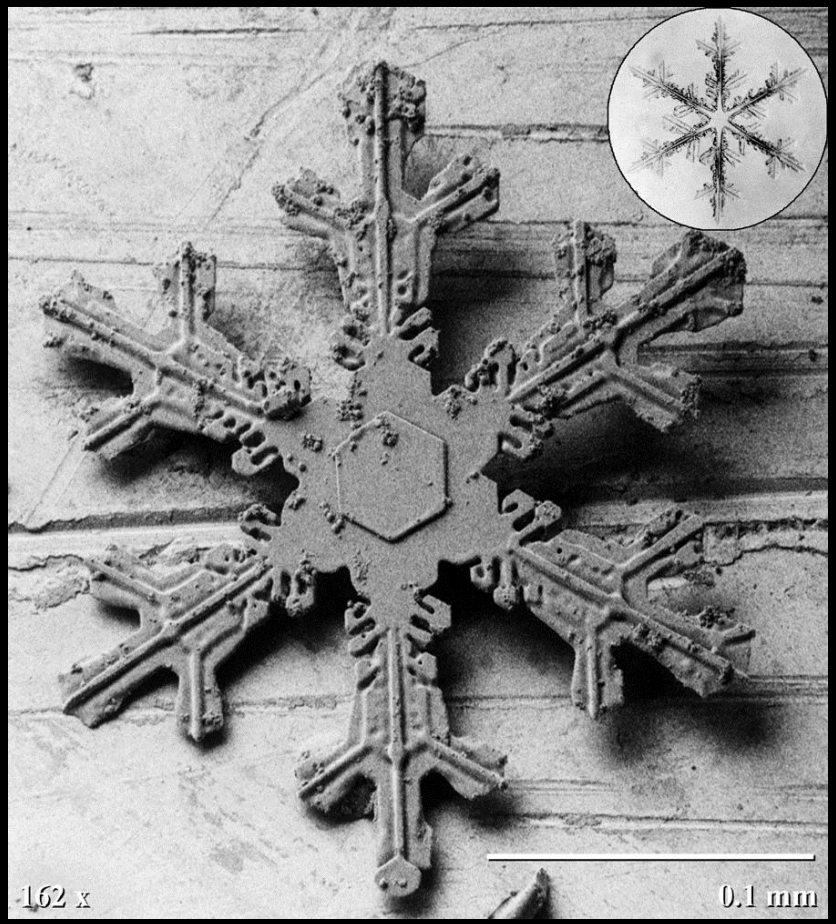
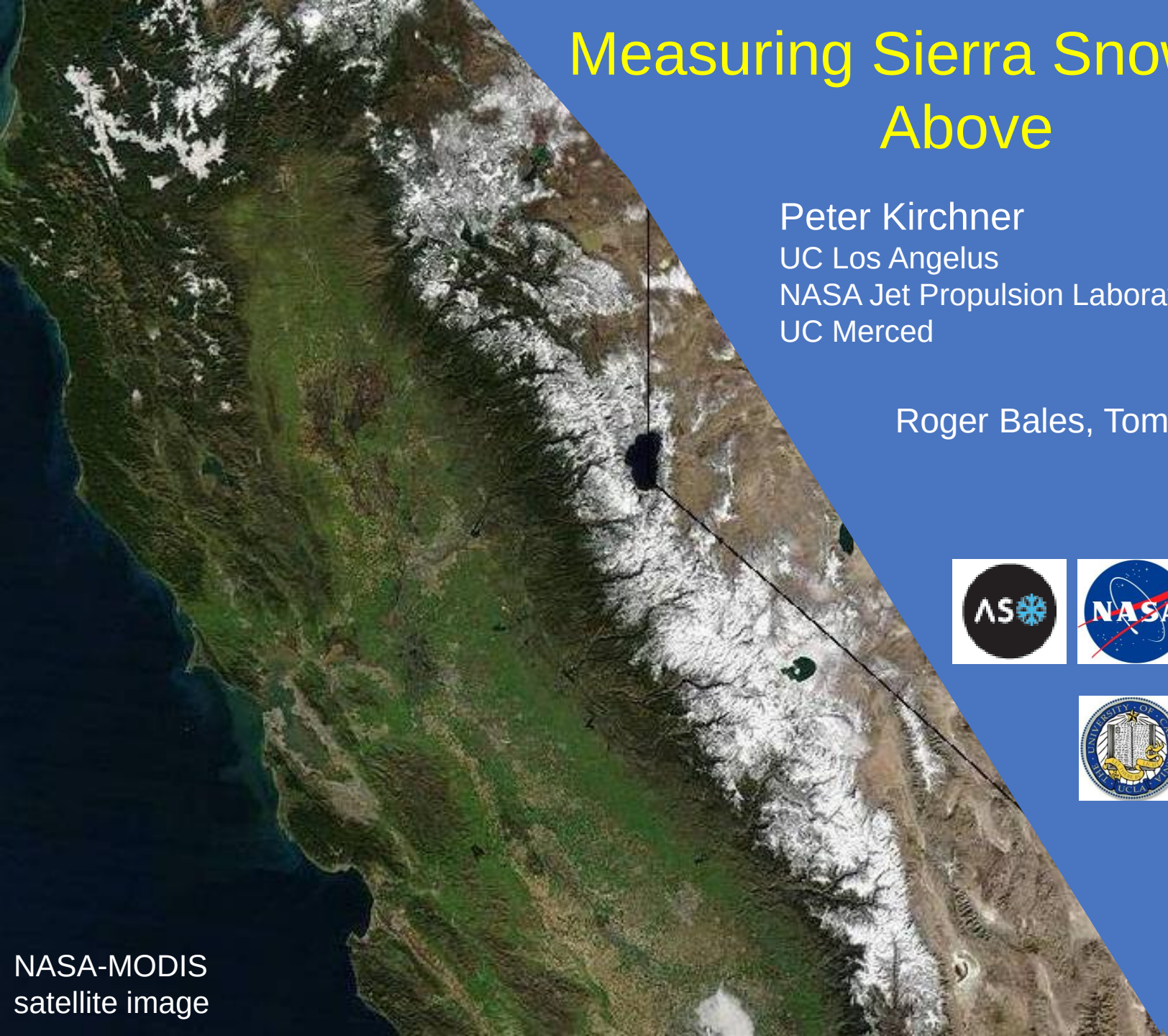

162 x
0.1 mm

Measuring Sierra Snow From Above

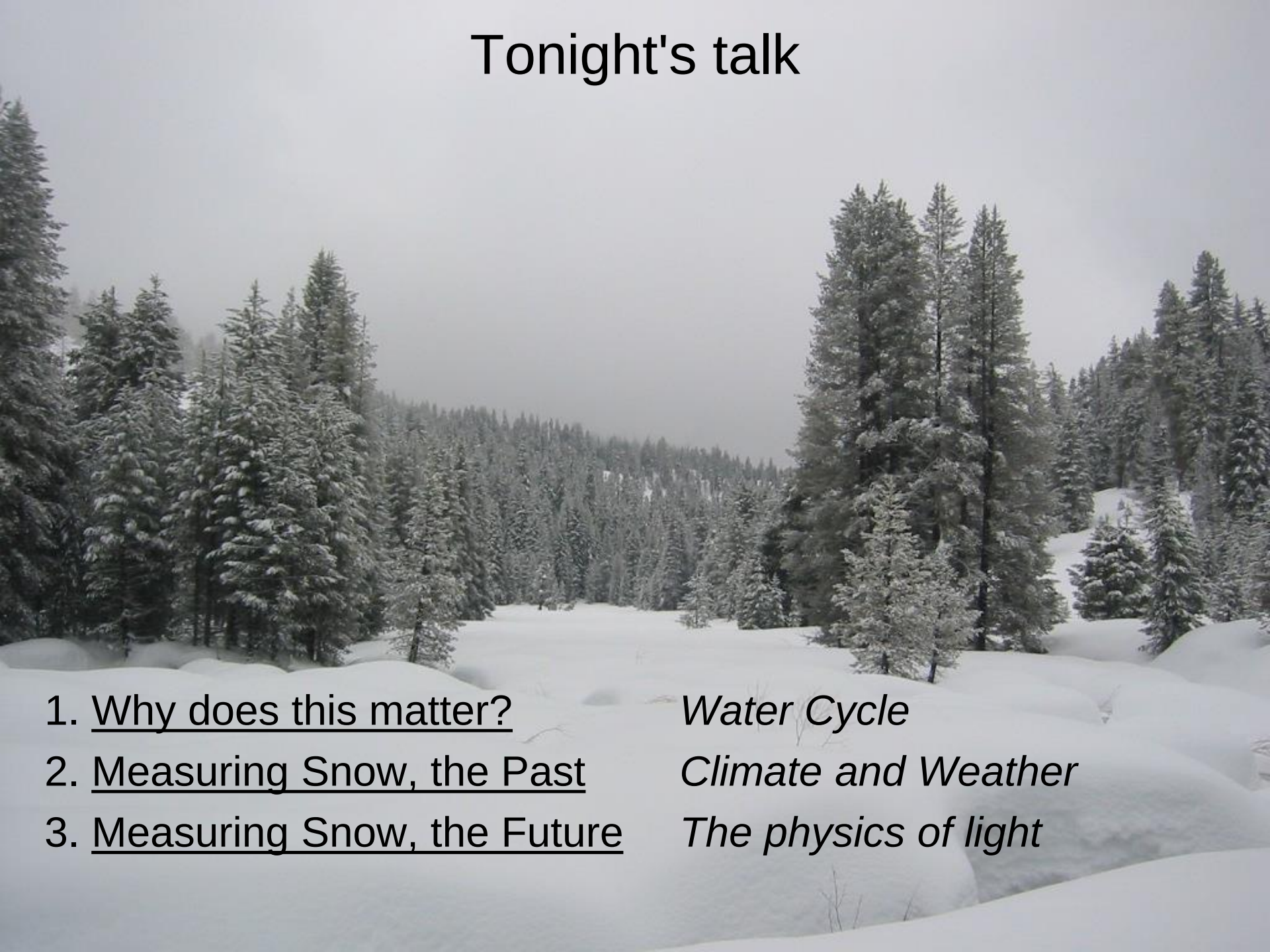
Peter Kirchner
UC Los Angelus
NASA Jet Propulsion Laboratory
UC Merced

Roger Bales, Tom Painter



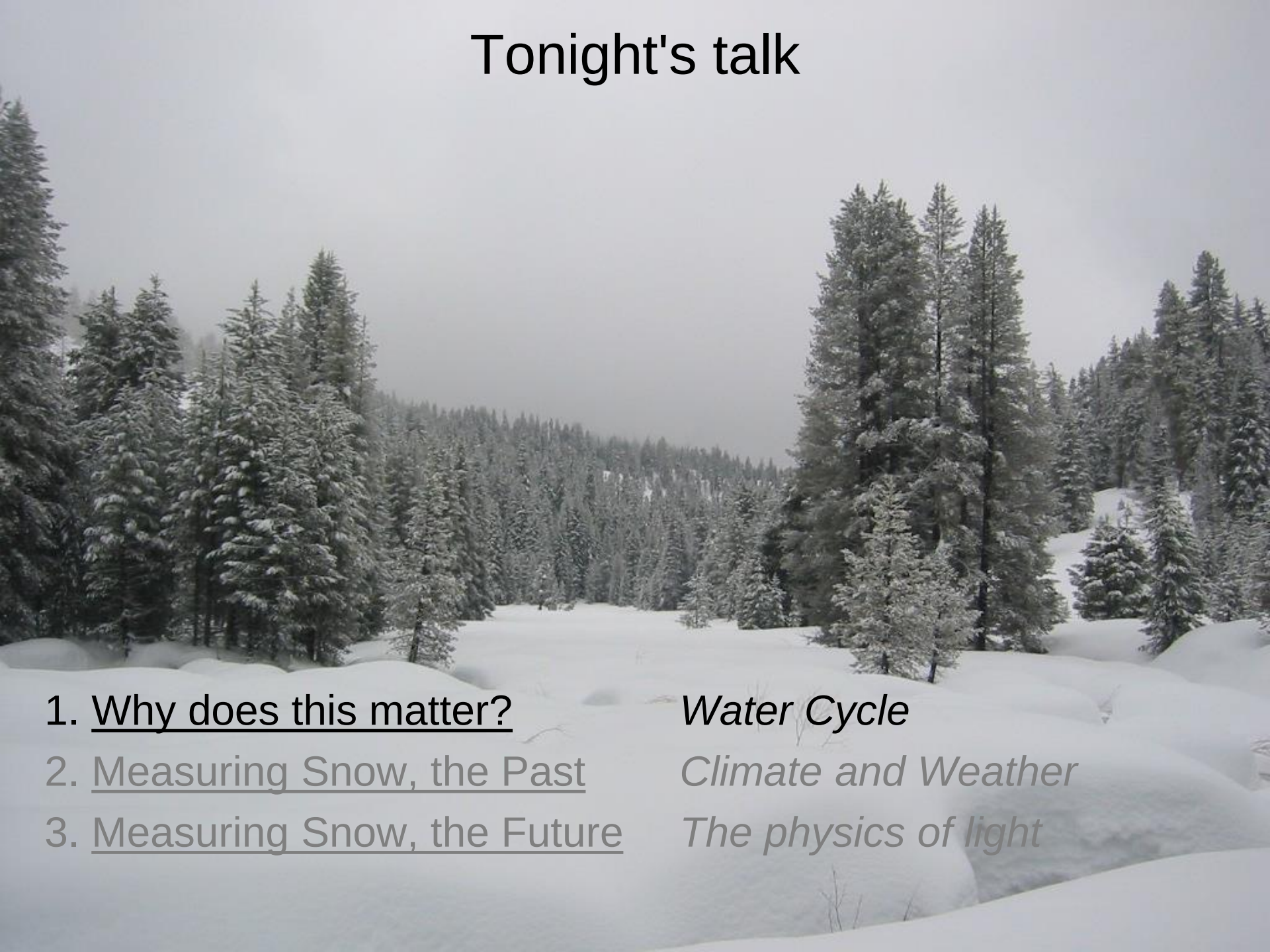
NASA-MODIS
satellite image

Tonight's talk



1. Why does this matter? *Water Cycle*
2. Measuring Snow, the Past *Climate and Weather*
3. Measuring Snow, the Future *The physics of light*

Tonight's talk



1. Why does this matter? *Water Cycle*
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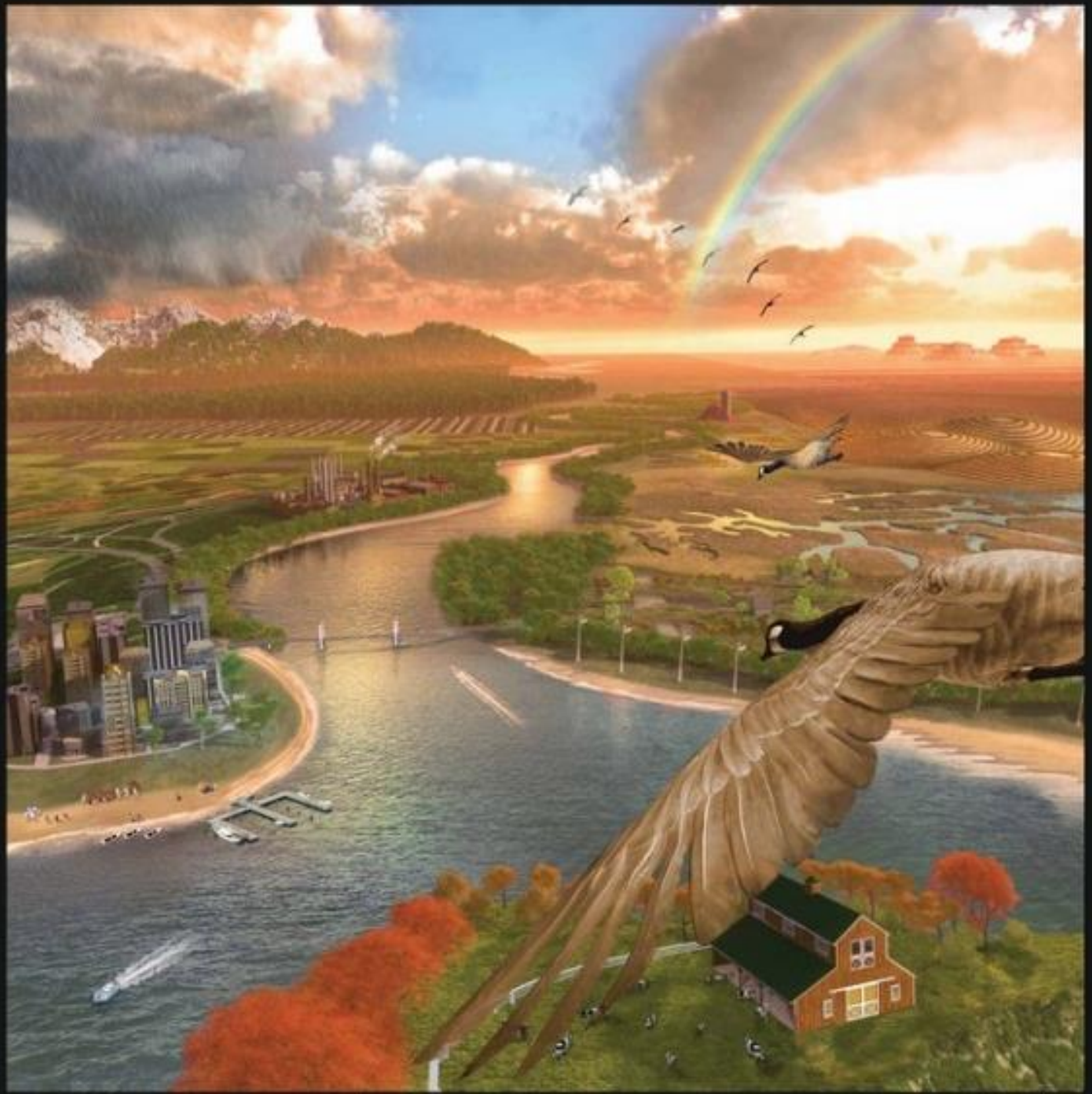
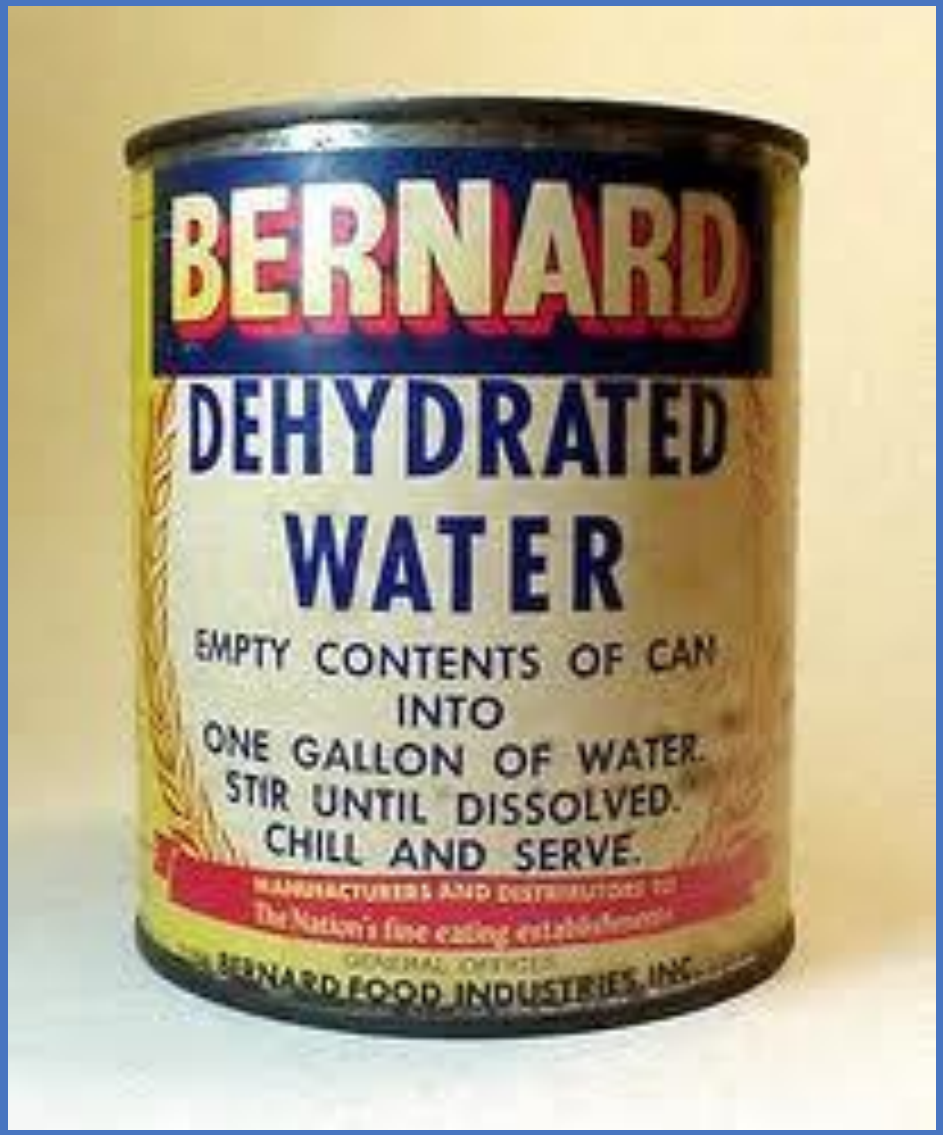


35 %

65 %


BERNARD
DEHYDRATED
WATER
EMPTY CONTENTS OF CAN
INTO
ONE GALLON OF WATER.
STIR UNTIL DISSOLVED.
CHILL AND SERVE.
BERNARD FOOD INDUSTRIES, INC.

Discussing Water Rights, A Western Pastime

Frequently there’s not enough

Paul Stanton Duckboy Cards

Flooding Prompts Visalia to Declare Local Emergency

Dec 19, 2010

Sometimes there’s too much

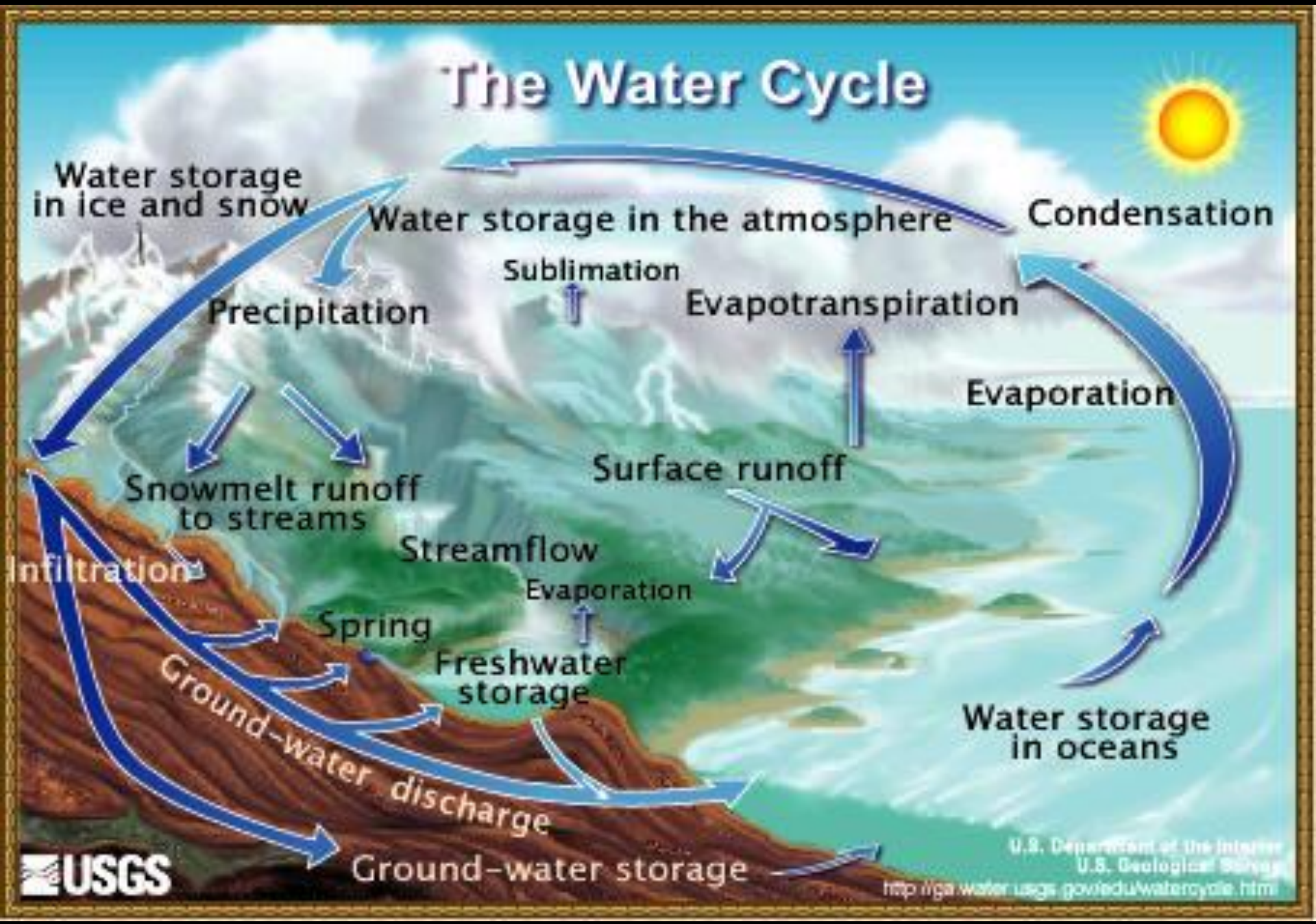
Dec 22nd, 1955
Tulare co. library

K, STREET, FROM THE LEVEE.

INUNDATION OF THE STATE CAPITOL,

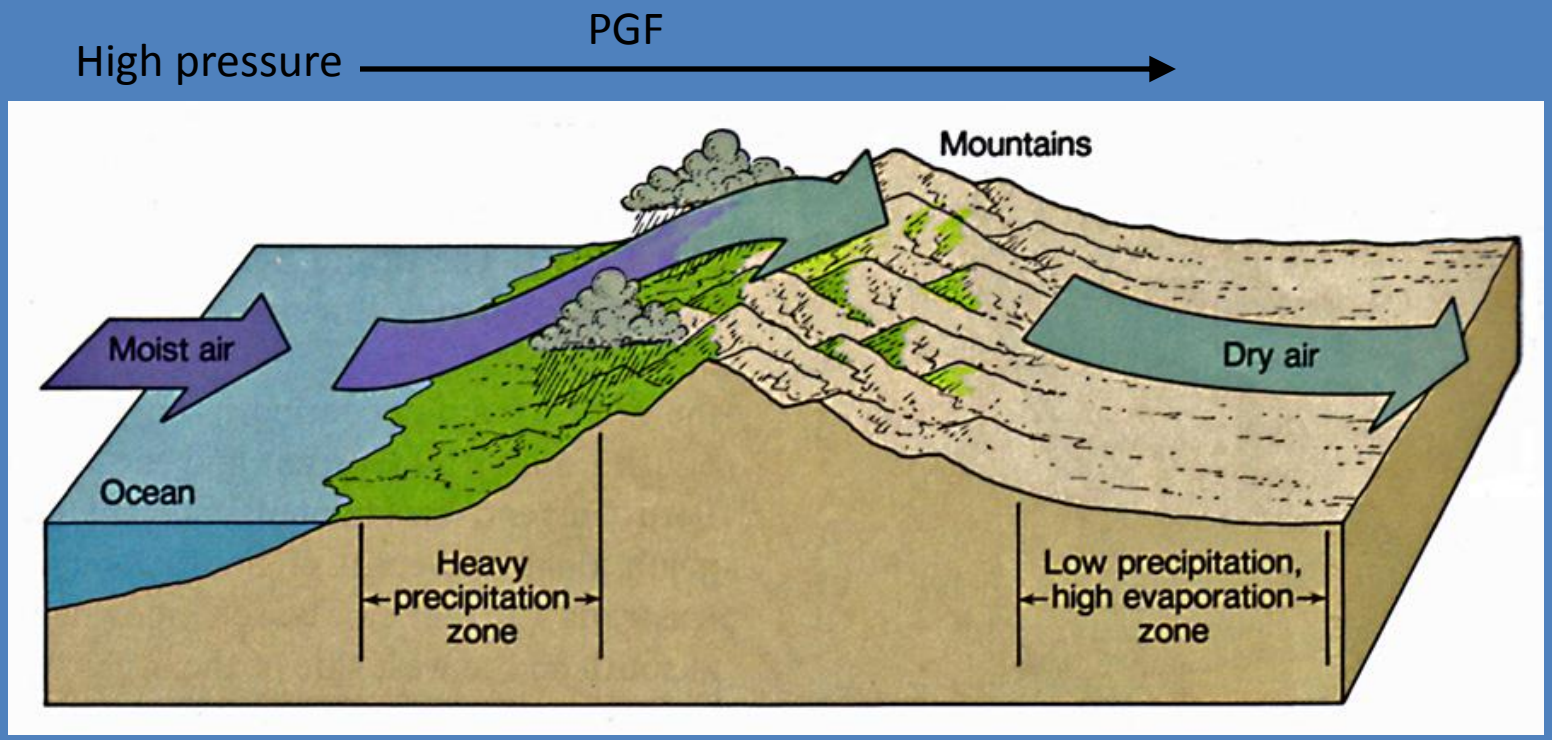
City of Sacramento, 1862.

43 day megastorm started in December 1861 and left much of the state flooded for months


The Water Cycle
Water storage in ice and snow
Water storage in the atmosphere
Condensation
Sublimation
Precipitation
Evapotranspiration
Evaporation
Surface runoff
Snowmelt runoff to streams
Streamflow
Infiltration
Evaporation
Spring
Freshwater storage
Ground-water discharge
Water storage in oceans
Ground-water storage
USGS
U.S. Department of the Interior
U.S. Geological Survey
http://ga.water.usgs.gov/edu/watercycle.html

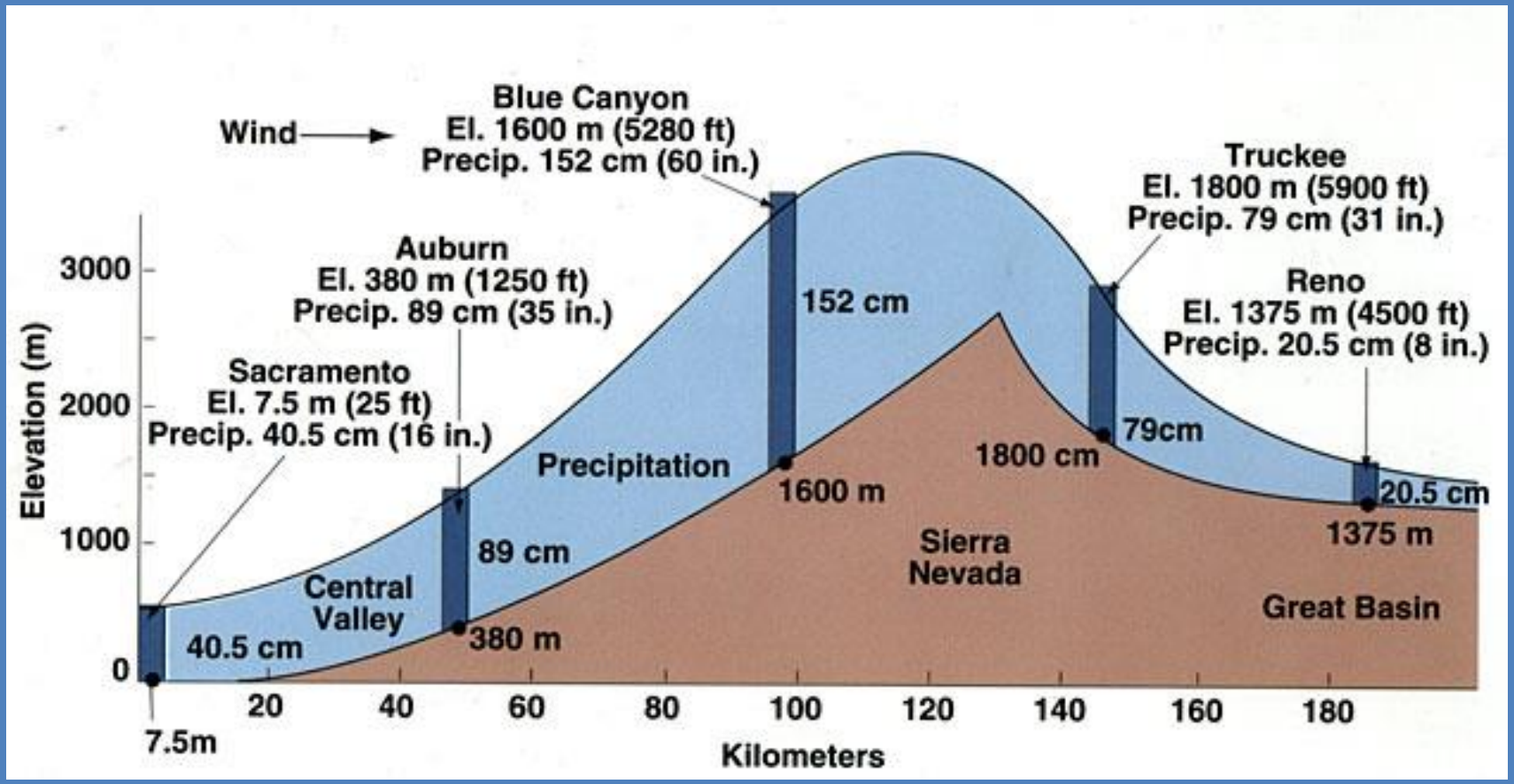
Mechanisms that cool air to generate precipitation; Orographic lifting

- Pressure-gradient force large enough to drive air up and over a mountain range



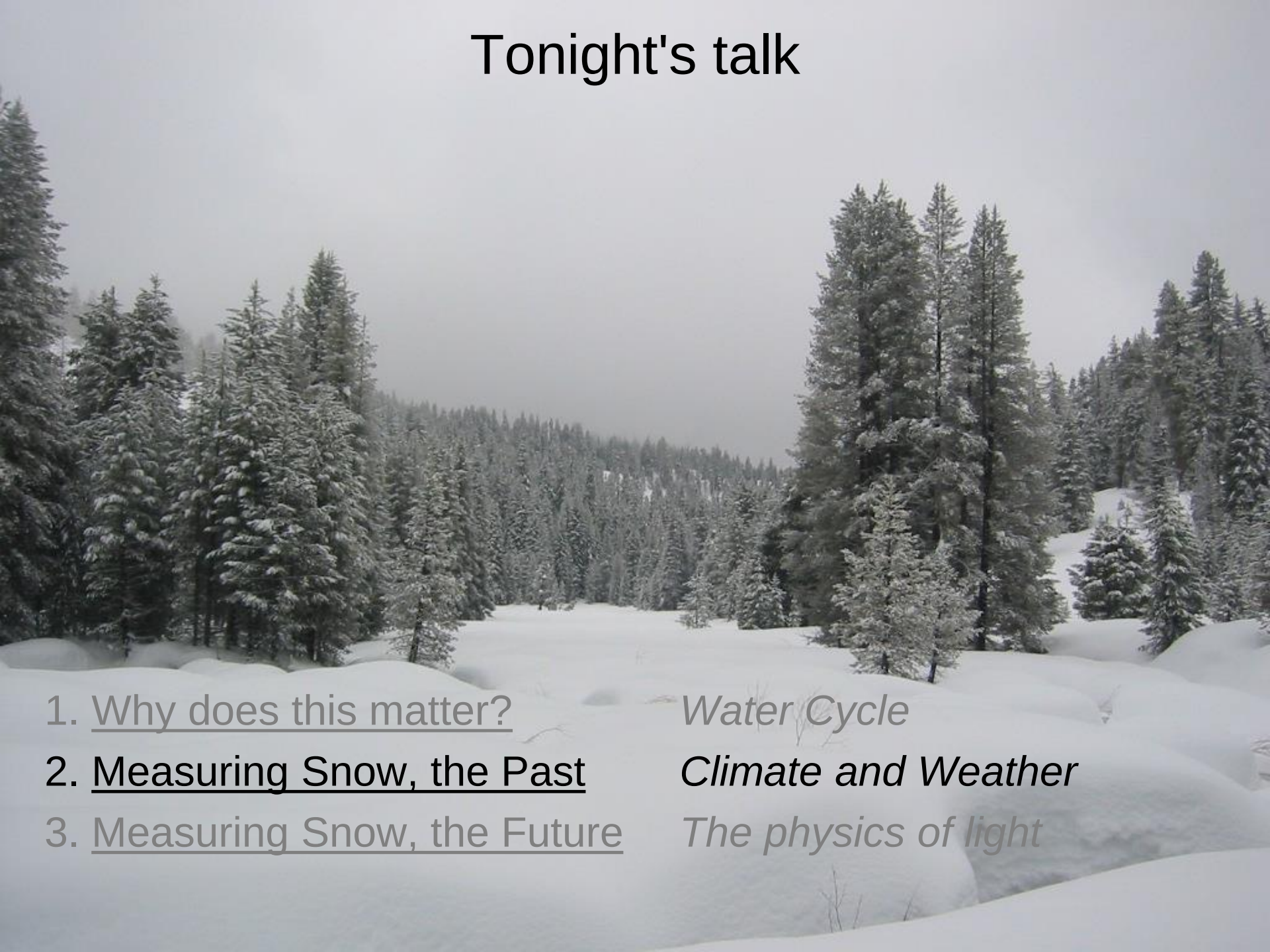
Aguado & Blunt

Orographic precipitation in the Sierra Nevada



http://geography.sierra.cc.ca.us/

Tonight's talk



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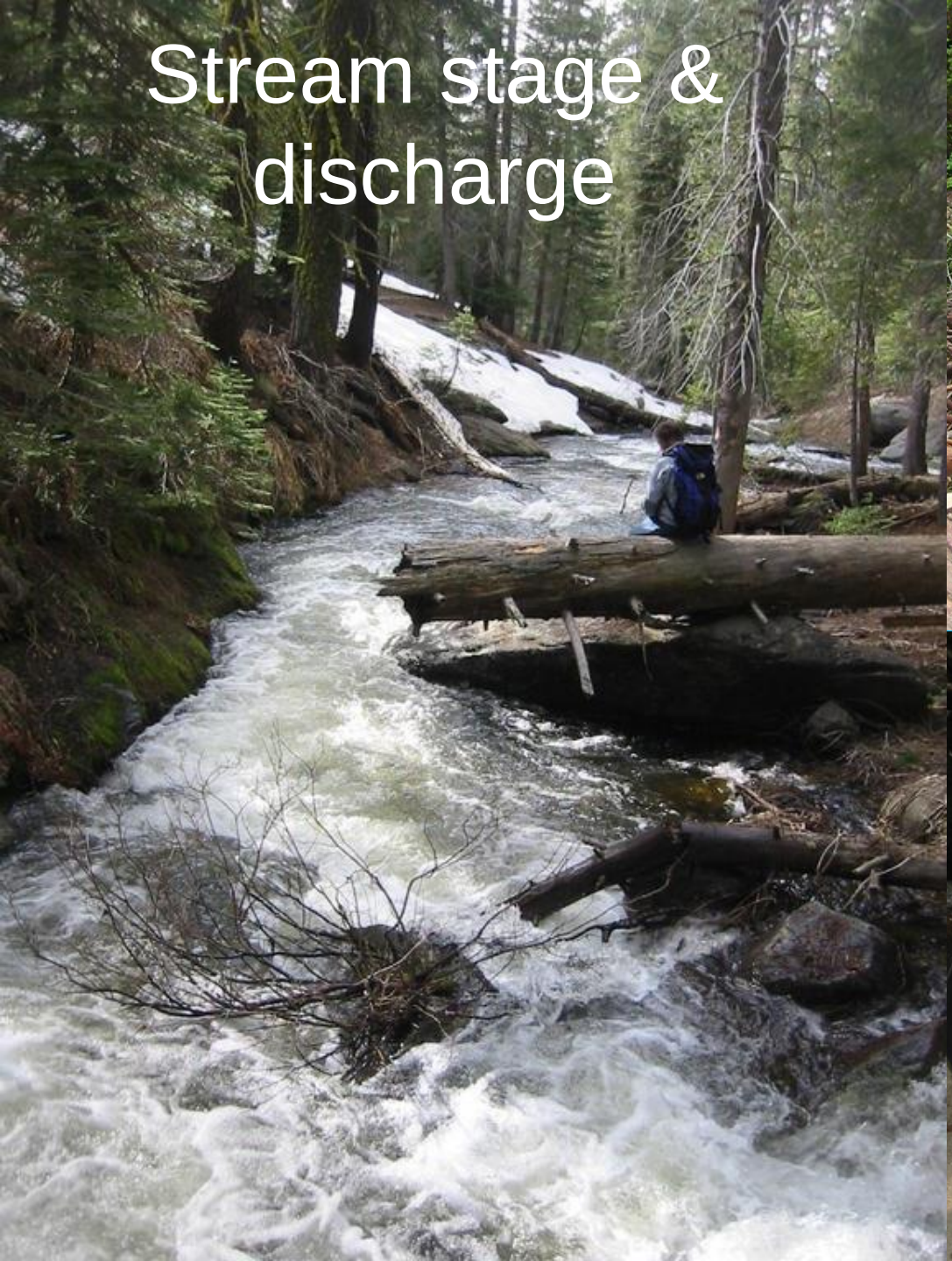
THE PROGRESS OF MOUNT ROSE OBSERVATORY, 1906–1912

Mount Rose Observatory, although the youngest of the meteorological observatories in America, has an environment so unique that its staff has not only obtained a series of problems of prime importance to pure science and to agriculture but has also found such abundant material that rapid progress has been possible in their solution. A brief statement of plans and progress at this observatory may, therefore, not be without interest to workers in the meteorological field.

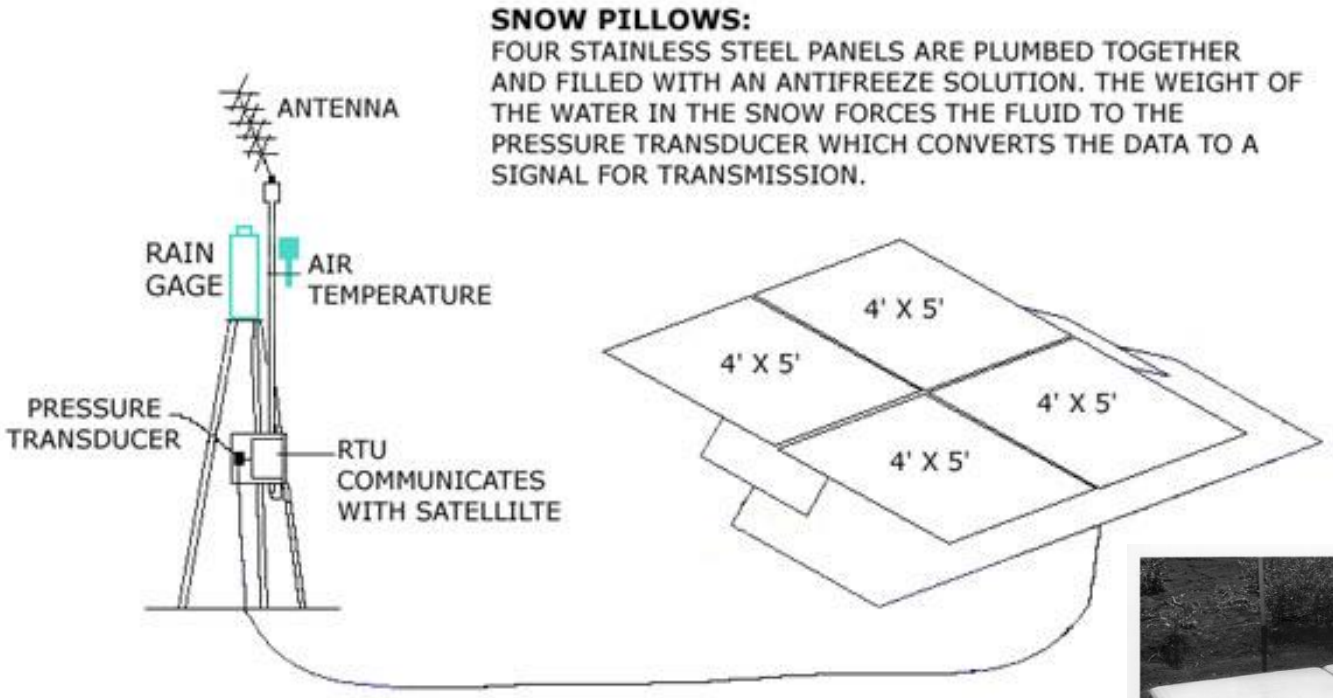
Mount Rose is a peak of the Sierra Nevada Mountains at the western edge of the Great Plateau. The observatory on the summit, which is 3,292 meters above sea level, at present is the highest meteorological station in the United States, and was established privately for the purpose of ascertaining the winter

Manual measurement of SWE

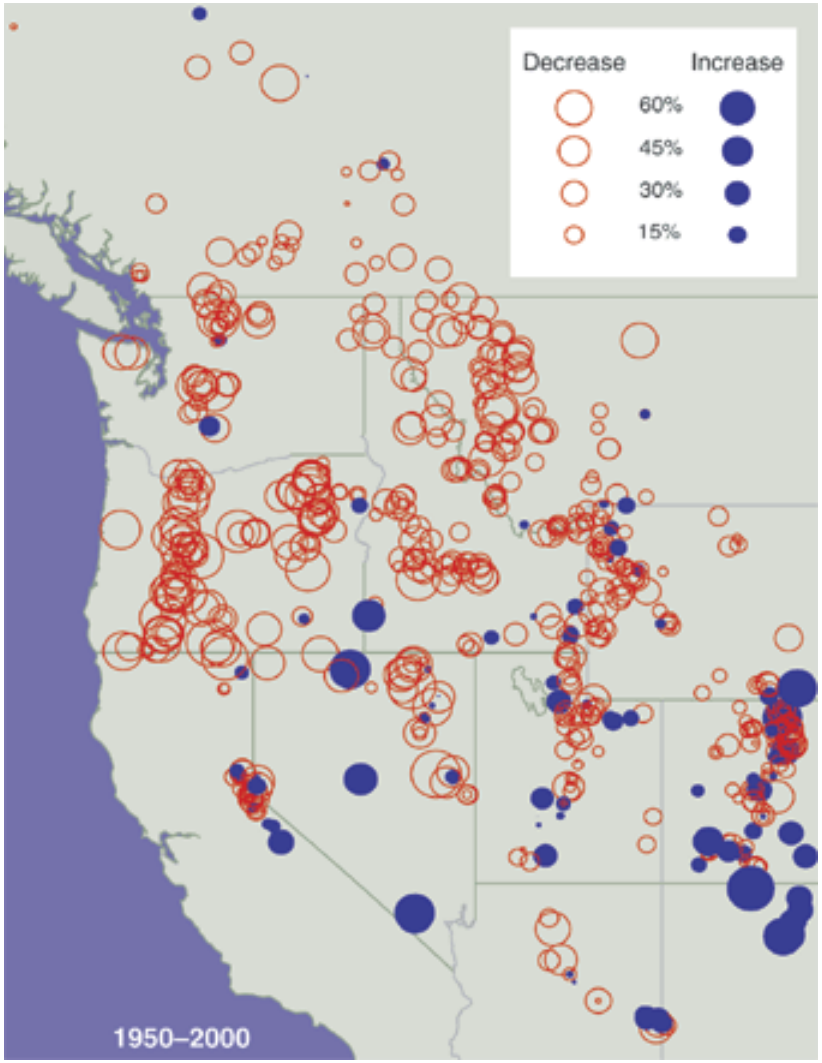
Stream stage & discharge

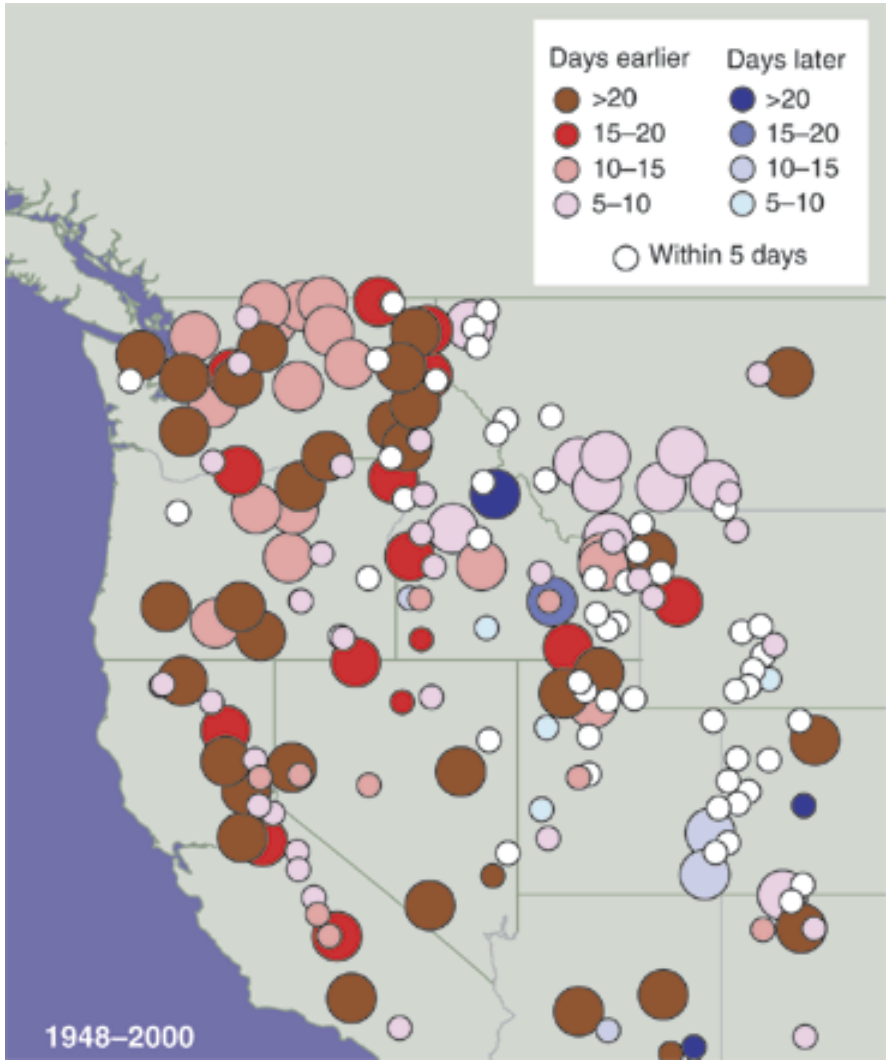


Automated measurement with snow pillow



A changing western snowpack?





Less snow?

Earlier melt?

Service, R. F., As the West goes dry, *Science,* 20 Feb 2004

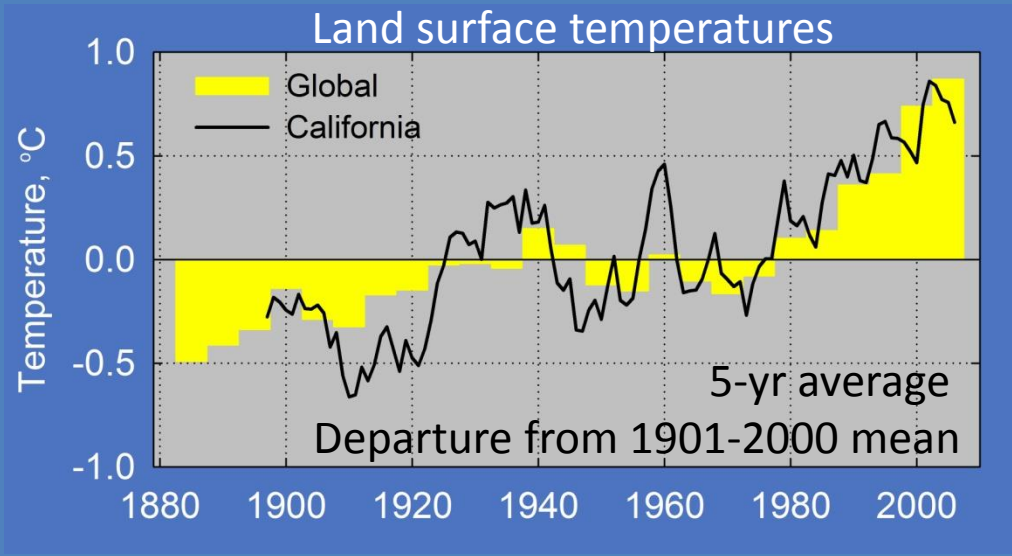
Mountain water cycle & climate change

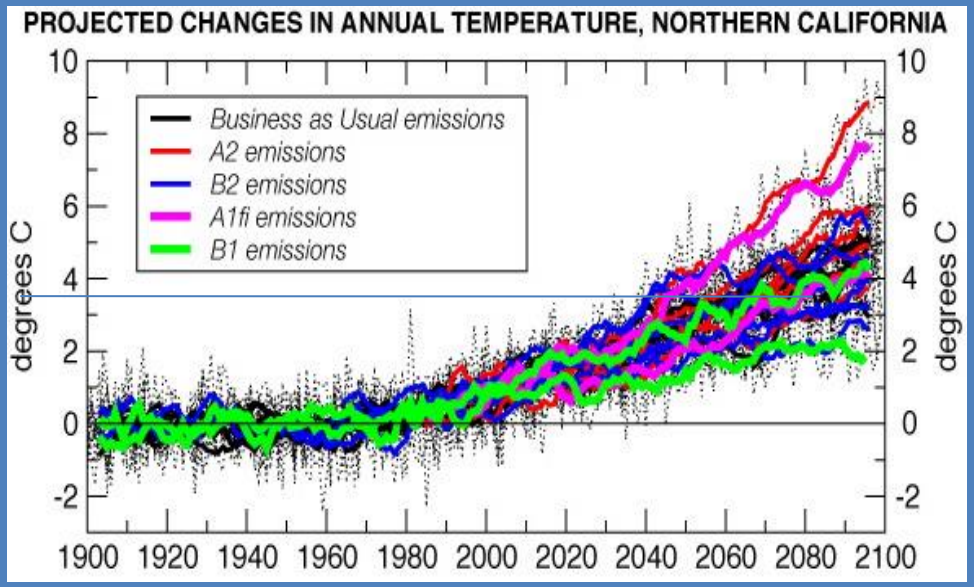
Warming by +2 to +6°C drives significant changes:

– rain-vs-snow storms *
– snowpack amounts *
– snowmelt timing *
– flood risk
– streamflow timing *
– growing seasons *
– groundwater recharge

Precipitation changes are uncertain

Already observed (*)





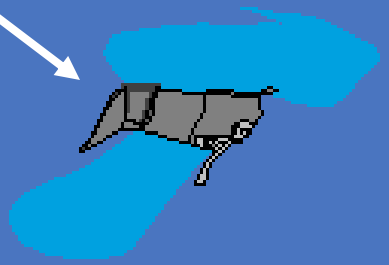
Enhancing seasonal water-supply forecasting

Ground data

Empirical & regression methods

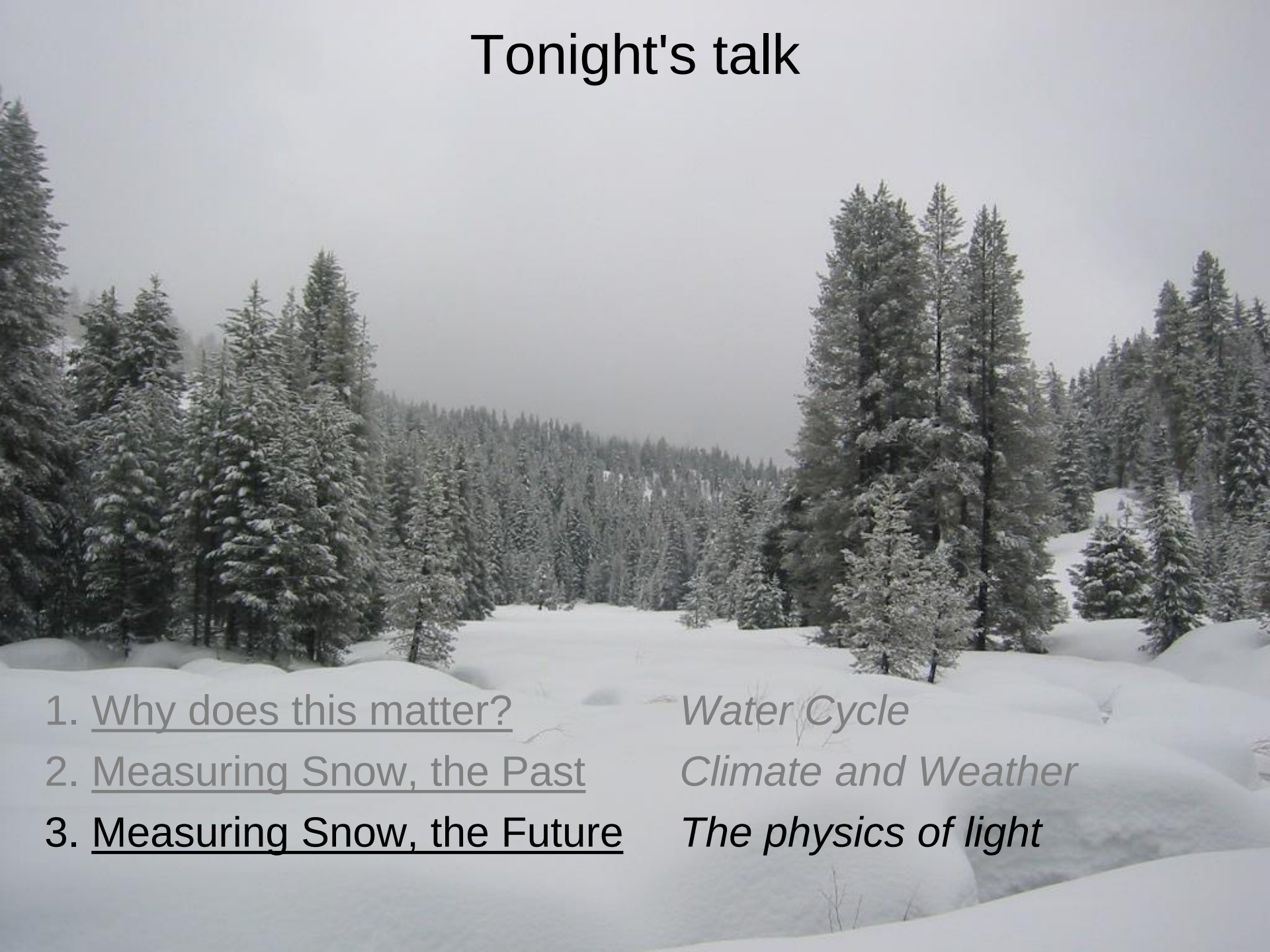
Volume forecasts

Precipitation forecast



Decision making

Tonight's talk



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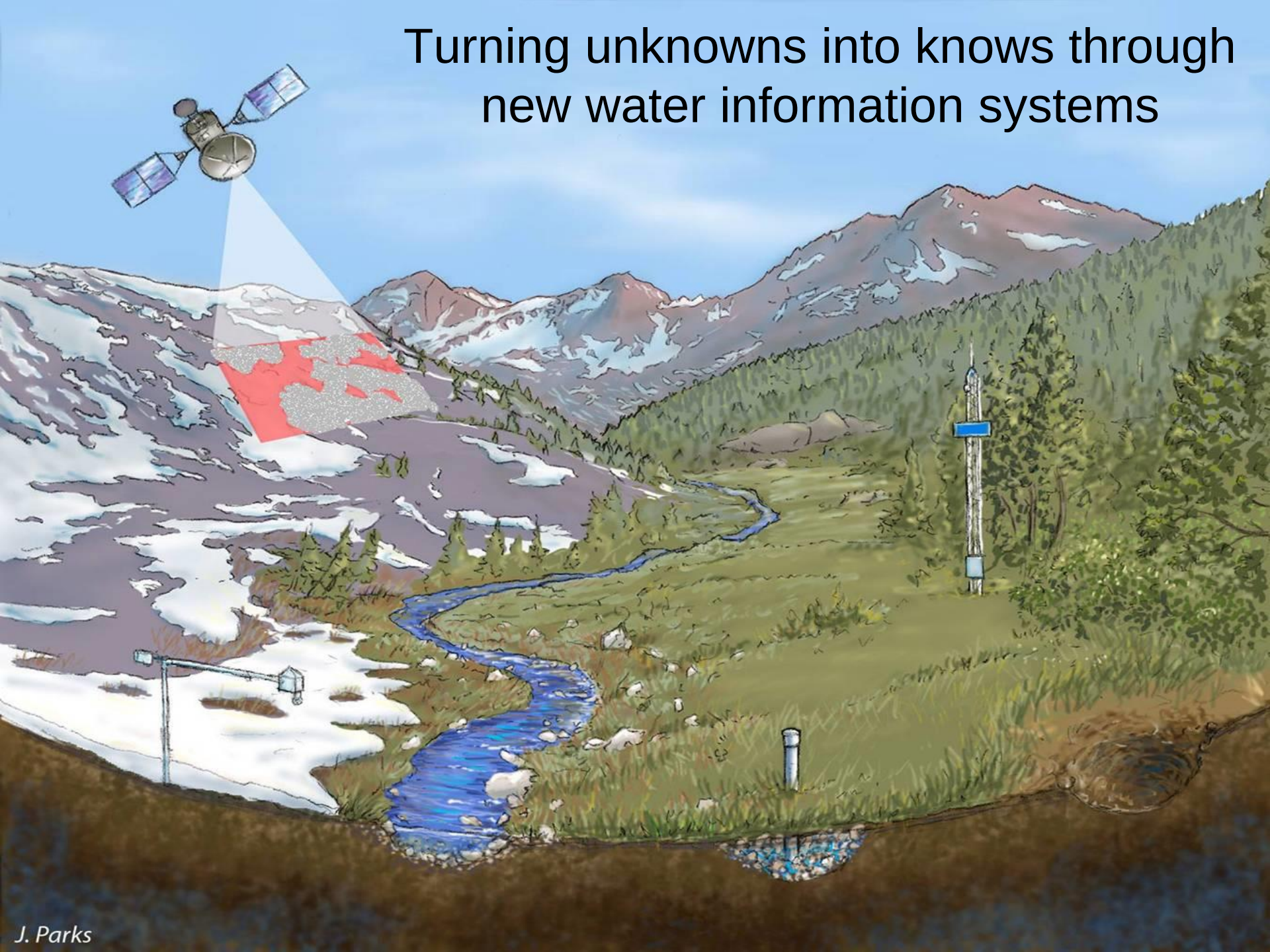
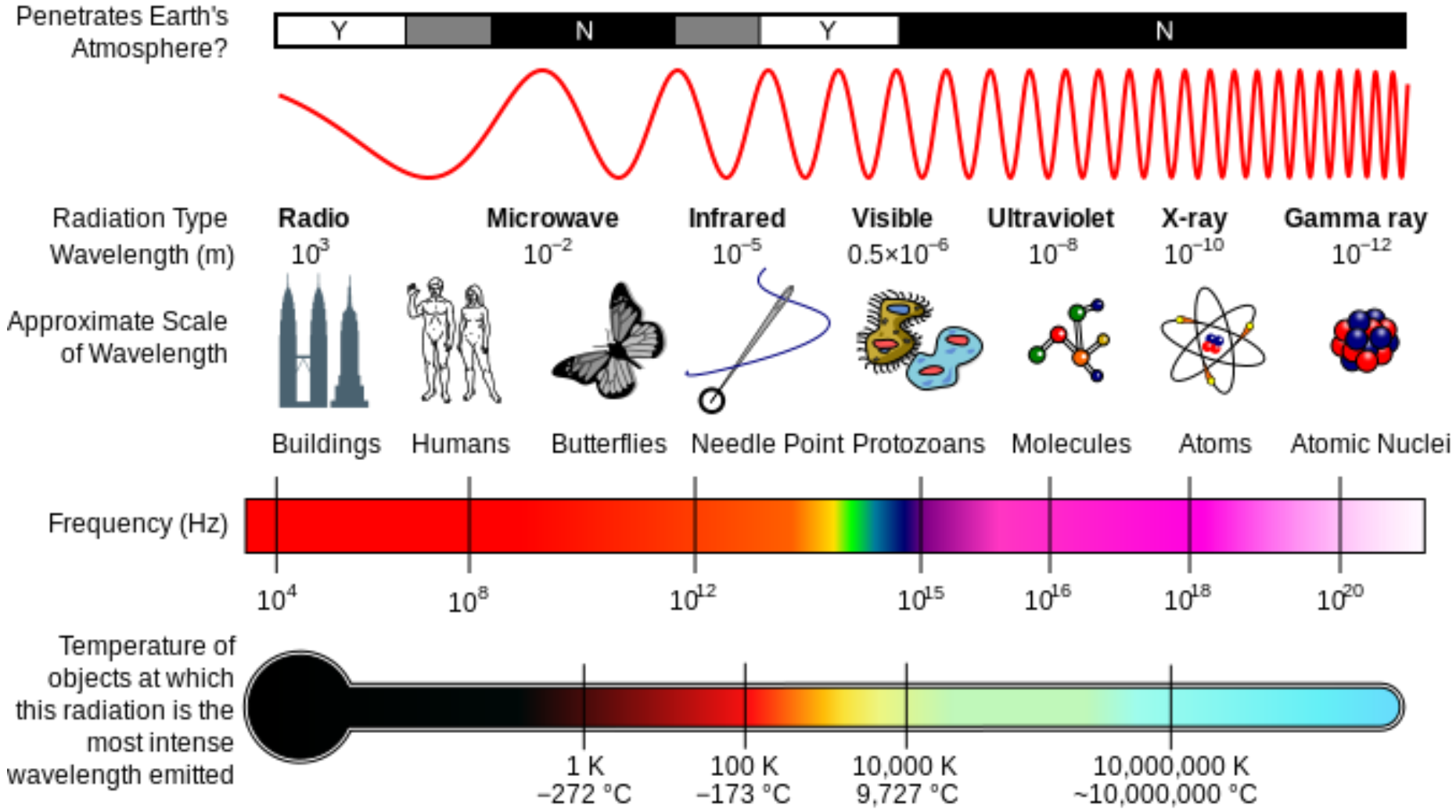
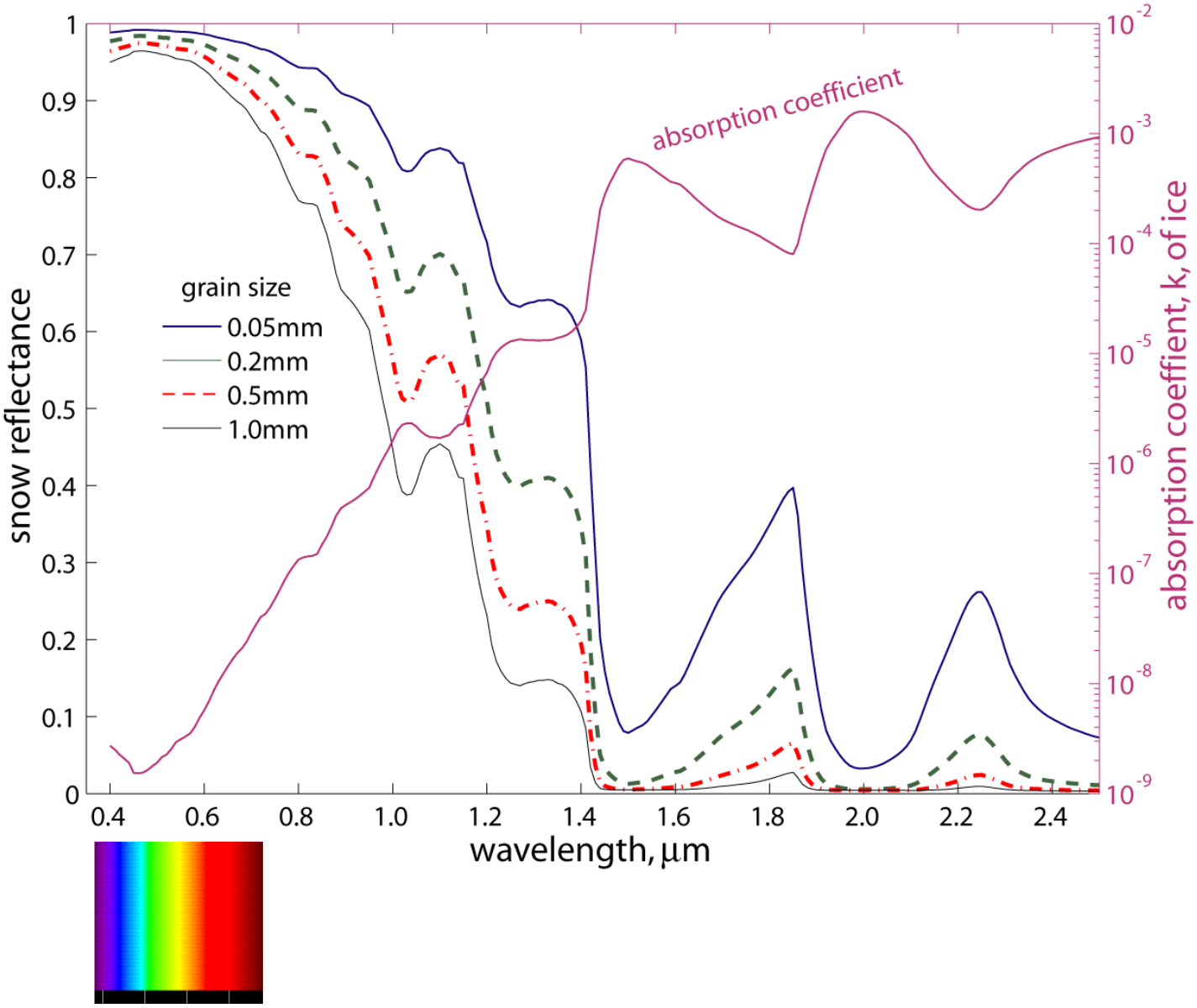
Turning unknowns into knows through new water information systems




Penetrates Earth's Atmosphere?
Y
N
Y
N
Radiation Type
Wavelength (m)
Approximate Scale of Wavelength
Radio
10^{3}
Microwave
10^{-2}
Infrared
10^{-5}
Visible
0.5×10^{-6}
Ultraviolet
10^{-8}
X-ray
10^{-10}
Gamma ray
10^{-12}
Buildings
Humans
Butterflies
Needle Point
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^{4}
10^{8}
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}
Temperature of objects at which this radiation is the most intense wavelength emitted
1 K
−272 °C
100 K
−173 °C
10,000 K
9,727 °C
10,000,000 K
~10,000,000 °C

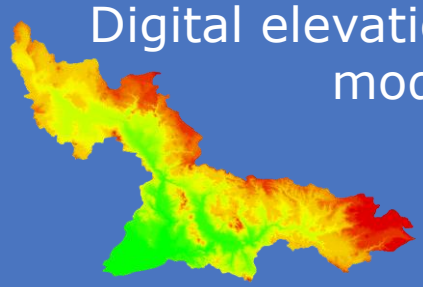
Snow is a collection of scattering grains

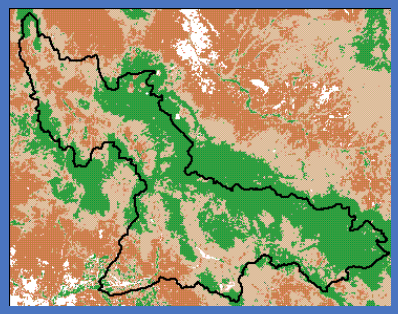


Snow spectral reflectance

Enhancing seasonal water-supply forecasting

Digital elevation model

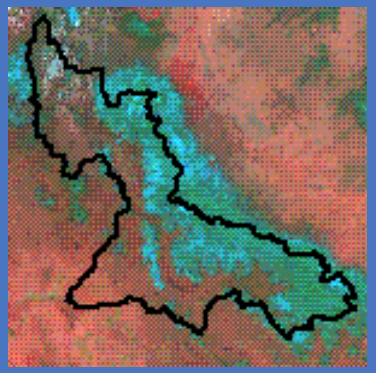




Landcover information

Enhanced ground data

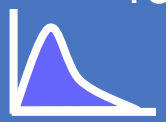
Satellite snowcover

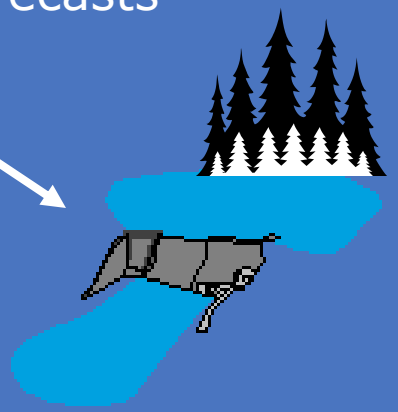


Integration & modeling

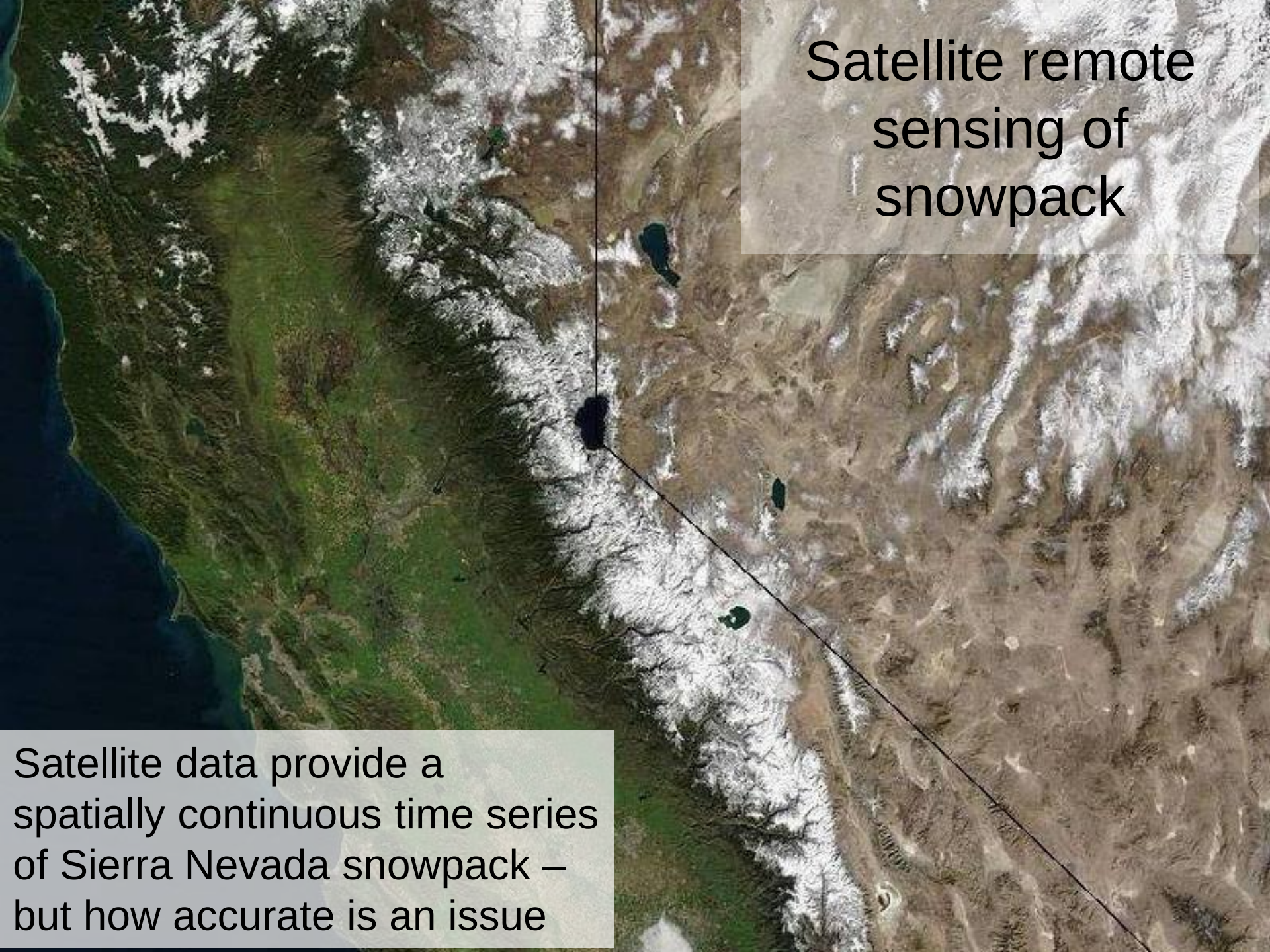
Precipitation forecast

Streamflow forecasts





Satellite remote sensing of snowpack

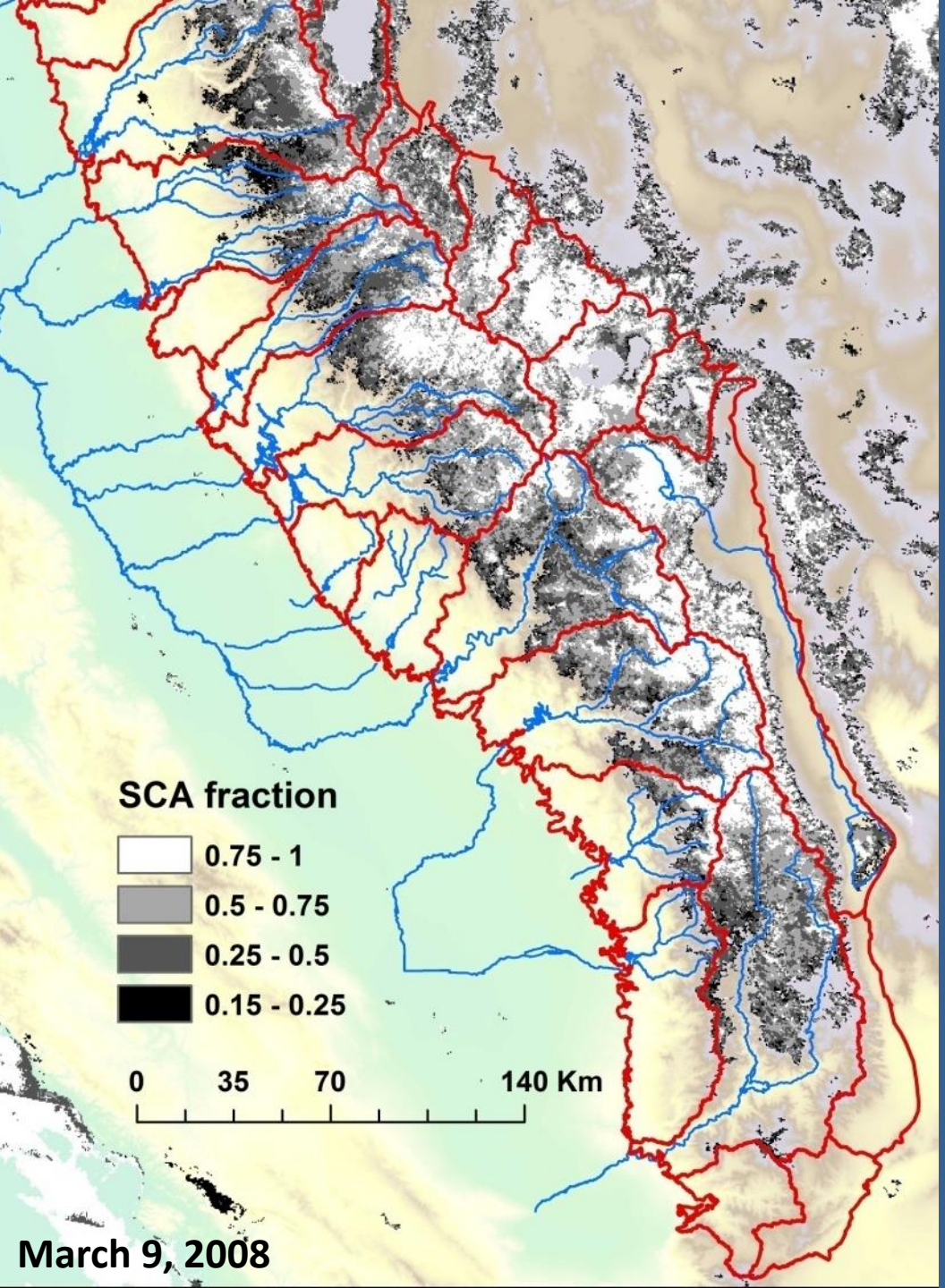


Satellite data provide a spatially continuous time series of Sierra Nevada snowpack – but how accurate is an issue

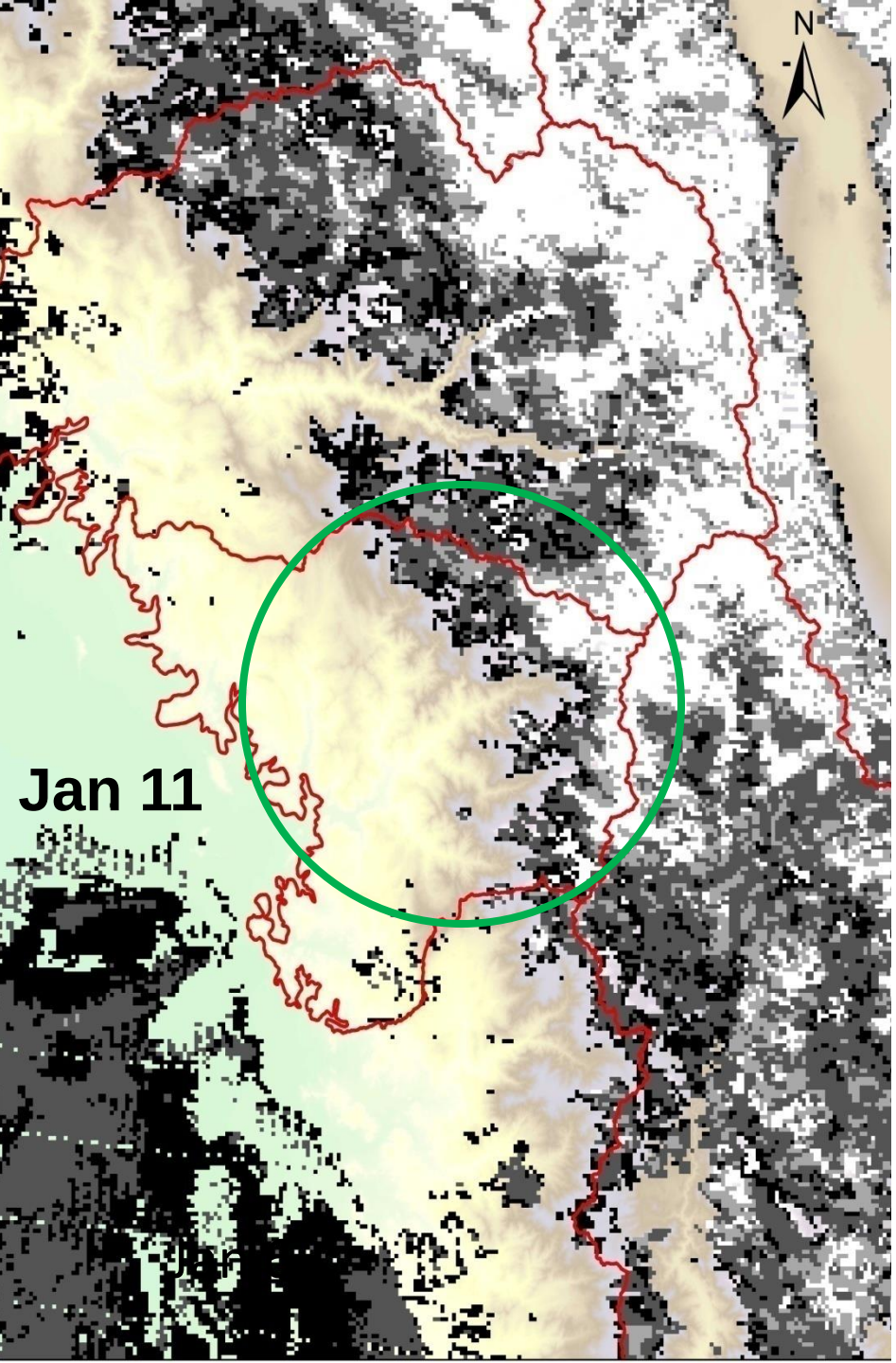
-Sierra Nevada fractional snow covered area (SCA) from MODIS, MODSCAG

(Painter et al., 2008)

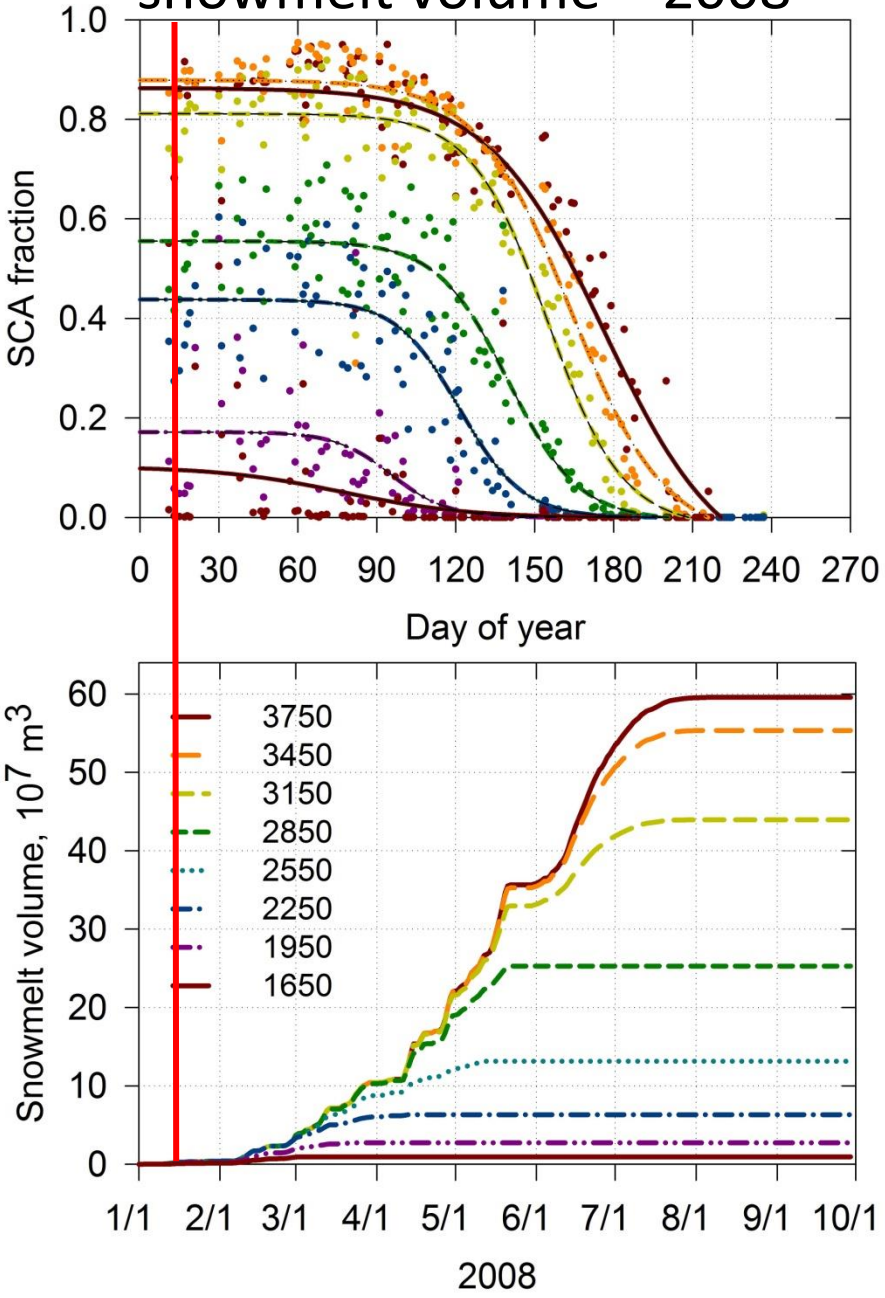
-SCA is binned into 4 classes for ease of viewing pixel size 500 m

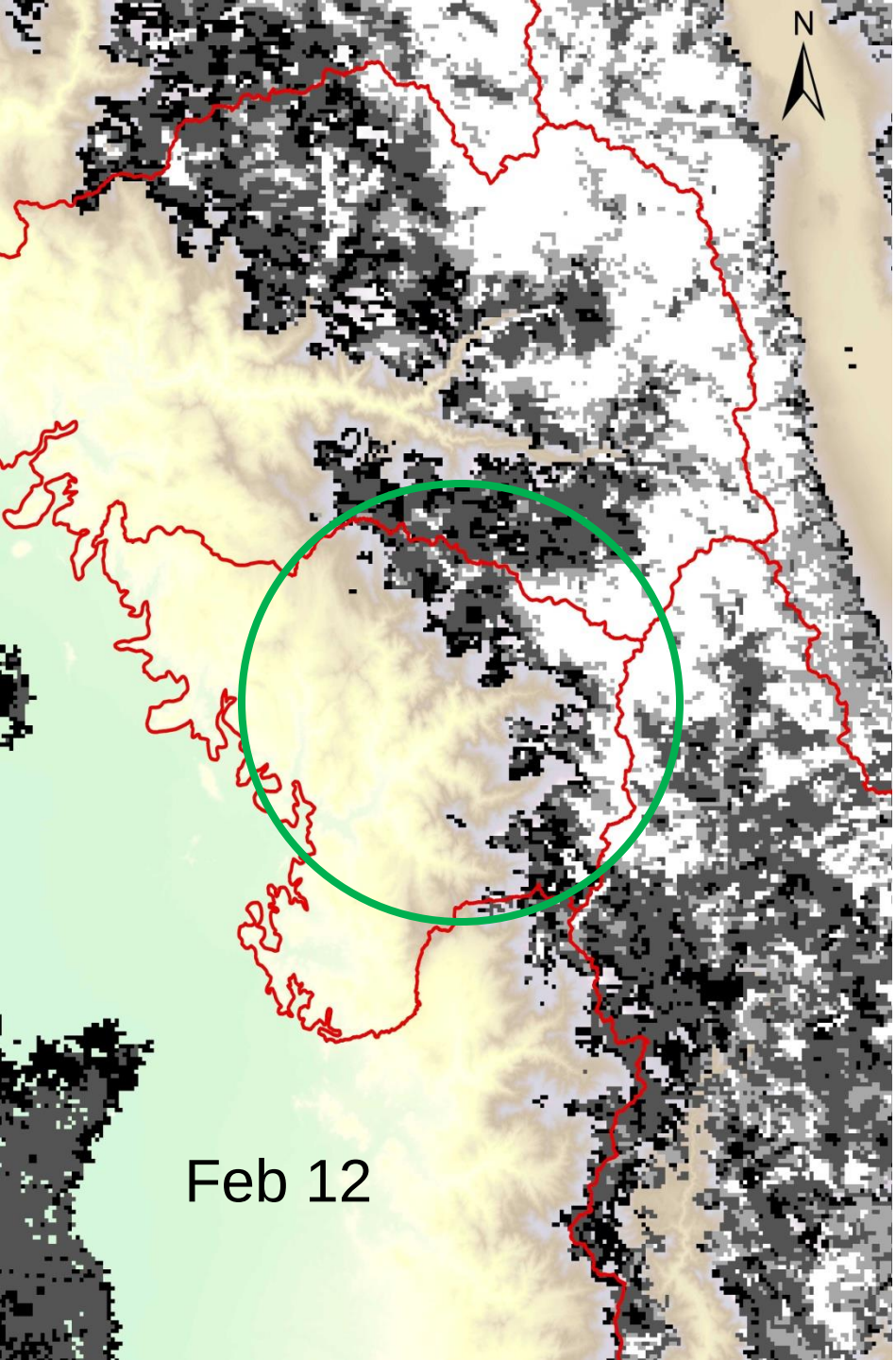


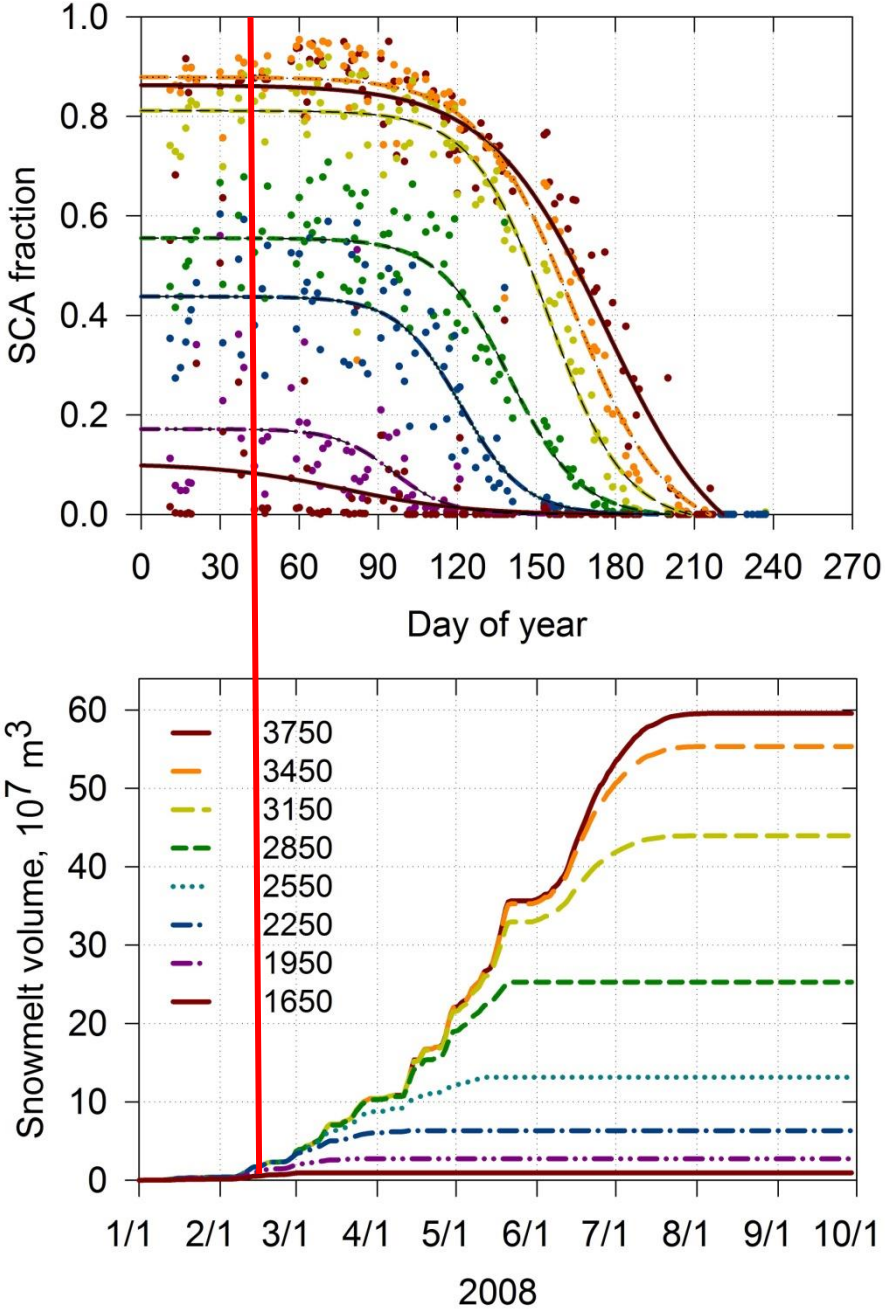
Sierra Nevada frac
covered area (SC
MODSCAG algorith
al., 2008
SCA is binned into
ease of viewing
Pixel size: 500 m
Data available for

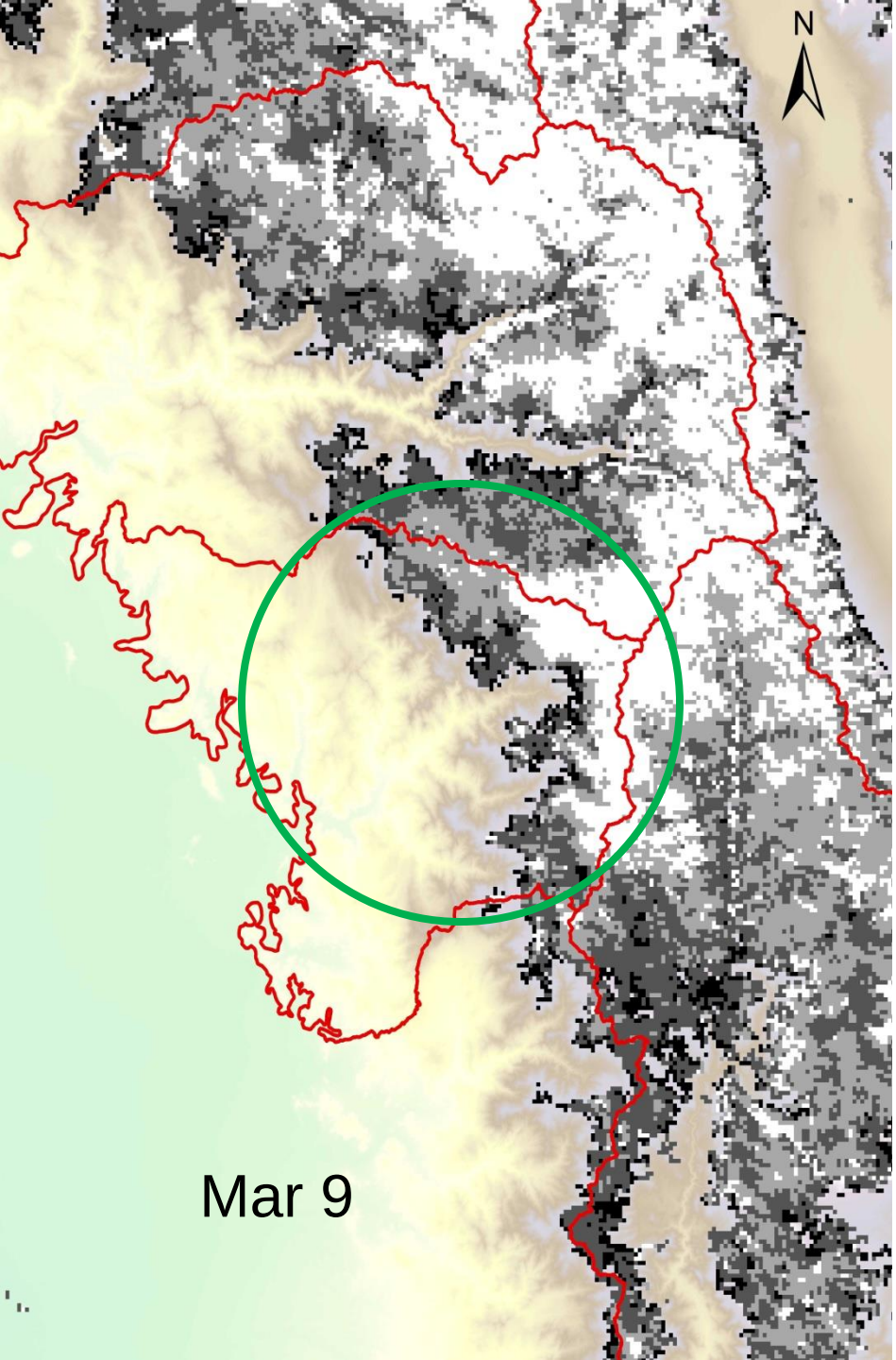


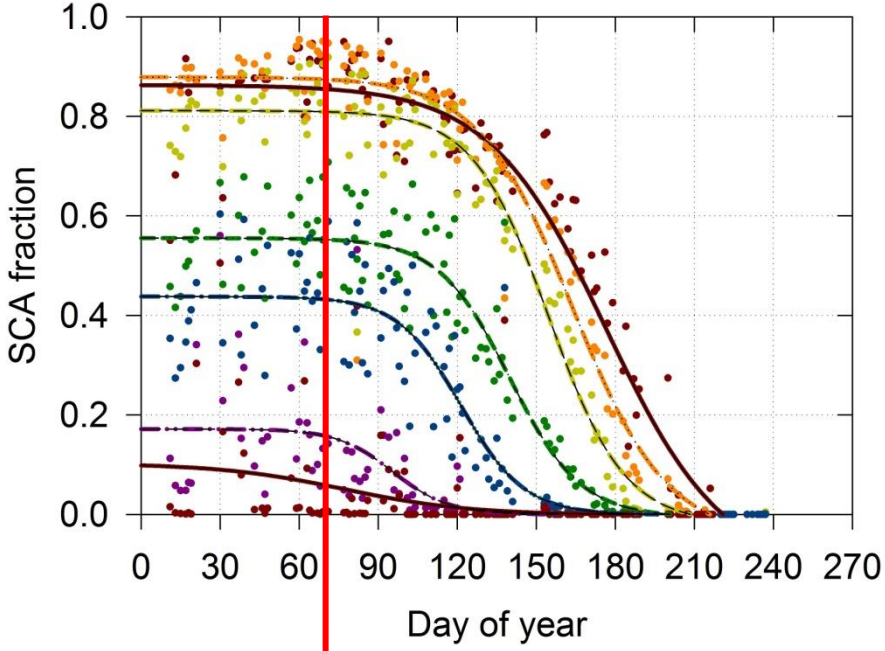
Kaweah River basin SCA & snowmelt volume – 2008

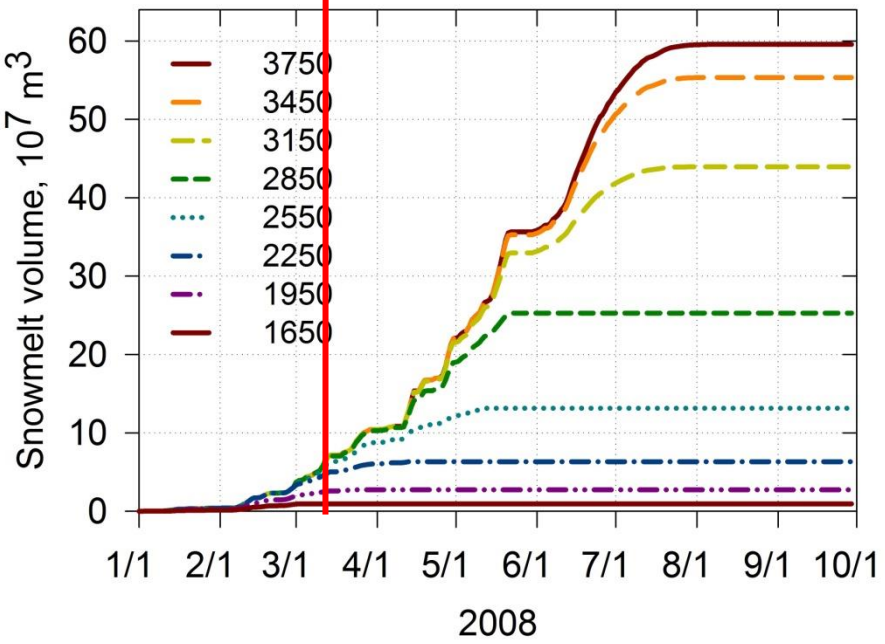



N
Feb 12


SCA fraction
1.0
0.8
0.6
0.4
0.2
0.0
0
30
60
90
120
150
180
210
240
270
Day of year
Snowmelt volume, 10^7 m^3
60
50
40
30
20
10
0
3750
3450
3150
2850
2550
2250
1950
1650
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
2008


N
Mar 9


SCA fraction
1.0
0.8
0.6
0.4
0.2
0.0
0
30
60
90
120
150
180
210
240
270
Day of year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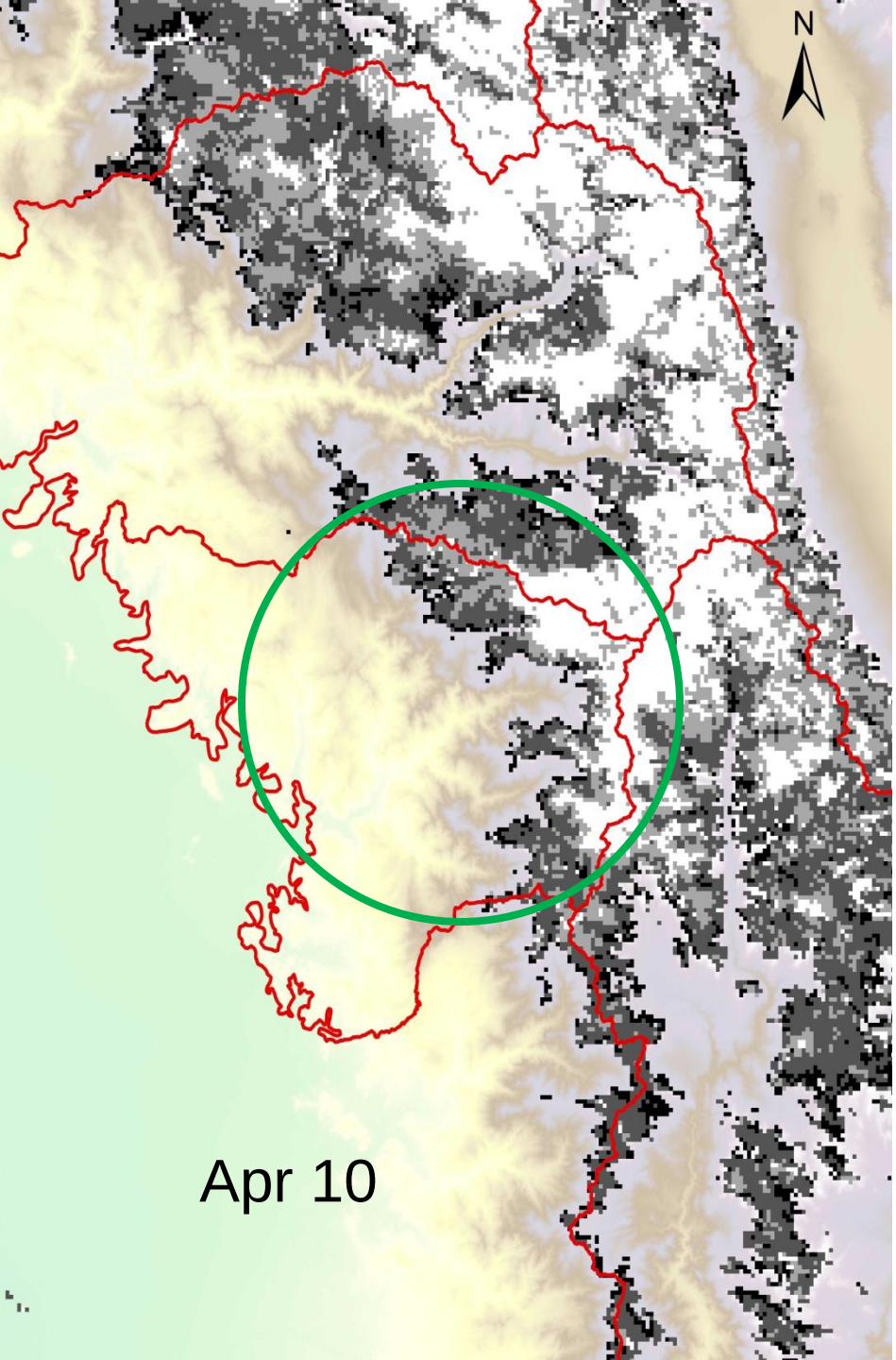
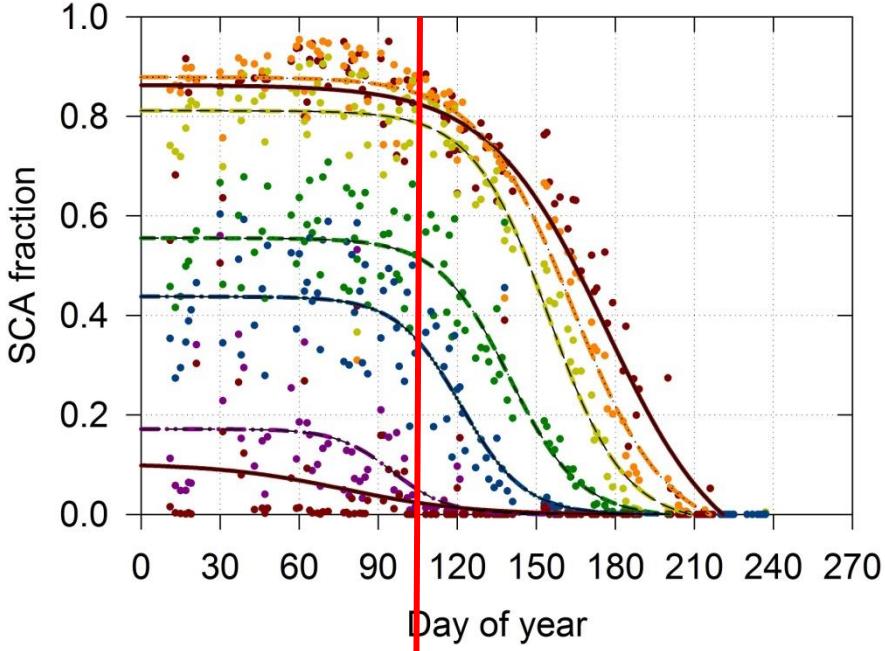
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
2008


N
Apr 10


SCA fraction
1.0
0.8
0.6
0.4
0.2
0.0
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30
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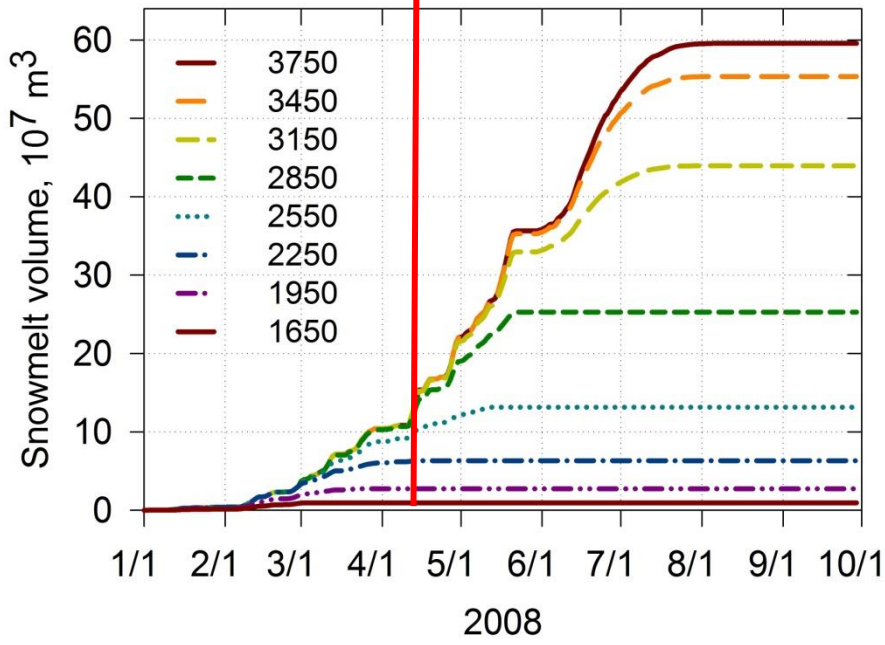
270
Day of year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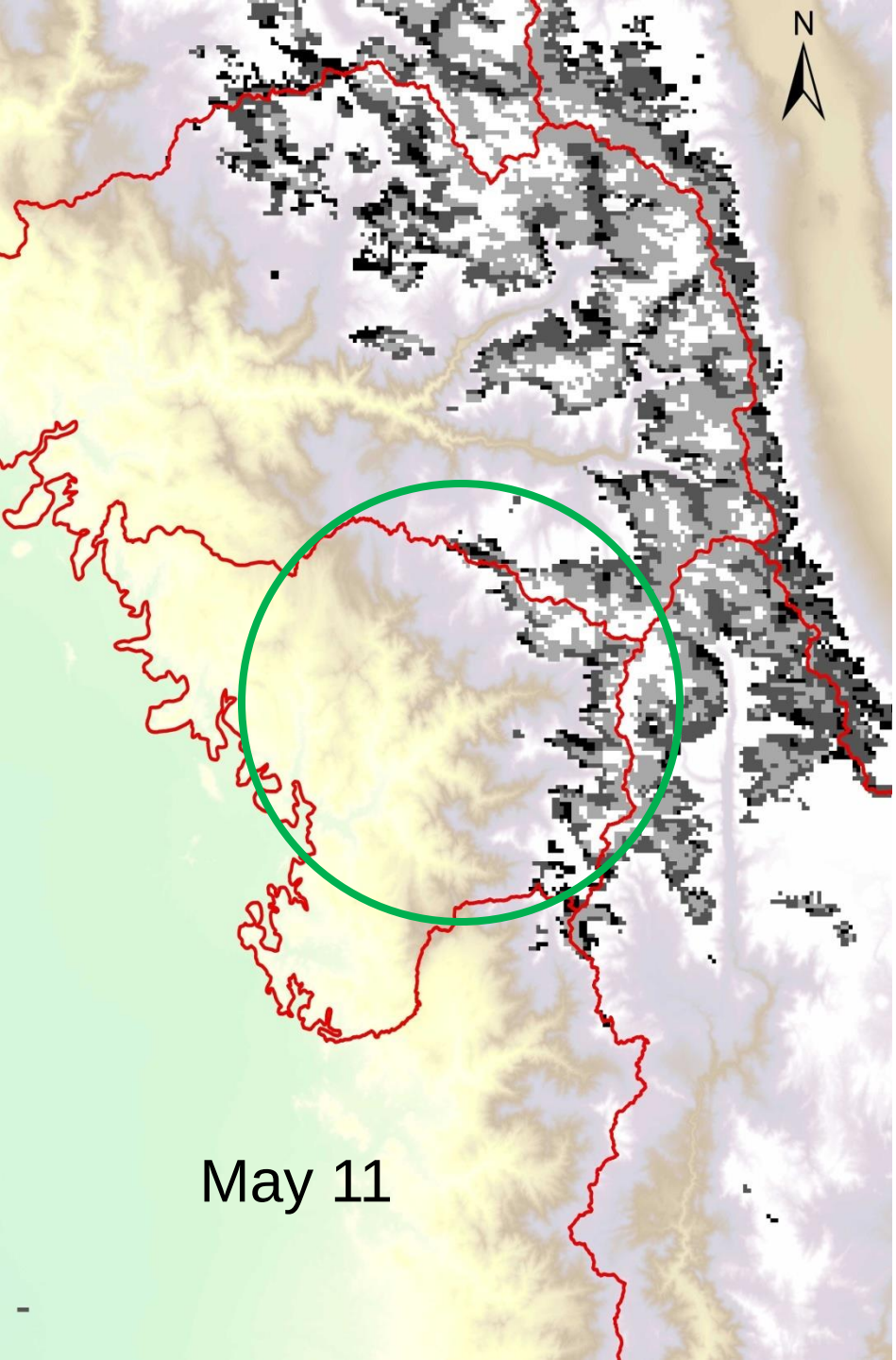
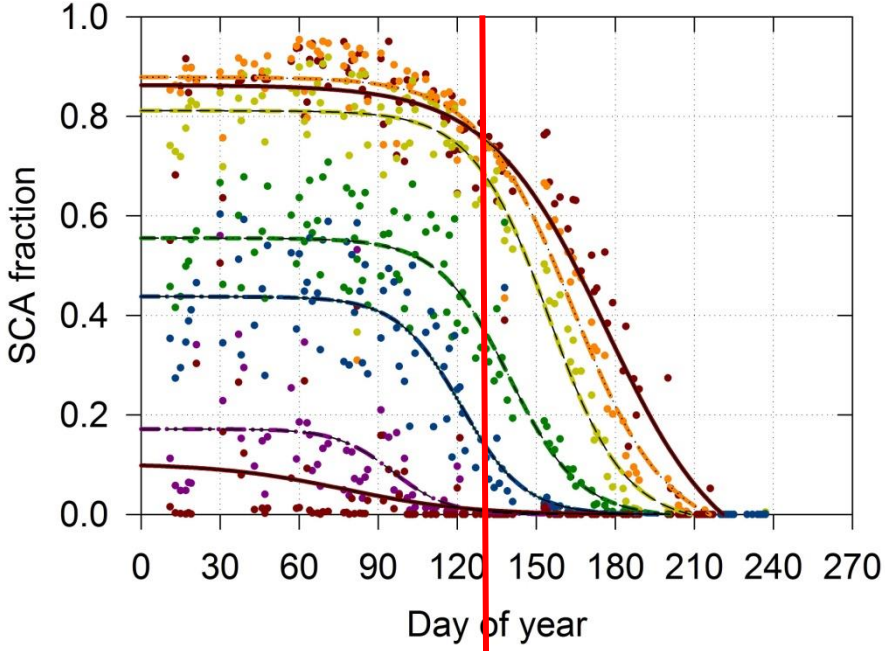
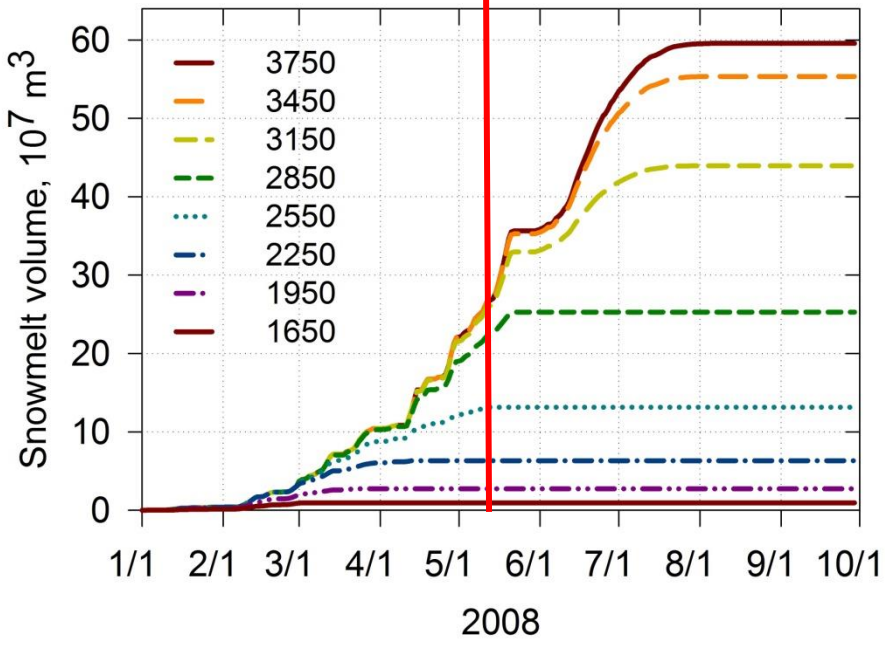
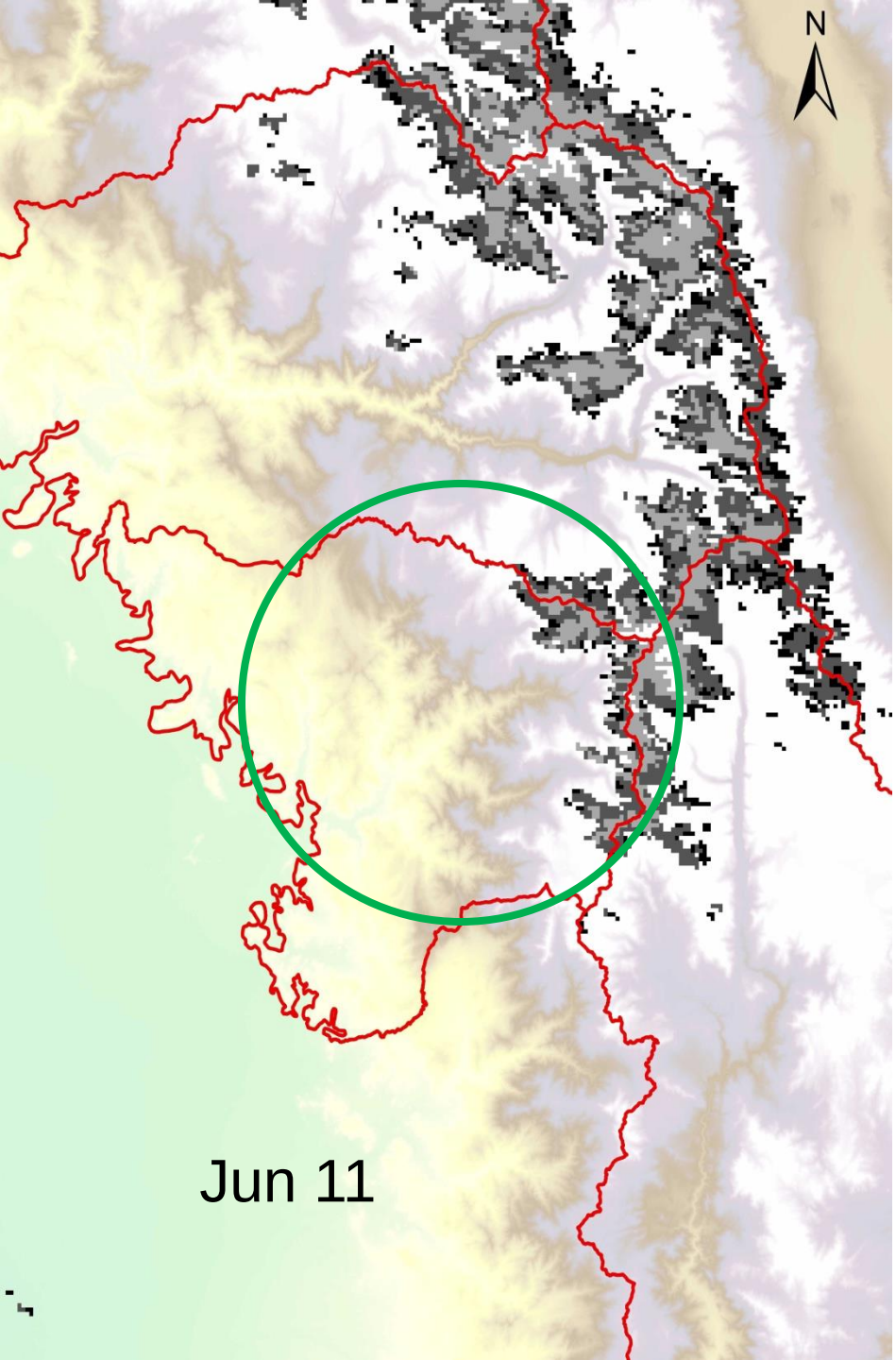
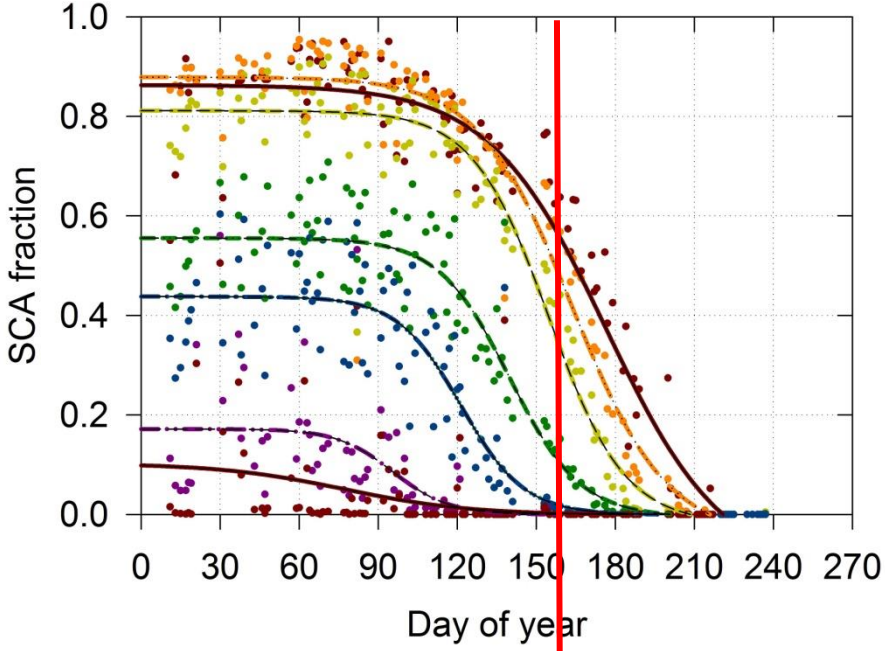
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
2008

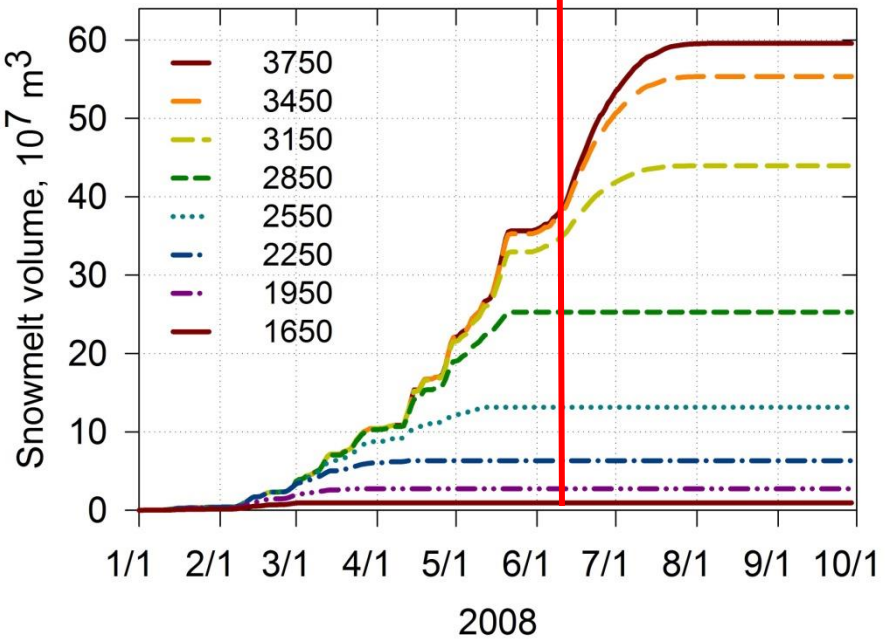

N
May 11

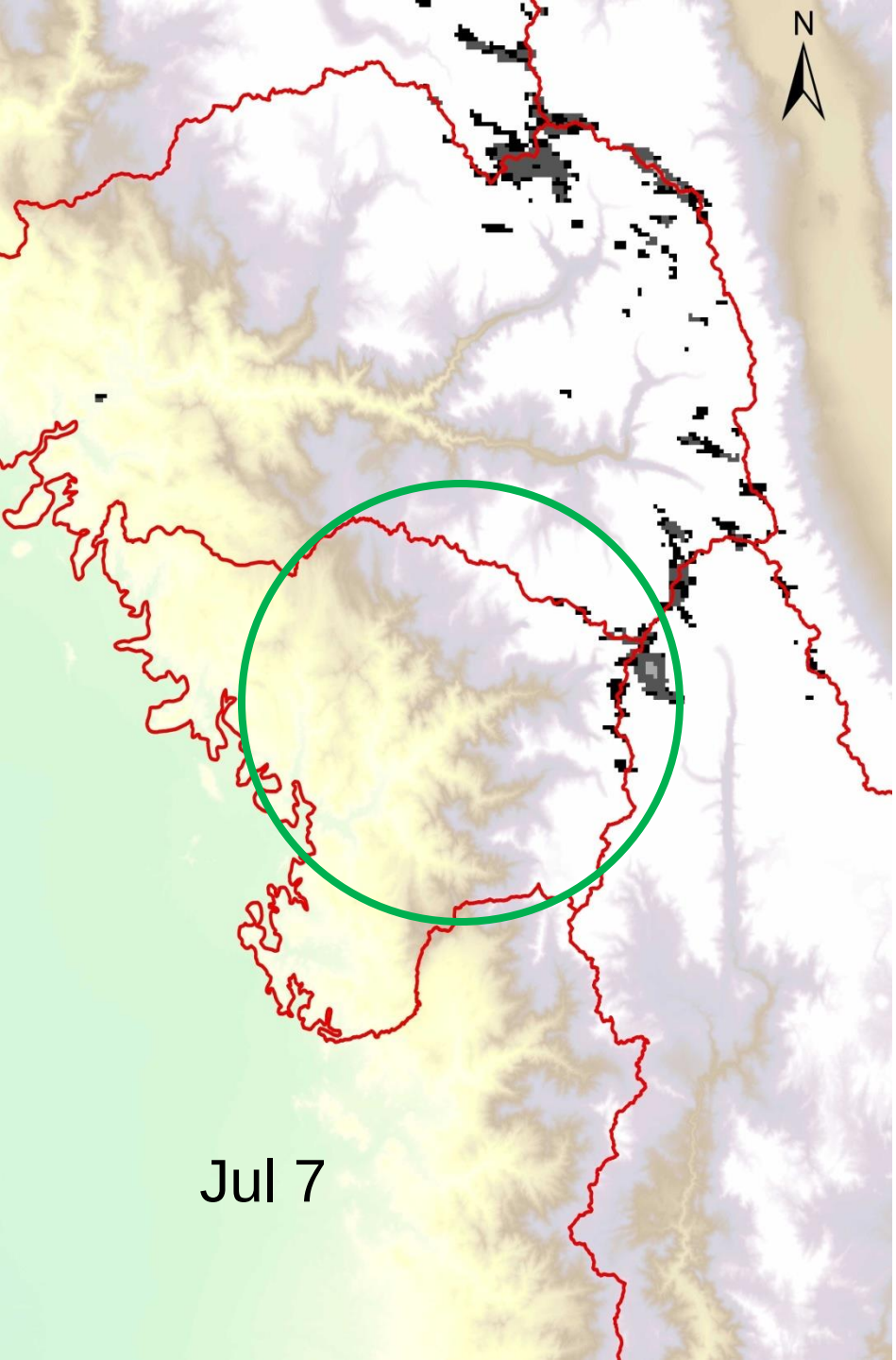

SCA fraction
1.0
0.8
0.6
0.4
0.2
0.0
0
30
60
90
120
150
180
210
240
270
Day of year

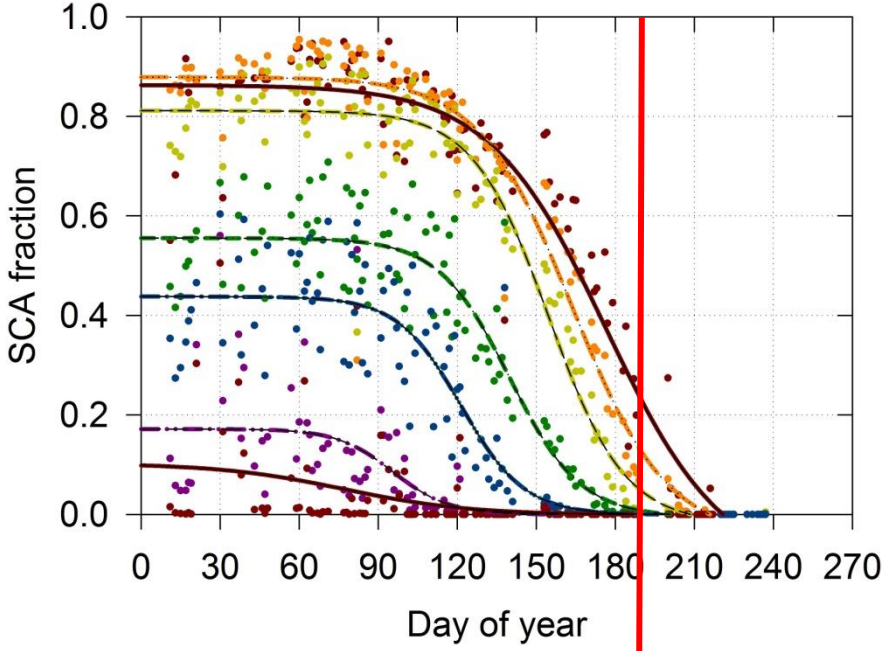

Snowmelt volume, 10^7 m^3
60
50
40
30
20
10
0
3750
3450
3150
2850
2550
2250
1950
1650
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
2008

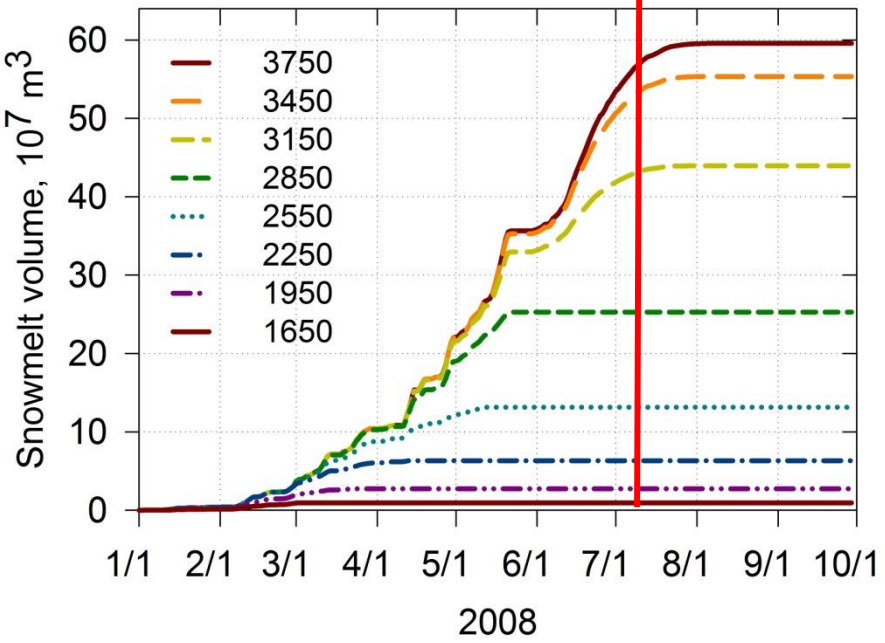

N
Jun 11


SCA fraction
1.0
0.8
0.6
0.4
0.2
0.0
0
30
60
90
120
150
180
210
240
270
Day of year


Snowmelt volume, 10^7 m^3
60
50
40
30
20
10
0
3750
3450
3150
2850
2550
2250
1950
1650
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
2008


N
Jul 7


SCA fraction
1.0
0.8
0.6
0.4
0.2
0.0
0
30
60
90
120
150
180
210
240
270
Day of year


Snowmelt volume, 10^7 m^3
60
50
40
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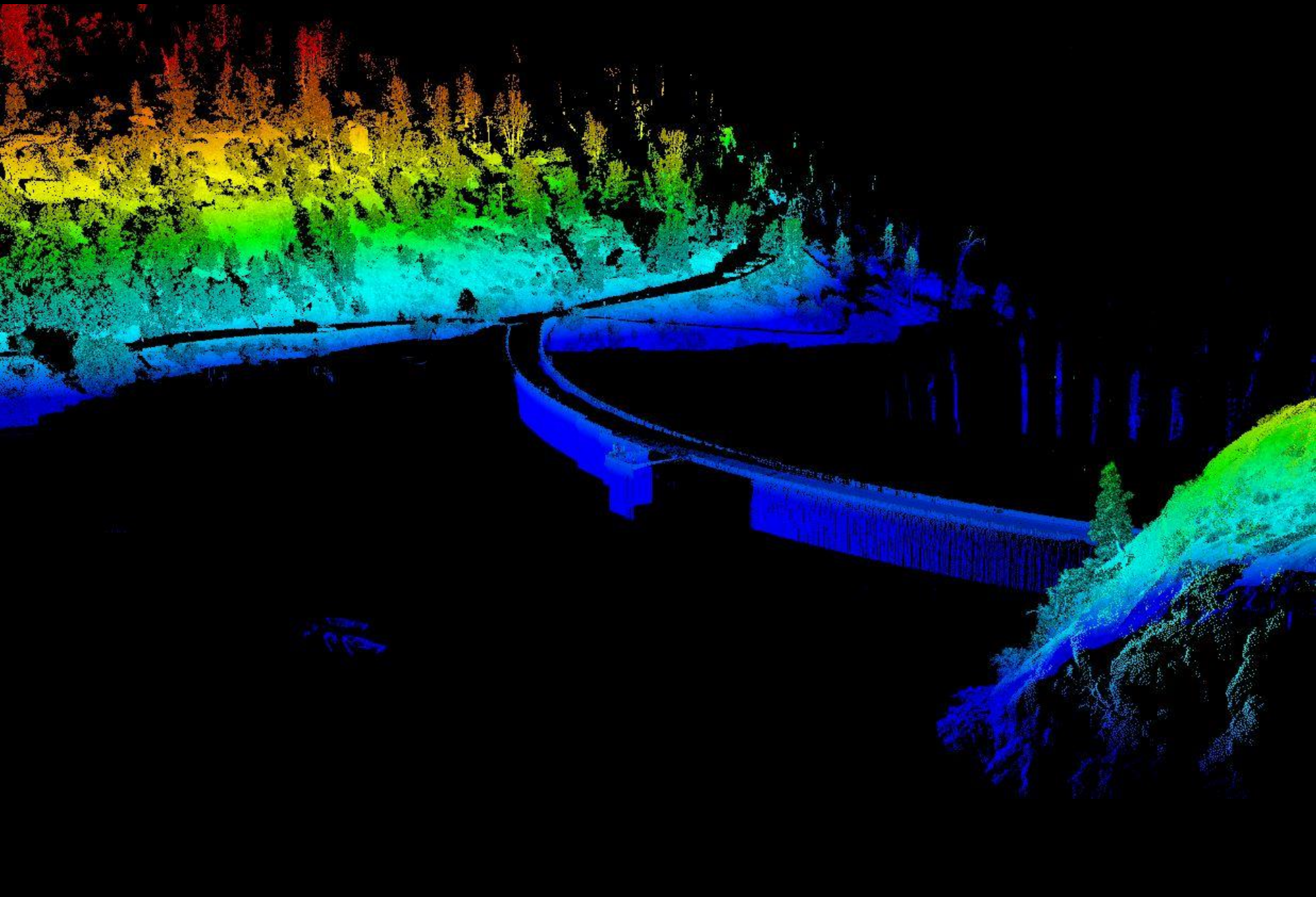
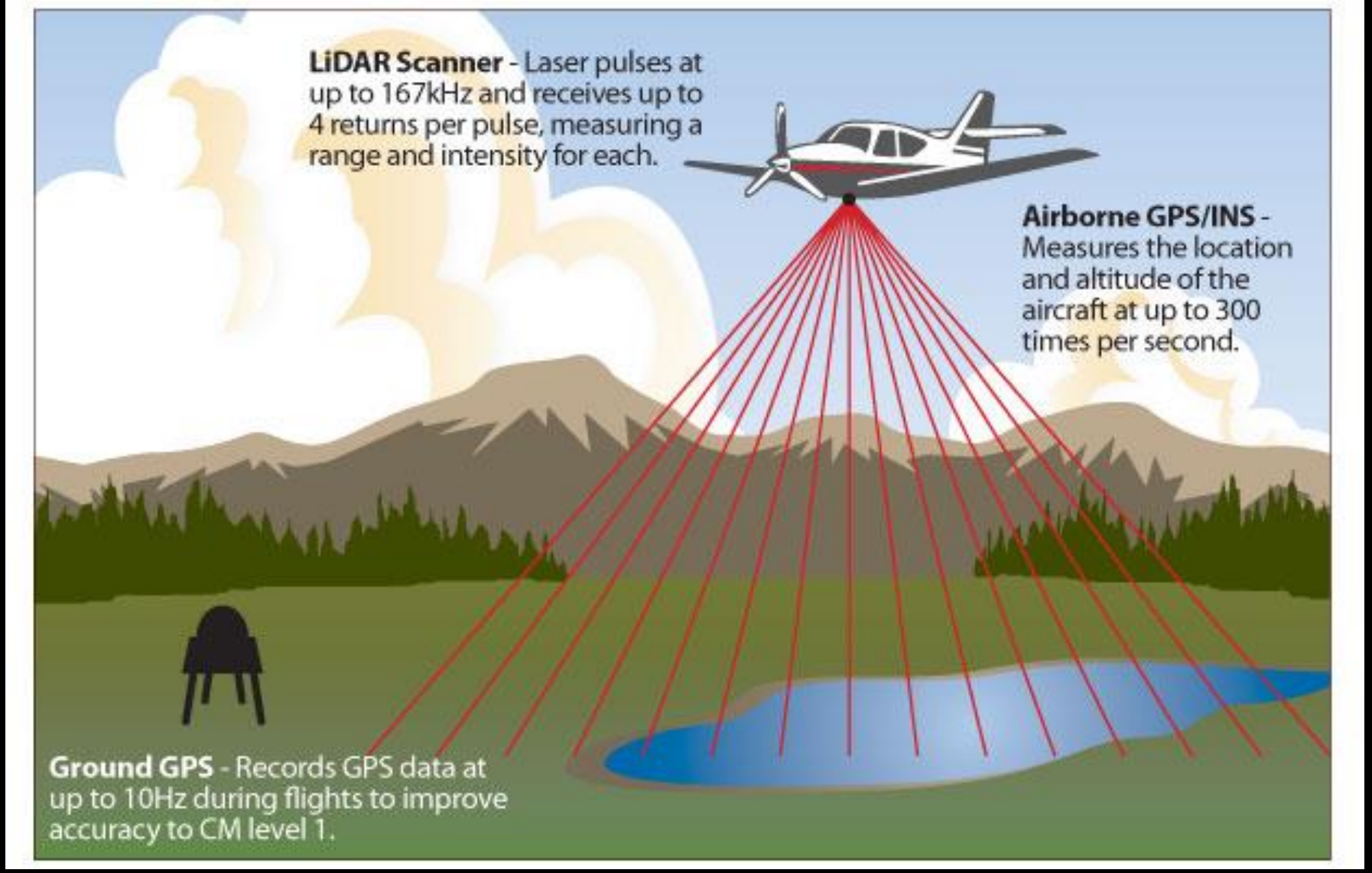
2850
2550
2250
1950
1650
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
2008

Photo courtesy Jeff Deems

100 m





vertical accuracy 5 to 10 cm
horizontal accuracy 10 to 70 cm, dependent on altitude

Source: ncalm.cive.uh.edu and pictometry.com

Imaging Spectrometer
0.35-1.05 µm
2 m spatial resolution from 4000 m AGL

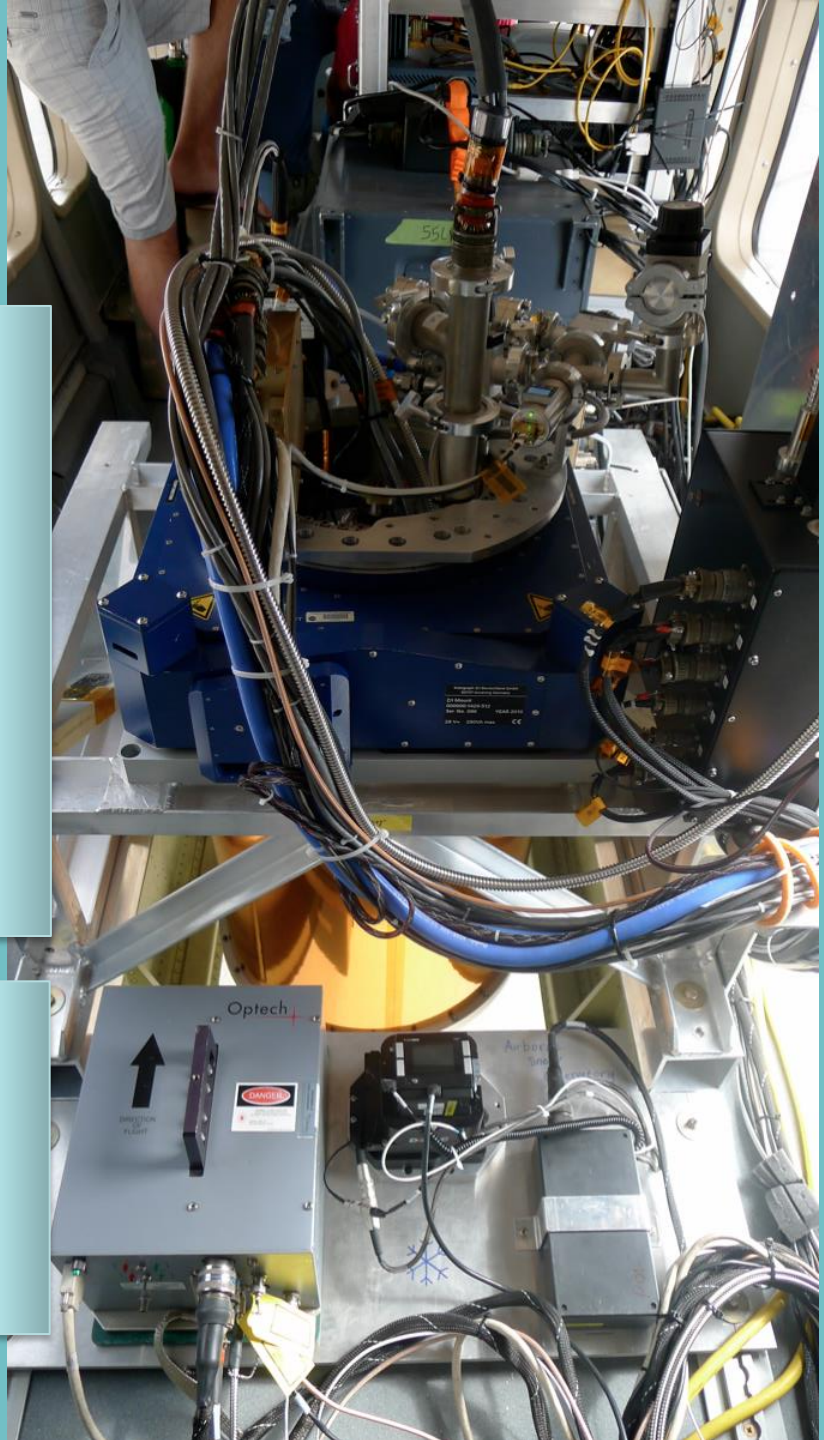
Albedo

Uncertainty < 2%

3D Scanning LiDAR
1064 nm
1 m spatial resolution

SWE

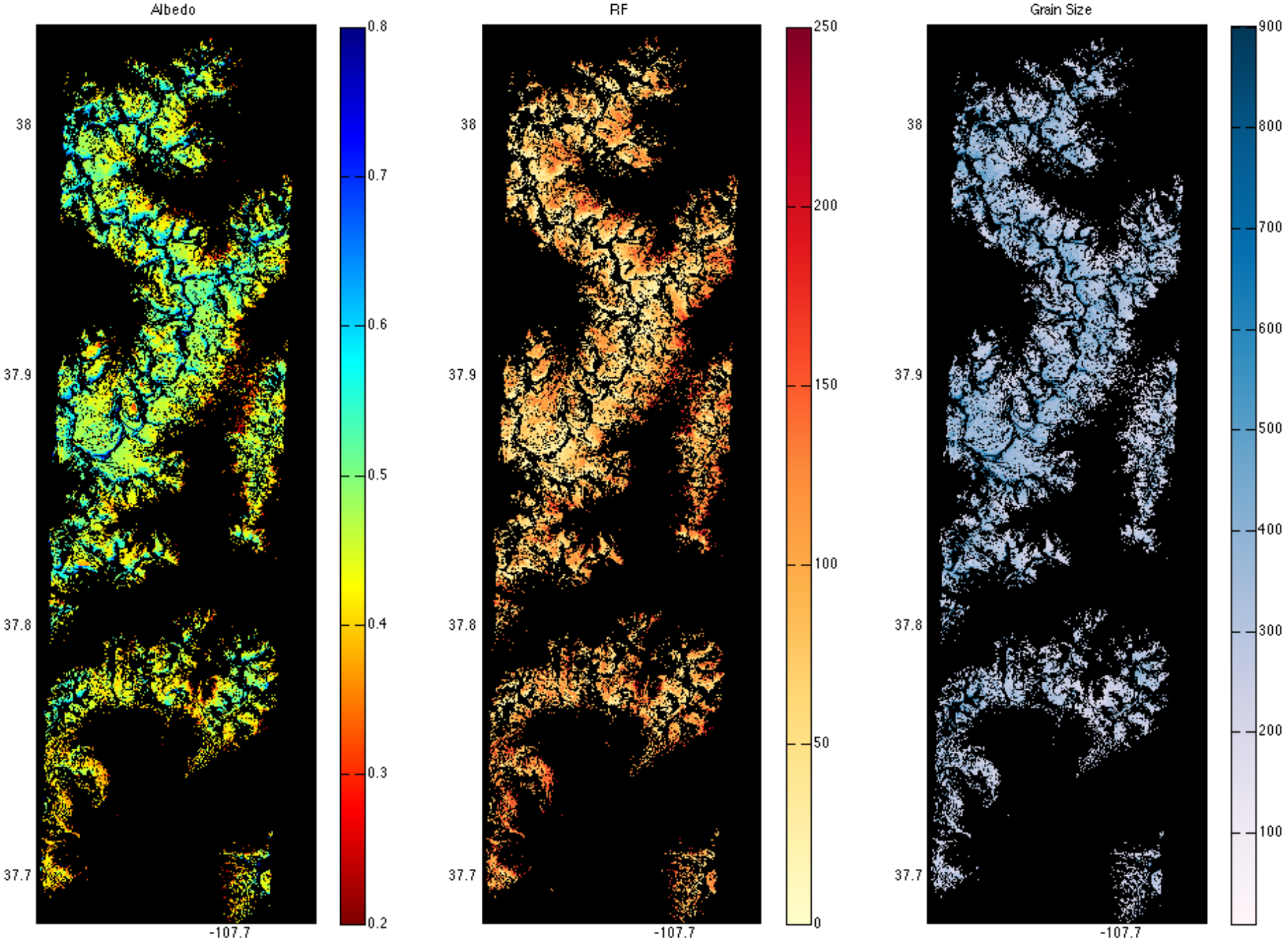
Uncertainty < 5 cm



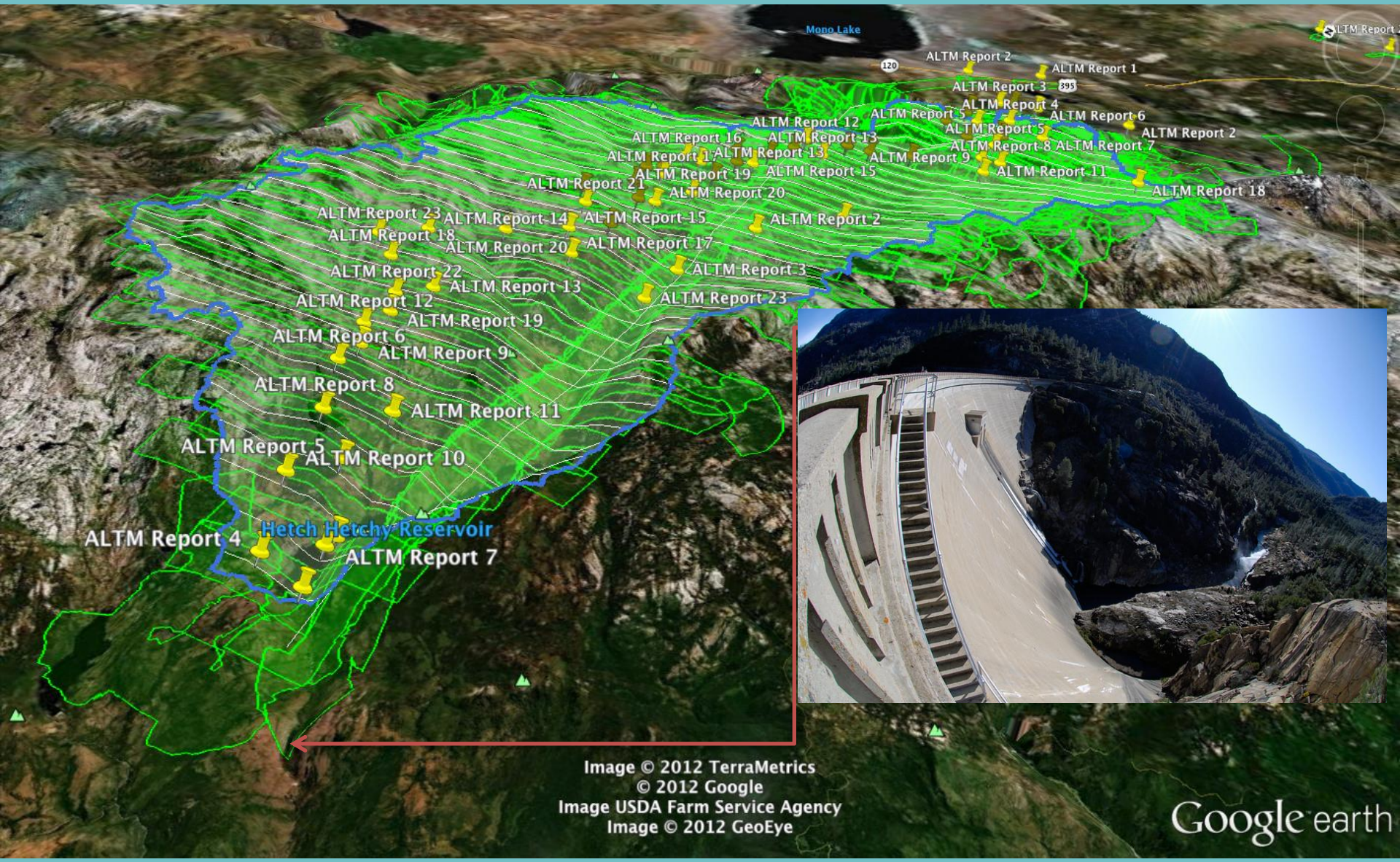
Color Composite

Direct Irradiance

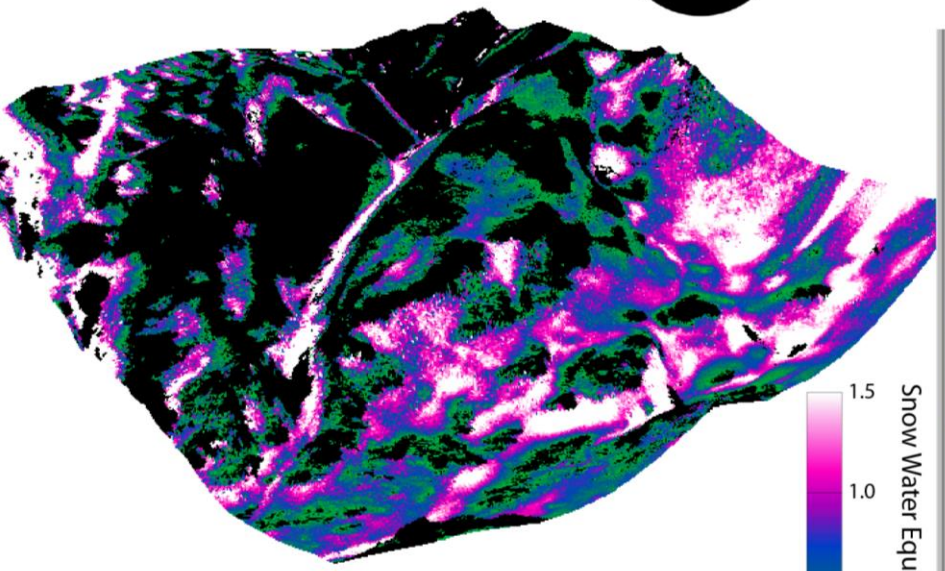
Diffuse Irradiance


Albedo
RF
Grain Size
38
37.9
37.8
37.7
-107.7
0.8
0.7
0.6
0.5
0.4
0.3
0.2
250
200
150
100
50
0
900
800
700
600
500
400
300
200
100

Tuolumne River Basin – ASO snow-free

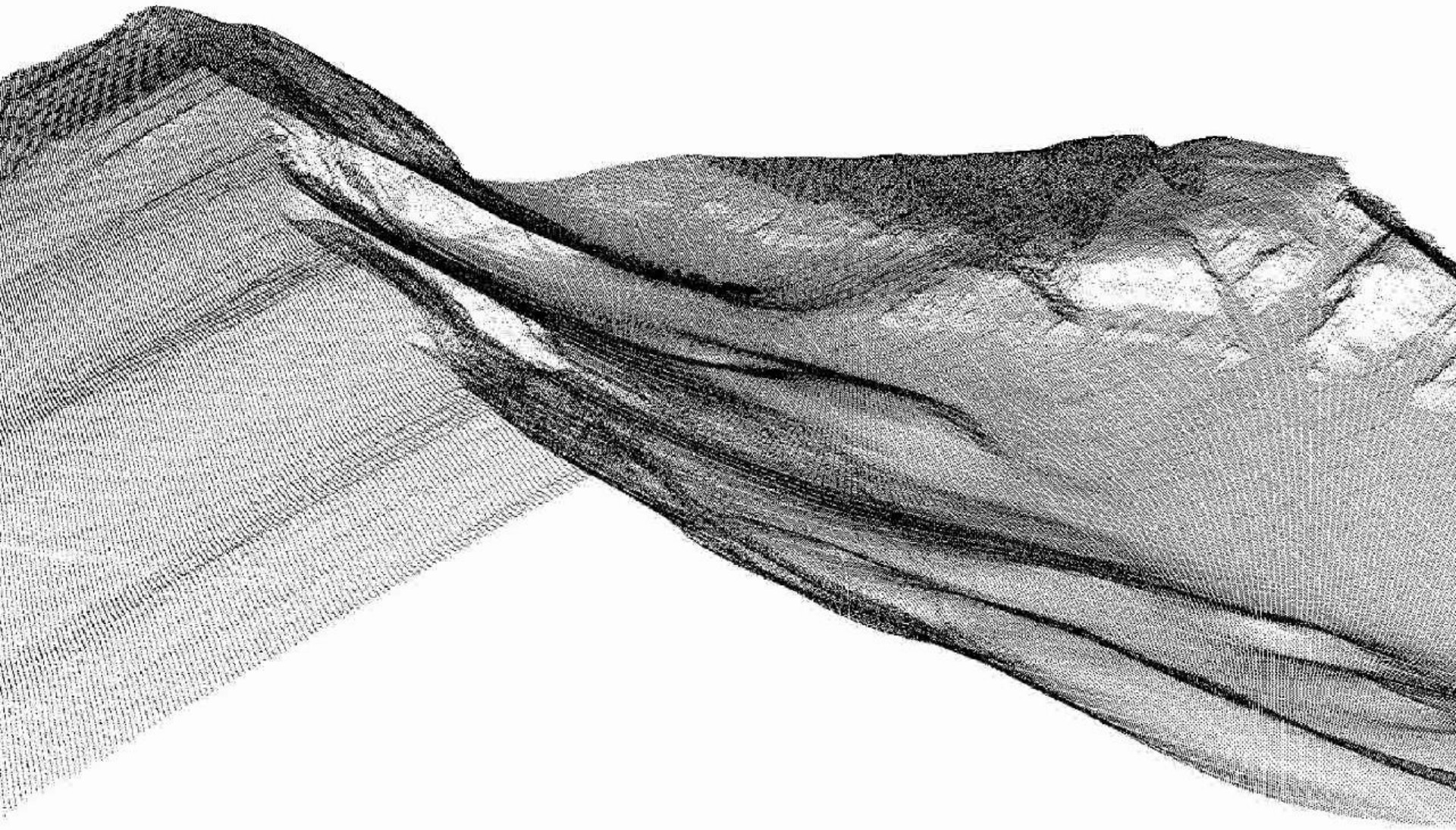


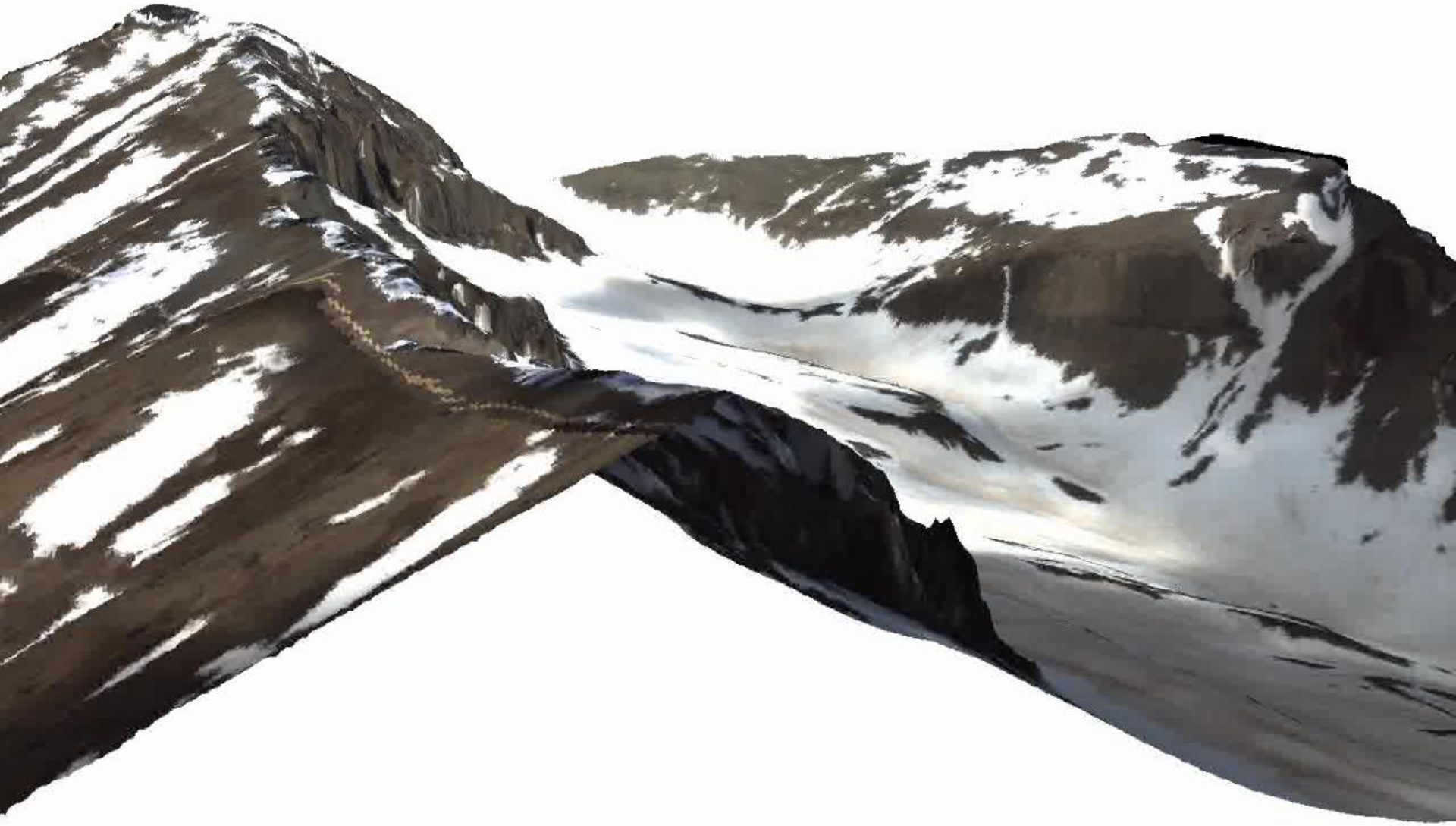
Airborne Snow Observatory

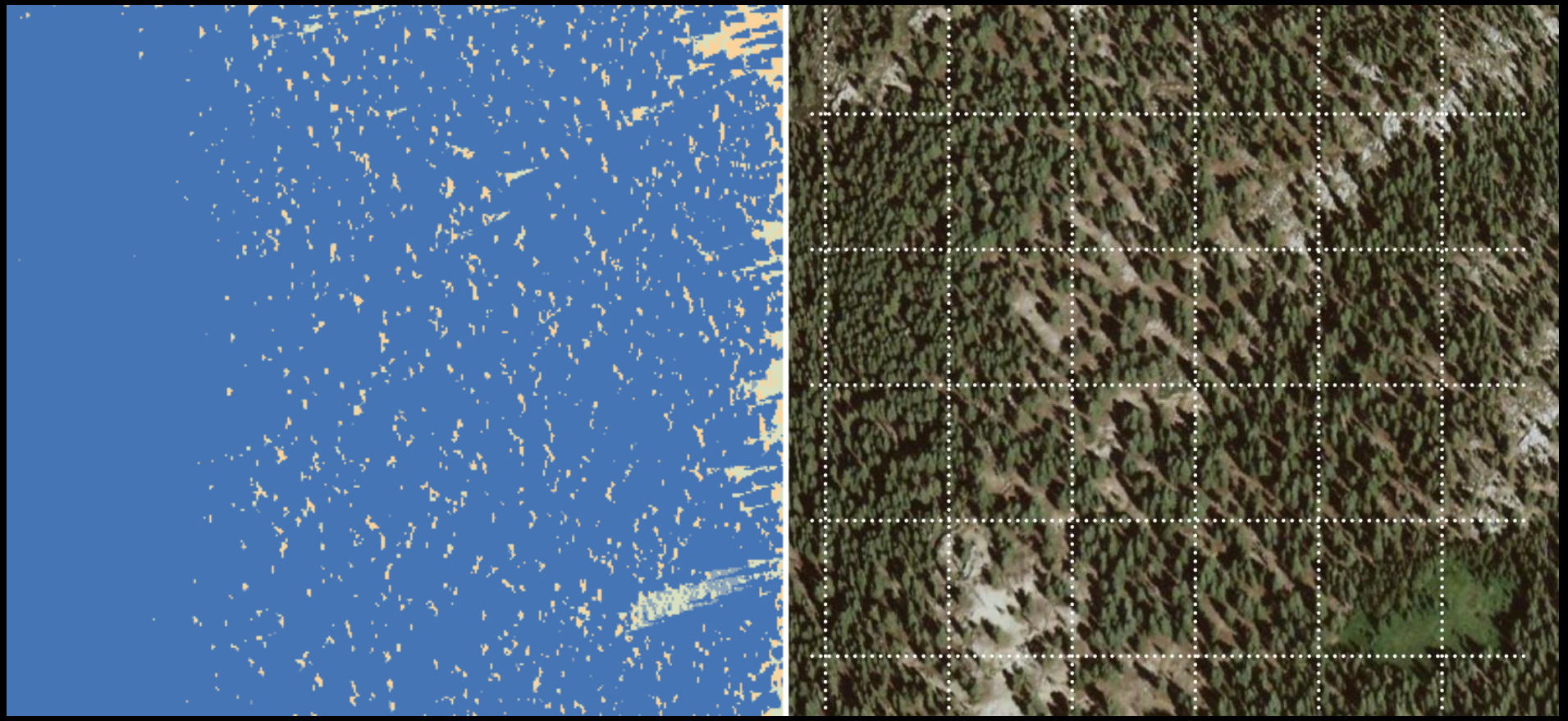


Snow water equivalent
San Juan Mountains
11 May 2012

AVIRISng color composite
San Juan Mountains
11 May 2012







Questions

Sylvain Masculine