

Subseasonal and Seasonal Research and Experimental Forecast Product Development at CW3E: Applications During WY24 and WY25

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Scripps Institution of Oceanography, UC San Diego*

2025 WSWC Workshop: Improving Subseasonal to Seasonal Precipitation Forecasting

Sponsoring Agencies:



Key Collaborators:



UC San Diego

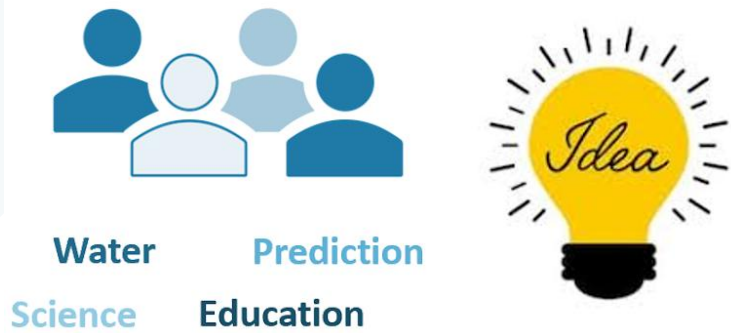
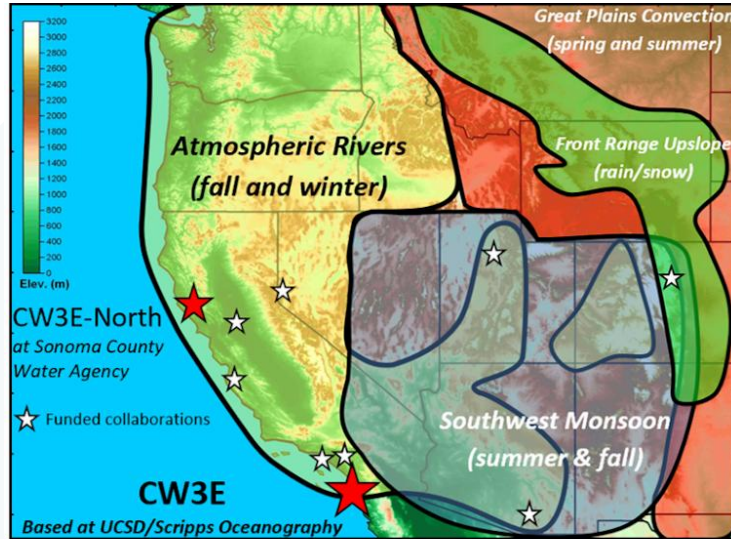


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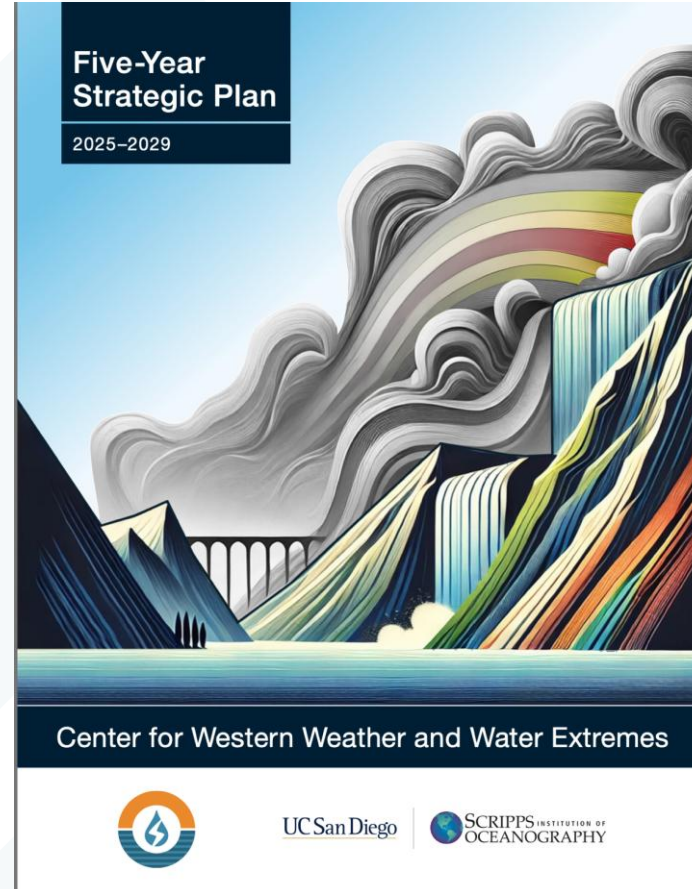


Center for Western Weather and Water Extremes (CW3E): Overview

2013/14: CW3E Launched



2023-2024: Development of CW3E's 2nd Five-Year Strategic Plan



2025: Strategic Plan Launched on CW3E Website

Strategic Priority Areas

- Atmospheric Rivers and Extreme Precipitation Research, Prediction and Applications
- FIRO: Resilient Water Management
- Novel Observations
- Advanced Precipitation and Streamflow Prediction

CW3E Director:
CW3E Director of Research:
CW3E Deputy Director of Operations:

Dr. F. Martin Ralph
Dr. Luca Delle Monache
Dr. Julie Kalansky

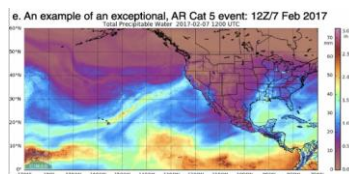
Western U.S. water managers need better S&S forecasts of precipitation

From Days to Decades: Lead-Dependent Water Management Decisions Impacted by Multi-Scale Weather and Climate Variability

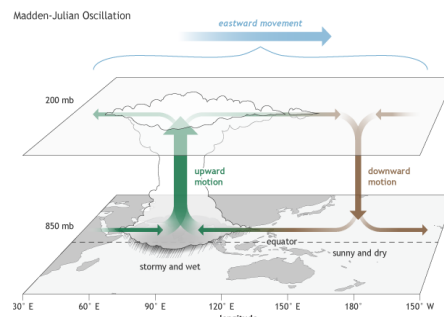
Water Management
Decision Support Needs

- Reservoir Management
- Flood Emergency Response
- Situational Awareness
- Resource Positioning
- Advance Planning
- Extremes Response
- Extremes Response
- Resource Planning
- Situational Awareness
- Extremes Response
- Program Funding
- Situational Awareness for Governance
- Identify Vulnerabilities
- Develop Adaptation Strategies
- Prioritize Implementation

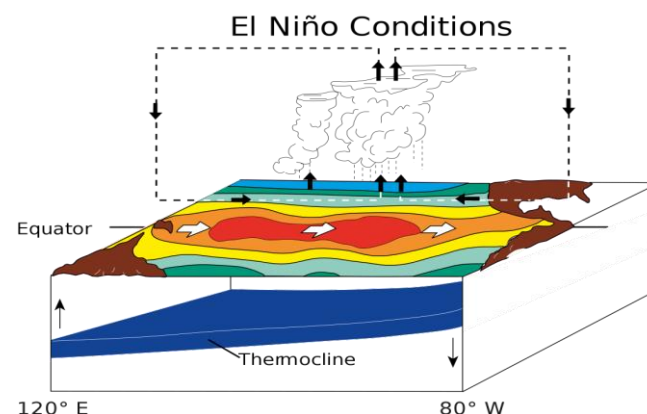
Physical Processes
Impacting Predictability



Atmospheric Rivers,
Transient Eddies



Madden-Julian Oscillation
(MJO), Quasi-Biennial
Oscillation (QBO)



El Niño-Southern Oscillation (ENSO)



Lake Oroville, 2014 (top) vs. 2017 (bottom).
Image credit: Justin Sullivan

Climate Change

“Weather”

daily to weekly

“Climate”

decadal to century

subseasonal

seasonal

annual to interannual

Forecast Lead Time

Adapted from Merryfield et al. 2020 (Fig 1).

Image credits: Ralph et al. 2019;
NOAA; NOAA; Josef Friedhuber

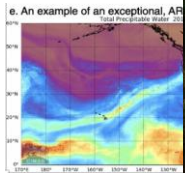
DeFlorio, M. J., F. M. Ralph, D. E. Waliser, J. Jones, and M. L. Anderson (2021): **Emerging methods supporting water management at subseasonal-to-seasonal (S2S) lead times.** *EOS*, 102, <https://doi.org/10.1029/2021EO159749>.

Western U.S. water managers need better S&S forecasts of precipitation

From Days to Months

Water Management
Decision Support Needs

- Reservoir
- Flood Em
- Response
- Situationa



Physical Processes
Impacting Predictability

Atmospheric
Transient

“Weather”
daily to w



The water level in Lake Oroville near Enterprise Bridge in Butte County, California, was 52% below its historical average level when this photograph was taken, on 23 October 2015. Credit: Zack Cunningham/California Department of Water Resources

Better Subseasonal-to-Seasonal Forecasts for Water Management

Emerging methods that improve precipitation forecasting over weeks to months could support more informed resource management and increase lead times for responding to droughts and floods.

By Michael J. DeFlorio, F. Martin Ralph, Duane E. Waliser, Jeanine Jones, and Michael L. Anderson

Multi-Scale Weather and

Identify Vulnerabilities
Develop Adaptation
Strategies
Prioritize Implementation



Lake Oroville, 2014 (top) vs. 2017 (bottom).
Image credit: Justin Sullivan

Climate Change

“Weather”

decadal to century

Image credits: Ralph et al. 2019;
NOAA; NOAA; Josef Friedhuber

Adapted from Merryfield et al.

DeFlorio, M. J., F. M. Ralph, D. E. Waliser, J. Jones, and M. L. Anderson (2021): **Emerging methods supporting water management at subseasonal-to-seasonal (S2S) lead times.** *EOS*, 102, <https://doi.org/10.1029/2021EO159749>.

Overview of CW3E Subseasonal Research and Experimental Forecast Products

Forecast Product	Lead(s)	Predictands	Lead Times	Development stage	Associated Publication(s)
Weeks 2-4 AR activity outlooks	Mike DeFlorio ¹	AR frequency	Subseasonal	Public	DeFlorio et al. 2019a,b (Cli. Dyn., JGR-A)
Weeks 1-6 ridging outlooks	Peter Gibson ⁵	Z500/ridge types	Subseasonal	Public	Gibson et al. 2020a,b (J. Clim., JGR-A)
Weeks 2-4 AR intensity outlooks	Zhenhai Zhang ¹	AR intensity	Subseasonal	Public	Zhang et al. 2023 (JGR-A)
Weeks 1-6 AR/IVT anomaly outlooks	Chris Castellano ¹	Total IVT and AR frequency	Subseasonal	Public	Castellano et al. 2023 (JGR-A); Wang et al. 2023 (JHM)
Weeks 1-6 weather regime outlooks	Andy Robertson ³ , Juan Ying ³ , Bohar Singh ³ , Ángel Muñoz ³	Circulation regimes	Subseasonal	Public	Robertson et al. 2020 (MWR)
Weeks 2-4 AR cluster outlooks	Zhiqi Yang ¹ , Mike DeFlorio ¹	Unique AR clusters	Subseasonal	Internal	Yang et al. 2024 (Nat. Comm.)

¹ CW3E/SIO-UCSD; ² NASA JPL; ³ IRI; ⁴ University of Arizona; ⁵ NIWA

Green = subseasonal lead times

CW3E S&S Advisory Panel: 2023-2026 Members



F. Martin Ralph
(Chair; Director, CW3E)



Kristen Guirguis
(SIO/CW3E)



Andrew W. Roberston
(IRI)



Cristiana Stan
(GMU)



Xubin Zeng
(U. Arizona)

- Recruitment of new S&S Advisory Panel focused on **expanding diversity** (including gender, institution, career stage, expertise)
- A key objective in recruiting a 2nd Advisory Panel team: continue to foster CW3E's role within the S&S Community as a **magnet for collaboration, inclusivity, innovation, and connecting research to stakeholder needs**



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CW3E Subseasonal & Seasonal Outlooks: A Collaboration between CW3E and DWR

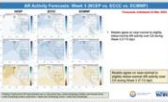


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AboutObservationsAR ReconnaissanceForecastsFIRONews & PublicationsCW3E North

CW3E Subseasonal and Seasonal (S&S) Outlook Archive

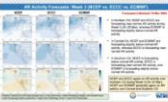
CW3E produces S&S outlooks weekly/biweekly during the October – March wet season. These outlooks include multi model forecast tools developed at CW3E focused on precipitation, atmospheric rivers, and ridging over the Northeast Pacific and Western U.S. with input and interpretation from CW3E personnel alongside these forecast tools. The first outlook of each month will include monthly updating seasonal forecasts out to several months, and both monthly outlooks will include subseasonal forecast tools with lead times up to six weeks.



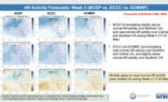
CW3E Subseasonal Outlook: 25 March 2025



CW3E Subseasonal Outlook: 18 March 2025



CW3E Subseasonal Outlook: 11 March 2025



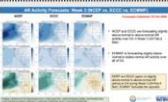
CW3E Subseasonal Outlook: 4 March 2025



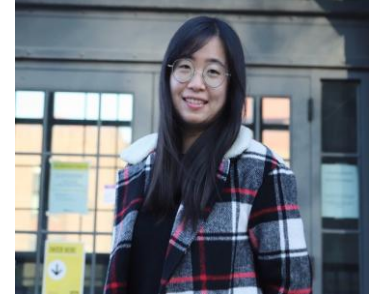
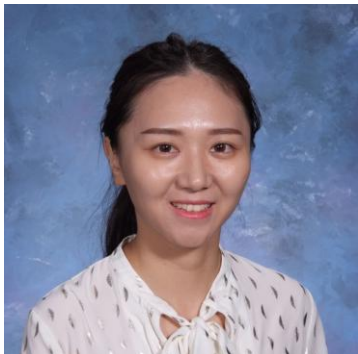
CW3E Subseasonal Outlook: 25 February 2025



CW3E Subseasonal Outlook: 18 February 2025



CW3E Subseasonal Outlook: 11 February 2025



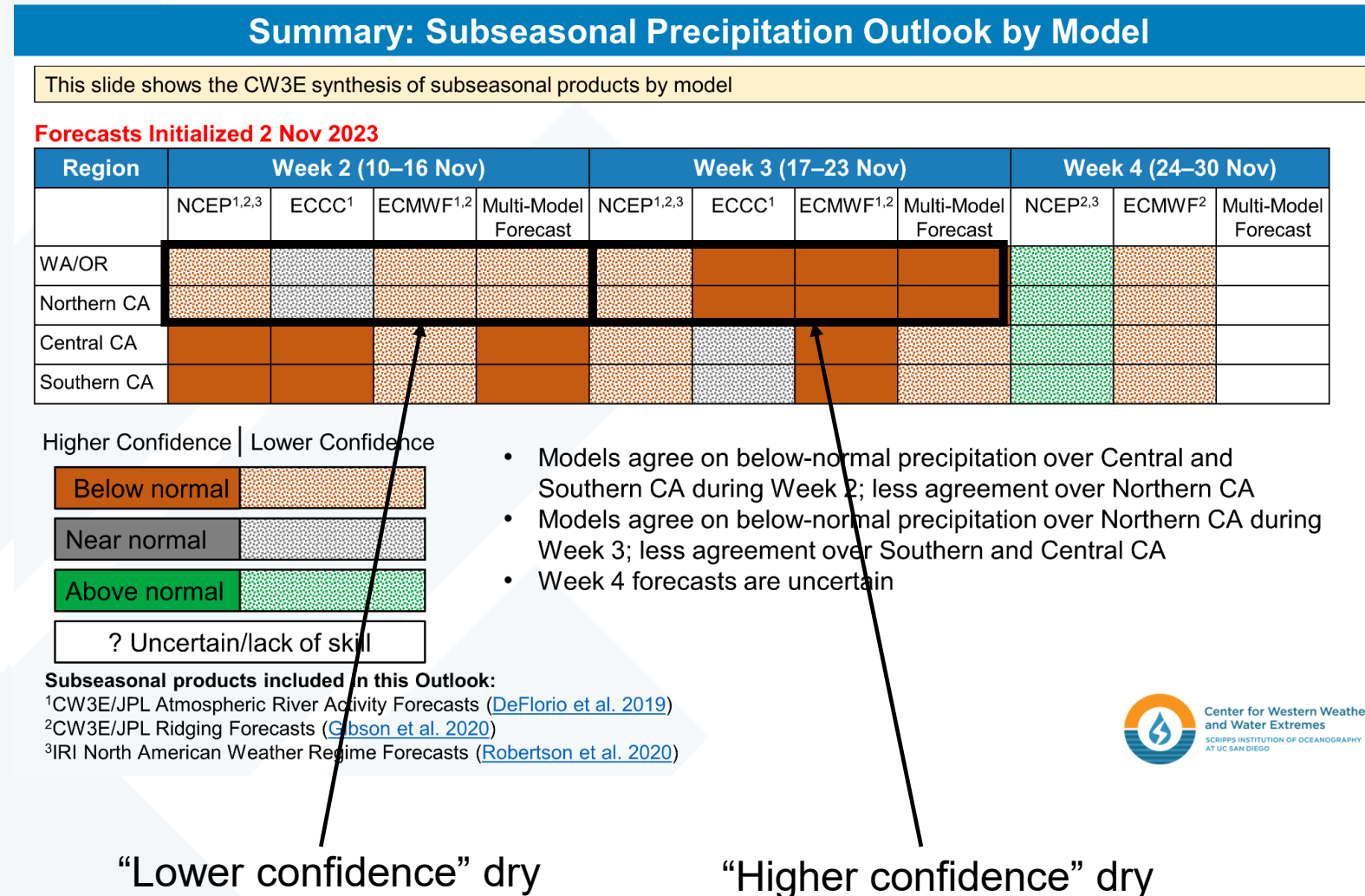
CW3E-DWR Subseasonal and Seasonal Outlook Team

Chris Castellano, Jiabao Wang, Zhiqi Yang
(Leads)

Julie Kalansky, Mike DeFlorio, Marty Ralph,
Lauren Alkire (DWR), Anthony Burdock (DWR),
Mike Anderson (DWR), Angelique Fabbiani-
Leon (DWR), Ramesh Guatam (DWR), Dave
Rizzardo (DWR)

CW3E increased Subseasonal and Seasonal Outlook frequency and breadth of content during WY25

- CW3E produced 19 Subseasonal and 2 Seasonal Outlooks during WY25
(https://cw3e.ucsd.edu/cw3e_s2s_outlook_archive/)
- These outlooks summarize and consolidate subseasonal (2-6 week lead) and seasonal (1-3 month lead) forecast information from multiple models and institutions, and also provide Water Year to Date observations of precipitation and snowpack across the western U.S.
- Each spring/summer, CW3E collaborates directly with DWR end users to modify and improve the outlooks



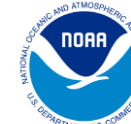


Applications of Subseasonal Research and Experimental Forecasting Products in Recent WYs

From California's Extreme Drought to Major Flooding

Evaluating and Synthesizing Experimental Seasonal and Subseasonal Forecasts of Landfalling Atmospheric Rivers and Extreme Precipitation during Winter 2022/23

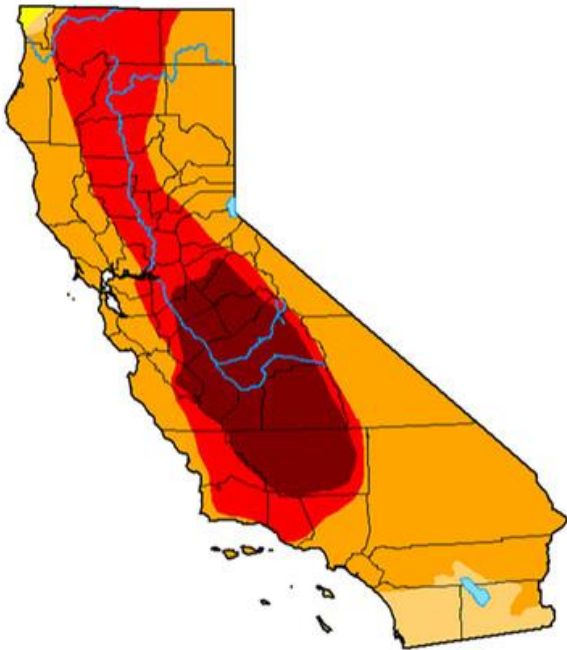
Michael J. DeFlorio, Agniv Sengupta, Christopher M. Castellano, Jiabao Wang, Zhenhai Zhang, Alexander Gershunov, Kristen Guirguis, Rosa Luna Niño, Rachel E. S. Clemesha, Ming Pan, Mu Xiao, Brian Kawzenuk, Peter B. Gibson, William Scheftic, Patrick D. Broxton, Matthew B. Switanek, Jing Yuan, Michael D. Dettinger, Chad W. Hecht, Daniel R. Cayan, Bruce D. Cornuelle, Arthur J. Miller, Julie Kalansky, Luca Delle Monache, F. Martin Ralph, Duane E. Waliser, Andrew W. Robertson, Xubin Zeng, David G. DeWitt, Jeanine Jones, and Michael L. Anderson



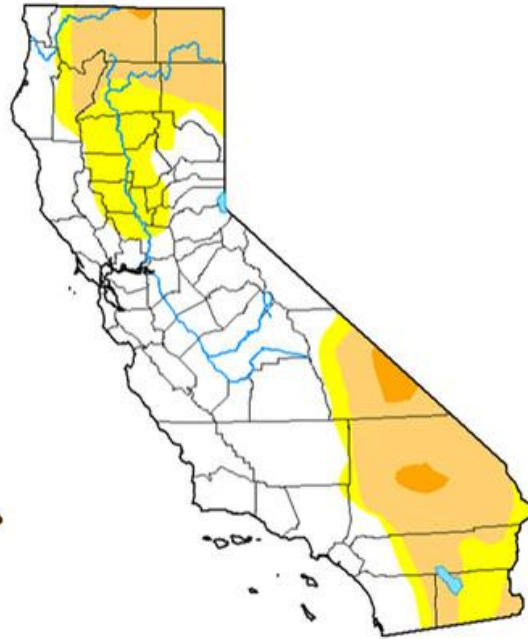
California Drought Conditions: before and after Winter 2022-2023

California Drought Conditions: Late September 2022 vs. Late March 2023

September 27, 2022



March 28, 2023



	Drought Conditions (Percent Area)					
	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	55.34	44.66	28.11	1.95	0.00	0.00
Last Week 03-21-2023	48.51	51.49	35.88	8.49	0.00	0.00
3 Months Ago 12-27-2022	0.00	100.00	97.94	80.56	35.50	7.16
Start of Calendar Year 01-03-2023	0.00	100.00	97.93	71.14	27.10	0.00
Start of Water Year 09-27-2022	0.00	100.00	99.76	94.01	40.91	16.57
One Year Ago 03-29-2022	0.00	100.00	100.00	93.65	40.25	0.00

Intensity



The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. For more information on the Drought Monitor, go to <https://droughtmonitor.unl.edu/About.aspx>

Author

Curtis Riganti
National Drought Mitigation Center



droughtmonitor.unl.edu

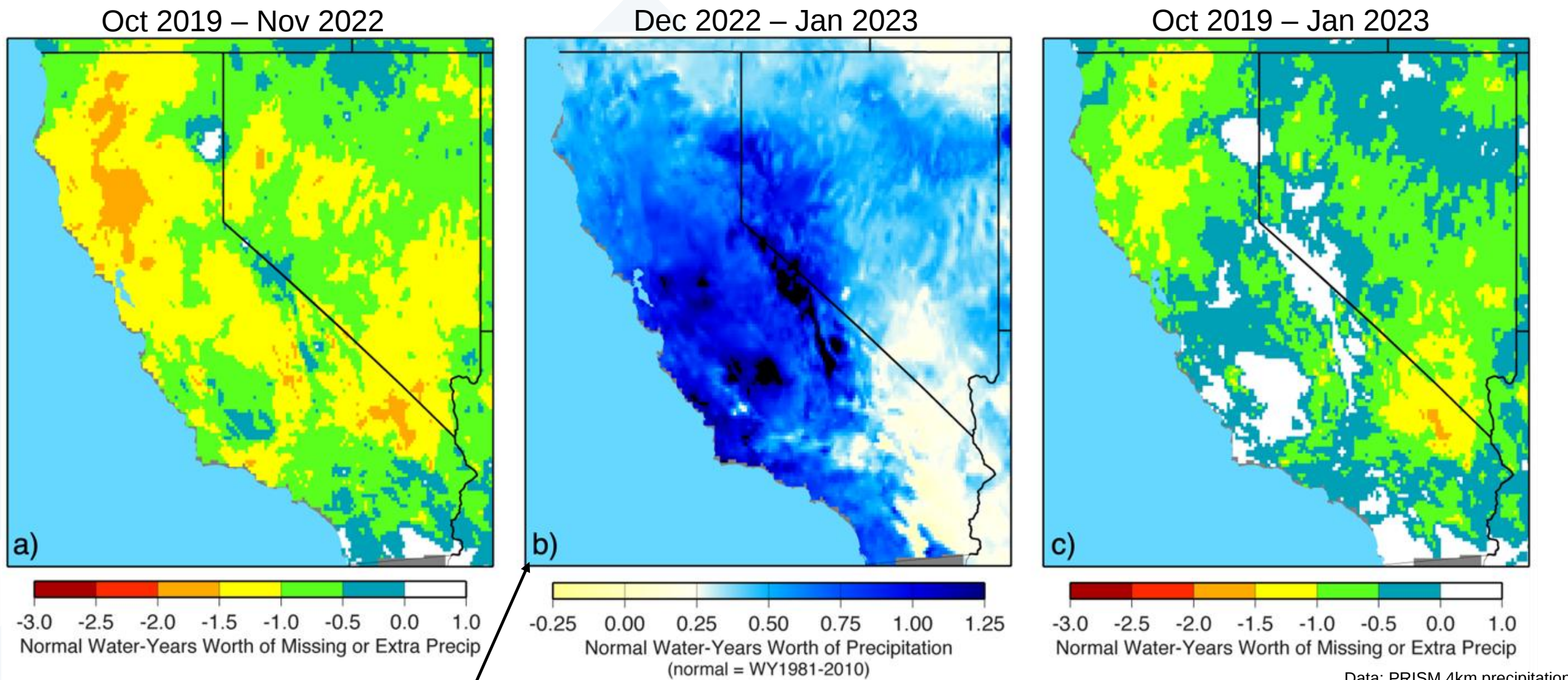
- Entering Winter 2022-2023, 94% of California was experiencing at least Severe drought conditions according to the U.S. Drought Monitor, and 41% of California was experiencing Extreme or Exceptional drought
- By the end of the winter, less than 10% of the state of California was experiencing Severe drought conditions, and the Extreme and Exceptional drought that had evolved over years prior had been eliminated

Drought-Mitigating California AR Landfalls: 26 December 2022 – 17 January 2023



- Nine ARs made landfall along the California coastline during the three-week period spanning from 26 December 2022 – 17 January 2023
- This family of landfalling ARs alleviated multiyear drought and replenished reservoirs across the state

Water-Years worth of missing or extra precipitation: before and after December 2022 – January 2023 regime shift into strong AR conditions that alleviated state-wide drought



Data: PRISM 4km precipitation

CW3E Subseasonal AR Activity Forecasts: December 2022 – January 2023

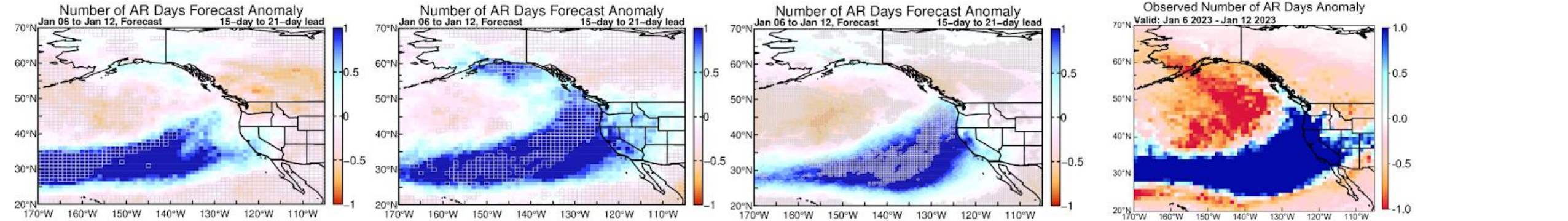
Forecasts Initialized 22 Dec 2022; Valid 6–12 Jan 2023

NCEP

EC3C

ECMWF

ERA5



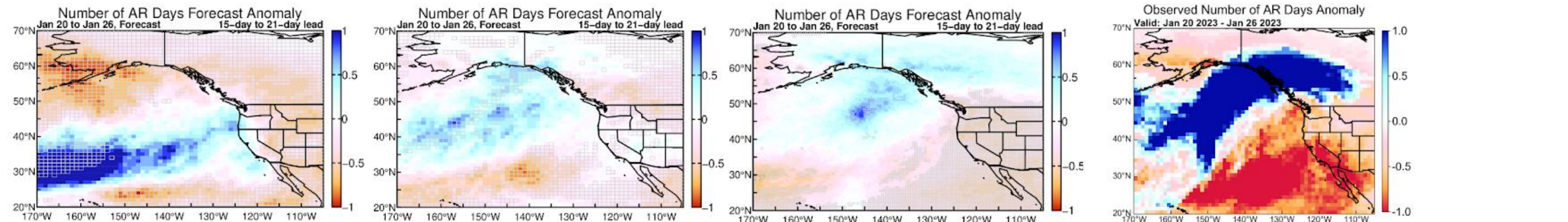
Forecasts Initialized 5 Jan 2023; Valid 20–26 Jan 2023

NCEP

EC3C

ECMWF

ERA5



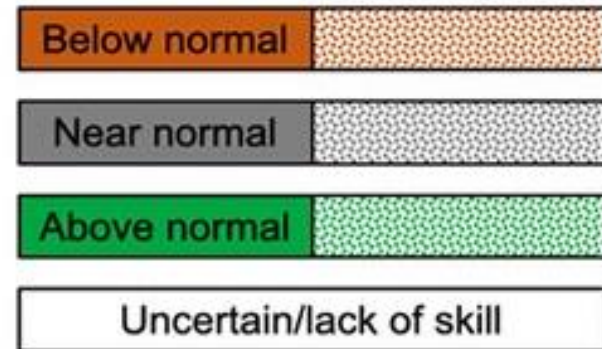
- AR activity outlooks from early December skillfully predicted a large signal of AR activity impacting the western U.S. coastline at week-3 lead, but there were errors in the timing and landfall location of ARs
- AR activity outlooks from late December skillfully predicted impactful AR activity along the entire western U.S. coastline at week-3 lead, but there was an underestimation of inland-penetrating AR activity
- EC3C and ECMWF week-3 forecasts captured return to below normal AR activity in late January 2023

CW3E Subseasonal AR Activity Forecasts: December 2022 – January 2023

Forecasts Initialized 22 Dec 2022

Week 2 (30 Dec – 5 Jan)		NCEP ^{1,2,3}	ECCC ¹	ECMWF ^{1,2}	Multi-Model Forecast
	WA/OR				
	Northern CA				
	Central CA				
	Southern CA				
Week 3 (6–12 Jan)		NCEP ^{1,2,3}	ECCC ¹	ECMWF ^{1,2}	Multi-Model Forecast
	WA/OR				
	Northern CA				
	Central CA				
	Southern CA				
Week 4 (13–19 Jan)		NCEP ^{2,3}	ECCC	ECMWF ²	Multi-Model Forecast
	WA/OR		N/A		
	Northern CA		N/A		
	Central CA		N/A		
	Southern CA		N/A		

Higher Confidence | Lower Confidence

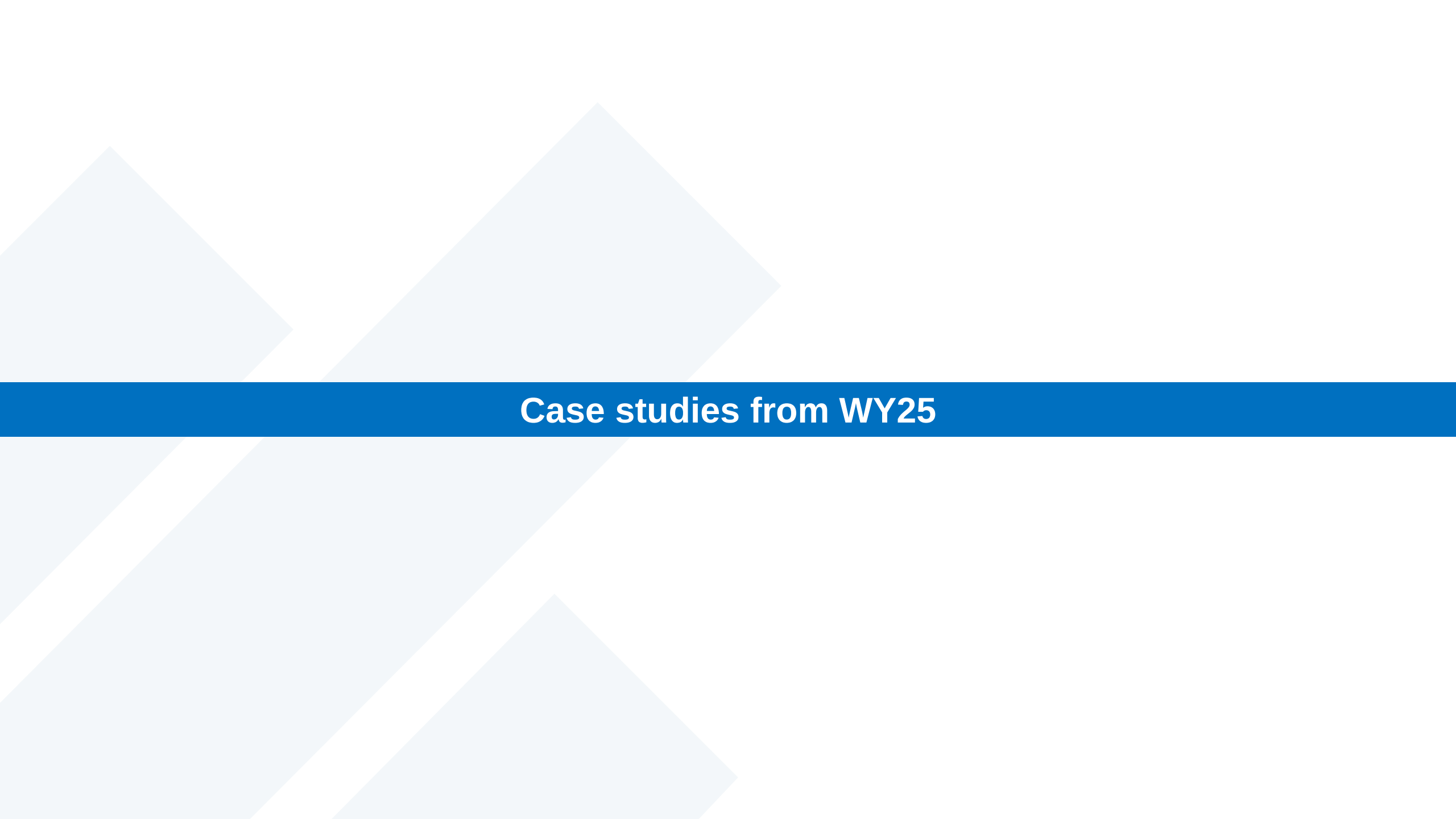


Subseasonal products included in this table:

¹CW3E/JPL Atmospheric River Activity Forecasts ([DeFlorio et al. 2019](#))

²CW3E/JPL Ridging Forecasts ([Gibson et al. 2020](#))

³IRI North American Weather Regime Forecasts ([Robertson et al. 2020](#))



Case studies from WY25

Southern California Wildfires: January 2025



Image credit: AP



Image credit: AP

- 14 destructive wildfires impacted Los Angeles and San Diego counties between January 7, 2025 – January 31, 2025
- Estimated damages range from \$10-\$20 billion for insurance claims (source: Moody's)
 - Likely an order of magnitude higher for total damage (including property)

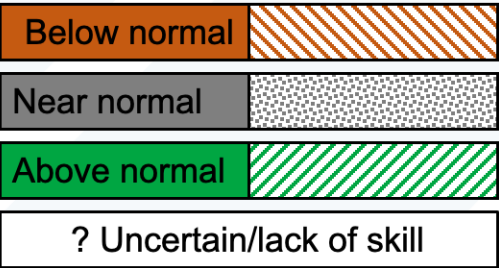
Summary: Subseasonal Precipitation Outlook by Model

This slide shows the CW3E synthesis of subseasonal products by model

Forecasts Initialized 19 Dec 2024

Region	Week 2 (26 Dec–1 Jan)				Week 3 (2–8 Jan)				Week 4 (9–15 Jan)			
	NCEP ^{1,2,3}	ECCC ¹	ECMWF ^{1,2}	Multi-Model Forecast	NCEP ^{1,2,3}	ECCC ¹	ECMWF ^{1,2}	Multi-Model Forecast	NCEP ^{1,2,3}	ECCC ¹	ECMWF ^{1,2}	Multi-Model Forecast
WA/OR												
Northern CA												
Central CA												
Southern CA												

Higher Confidence | Lower Confidence



- High degree of uncertainty in precipitation over all of CA during Week 2
- Models lean towards below-normal precipitation over all of CA (with low confidence) during Weeks 3–4

Subseasonal products included in this Outlook:

¹CW3E/JPL Atmospheric River Activity Forecasts ([DeFlorio et al. 2019](#), [Zhang et al. 2023](#))

²CW3E/JPL Ridging Forecasts ([Gibson et al. 2020](#))

³IRI North American Weather Regime Forecasts ([Robertson et al. 2020](#))

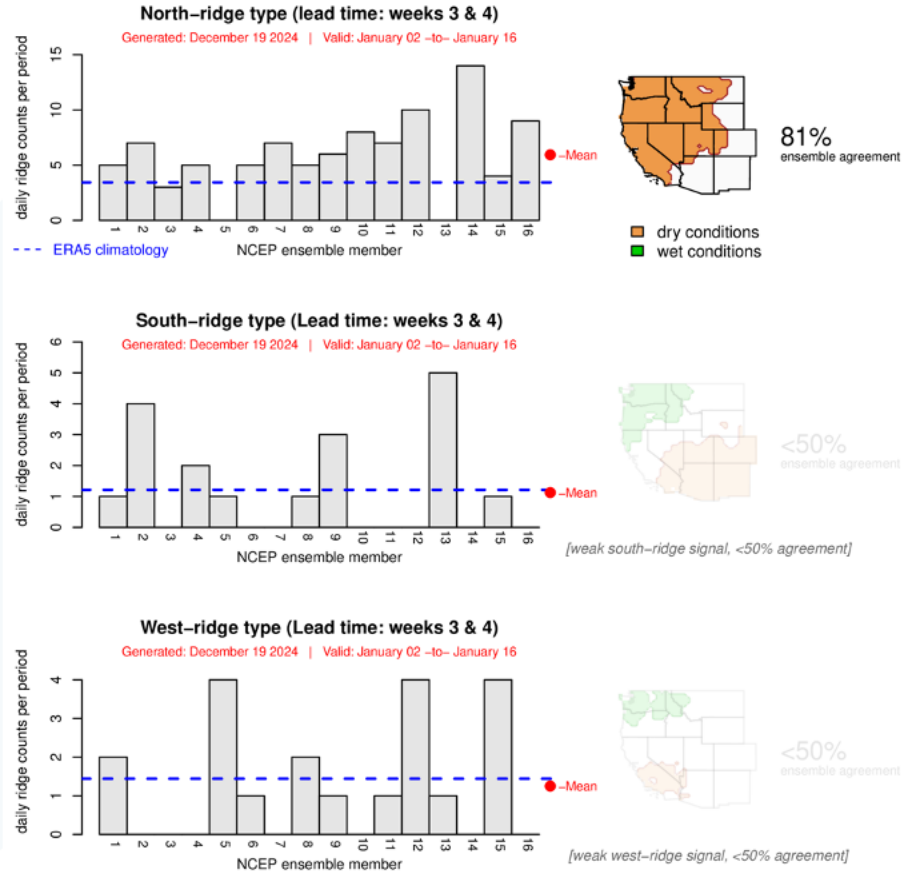


- Multi-model subseasonal synthesis forecasts for January 2-8 (week-3) and January 9-15 (week-4) **tilted odds towards drier than normal conditions** across the western U.S. coastline

Ridging Forecasts: Weeks 3–4 (NCEP vs. ECMWF)

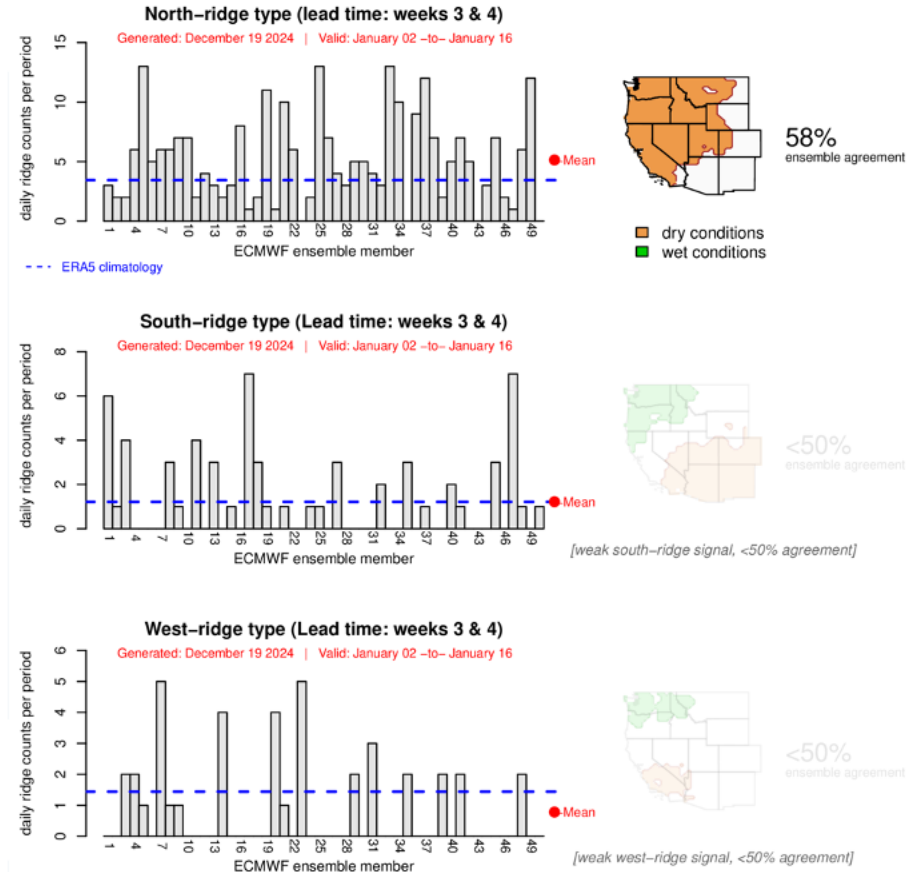
NCEP

CW3E Subseasonal Ridging Forecast (Uses NCEP CFSv2 model)



ECMWF

CW3E Subseasonal Ridging Forecast (Uses ECMWF model)



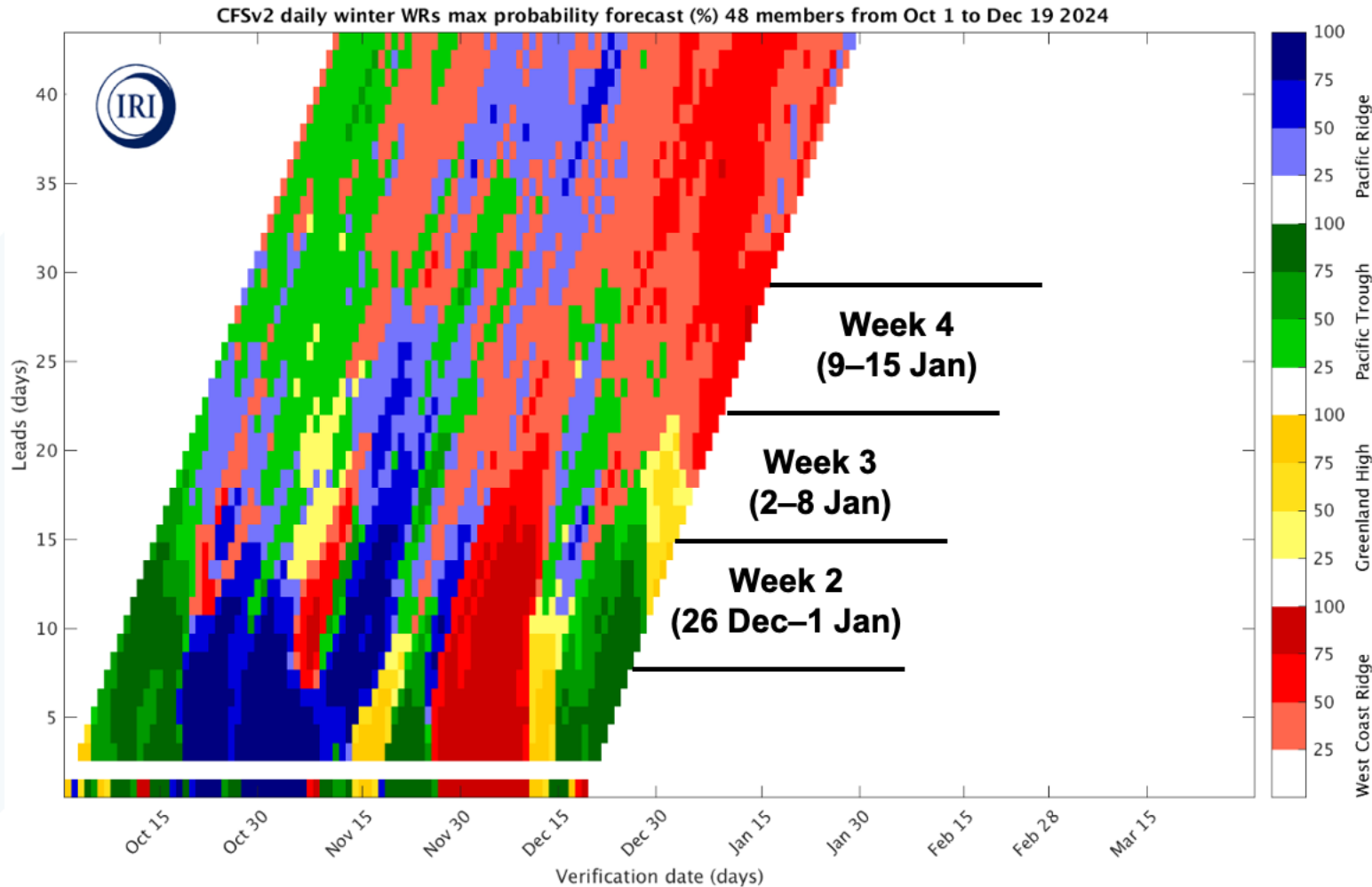
Forecasts Initialized 19 Dec 2024

- NCEP is forecasting a high likelihood (81% ensemble agreement) of above-normal North-ridge activity during Weeks 3–4 (2–16 Jan)
- ECMWF is also forecasting above-normal North-ridge activity with moderate likelihood (58% ensemble agreement)
- Both models are forecasting near-normal South-ridge activity

Models agree on moderate-to-high likelihood of above-normal ridging activity over the Pacific Northwest during Weeks 3–4 (2–16 Jan)

IRI North American Weather Regime Forecasts

Forecast Initialized 19 Dec 2024



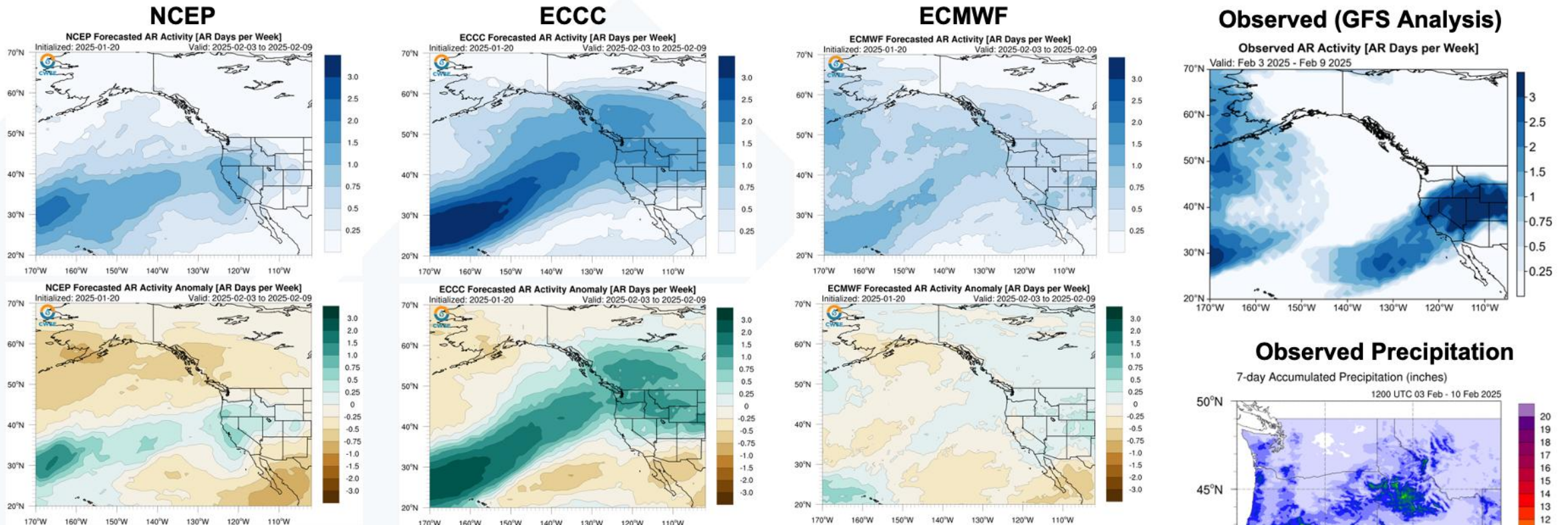
- Daily forecast out to 45-day lead time based on NCEP CFSv2 ensemble
- High likelihood (> 75% ensemble agreement) of regime transition from Pacific Trough to Greenland High during Week 2 (26 Dec – 1 Jan)
- Moderate likelihood (50–75% ensemble agreement) of regime transition from Greenland High to West Coast Ridge during Week 3 (2–8 Jan)
- Moderate likelihood (50–75% ensemble agreement) of West Coast Ridge persisting to Week 4 (9–15 Jan)

This graphic shows the which of the four North American weather regimes (different colors) is most likely to occur over the next 45 days. Darker (lighter) shading denotes higher (lower) probability of a particular regime. See the next slide for temperature/precipitation implications.

For more information about the forecast product: <https://wiki.iri.columbia.edu/index.php?n=Climate.S2S-WRs>

Subsequent AR/precipitation period: early February 2025

Forecasts Initialized 20 Jan 2025; Valid: 3-9 Feb 2025



Shading: Fractional # of AR days forecast over a 7-day period (top) and forecast minus model climatology (bottom; green/blue = higher than climatology; brown = lower than climatology)

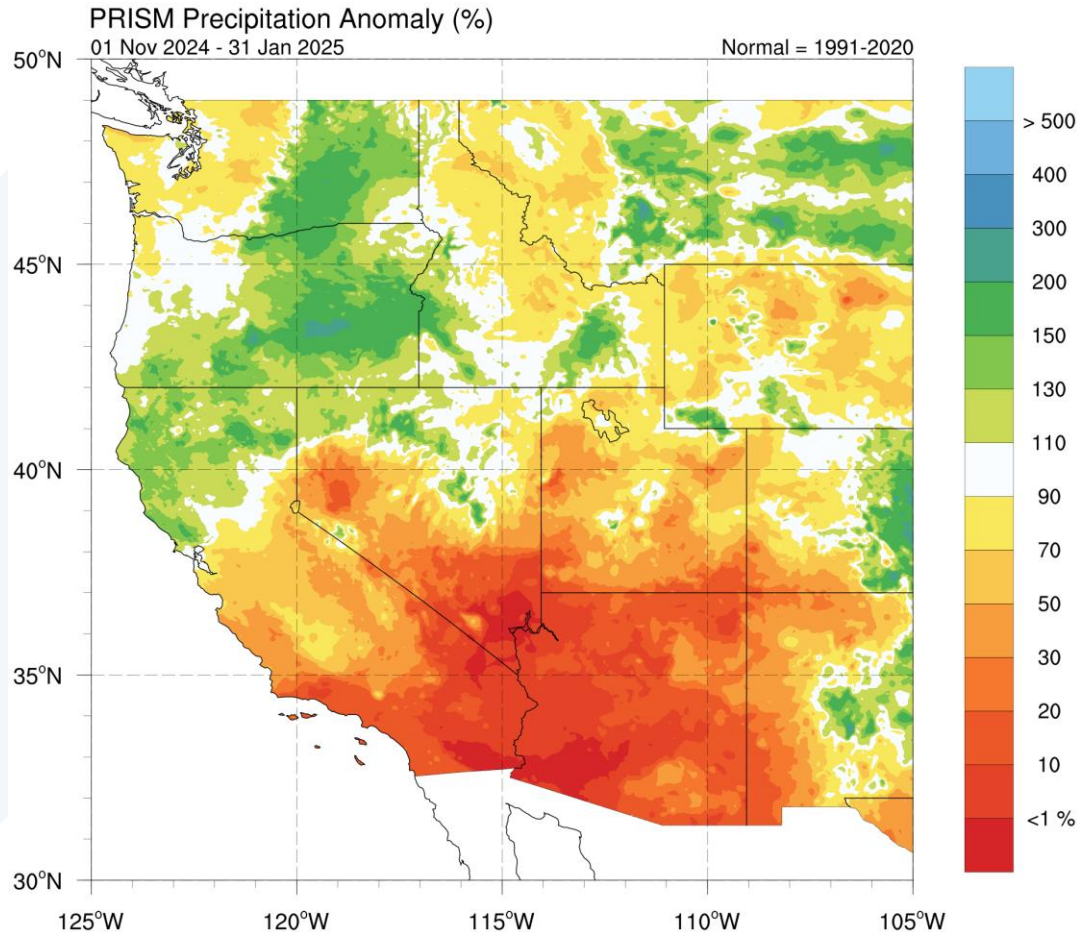
- NCEP and ECCC correctly predicted the AR activity over Northern CA and OR, although with underestimation of the magnitude; ECCC predicted the center of AR activity too far north compared to what was observed; ECMWF predicted too little AR activity over the western US
- NCEP and ECMWF underestimated the inland penetration of AR activity over the interior western US
- A few ARs produced heavy precipitation (5-13 inches) over Northern CA, Sierra Nevada, and coastal CA during 3-5 Feb and 7 Feb



NDJ and JFM Seasonal Forecasts: WY25

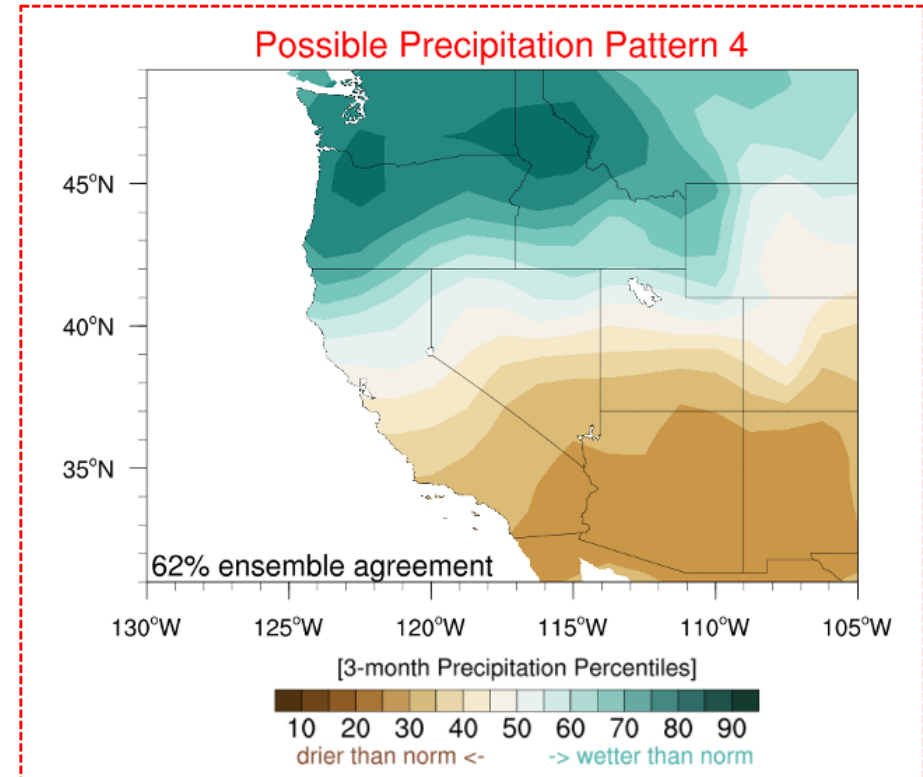
CW3E Seasonal Machine Learning Forecasts: NDJ 24-25

OBS (NDJ)



FORECAST (NDJ)

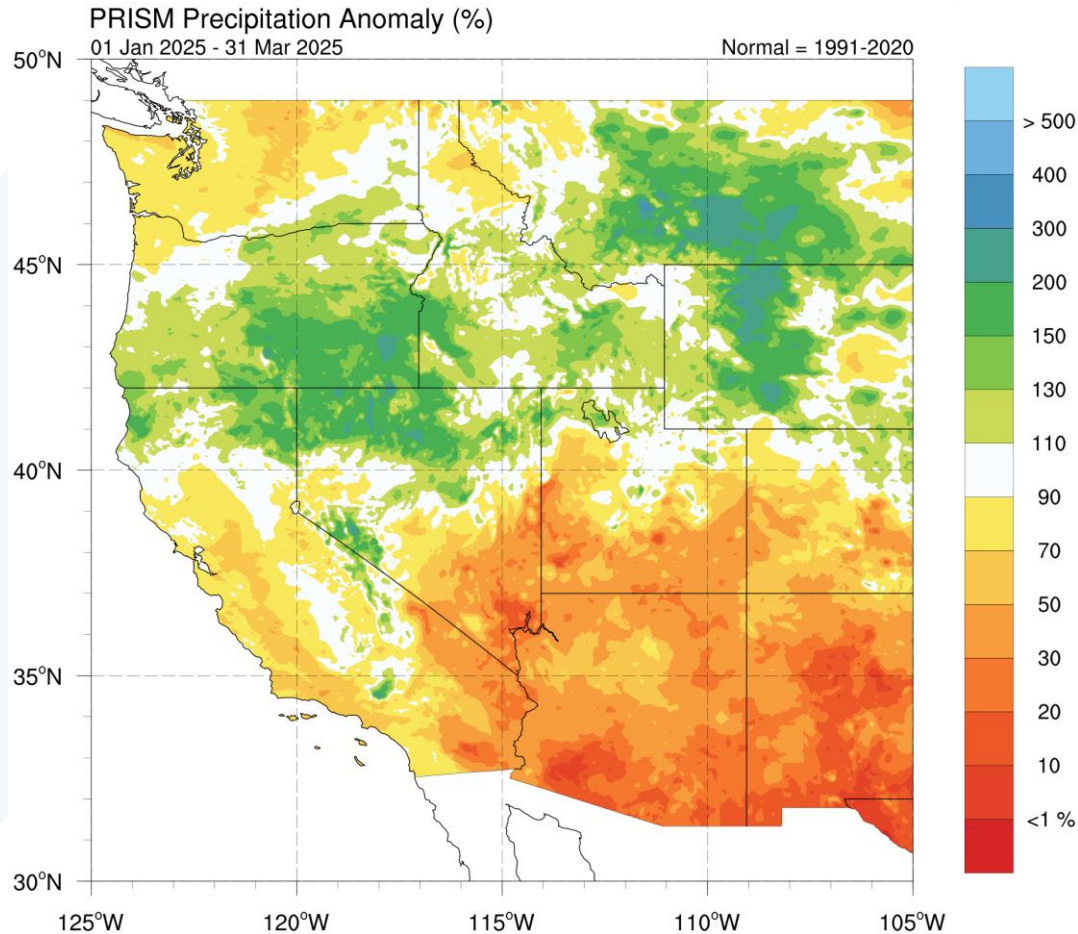
62% chance of a wet north and dry south in the Western U.S.



- 62% of ensemble members (CW3E ML models + NMME) tilted odds towards **wetter than normal conditions** over Pac NW / NorCal and **drier than normal conditions** over SoCal/desert SW

CW3E Seasonal Machine Learning Forecasts: JFM 24-25

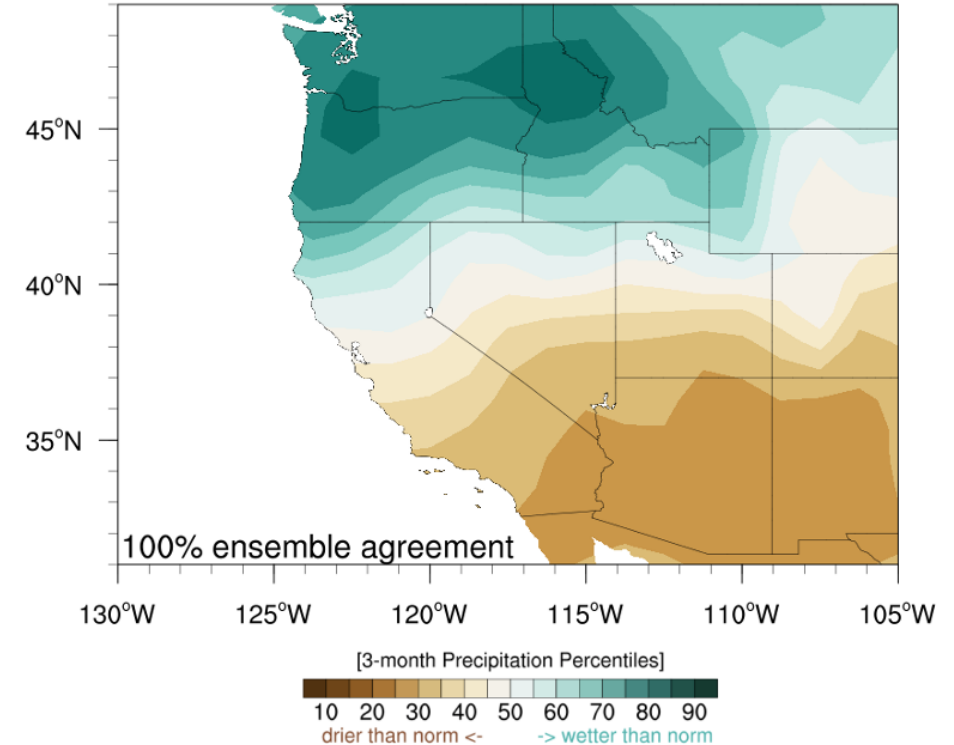
OBS (JFM)



FORECAST (JFM)

All models favor a wet north/dry south pattern in the Western US

Possible Precipitation Pattern 4



- All ensemble members (CW3E ML models + NMME) tilted odds towards **wetter than normal conditions** over Pac NW / NorCal and **drier than normal conditions** over SoCal/desert SW

Future Directions

- Quantitative verification of Subseasonal and Seasonal WY25 products is ongoing (3RD Annual DWR/CW3E S&S Verification Workshop: 26 Aug 2025, SIO/Virtual)
- Exploring use of data-driven models to improve fidelity of subseasonal forecasts of ARs over California (Z. Yang, J. Wang, A. Sengupta and others)
- Introducing hybrid dynamical-statistical subseasonal prediction system for ARs, temperature, Santa Ana Winds, and other relevant impacts over California (Guirguis et al. 2023, Guirguis et al. 2020)
 - Plan to launch this on CW3E S&S Website at start of WY26
- New seasonal prediction system for western U.S. precipitation based on evolving sea surface temperature information will be launch on CW3E S&S website in November 2025 (Sengupta et al. 2025)



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Thank you!

mdeflorio@ucsd.edu

cw3e.ucsd.edu/s_and_s_forecasts



Rancho Mission Viejo/Santa Ana Mountains
Photo credit: M. DeFlorio, 2024