# The NASA JPL Airborne Snow Observatory in the Southern Sierra Nevada

Thomas H. Painter[1,2], Kostas Andreadis[2], Joe Boardman[3], Jeffrey S. Deems[4], Frank Gehrke[5], Cate Heneghan[2], Bruce McGurk[6], Felix Seidel[2], Amy Trangsrud[2], * Peter Kirchner[1]

[1]Joint Institute for Regional Earth System Science and Engineering, [2]Jet Propulsion Laboratory, California Institute of Technology, [3]Analytical Imaging and Geophysics, [4]National Snow and Ice Data Center, [5]California Department of Water Resources, [6]McGurk Hydrologic

## Introduction

Water, as the arbiter of energy and the essential nutrients of life, is a defining feature for the location health and condition of ecosystems. Precipitation in the form of winter snow dominates the regional climate and water resources of the Southern Sierra Nevada. Understanding the quantity and distribution of snow accumulation and the timing and magnitude of snow-melt is fundamental to water resource and ecosystem management in the region. The aim of the Airborne Snow Observatory (ASO) is to quantify the hydrologic and energetic properties of the snow covered landscapes of the Western U. S.

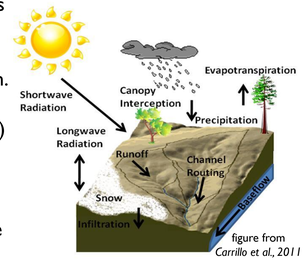
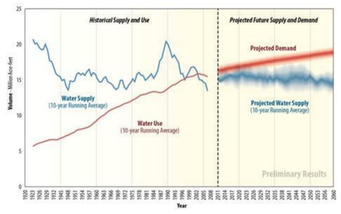


figure from *Carrillo et al., 2011*

## Rationale

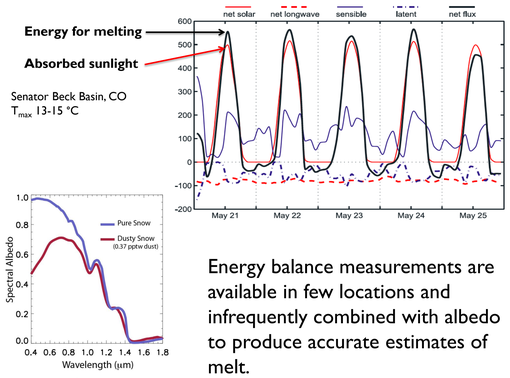
Snowmelt in the western US not only sustains mountain ecosystems it is the predominant source of freshwater for tens of millions of people and the main source of groundwater recharge to one of the most productive agricultural regions in the world.



US Bureau of Reclamation Colorado River Basin Study (2012)

Future water supply from snowmelt faces increasing demand and greater uncertainty.

The two most critical properties for understanding discharge quantity and timing of snowmelt are the spatial distributions of snow water equivalent (SWE) and snow albedo. Despite their importance, these snowpack properties are poorly quantified in the US and not at all in most of the globe, leaving runoff models poorly constrained.



**Elk Range**, Colorado River Basin, April 2009

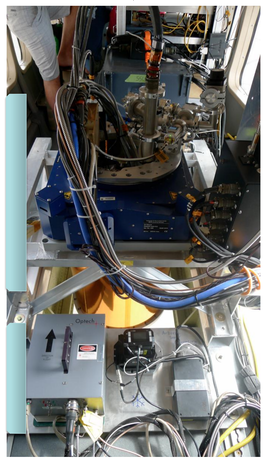
Energy balance measurements are available in few locations and infrequently combined with albedo to produce accurate estimates of melt.

## Methods

The ASO couples a programmable visible through near infrared imaging spectrometer (ITRES, CASI) with a high-altitude scanning LiDAR system (Optech, Gemini) with in-situ measurements and automated data processing. The spectrometer will measure reflected solar radiance and the LiDAR will provide highly accurate surface elevation maps, allowing mapping of snow depth at 1.5 m. The spectrometer data will be used to create surface reflectance, modeled irradiance, surface albedo and radiative forcing from dust and black carbon. The snow depth maps, combined with field and automated measurements of snow density, will be used to produce maps of Snow Water Equivalent (SWE).

### Airborne Acquisition

Twin Otter aircraft will collect spatially and temporally collocated data at altitudes from 1500 - 4000 m. Future missions may be flow at higher elevations to increase area and decrease time.



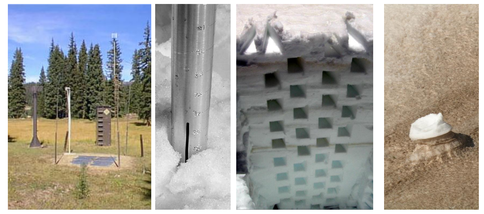
**Albedo**
CASI Imaging spectrometer
0.38 -1.50 μm
1.5 m spatial resolution
Uncertainty < 2%

**SWE**
3D Scanning LiDAR 1064 nm
1.5 m spatial resolution
SWE uncertainty ~ 5 cm

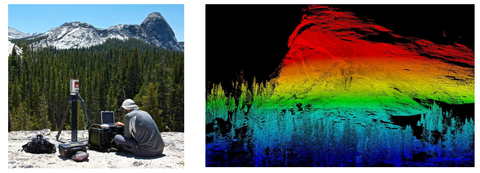
**Digital image**
Registered digital photo 1.5 m resolution (not shown)

### Validation and Calibration

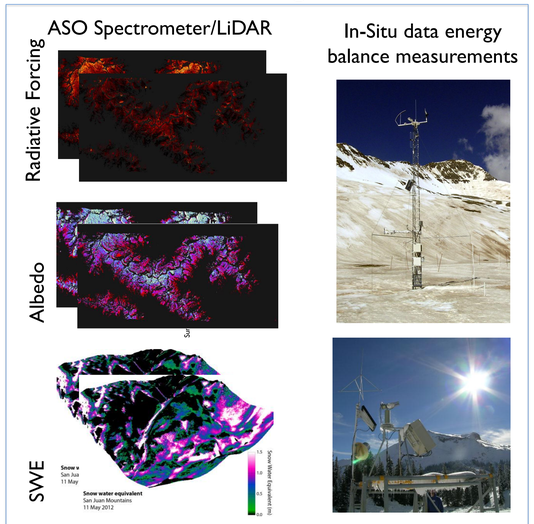
Stratified sampling of depth and density and spectroscopic properties across the measurement domain are used to estimate SWE, albedo, and irradiance. These are measured using a variety of methods including automated pillows, snow tubes, snow pits, radar and handheld spectrometers.



Terrestrial LiDAR scans create high resolution altimetry for smaller areas for validation, calibration and data acquisition from areas with limited airborne LiDAR returns.

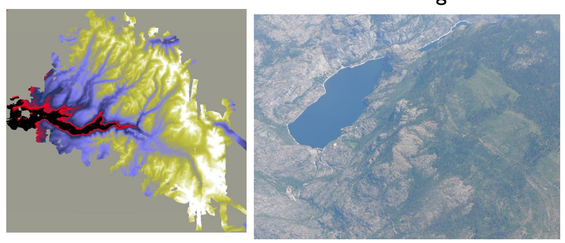


### Assimilation and Modeling




### Operational Products

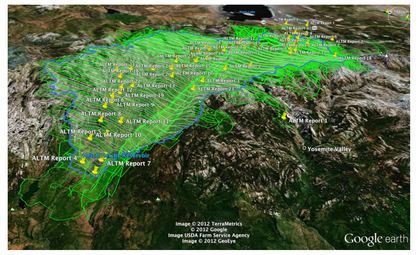
Near real time Runoff Forecasting

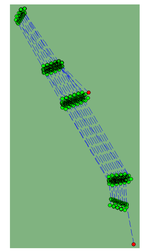


| | |
|---|---|
| CBRFC Snow-17 + Reclamation Forecasting | DHSVM<br>Gridded distributed energy balance model<br>PRMS<br>Hydrologic unit distributed hydrologic model<br>iSNOBAL<br>Gridded distributed energy balance model |

## Demonstration Mission

The first ASO Demonstration Mission will include the Upper Tuolumne River Basin. (City of San Francisco water supply). The ASO acquired snow-free data in August and will commence weekly flights and monthly ground validations early April through the snow melt period. validating SWE predictions with observed discharge.

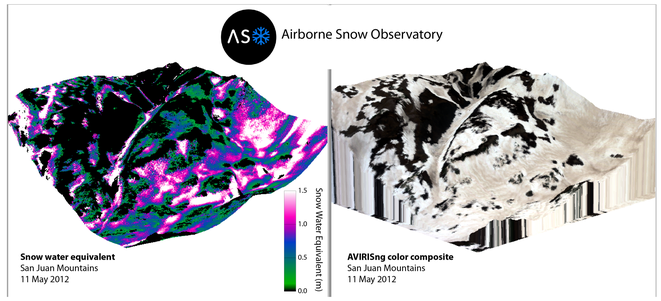



Future missions will evaluate high altitude platforms and data retrieval of SWE and reflectance for the entire Sierra Nevada region over two day period, providing operational data products to stakeholders within 24 hours of collection.

## Collaboration

The need to scale remote sensing and analytical products to smaller watersheds in a timely manner has never been more critical and the NASA/JPL, ASO addresses this need. In addition to the hydrologic applications described ASO data products also have the potential to address many resource management needs from ecosystem characterization, vegetative health, fire risk, and species vulnerability assessments. We welcome further collaborations, for more information please contact: Thomas.Painter@jpl.nasa.gov.




*Peter.Kirchner@jpl.nasa.gov
**National Aeronautics and Space Administration Jet Propulsion Laboratory**
233-304, California Institute of Technology, 4800 Oak Grove Drive Pasadena CA 91109