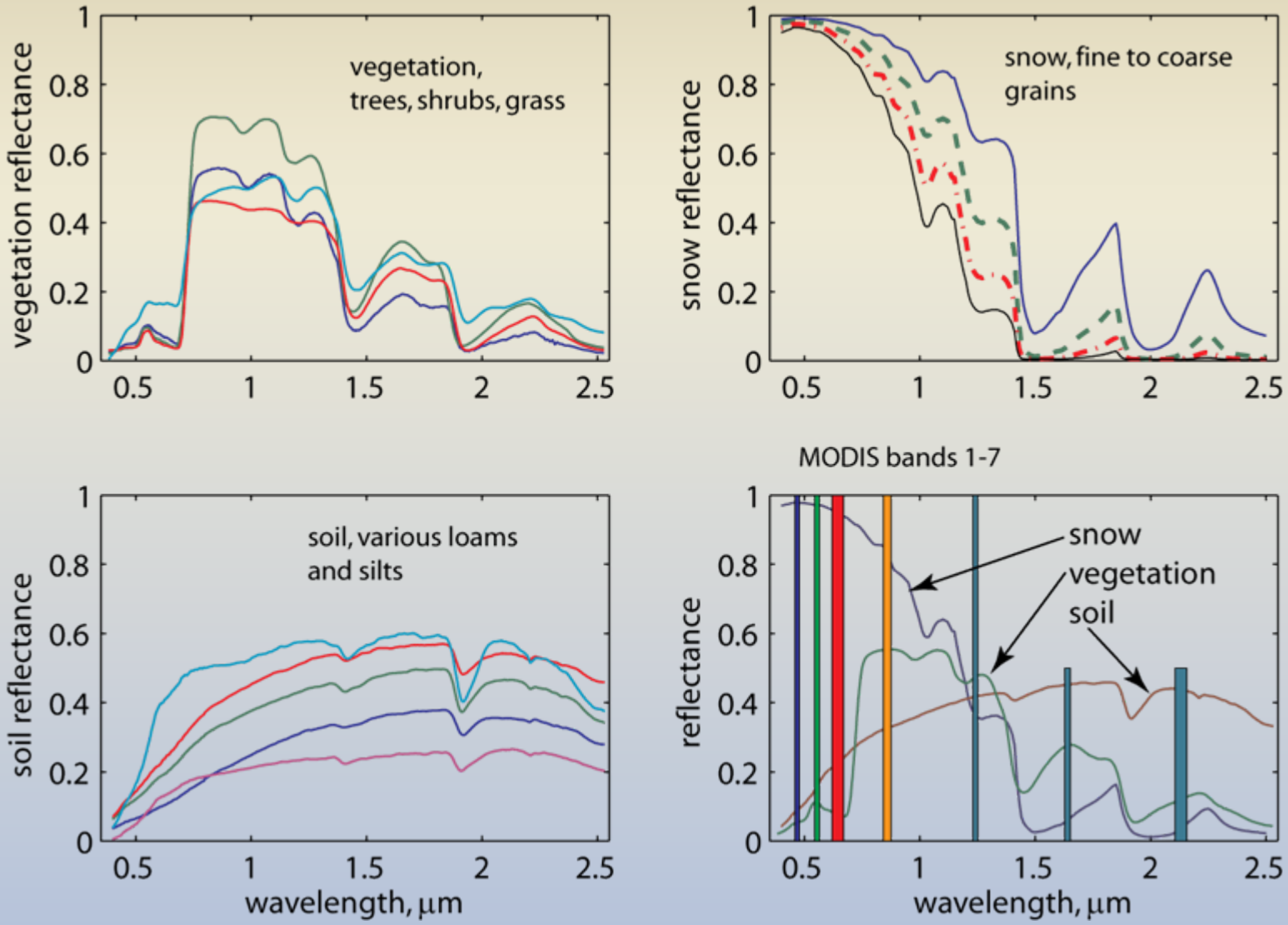
Radiative forcing by dust in snow







Spectra with MODIS "land" bands



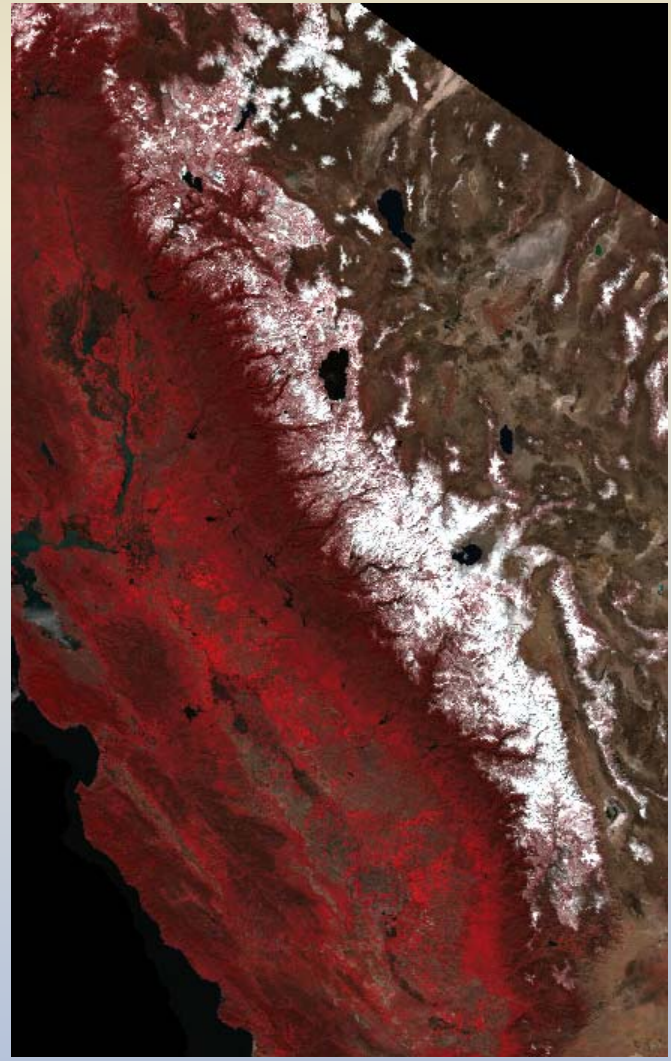
MODIS image of Sierra Nevada

EOS Terra MODIS

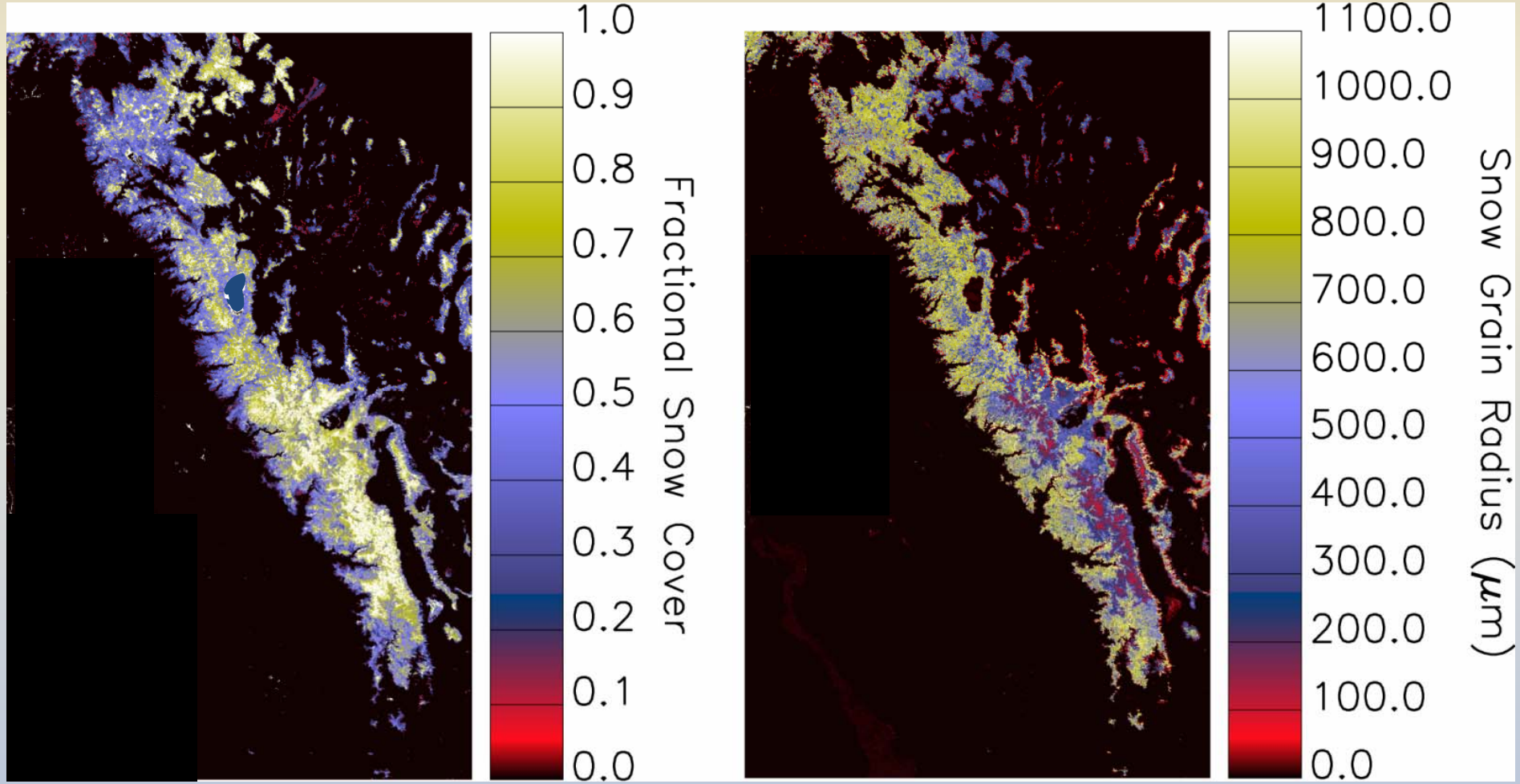
07 March 2004

MOD09 Surface Reflectance

0.555 0.645 0.858



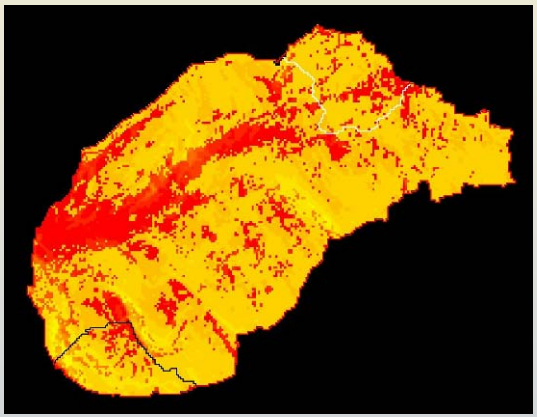
Snow covered-area and grain size – Sierra Nevada



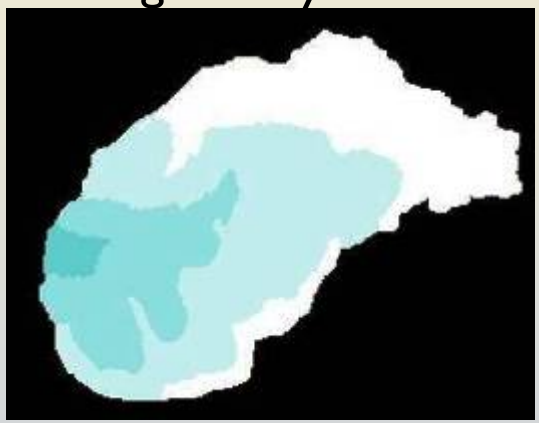
Applications: snowmelt modeling, Marble Fork of the Kaweah River

$$\text{Melt Flux} = \left(R_{net} m_q + T_d a_r\right) \times SCA$$

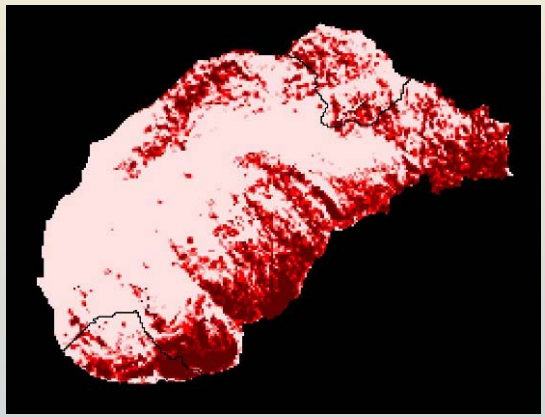
net radiation > 0



degree days > 0



Snow Covered Area

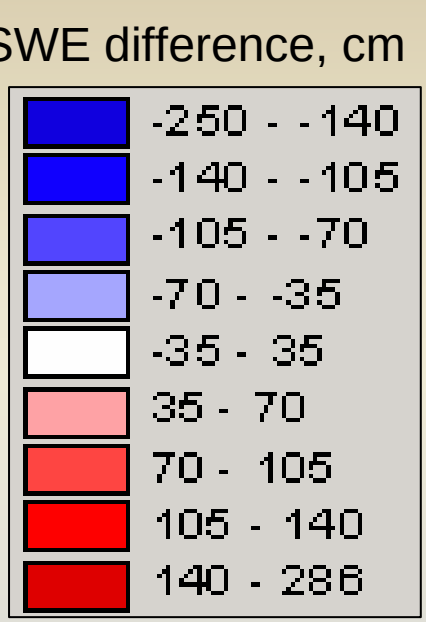


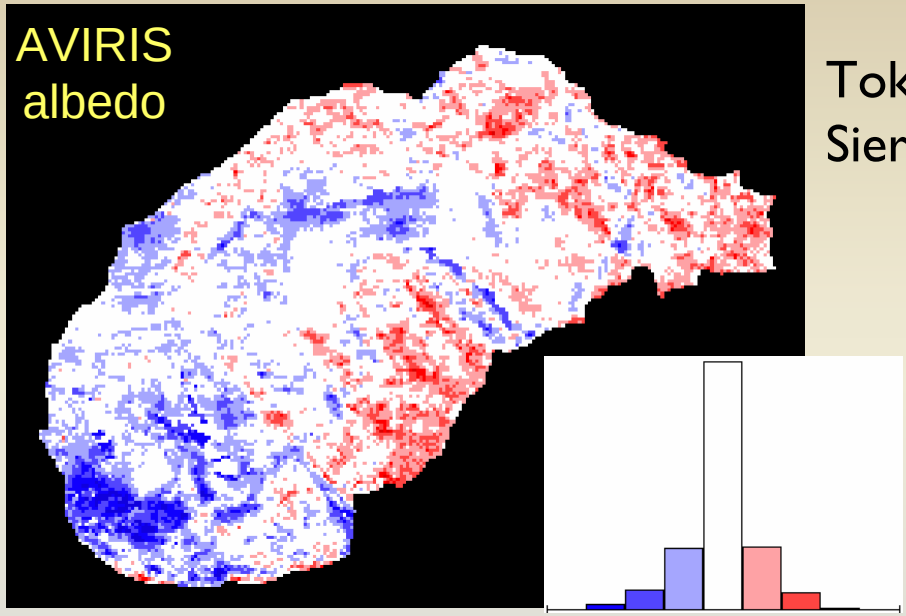
where:

m_q = Energy to water depth conversion, 0.026 cm W^{-1} m^2 day^{-1}

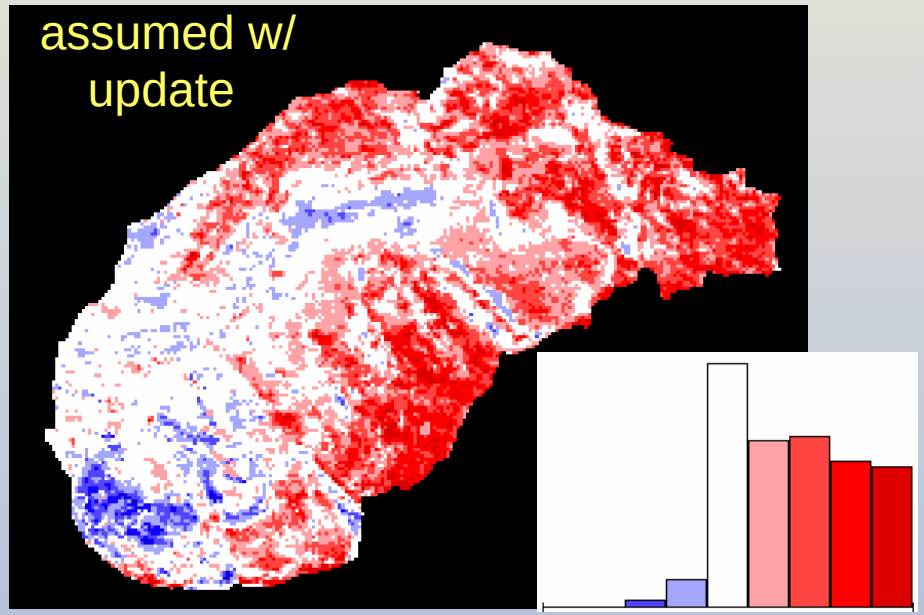
a_r = Convection parameter, based on wind speed, temperature, humidity, and roughness

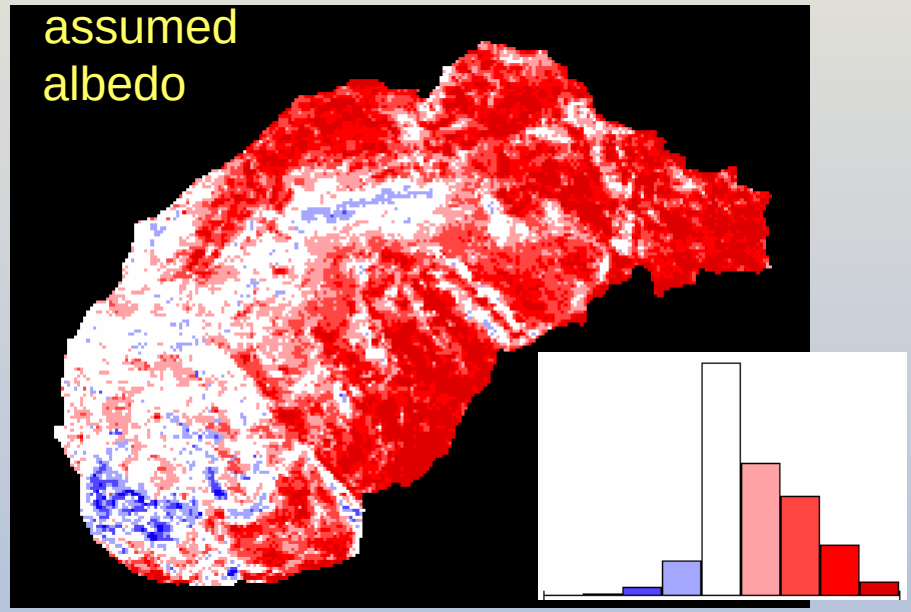
Magnitude of snowmelt: Modeled – Observed snow water equivalent





Tokopah basin,
Sierra Nevada





In memory of Walter Rosenthal

- Walter died in a tragic accident on Mammoth Mountain, April 6, 2006
- In trying to rescue two other ski patrollers who had fallen into a hole in the deep snowpack caused by heat from a volcanic fumerole, he succumbed to the gases that had filled the hole