



Microsoft® Research

FacultySummit 2011

Cartagena, Colombia | May 18-20 | In partnership with COLCIENCIAS

Water from the mountains, *The Fourth Paradigm*, and the color of snow

Jeff Dozier

University of California, Santa Barbara



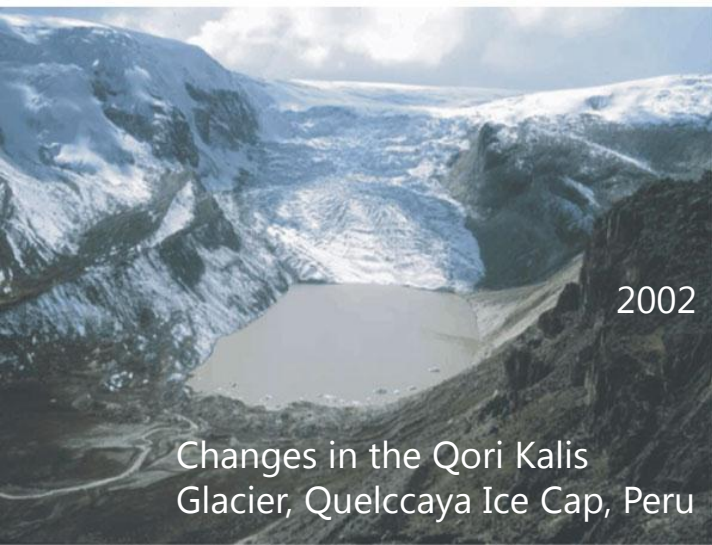
UCSB

1978



1978

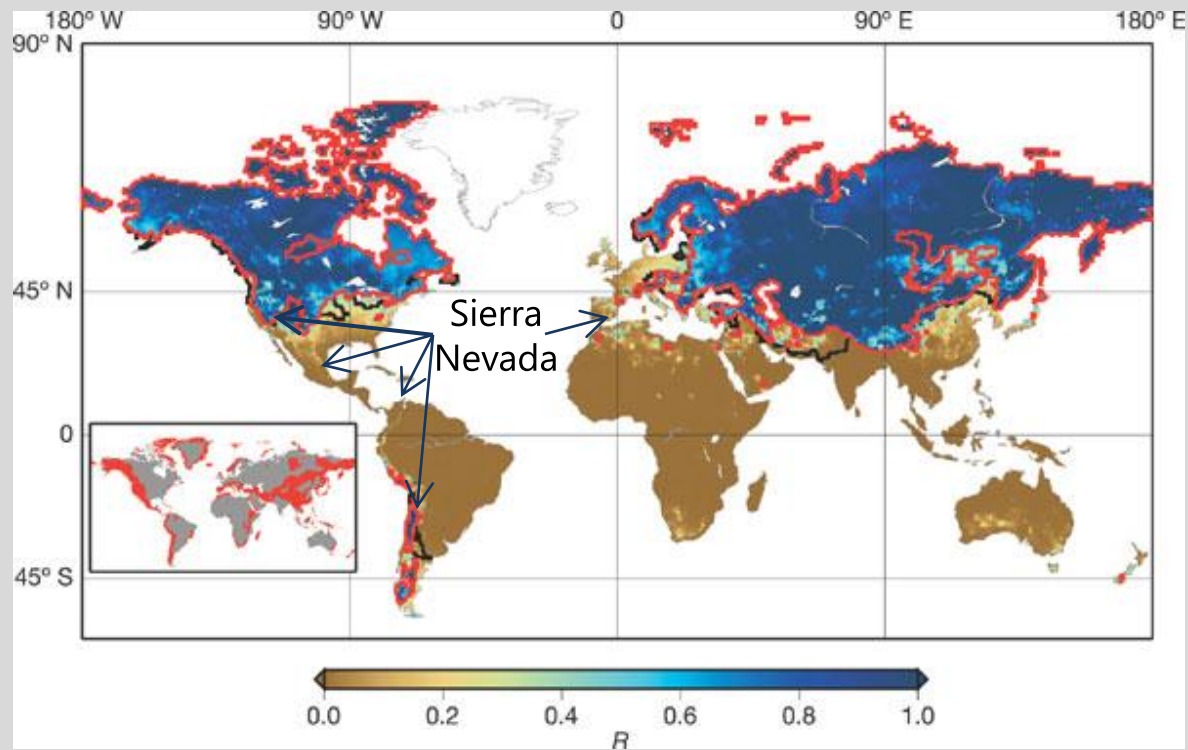
b 2002



2002

Changes in the Qori Kalis Glacier, Quelccaya Ice Cap, Peru

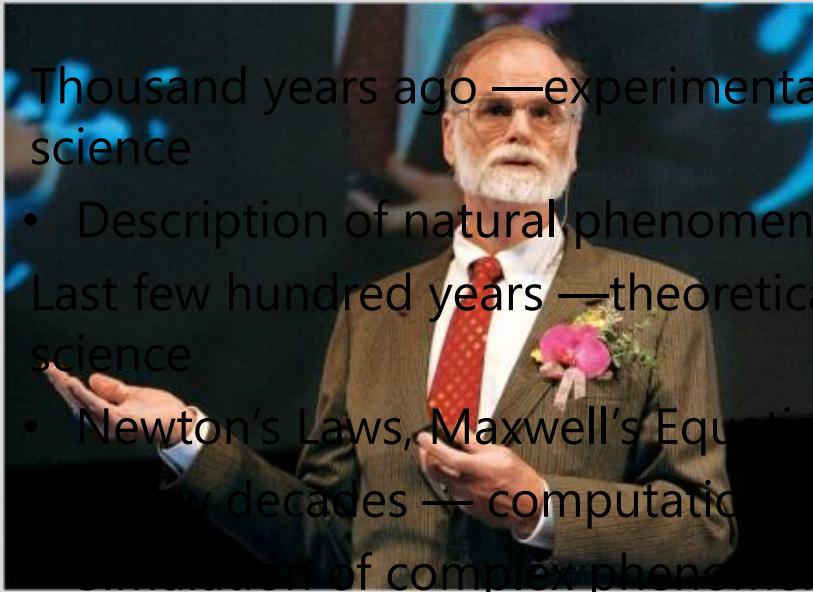
1/5th of Earth's population gets water from snow and ice



(L. Thompson)

(Barnett et al., 2005)

- Thousand years ago — experimental science
 - Description of natural phenomena
- Last few hundred years — theoretical science
 - Newton's Laws, Maxwell's Equations . . .
- Last few decades — computational science
 - Simulation of complex phenomena
- Today — data-intensive science
 - Model/Data integration
 - Data mining
 - Higher-order products, sharing
<http://fourthparadigm.org>



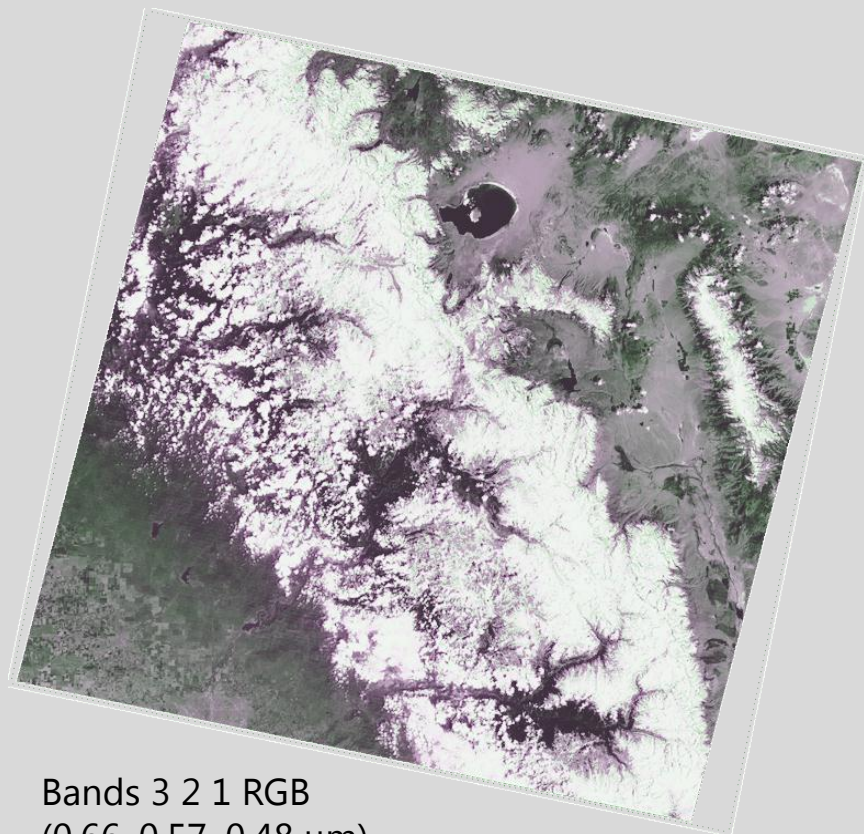
The
F O U R T H
P A R A D I G M

DATA-INTENSIVE SCIENTIFIC DISCOVERY

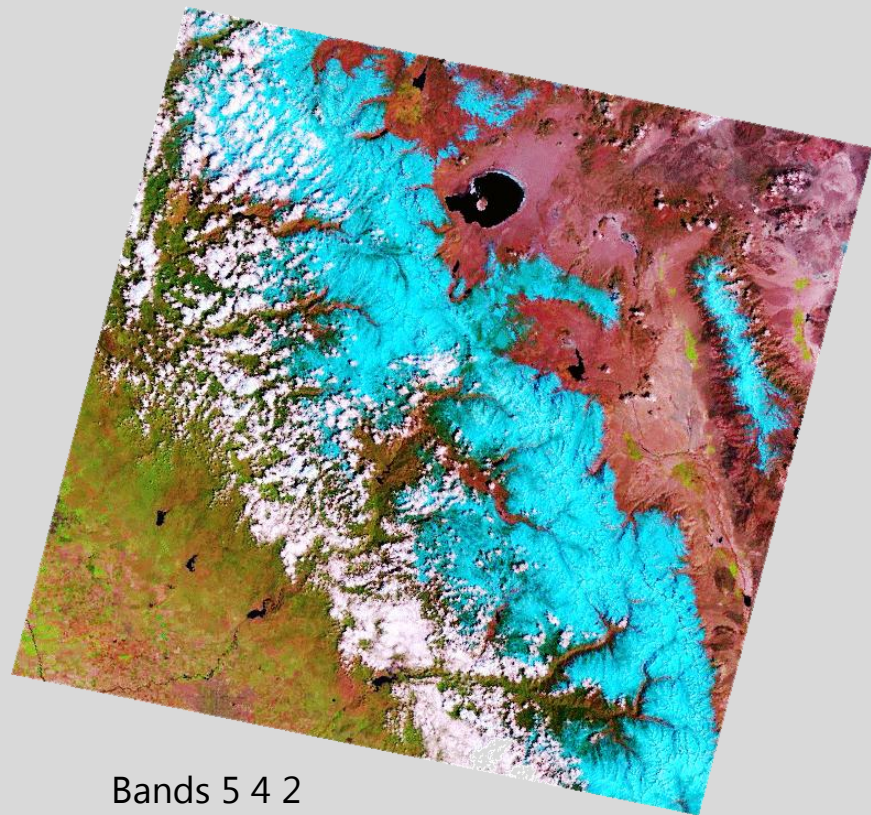
DATA-INTENSIVE SCIENTIFIC DISCOVERY

Б А В Д И С М
 Е О П К Л Н

Snow is one of nature's most colorful materials (Landsat Thematic Mapper snow & cloud)



Bands 3 2 1 RGB
(0.66, 0.57, 0.48 μm)



Bands 5 4 2
(1.65, 0.83, 0.57 μm)

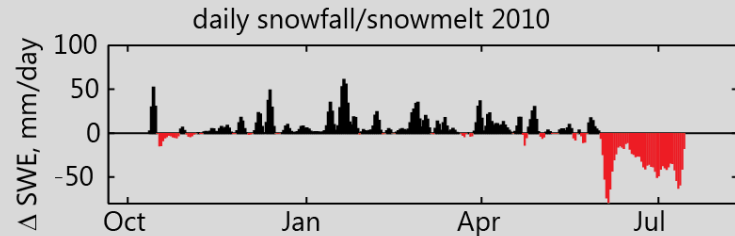
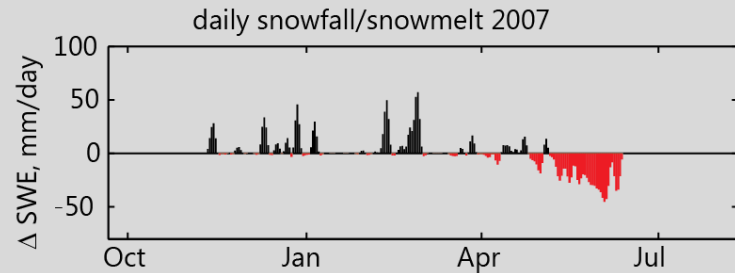
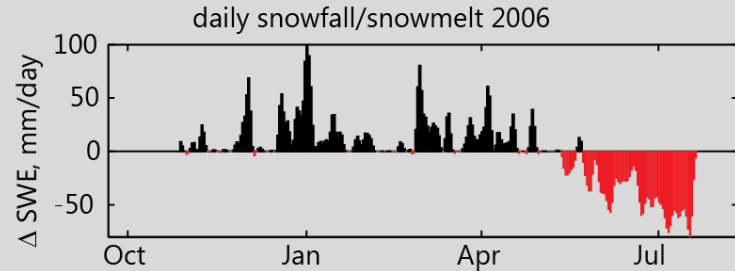
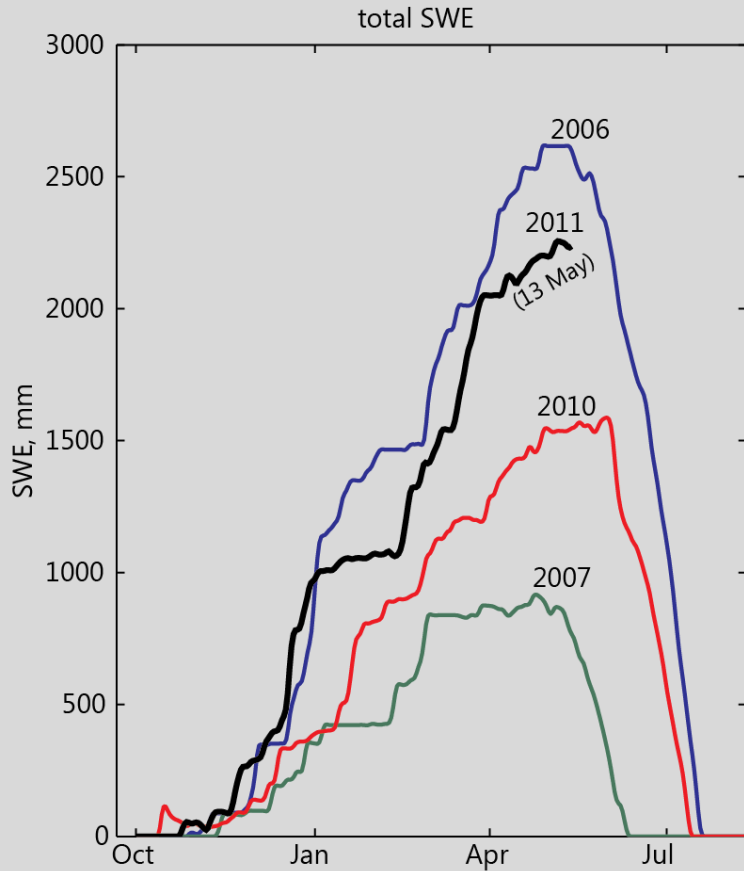
Automated measurement with snow pillow

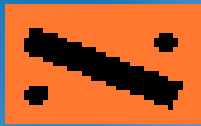


(R. Julander)

- Measures the *snow water equivalent (SWE)*
 - amount of water that would result if the snow melted
 - $\rho_{snow} \times \text{depth} = \text{kg m}^{-2}$ (mass/area)
 - $(\rho_{snow} \times \text{depth}) / \rho_{water} =$ depth of water equivalent
 - $1 \text{ kg m}^{-2} = 1 \text{ mm depth}$

Snow-pillow data for Leavitt Lake, 2929 m, Sierra Nevada

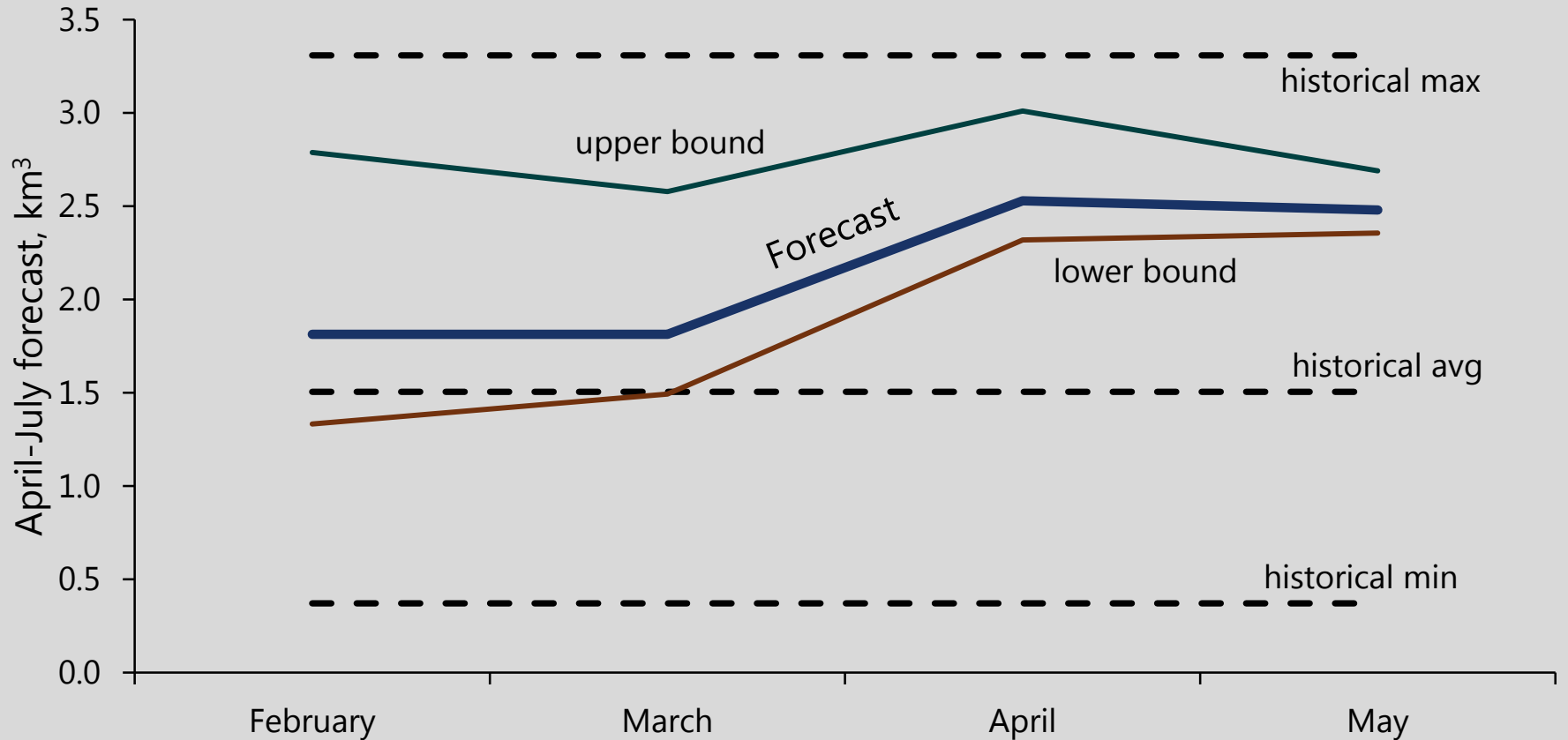




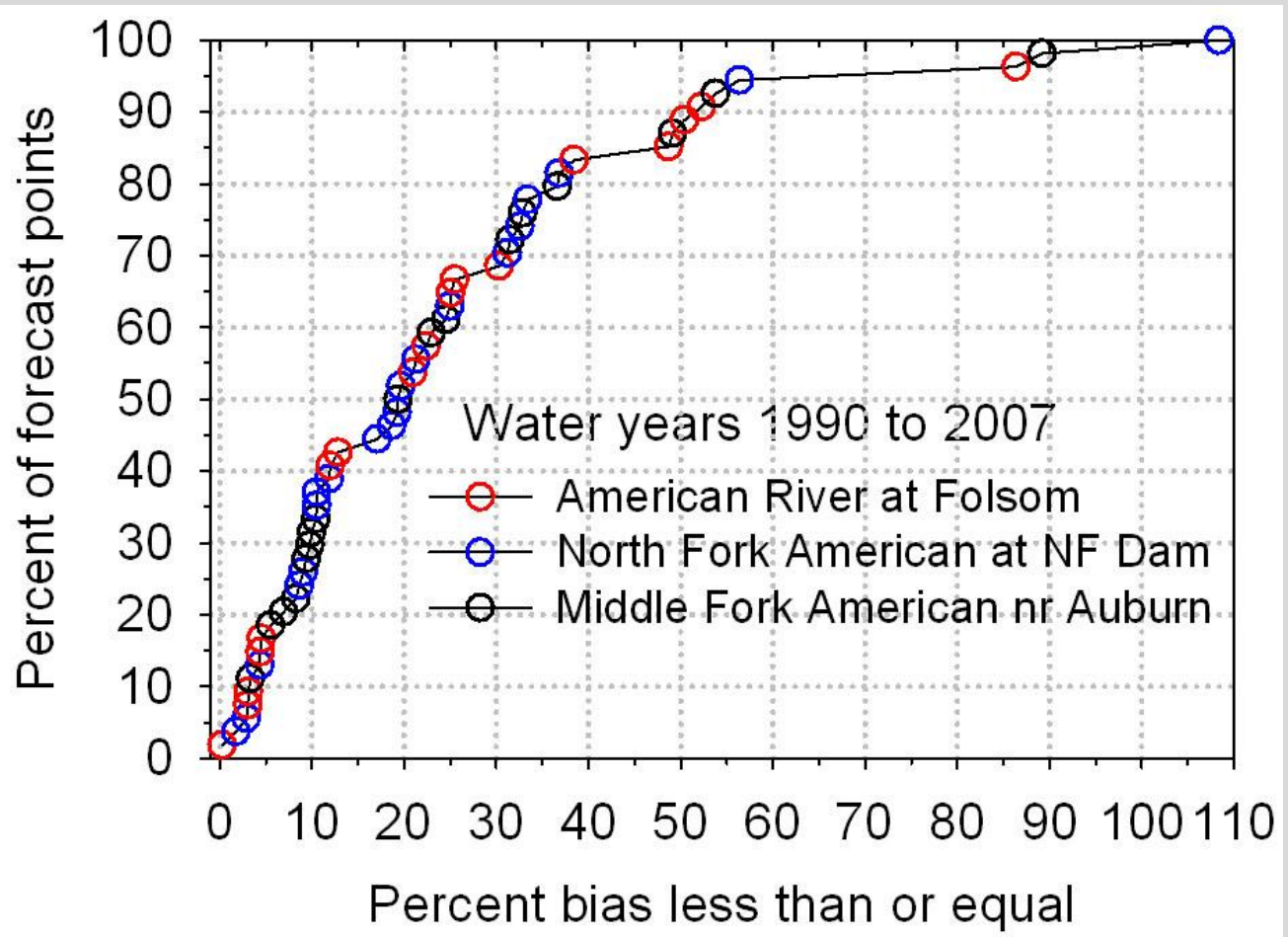
Manual measurement started in the Sierra Nevada in 1910



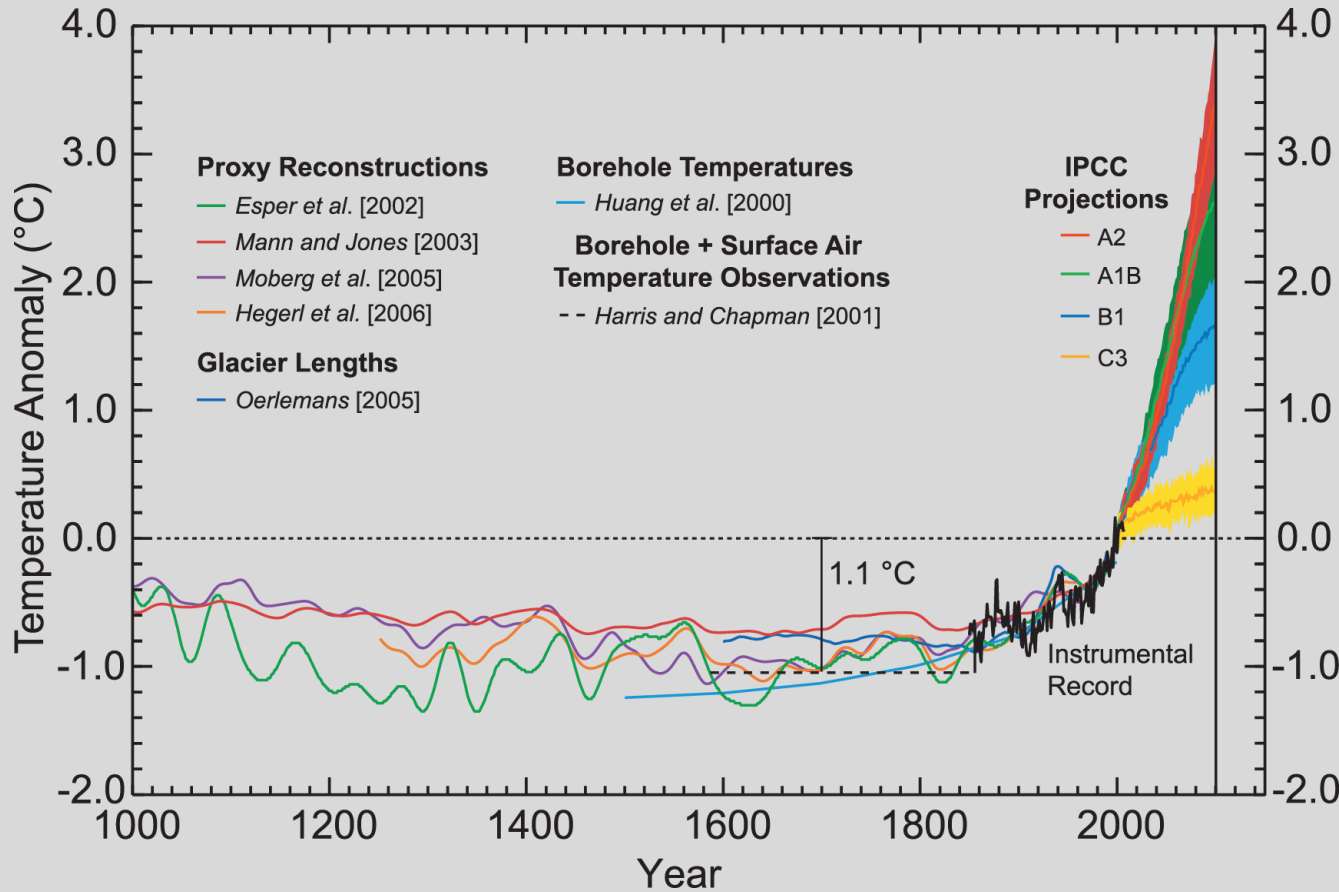
April-July 2011 forecast, Tuolumne River



Distribution of errors in the April-July forecast

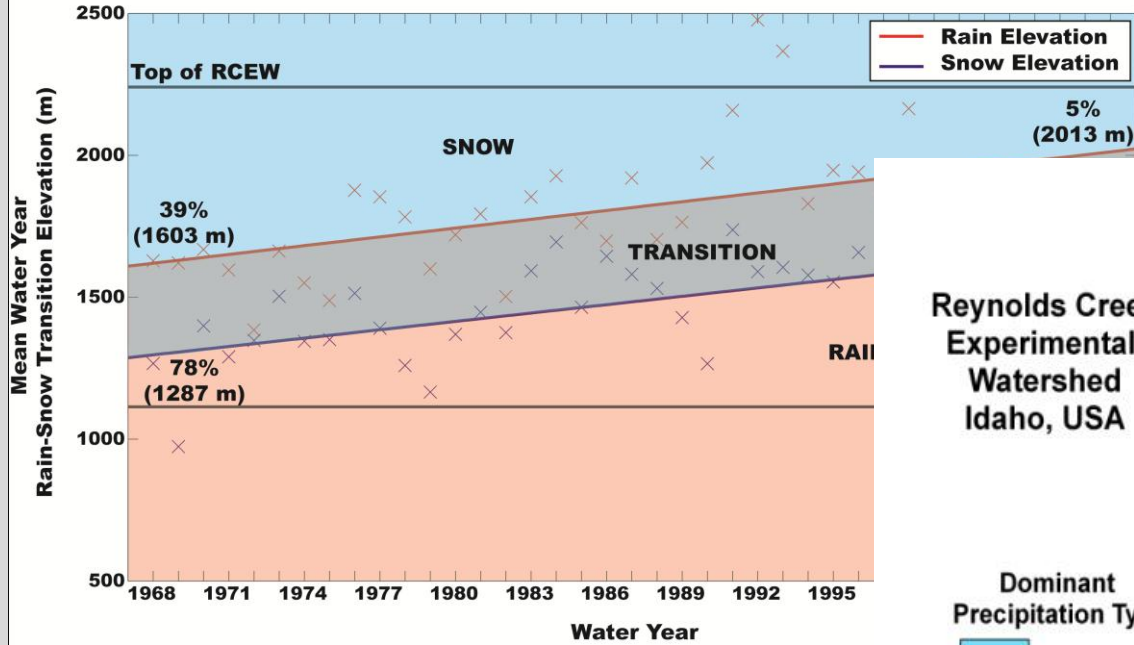


Historical record during a period of climate change

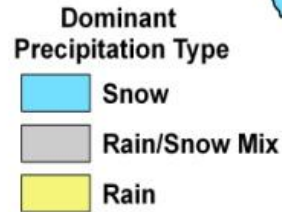


[Chapman & Davis,
2010]

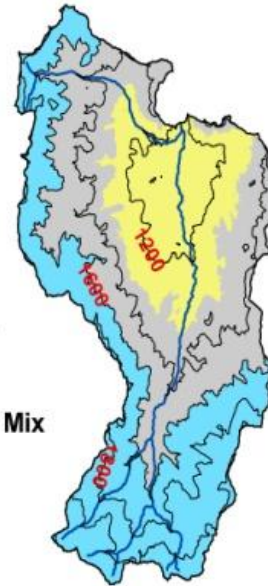
Changes in the Rain/Snow Transition Elevation 1968-2006 Water Years



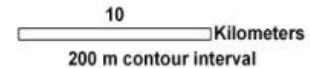
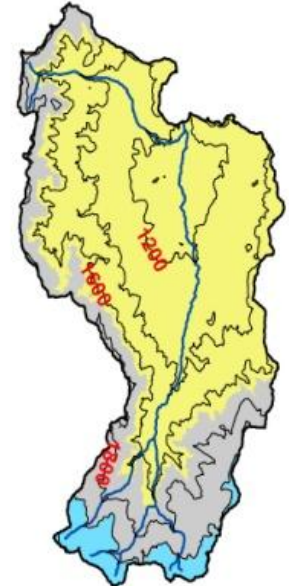
Reynolds Creek Experimental Watershed Idaho, USA



1968

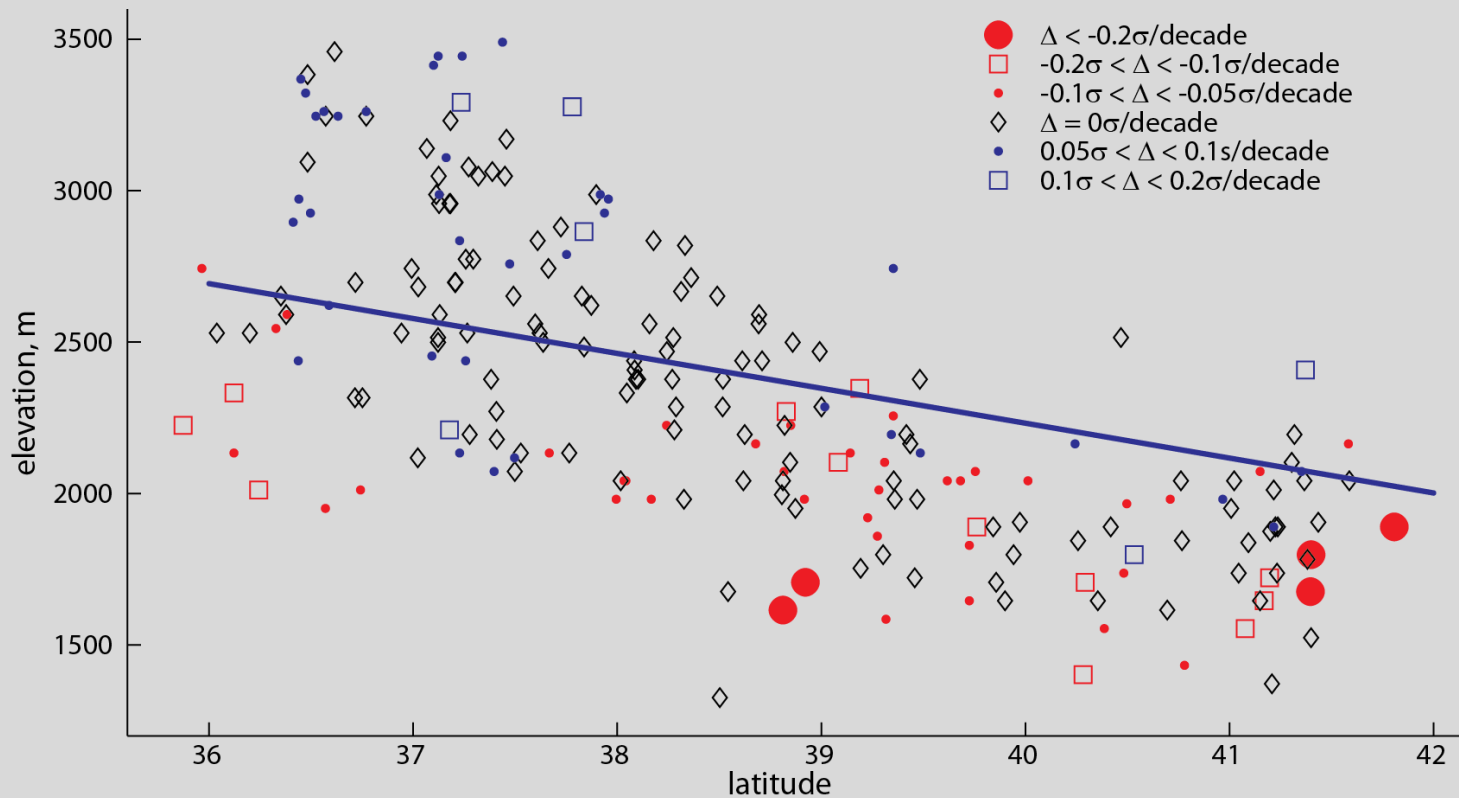


2006

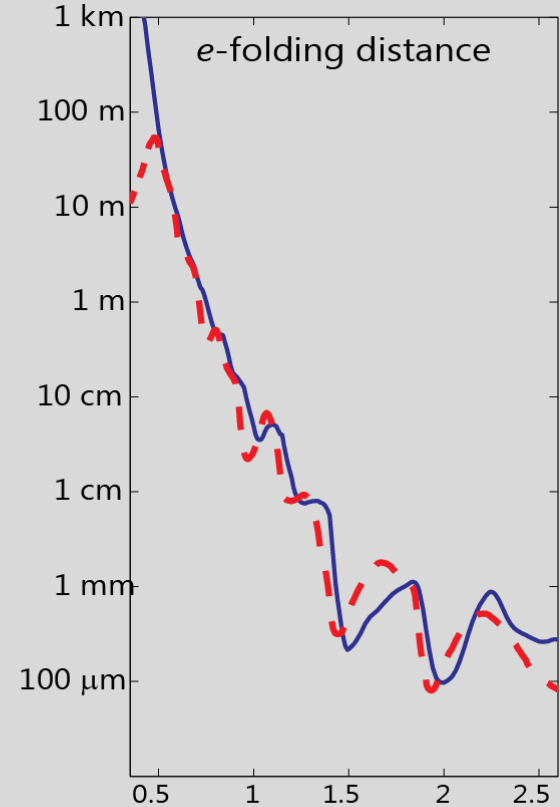
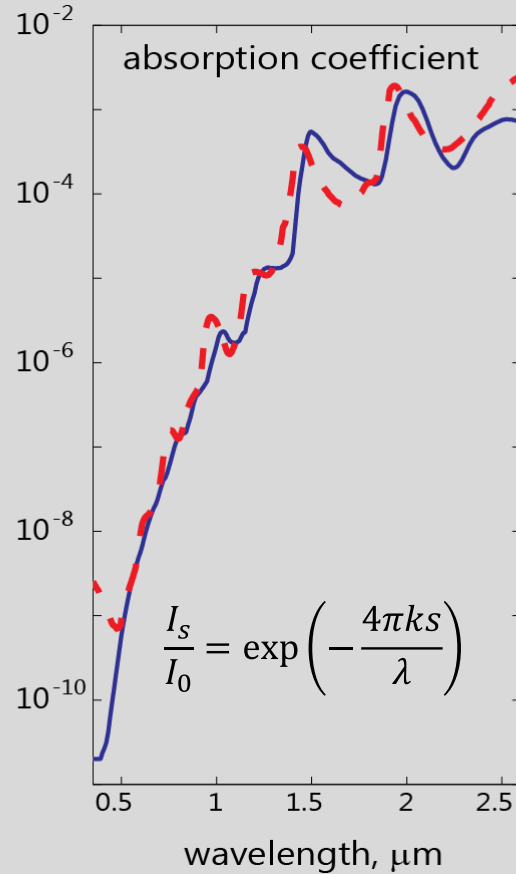
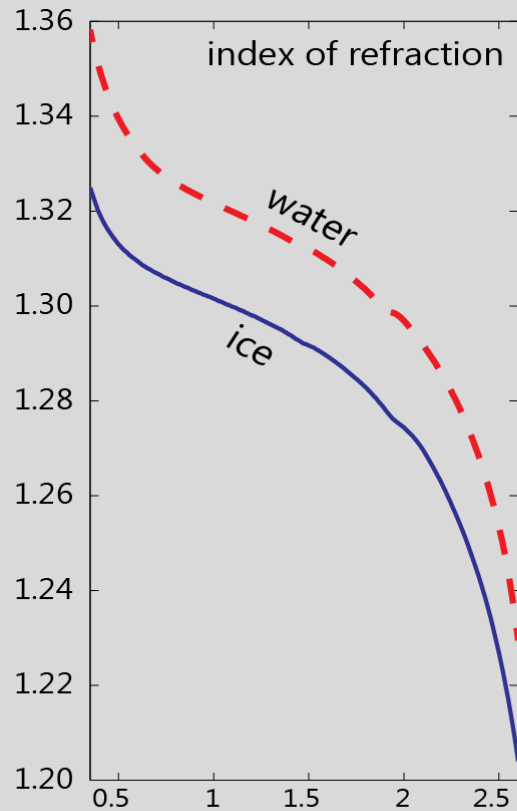


[D. Marks]

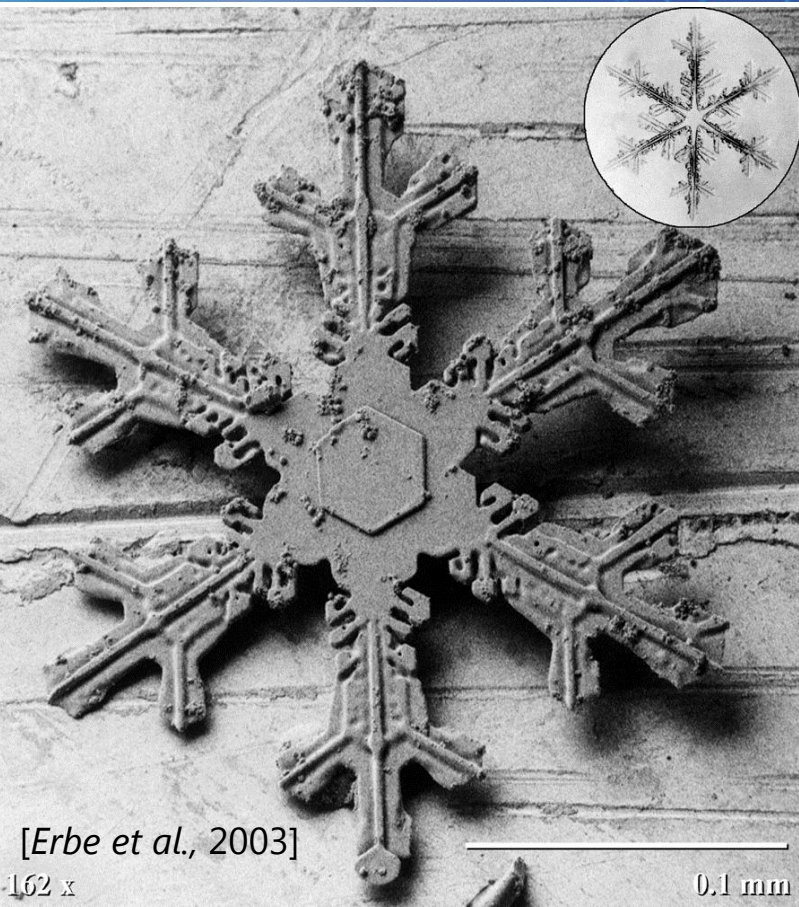
Sierra Nevada, trends in 220 long-term snow courses (> 50 years, continuing to present)



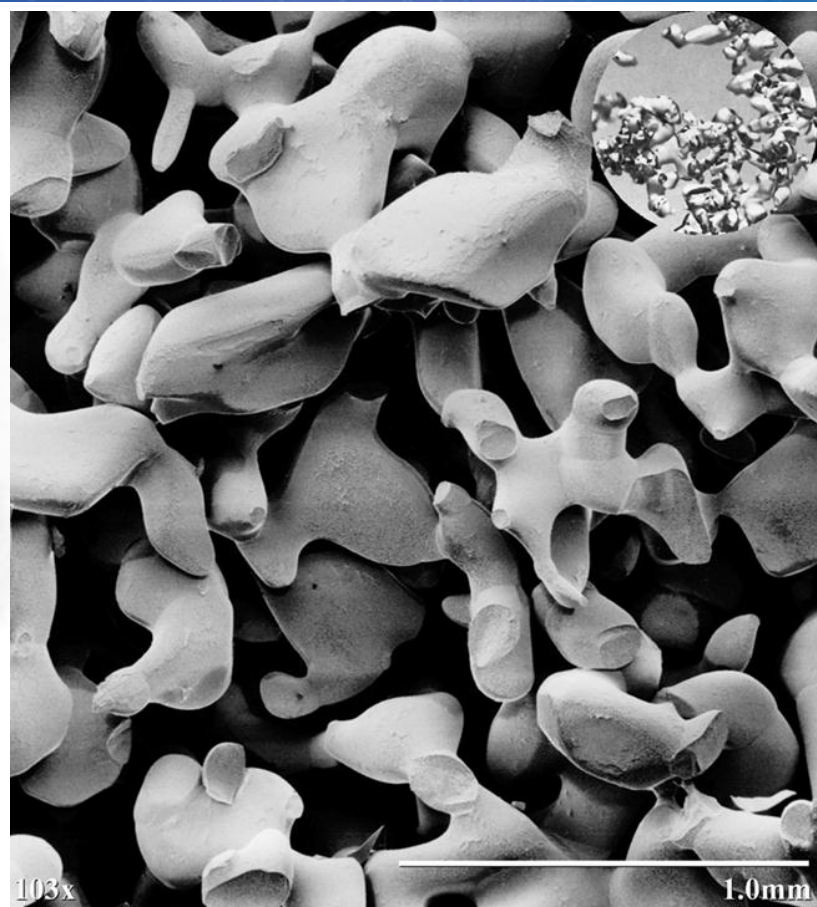
Optical properties of ice and water



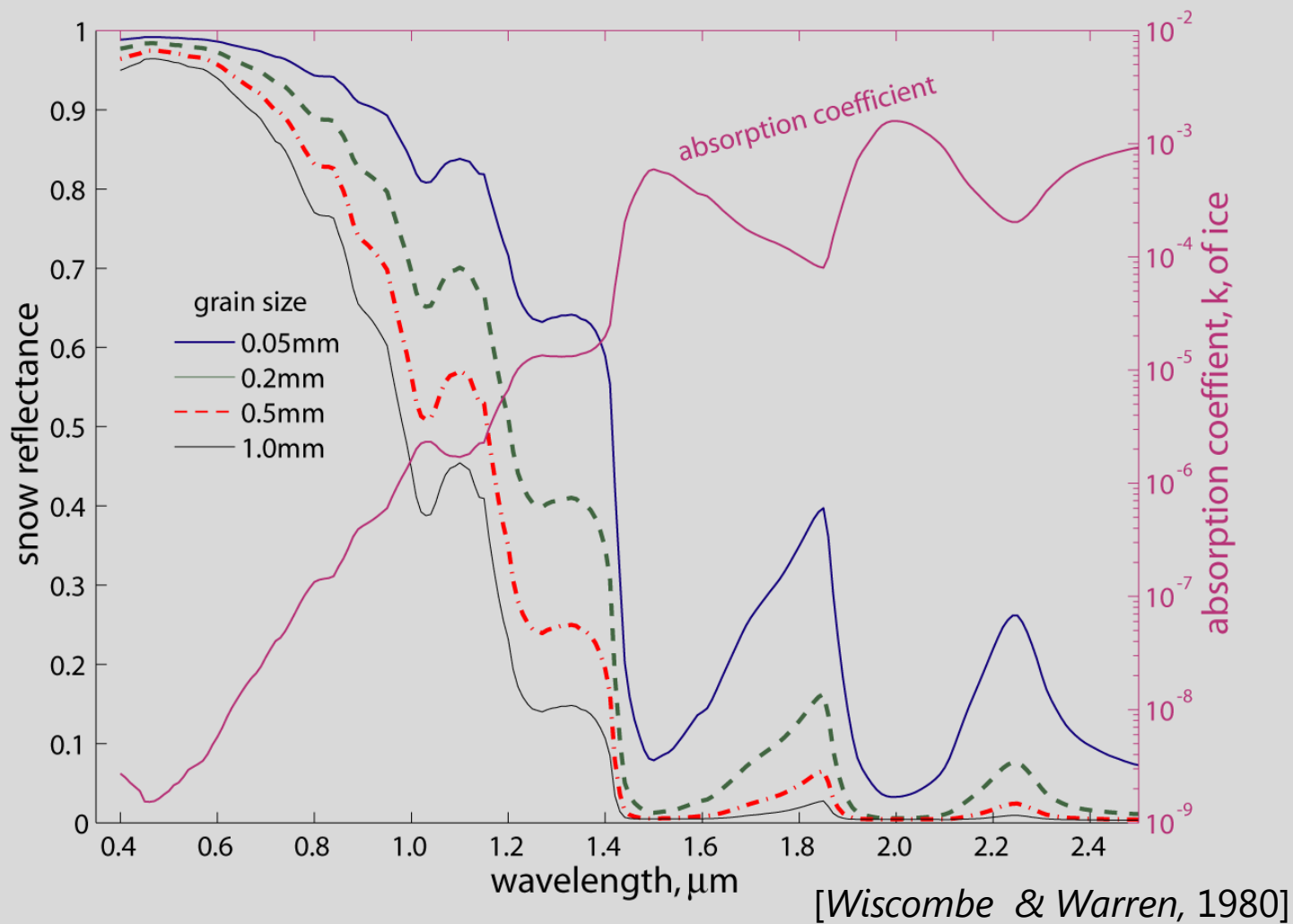
"Snowflakes are hieroglyphs sent from the sky"



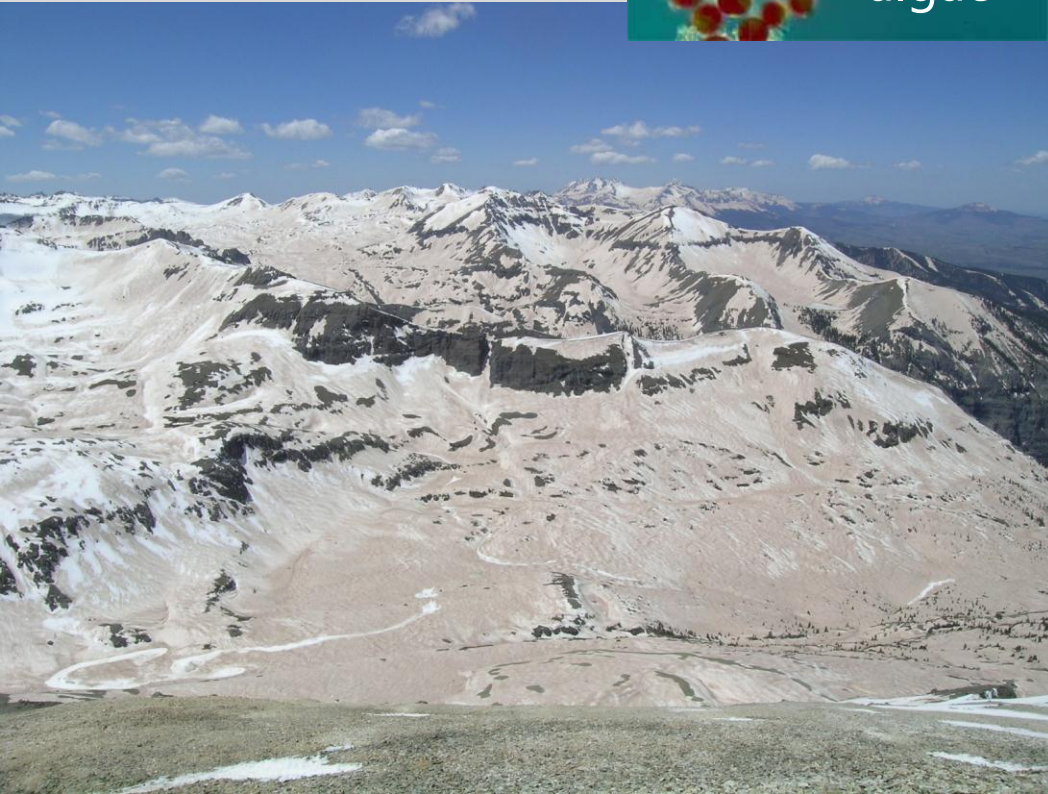
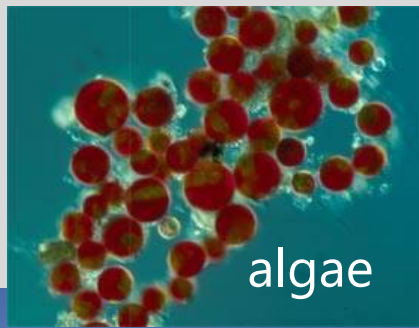
Ukichiro
Nakaya



Snow spectral reflectivity (albedo) is sensitive to the absorption coefficient of ice

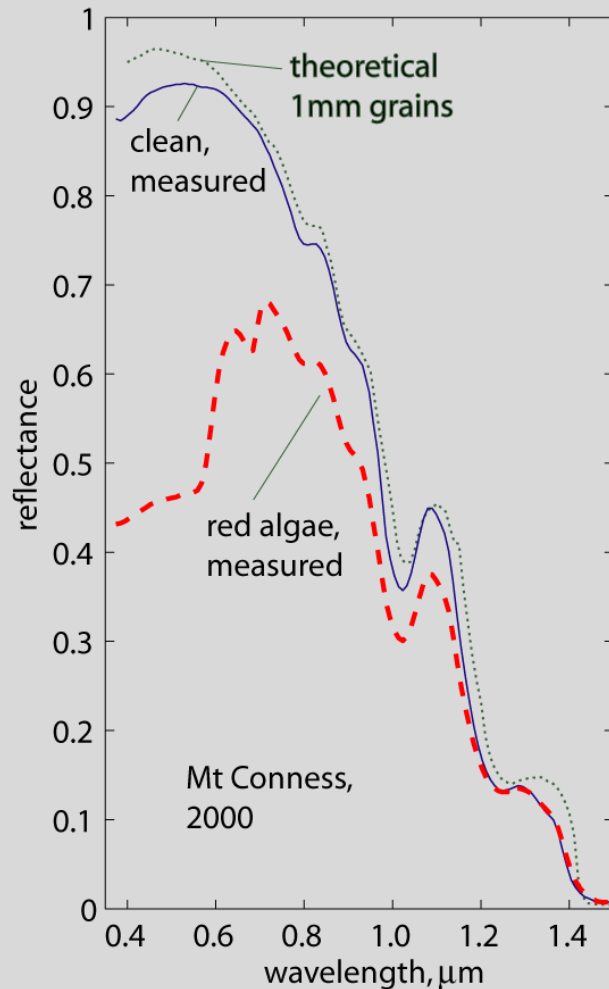
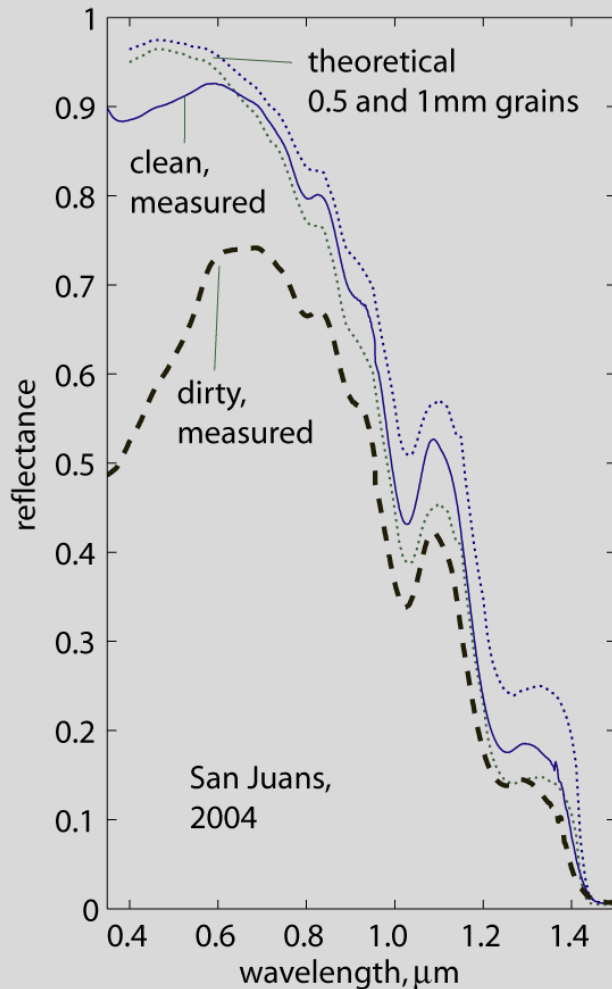


Dust



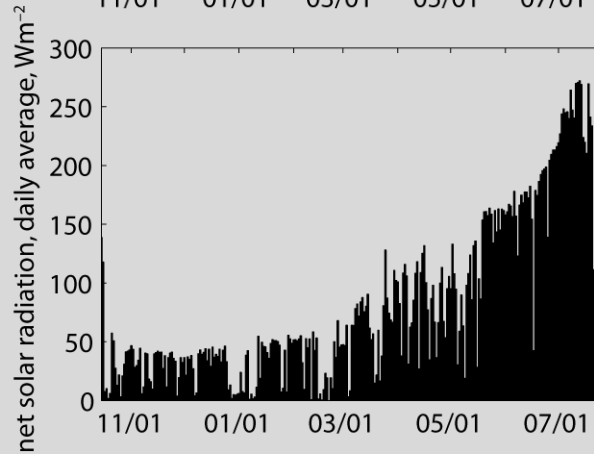
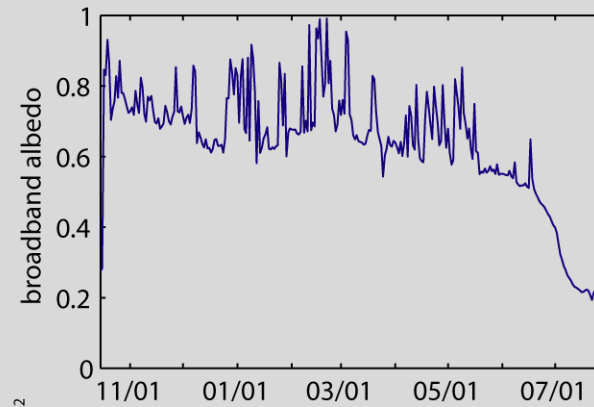
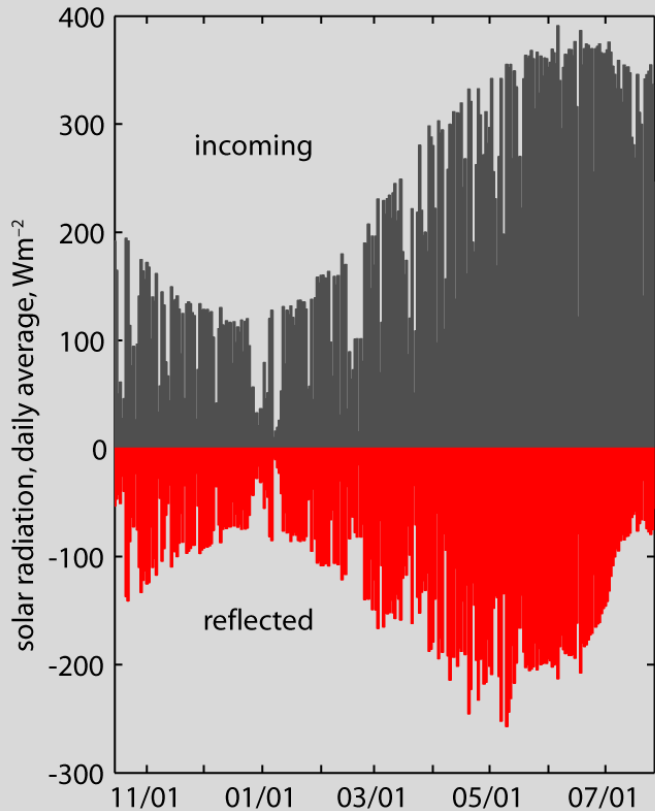
(M. Skiles)

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

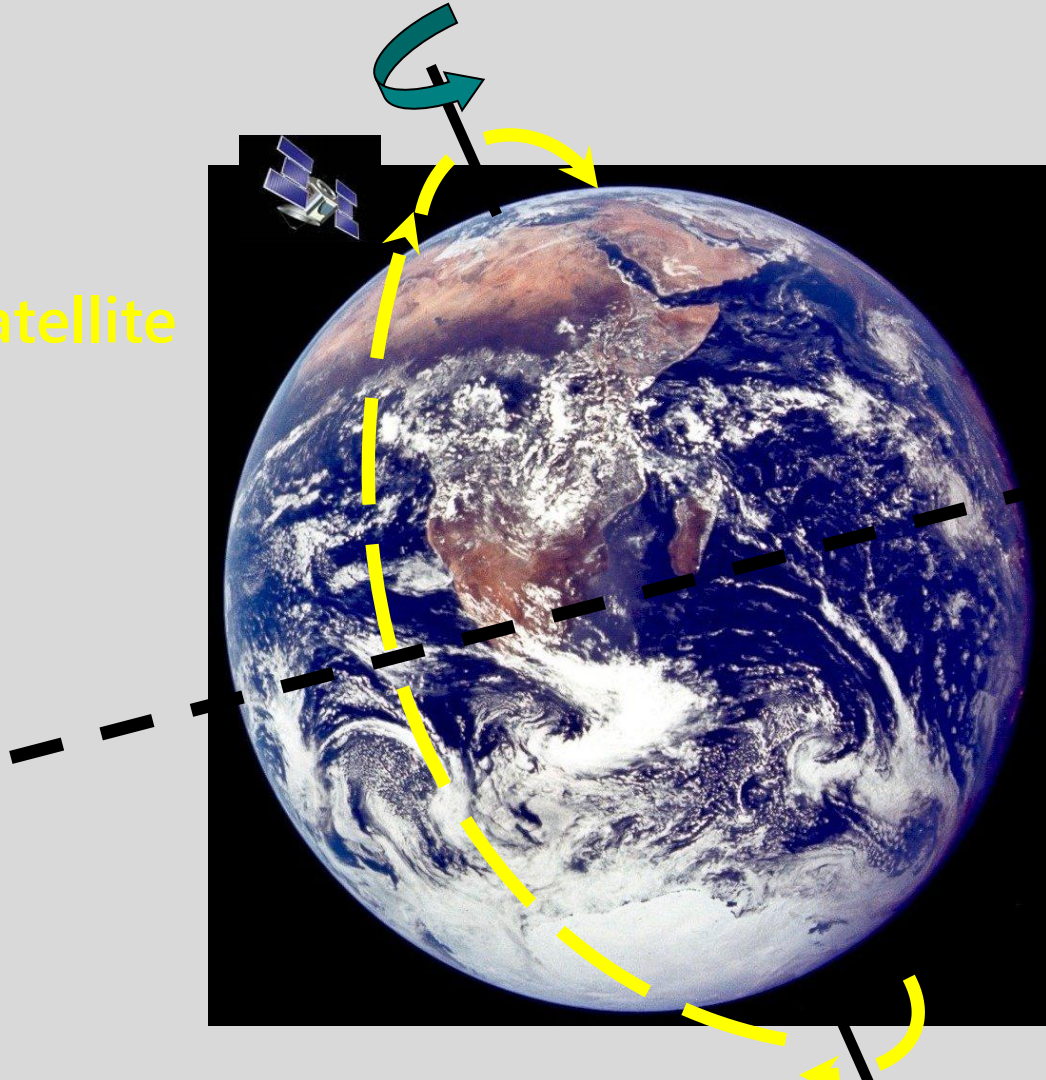


[Painter et al., 2001]

Seasonal solar radiation (Mammoth Mtn, 2005)



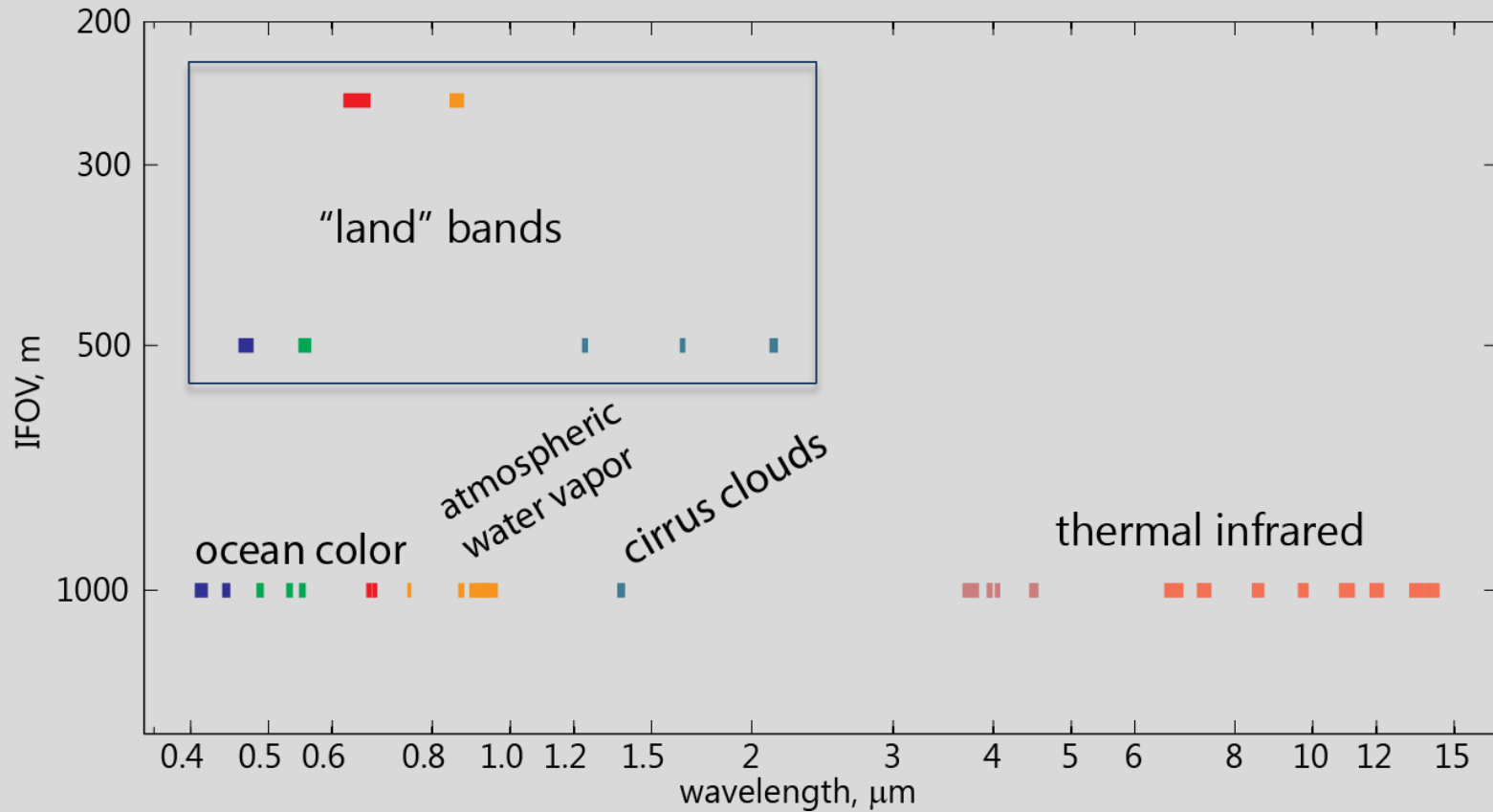
Path of Satellite



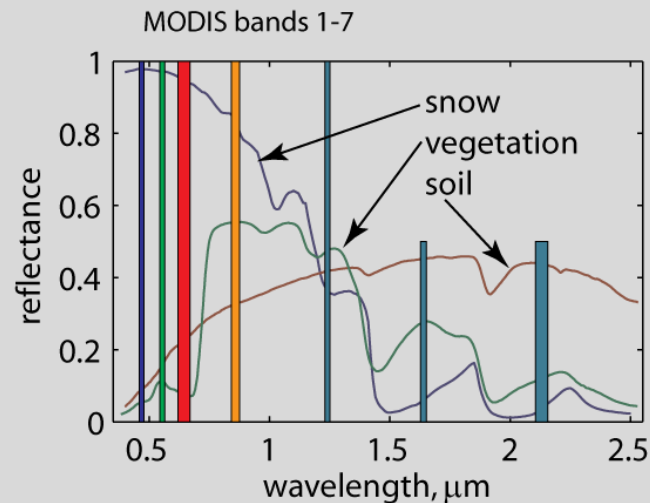
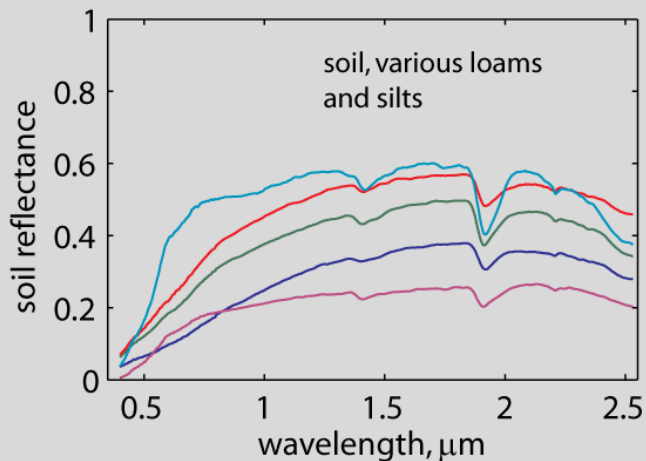
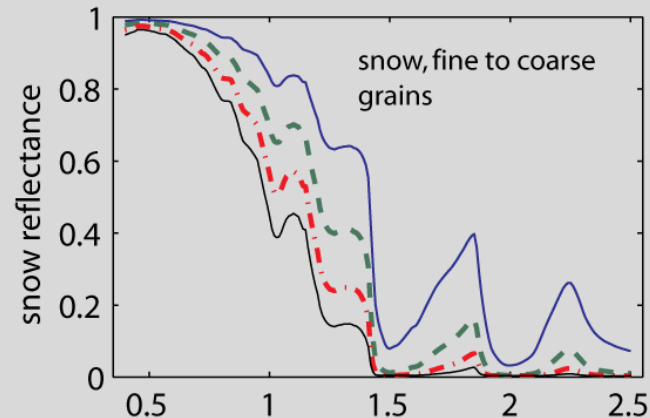
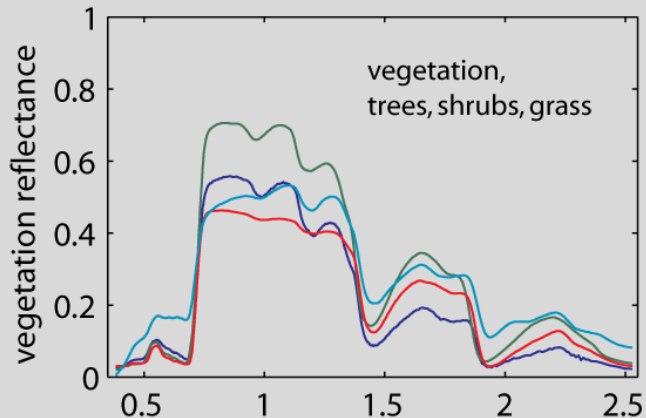
Terra satellite
705 km altitude
orbit 98 minutes

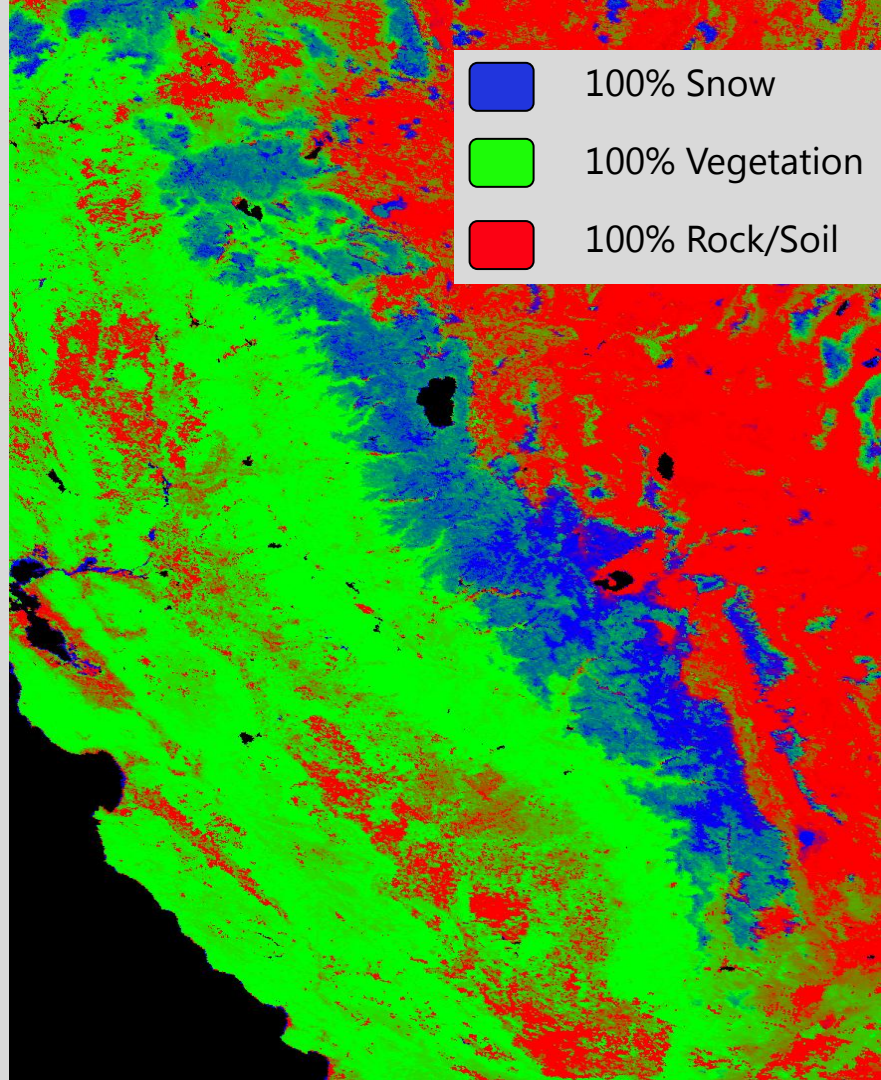
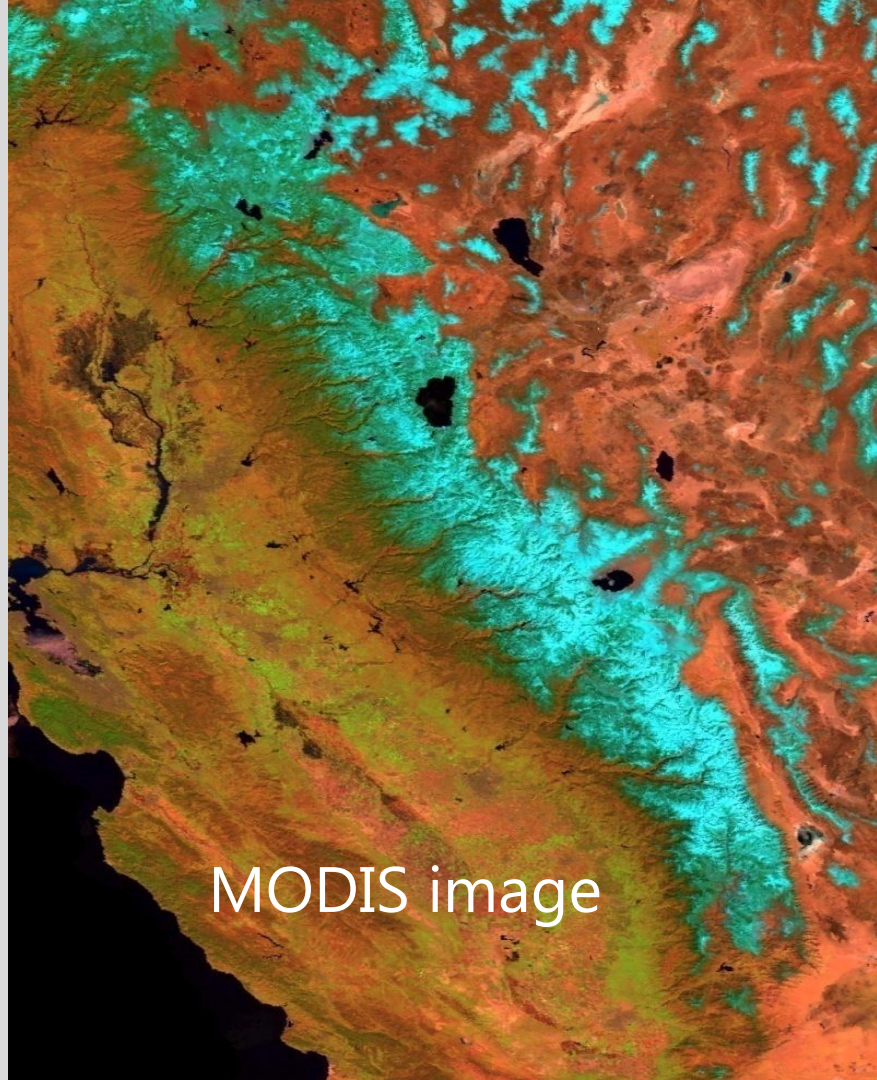
MODIS
instrument sees
all of Earth's
surface in 2 days
(almost all in 1
day)

(moderate resolution imaging spectroradiometer) MODIS spectral bands



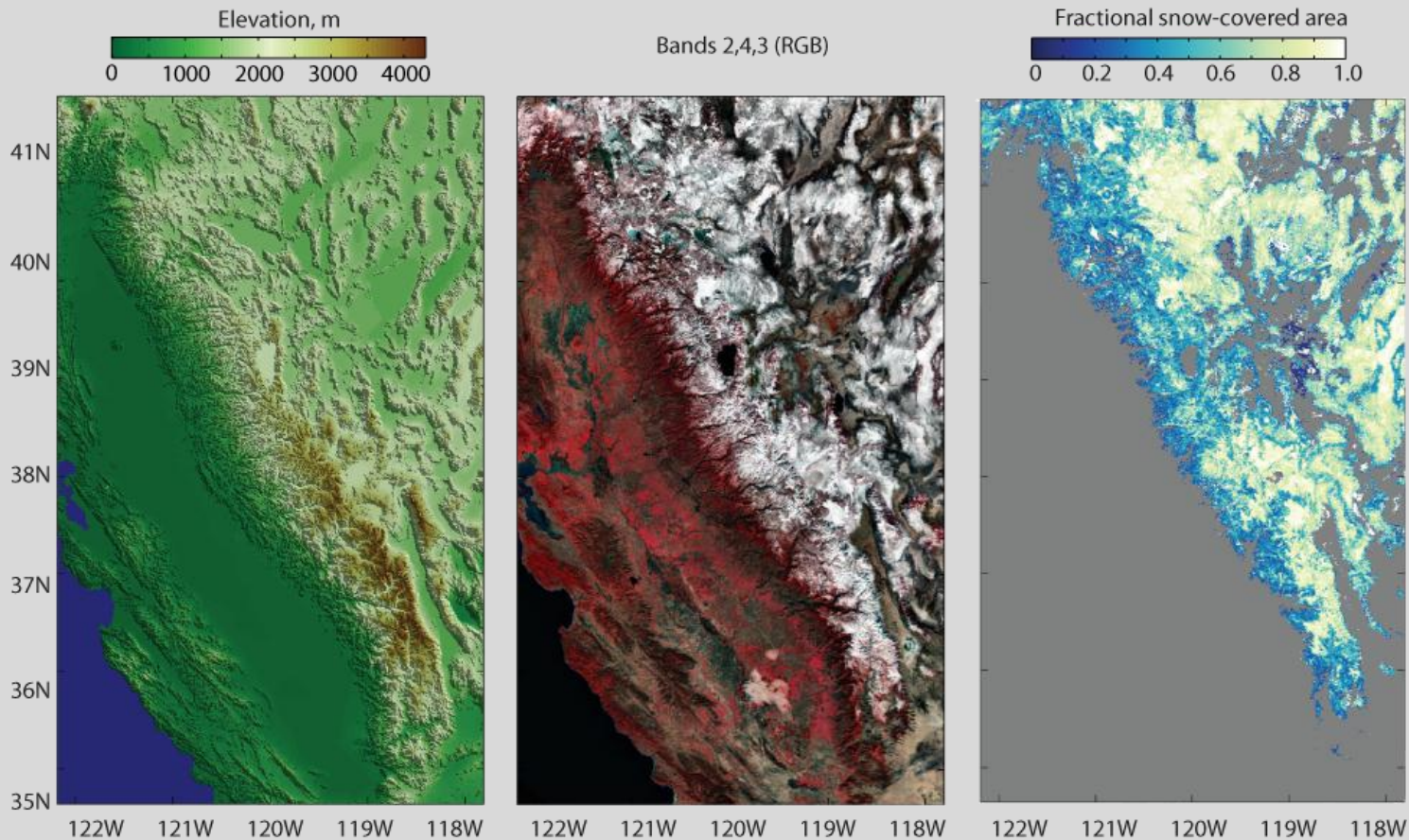
Spectra
with 7
MODIS
"land"
bands
(500 m
resolution,
daily
coverage)





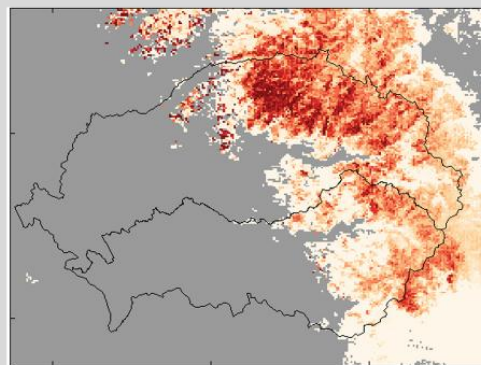
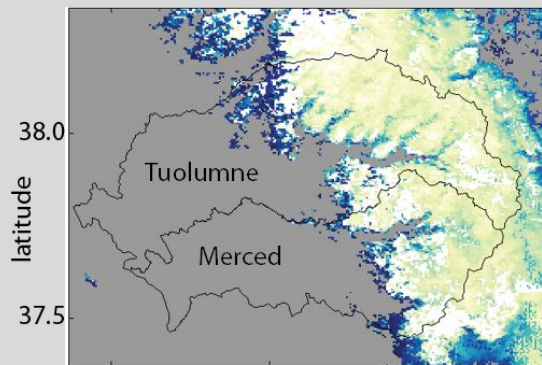
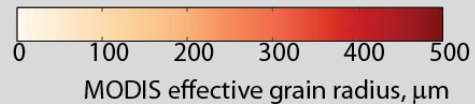
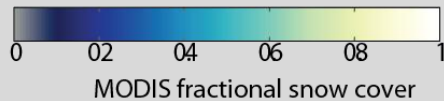
Fractional snow-covered area, Sierra Nevada (MODIS images available daily)

MODIS, 19 Jan 2008



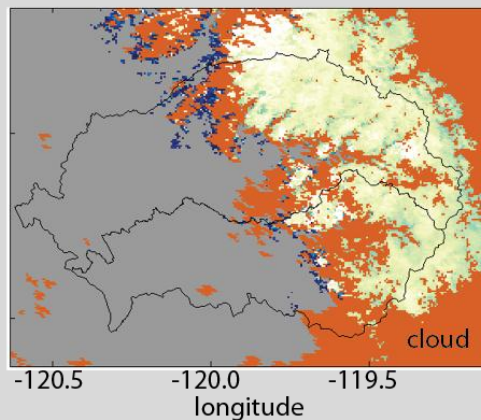
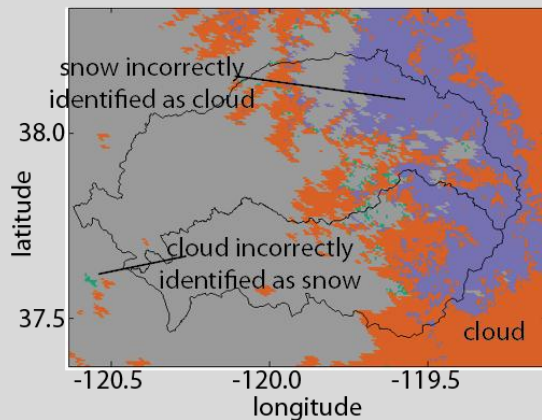
Not just
snow
cover, but
also its
reflectivity

11 March 2007



MODIS cloud mask

fractional snow cover with corrected cloud mask



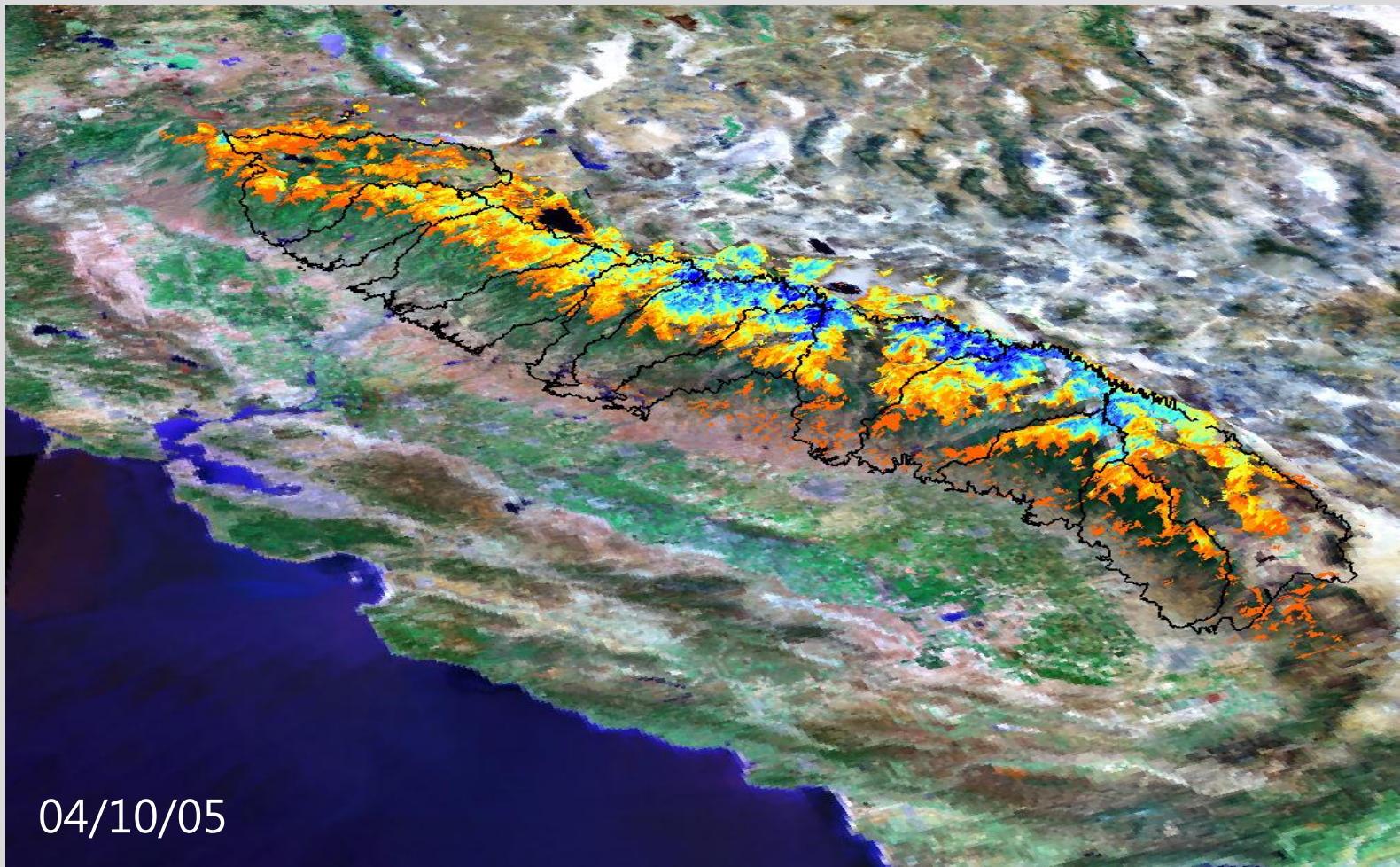
Spatially distributed snow water equivalent

SWE, mm



(N. Molotch)

04/10/05



Three independent ways

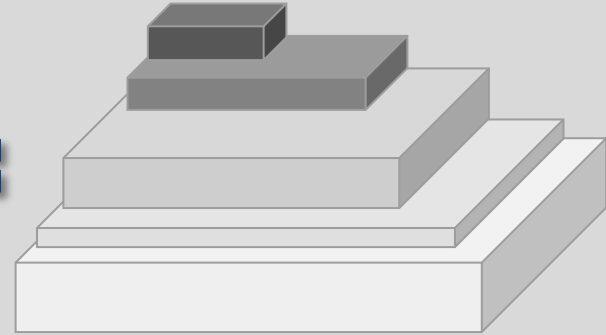
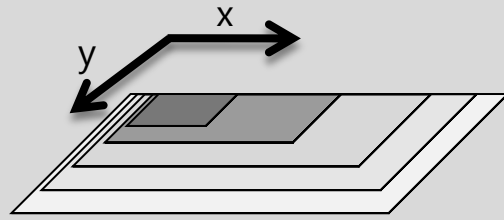
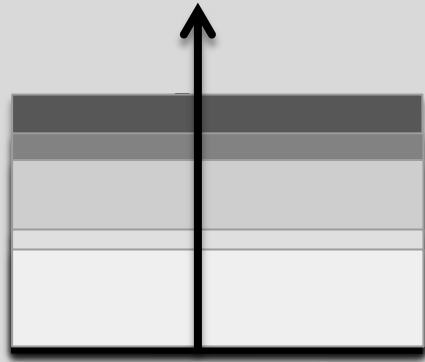
- Interpolation
 - statistical 3D interpolation from snow pillows and snow courses, constrained by remotely sensed snow-covered area
- SNODAS – the U.S. “national snow model”
 - assimilate numerical weather & snowmelt models with surface data & remote sensing
- Reconstruction (after the snow is gone)
 - from remotely sensed snow cover, estimate rate of snowmelt from energy input, and back-calculate how much snow there was.

Snow redistribution and drifting



(D. Marks)

Reconstruction of heterogeneous snow in a grid cell



Daily potential melt

f_{SCA}

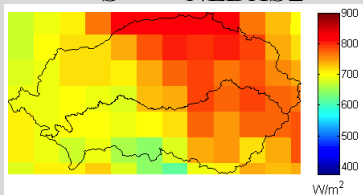
Reconstructed SWE

A. Kahl

[Homan et al., 2010]

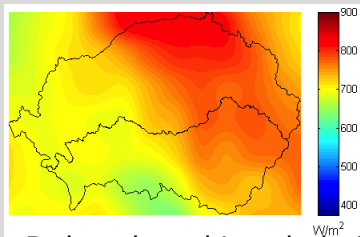
Solar radiation at 1 hr time steps – details

$S^{1/8^\circ}$ – NLDAS2



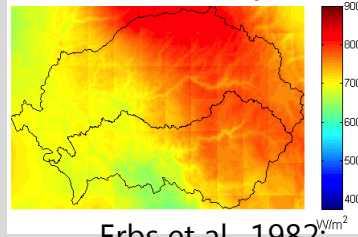
Cosgrove et al., 2003;
Pinker et al., 2003;
Mitchell et al., 2004

S^{100m} – Spatially Integrated



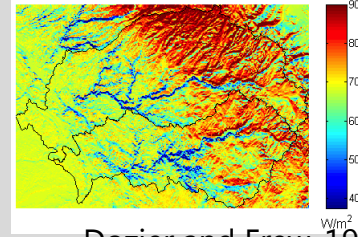
Dubayah and Loebel, 1997

S^{100m} – Corrected for elevation



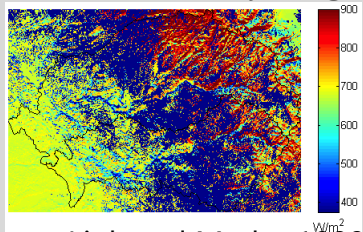
Erbs et al., 1982,
Olyphant et al., 1984

S^{100m} – Corrected for topography



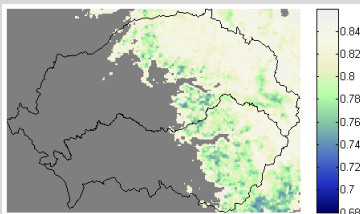
Dozier and Frew, 1990

S^{100m} – Corrected for vegetation



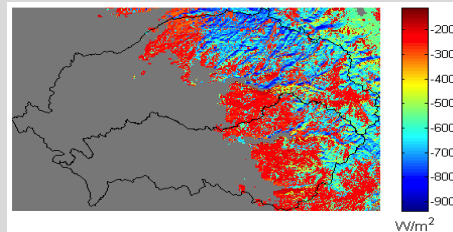
Link and Marks, 1999;
Garren and Marks, 2005

a , Snow Albedo



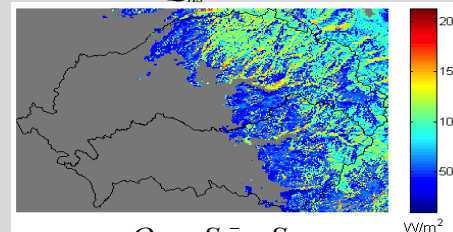
Painter et al., 2009;
Dozier et al., 2008

S^{100m} –



$S^- = a S^-$

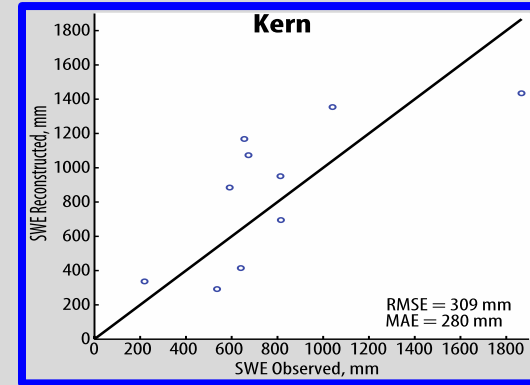
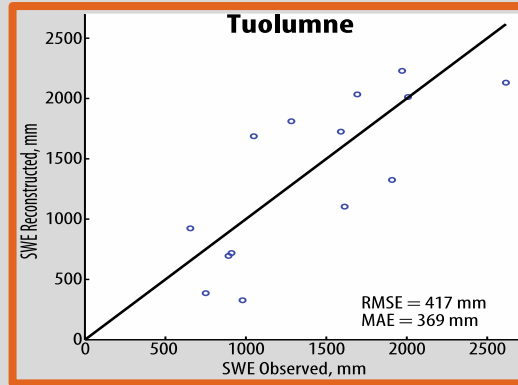
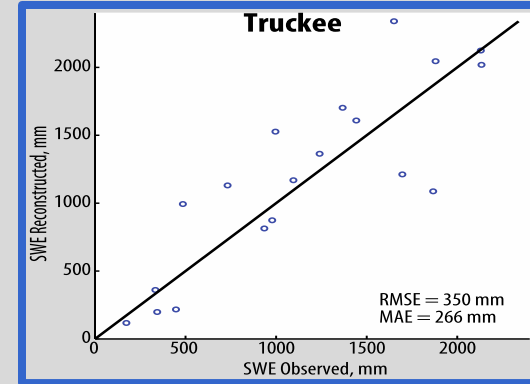
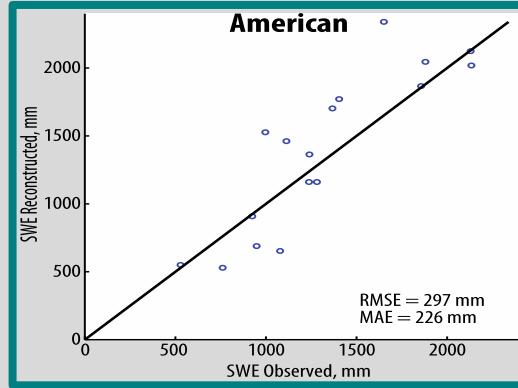
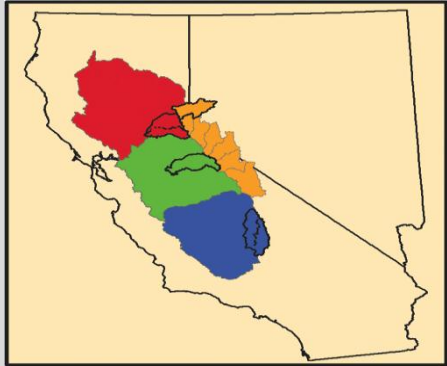
Q_{ns}^{100m}



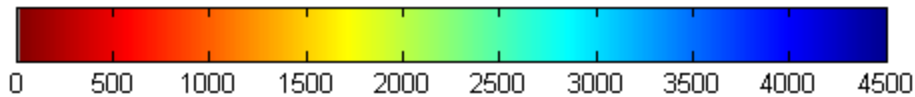
$Q_{ns} = S^- + S^-$

$$M_{P_j} = m_Q R_d + a_r T_D$$

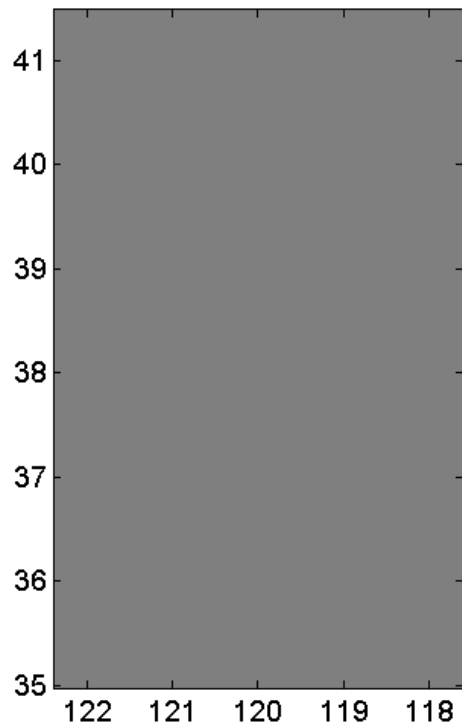
Comparison of modeled and observed SWE, April 1, 2006



"All models

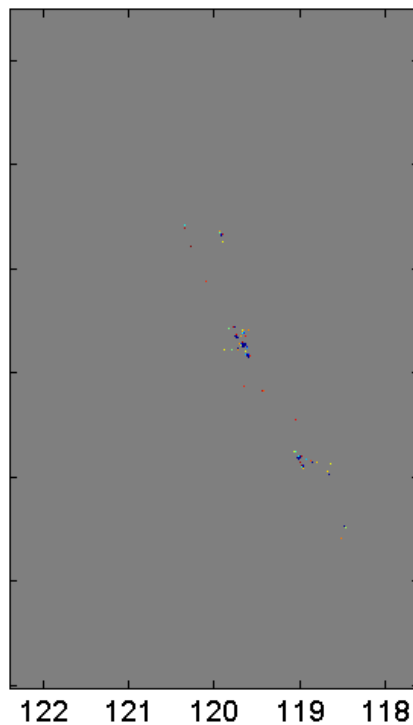


Box



Interpolation

2006



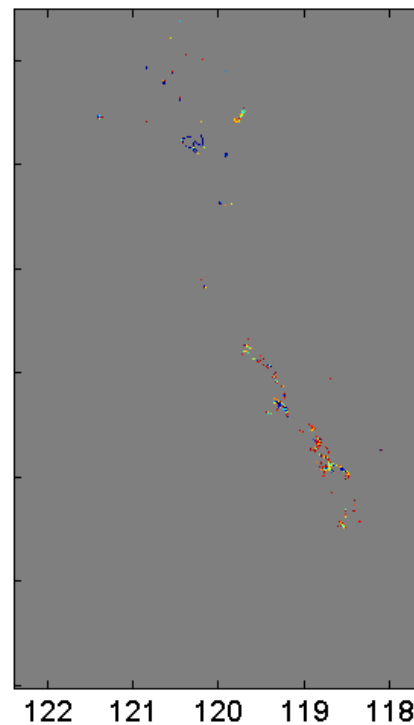
SNODAS

April

May

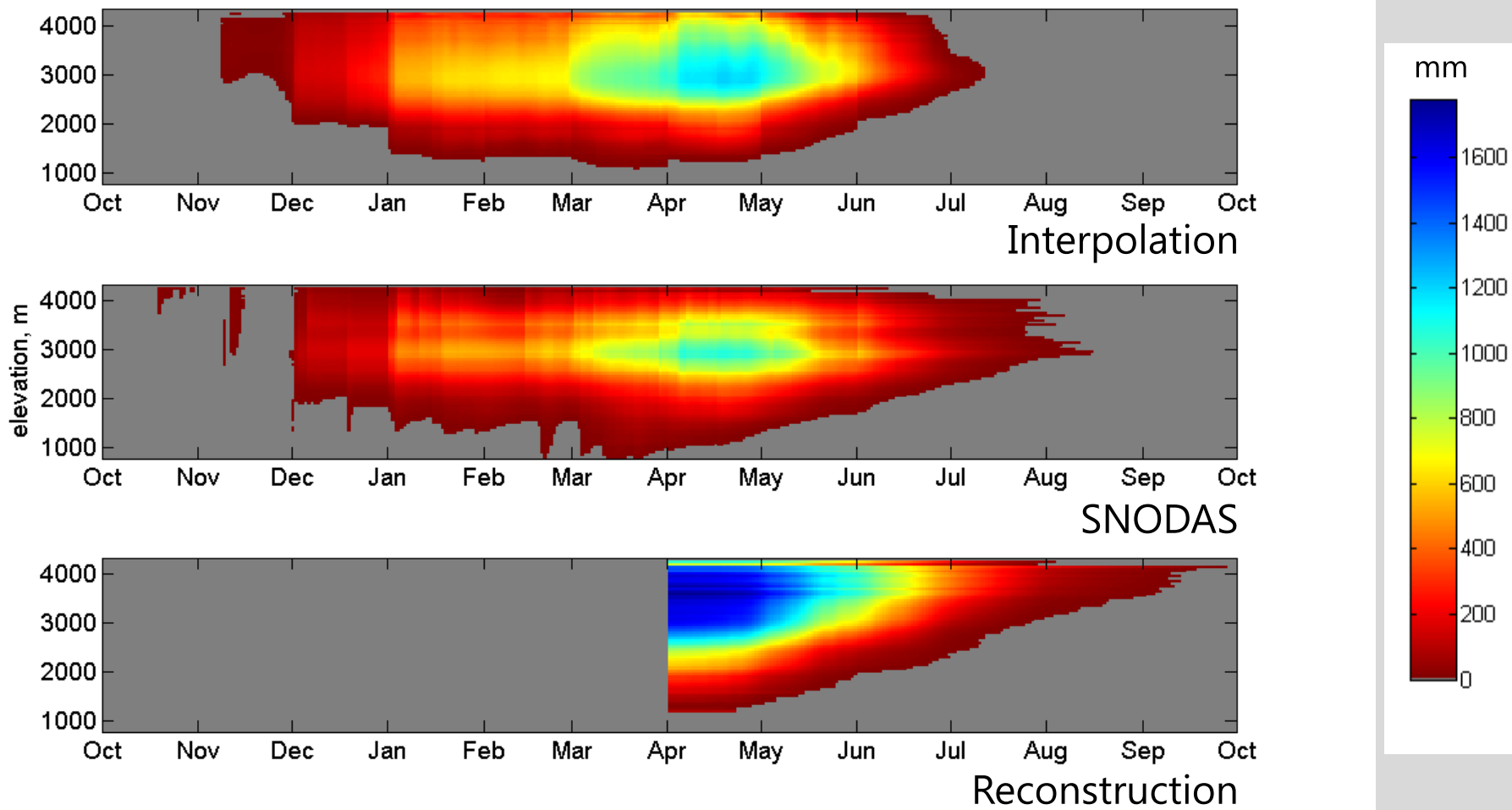
June

July

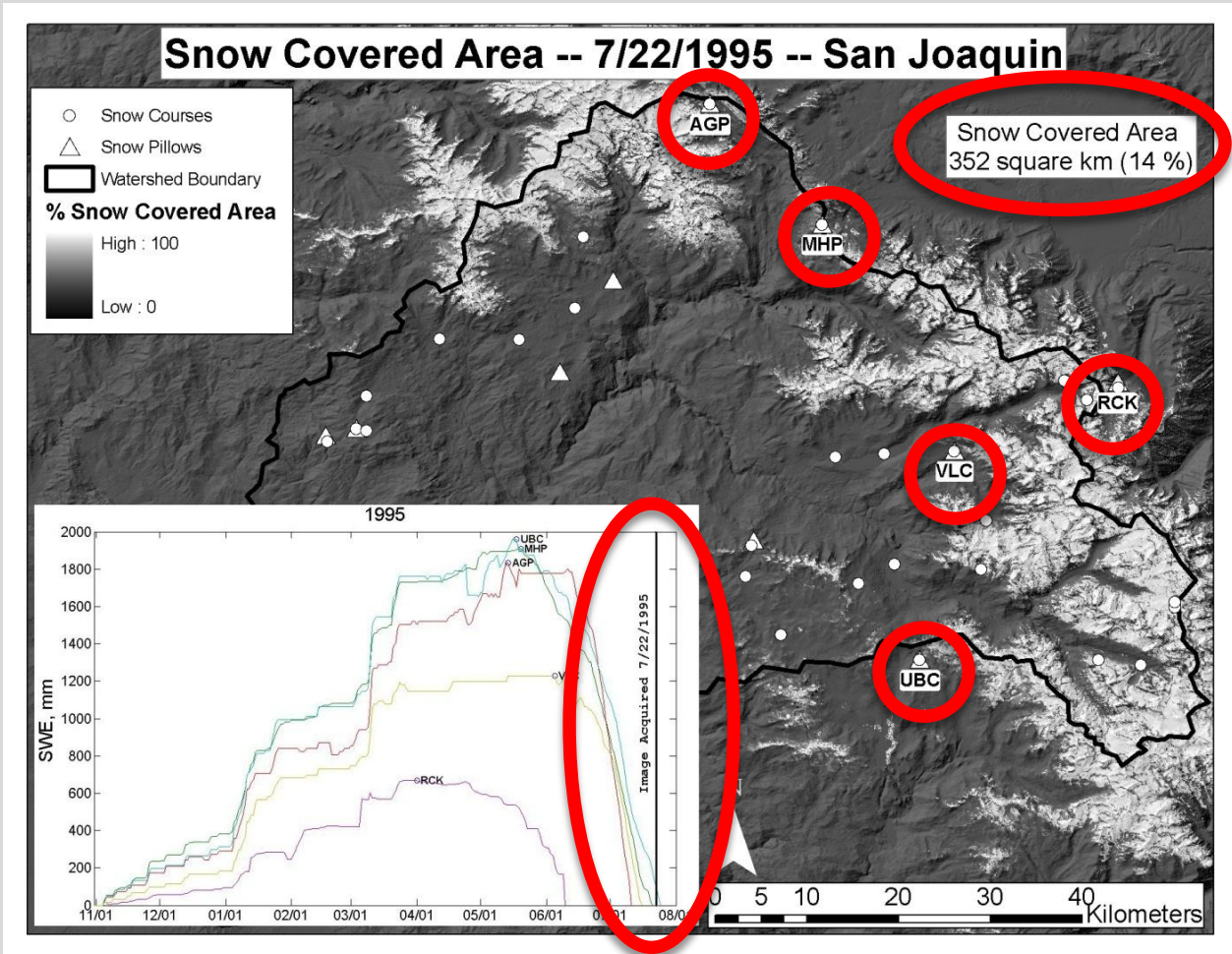


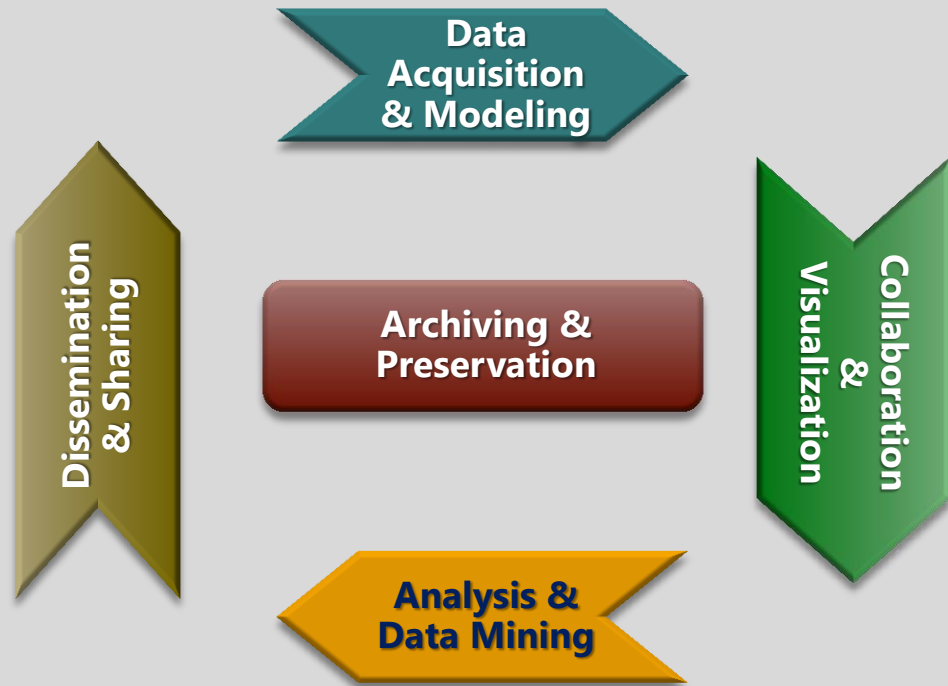
Reconstruction

August



Persistent, high-elevation snowpack not measured by surface stations



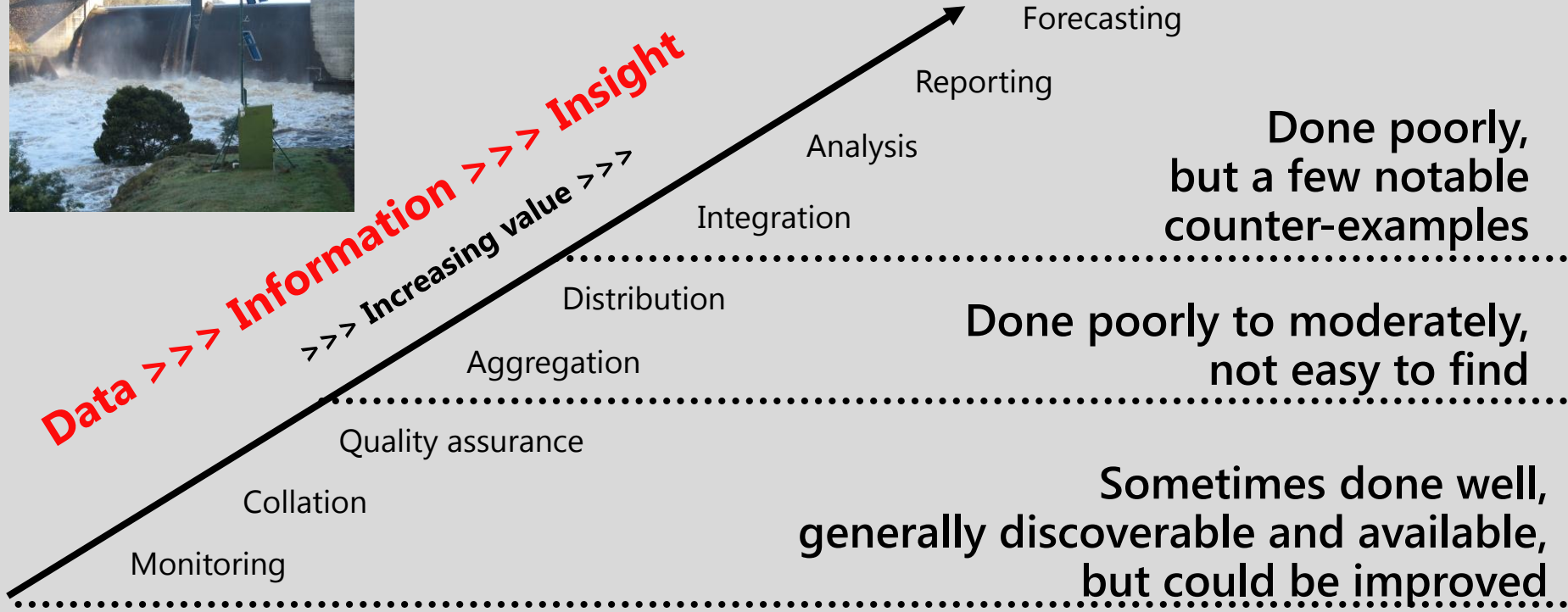


(J. Frew, T. Hey)

<http://fourthparadigm.org>



Information about water is more useful as we climb the value ladder



MODIS Products

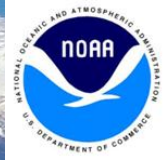
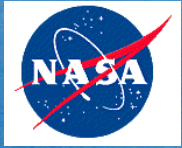
(MOD for Terra/MYD for Aqua)

MOD01	Level-1A Radiance Counts	MOD23	Suspended-Solids Conc, Ocean Water
MOD02	Level-1B Calibrated Geolocated Radiances	MOD24	Organic Matter Concentration
	-also Level 1B "subsampled" 5kmX5km pro	MOD25	Coccolith Concentration
MOD03	Geolocation Data Set	MOD26	*Ocean Water Attenuation Coefficient
MOD04	Aerosol Product	MOD27	Ocean Primary Productivity
MOD05	Total Precipitable Water	MOD28	*Sea Surface Temperature
MOD06	Cloud Products	MOD29	Sea Ice Cover
MOD07	Atmospheric Profiles		
MOD08	Gridded Atmospheric Product (Level 3)	MOD32	Processing Framework & Match-up Database
MOD09	Atmospherically-corrected Surface Reflectance	MOD33	Gridded Snow Cover
MOD10	Snow Cover	MOD34	Gridded Vegetation Indices
MOD11	Land Surface Temperature & Emissivity	MOD35	Cloud Mask
MOD12	Land Cover/Land Cover Change	MOD36	Total Absorption Coefficient
MOD13	Vegetation Indices	*MOD37	Ocean Aerosol Optical Thickness
MOD14	Thermal Anomalies, Fires & Biomass Burning	MOD39	Clear Water Epsilon
MOD15	Leaf Area Index & FPAR	MOD43	Albedo 16-day L3
MOD16	Surface Resistance & Evapotranspiration	MOD44	Vegetation Cover Conversion
MOD17	Vegetation Production, Net Primary Productivity		
MOD18	*Normalized Water-leaving Radiance		
MOD19	Pigment Concentration		
MOD20	Chlorophyll Fluorescence		
MOD21	*Chlorophyll_a Pigment Concentration		
MOD22	Photosynthetically Active Radiation (PAR)		



Finis

“the author of all books”
– James Joyce, *Finnegan’s Wake*



<http://www.slideshare.net/JeffDozier>



SNO-FOO
AWARD



TO ERR IS HUMAN.
TO FORGET IT WOULD BE DIVINE