

WELCOME

8TH ANNUAL CA WATER DATA SUMMIT

INTELLIGENT QUESTIONING (IQ) SHARING WATER WISDOM

SEPTEMBER 7&8, 2023



STANFORD UNIVERSITY | PALO ALTO, CA

[#CAWaterDataSummit](#) [#IntelligentQuestioning](#)

DAY ONE
11:30AM - 12:30PM

SNOWPACK MONITORING AND WATER SUPPLY FORECASTING: EMERGING TECHNOLOGIES & MODELING IMPROVEMENTS: WHAT ARE EMERGING TECHNOLOGIES AND MODELING FOR EFFECTIVE SUPPLY FORECASTING?

MODERATOR



Lindsay McPhail
Associate Resource Specialist,
Metropolitan Water District of
Southern California



Brad Coffey
Water Resources Management Group
Manager, Metropolitan Water District
of Southern California



Thomas H. Painter, PhD
Founder/CEO, Airborne Snow
Observatories, Inc.



Andrew Schwartz
Lead Scientist/Station Manager,
University of California, Berkeley -
Central Sierra Snow Laboratory

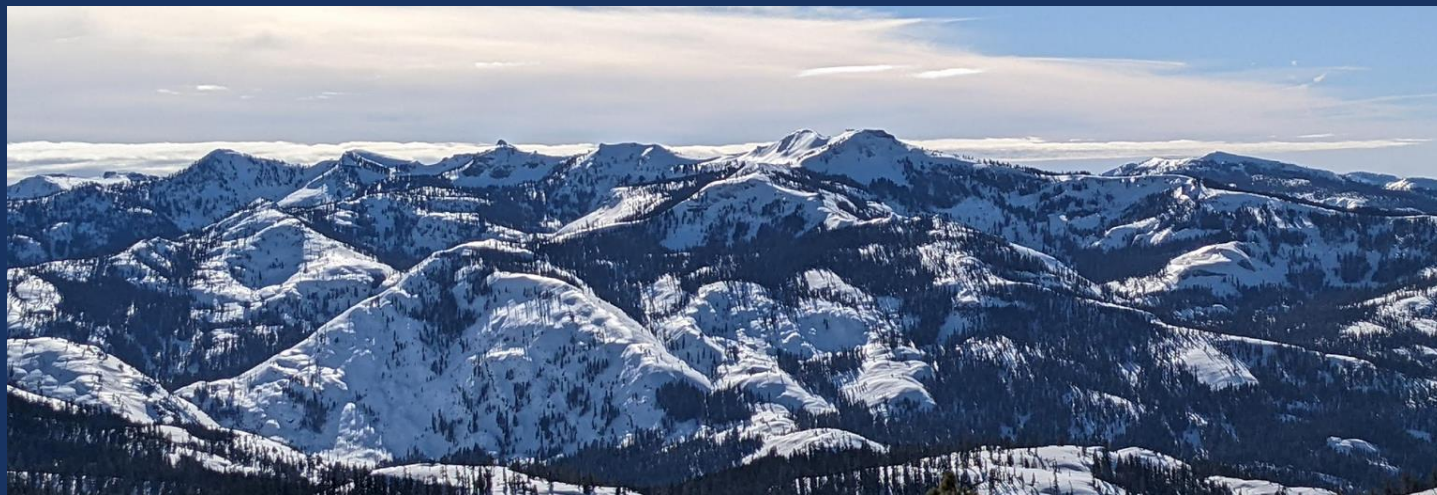
8TH ANNUAL CA WATER DATA SUMMIT
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STANFORD UNIVERSITY | PALO ALTO, CA
CaWaterDataSummit.org

#CAWaterDataSummit #IntelligentQuestioning

Advancements in Snowpack Monitoring and Decision Support



Andrew Schwartz

Lab Director
UC Berkeley Central Sierra Snow Lab

Late 1800s Notable History

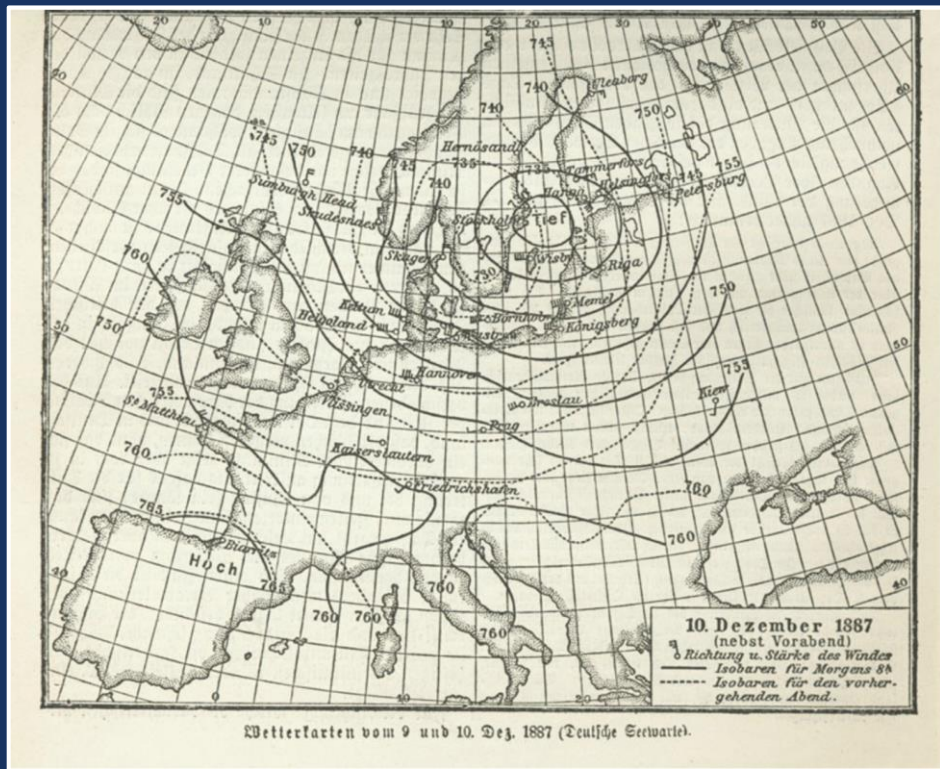


Source: Wikipedia



Source: Library of Congress

Late 1800s Notable History



THE WEATHER.

METEOROLOGICAL REPORTS.

Wednesday, July 31, 8 to 9 a.m.

	B.	E.	M.	D.	F.	C.	I.	S.
Nafn	29.54	57	56	W.S.W.	6	9	o.	3
Aberdeen	29.60	59	54	S.S.W.	5	1	b.	3
Leith	29.70	61	55	W.	3	5	c.	2
Berwick	29.69	59	55	W.S.W.	4	4	c.	2
Ardrossan	29.73	57	55	W.	5	4	c.	5
Portrush	29.72	57	54	S.W.	2	2	b.	2
Shields	29.80	59	54	W.S.W.	4	5	o.	3
Galway	29.33	65	62	W.	5	4	c.	4
Scarborough	29.85	59	56	W.	3	6	c.	2
Liverpool	29.91	61	56	S.W.	2	3	c.	2
Valentia	29.37	62	60	S.W.	2	5	o.	3
Queestown	29.33	61	59	W.	3	5	c.	2
Yarmouth	30.05	61	59	W.	5	2	c.	3
London	30.02	62	60	S.W.	3	2	b.	—
Dover	30.04	70	64	S.W.	3	7	o.	2
Portsmouth	30.01	61	59	W.	3	6	o.	2
Portland	30.03	63	59	S.W.	3	2	c.	3
Plymouth	30.00	62	59	W.	5	1	b.	4
Penzance	30.04	61	60	S.W.	2	6	c.	3
Copenhagen	29.94	64	—	W.S.W.	2	6	c.	3
Helder	29.99	63	—	W.S.W.	6	5	c.	3
Brest	30.09	60	—	S.W.	2	6	c.	5
Bayonne	30.13	68	—	—	—	9	m.	5
Lisbon	30.18	70	—	N.N.W.	4	3	b.	2

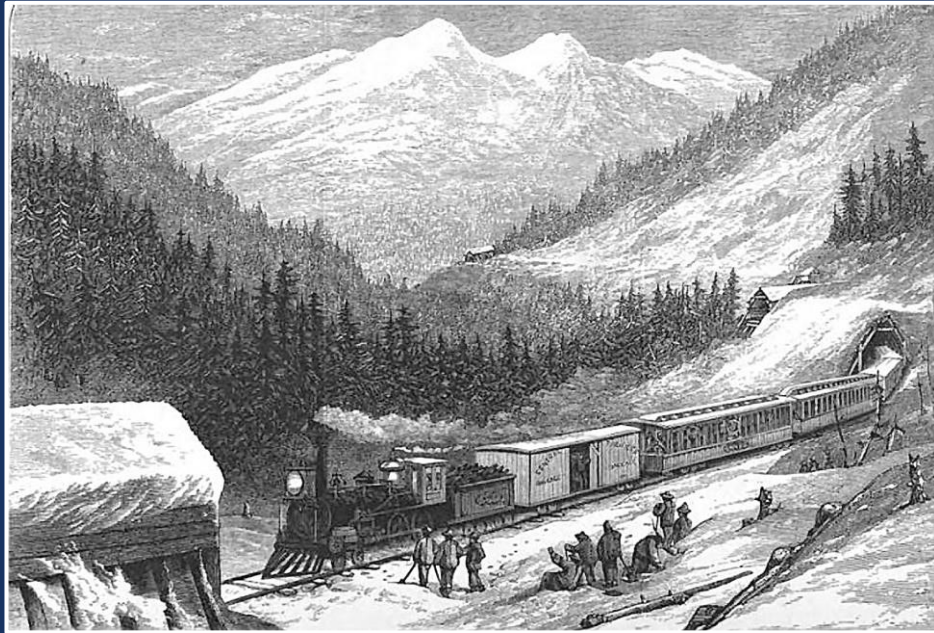
General weather probable during next two days in the—
 North—Moderate westerly wind; fine.
 West—Moderate south-westerly; fine.
 South—Fresh westerly; fine.

Explanation.
 B. Barometer, corrected and reduced to 32° at mean sea level; each 10 feet of vertical rise causing about one-hundredth of an inch diminution, and each 10° above 32° causing nearly three-hundredths increase. E. Exposed thermometer in shade. M. Moistened bulb (for evaporation and dew-point). D. Direction of wind (true—two points left of magnetic). F. Force (1 to 12—estimated). C. Cloud (1 to 9). I. Initials:—b., blue sky; c., clouds (detached); f., fog; h., hail; l., lightning; m., misty (hazy); o., overcast (dull); r., rain; s., snow; t., thunder. S. Sea disturbance (1 to 9).

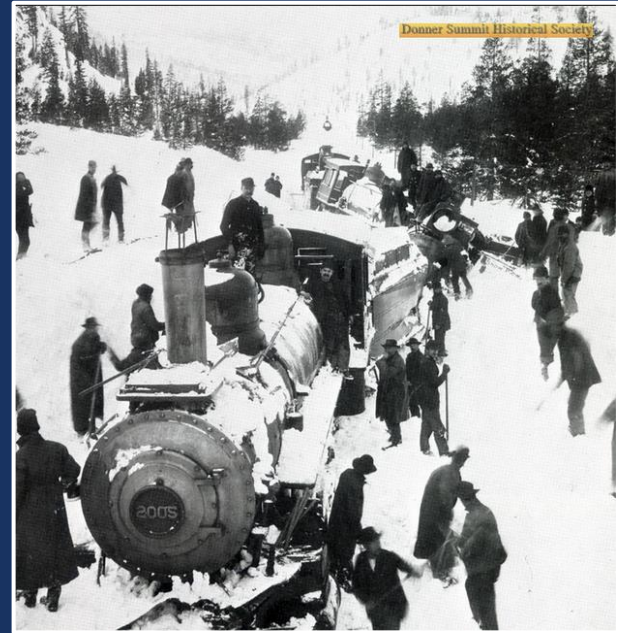
MET OFFICE

Source: UK Met Office

Late 1800s Notable History



Source: Donner Summit Historical Society



Donner Summit Snowfall and Snowpack || UC Berkeley Central Sierra Snow Lab

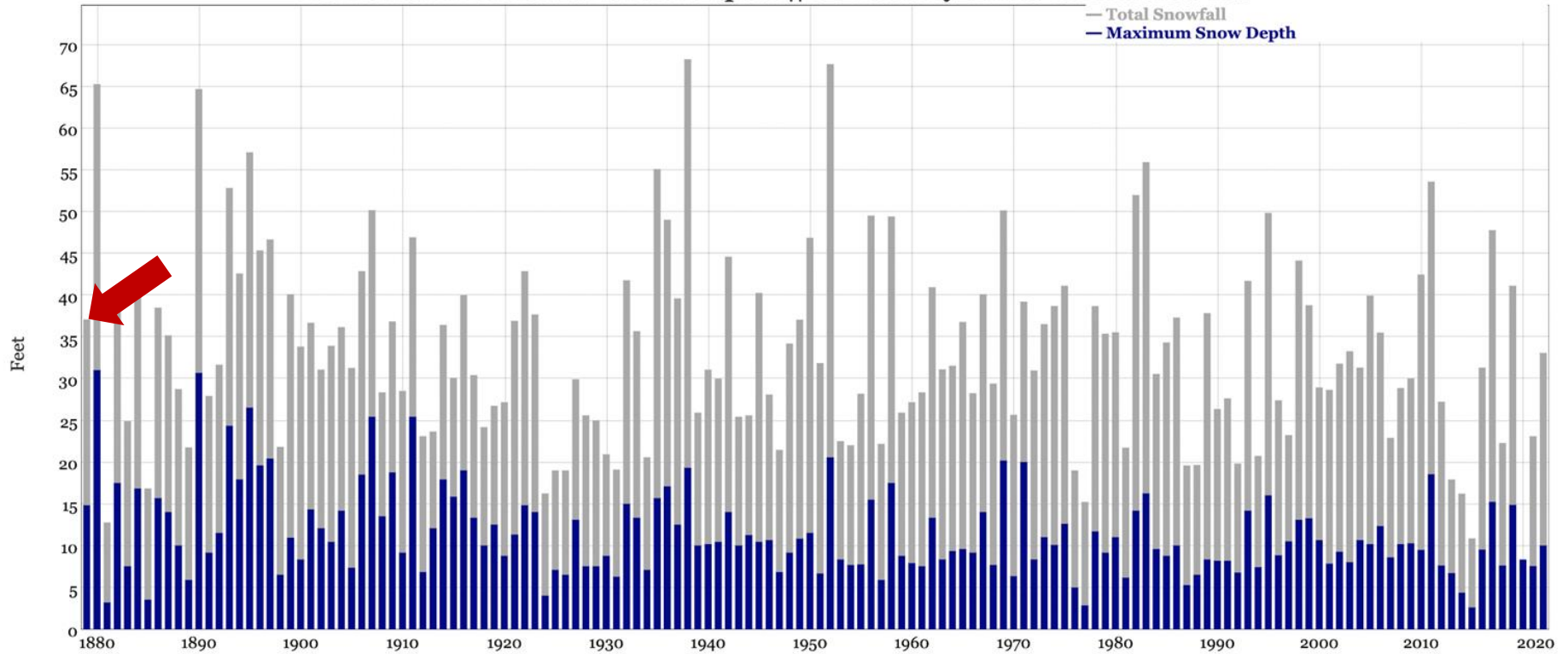




Photo credit: USDA.gov

Dr. James E. Church

Mt. Rose Sampler (now Federal Sampler)

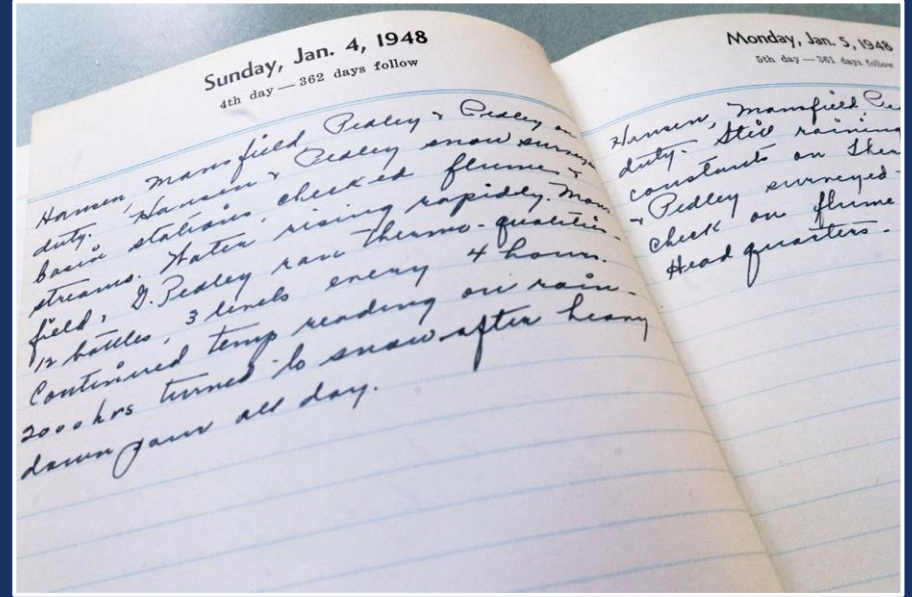


Photo credit: USDA.gov



Conducting Onion Creek Snow Survey

Central Sierra Snow Lab (CSSL) Est. 1946



Continued measurements that had already been occurring on Donner Summit for decades

Snowpack Monitoring Advancements: Depth, Density, SWE



Photo credit: USDA.gov

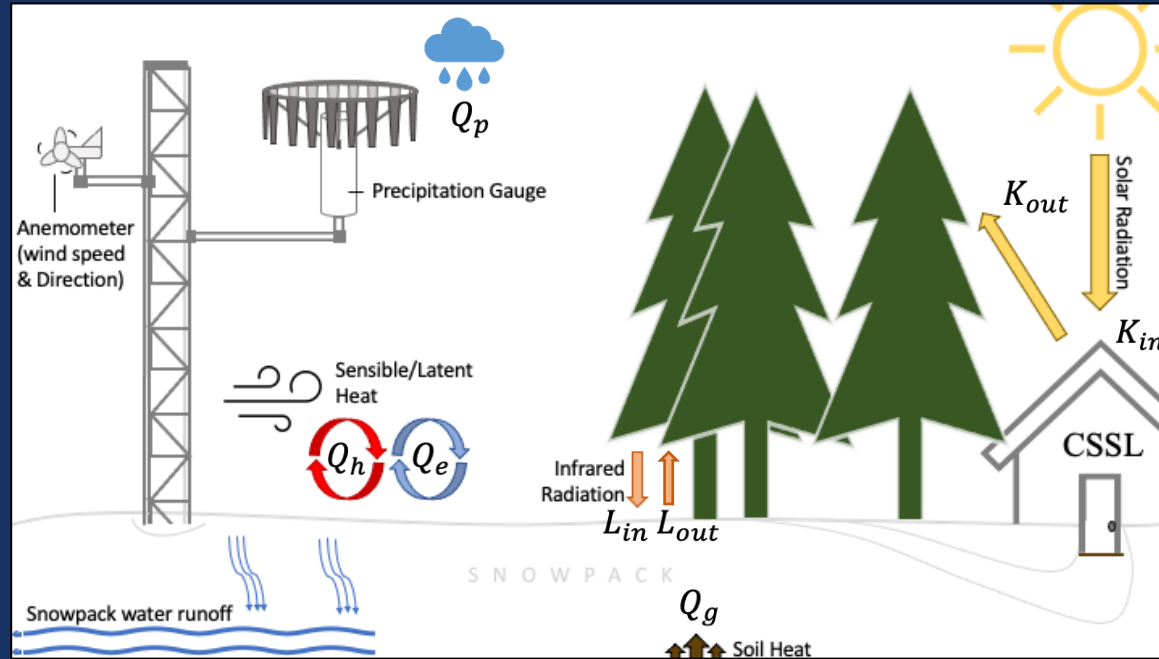


Photo credit: Climate.gov



Photo credit: Airborne Snow Observatories

Snowpack Monitoring Advancements: Energy Balance

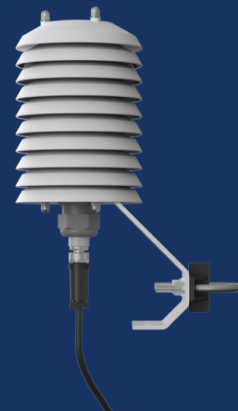


$$\Delta Q_i = Q_h + Q_e + Q_g + Q_p + (K_{in} - K_{out}) + (L_{in} - L_{out})$$

Energy Balance: Instrumentation and Measurement



EC150 – 3D Sonic Anemometer and Gas Analyzer



HMP155 – Temp/RH w/
Shield



CNR4 – 4 Way Radiation – Up/Down
Pyranometer and Pyrgeometer

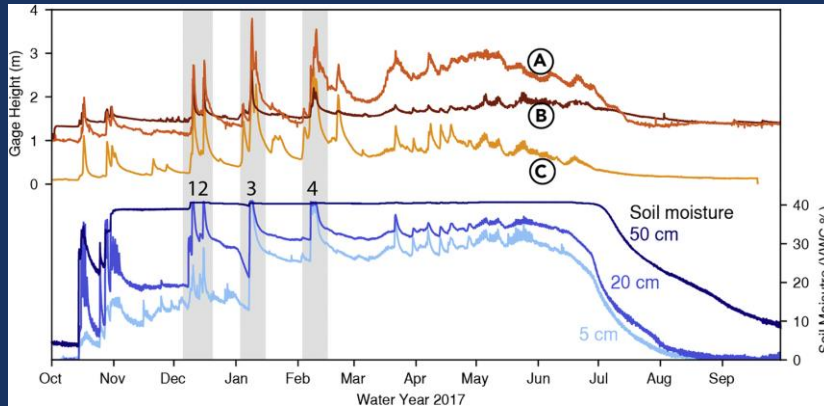


HFP01 – Soil and Surface Heat
Flux

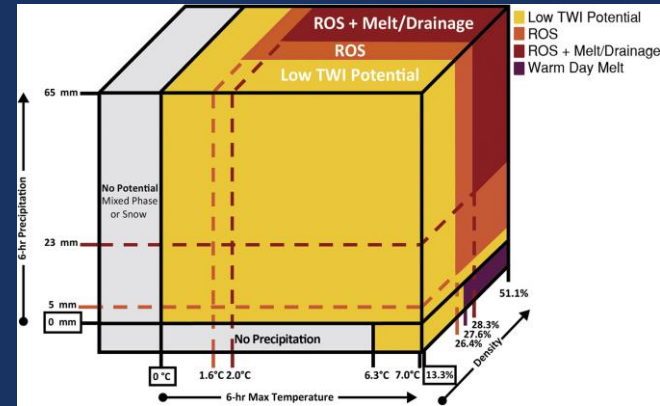
Snowpack Decision Support

Better measurement and monitoring capabilities have enabled decision support tools

- Inflows and peak flows
- Flooding potential



Heggli et al. 2022



Snowpack Decision Support

Decision support through modelling allows:

- Departure from reliance on 'average' snowpack conditions and planning.
- Greater understanding of spatial variability.

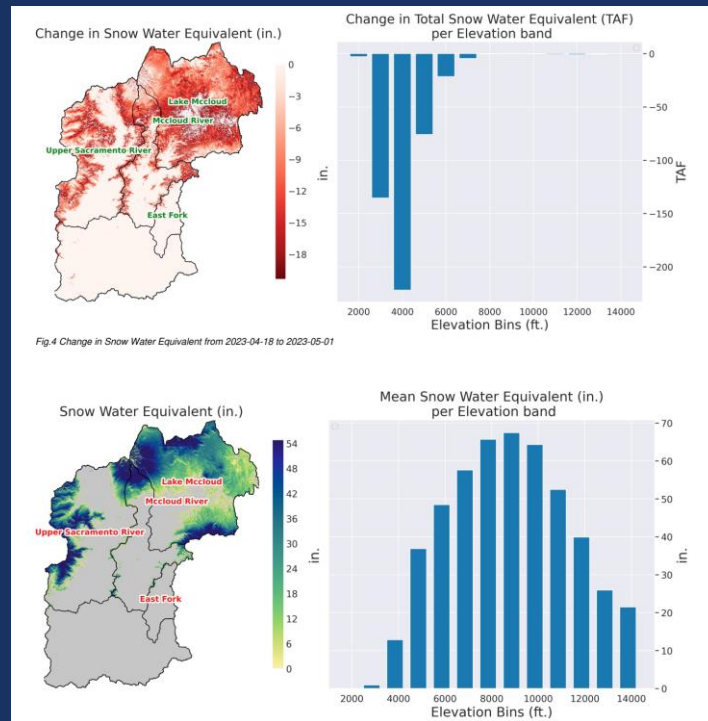


Fig.4 Change in Snow Water Equivalent from 2023-04-18 to 2023-05-01

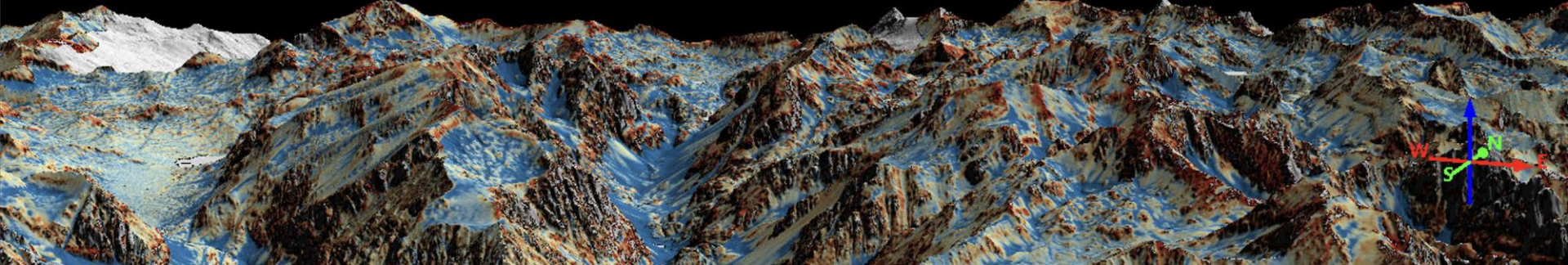
Image credit: iSNOBAL data from M3 Works

Decision Support for Compound Events



Thank you





Airborne Snow Observatories

Full-watershed snow mapping and forecasting for decision support

Thomas H. Painter | Airborne Snow Observatories, Inc.



ASO Snow Depth
Kings River, CA
February 2, 2023

Living at the new crossroads

The New York Times

Reminder: Snowpack represents 70-80% of the annual precipitation falling on the West and California

A Breakthrough Deal to Keep the Colorado River From Going Dry, for Now

The agreement on cuts, aided by a wet winter and \$1.2 billion in federal payments, expires at the end of 2026.

REUTERS® World Business Markets Sustainability More

United States

Record California snowpack bounty poses renewed flood risks

By Steve Gorman



Plaschke: Julio Urias simply cannot be allowed to pitch again for the Dodgers

SOCCERS
Dodgers pitcher Julio Urias arrested on suspicion of domestic violence

CALIFORNIA
Californians can now carry driver's license on their phone as part of pilot program

CALIFORNIA
Hilary 'reshaped the landscape' of Death Valley storm damage closes park, maybe for months

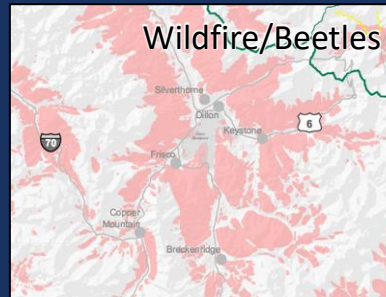
COMPANY TOWN
Why Hollywood's labor nightmare won't end soon: Frustration, fear and mistrust

ADVERTISMENT

Levels remain low. The lake, the largest reservoir in the State Water Project, is at 30% of year. (Ethan Slevin / Associated Press)

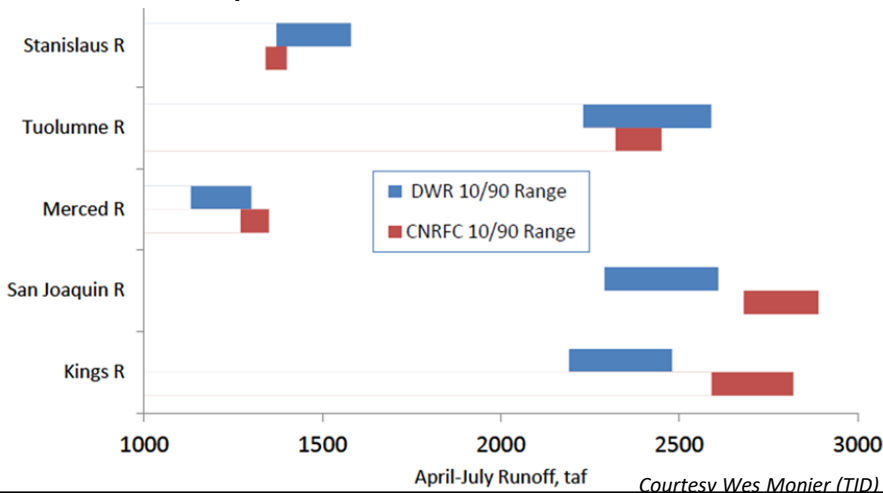
History is an increasingly poor guide to the present

- forecasts based on historic data assume that calibrations apply to current conditions
- forecast uncertainty requires a wide margin
- accurate & complete SWE mapping is a foundation for reduced forecast uncertainty



	April Foreca st	Obs Inflo w	% Difference
1999	120	197	-39%
2000	155	159	-2%
2001	150	146	3%
2002	59	57	4%
2003	170	173	-2%
2004	100	78	28%
2005	125	120	4%
2006	210	176	19%
2007	150	177	-15%
2008	200	195	2%
2009	180	192	-6%
2010	120	142	-15%
2011	225	272	-17%
2012	100	64	56%
2013	100	134	-25%
2014	250	242	3%
2015	166	202	-18%
2016	167	157	7%
2017	195	184	6%

CA DWR Bulletin 120 & CA/NV River Forecast Center
Apr-Jul Runoff Forecasts, May 2017



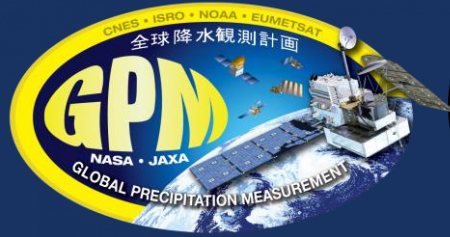
Forecast > 10% Low

Forecast > 10% High

NASA missions have clarified the water cycle

Precipitation

Rainfall
Snowfall



Groundwater

Evapotranspiration

Runoff

Observation
Forecasting



Airborne Snow Observatories, Inc.

mapping the most critical snow properties and forecasting runoff volume & timing

Snow Water Equivalent

Snow depth from lidar elevation
SWE from coupling with obs & modeled density

Snow Albedo

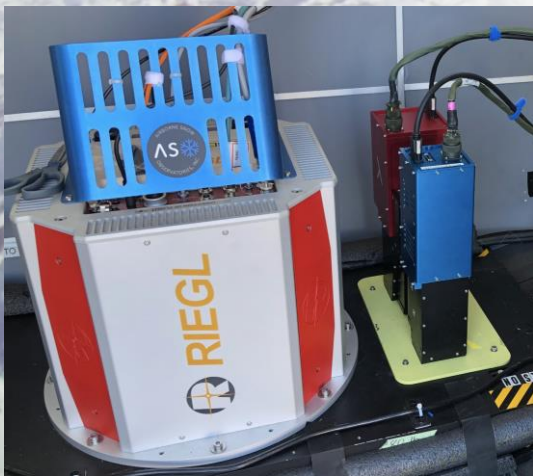
HySpex VSWIR spectrometers
Albedo & surface properties

Physical Modeling

Coupled lidar & spectrometer
Physical snowpack & runoff modeling
(iSnobal + WRF-Hydro)

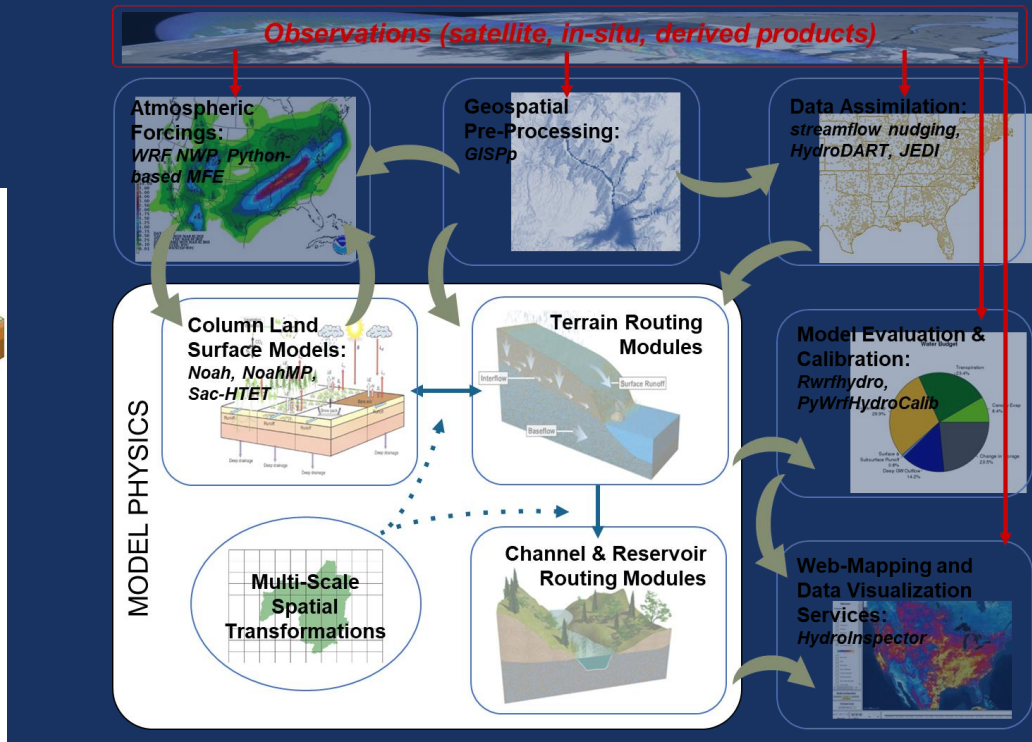
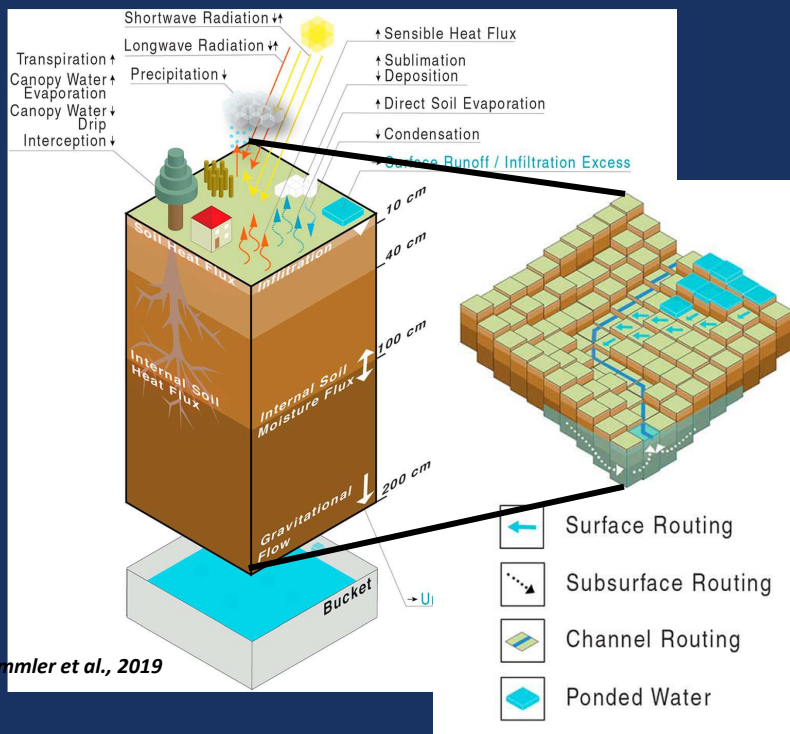
Operations

Unique high-altitude operations
Unique rapid product turnaround



JPL





- State of the art column land surface thermodynamics
- Dynamic, hyper-resolution terrestrial overland, sub-surface and channel routing
- Multi-spatial framework support
- **Current configuration using 1km column physics with 250m terrain routing**

Kings River, CA

Jan 22, 2023



Snow Depth (m)



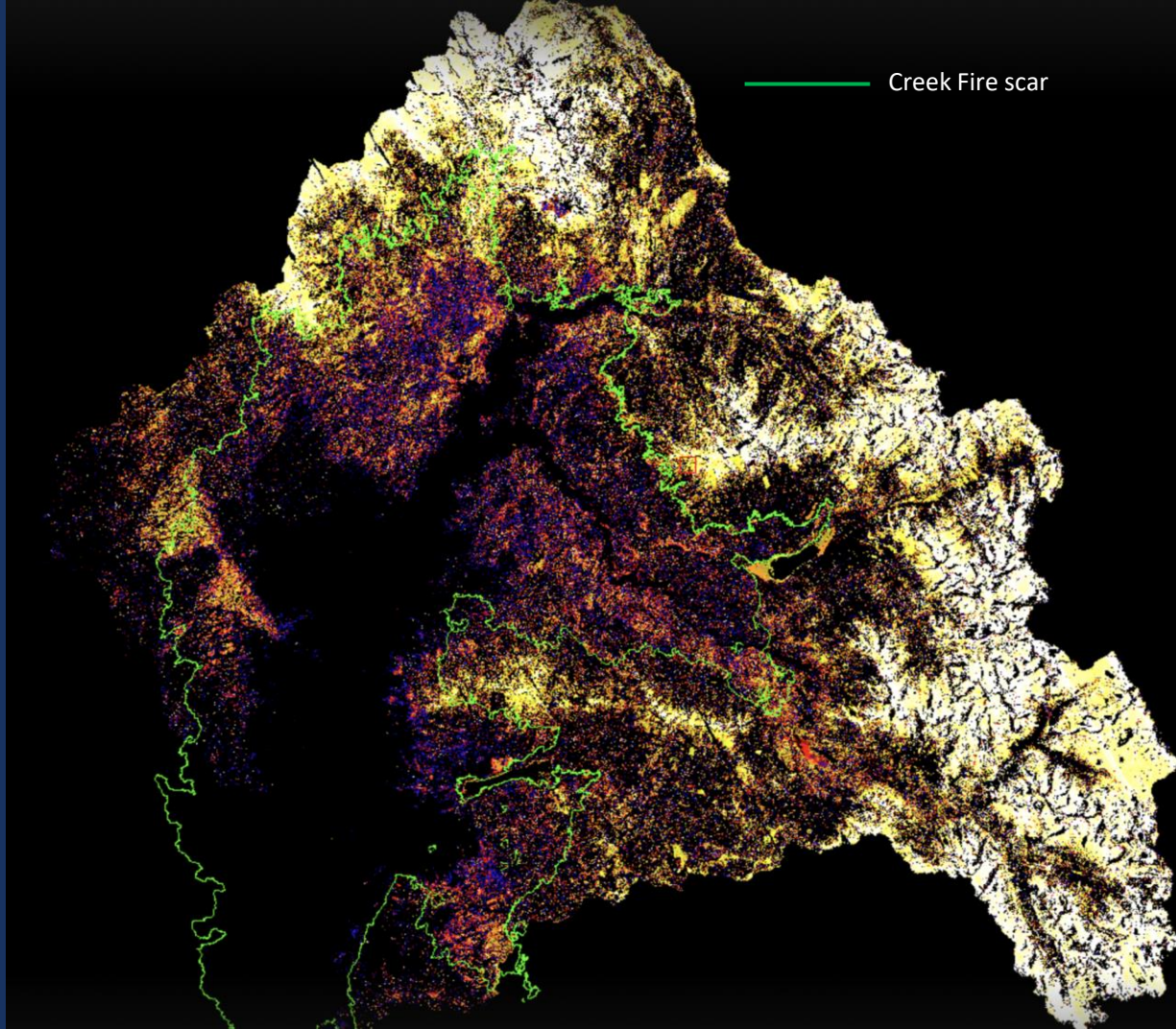
Kings River, CA

Jan 22, 2023



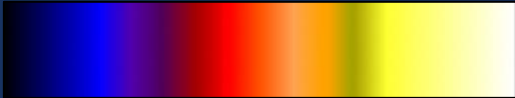
Snow Depth (m)





— Creek Fire scar

Visible Albedo
San Joaquin Basin, CA
14 April 2023



50

75

Snow Albedo¹⁰⁰(%)



Mammoth Mountain Ski Area

2 July 2023

Acquisition under contract with CA Department of
Water Resources and CA Office of Emergency
Services

Mammoth Mountain Ski Area

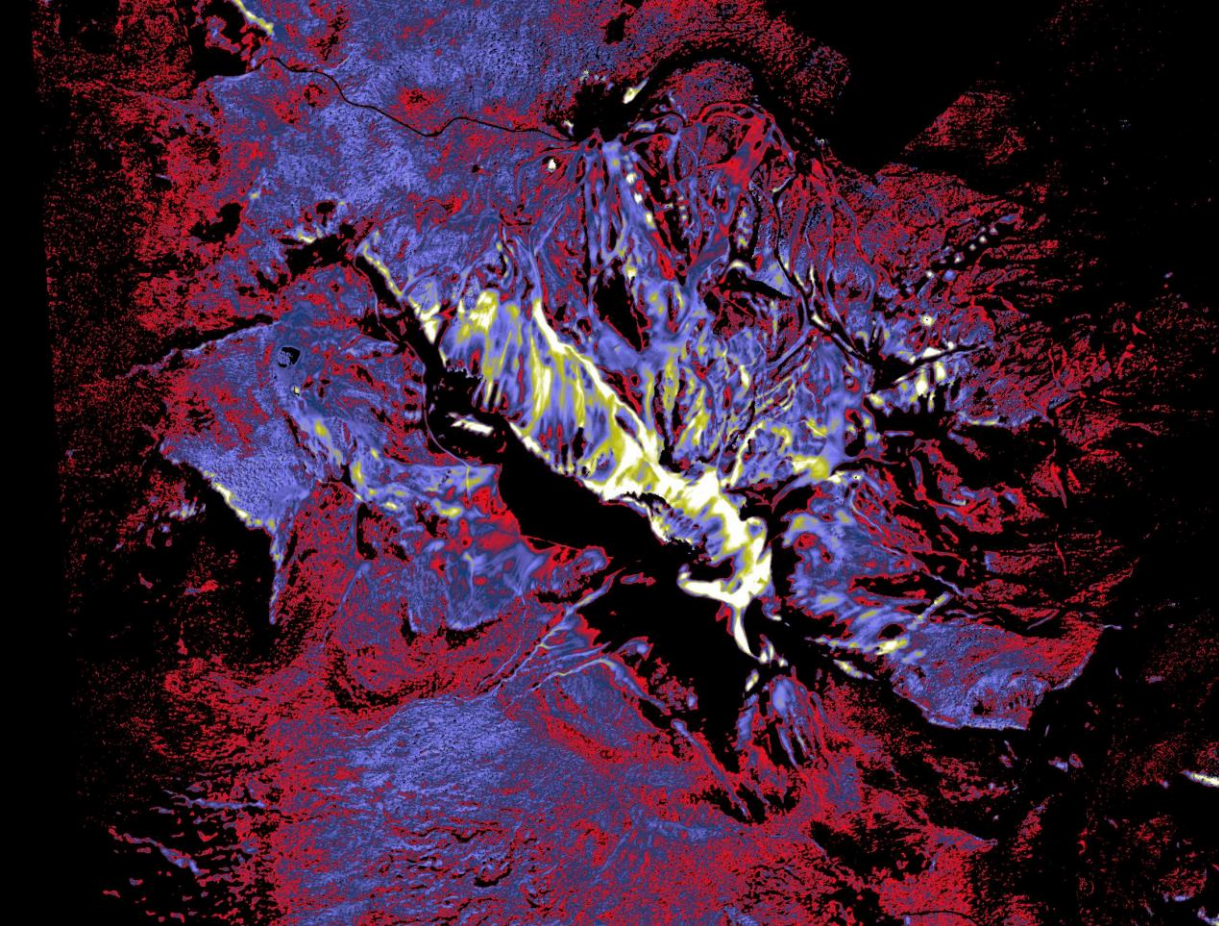
2 July 2023

Acquisition under contract with CA Department of
Water Resources and CA Office of Emergency
Services



0 1 2 3 4 5 6

Snow Depth (m)



ASO Program Evolution

2012 – First flights – partnership with NEON

2013 – First snow flights – NASA HQ support

2013 – JPL Riegl & itres CASI instrument purchases

2013 – Funding support from State of CA

2015 – Funding support from State of CO

2015 – NSIDC begins data archive & distribution

2016 – WSL/SLF Switzerland demo project

2016 – Science support from DoE, USFS

2017 – Southern Sierra Nevada extension

2019 – Transition to Airborne Snow Observatories, Inc.

2019 – Strategic Partnership with M3W & QSI/NV5

2020 – Strategic Partnership with Esri

2020 – First season as ASO Inc.

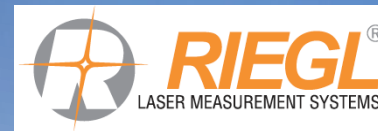
2020 – Strategic Partnership with NCAR for WRF-Hydro hydrologic modeling

2020 – ASO-specific Federal and State (CA) Legislation

2022 – Grew to multiple ASOs

2022 – Added VSWIR imaging spectrometers

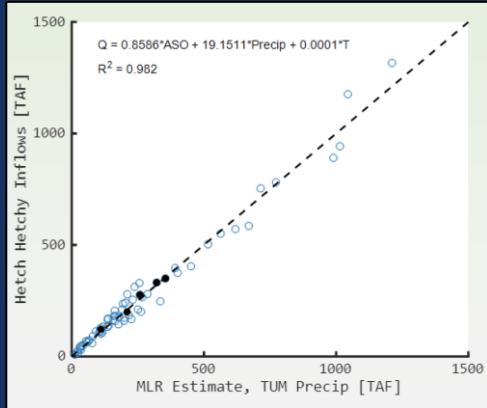
2022 – International implementation



Wide-range of decision-support applications

Reservoir operations

- Robust AJRO predictor
- lower bound confidence allowed ecology flows in drought years



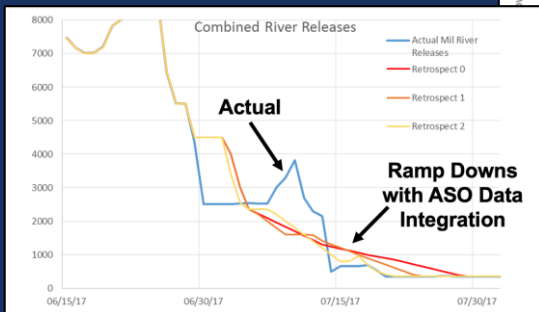
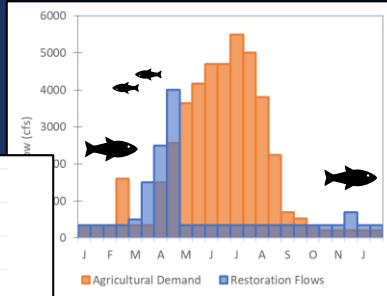
Proactive flood management

- Kings River, CA – 2019: flood designation avoided using ASO SWE volume guidance
- met supply obligations
- avoided costly water lease

Forecasts	Apr-Jul Runoff Forecast Exceedance		
	10%	50%	90%
CA DWR	2.1 MAF	1.8 MAF	1.6 MAF
NOAA RFC	2.3 MAF	2.1 MAF	1.9 MAF
ASO		2.5 MAF	

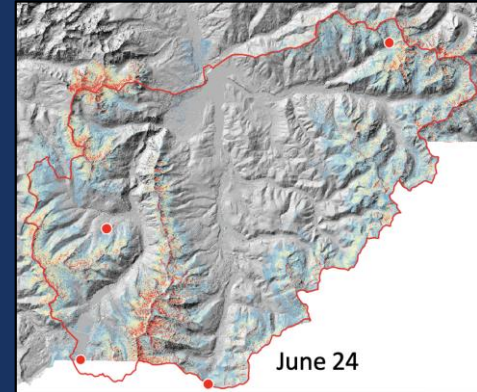
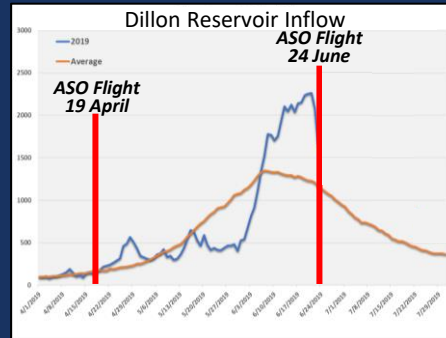
Ecologic & In-stream flows

- fish flow timing
- dam release ramping



Reservoir operations timing

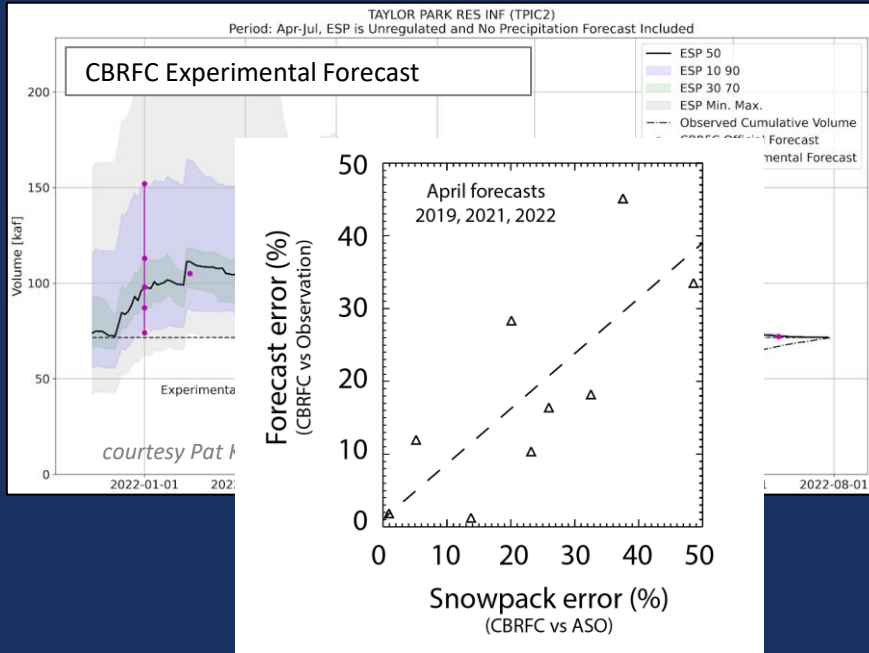
- Dillon Reservoir 2019
- captured 2nd runoff peak



Operational forecast integration

NWS River Forecast Center testing/evaluation

- experimental SNOW-17 forecasts with ASO ingest
- ASO validation of RFC SWE volumes

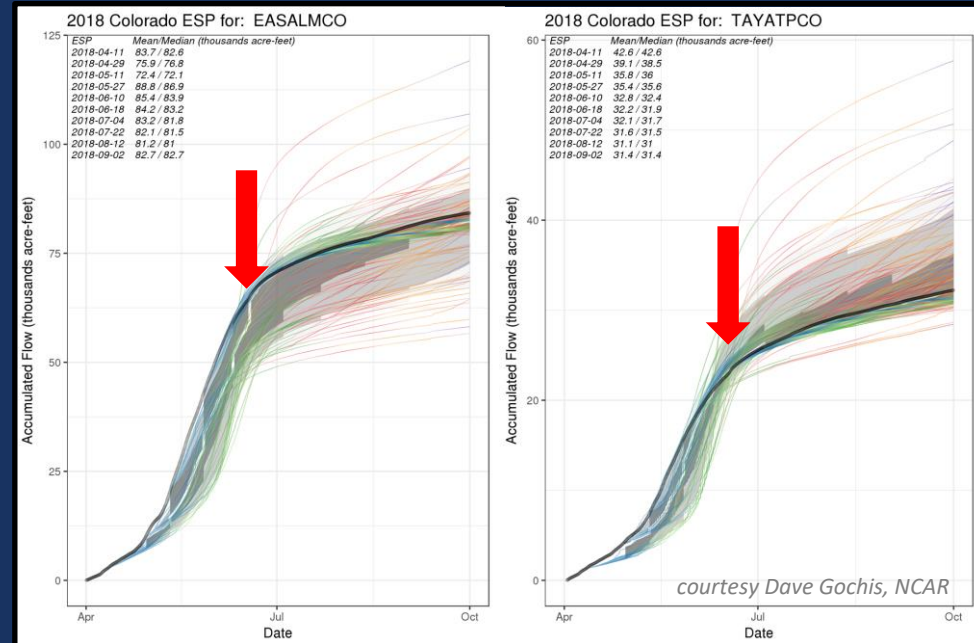


WRF-Hydro forecast with ASO data assimilation

- distributed, physics-based model
- ASO SWE ingest enforces spatial distribution of snow

East River @ Almont

Taylor River @ Taylor



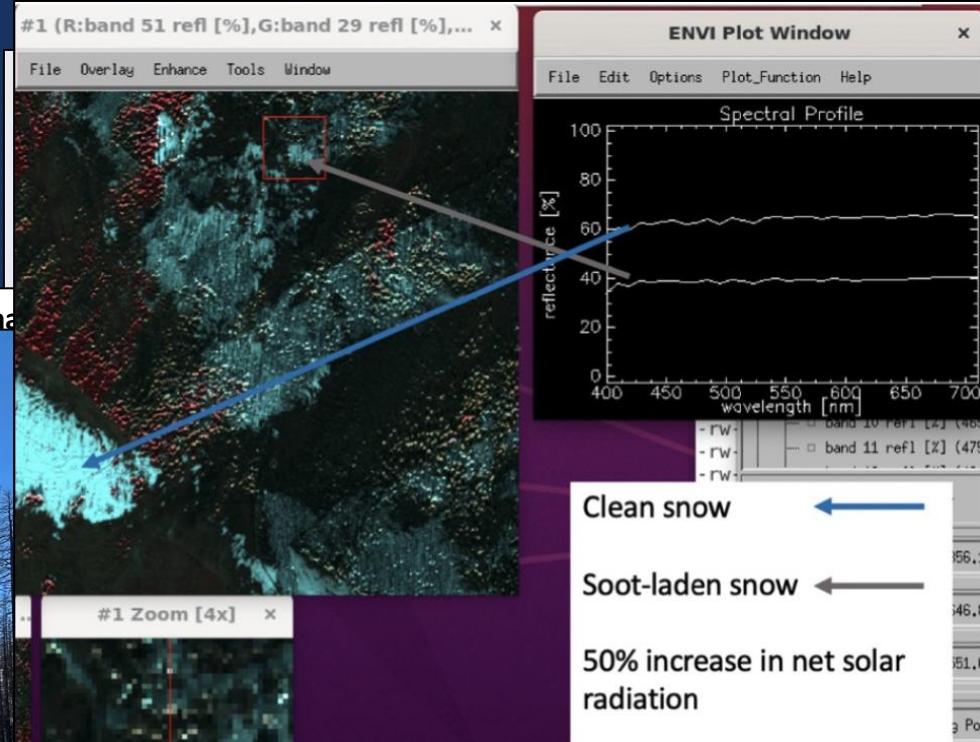
Adaptation in practice: Feather River, CA, 2022

Early warning of low snowpack

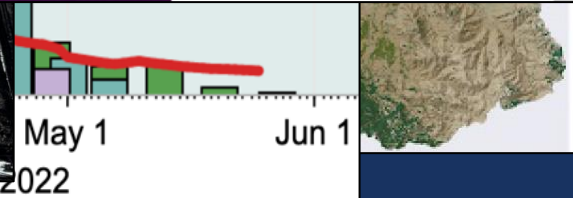
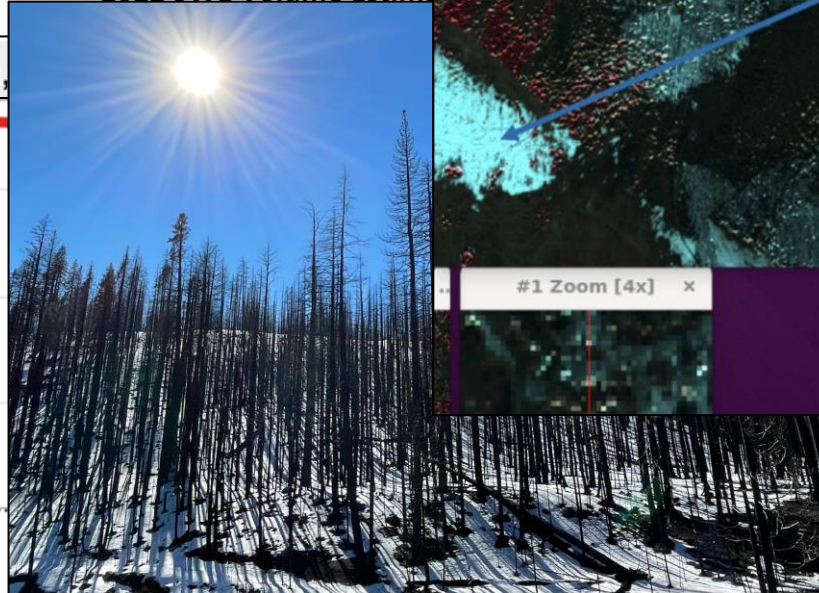
- snowpack peaked Jan 1st
- overestimated by conventional products

Wildfire impacts on hydrology

- >60% of basin burned in 4 years
- Large snow albedo reduction from soot




2022 SWE Volume Estima



The audit points to full ASO implementation

SUMMARY RECS INTRO ISSUES APPENDIX RESPONSE




Department of Water Resources

Its Forecasts Do Not Adequately Account for Climate Change and Its Reasons for Some Reservoir Releases Are Unclear

May 25, 2023
2022-106

The Governor of California
President pro Tempore of the Senate
Speaker of the Assembly
State Capitol



May 25, 2023

DWR Has Not Adequately Ensured That Its Water Supply Forecasts Account for the Effects of Climate Change

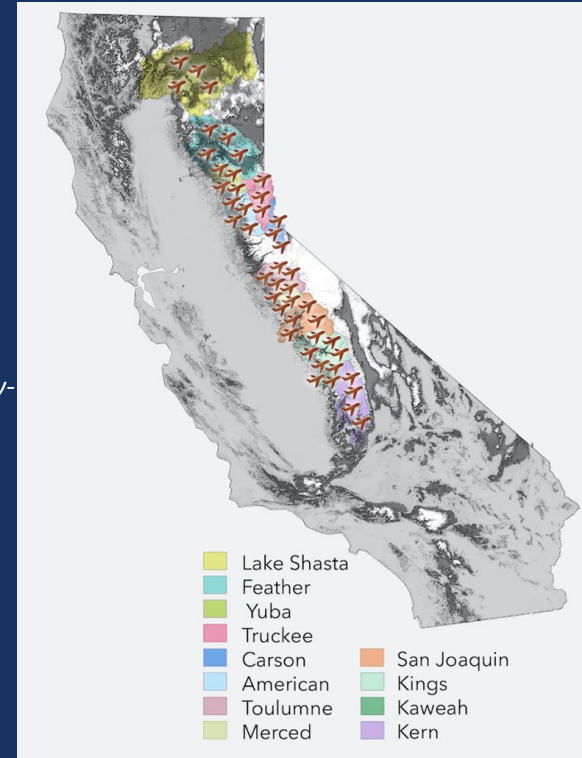
SUMMARY

Climate change has had significant ramifications for the State's water supply, and researchers project that its effects will increase in the future. Nonetheless, the Department of Water Resources (DWR) has been slow to account for the effects of climate change on key responsibilities related to managing the State's water resources.

For example, one of DWR's responsibilities is to develop water supply forecasts on which both state and local water agencies rely. However, DWR has not adequately ensured that its forecasts account for the effects of climate change. Similarly, it has not

DWR invested in ASO starting in 2013 and has done so since. They have tried to get the adequate funding for the complete program but have struggled.

The complete program is ASO with its physical snowpack constraint and physically-based runoff forecasting WRF-Hydro.





California Water Data Summit

Snowpack and Water Supply Data for Metropolitan Water District

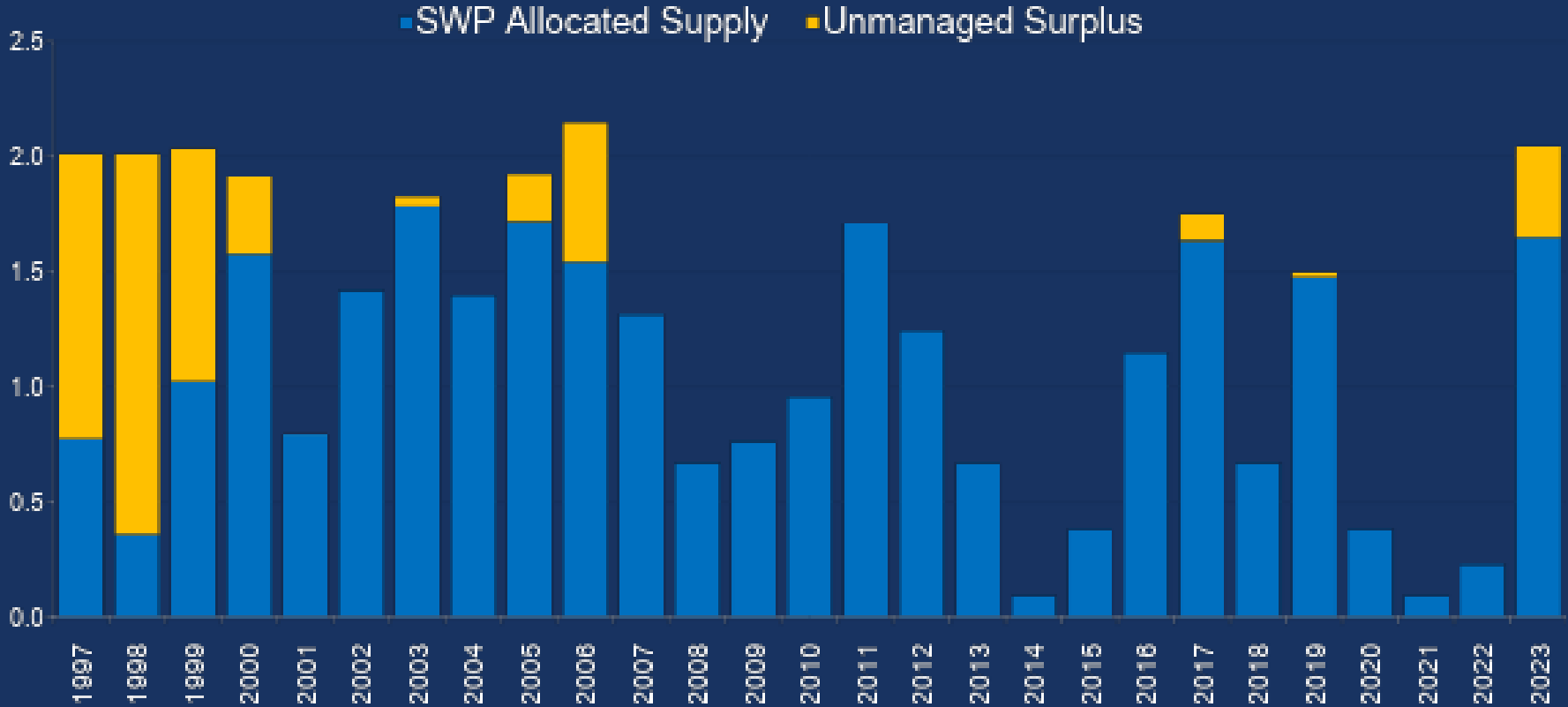
Brad Coffey, Water Resource Manager

September 7, 2023

Metropolitan Water District's Sources of Supplies

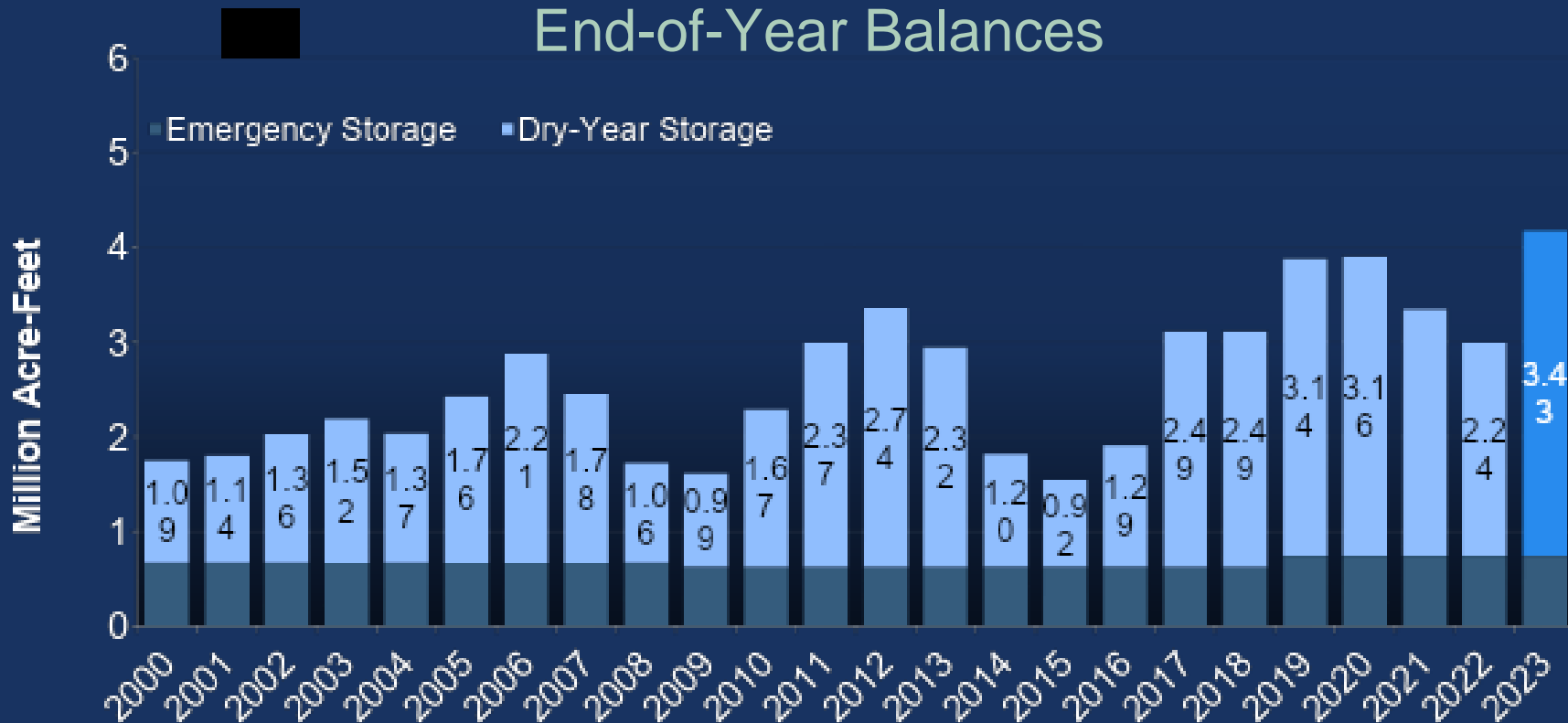


Historic Swings in State Water Project Availability



Metropolitan's Storage Capability

End-of-Year Balances

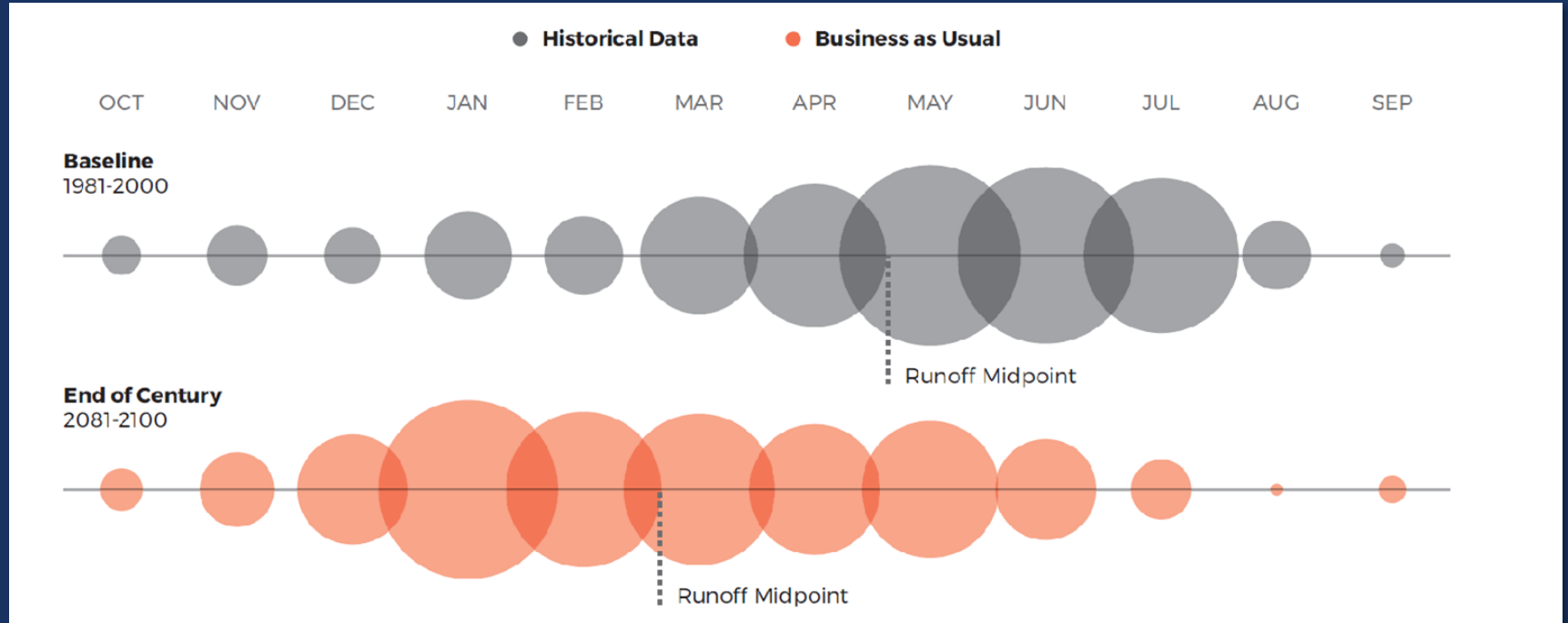


Note: 2023 end-of-year balance is preliminary as they are subject to DWR adjustments and USBR final accounting.

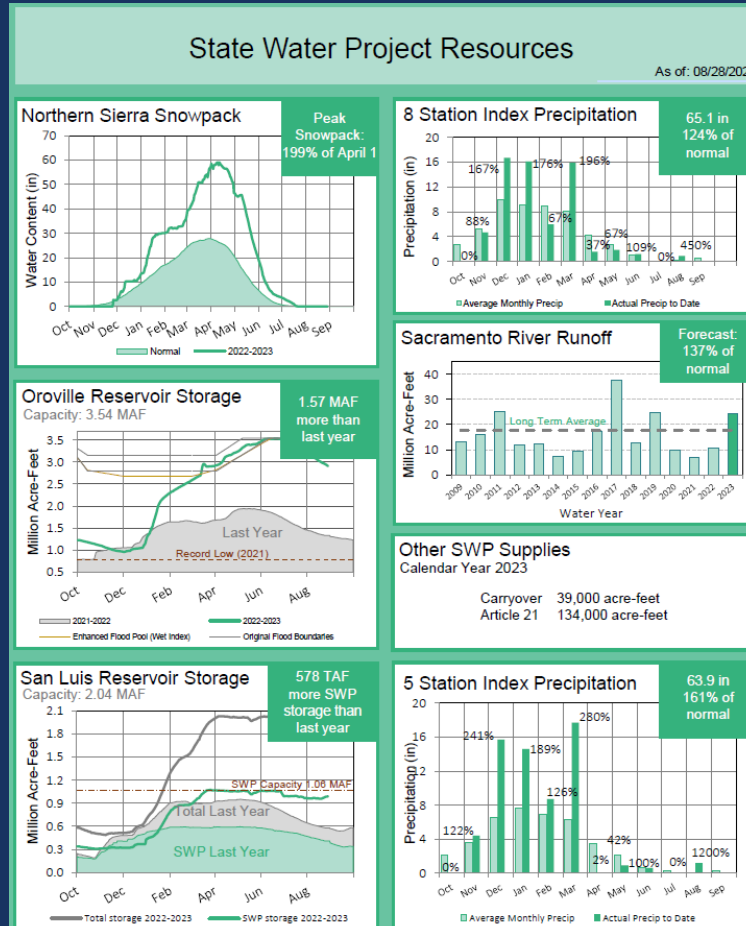
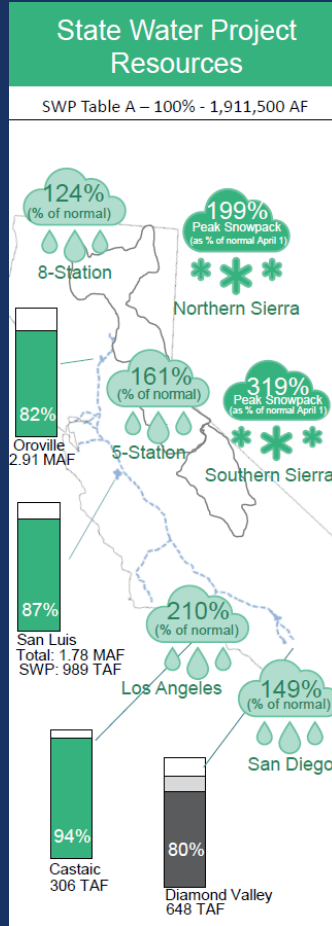
Multi-Purpose Storage Reservoirs – Lake Oroville



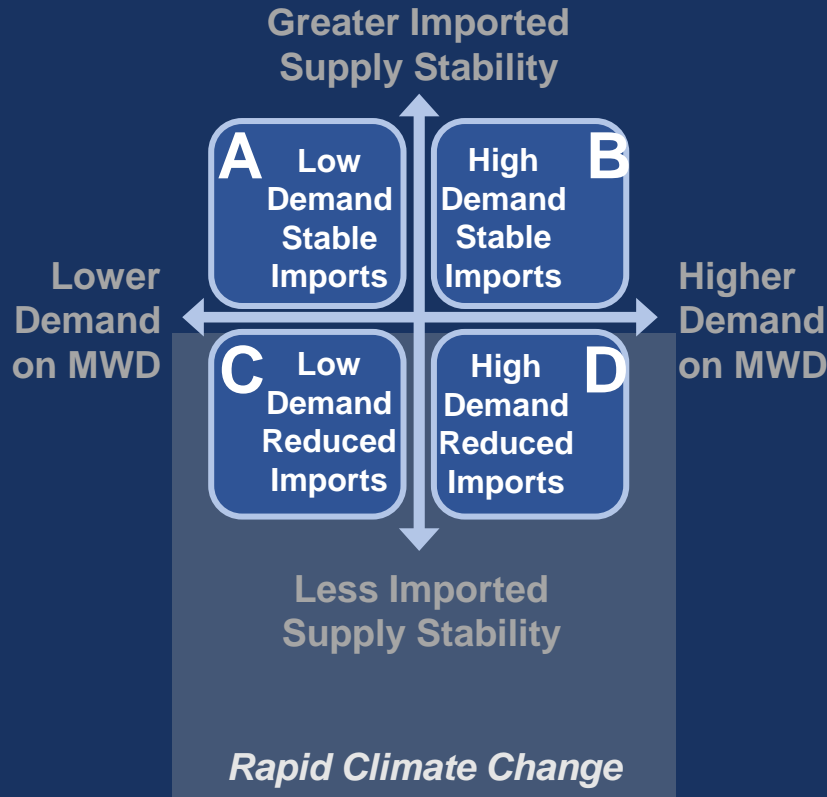
California's Water Infrastructure Challenge



Metropolitan's Water Supply Conditions Report



Pre-Experiencing Our Future



Climate Adaptation Master Plan for Water

Reliability
Resilience
Affordability
Financial
Sustainability



CONNECT WITH US!



Stanford Visitor
(no password needed)



@MNWDWater

@california-data-collaborative

@swanforum



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