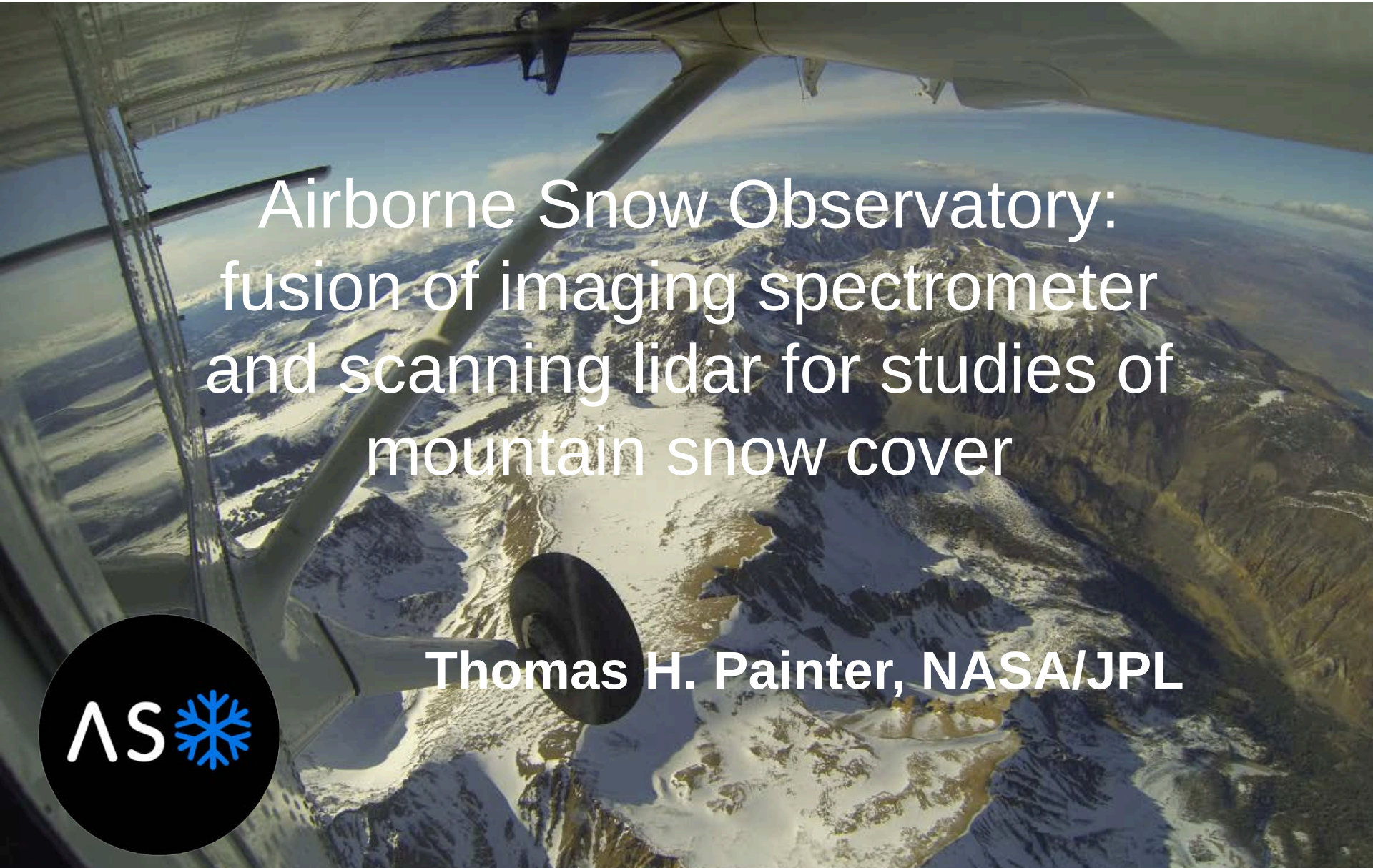


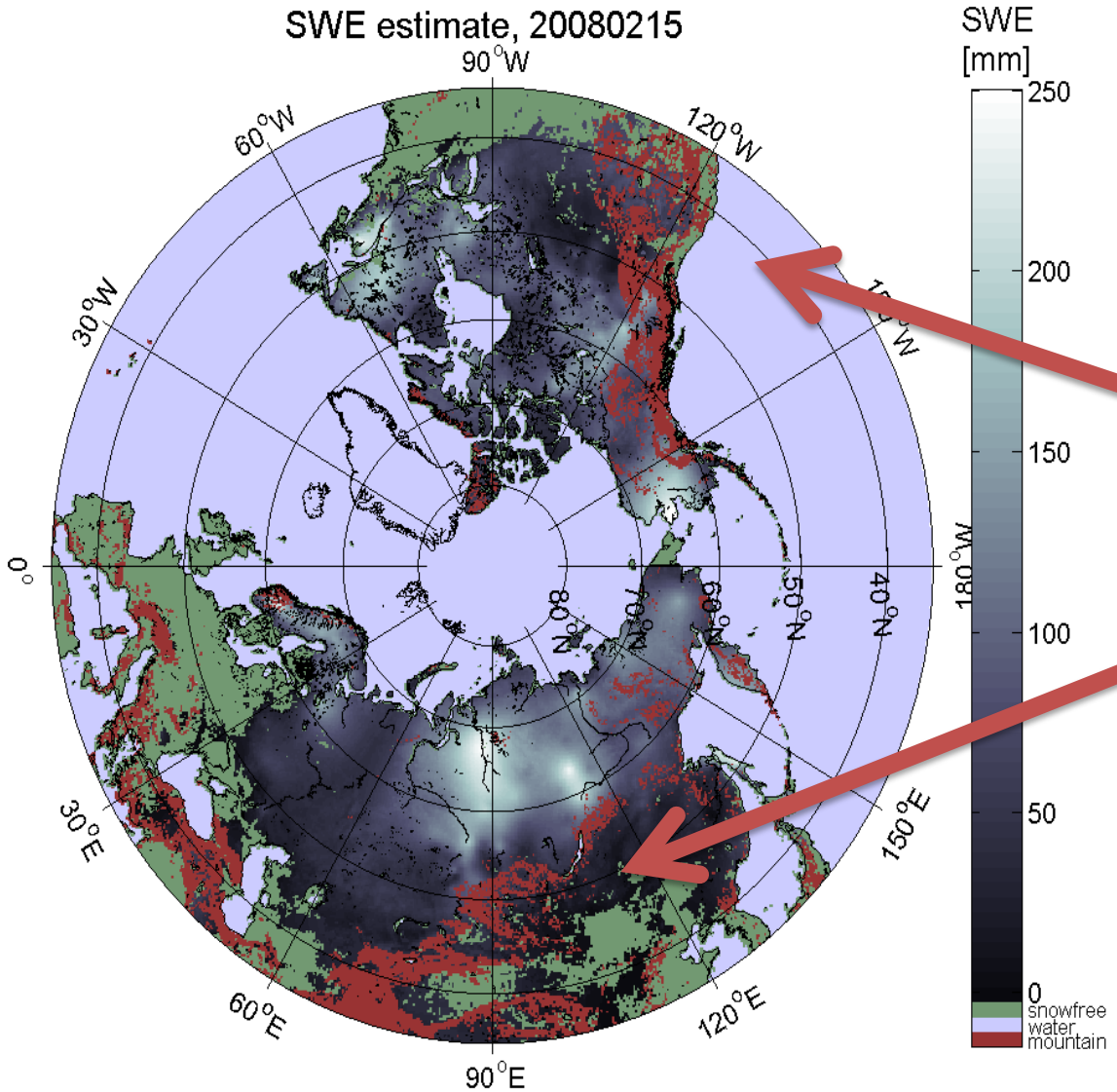
Airborne Snow Observatory: fusion of imaging spectrometer and scanning lidar for studies of mountain snow cover

Thomas H. Painter, NASA/JPL

Overview

- Science motivation
- Applied science motivation
- ASO concept
- ASO technology
- ASO Demonstration Mission 1 results
- ASO-driven runoff forecasting
- ASO Demonstration Missions+ plans

Best remote sensing of snow entirely omits mountain snow



Mountains masked out

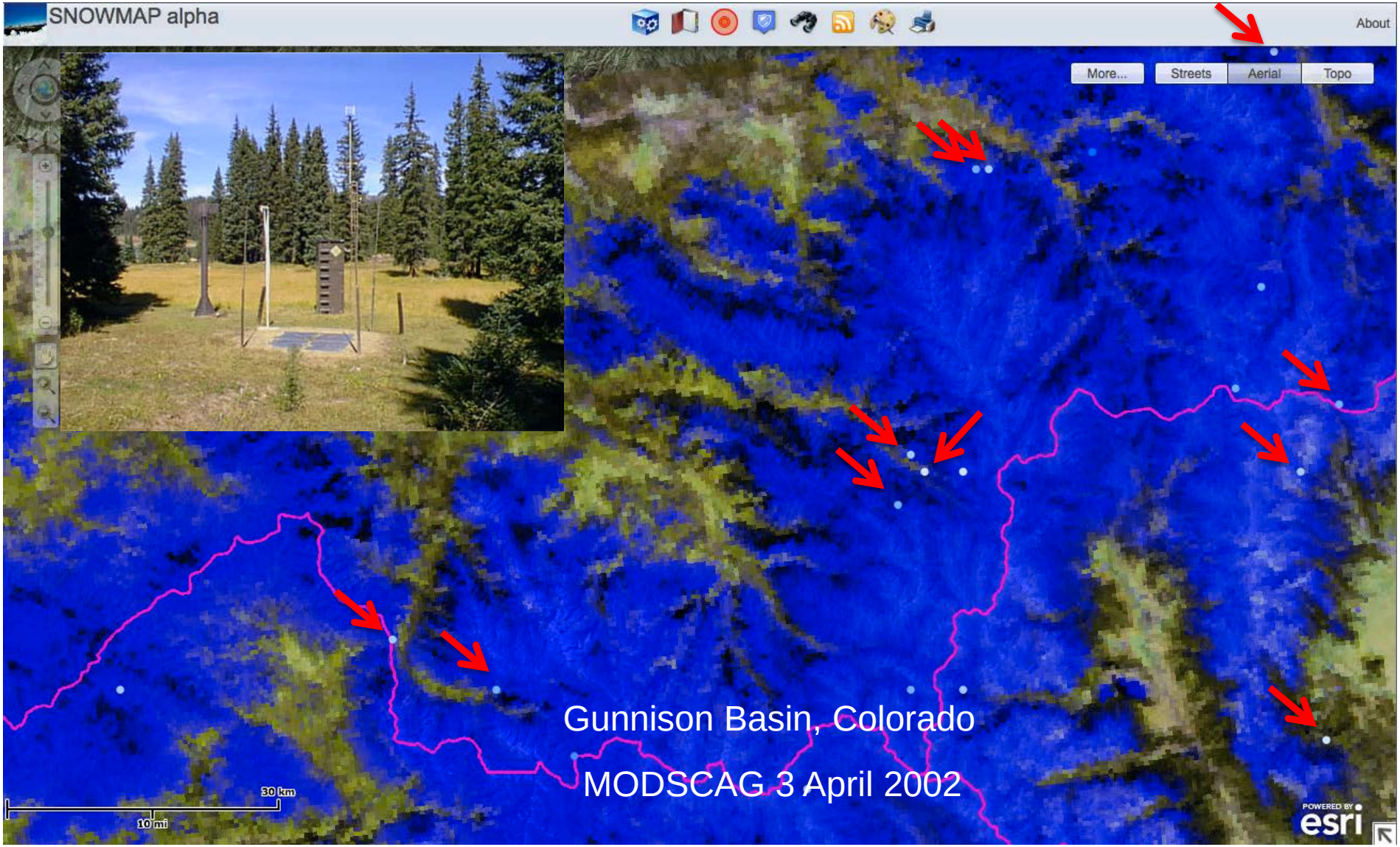
GlobSnow SWE

Courtesy C. Derksen

What does that omission do?

- In the Western US, ~80% of freshwater supply comes from snowmelt
- Hindu Kush-Himalaya snowmelt critical component of water supply for > 1 billion people
- We don’t know the control on mountain glacier melt and contribution to sea level rise
- We don’t understand regional hydroclimate and sensitivity of ecosystems to changes in snowmelt

Snow Water Equivalent

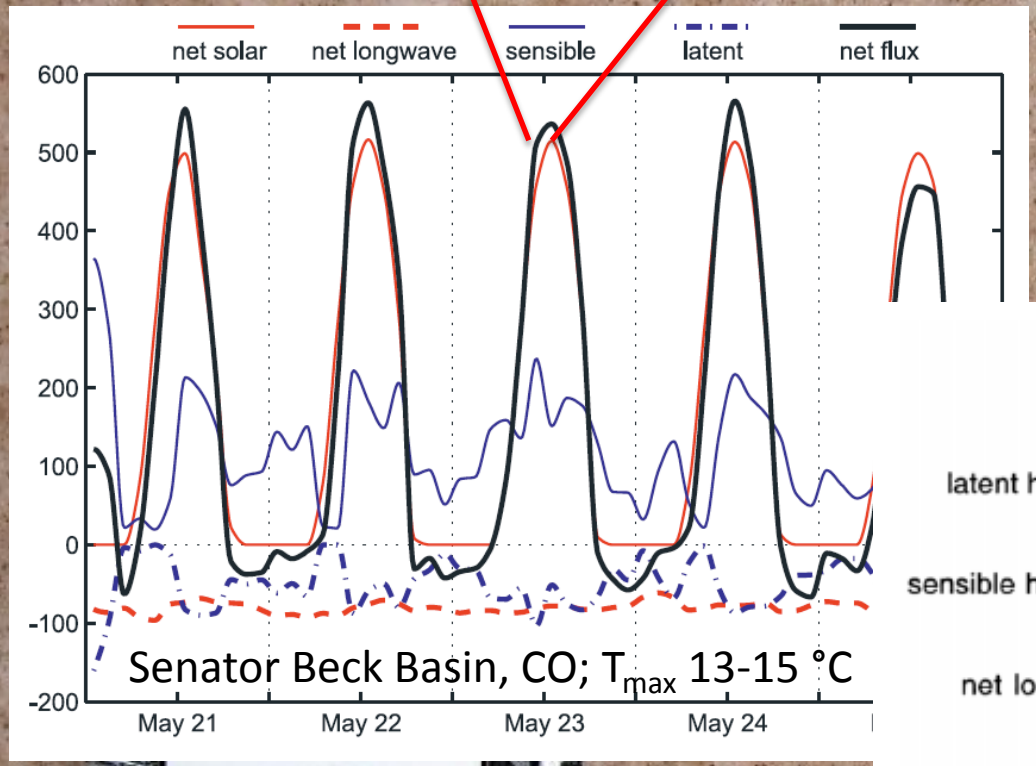


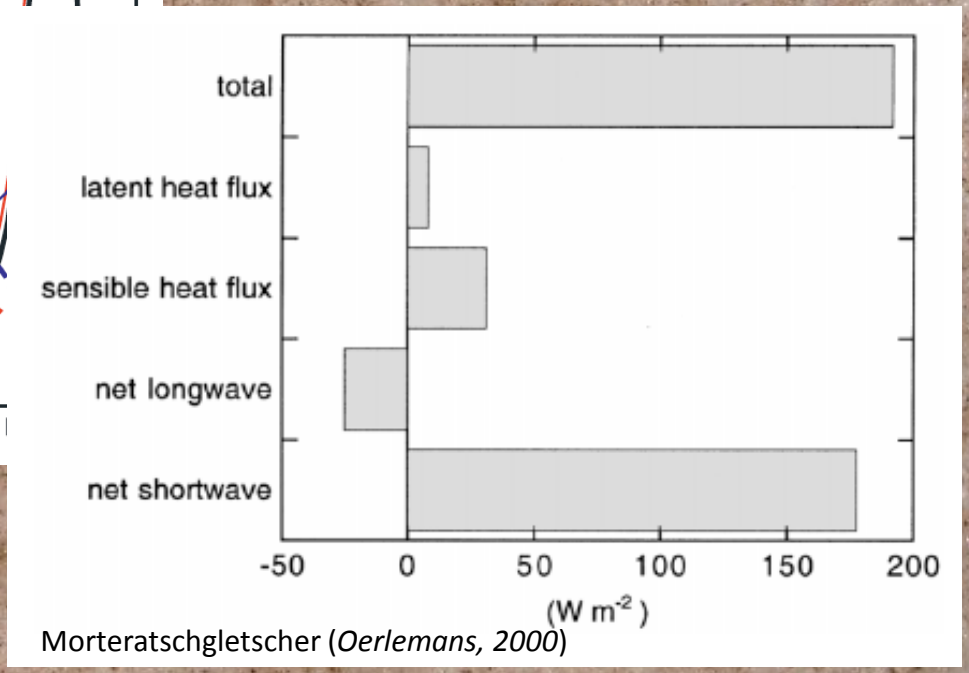
Gunnison Basin, Colorado

MODSCAG 3 April 2002

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

Absorbed sunlight dominates snowmelt





Morteratschgletscher (*Oerlemans, 2000*)

Elk Range, Colorado River Basin, April 2009

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

Albedo

Uncertainty < 2%

SWE

Uncertainty < 5 cm

3D Scanning LiDAR
1064 nm
1 m spatial resolution

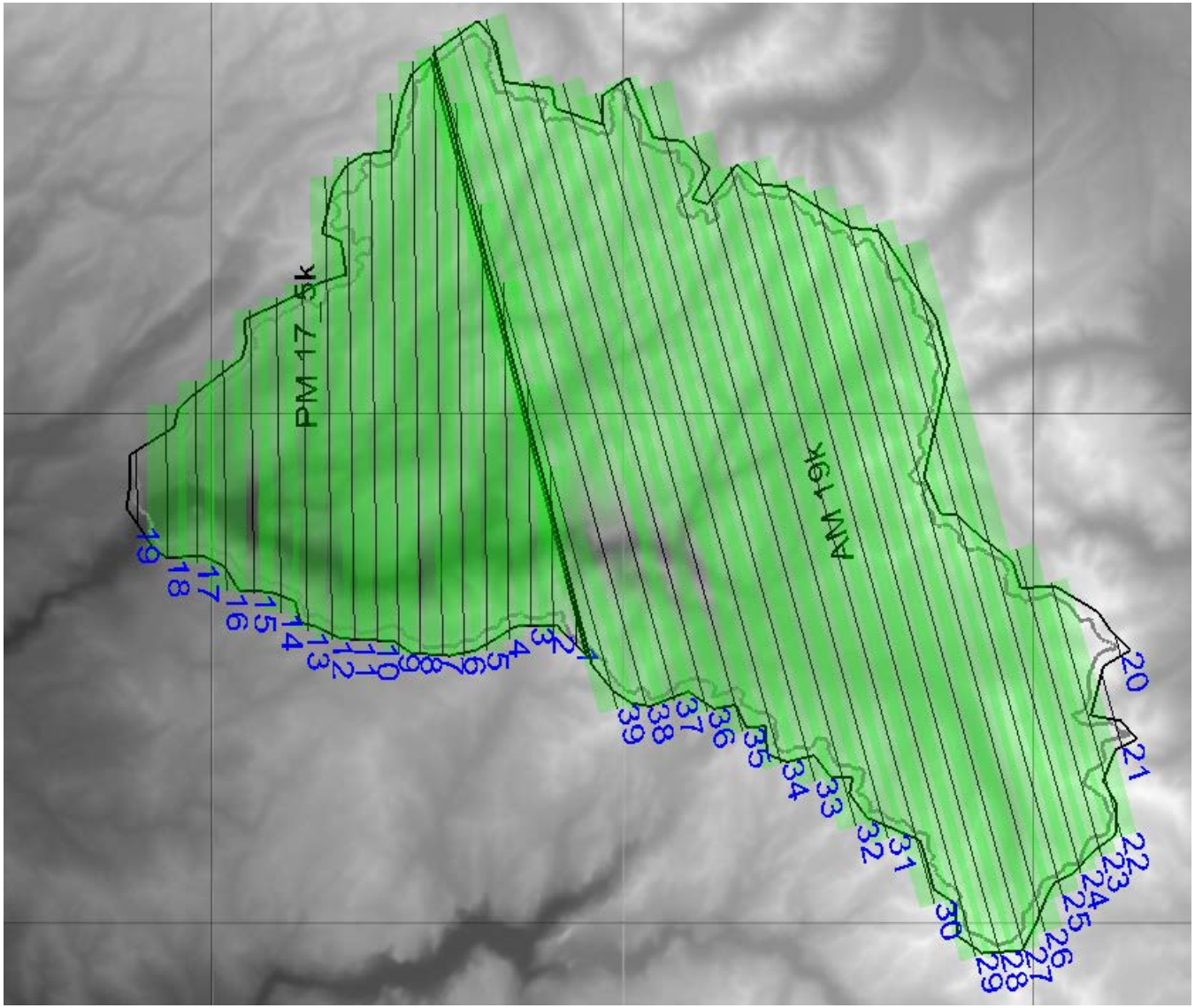
ASO's full span

Parameters defined at AGU Town Hall 2012	ASO	Component
Snow albedo	yes	Spectrometer
Snow grain size	yes	Spectrometer
Snow melt status	yes	Spectrometer
Snow depth	yes	Lidar
Snow under forest canopy	yes	Lidar
Snow water equivalent	yes	Lidar + assimilation of density
Radiative forcing by dust and black carbon	yes	Spectrometer

ASO Operational Concept

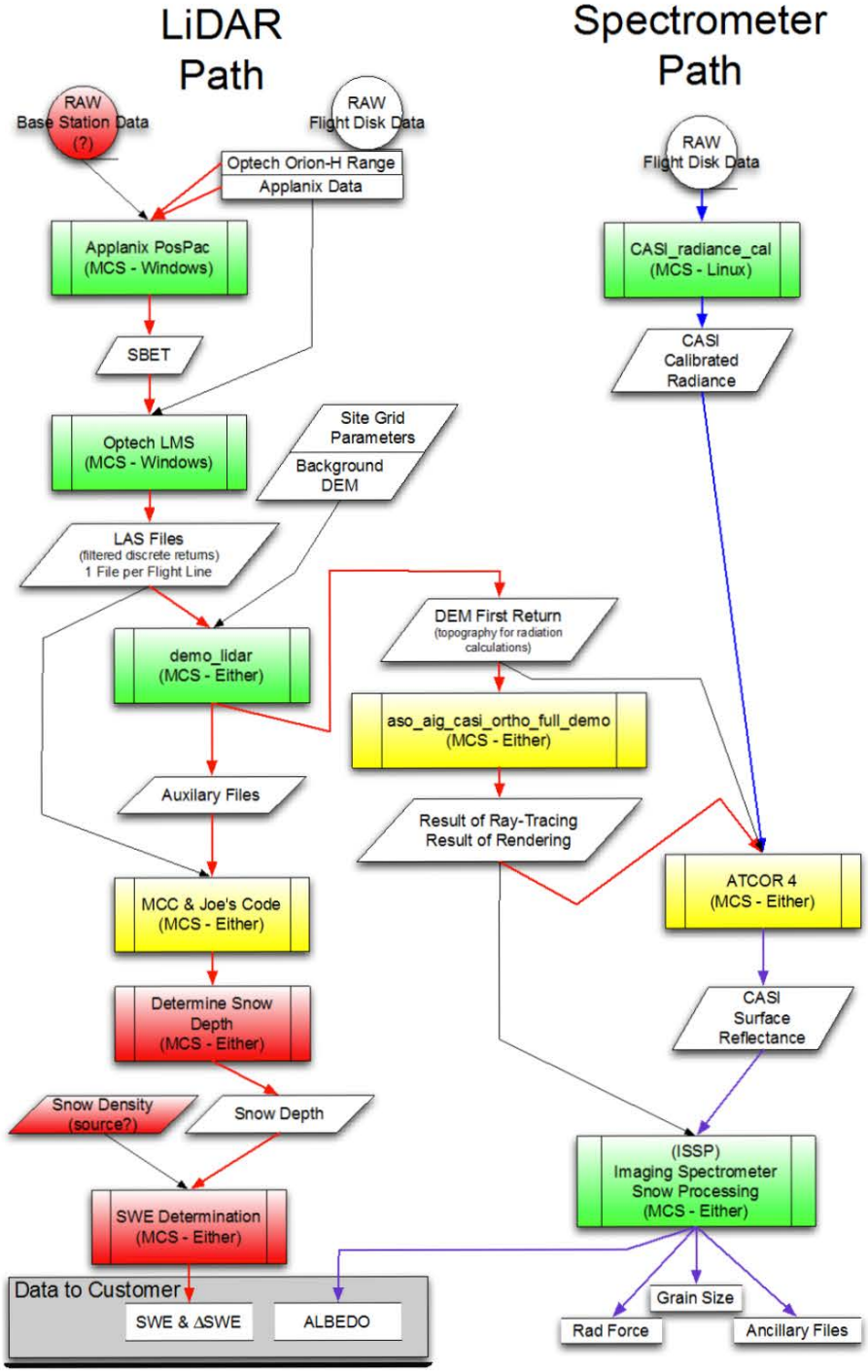
- Complete coverage of albedo and SWE across basins
- Closer to solar noon is better for illumination
- ~ weekly acquisitions across basin
- Rapid turnaround of products (< 24 hrs) – this was tall tent post of suffering, among many

Example lines for Tuolumne



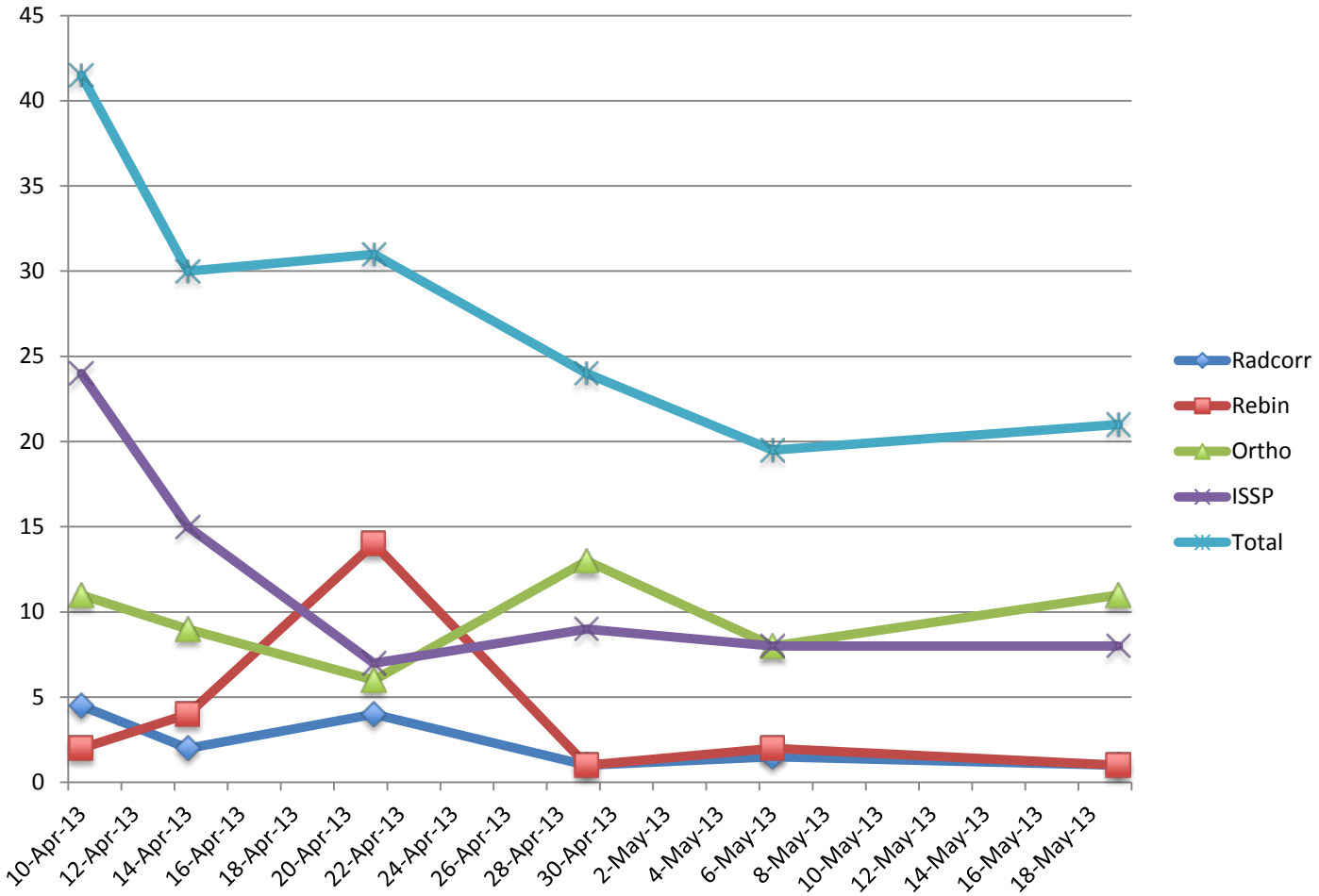
Inflight operations

PROCESSING PATH



Jet Propulsion Laboratory
California Institute of Technology

Converging to 24 hr latency



ASO concept for SWE

- Greatest variation in SWE comes from variation in depth.
- Density is relatively consistent and predictable (*Sturm et al*, 2010; *Bormann et al.*, 2013).
- **Map snow depth accurately and assimilate density information for snow water equivalent.**

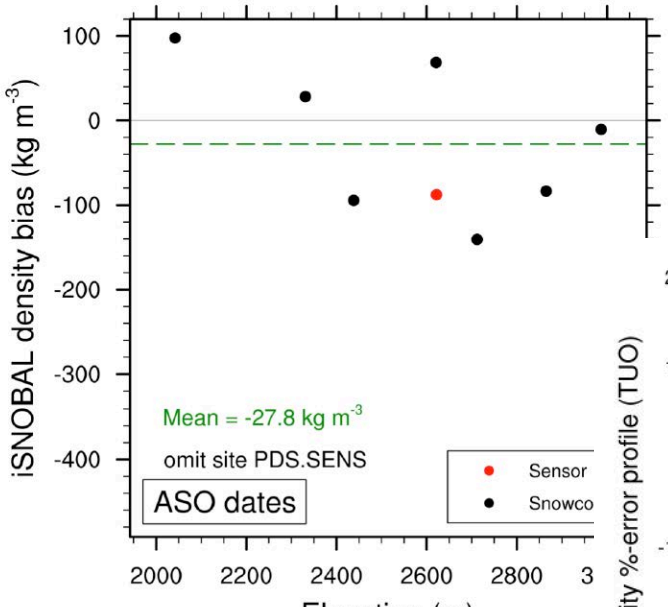
Snow Density Modeling (preliminary)

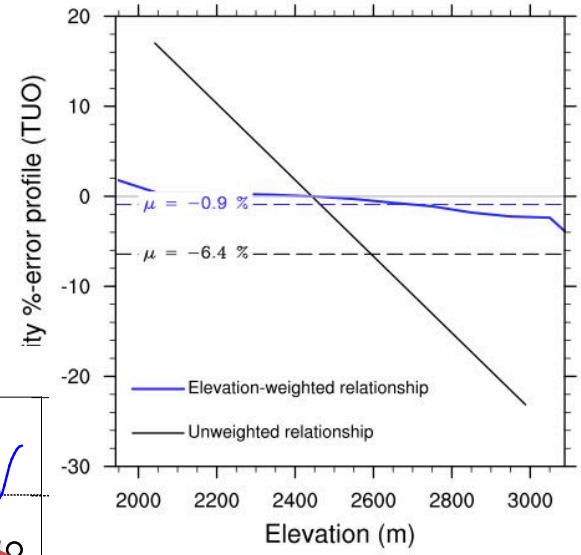
(in process)

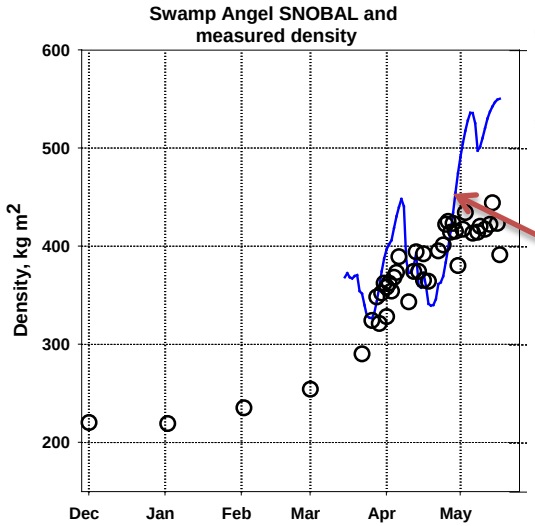
iSNOBAL model *Marks et al*, 1998) provides spatially explicit snow density estimates for ASO

These model runs without assimilation of ASO snow depth and snow albedo data.

Analysis with assimilation initiated

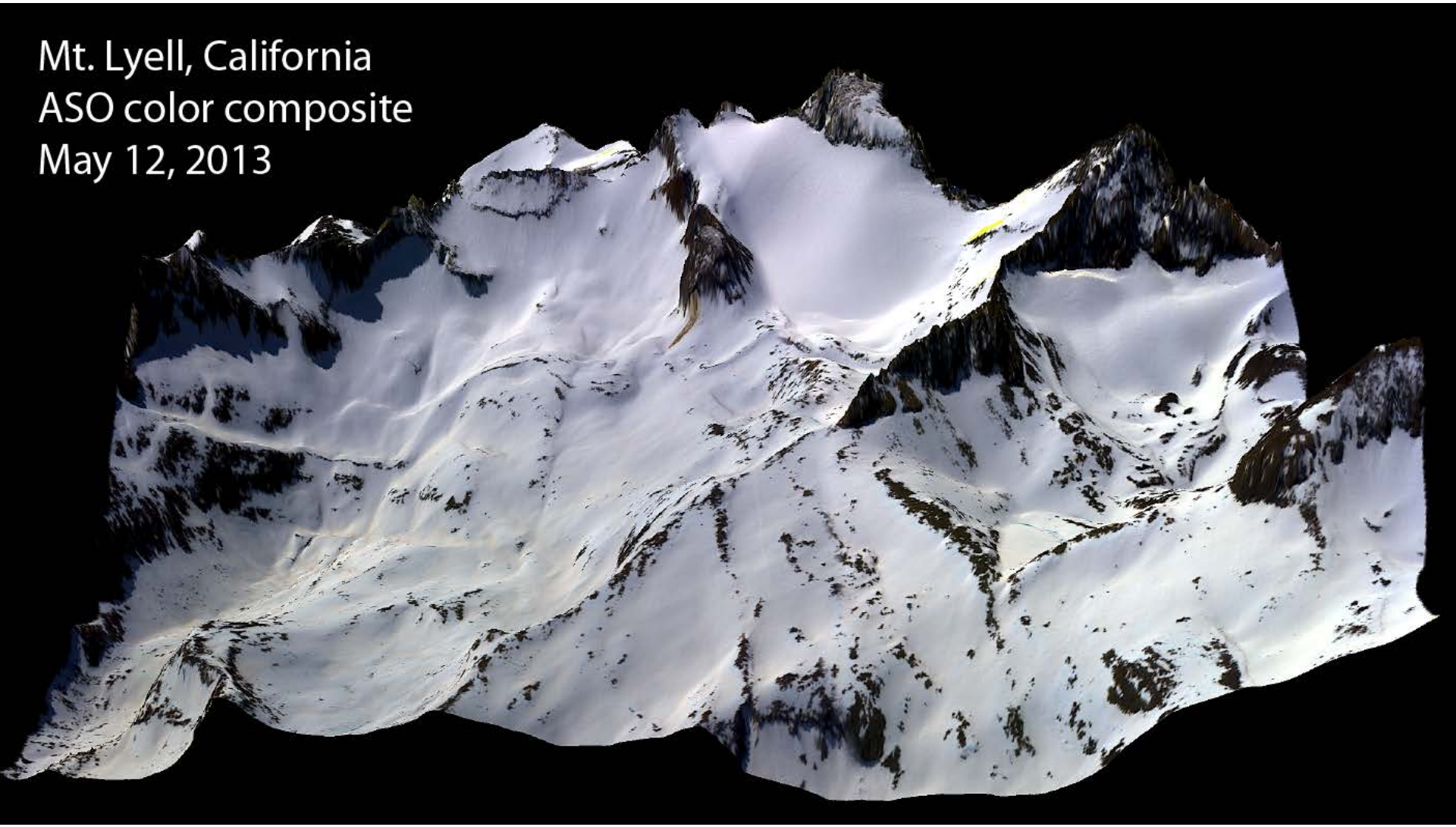




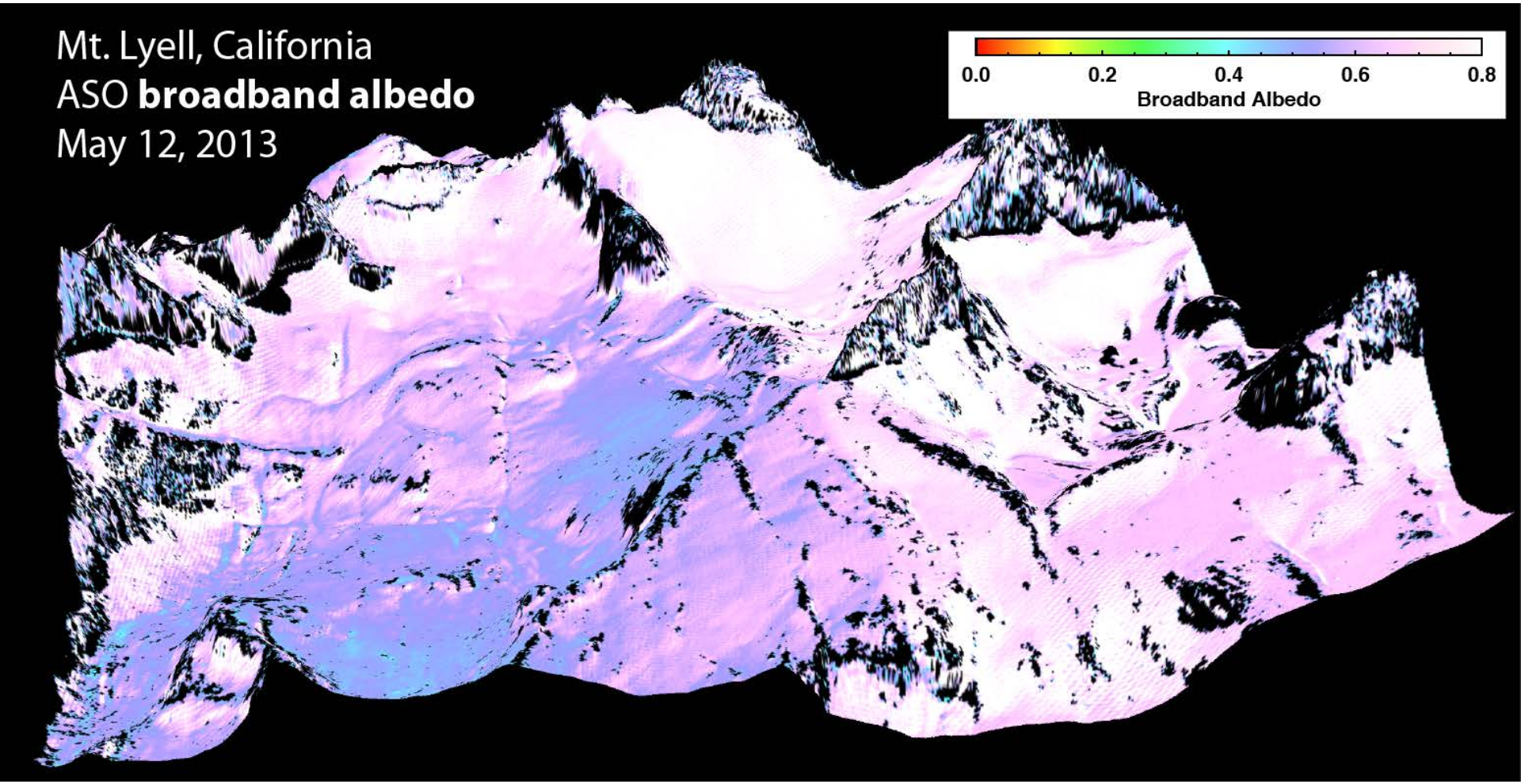


SWE very low is when densities fall apart -

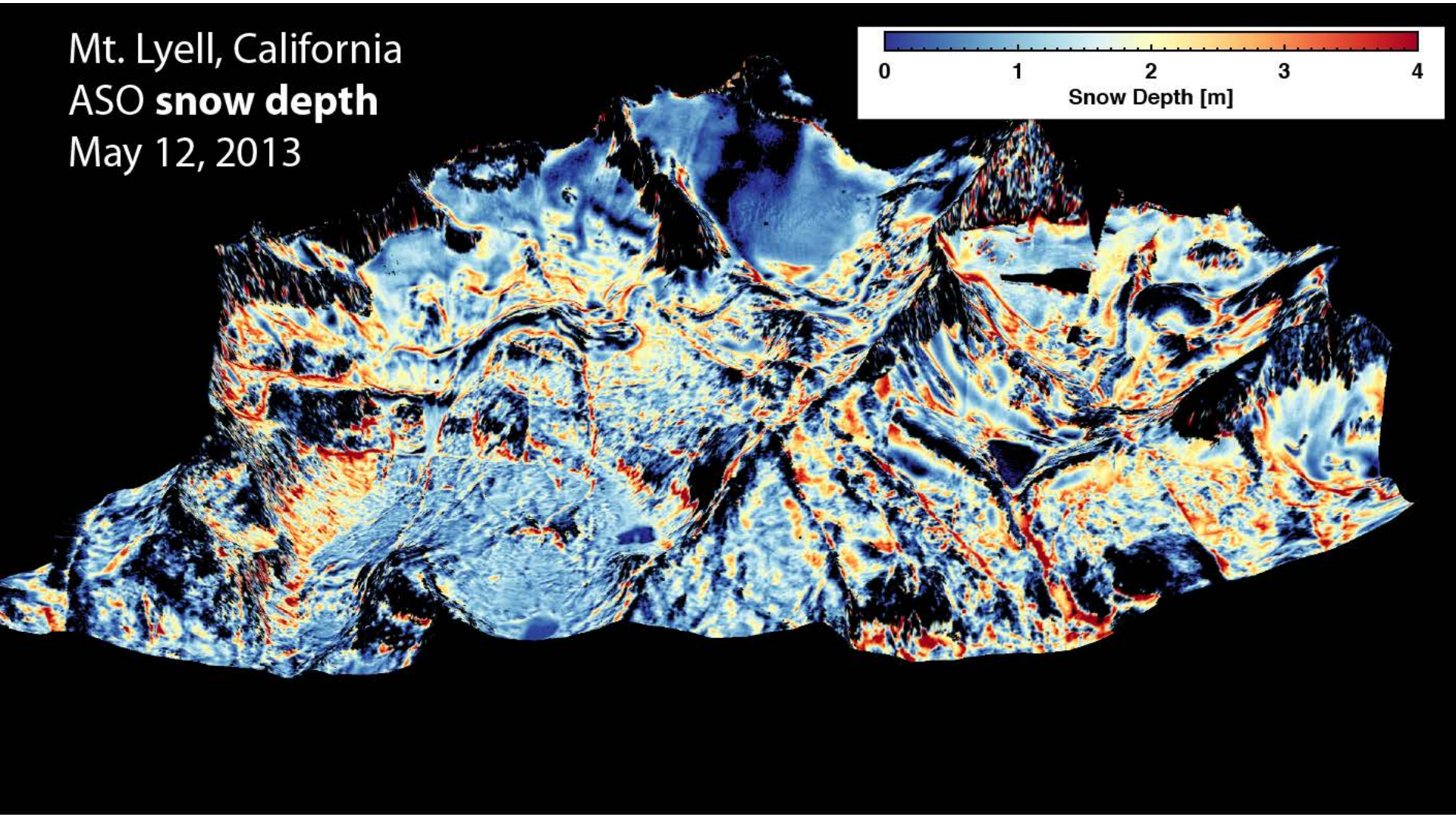
ASO-DM1 Results

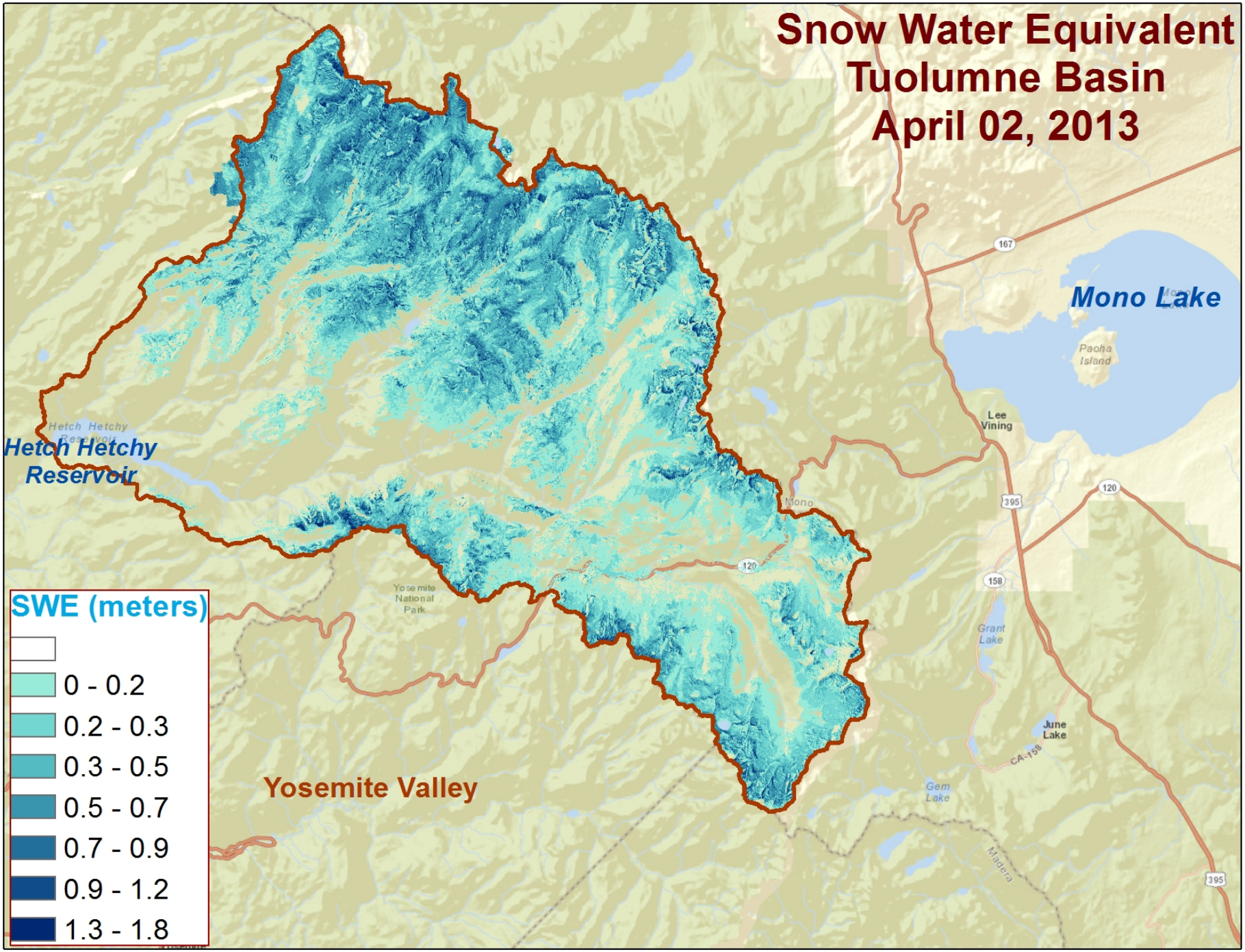


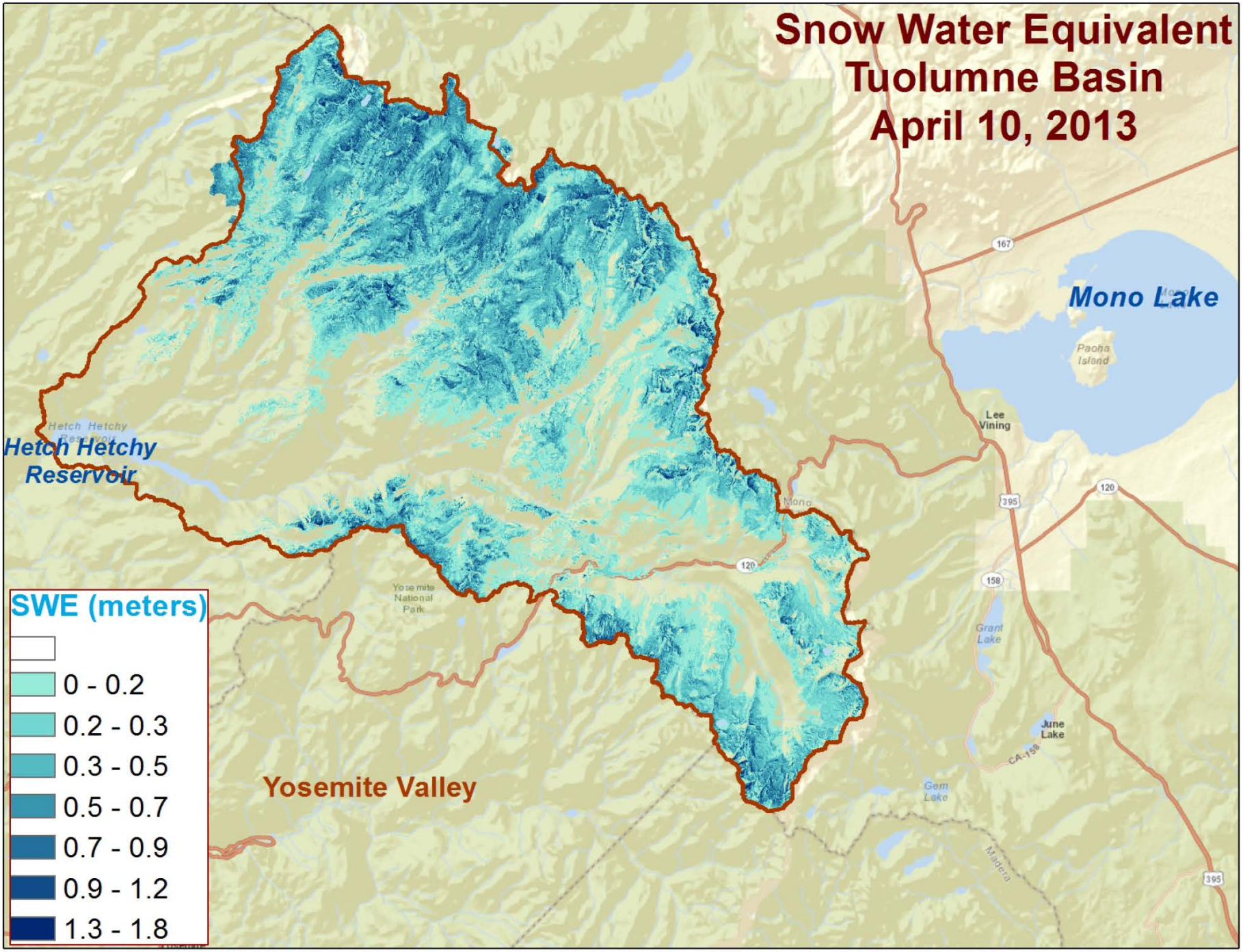
ASO-DM1 Results

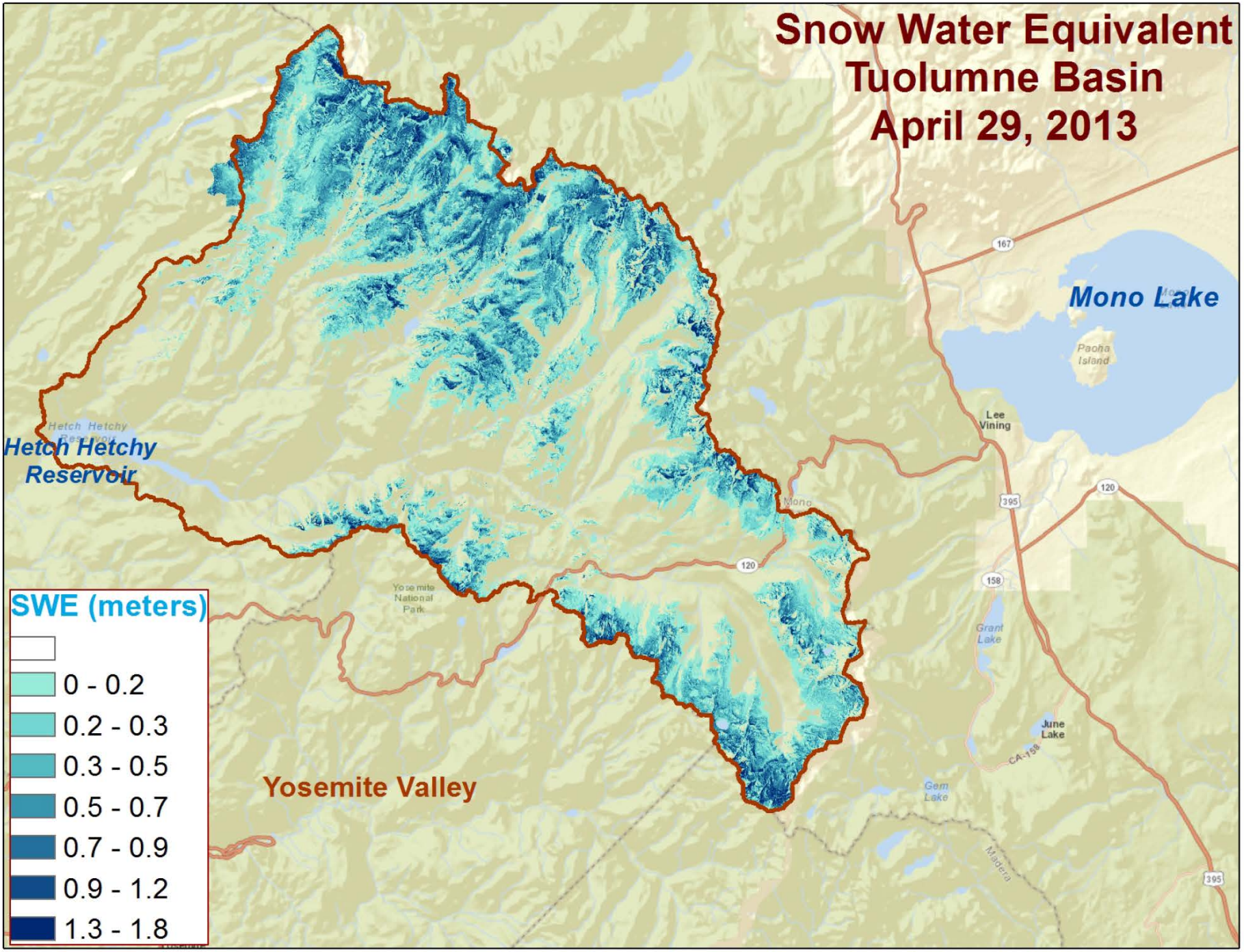


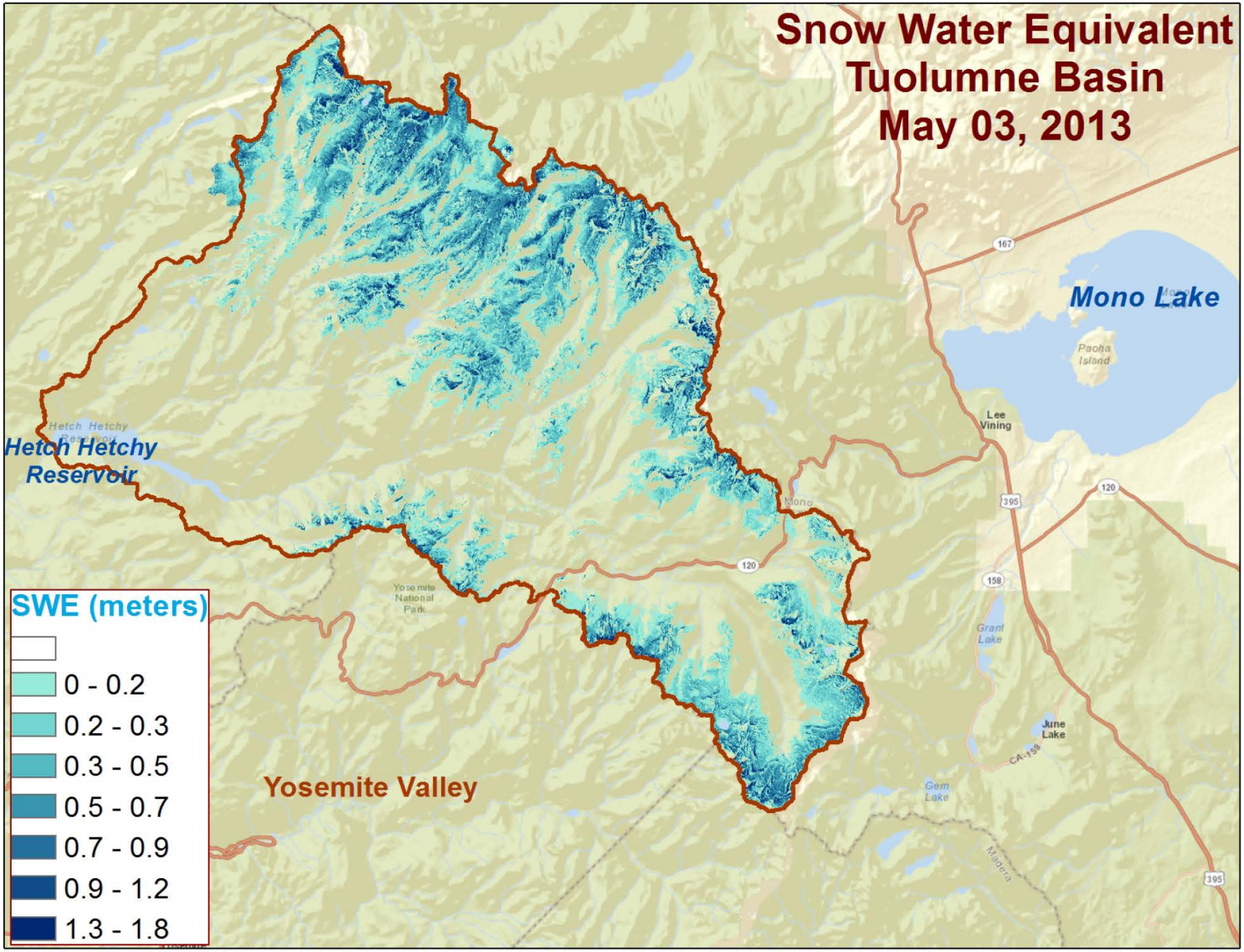
ASO-DM1 Results

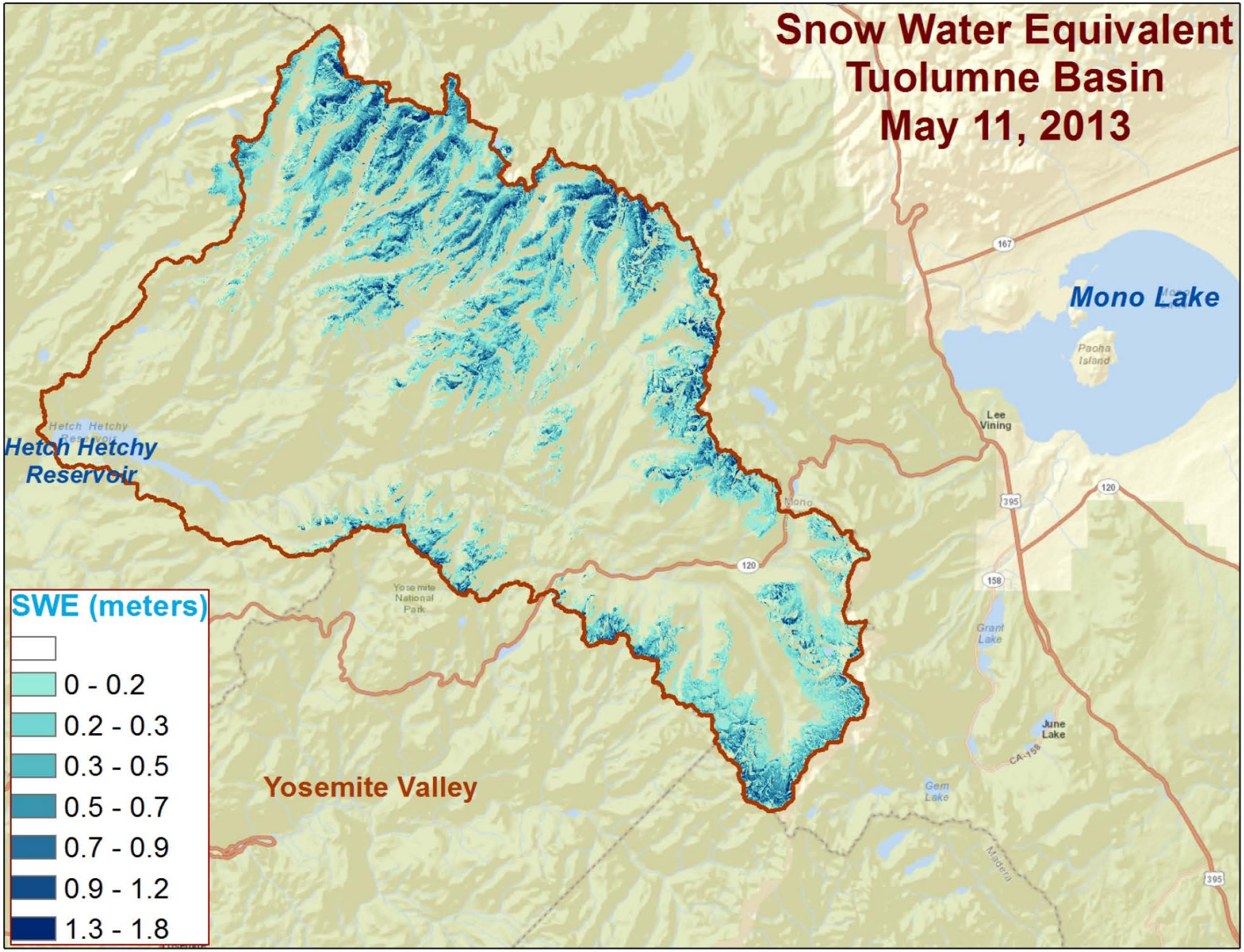


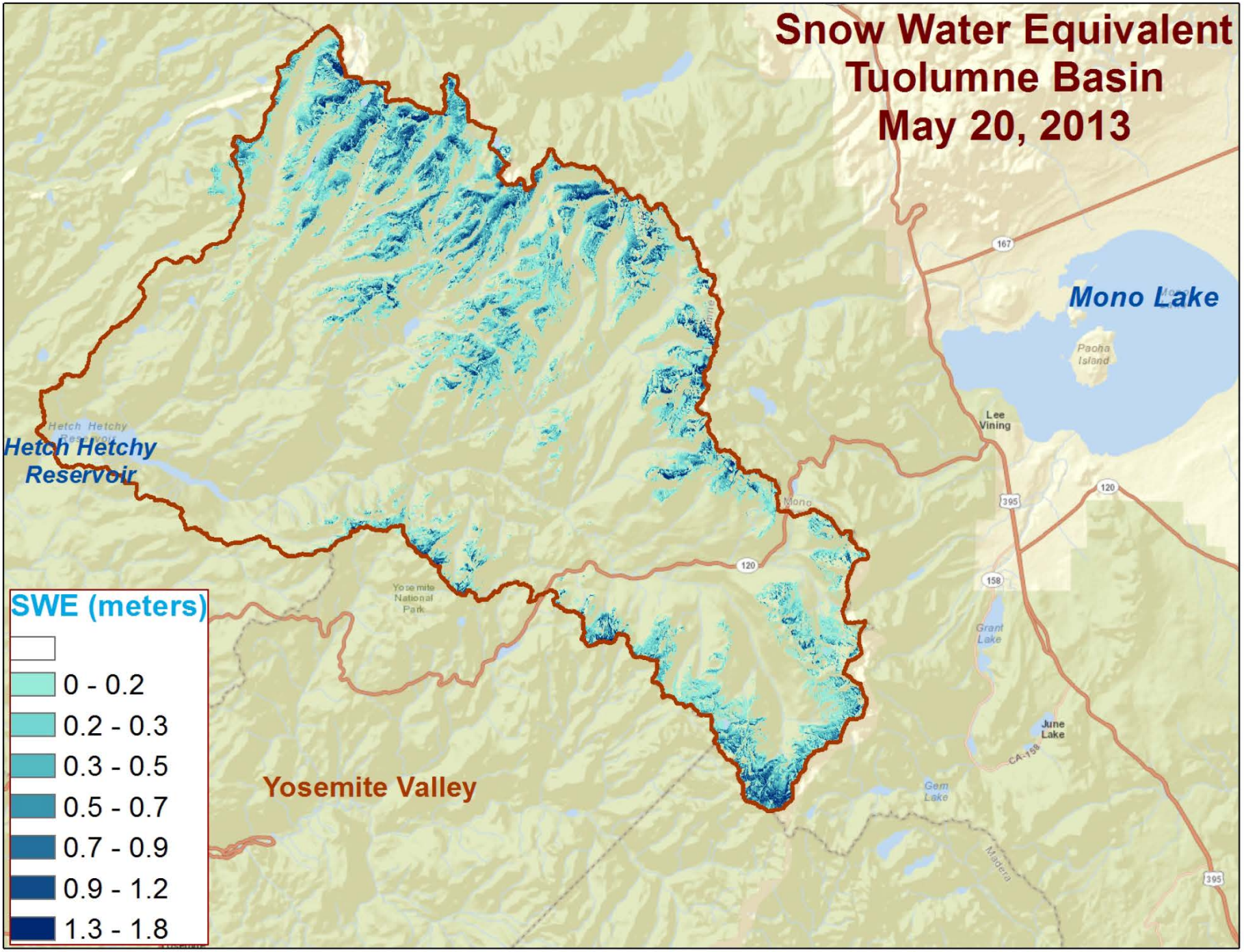

Snow Water Equivalent
Tuolumne Basin
April 02, 2013
Mono Lake
Hetch Hetchy
Reservoir
Yosemite Valley
SWE (meters)
0 - 0.2
0.2 - 0.3
0.3 - 0.5
0.5 - 0.7
0.7 - 0.9
0.9 - 1.2
1.3 - 1.8
Lee
Vining
June
Lake
Grant
Lake
Gem
Lake
Paoha
Island
Yosemite
National
Park
Mono
167
120
395
158
CA-158


Snow Water Equivalent
Tuolumne Basin
April 10, 2013
Mono Lake
Paoha Island
Lee Vining
Hetch Hetchy Reservoir
Mono
Yosemite National Park
Grant Lake
June Lake
Gem Lake
Madera
Yosemite Valley
SWE (meters)
0 - 0.2
0.2 - 0.3
0.3 - 0.5
0.5 - 0.7
0.7 - 0.9
0.9 - 1.2
1.3 - 1.8


Snow Water Equivalent
Tuolumne Basin
April 29, 2013
Mono Lake
Paoha Island
Lee Vining
Hetch Hetchy Reservoir
Mono
Yosemite National Park
Grant Lake
June Lake
Gem Lake
Madera
Yosemite Valley
SWE (meters)
0 - 0.2
0.2 - 0.3
0.3 - 0.5
0.5 - 0.7
0.7 - 0.9
0.9 - 1.2
1.3 - 1.8


Snow Water Equivalent
Tuolumne Basin
May 03, 2013
Mono Lake
Paoha Island
Lee Vining
Hetch Hetchy Reservoir
Yosemite National Park
Yosemite Valley
Grant Lake
June Lake
Gem Lake
Madera
167
120
395
158
CA-158
SWE (meters)
0 - 0.2
0.2 - 0.3
0.3 - 0.5
0.5 - 0.7
0.7 - 0.9
0.9 - 1.2
1.3 - 1.8


Snow Water Equivalent
Tuolumne Basin
May 11, 2013
Mono Lake
Hetch Hetchy
Reservoir
Yosemite Valley
SWE (meters)
0 - 0.2
0.2 - 0.3
0.3 - 0.5
0.5 - 0.7
0.7 - 0.9
0.9 - 1.2
1.3 - 1.8
Paoha Island
Lee Vining
Mono
Yosemite National Park
Grant Lake
June Lake
Gem Lake
Madera
167
120
395
158
CA-158


Snow Water Equivalent
Tuolumne Basin
May 20, 2013
Mono Lake
Hetch Hetchy
Reservoir
Yosemite Valley
SWE (meters)
0 - 0.2
0.2 - 0.3
0.3 - 0.5
0.5 - 0.7
0.7 - 0.9
0.9 - 1.2
1.3 - 1.8
Lee
Vining
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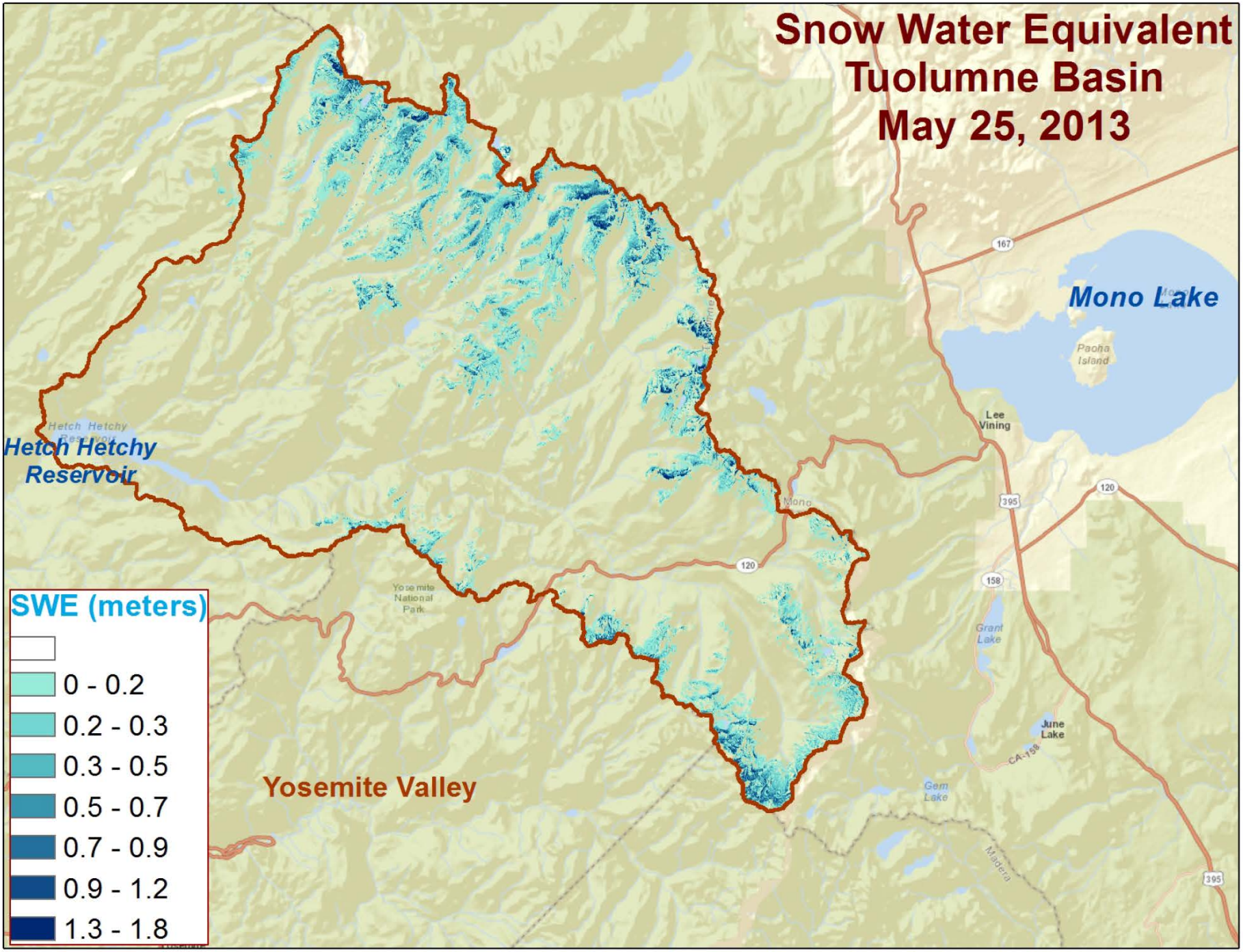
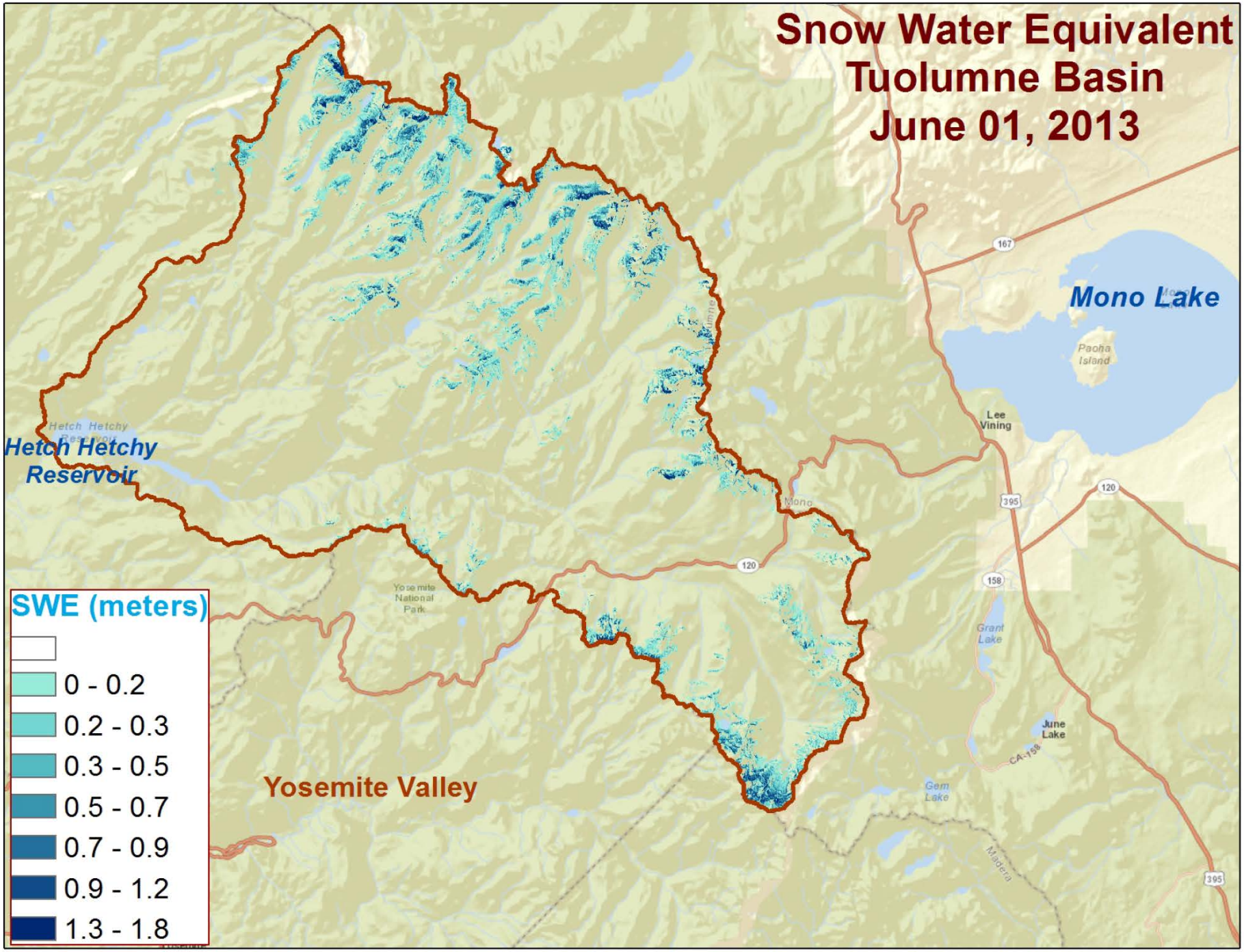
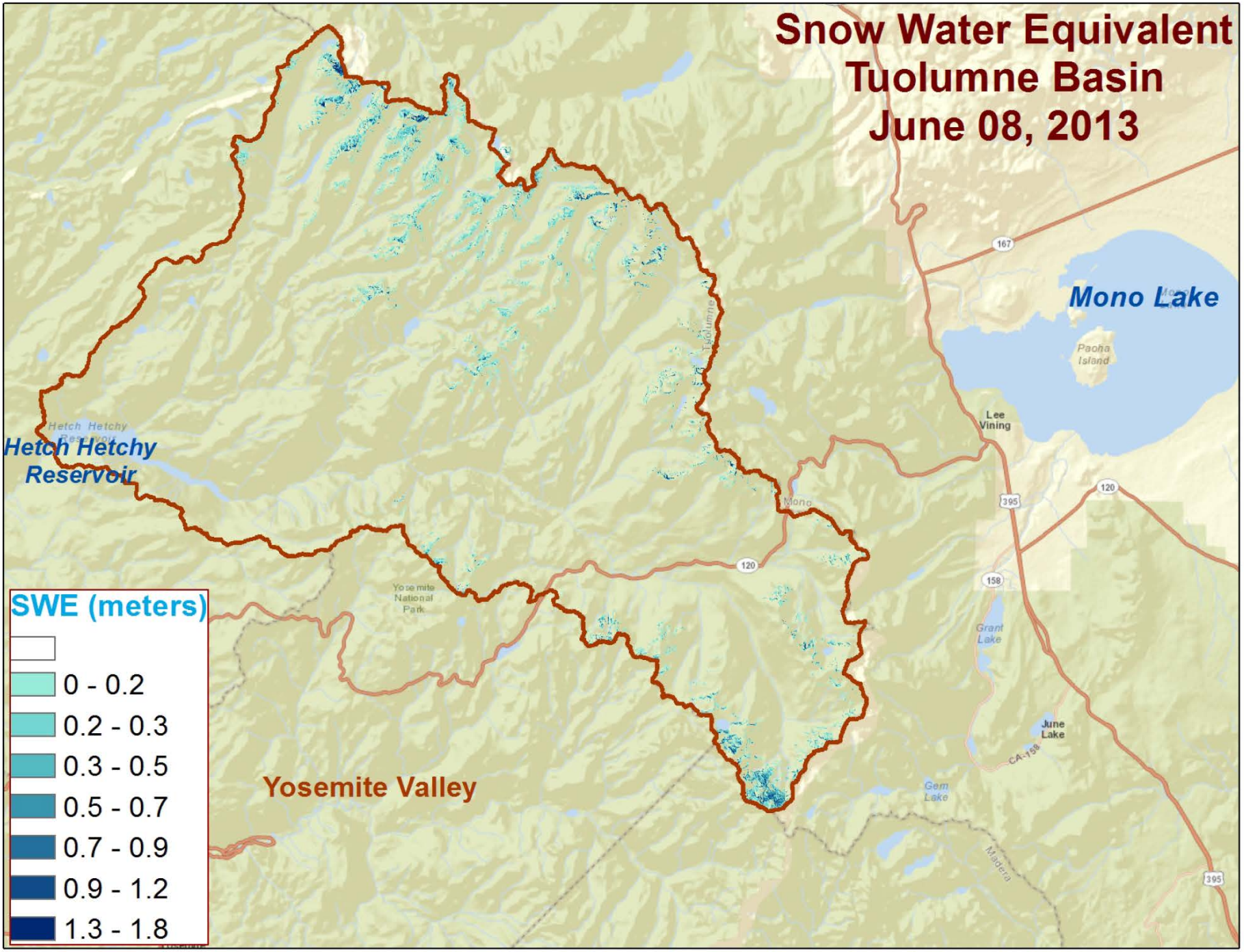
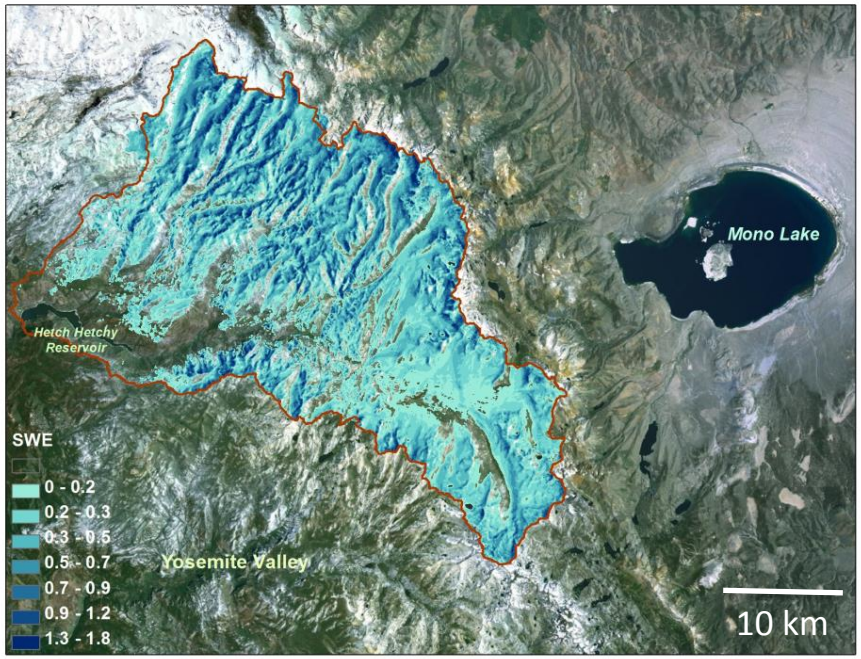
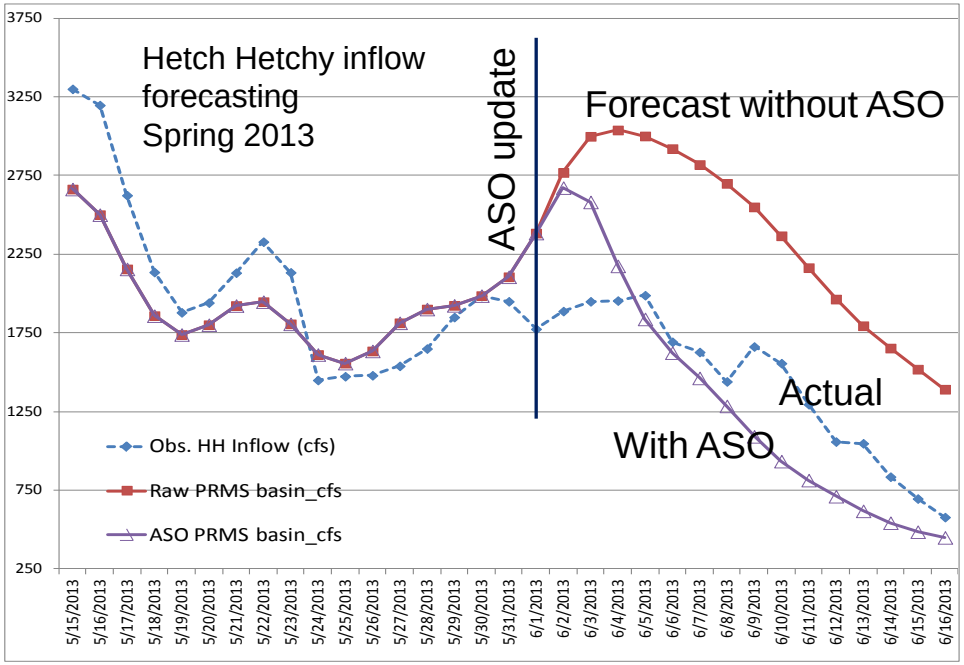

Snow Water Equivalent
Tuolumne Basin
May 25, 2013
Mono Lake
Paoha Island
Lee Vining
Hetch Hetchy Reservoir
Yosemite National Park
Yosemite Valley
Grant Lake
June Lake
Gem Lake
Madera
167
120
395
158
CA-158
SWE (meters)
0 - 0.2
0.2 - 0.3
0.3 - 0.5
0.5 - 0.7
0.7 - 0.9
0.9 - 1.2
1.3 - 1.8

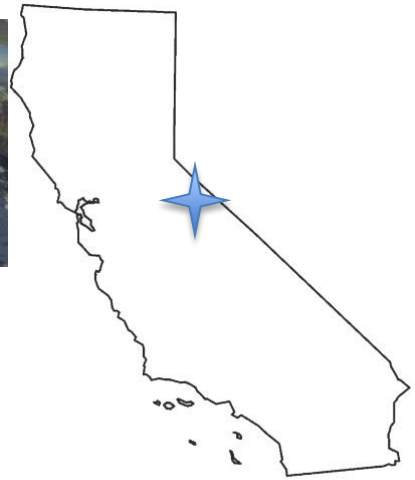

Snow Water Equivalent
Tuolumne Basin
June 01, 2013
Mono Lake
Paoha Island
Hetch Hetchy Reservoir
Lee Vining
Mono
Yosemite National Park
Grant Lake
June Lake
Gem Lake
Madera
Yosemite Valley
SWE (meters)
0 - 0.2
0.2 - 0.3
0.3 - 0.5
0.5 - 0.7
0.7 - 0.9
0.9 - 1.2
1.3 - 1.8


Snow Water Equivalent
Tuolumne Basin
June 08, 2013
Mono Lake
Paoha Island
Lee Vining
Hetch Hetchy Reservoir
Yosemite National Park
Yosemite Valley
Grant Lake
June Lake
Gem Lake
Madera
Tuolumne
Mono
167
120
395
158
CA-158
SWE (meters)
0 - 0.2
0.2 - 0.3
0.3 - 0.5
0.5 - 0.7
0.7 - 0.9
0.9 - 1.2
1.3 - 1.8

Improved Estimates for California Water Management

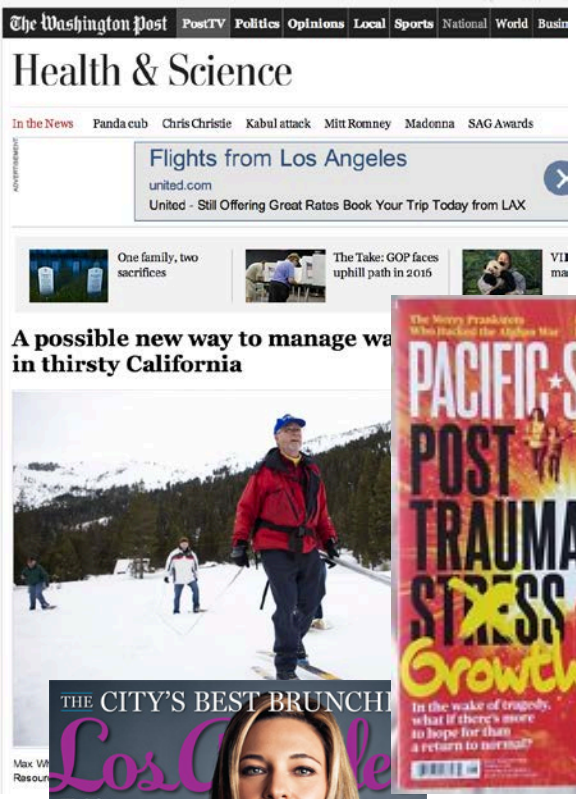






The JPL ASO team and California Dept. of Water Resources (DWR) prediction of water inflow into the Hetch Hetchy Reservoir in thousand acre feet (shown in red) was modified on June 1, 2013 based on snow water equivalent (SWE) data from the NASA/JPL Airborne Snow Observatory. The new forecast (shown in purple) provided a factor of 2 better estimate of the actual inflow (shown in blue) and enabled water managers to optimize reservoir operations in its first year.

Media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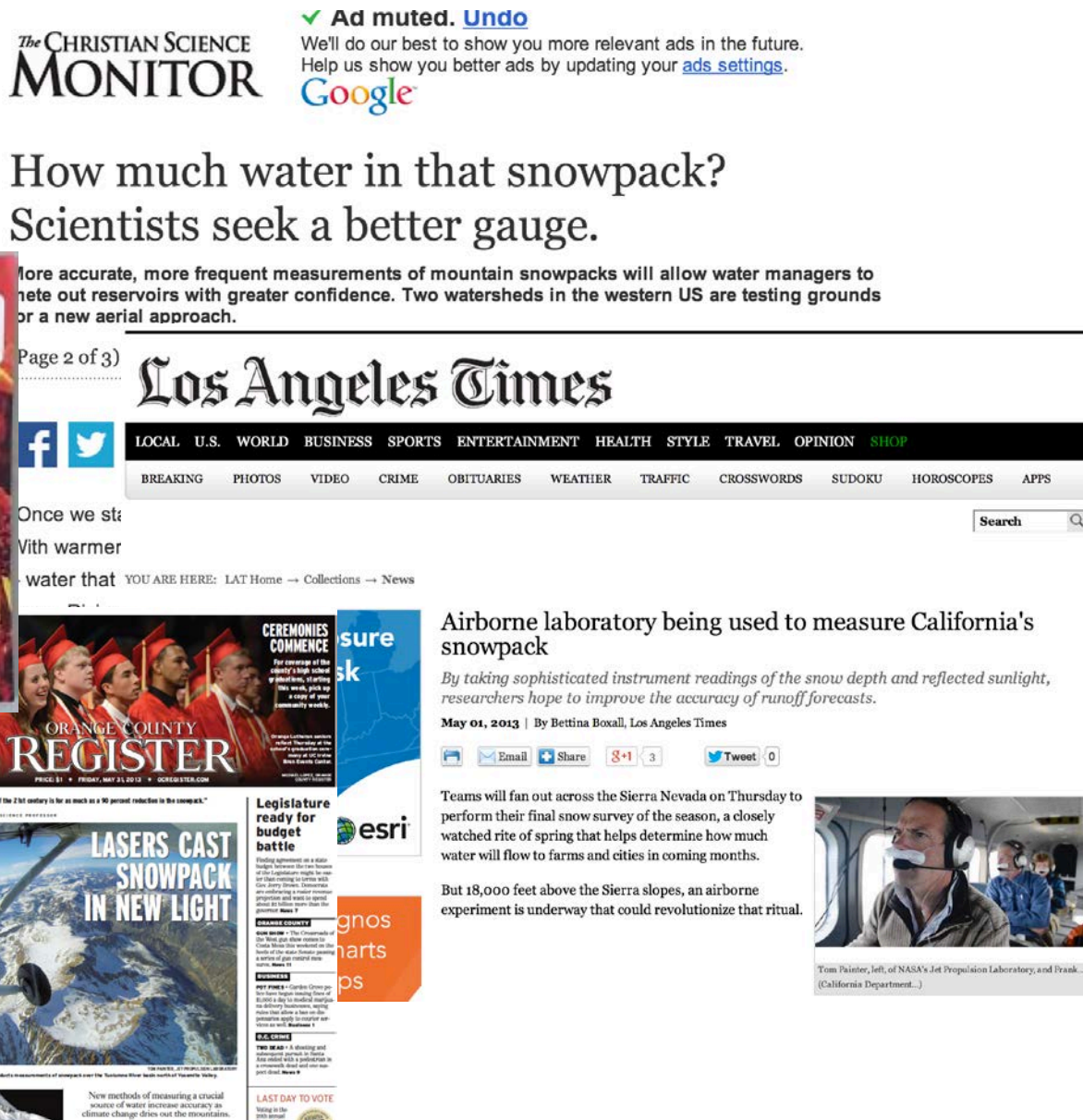
THE L.A. WOMAN
ARRESTING: FALL FASHION GOES ON THE LAM
ARE WE IN DEEP WATER WITH OUR MOST PRECIOUS RESOURCE?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Scientists seek a better gauge.
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Airborne laboratory being used to measure California's snowpack
By taking sophisticated instrument readings of the snow depth and reflected sunlight, researchers hope to improve the accuracy of runoff forecasts.
May 01, 2013 | By Bettina Boxall, Los Angeles Times
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Teams will fan out across the Sierra Nevada on Thursday to perform their final snow survey of the season, a closely watched rite of spring that helps determine how much water will flow to farms and cities in coming months.
But 18,000 feet above the Sierra slopes, an airborne experiment is underway that could revolutionize that ritual.
Once we sta
With warmer
water that
CEREMONIES COMMENCE
ORANGE COUNTY REGISTER
LASERS CAST SNOWPACK IN NEW LIGHT
Legislature ready for budget battle
esri

Science and Applied Science in ASO Demonstration Mission 2 (2014)

- California is in its most extreme water year drought on record – Governor has declared drought emergency – this spring is likely to be endmember snow season
- Rim Fire of 2013 in and near Yosemite is a science target for California, ecosystem scientists, and hydrologists. Our flights are key to understanding hydrologic response
- Implementation of new Riegl Q1560 lidar
- Implementation of new density modeling and physical constraints on density modeling