Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

An Overview of Water Year 2023 in the western U.S.

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Center for Western Weather and Water Extremes, UCSD Scripps Institution of Oceanography

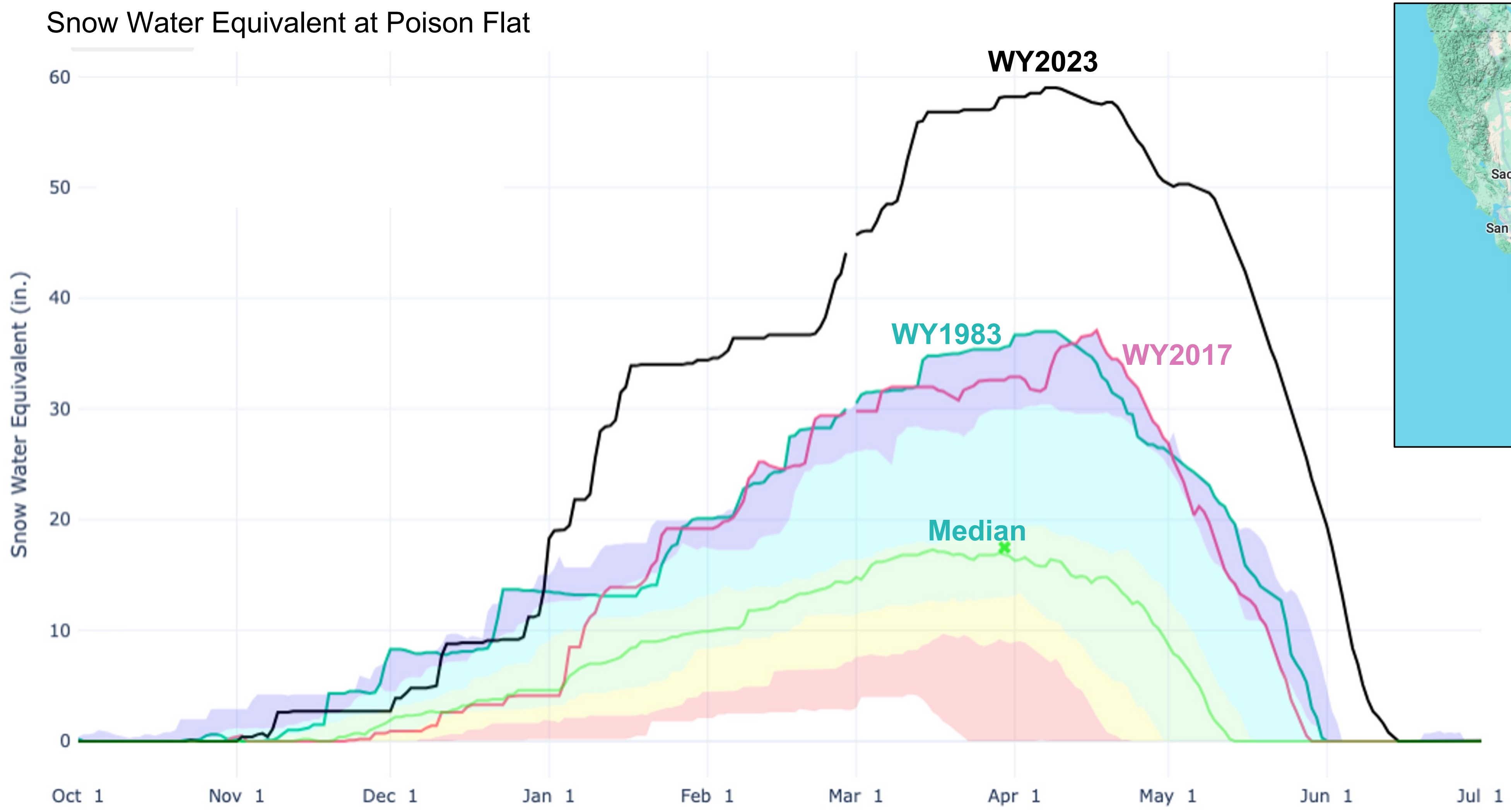
With support from the whole CW3E team, especially by C. Castellano, T. Brandt, K. Haleakala, and Z. Zhang

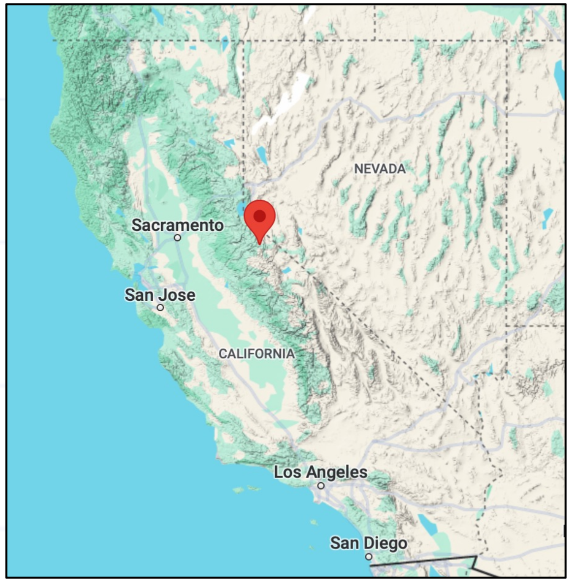
UC San Diego | SCRIPPS INSTITUTION OF OCEANOGRAPHY

Thursday, 29 February 2024
WPC WWE Seminar

Water Year Summary

Sierra Snows: WY2023 was a big snow year out West

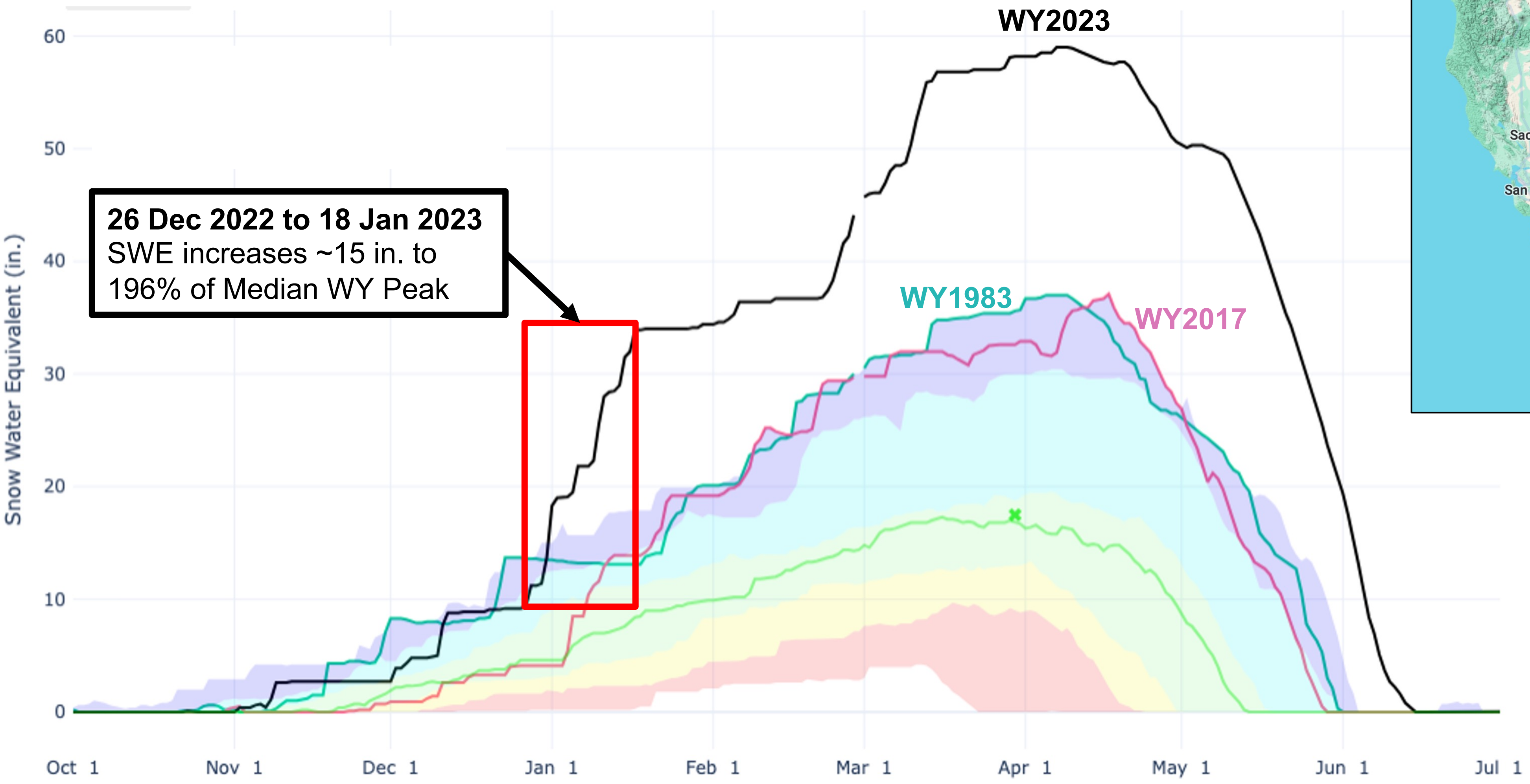


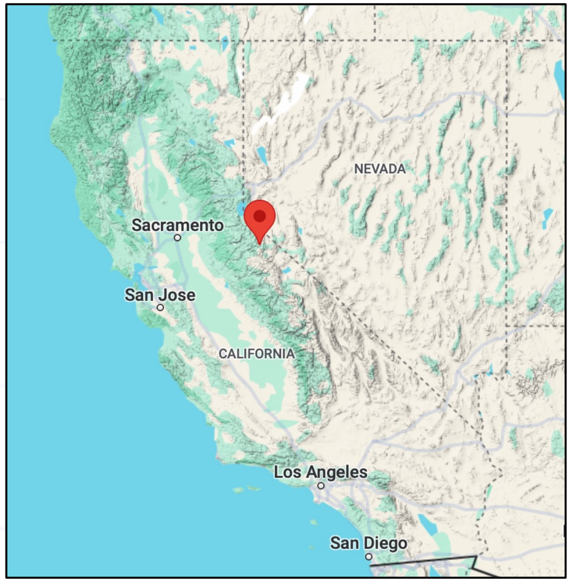


Source: USDA NRCS National Water & Climate Center

Sierra Snows: WY2023 was a big snow year out West

Snow Water Equivalent at Poison Flat





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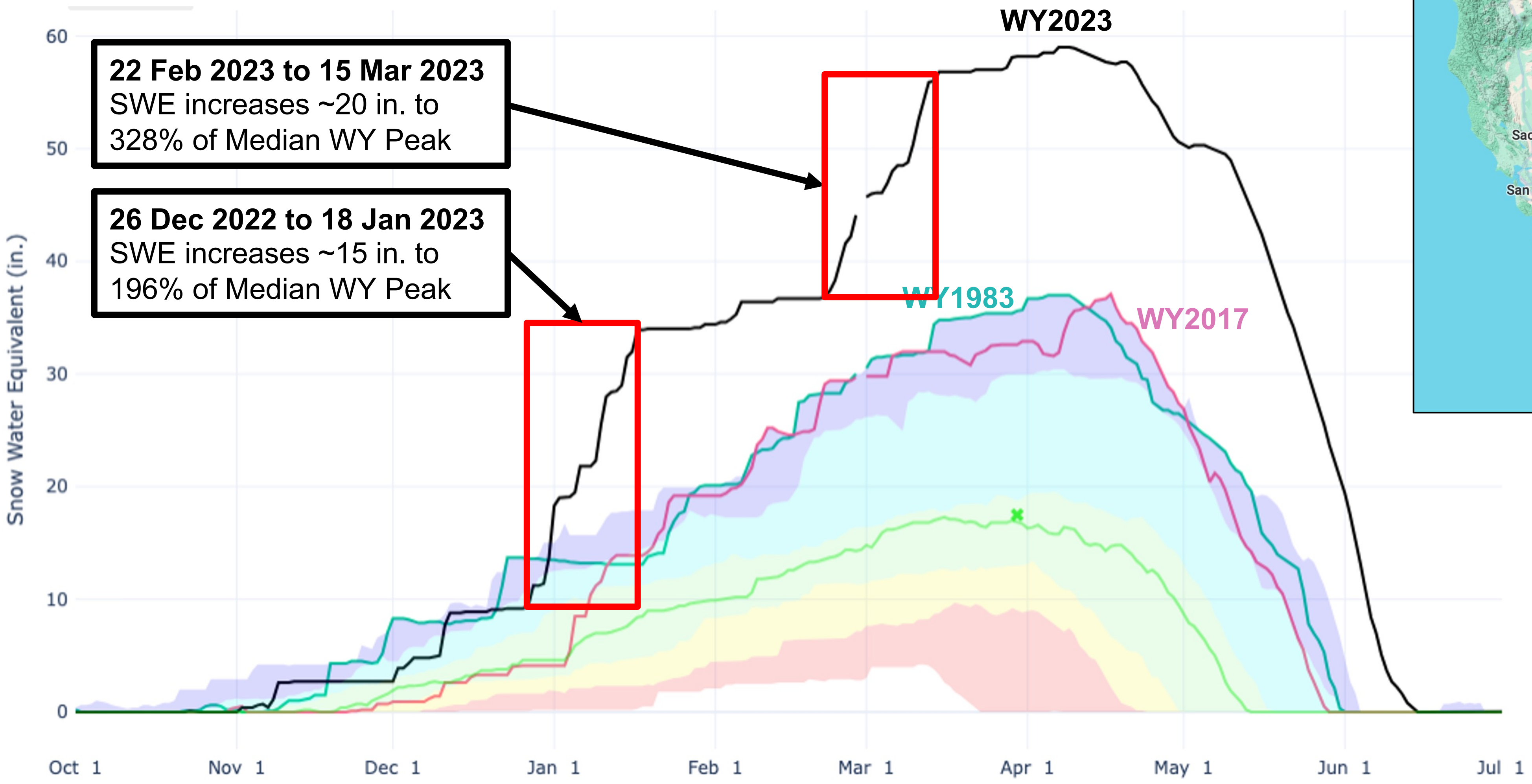

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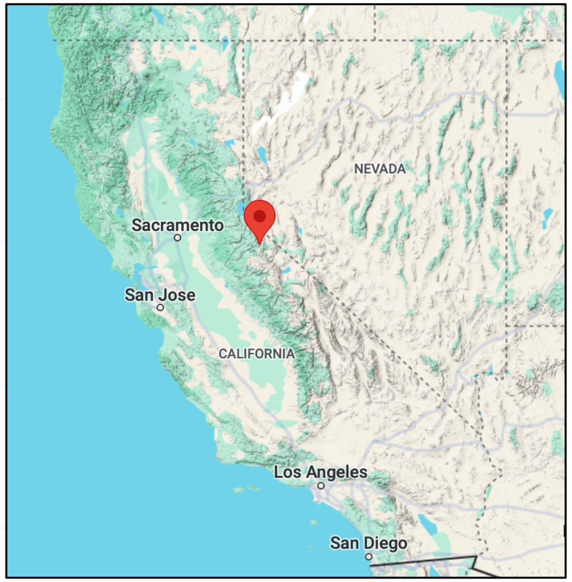

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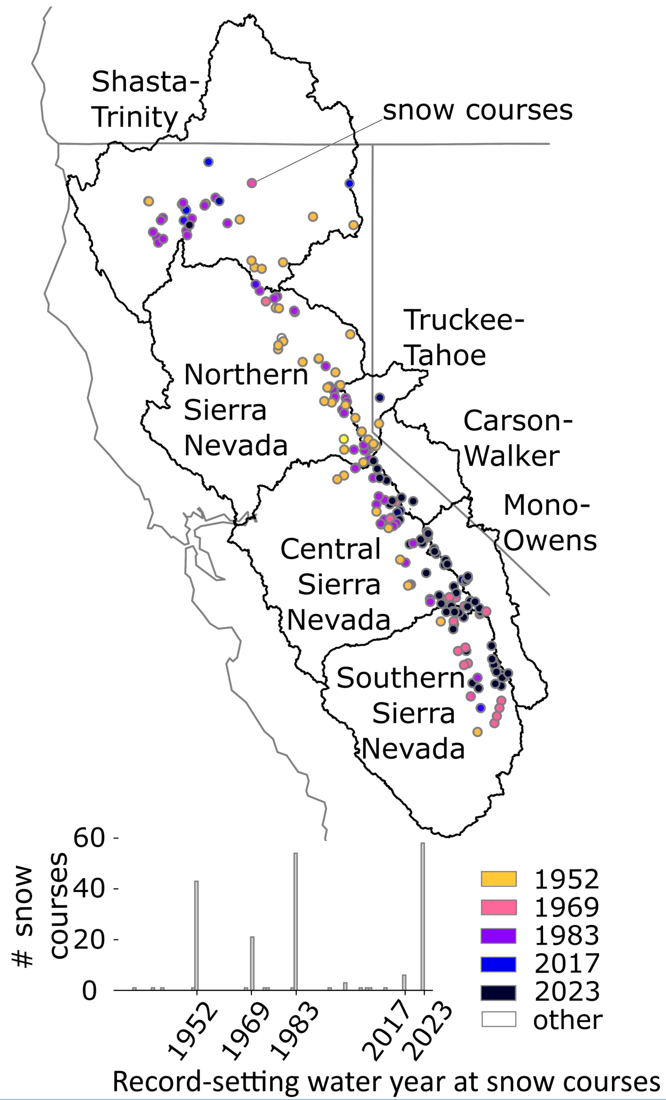
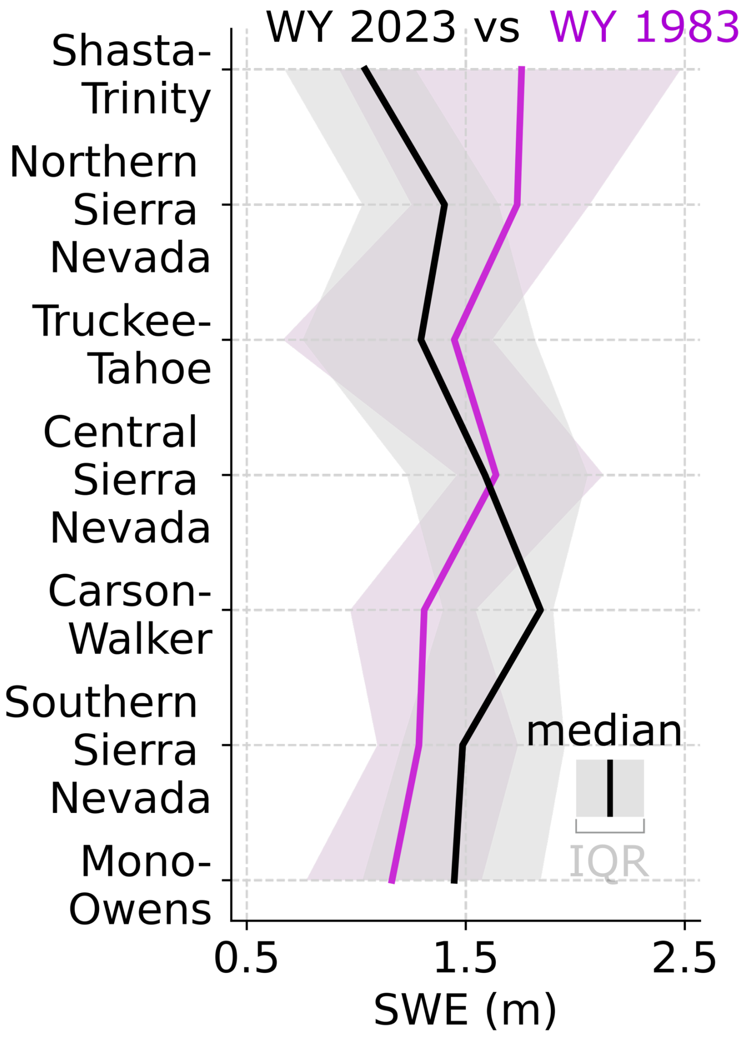
Sierra Snows: WY2023 was a big snow year out West

Summary of snowfall:

- Ranked peak SWE from snow courses (~200) from 1930's through 2023
- Big years: 1952, 1969, **1983**, 2017 and 2023
- Northern, central and southern shifts observed
- WY2023 was particularly "large" in the southern and central Sierra Nevada





Slide courtesy Ty Brandt and Kayden Haleakala

Upper Colorado Snows: WY2023 was a big snow year out West

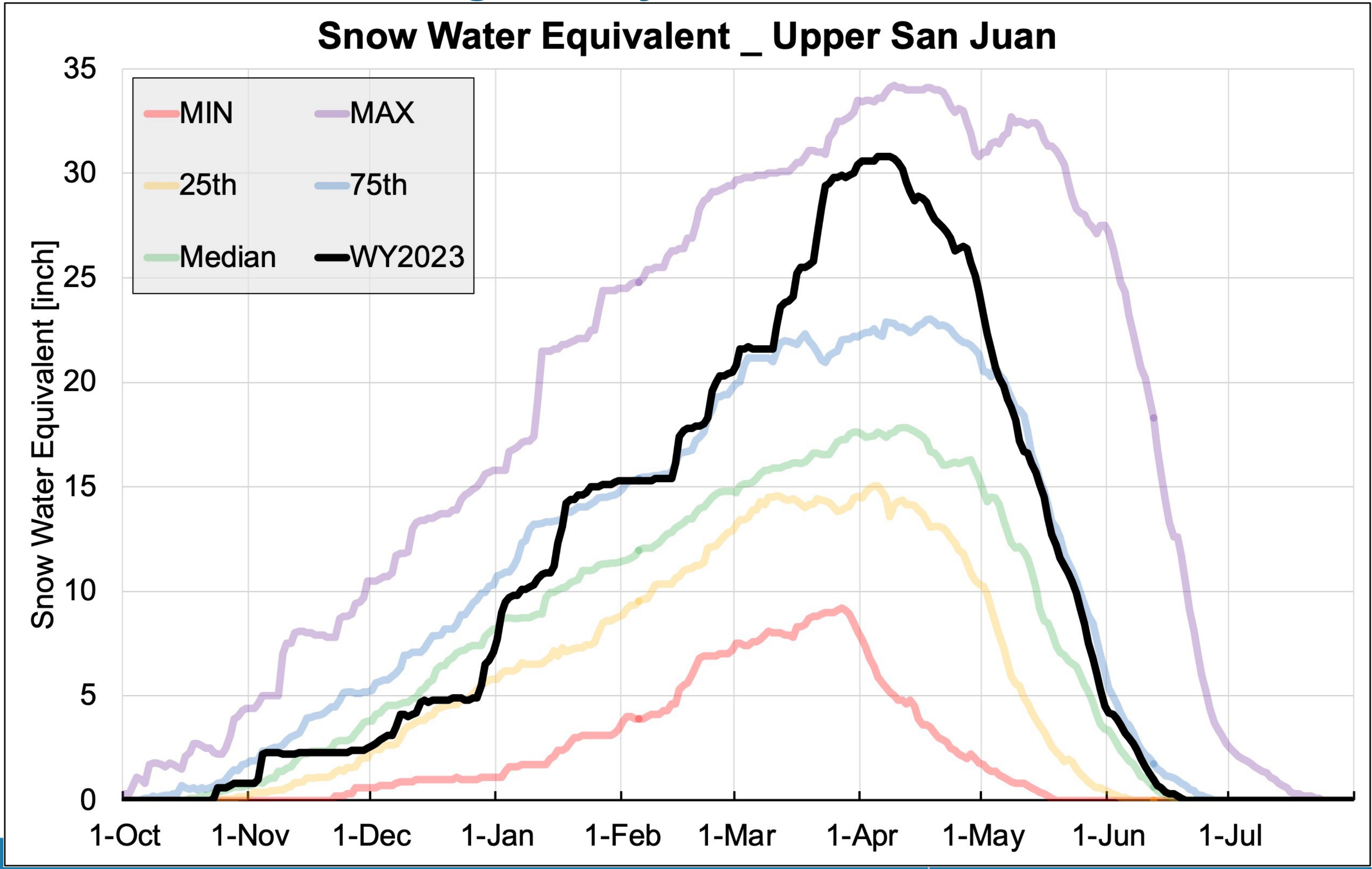
WY2023 SWE in San Juan Basin (16 SNOTEL Sites)

Peak in WY 2023:

- **30.8 inches SWE**
- **152% of normal SWE peak in San Juan**

(normal SWE peak: annual median SWE peak during WY 1991-2022, 20.3 in.)

The Min., Max., median, 25th and 75th percentile of SWE are based on the data during WY1991–WY2022.



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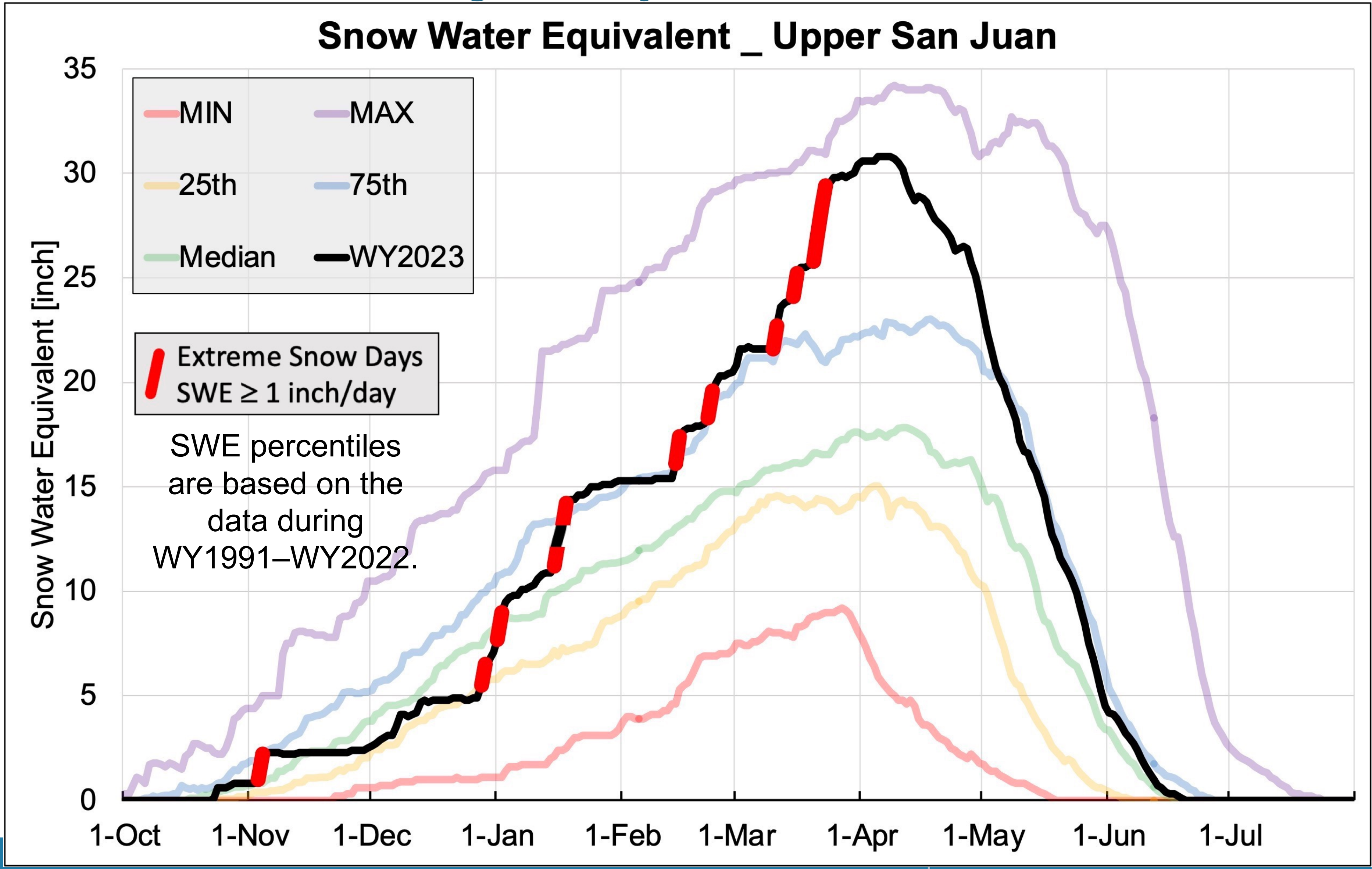
(normal SWE peak: annual median SWE peak during WY 1991-2022, 20.3 in.)

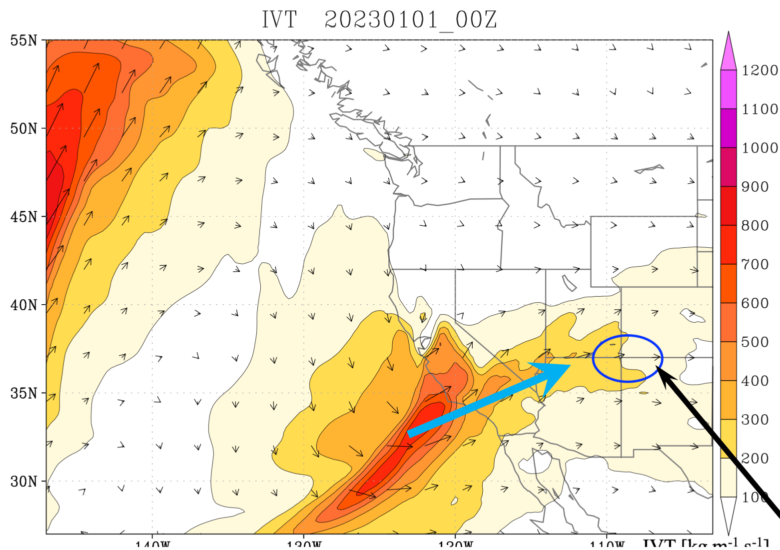
12 Extreme Snow Days (SWE ≥ 1 in/day):

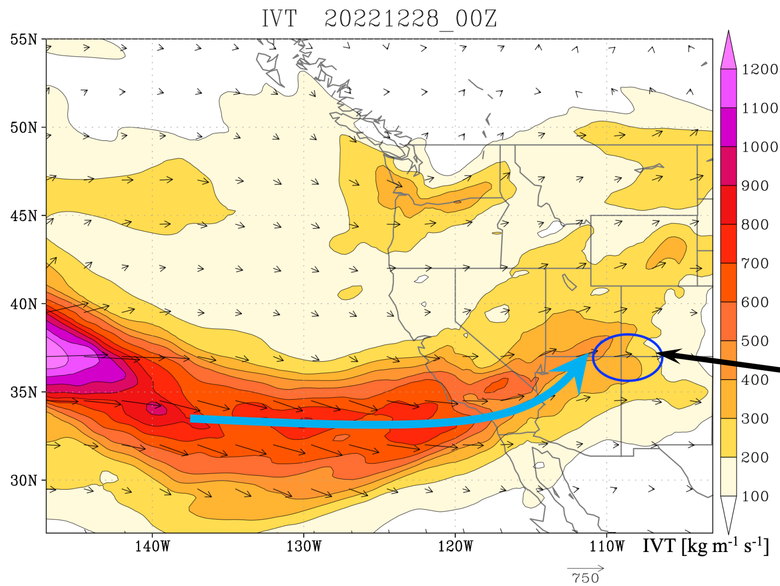
- **14.1 inches SWE**
- **70% of normal SWE peak**
- **46% of WY2023 SWE peak**



Slide courtesy Zhenhai Zhang

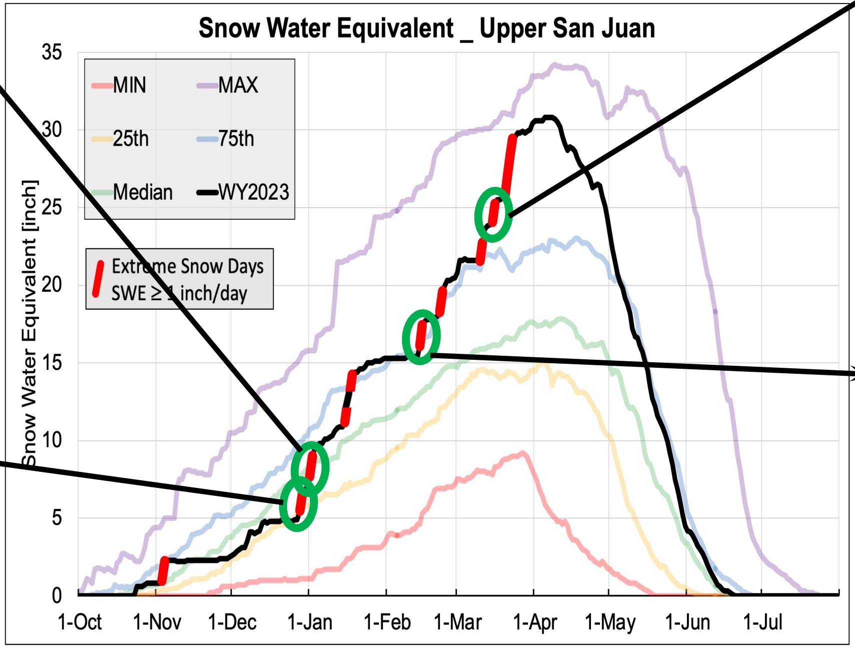
Upper Colorado Snows: Contribution of ARs

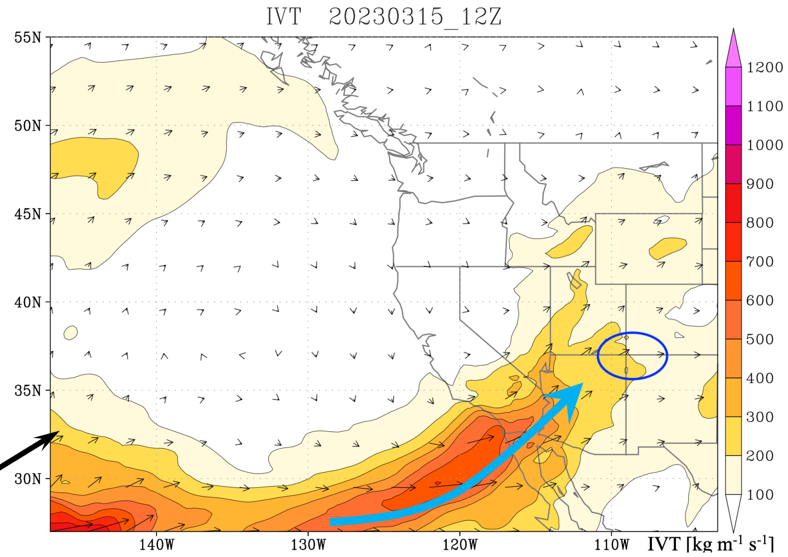


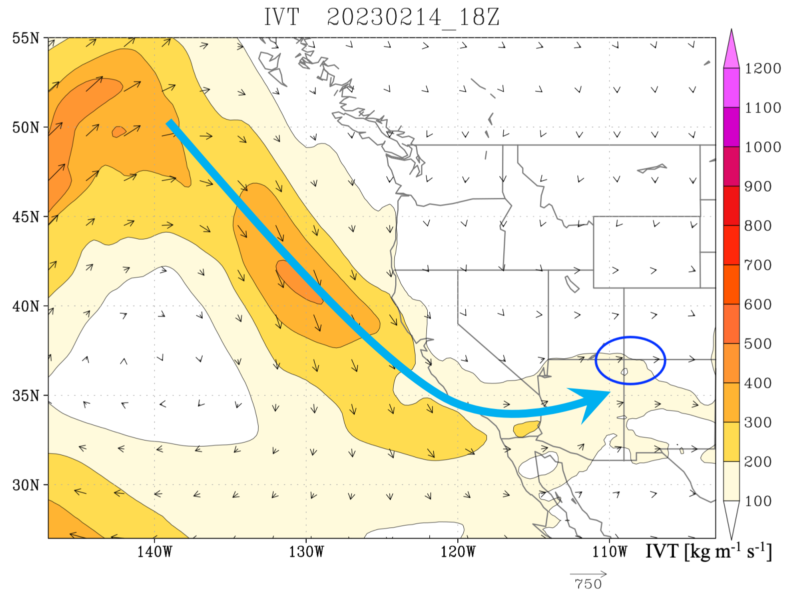


Landfalling ARs
over the Southern–Baja
California penetrating into the
Southwest U.S.

San Juan Basin

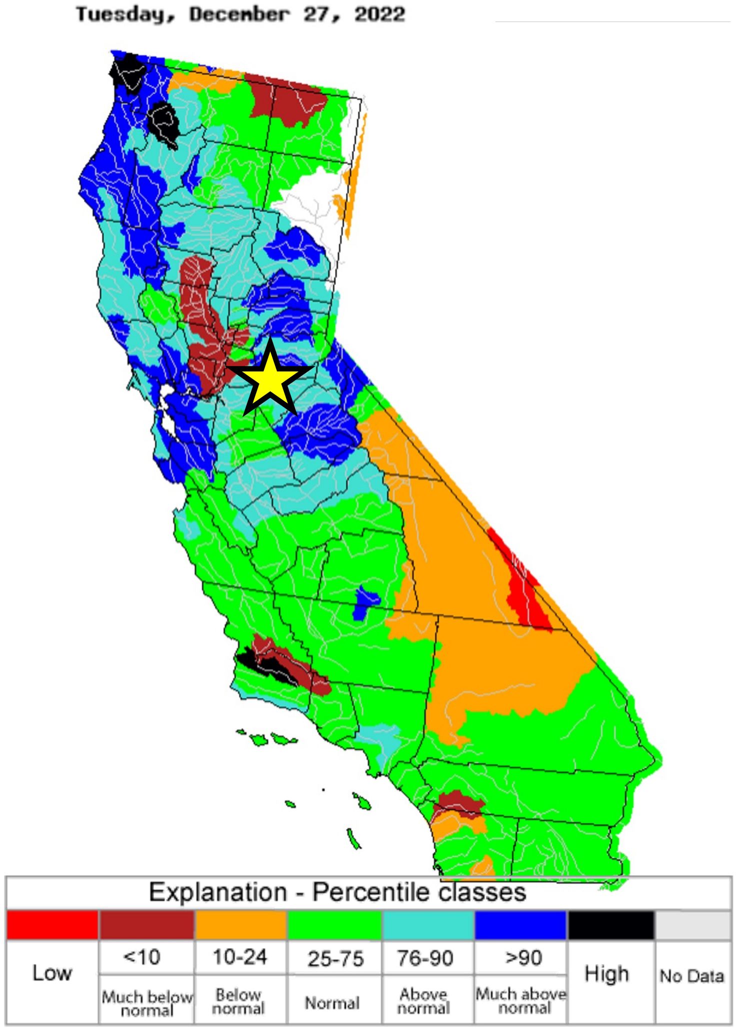


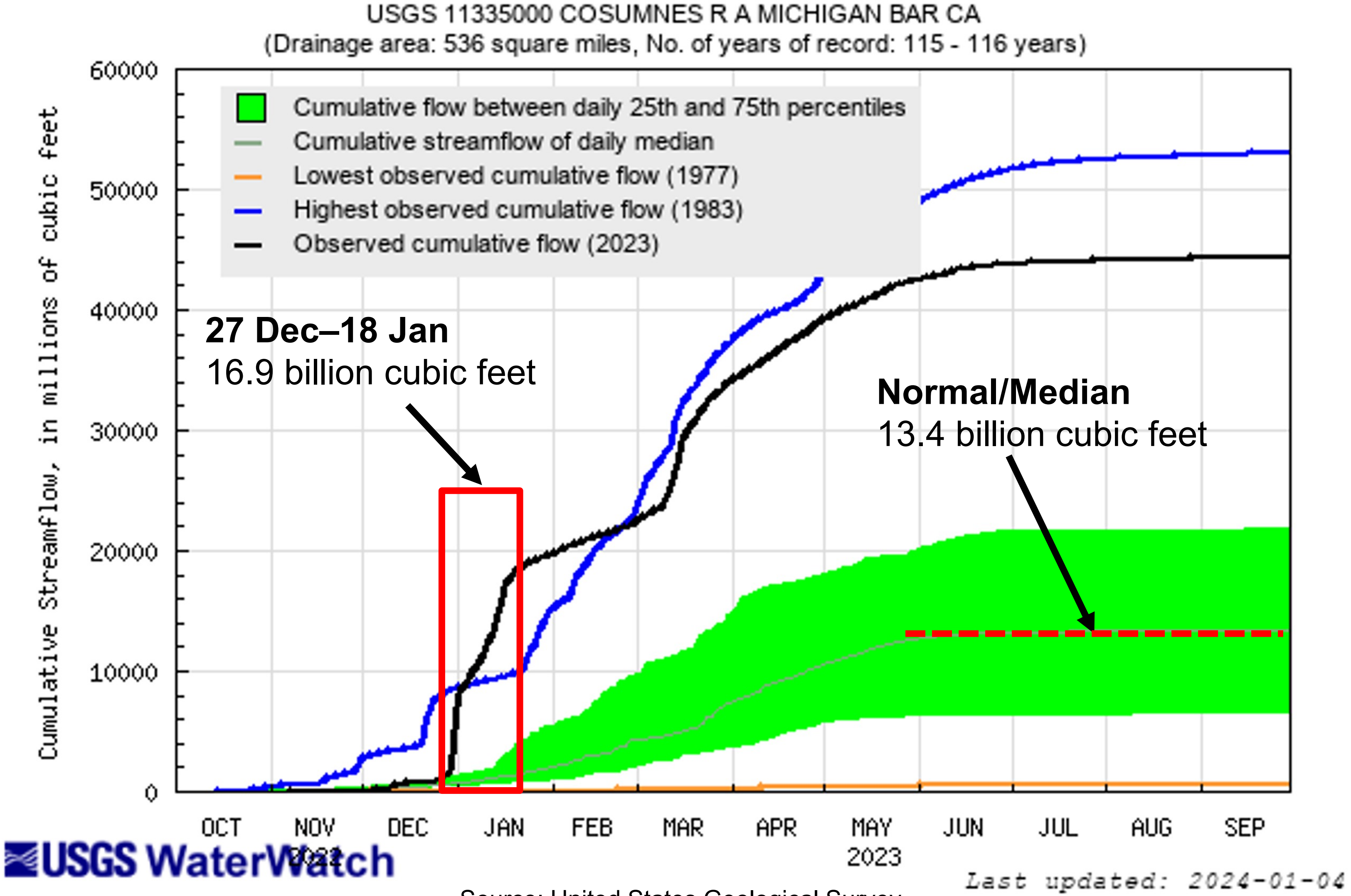




California Water: WY2023 was a big year for water resources

Daily Streamflow (HUC8)





Source: United States Geological Survey

California Water: WY2023 was a big year for water resources

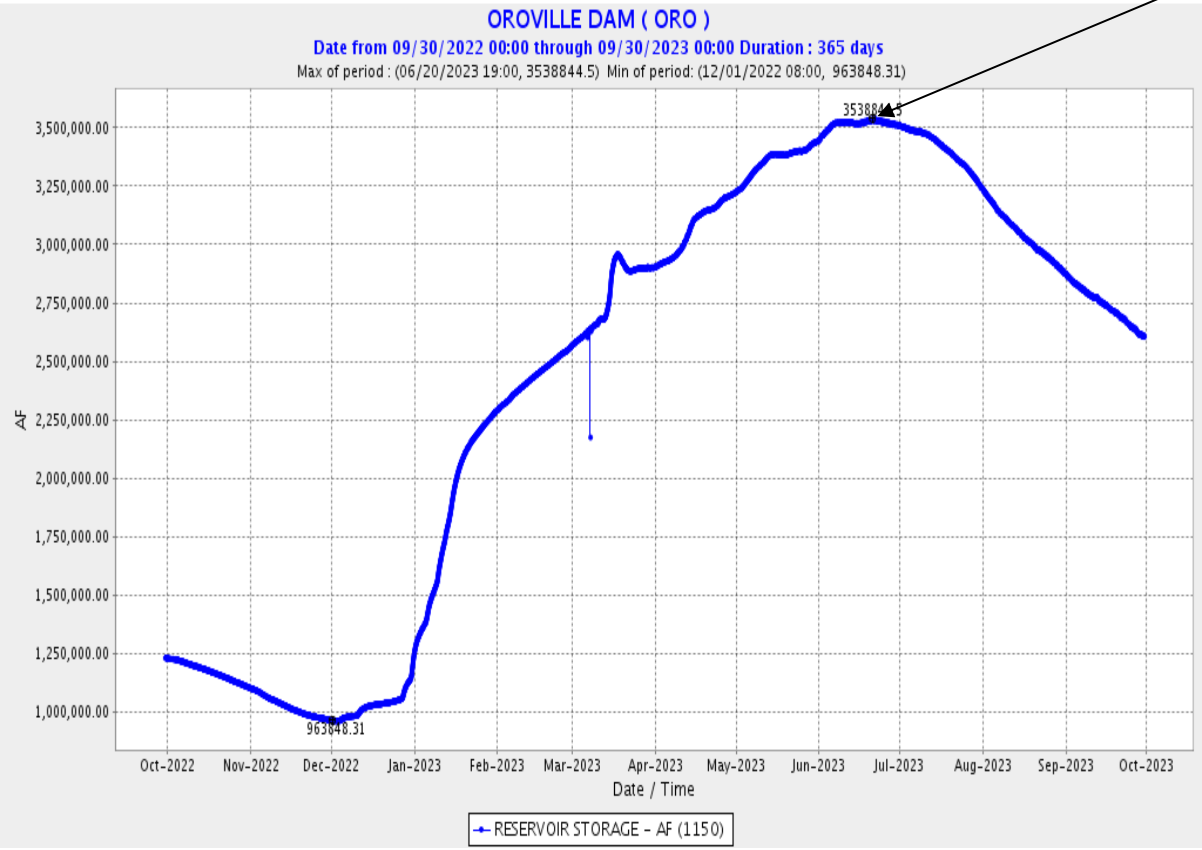
Lake Oroville:
22 July 2021

Lake Oroville:
15 June 2023

Photo Credits: Before Justin Sullivan / Getty Images **After** Justin Sullivan / Getty Images

California Water: WY2023 was a big year for water resources

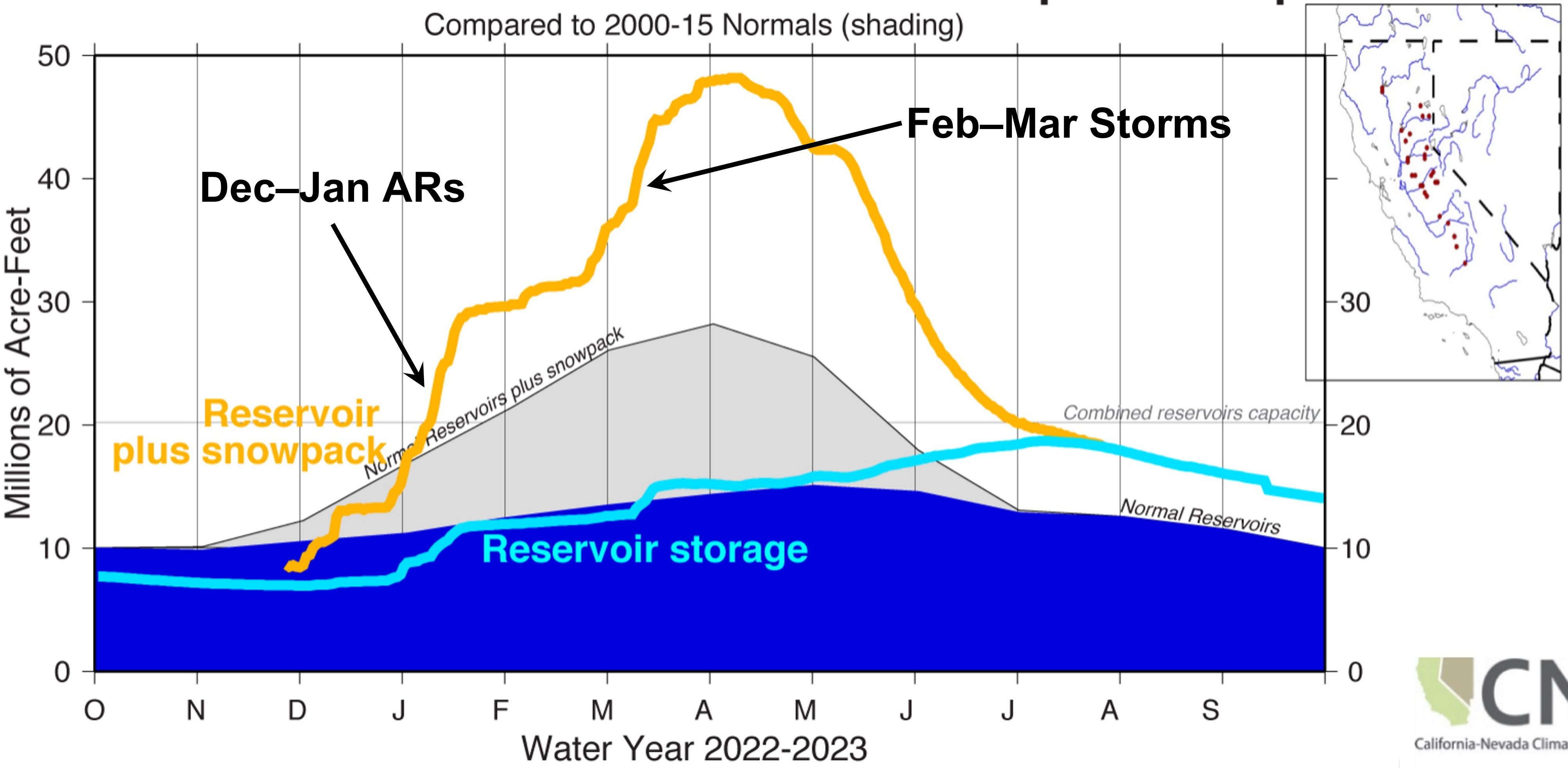
Lake Oroville: Storage WY2023



Lake Oroville: 15 June 2023

California Water: WY2023 was a big year for water resources

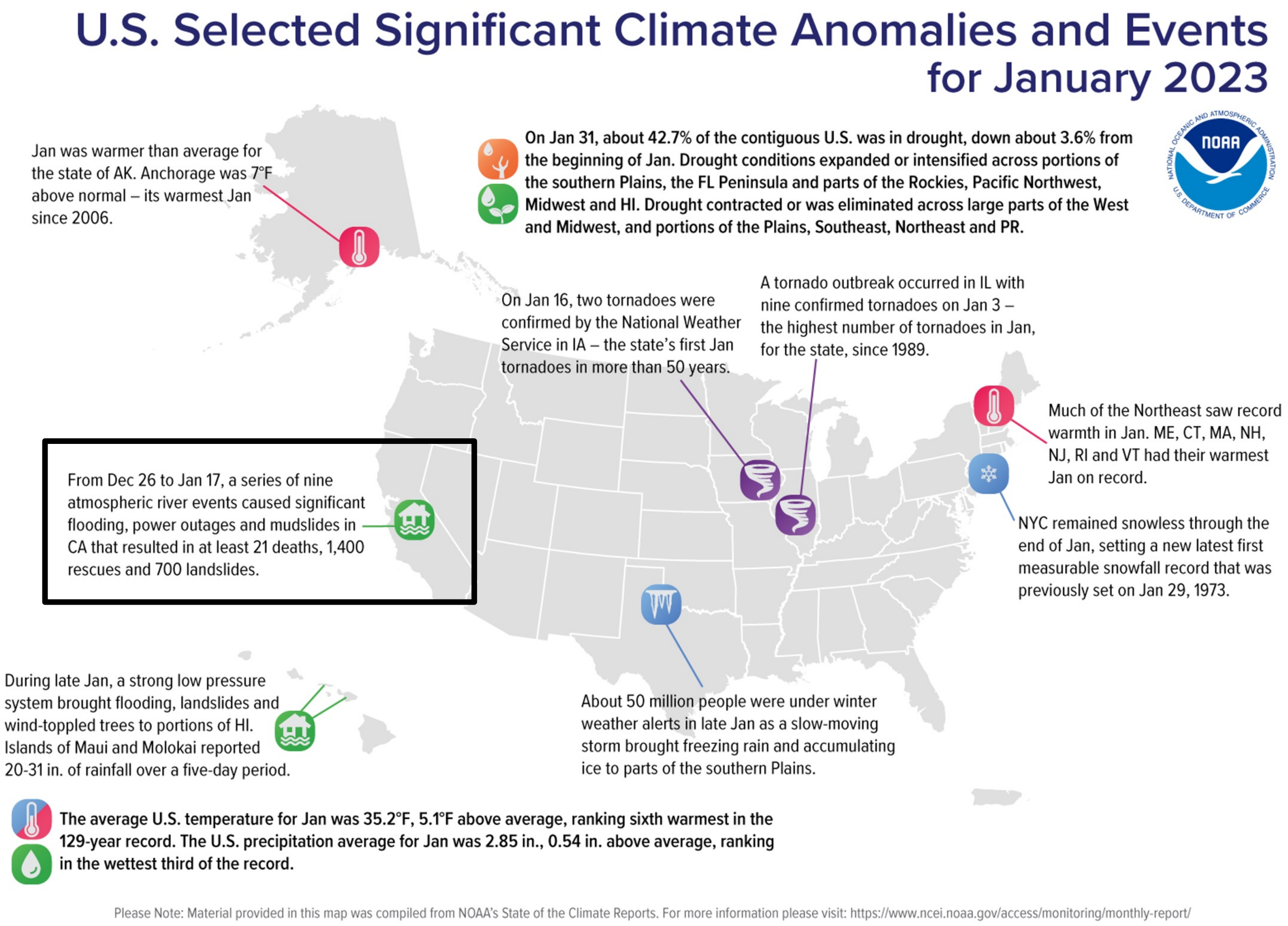
Water Stored in 28 Western Sierra Reservoirs plus Snowpack

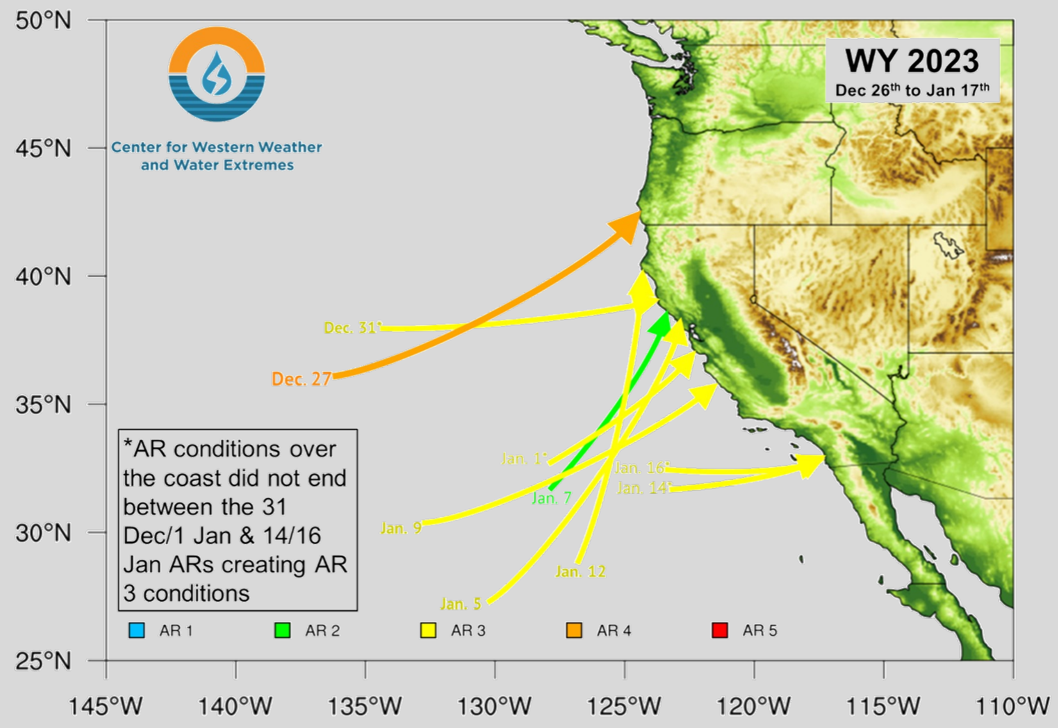


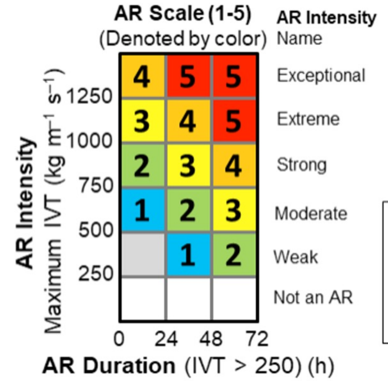
California-Nevada Climate Applications Program
A NOAA RISA team

Atmospheric Rivers

ARs: Late December into Early January Featured several landfalling ARs







- The Atmospheric River Scale is based on ***Duration*** and max ***Intensity*** (IVT) at a specific location
- The AR Scale communicates the potential benefits and hazards associated with ARs

IMPACTS

- AR 5 – Primarily hazardous
- AR 4 – Mostly hazardous, also beneficial
- AR 3 – Balance of beneficial and hazardous
- AR 2 – Mostly beneficial, also hazardous
- AR 1 – Primarily beneficial

Ralph et al., *BAMS*, 2019.

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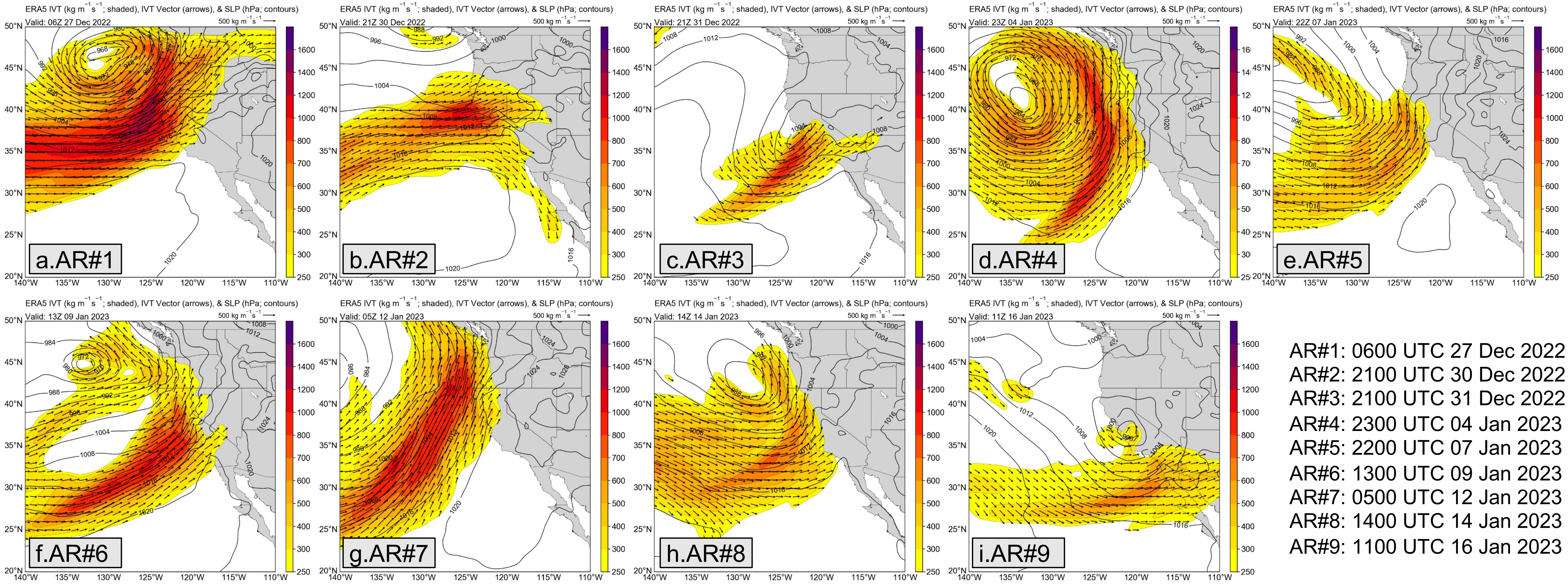
Storm Snapshots: Nine ARs at their time of maximum coastal IVT magnitude



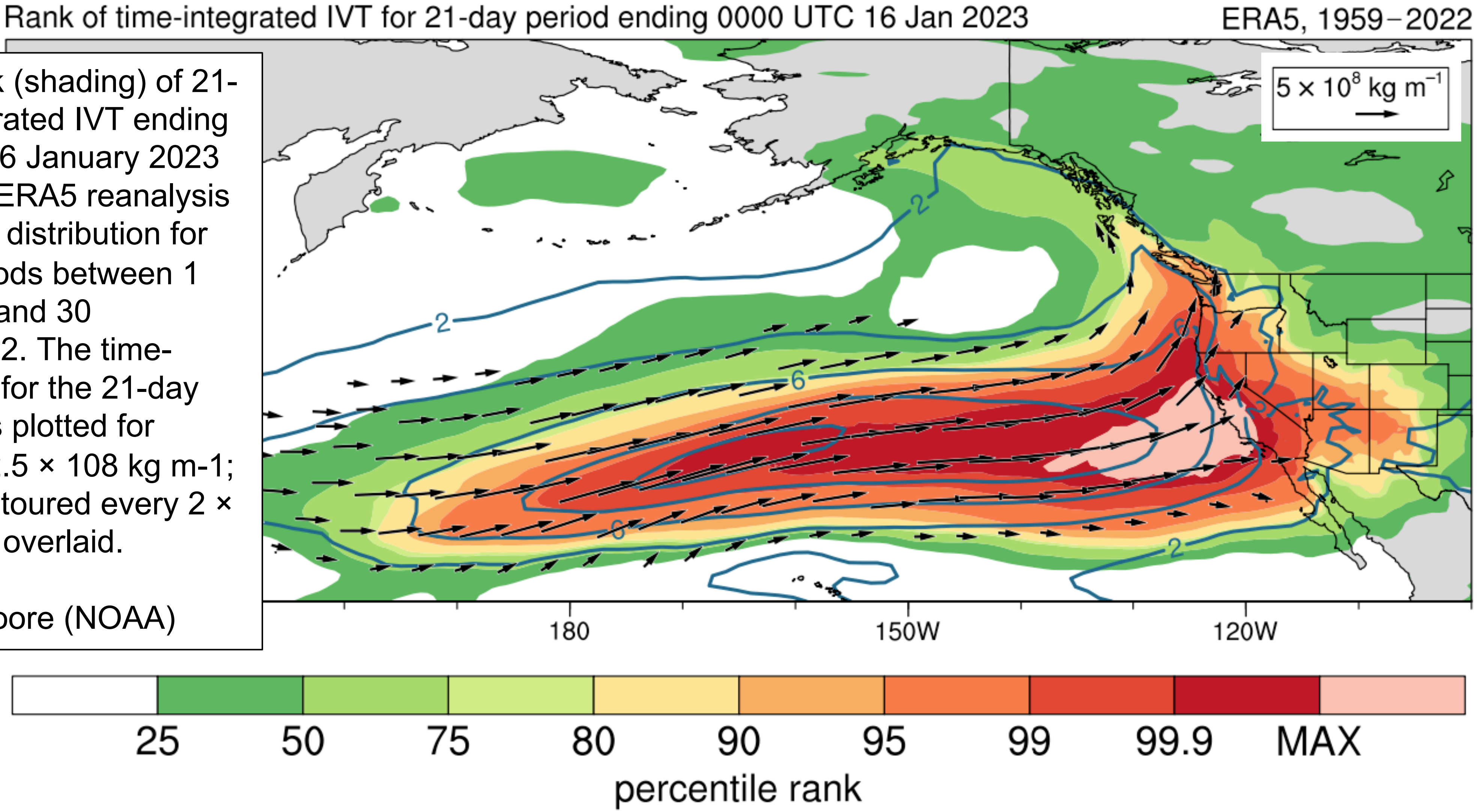
AR#1: 0600 UTC 27 Dec 2022
AR#2: 2100 UTC 30 Dec 2022
AR#3: 2100 UTC 31 Dec 2022
AR#4: 2300 UTC 04 Jan 2023
AR#5: 2200 UTC 07 Jan 2023
AR#6: 1300 UTC 09 Jan 2023
AR#7: 0500 UTC 12 Jan 2023
AR#8: 1400 UTC 14 Jan 2023
AR#9: 1100 UTC 16 Jan 2023

Integrated water vapor transport (IVT) magnitude (kg/ms; shaded according to scale) and direction (vectors according to reference; top right) with sea-level pressure (hPa; contours) at time of maximum IVT magnitude over coastal California for each of nine landfalling ARs on 27 December 2022 through 16 January 2023. Data source is ECMWF ERA5.

Climatological Perspective: Time-Integrated IVT

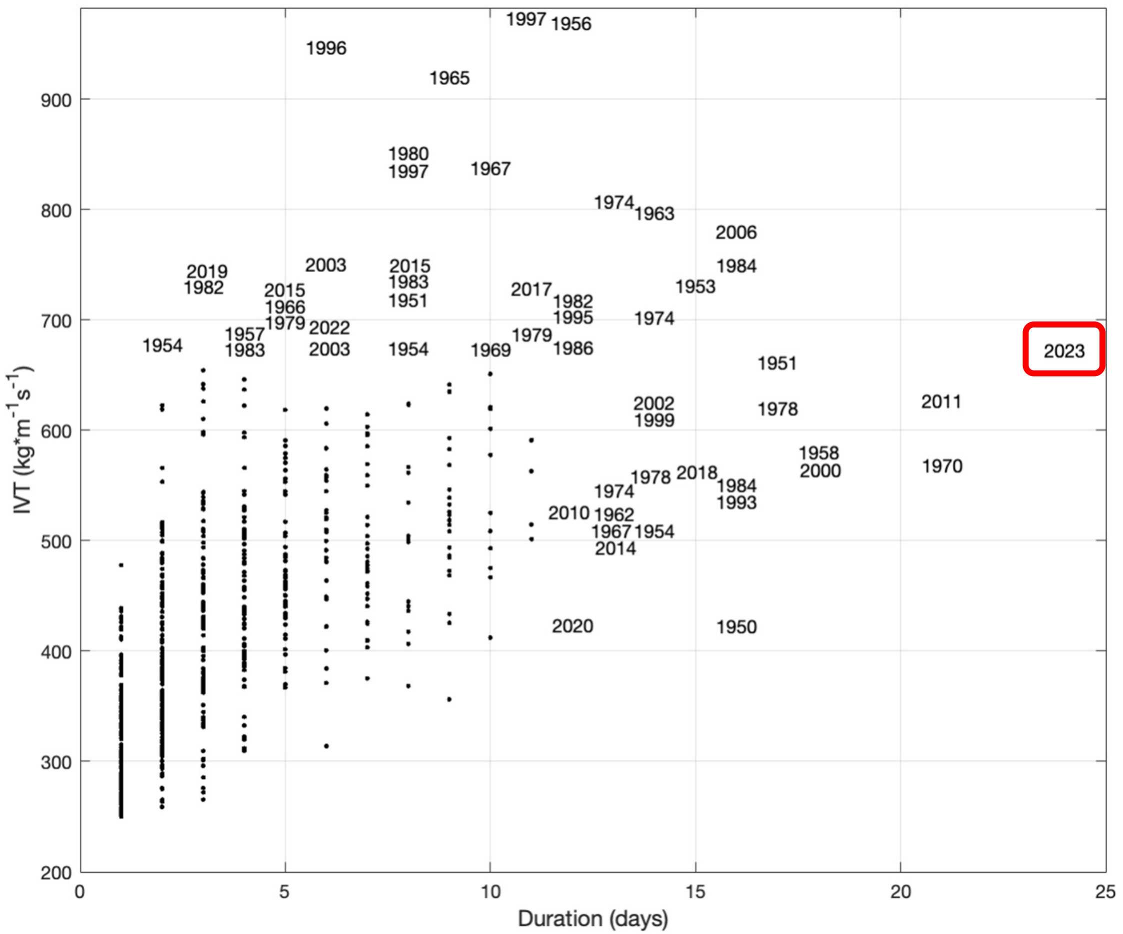
Percentile rank (shading) of 21-day time-integrated IVT ending at 0000 UTC 16 January 2023 from ECMWF ERA5 reanalysis with respect to distribution for all 21-day periods between 1 January 1959 and 30 November 2022. The time-integrated IVT for the 21-day period (vectors plotted for magnitudes >2.5 × 108 kg m-1; magnitude contoured every 2 × 108 kg m-1) is overlaid.

Image: Ben Moore (NOAA)



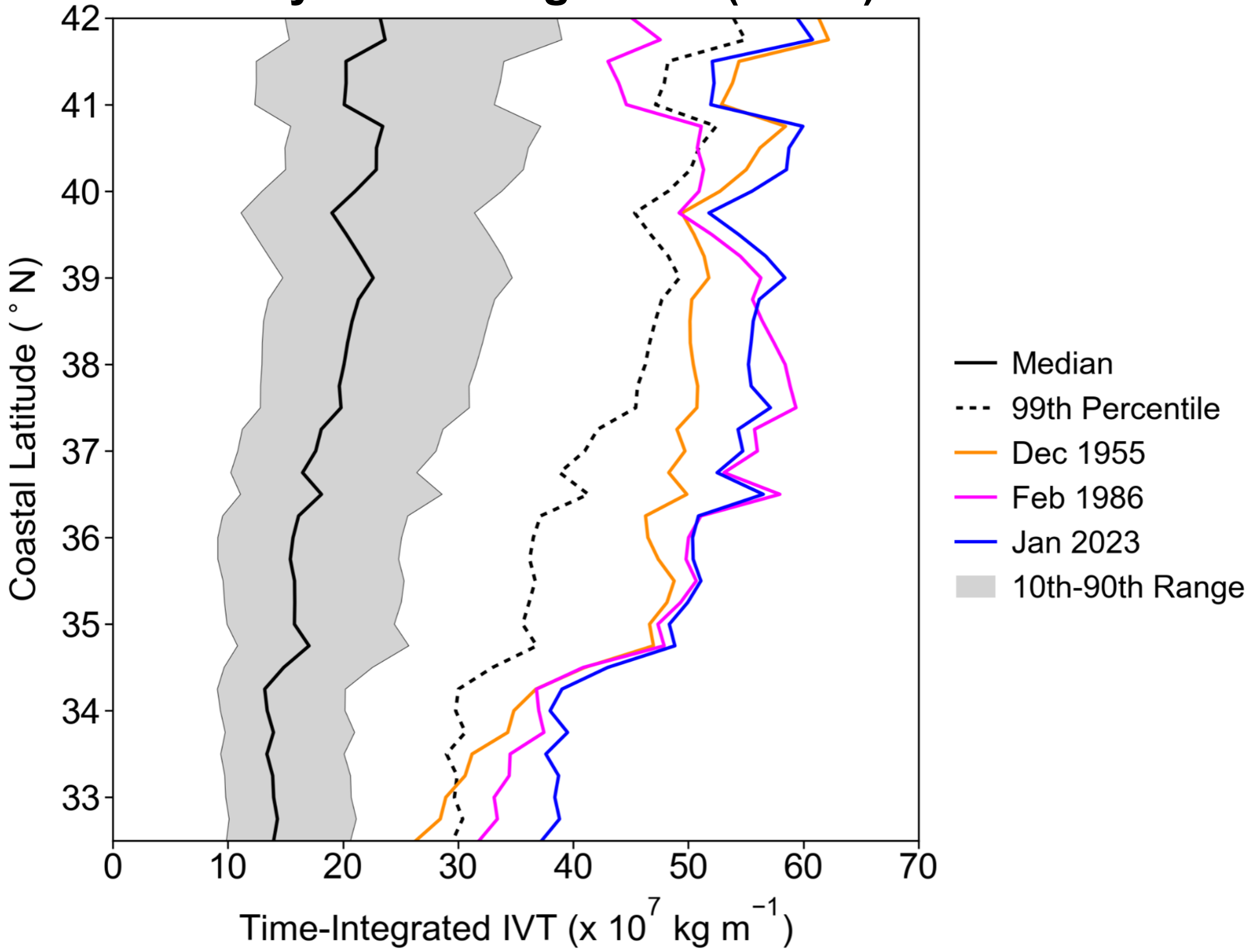
Climatological Perspective: Time-Integrated IVT

Duration and IVT Magnitude of AR Families

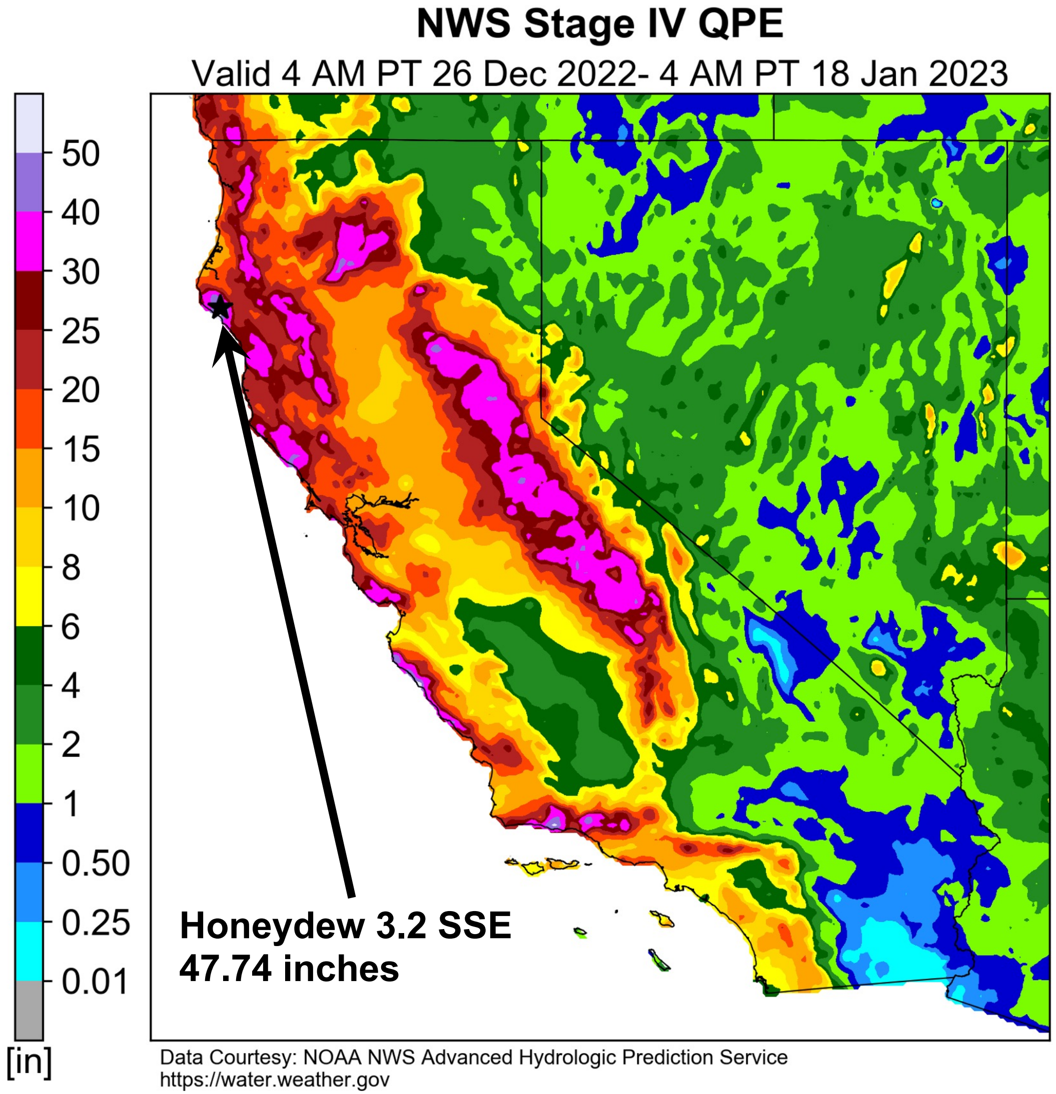


*As identified by SIO/CW3E's AR detection algorithm using NCEP/NCAR Reanalysis

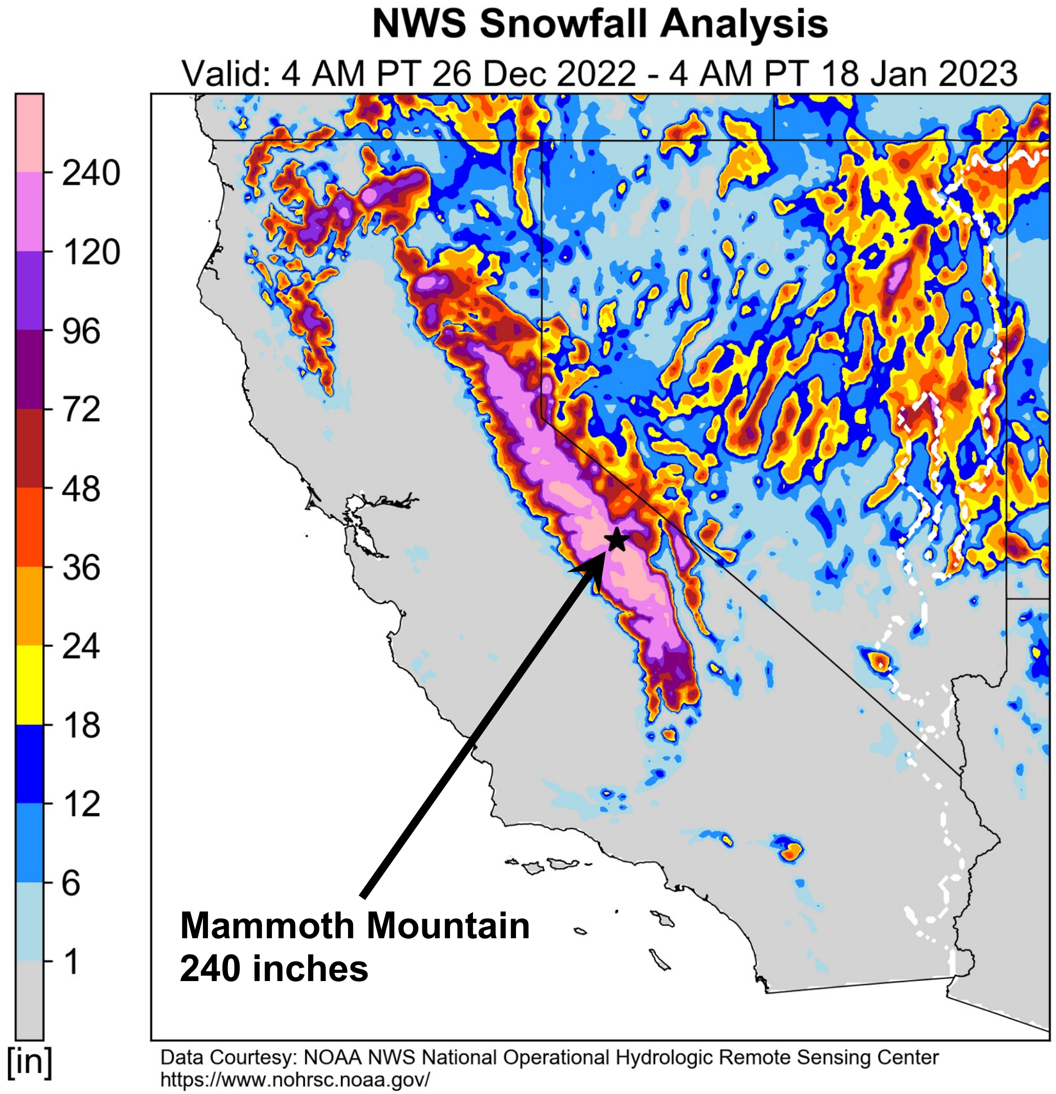
23-day TIVT Along Coast (ERA5)



Impacts: Three-Week Rainfall and Snowfall Totals

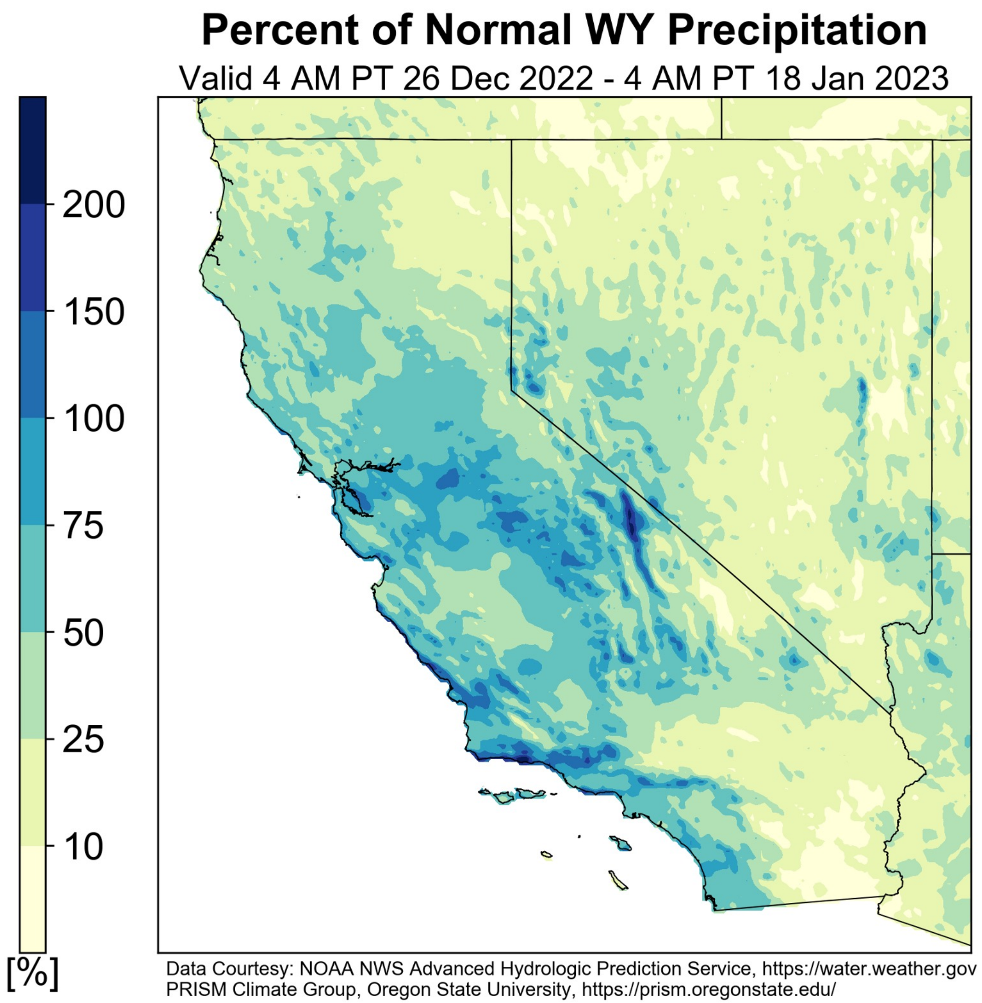


Data Courtesy: NOAA NWS Advanced Hydrologic Prediction Service
https://water.weather.gov



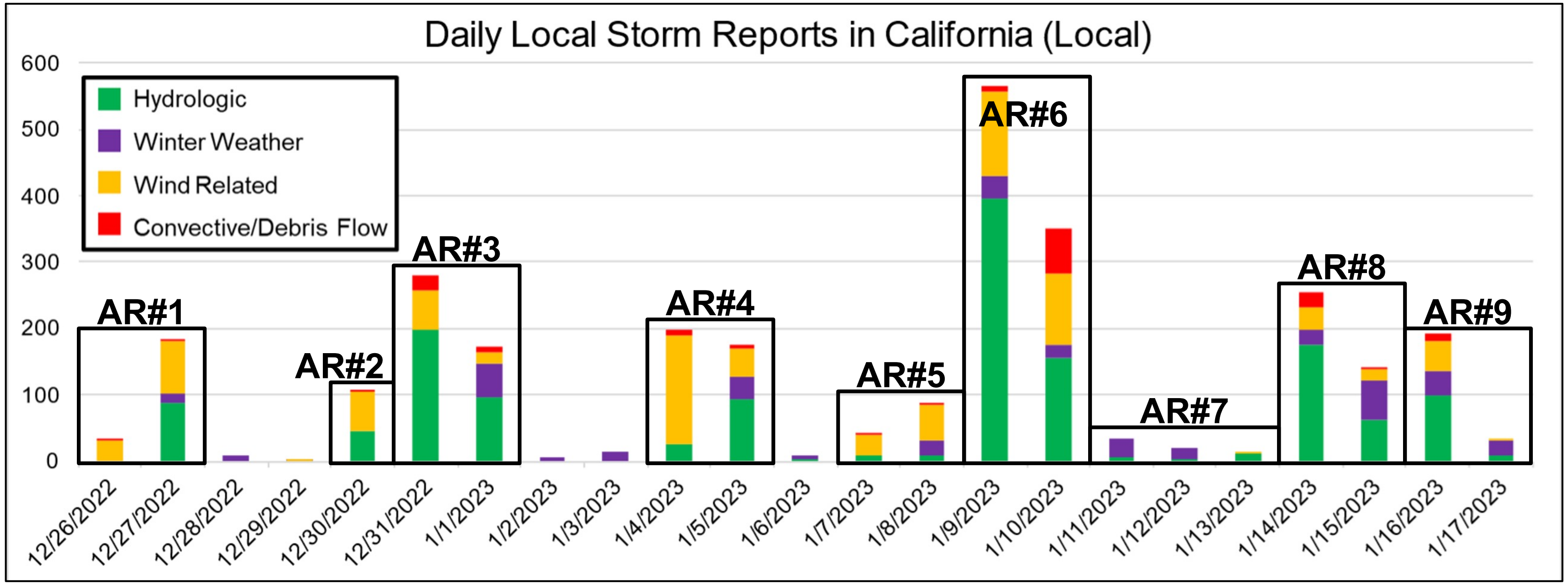
Data Courtesy: NOAA NWS National Operational Hydrologic Remote Sensing Center
https://www.nohrsc.noaa.gov/

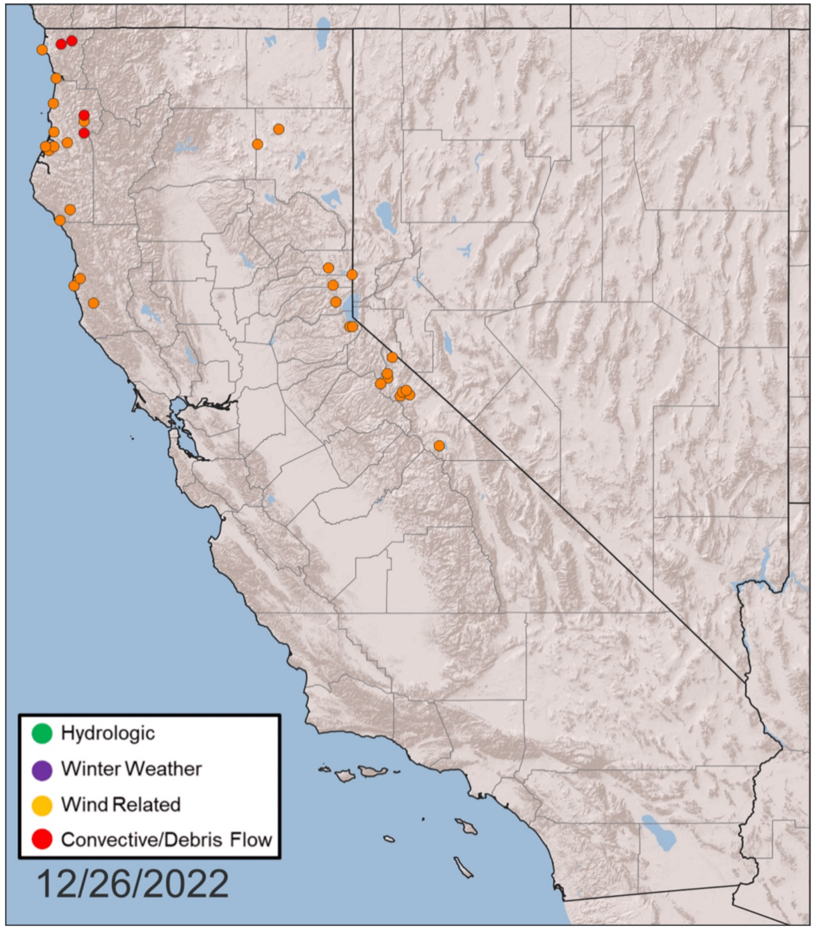
Impacts: Precipitation Contributions of Period to Water Year



Station	23-day Precip (in)	Normal WY Precip (in)	% of Normal WY Precip
Oakland	18.33	22.61	81
Stockton	10.79	13.45	80
UCLA	14.03	17.73	79
San Francisco Apt	15.28	19.64	78
San Francisco City	17.64	22.89	77
Lompoc	11.72	15.41	76
Paso Robles	11.57	15.26	76
Santa Maria	9.98	13.32	75

Impacts: Daily Local Storm Reports





Hydrologic: Flash Flood, Flood, Coastal Flood, Heavy Rain

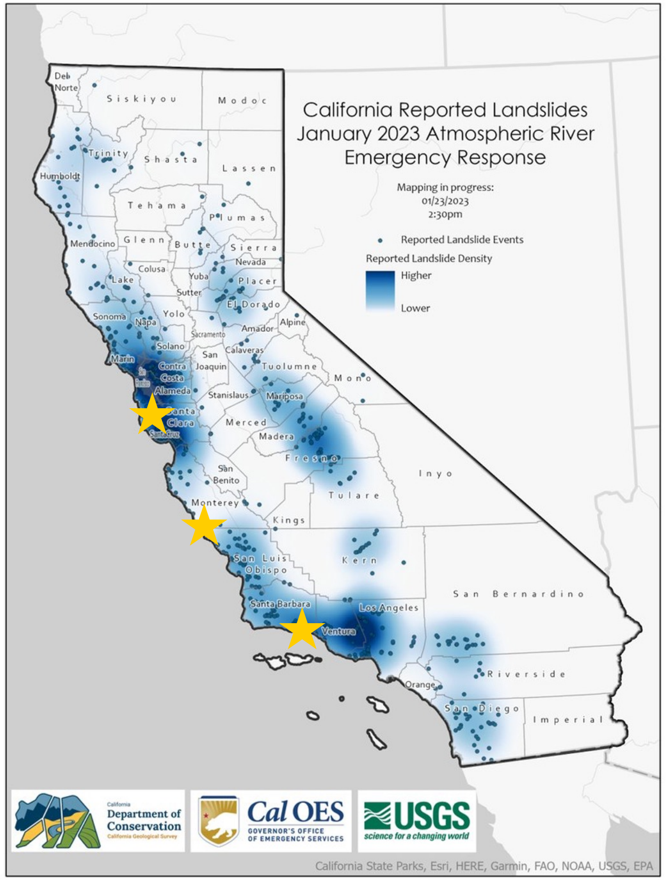
Winter Weather: Snow, Heavy Snow

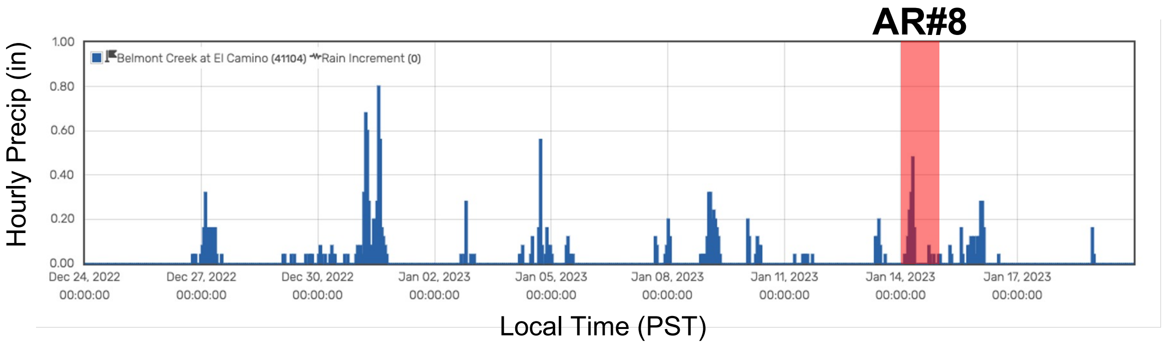
Wind Related: Non-TS Wind, Non-TS Wind Gust, High Sustained Winds

Convective: TS Wind/Gust, Hail, Funnel Cloud, Tornado

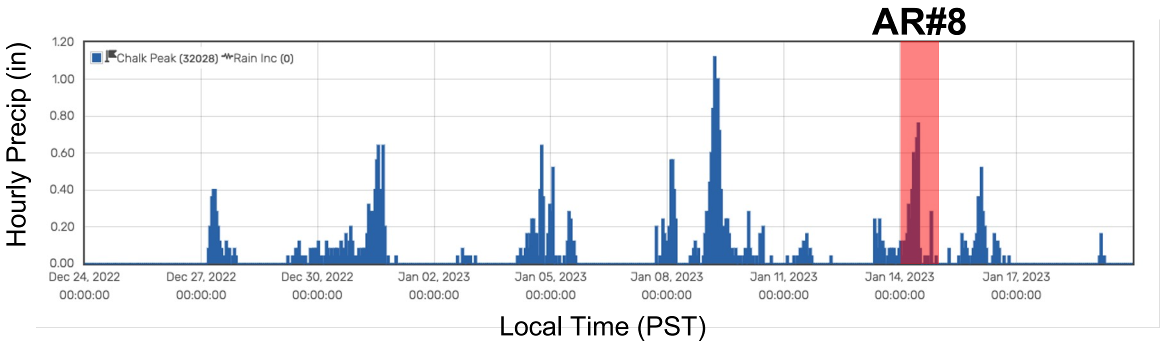
Debris Flow: Debris Flow

Impacts: Landslides

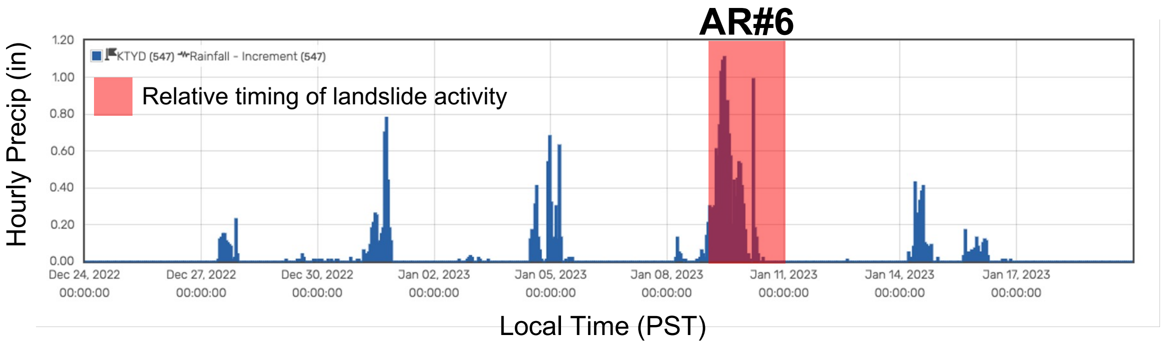




Shallow landslide in Belmont, San Mateo County (Belmont Public Works Department)



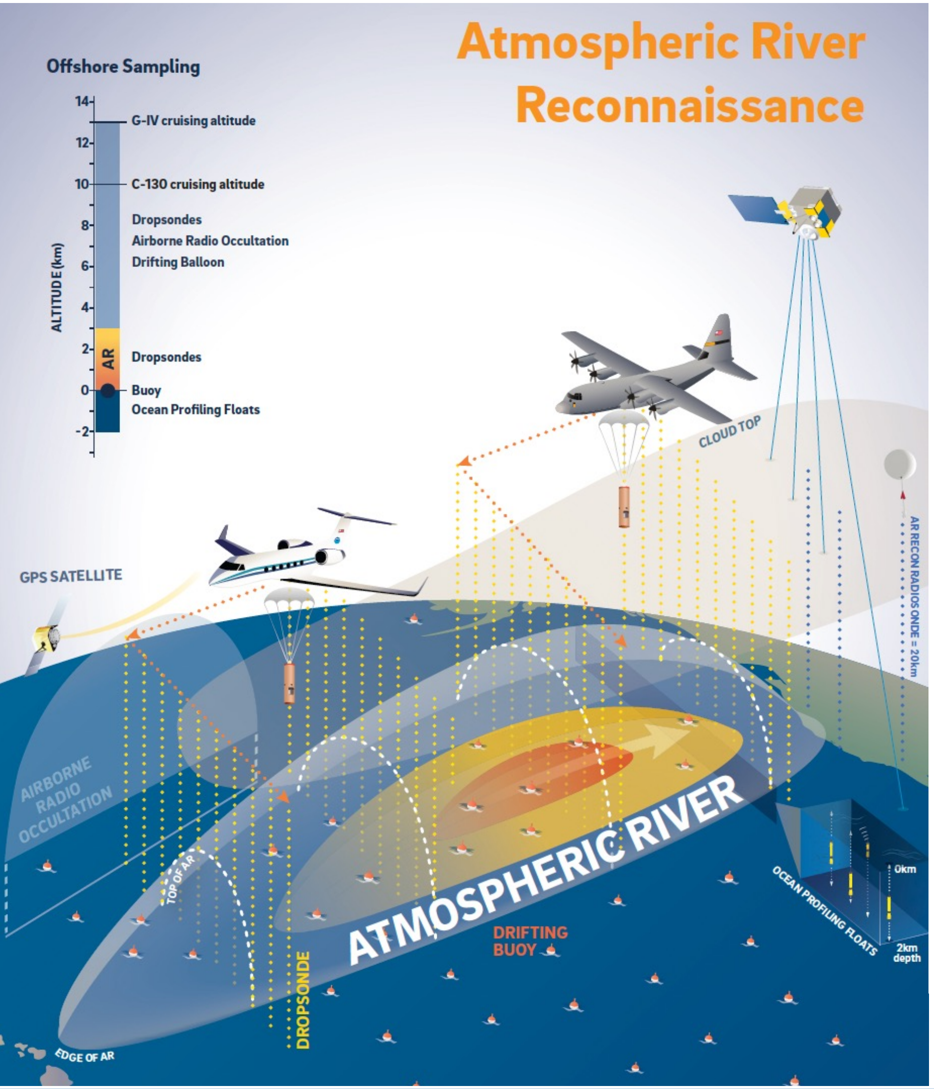
Landslide on Hwy 1 near Mill Creek in Monterey County (Caltrans)

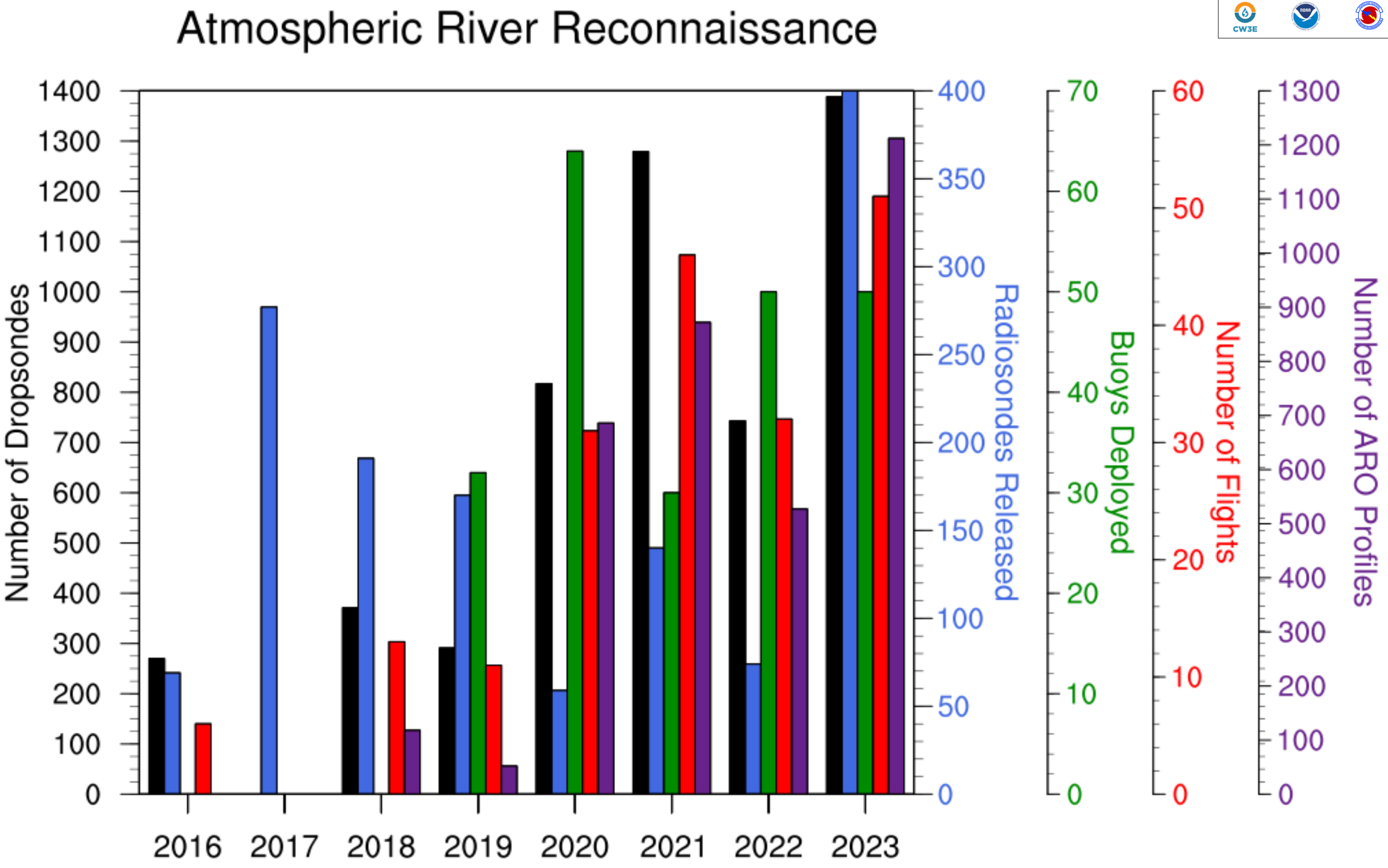


San Ysidro Creek Debris Basin in Santa Barbara County (KEYT News)

Atmospheric River Reconnaissance

AR Recon: What is it?

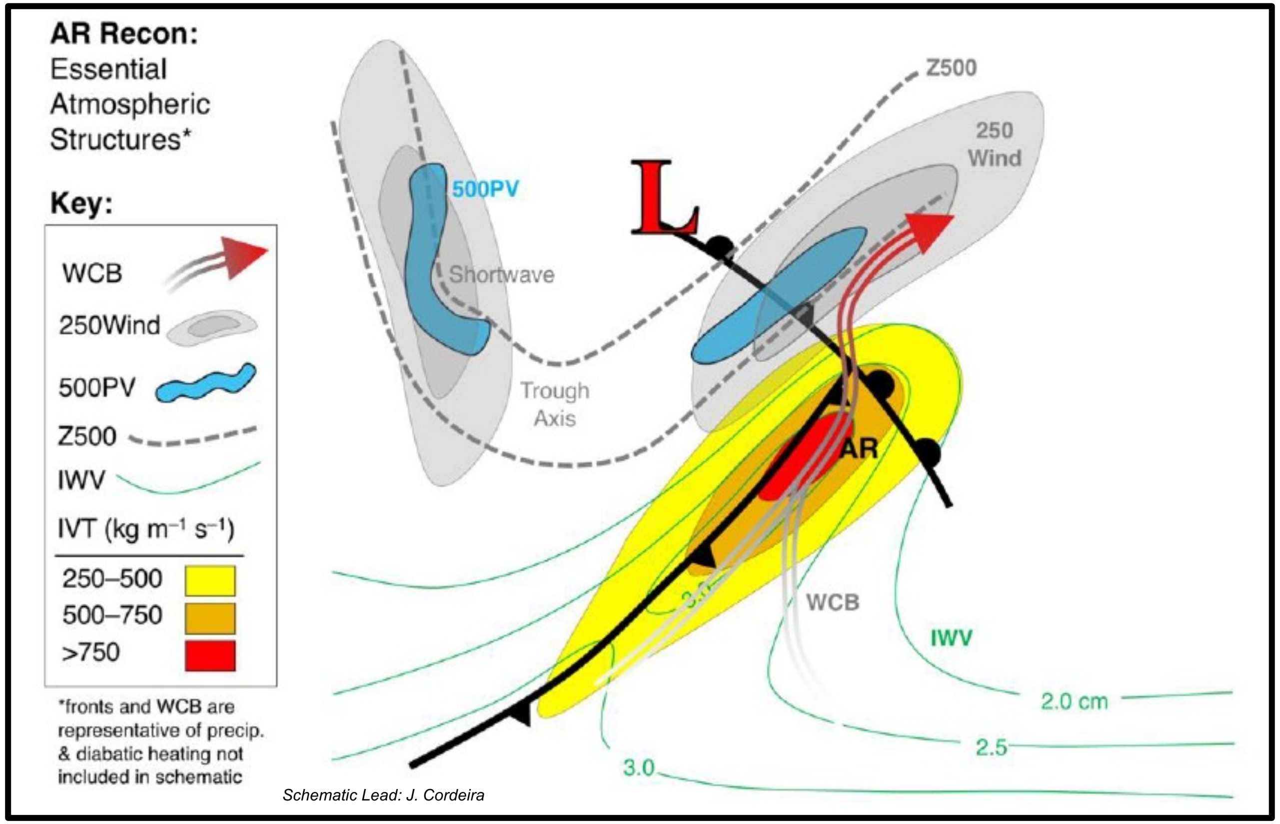


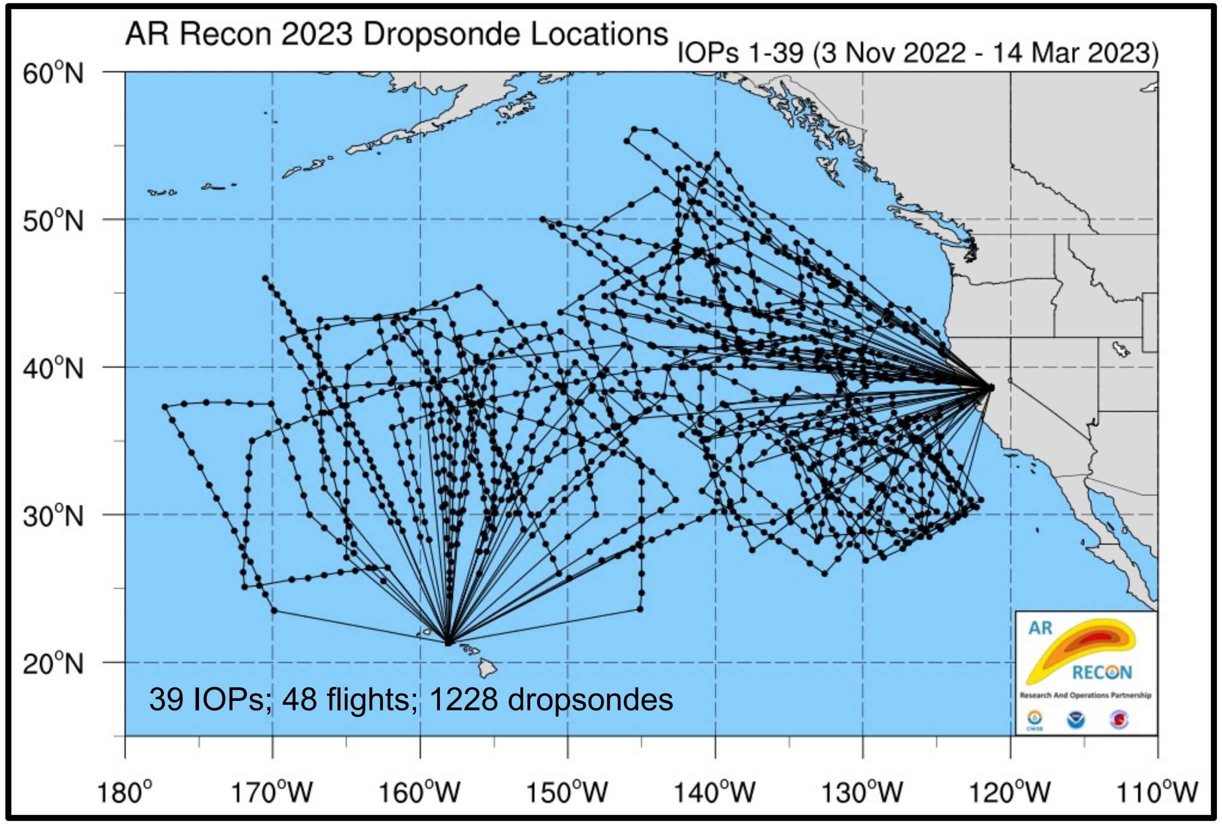


AR Recon Leads:

- F. Martin Ralph (UCSD/SIO/CW3E) – PI
- Vijay Tallapragada (NWS/NCEP) - Co-PI

AR Recon: Targeting ARs, Essential Structures, and Sensitivity





How do we determine where to fly and where to drop?

Fundamental physics knowledge, Adjoint model sensitivity (NRL), Ensemble sensitivity (U Albany, NCEP)

Wilson, A. M., Cobb, A., Ralph, F. M., Tallapragada, V., Davis, C., Doyle, J., Delle Monache, L., Pappenberger, F., Reynolds, C., Subramanian, A., Cannon, F., Cordeira, J., Haase, J., Hecht, C., Lavers, D., Rutz, J. J., & Zheng, M. (2022). Atmospheric River Reconnaissance Workshop Promotes Research and Operations Partnership, *Bulletin of the American Meteorological Society*, **103**, E810-E816. https://doi.org/10.1175/BAMS-D-21-0259.1

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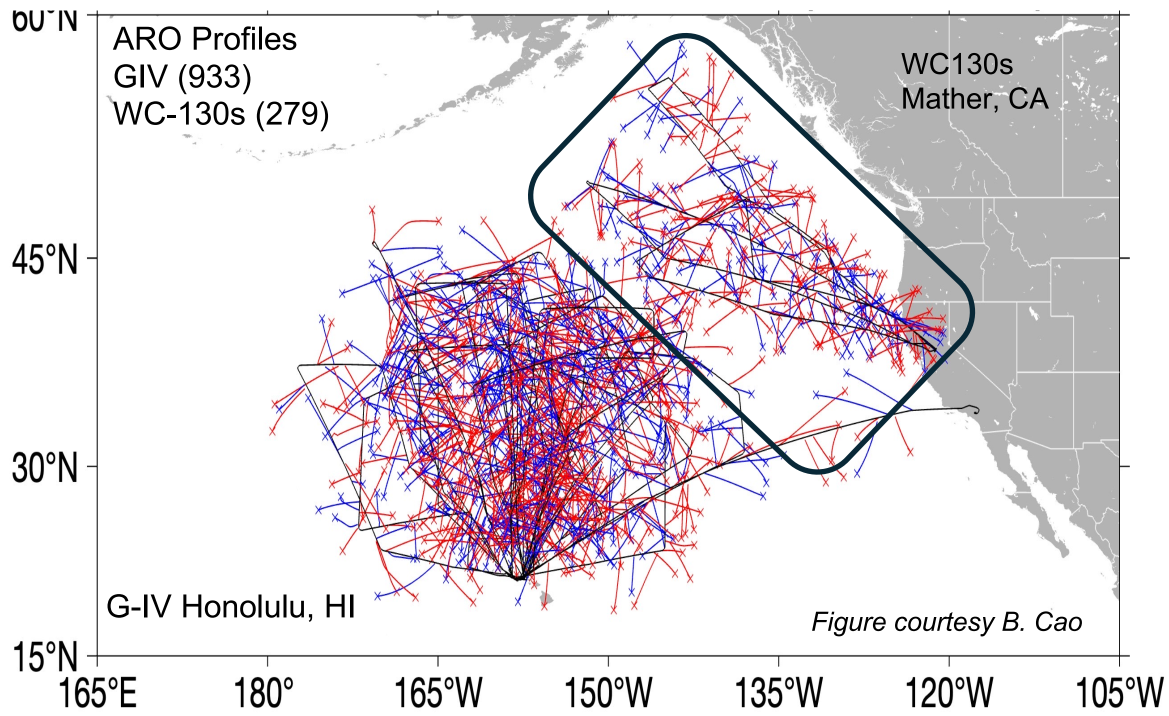
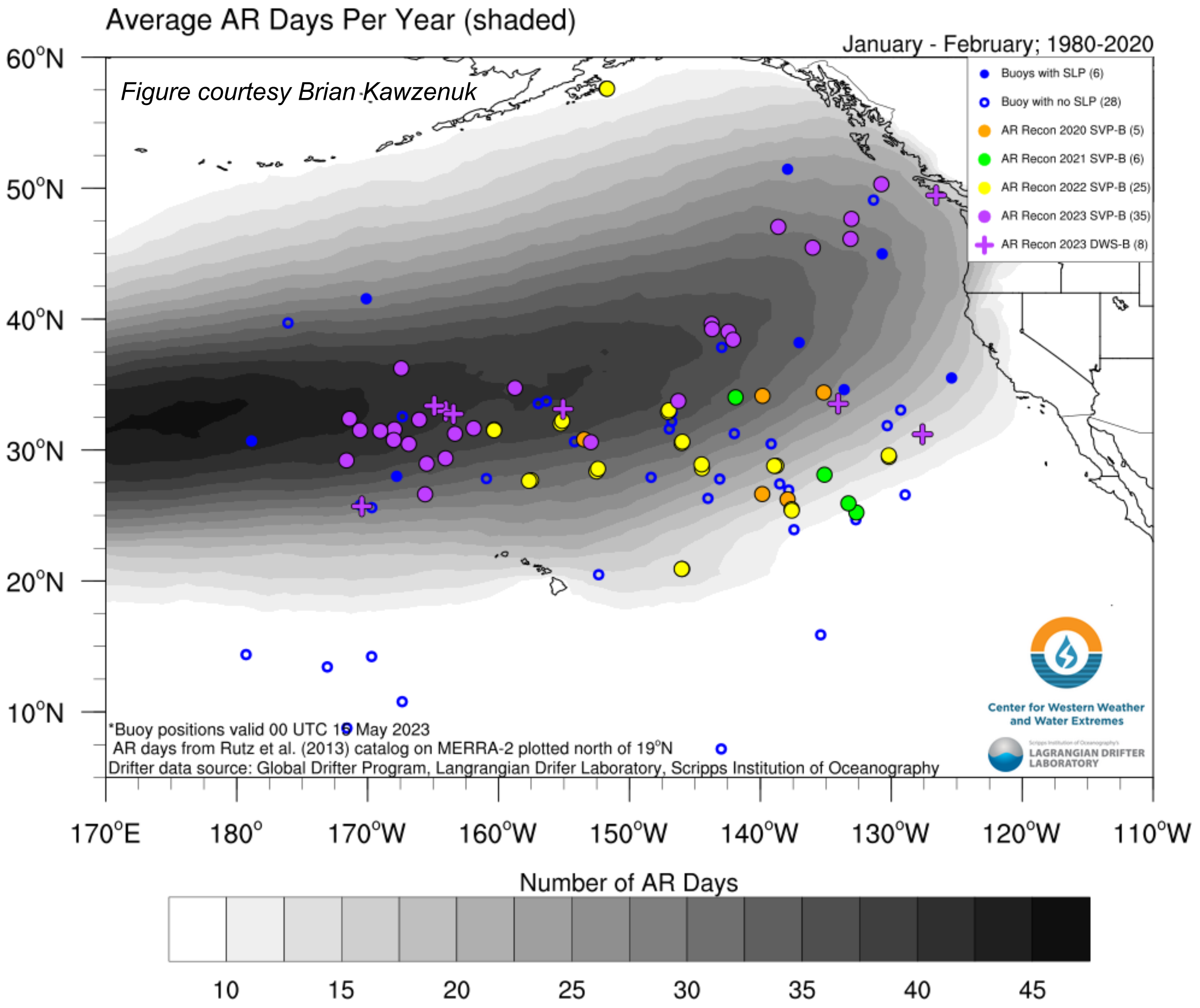
AR Recon: Collaborations and Partnerships





- Drifters: NOAA-funded Global Drifter Program at Scripps' Lagrangian Drifter Laboratory (PI, Dr L Centurioni). Up to 64 drifters deployed each year – goal to ramp up to 128
- Airborne Radio Occultation (PI, Dr J Haase, Scripps). WY2024 – equipment on NOAA and 2 Air Force aircraft, ramping up to 2 NOAA and 10 Air Force aircraft.

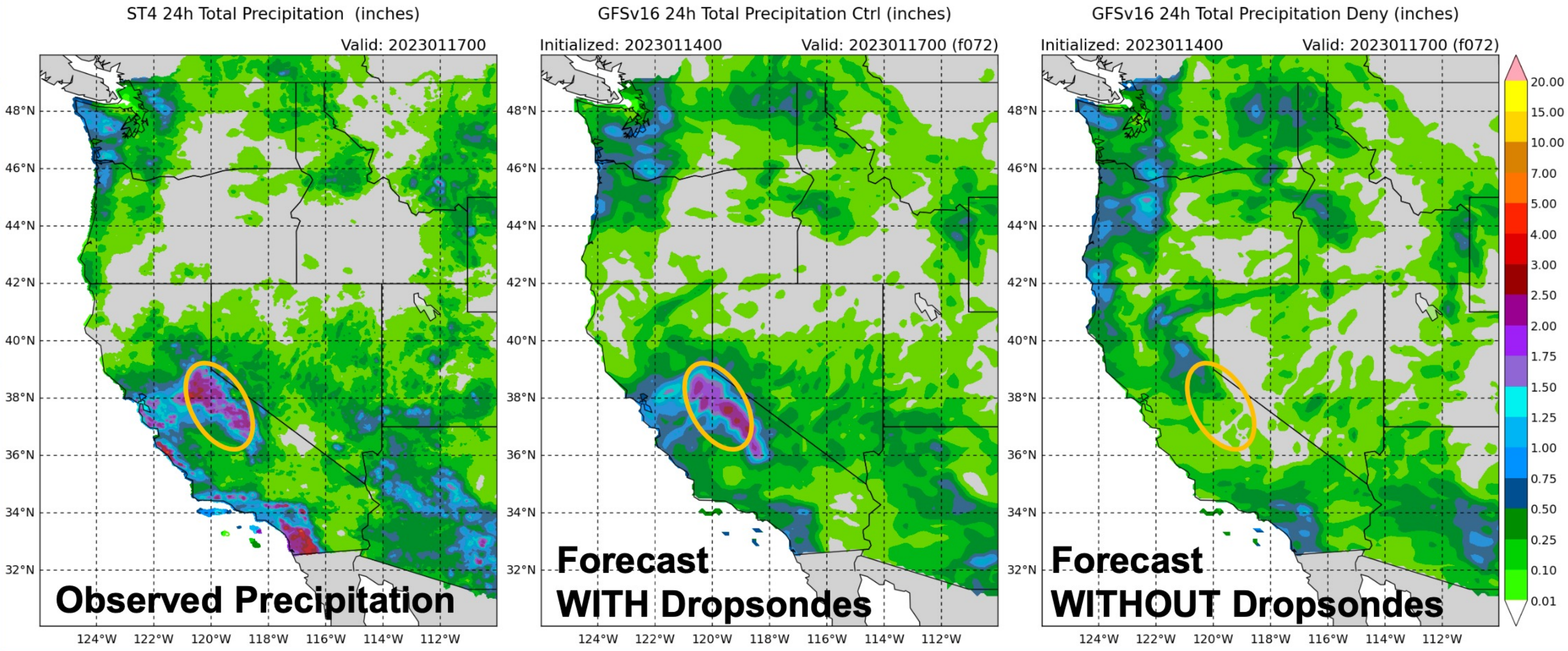
AR Recon: Better observations → Improved Forecast Skill (WY23)

Presentation
by V. Tallapragada

AR Recon Workshop
June 2023
@ECMWF

GFS model forecast with assimilated dropsondes is far more skillful than model assimilated without dropsondes

Case Study: IOP 14 (00Z Jan 14)
72-hour forecast, verify at 00Z Jan 17



NATIONAL WEATHER SERVICE

Building a Weather-Ready Nation // 15

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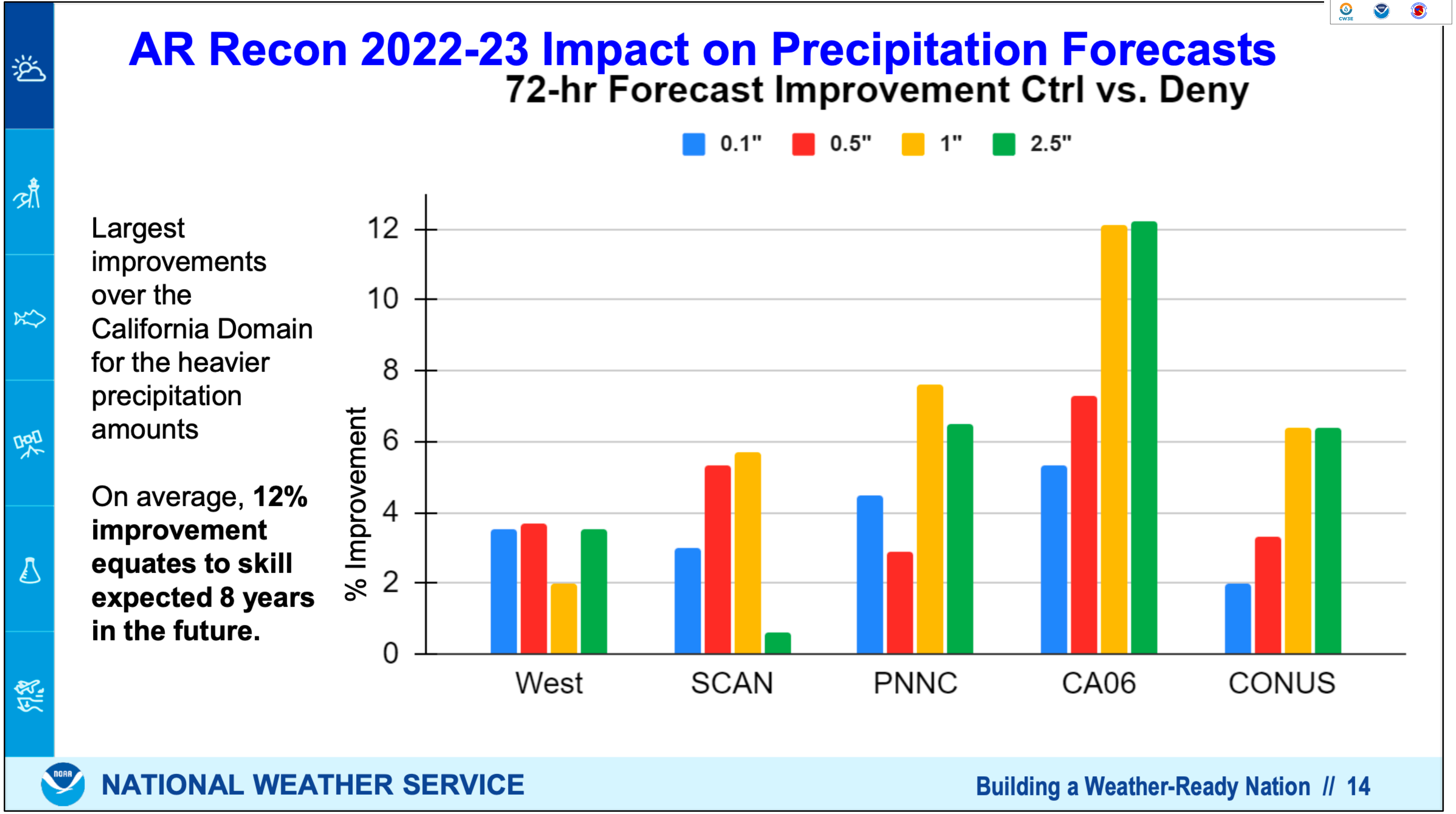
AR Recon: Better observations → Improved Forecast Skill (WY23)

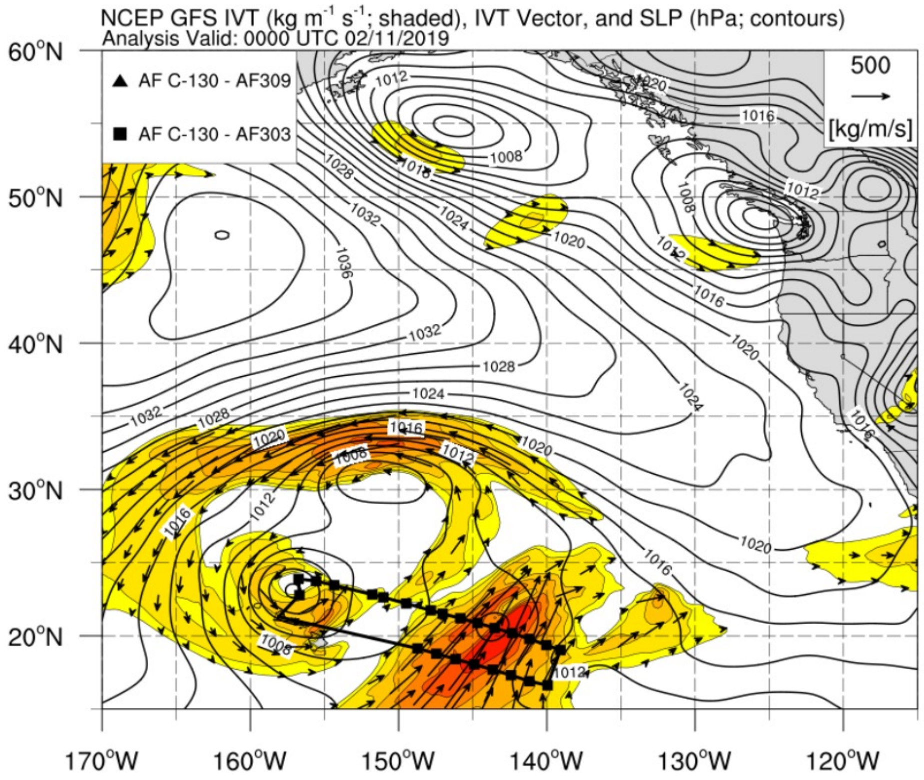
Presentation
by V. Tallapragada

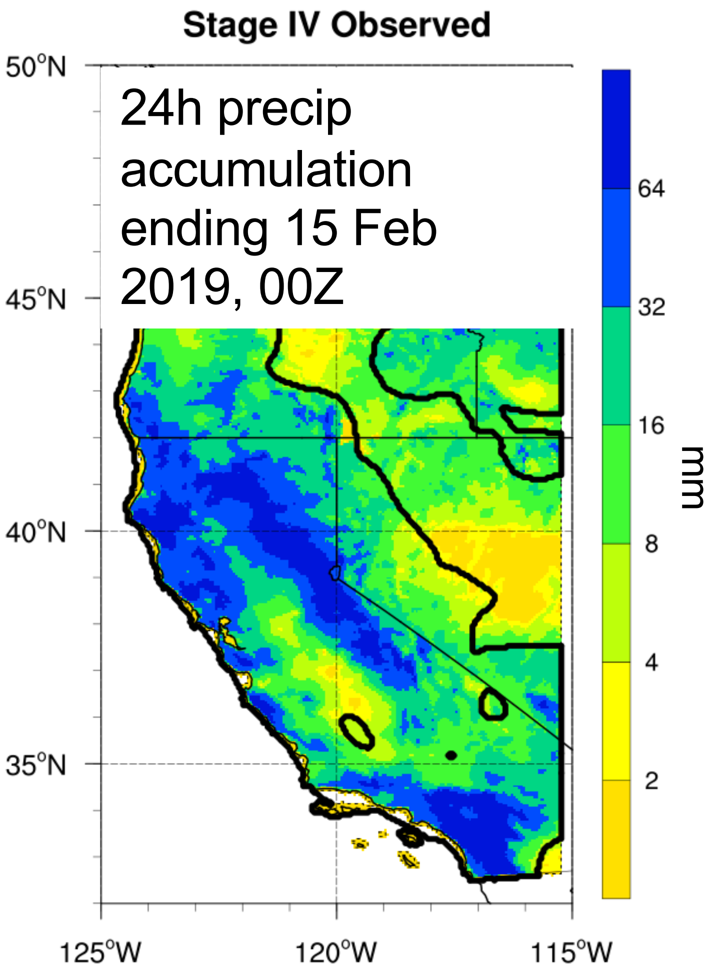
AR Recon Workshop
June 2023
@ECMWF

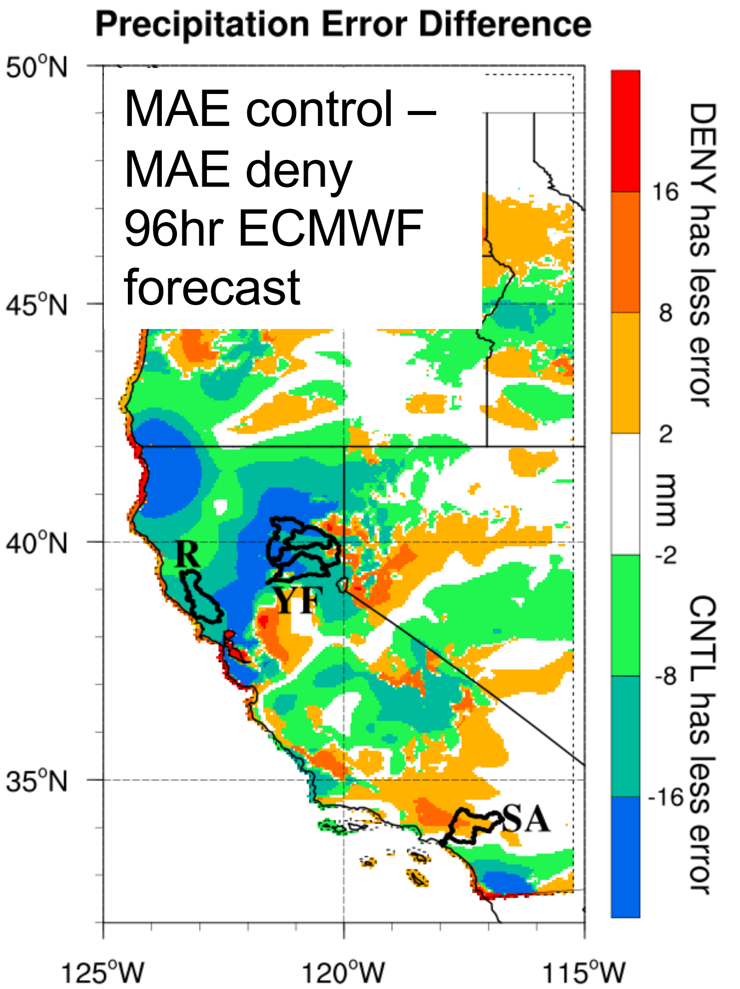
Not only is skill improved over West Coast, but also over western U.S. and CONUS! Regionally upwards of 12% improvement!



AR Recon: Better observations → Improved Forecast Skill







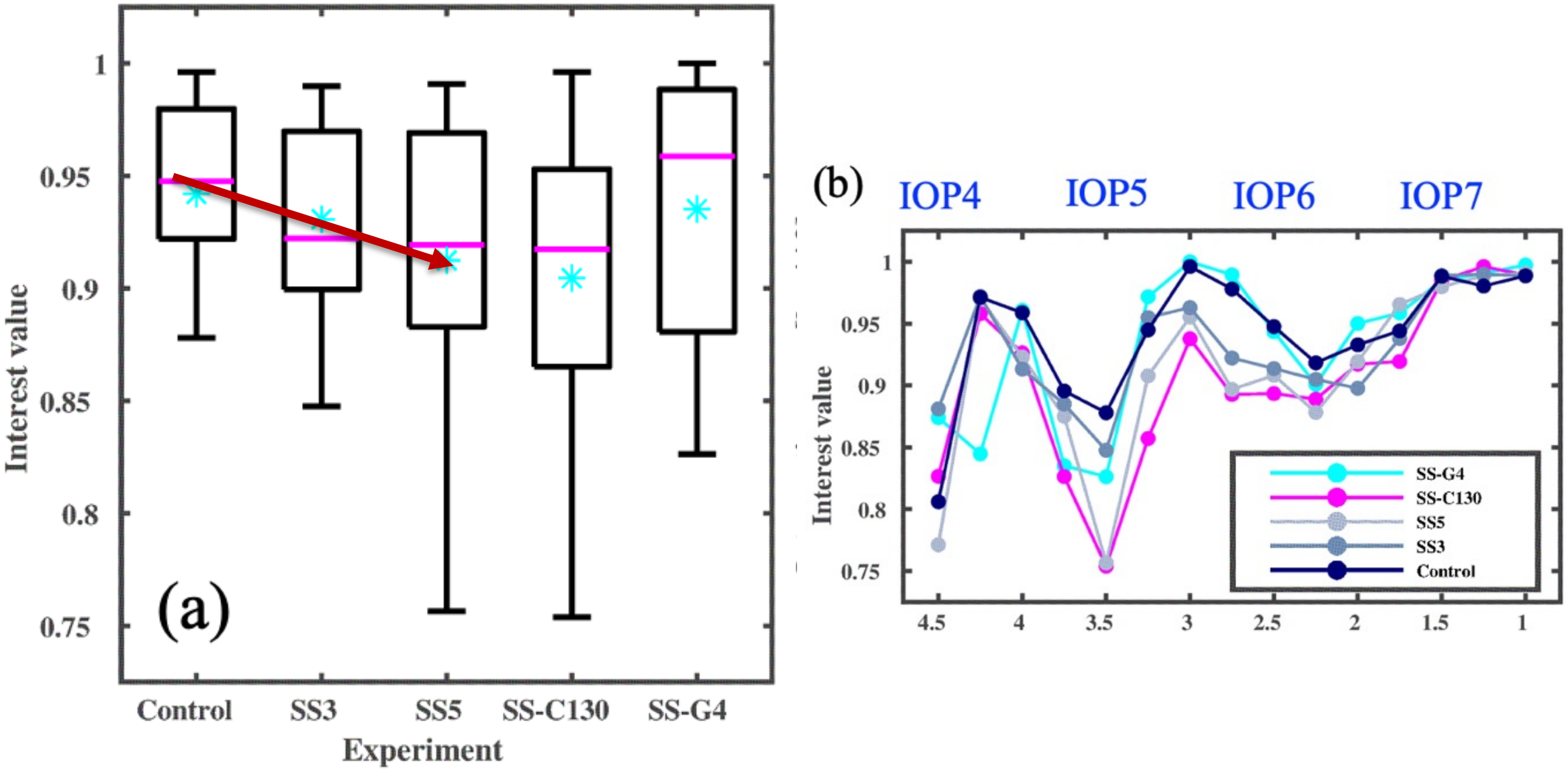
DeHaan, L., A.M. Wilson, B. Kawzenuk, M. Zheng, L. Delle Monache, X. Wu, D.A. Lavers, B. Ingleby, V. Tallapragada, F. Pappenberger, and F.M. Ralph, 2023: Impacts of Dropsonde Observations on Forecasts of Atmospheric Rivers and Associated Precipitation in the NCEP GFS and ECMWF IFS Models. *Wea. Forecast.*, **38**, 2397-2413.

AR Recon: Better observations → Improved Forecast Skill

Major findings:

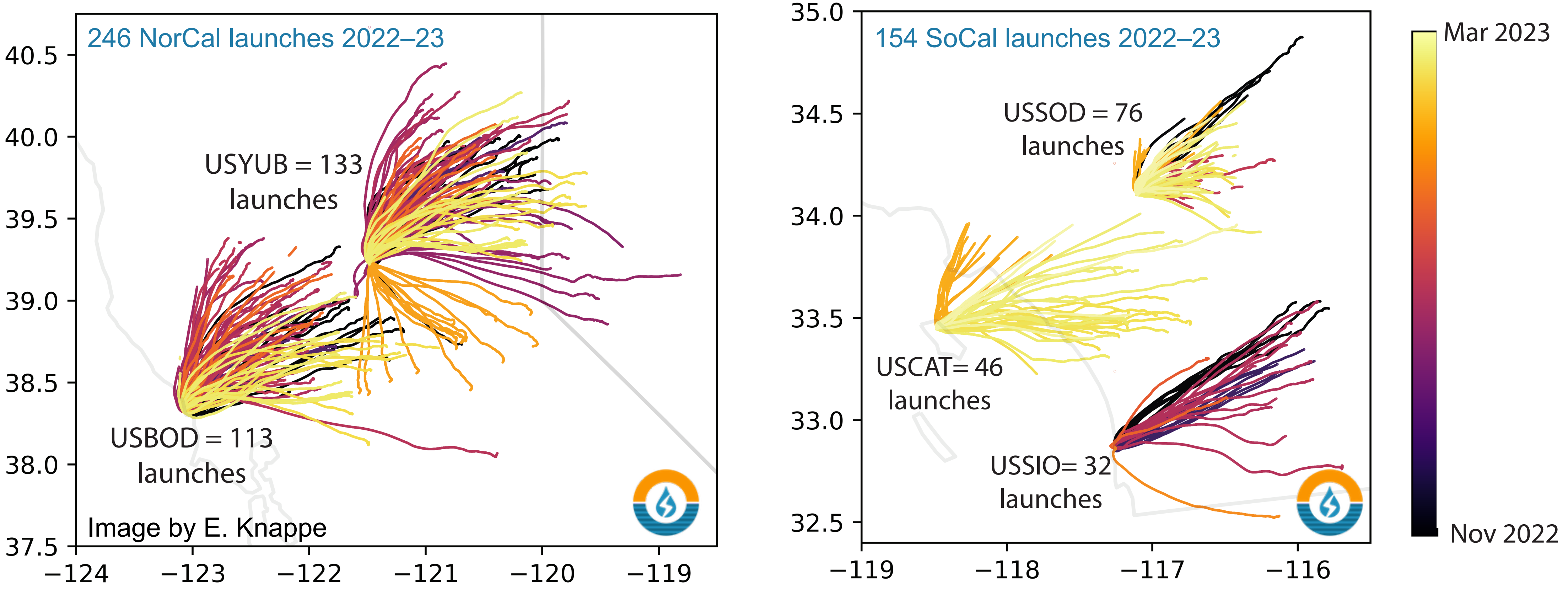
1. Dropsondes improve the representation of ARs in the model analyses, especially near sharp gradients.
2. Reduced mission frequency and reduced dropsonde horizontal spacing both degrade forecast skill.
3. The inclusion of two types of aircraft (G-IV & C-130s), sampling different regions, is an effective strategy to enable the benefits of consecutive missions.

Impact of spatial sampling & aircraft



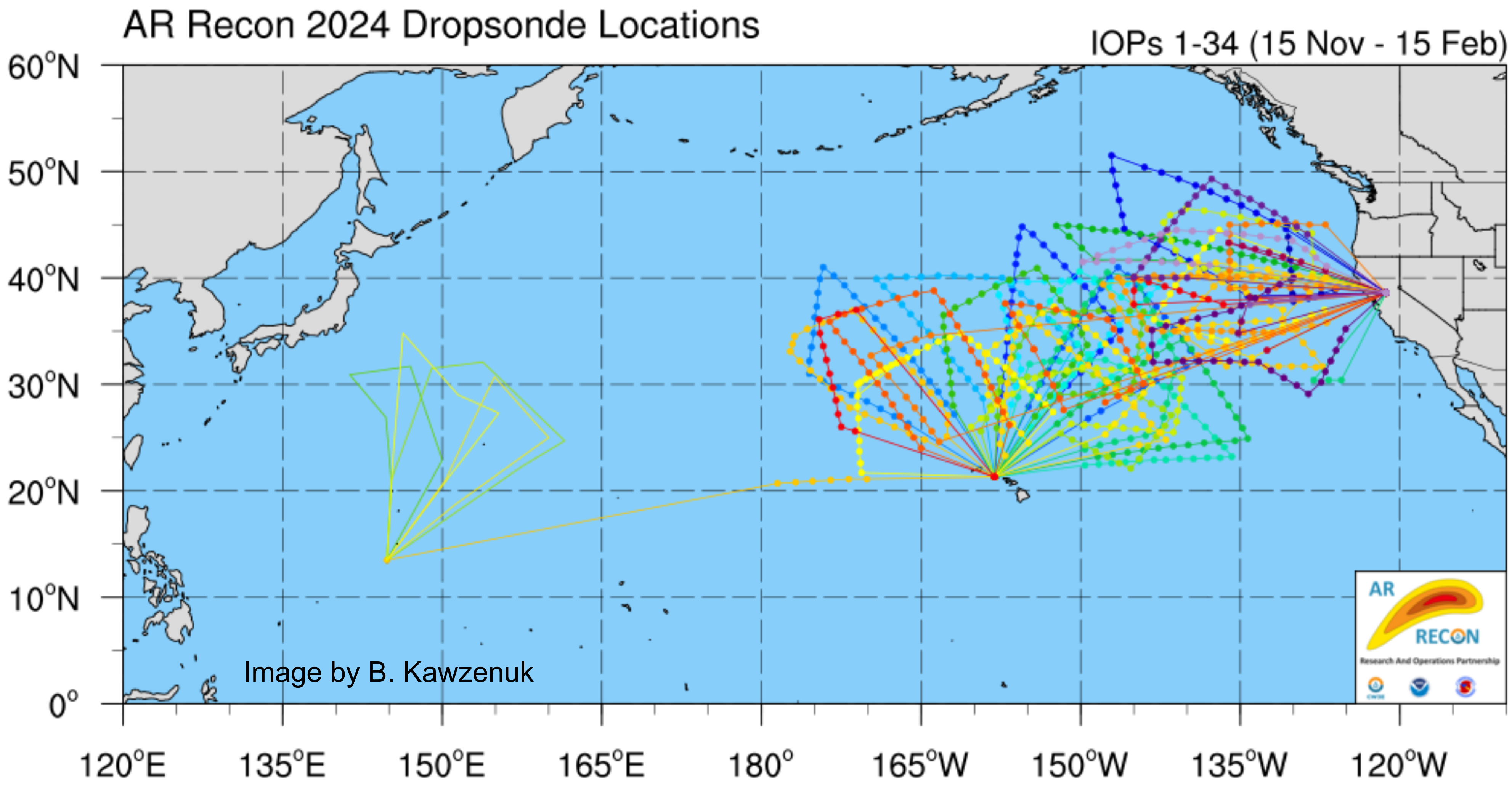
Zheng, M., R. Torn, L. Delle Monache, J. Doyle, F.M. Ralph, V.S. Tallapragada, C. Davis, D. Steinhoff, X. Wu, A. Wilson, et al. 2024: An Assessment of Dropsonde Sampling Strategies for Atmospheric River Reconnaissance. *Mon. Wea. Rev.*, **in press**.

CW3E In-situ Observations: Research and Operations



- USACE-funded FIRO enables CW3E to conduct storm sampling campaigns using radiosondes from 4 (of 5) locations in CA simultaneously during storms, at least every 3 hours throughout landfalling ARs
- New locations in Washington, with USACE and Tacoma Water, planned for 2023–24
- Improved understanding of landfalling AR, increased obs for model assim., verification, & improvement

AR Recon: Quick Look at Water Year 2024



Expansion to Guam: drifter deployment; aircraft missions

Tacoma radiosonde site added

Dropsondes to date (29 Feb 2024): 1475 profiles 40 IOPs

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AR Recon Leads:

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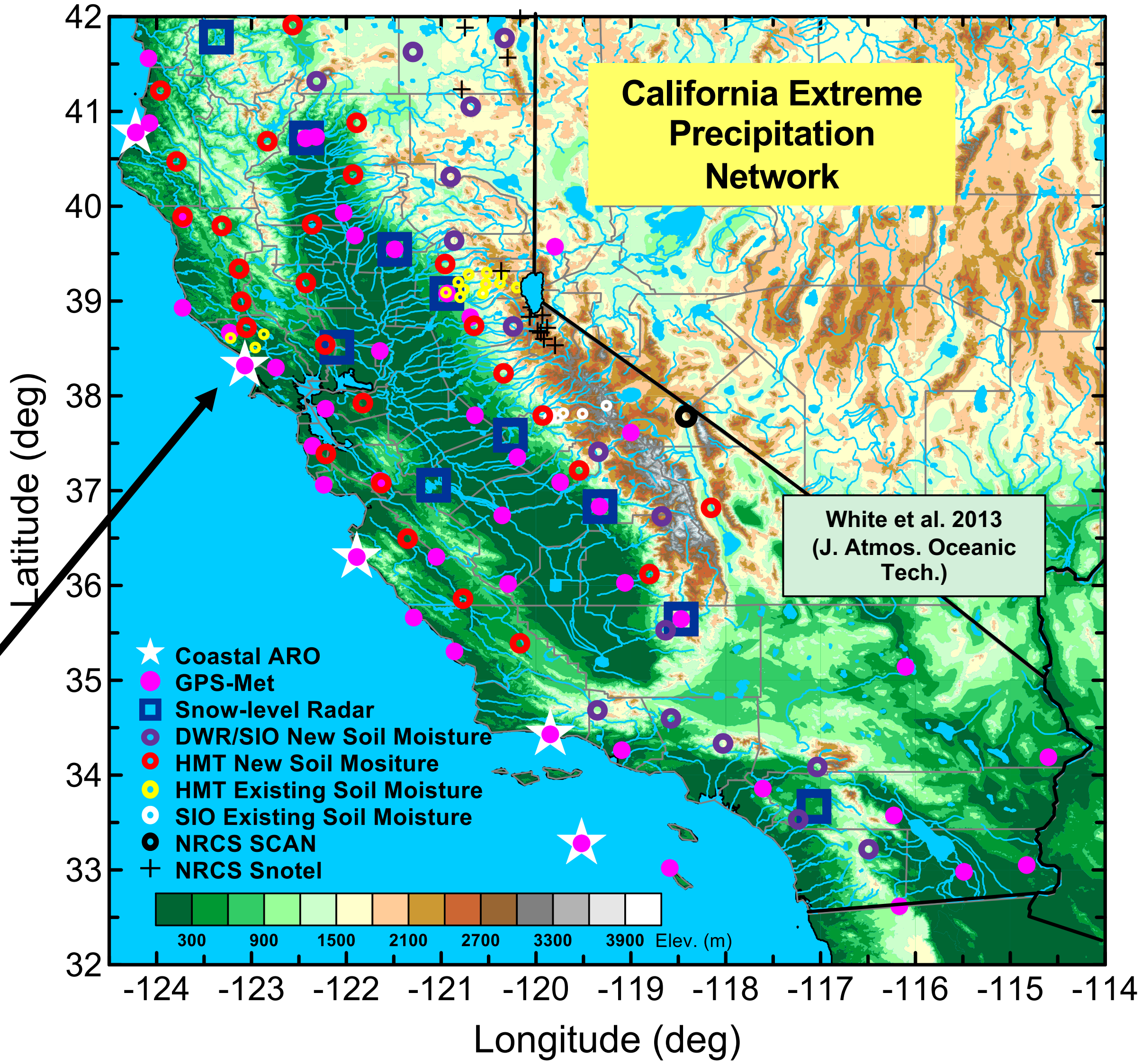
CW3E In-situ Observations: Building on a Foundational Network

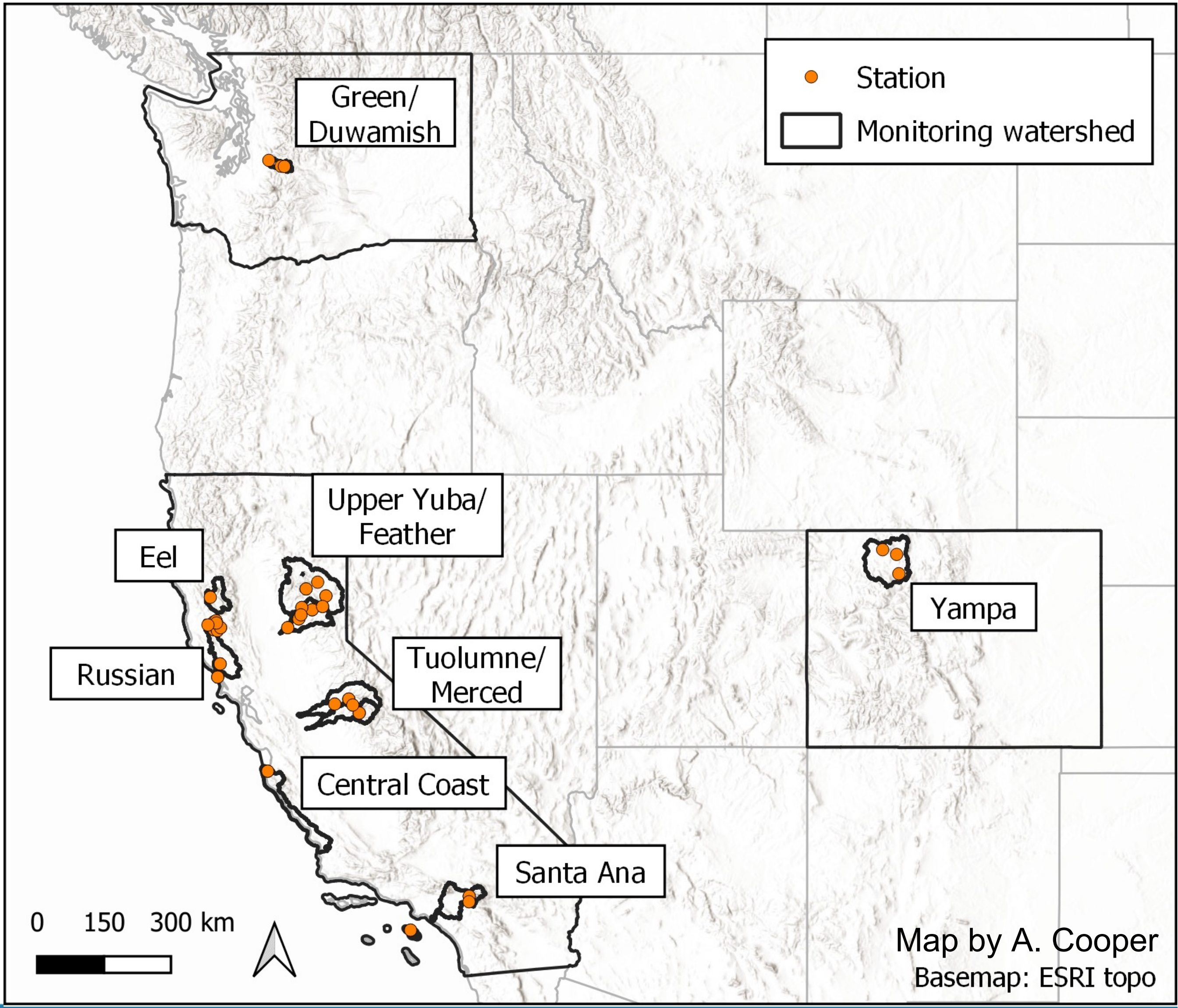
Atmospheric River Observatories ~250km apart: all impactful ARs hitting the west coast will be sampled with this "picket fence" approach

Vertically pointing radars throughout the Sierra foothills – will watersheds receive snow or rain?



CW3E In-situ Observations: Network Enhancements

- Leveraging CA's foundational statewide "storm-scale" observation network (e.g., AR Observatories, Sierra foothills vertically pointing radars)
- CW3E operates >70 sites in 10 watersheds in CA, WA, CO
- Observations: stream sampling, soil moisture, vertically pointing radars, & wind profilers/radiosondes
- Used for model verification, awareness of antecedent watershed conditions, and improvement of process-based understanding



YUBA WATER AGENCY
TACOMA WATER TACOMA PUBLIC UTILITIES
UPPER YAMPA WATER CONSERVANCY DISTRICT
DEPARTMENT OF WATER RESOURCES STATE OF CALIFORNIA
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE
COLORADO RIVER DISTRICT

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Thank You.

Questions, Comments, and Feedback always welcome.

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