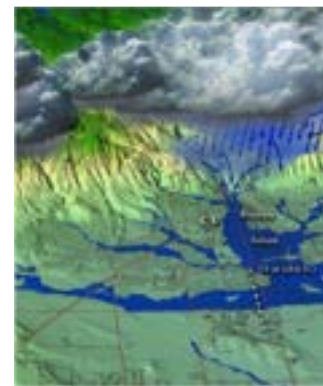


A Tour of SAIL Science Accomplishments and a Preview of Ongoing and Upcoming SAIL Research

Dr. Dan Feldman,
LBNL Staff Scientist and PI of SAIL
drfeldman@lbl.gov and <https://sail.lbl.gov>
With contributions from many, many others



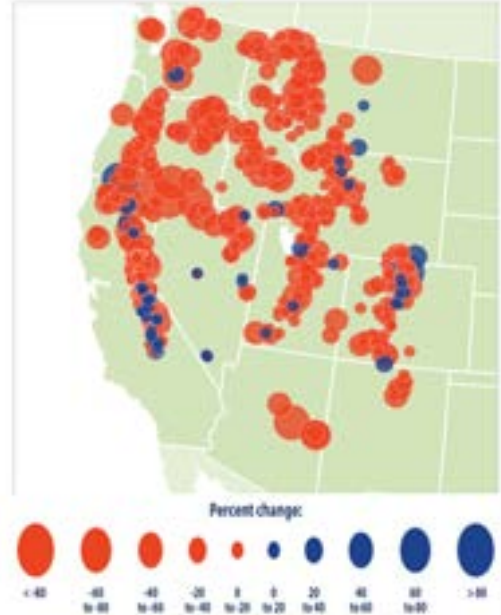
This work was supported by the U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research and the Atmospheric System Research under U.S. Department of Energy Contract No. DE-AC02-05CH11231.



- ❑ The changing face of water in the West to motivate SAIL
- ❑ What SAIL measured
- ❑ What we have learned from the SAIL data so far
- ❑ Summary and next steps

The Colorado River Watershed is changing

1955-2016 trends in April Snowpack



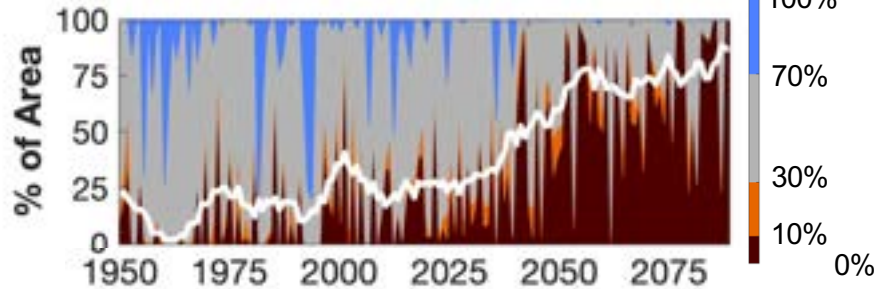
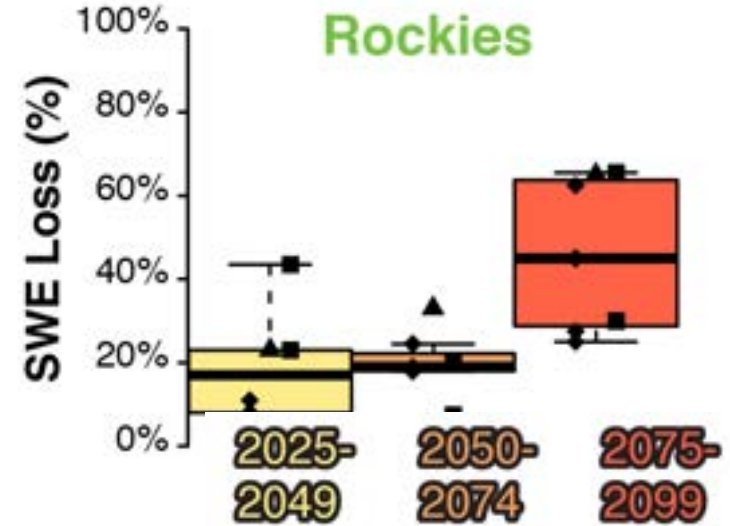
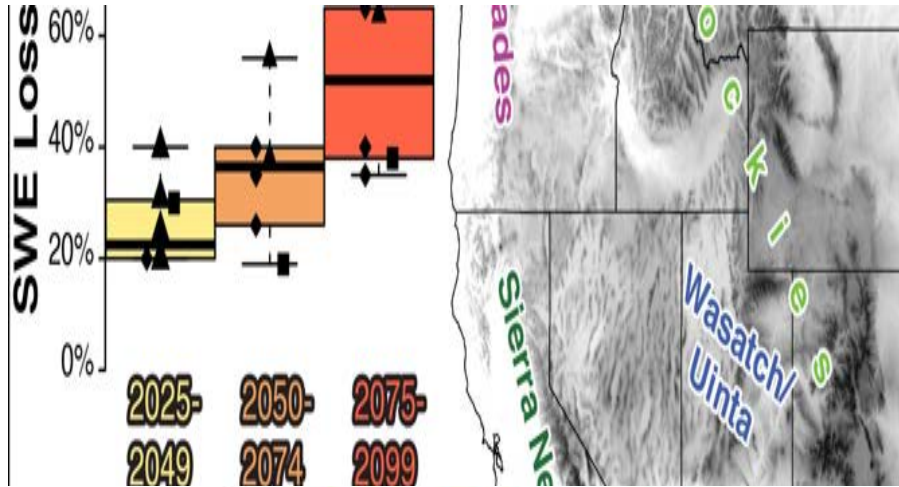
Mote and Sharp, 2016

Market Intel
September 13, 2017

First-Ever Colorado River Water Shortage Declaration Spurs Water Cuts in the Southwest



Projections of the water availability in the West



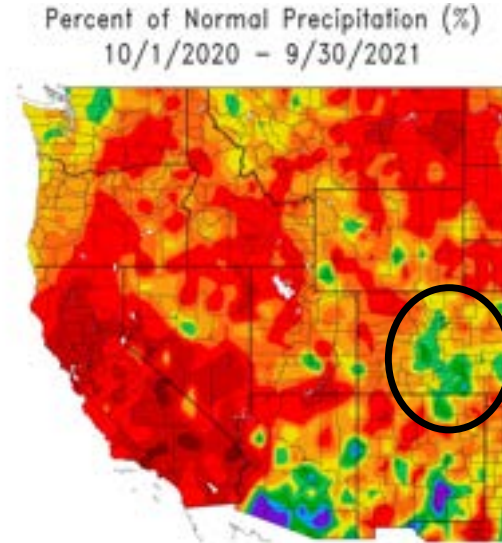
This is a big range!

The Mystery of the Missing Water

The 2021 Drought Emergency was a wake-up call, not just for water management, but for the science too.

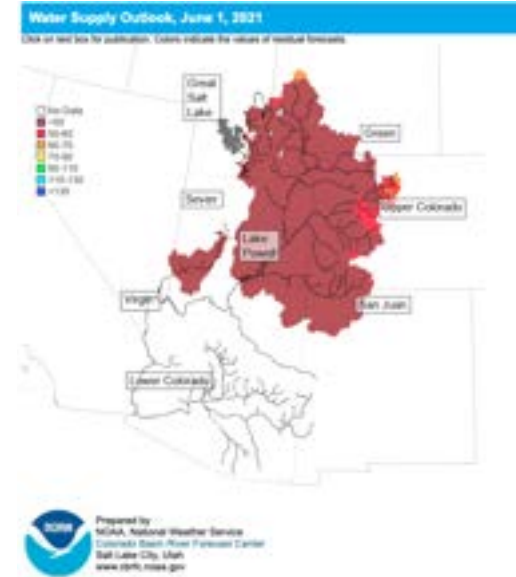
The emergency occurred in a year of slightly-below-normal precipitation, with potential to directly impact hydropower generation.

Where did that water go?!?!



Generated 10/2/2021 at HPRCC using provisional data.

NOAA Regional Climate Centers



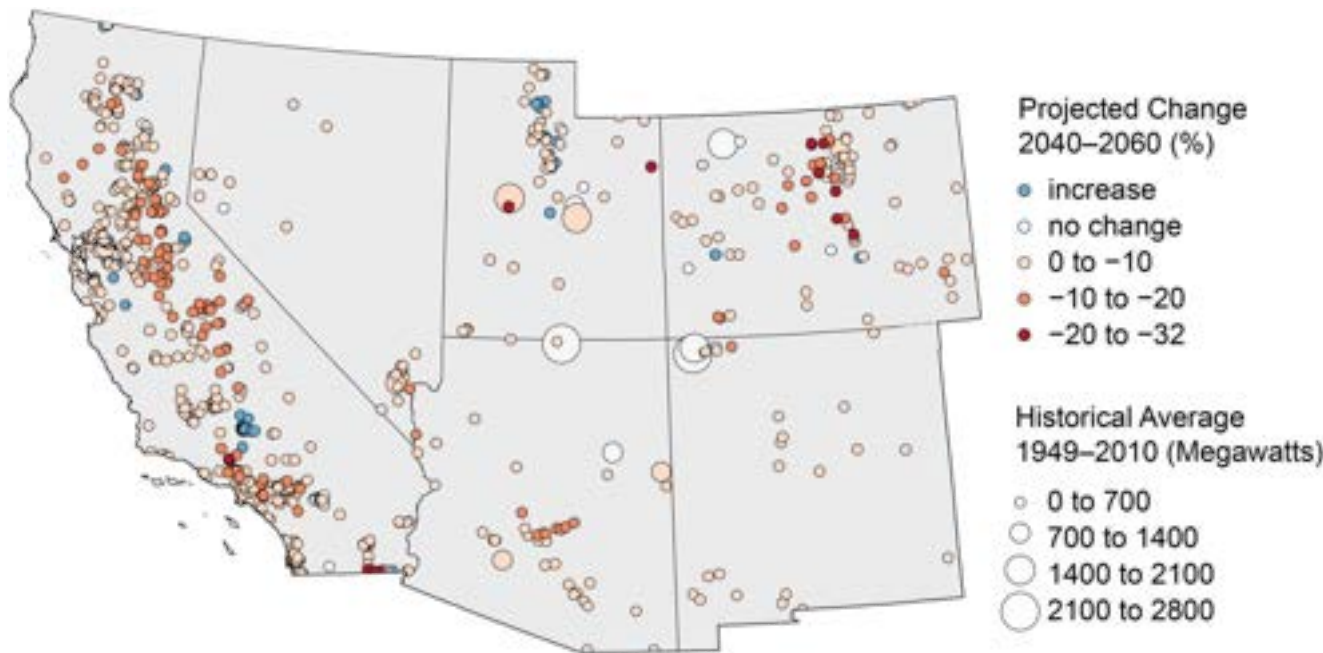
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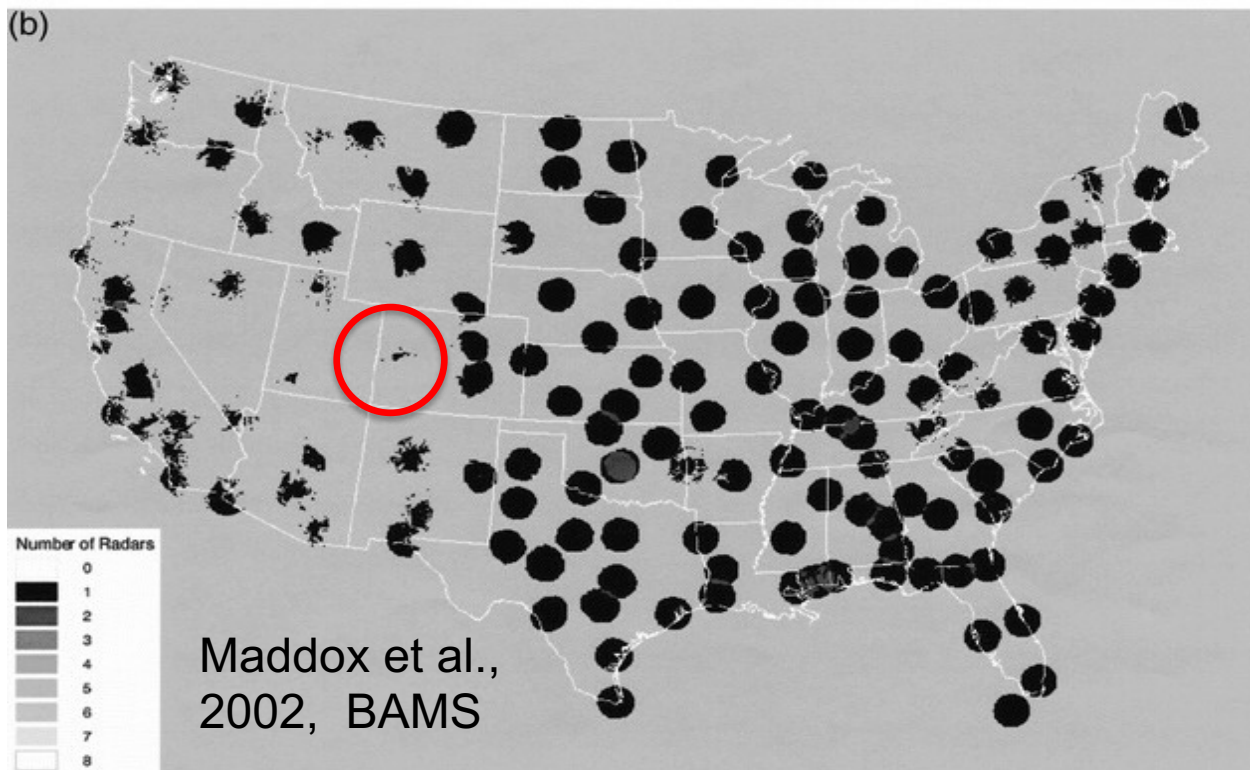
Where did that water go?!?!



Let's Go Where the Water Is ...



But That's Not Always so Easy ...



But That's Not Always so Easy ...



But That's Not Always so Easy ...



SAIL Science Objectives



The Surface Atmosphere Integrated Field Laboratory (SAIL) Campaign deployed the AMF2 near Crested Butte, Colorado from 9/21 to 6/23 to study atmosphere-hydrology connections including:

1. Precipitation: how and how much.
2. Winds: sublimation and snow redistribution.
3. Aerosols: surface and atmosphere radiative impacts
4. Aerosols: interactions with precipitation.
5. Surface fluxes: controls on the surface energy and mass balance.



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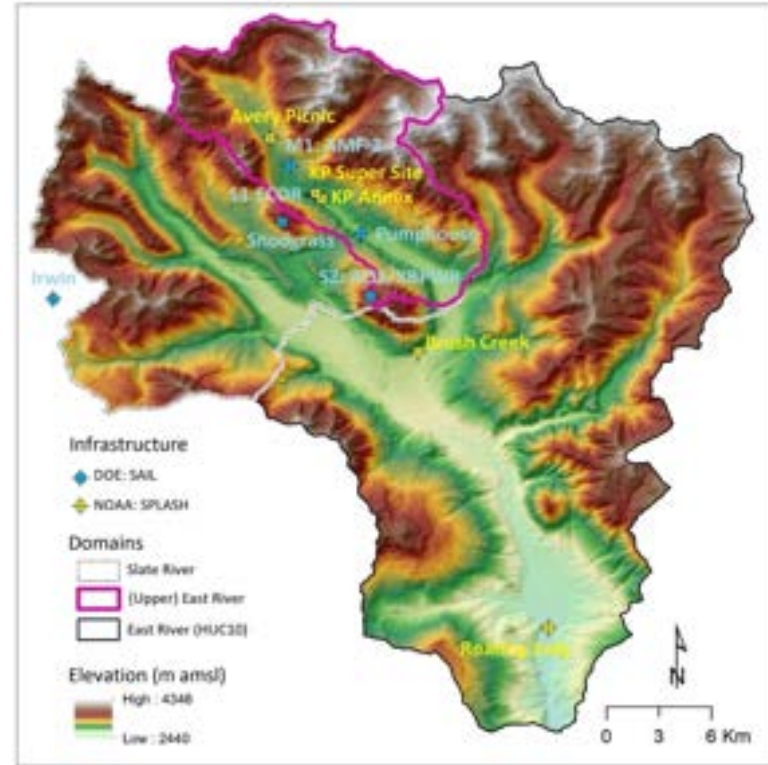


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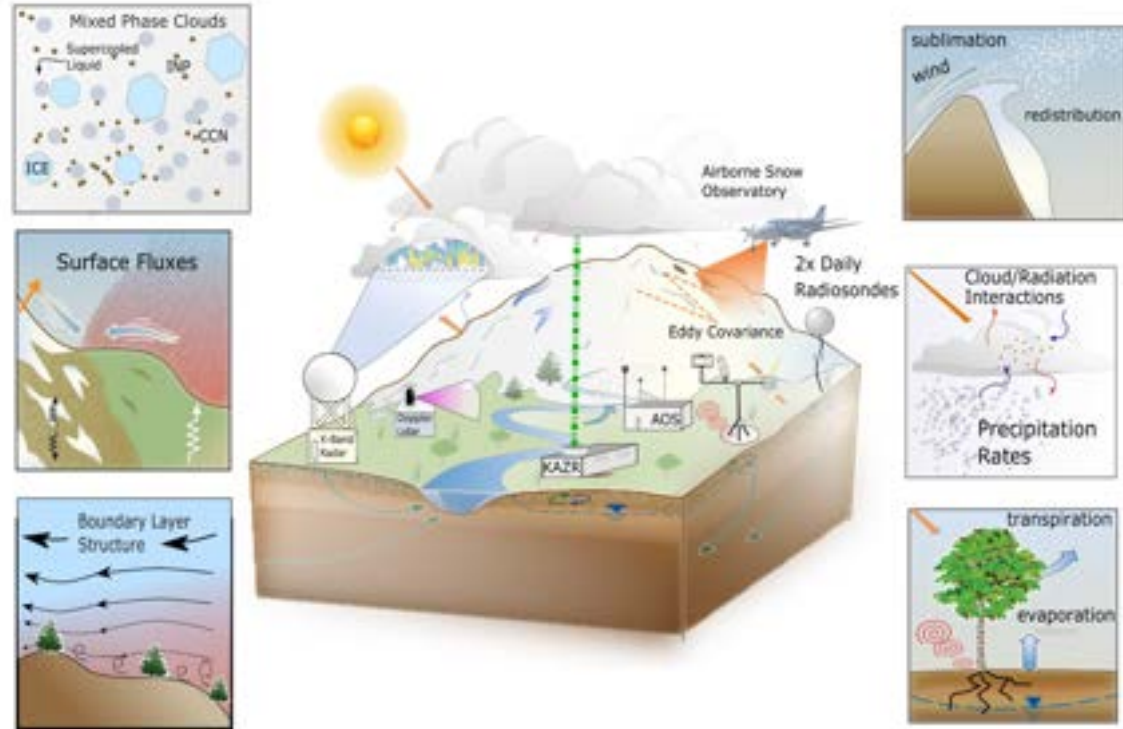


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Precipitation, Clouds, Winds, Aerosols, Radiation, Temperature, Humidity ...

- Numerous datastreams collected.
- <https://sail.lbl.gov/what-we-measure>



*Images
courtesy of
ARM Flickr
Account*

And Even More with TBS and Guest Instruments

- Seven separate TBS deployments across seasons.
- A dozen guest instruments supported.



FY23 FICUS Awardee



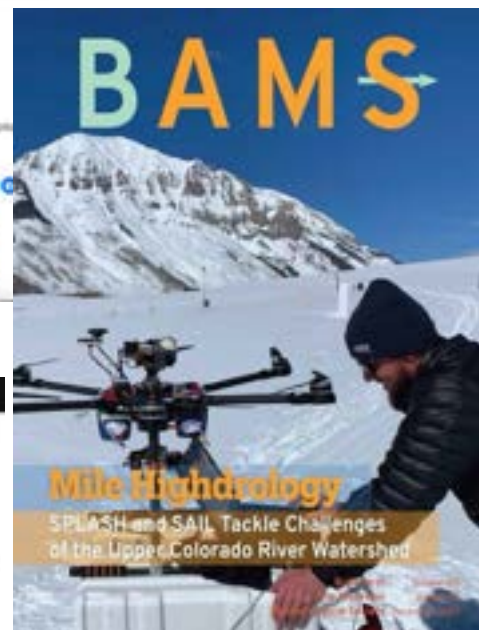
Allison Aiken
Los Alamos National Laboratory

Seasonal Vertical Aerosol Profiling for Aerosol-cloud-precipitation interactions to Advance Mountainous Hydrological Process Science

Aerosols are critical for understanding the water cycle of mountainous regions, but a complete understanding cannot be provided without vertically resolved observations. This project aims to provide a greater understanding of aerosols and associated meteorological conditions for complex mountainous terrain in the East River Watershed of the Upper Colorado River.

FICUS-40 | CH2L | JMI | ENERGY

SAIL in the news!



Atmospheric research seeks to inform water policy

Tom Oates

At a time of critical concerns about climate change and federally declared water shortages, a Surface Atmosphere Integrated Field Laboratory (SAIL) site began operations on September 1, close to the headwaters of the Colorado River, near Crested Butte, Colorado. Called the first-ever “bedrock-to-atmosphere” observation system, the SAIL project’s primary objective is to monitor and predict rain, snowfall, and water availability in the Col-

orado region. “As precipitation occurs, it eventually flows as water,” says Ken Williams, SAIL co-investigator and LERND water resources program lead (Crested Butte, CO). “When should we release water from a dam? How much should we release and how much should we hold? We believe the data we gather will be very useful for those policy-making decisions.”

“The threats are multidimensional. It’s not just temperature,” says Alejandro Flores, an eco-hydrologist with SAIL and associate professor at Boise State University (Boise, ID). For example, “dark aerosols influence how quickly snow melts and are linked back to human activity.

Also, “plant influence mountain hilltops can be moves from the ground to sky to ground. The better we understand the climate system, the better our ability to understand the pumps, which are plant stomata, co-principal in the LERND US DOE Watershed SFA and professor at Fort L (Durango, CO).

“As scientists engage resources policies, as we place where water becomes I think they will need to be ready to pro-

He spent almost 50 years alone at 10,000 feet. His hobby helped shape climate research in the Rockies.

An amateur scientist began logging snowfall to keep busy. Along the way, he became an unwitting chronicler of climate change in a region known as the water tower for the drying American West.

By Katie Hultquist
November 21, 2023 at 1:00 p.m. MST

SAIL Team: It takes a (large) village

- The science team covers 4 National Labs, 10 universities, and 2 research centers.
- Supported by ARM Program: operations team led by LANL, significant support across Nat'l Labs
- Much larger extended community of researchers across multiple disciplines.



A Snowball Effect

- SAIL began with a close partnership with ESS's Watershed Function SFA.
- It grew to include NOAA Study of Precipitation, the Lower Atmosphere, and Surface for Hydrometeorology (SPLASH) and NSF Sublimation of Snow (SOS)



SAIL/SPLASH/SOS (S³) Science Summits



CU-Boulder, November 1-3, 2023



LBLN, November 1-3, 2023



SAIL/SPLASH/SOS (S³) Science Summits



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S³ 2025: High-Water Mark for UCRB Analysis



- Lots of SAIL data! https://adc.arm.gov//discovery/#/results/site_code::guc
- Lots of SPLASH data!
<https://zenodo.org/communities/splash/records?q=&l=list&p=1&s=10&sort=newest>
- Lots of SOS data! https://data.eol.ucar.edu/master_lists/generated/sos/
- These data provide unprecedented data density for the UCRB!

SAIL by the Numbers

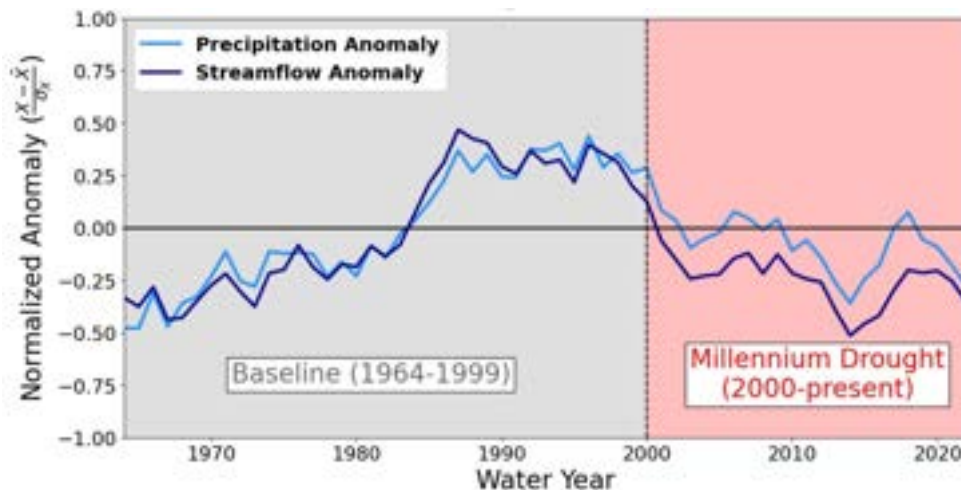


Publications, Reports, Seminars, Scientific Meeting Presentations ...

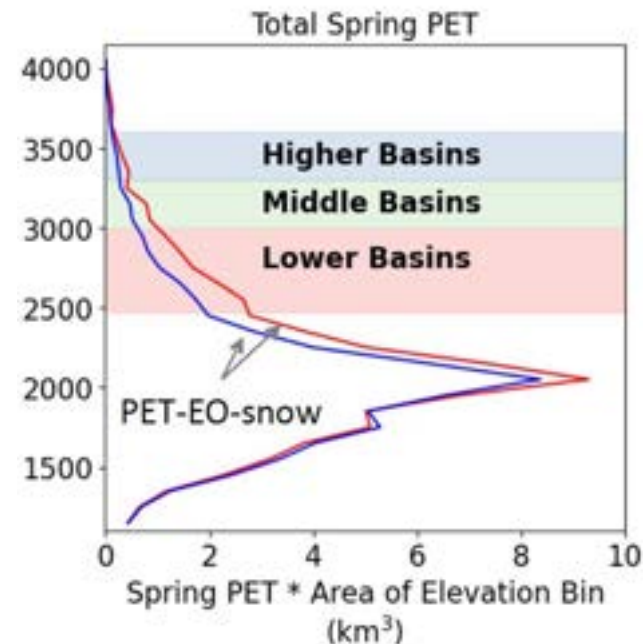
- 51 S³ seminars (and counting)
- 20 publications, 36 reports (and counting)



Missing Water Mystery Solved ... For Now



Reduced spring precipitation and potential evapotranspiration (PET) were the main culprits. Other processes may cause future reduced water resources.

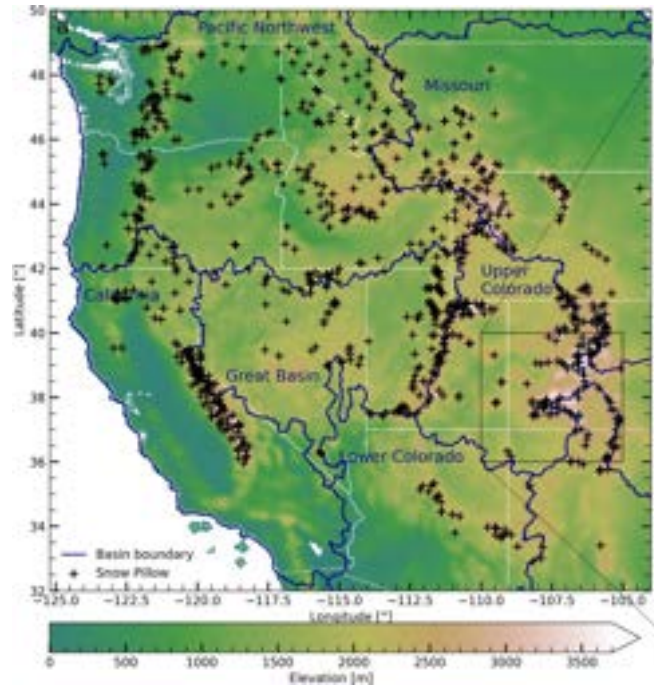


- Driest Springs between 2001 and 2017 (2002, 2012)
- Wettest Springs between 2001 and 2017 (2009, 2011)

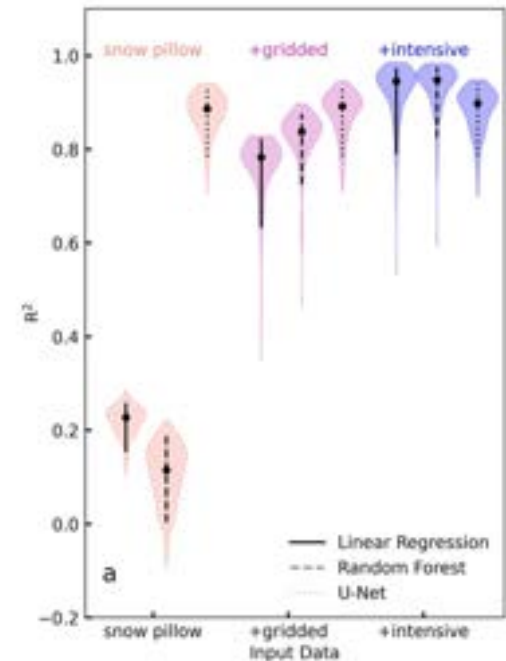
AI for Resilient Snowpack Estimation



- The network for estimating snowpack across the Mountain West is sparse and hard to augment.
- We can use different data sources and algorithms for accurately estimating snowpack in bad snow years.
- Snowpack estimation skill will be significantly degraded without intensive data, like SAIL, and/or AI methods.



Current in situ snowpack measurement network

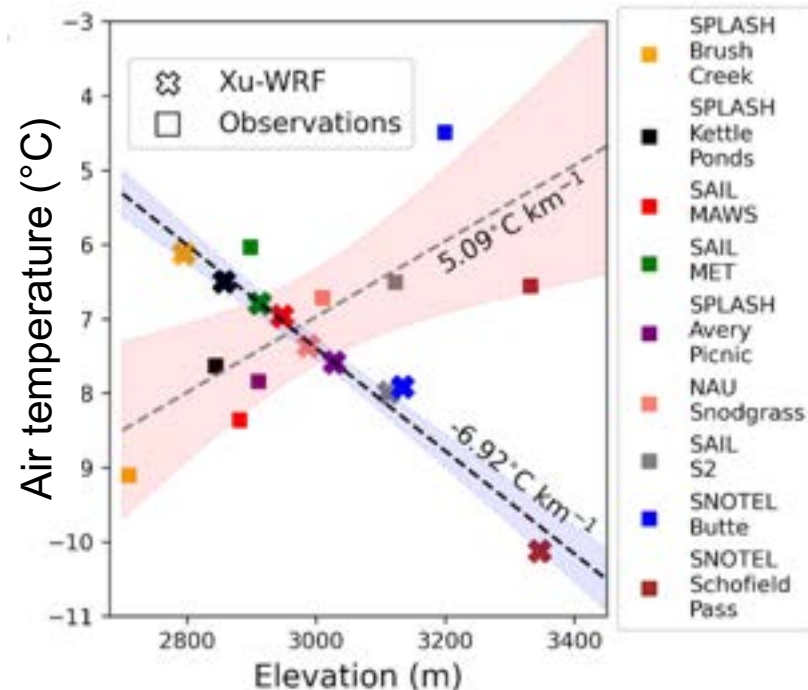


Snowpack estimation skill in the 21st Century using three levels of obs. information and data algorithms.

Pervasive Cold Biases in Surface Temperature



Pervasive T2m cold biases in atmospheric process models over mountainous regions exist. SAIL data identified the multiple underlying causes of this bias.

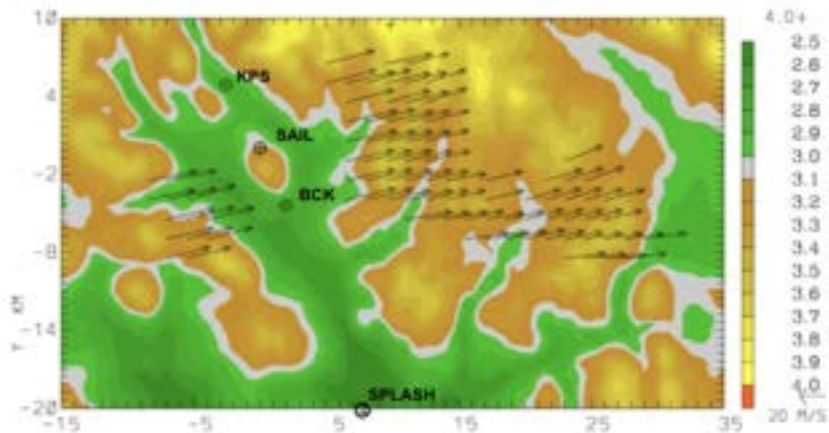


Case Study on the Santa Slammer Precipitation

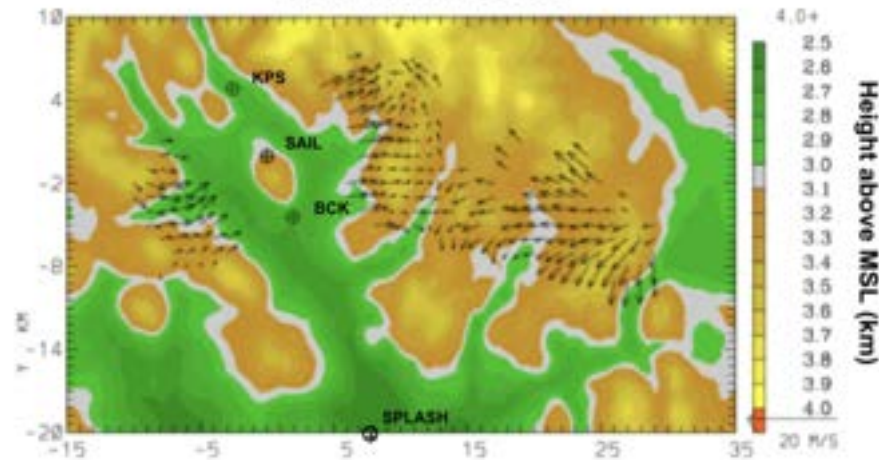


- Why are there very different patterns of snowfall for major storms, even at the same elevation?
- Coordinated radar scans, radiosonde data, and surface observations from the SAIL and SPLASH show how snow crystal formation and mountain-driven wind patterns produce snowfall near the surface.

(a) 12:30:10 - 12:34:20 UTC 24 Dec 2021 at 4.80 km above MSL
Wind Vectors



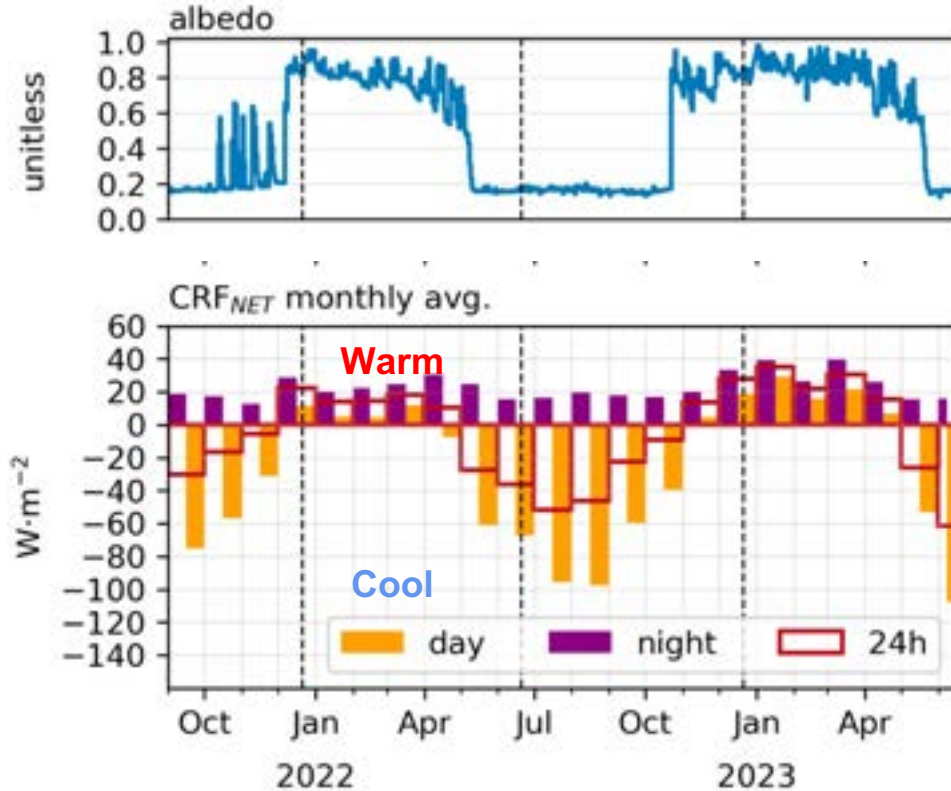
(b) Perturbation Wind Vectors



Seasonal Cloud Radiative Forcing in Complex Terrain



- When do clouds warm or cool the surface in high-altitude complex terrain?
- SAIL data show that clouds warm snow-covered surfaces and cool snow-free surfaces.
- The flip in spring is influenced by snow impurities.



SAIL Activities at 2024 ARM Summer School



- What are the best ways to foster a rising class of scientists to use ever-advancing ARM data?
- Open science approaches foster workforce development and rapid science.
- Cohort found SAIL snow albedo dropped from impurities, but WRF simulations don't.



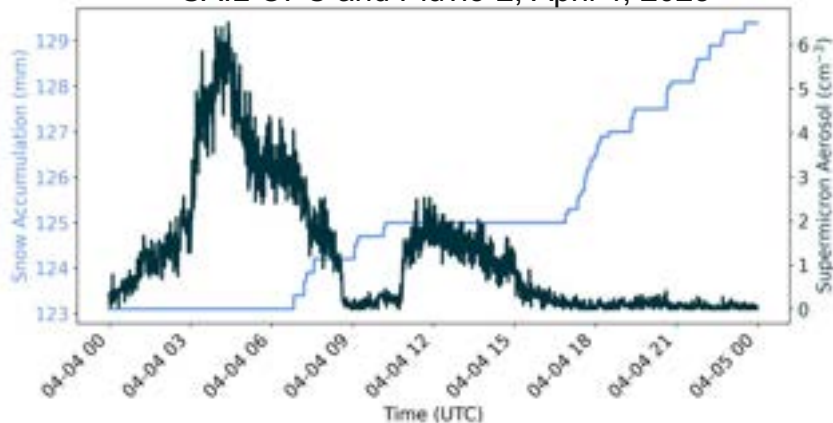
The 2024 ARM Summer School Cohort

Trojan-Horse Snowfall

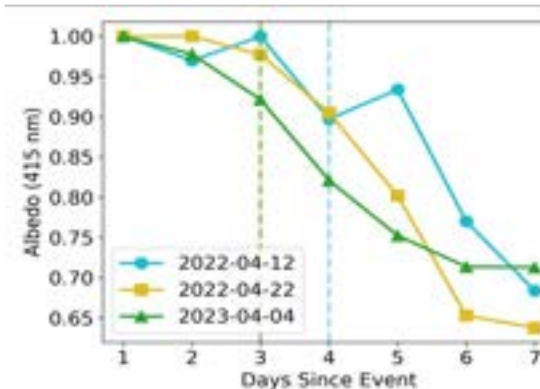


- Many SAIL observations allow us to infer that most dust deposition is actually from snow scavenging.
- Quantified snowpack albedo change from dust hidden in snowfall.
- Some snow appears to be a gift for the snowpack, but it has dust inside. An earlier snowpack melt-out date results.

SAIL OPC and Pluvio-2, April 4, 2023



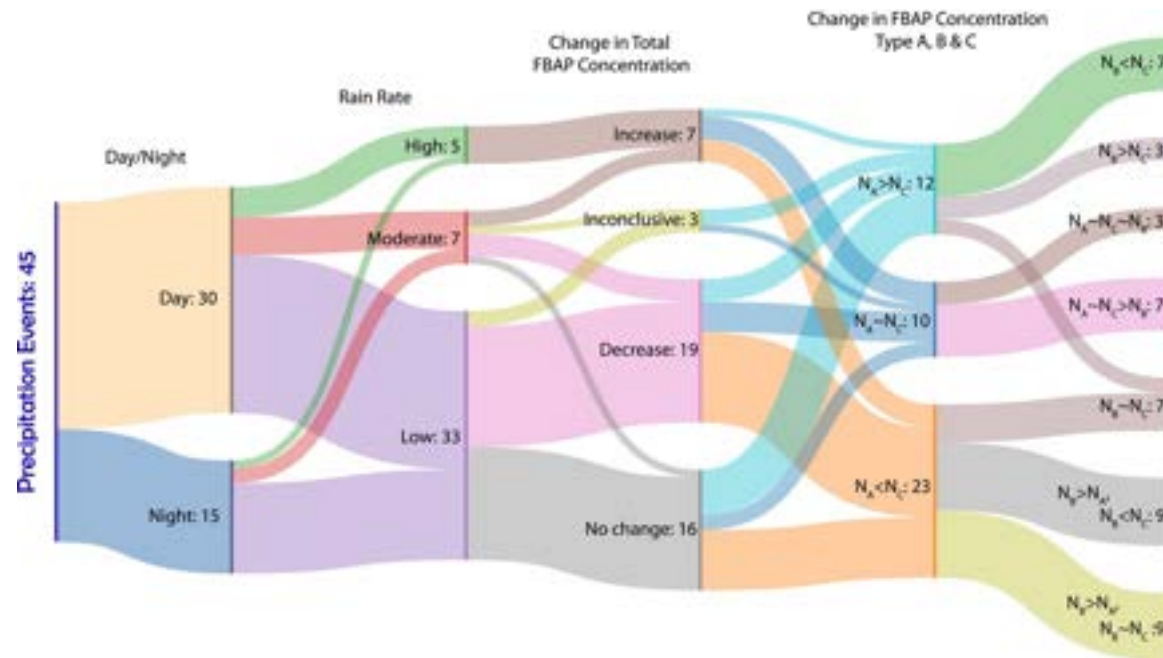
SAIL MFR/MFRSR



A Diurnal Cycle in Fluorescent Bioaerosol

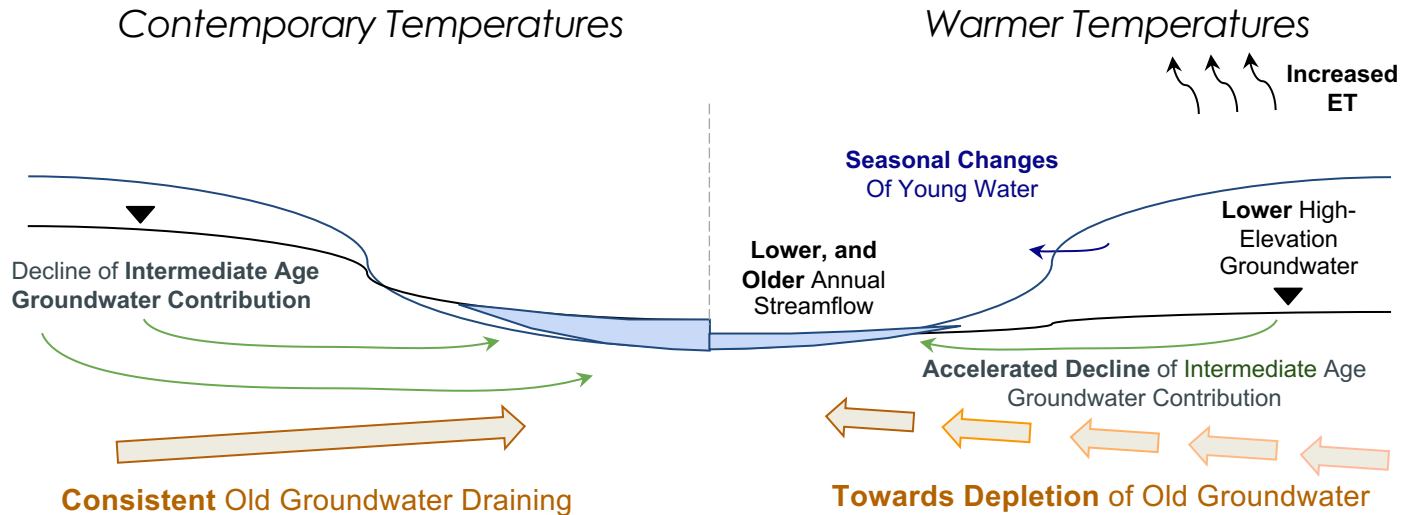


- SAIL observed many fluorescent bioaerosol particles.
- Distinct diurnal cycle in FBAP.
- Precipitation causes both emissions and removal of FBAP.



Warmer temperatures decrease streamflow

- Integrated hydrologic modeling, forced with SAIL data, show how warming temperatures lead to streamflow tipping points.



Joint ARM User Facility and ASR PI Meeting Posters



Check out the 12 SAIL-related posters!

- **Robert Jackson**: Quantitative precipitation estimation from SAIL (Session 2, Poster 51)
- **Will Rudisill**: Albedo dependence of cloud radiative forcing (Session 5, Poster 1)
- **Matthew Rybecky**: Snowpack & atmospheric processes from vapor isotopes (Session 5, Poster 3)
- **Katherine Benedict**: Supermicron aerosol science (Session 5, Poster 5)
- **Ethan Gutmann**: Diurnal energy cycle and net water vapor flux (Session 5, Poster 21)
- **Bianca Adler**: Boundary layer, clouds, and aerosols (Session 5, Poster 22)
- **Jingfeng Wang**: Observations and modeling of snow energy budget (Session 5, Poster 23)
- **Sierra Liotta**: Precipitation processes in the Rockies (Session 5, Poster 45)

- **Daniel Feldman**: Super-unit albedo (Session 6, Poster 11)
- **Russell Perkins**: Ice-nucleating particle science (Session 6, Poster 13)
- **Marianne Cowherd**: Snow bedforms with terrestrial scanning lidar (Session 6, Poster 16)
- **Swarup China**: Machine-learning for primary biological aerosol particles (Session 6, Poster 20)

Summary

- ❑ Atmospheric and surface processes are central to the Mountain West, its water resources, and associated hydropower capacity.
- ❑ SAIL and partners headed up to the mountains, gathered data, and solved some missing water mysteries ...
- ❑ ... but uncovered a few more. Many, many science opportunities remain.
- ❑ Join the community! We have bi-weekly S³ seminars, and monthly work sessions and aerosol science meetings.

Email me drfeldman@lbl.gov and/or Sara Hefty (shefty@lbl.gov) to join!