

CW3E Event Summary: 10–14 December 2021

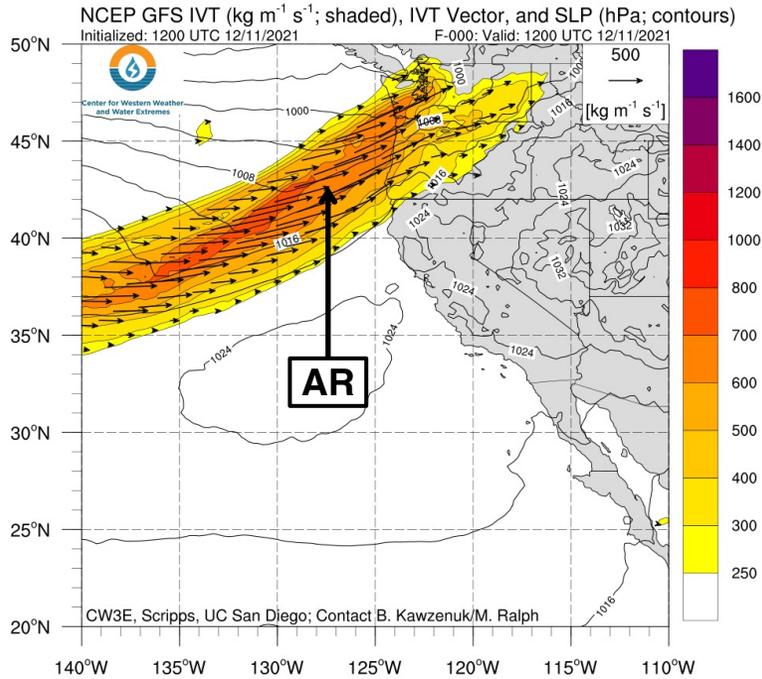
Atmospheric River Brings Heavy Rain and Snow to the Western US

- An atmospheric river (AR) made landfall over the Pacific Northwest on 10 Dec and gradually moved south along the US West Coast
- When the AR reached the San Francisco Bay Area, it temporarily stalled and began to re-intensify as it interacted with an upper-level trough to the west
- AR conditions persisted for at least 48 hours over the Bay Area and the foothills of the Northern Sierra Nevada, resulting in an AR 2/AR 3 (based on the Ralph et al. 2019 AR Scale)
- AR 1 conditions were observed in coastal Southern California
- More than 5 inches of storm-total precipitation fell across the Pacific Coast Ranges, the Cascades, the Sierra Nevada, and the Southern California Transverse Ranges
- Some locations in the California Coast Ranges reported more than 10 inches of precipitation
- Several feet of snow fell in the Olympic Mountains, the Cascades, the Northern Rockies, and the Sierra Nevada
- Low freezing levels supported significant snowfall accumulations below 6,000 feet in the Sierra Nevada as well as in the Southern Oregon and Northern California Coast Ranges
- Intense rainfall on 13–14 Dec caused flooding and slides in the Bay Area and in Southern California

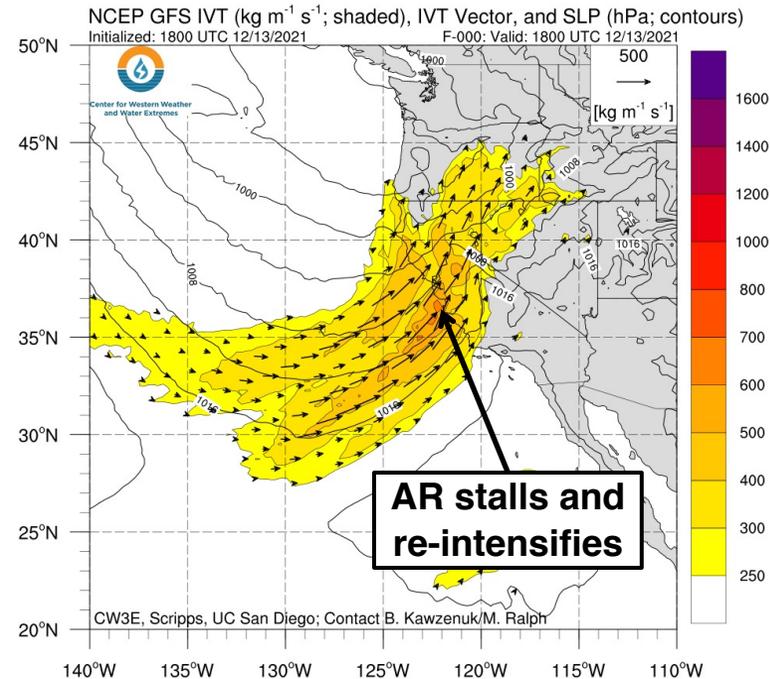
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GFS IVT Analyses

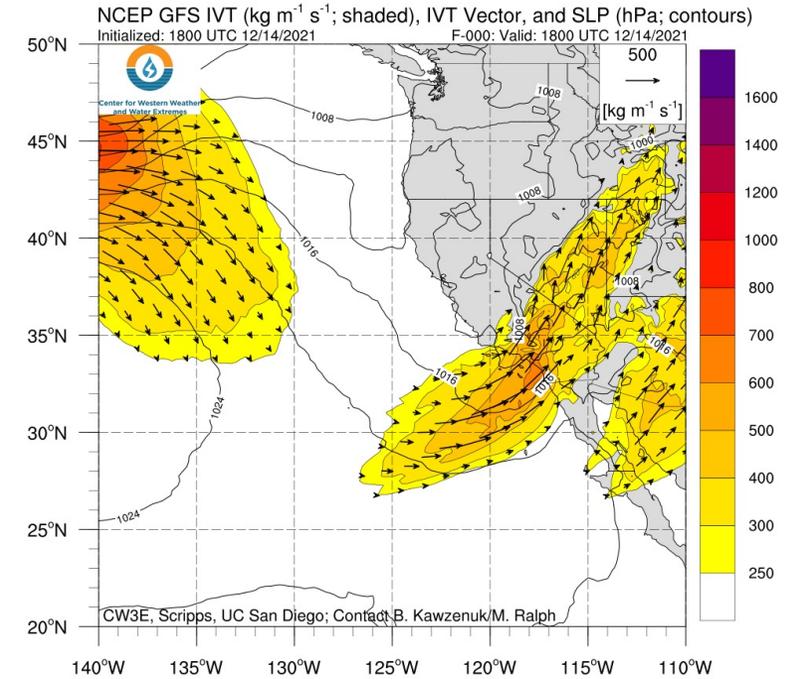
A) Valid: 4 AM PT 11 Dec



B) Valid: 10 AM PT 13 Dec



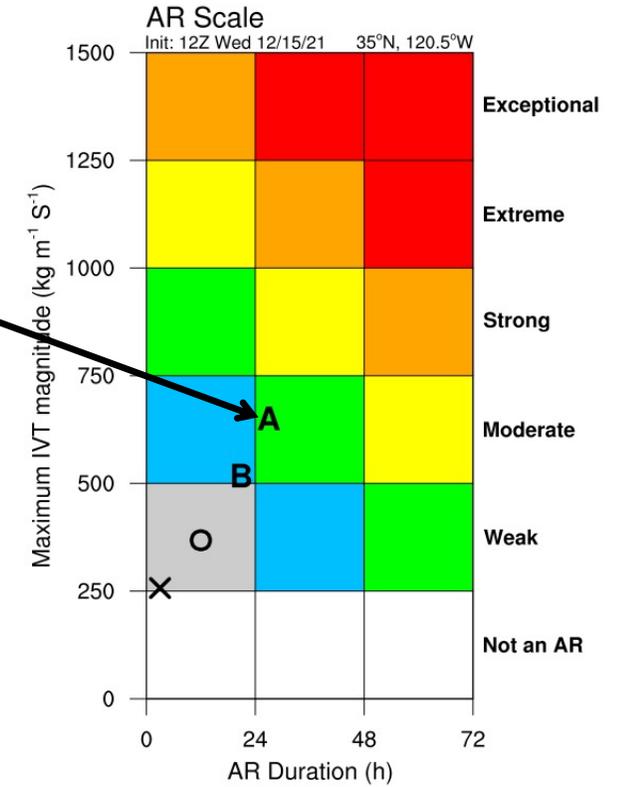
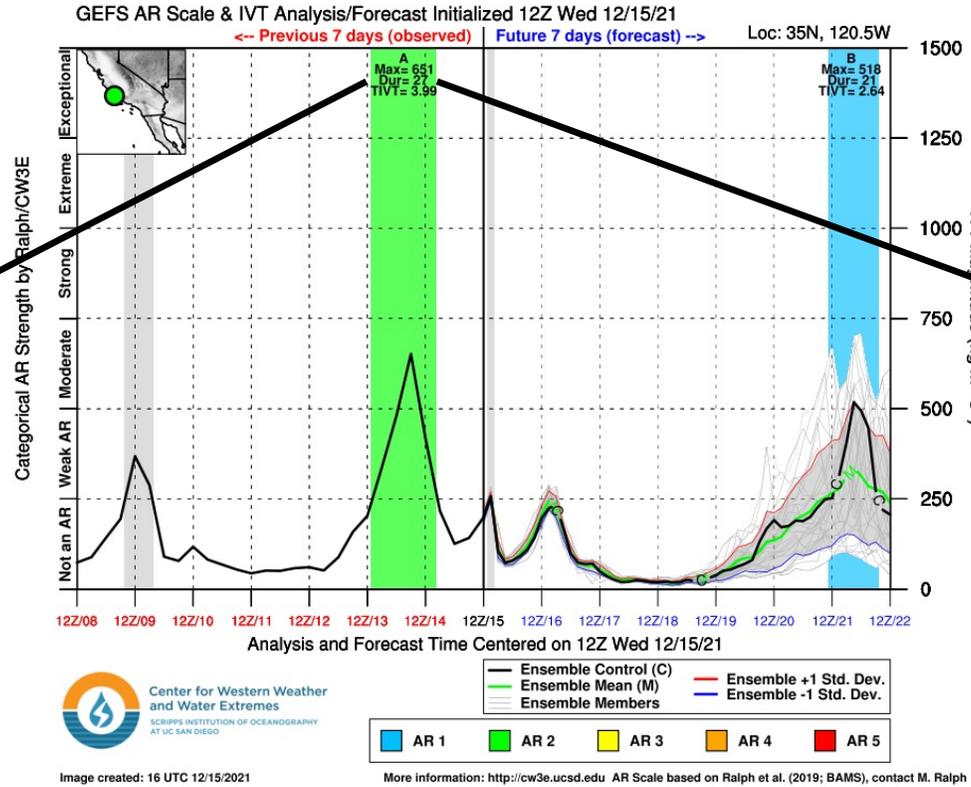
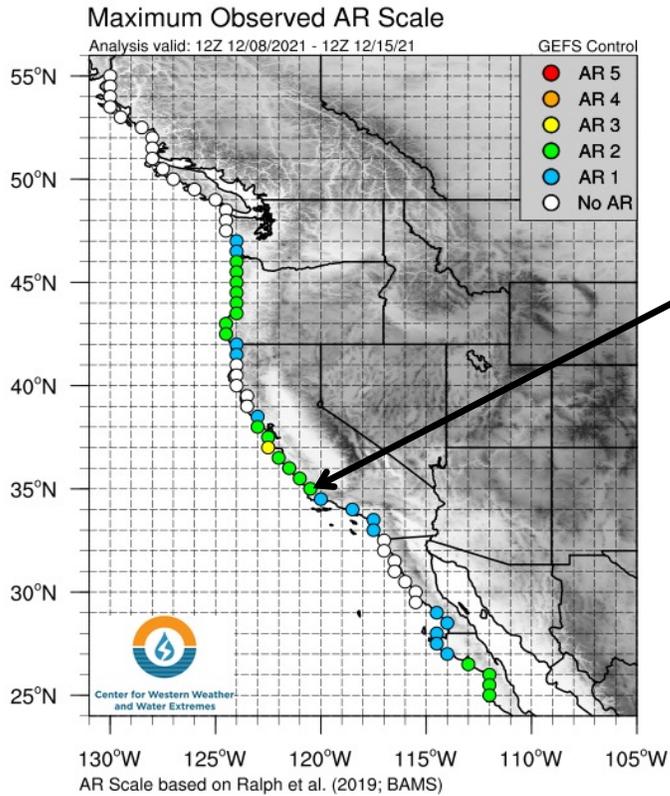
C) Valid: 10 AM PT 14 Dec



- The AR initially made landfall over the Pacific Northwest during the evening of 11 Dec, bringing IVT magnitudes $> 600 \text{ kg m}^{-1} \text{ s}^{-1}$ to coastal Washington and Oregon (Figure A)
- On 12–13 Dec, the AR temporarily stalled and began to re-intensify over Northern and Central California as it interacted with an upper-level trough to the west (Figure B)
- The AR eventually moved southeastward, bringing a brief period of moderate AR conditions ($\text{IVT} > 500 \text{ kg m}^{-1} \text{ s}^{-1}$) to Southern California (Figure C)

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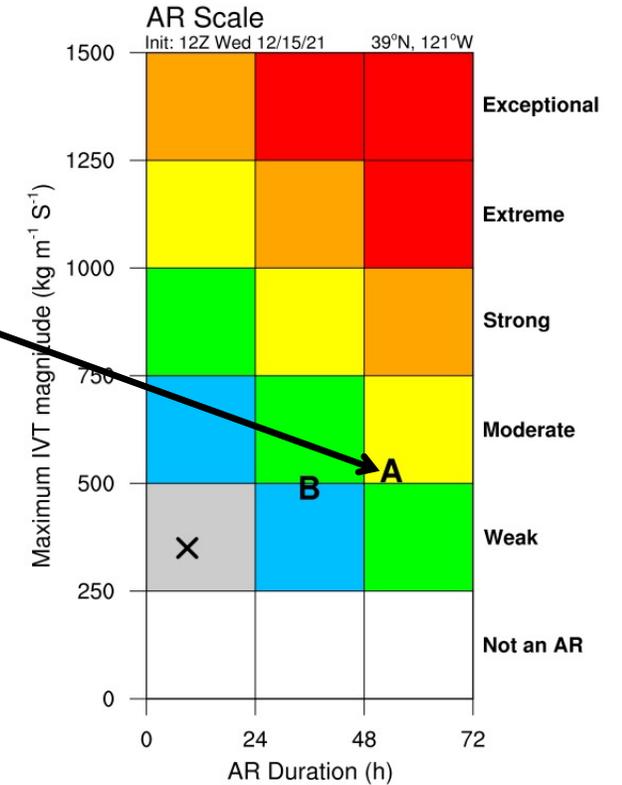
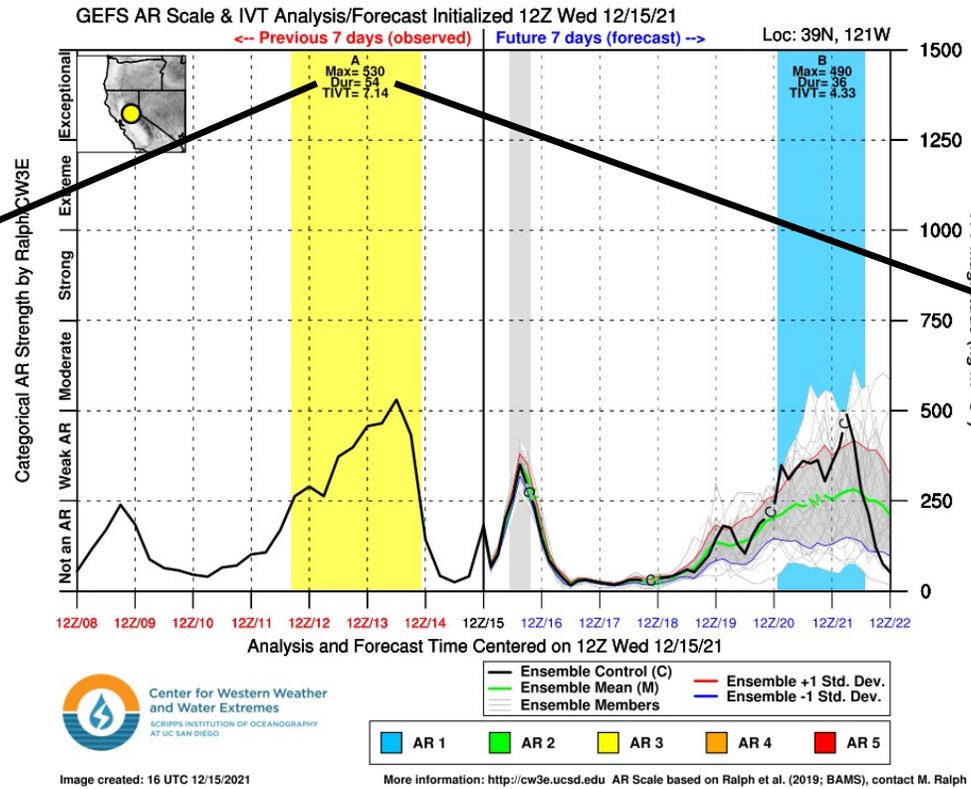
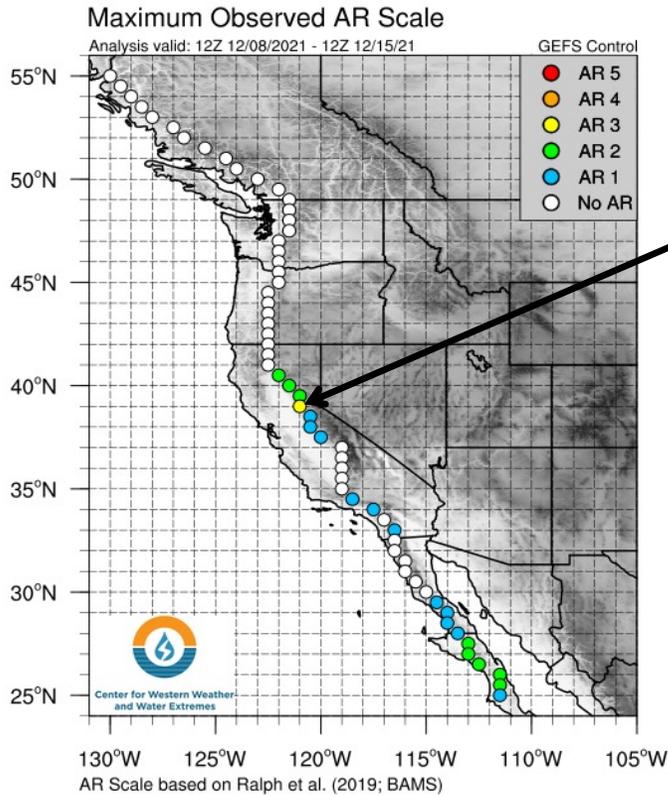
GEFS AR Scale & IVT Analyses: Coastal



- This AR produced AR 2/AR 3 conditions (based on the Ralph et al. 2019 AR Scale) over the Bay Area and the Central California coast
- San Mateo and Santa Cruz Counties experienced AR conditions for at least 48 consecutive hours
- AR 1 conditions were observed along the Southern California coast, where the AR passed through rather quickly
- The strongest moisture transport was observed at 35°N, 120.5°W (near Santa Maria, CA) around 06Z 14 Dec, with IVT values reaching $651 \text{ kg m}^{-1} \text{ s}^{-1}$

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GEFS AR Scale & IVT Analyses: Foothills



- AR 2/AR 3 conditions were also observed in the foothills of the Northern Sierra Nevada, where IVT magnitudes exceeded $250 \text{ kg m}^{-1} \text{ s}^{-1}$ for at least 48 consecutive hours
- A maximum IVT of $530 \text{ kg m}^{-1} \text{ s}^{-1}$ and an AR duration of 54 hours were observed at 39°N , 121°W (near Auburn, CA)

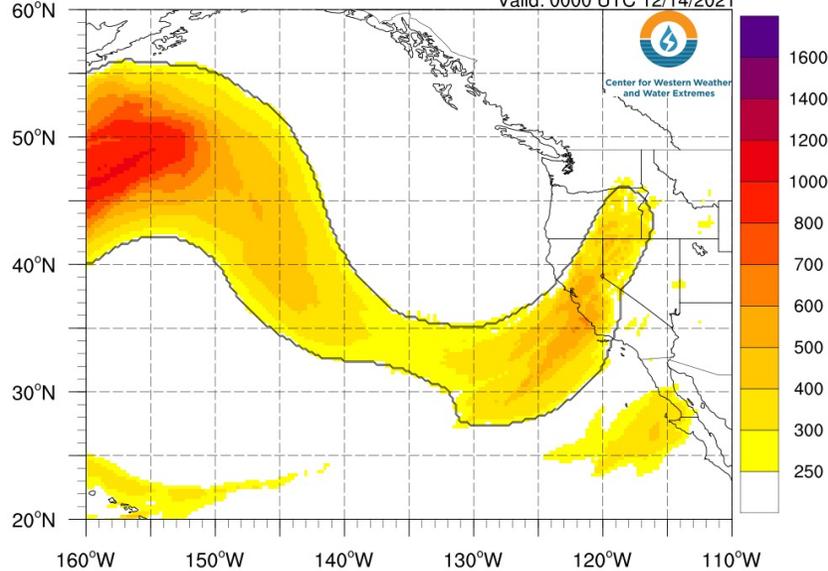
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GFS AR/IVT Forecast Verification: Valid 00Z 14 Dec

Model Analysis

GFS Analysis IVT ($\text{kg m}^{-1}\text{s}^{-1}$)

Valid: 0000 UTC 12/14/2021

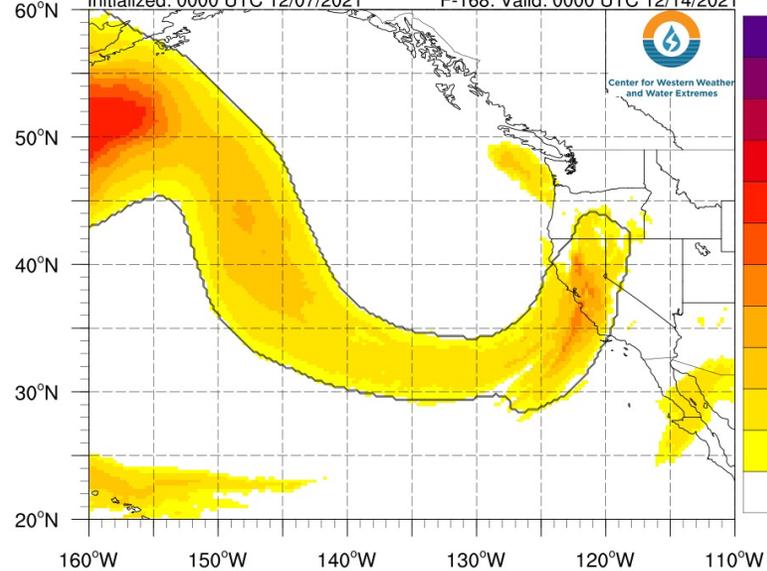


168-h Forecast

GFS IVT ($\text{kg m}^{-1}\text{s}^{-1}$)

Initialized: 0000 UTC 12/07/2021

F-168: Valid: 0000 UTC 12/14/2021

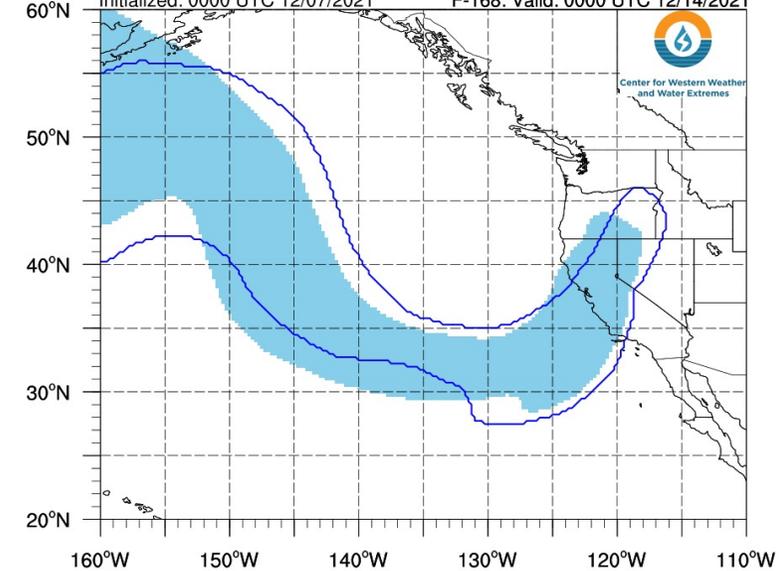


Object Verification

GFS IVT Verification ($250 \text{ kg m}^{-1}\text{s}^{-1}$)

Initialized: 0000 UTC 12/07/2021

F-168: Valid: 0000 UTC 12/14/2021



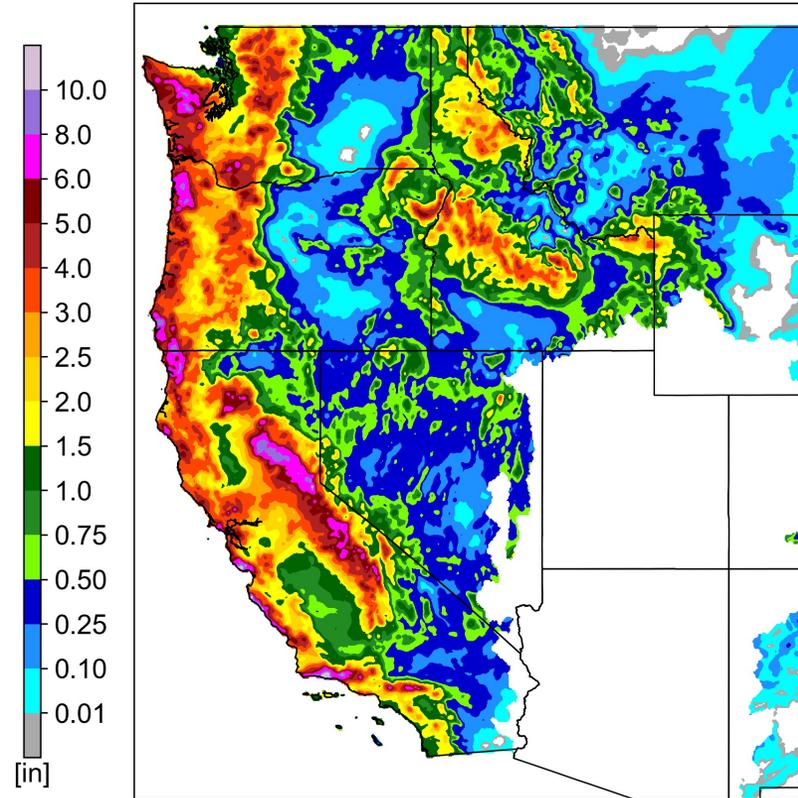
Forecast objects shaded (unmatched objects in gray)
Observed objects contoured (unmatched objects in black)
Objects defined based on $\text{IVT} > 250 \text{ kg m}^{-1}\text{s}^{-1}$

- Despite the large amount of uncertainty in global ensemble prediction systems leading up to this event, the spatial characteristics of the AR were predicted quite well by the deterministic GFS model at least 7 days in advance
- The AR in the 168-hour forecast was slightly stronger and exhibited a more meridional orientation than the observed AR
- In addition, the forecasted AR did not extend as far into the interior northwestern US as the observed AR

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NCEP Stage IV 120-h QPE

Valid: 4 AM PT 10–15 Dec

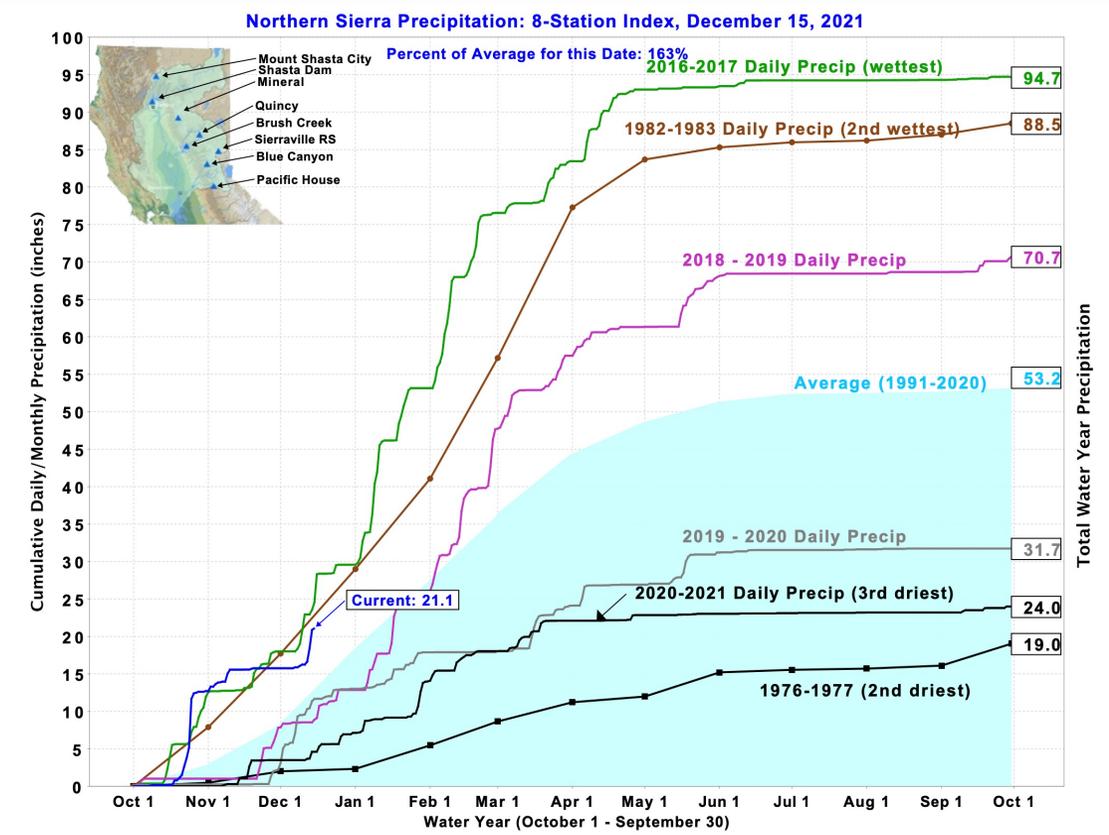


Station	Storm-Total Precip (in)	WY-to-Date Precip (in)	Normal WY-to-Date Precip (in)	% of Normal Precip)
Sacramento Executive Airport	3.02	10.66	3.99	267%
Downtown Sacramento	2.83	10.55	4.20	251%
San Francisco Airport	4.05	10.60	4.62	229%
Oakland	3.94	10.22	4.54	225%
Modesto	2.37	5.69	2.54	224%
Downtown San Francisco	3.38	11.75	5.62	209%
Santa Rosa	3.20	16.94	8.14	208%
Stockton	1.59	6.02	3.12	193%
Blue Canyon	6.66	29.65	16.20	183%
Bakersfield	0.97	2.07	1.21	171%
Hanford	0.92	2.48	1.58	157%
Fresno	1.29	3.27	2.10	156%

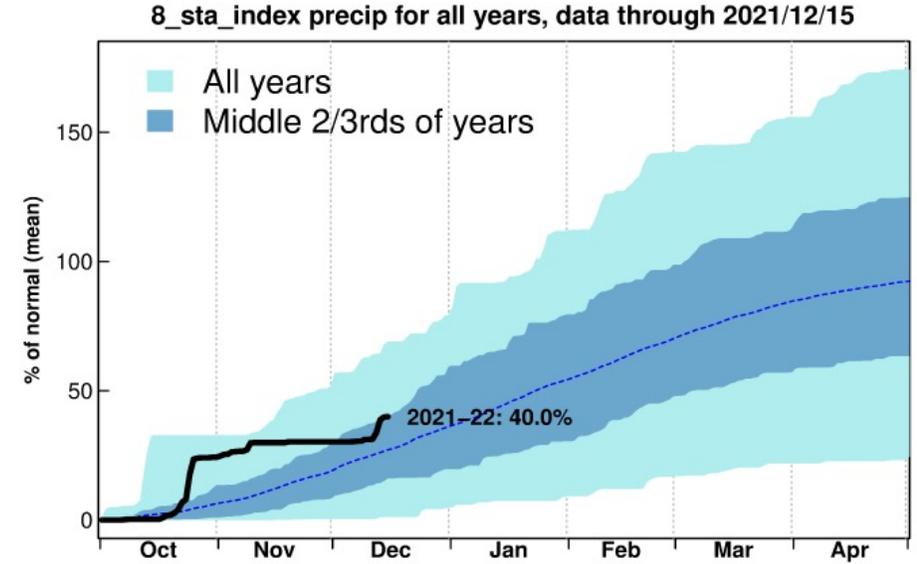
Sources: NWS Hanford, NWS Sacramento, NWS San Francisco

- This event produced widespread moderate-to-heavy precipitation along the US West Coast
- More than 5 inches of storm-total precipitation fell across the Pacific Coast Ranges, the Cascades, the Sierra Nevada, and the Southern California Transverse Ranges
- Some locations in the California Coast Ranges reported more than 10 inches of precipitation
- Many stations in California set new daily precipitation records on 13 Dec and 14 Dec
- As of 15 Dec, portions of the Bay Area and the Central Valley have received > 200% of the normal water-year-to-date (since 1 Oct) precipitation

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Source: California Department of Water Resources



Northern Sierra Nevada 8-Station Index ([station list](#); a traditional indicator of CA water supply) ([archive of past tables](#))

Current:	39.7%	1-day Δ:	0.97%	2-day Δ:	5.83%	3-day Δ:	8.39%
(1959/12/14)							
Rec_low:	1.1%	50-ptile:	0.32%	50-ptile:	0.60%	50-ptile:	0.90%
Typ_low:	15.2%	90-ptile:	2.53%	90-ptile:	4.16%	90-ptile:	5.73%
Mean:	26.6%	95-ptile:	3.49%	95-ptile:	5.83%	95-ptile:	7.67%
Typ_high:	39.5%	99-ptile:	5.75%	99-ptile:	9.38%	99-ptile:	11.83%
Rec_high:	67.9%	Record:	13.53%	Record:	20.75%	Record:	27.21%
	(1950/12/14)		(1964/12/22)		(1964/12/23)		(1964/12/23)

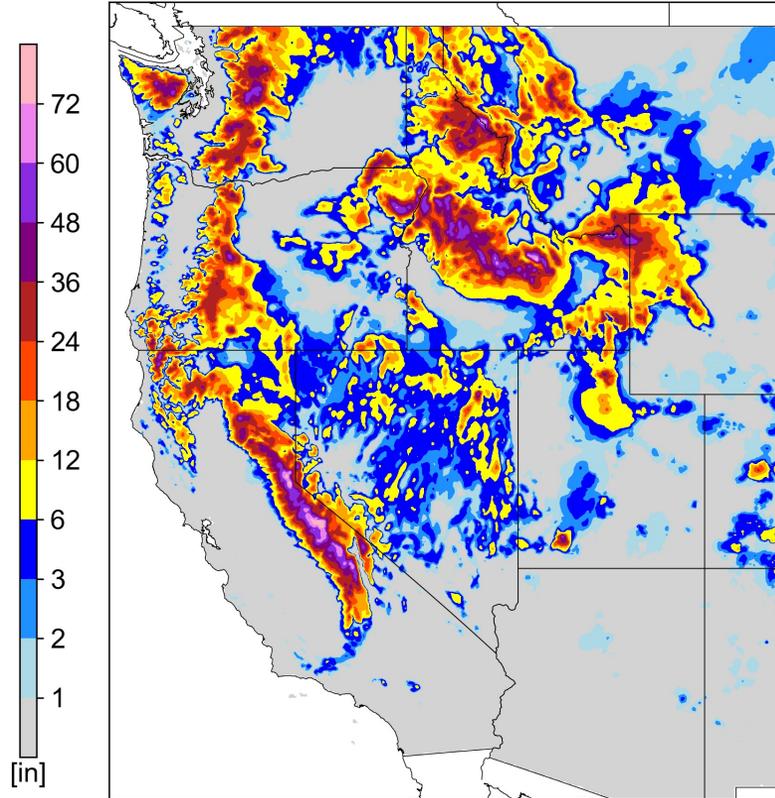
Source: California–Nevada Applications Program

- The 8-station index shows that water-year-to-date precipitation is running well above normal in the Northern Sierra Nevada
- As of 15 Dec, the Northern Sierra region has already received about 40% of its normal total water year precipitation
- Although not quite as impactful as the late October 2021 event, this storm produced more than 8% of the region’s normal total water year precipitation

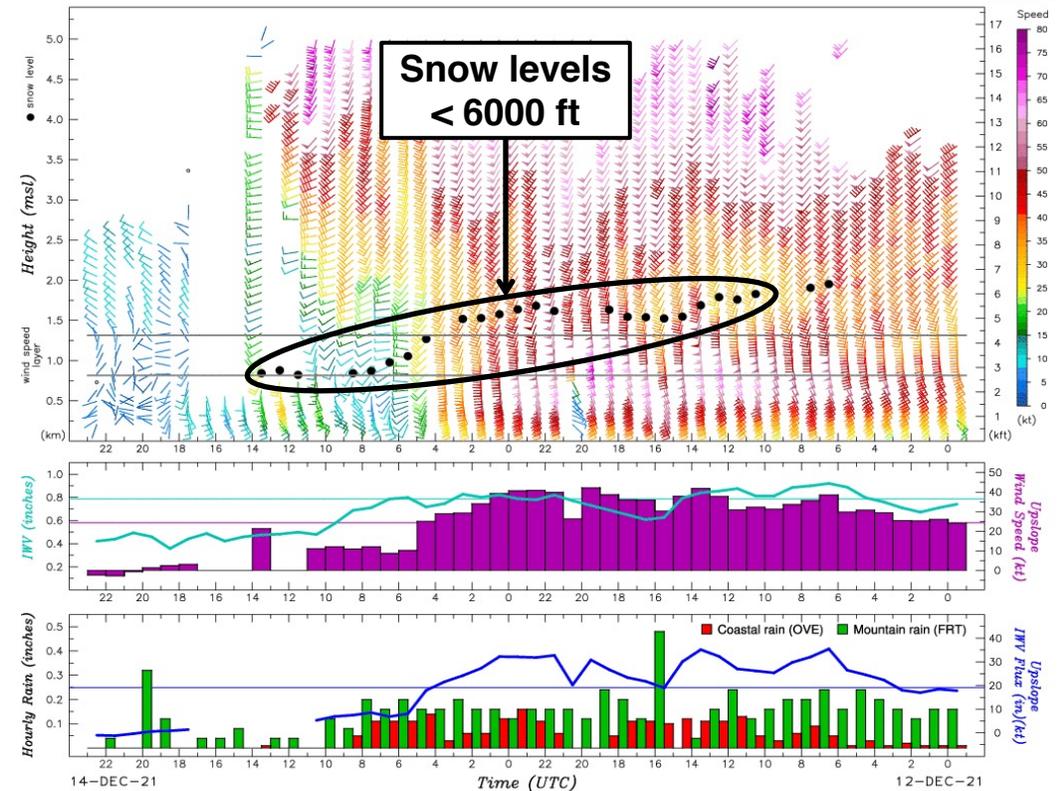
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NOHRSC 120-h Interpolated Snowfall

Valid: 4 AM PT 10–15 Dec



NOAA Physical Sciences Laboratory
Coastal Atmospheric River Monitoring and Early Warning System



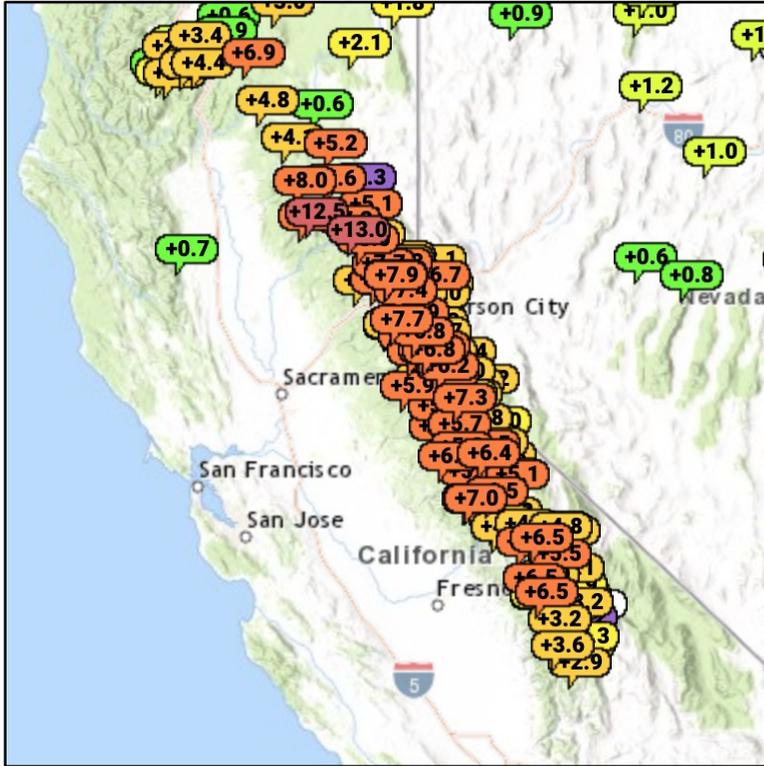
Oroville, CA (OVE)
39.5119 N, 121.6292 W, 56 m
Four Trees, CA (FRT)
39.81306 N, 121.32111 W, 1569 m

Upslope Direction = 220 deg
OVE 48-hr precip: 2.35 in
FRT 48-hr precip: 6.64 in

- More than 2 feet of snow fell in the Olympic Mountains, the Cascades, the Northern Rockies, and the Sierra Nevada
- The highest snowfall accumulations (locally > 6 feet) were observed along the Sierra crest
- Low freezing levels allowed for significant snowfall accumulations below 6,000 feet in the Sierra Nevada and in portions of the Coast Ranges in southern Oregon and Northern California

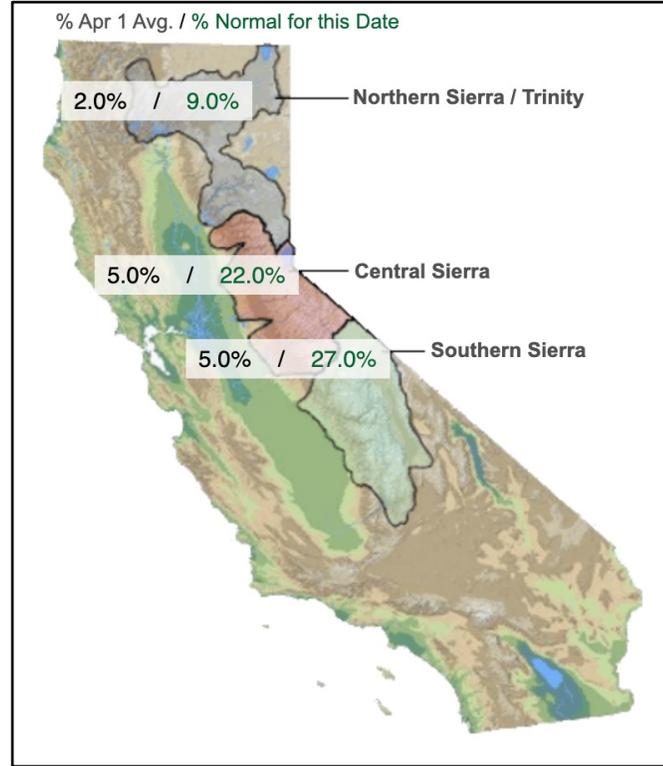
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5-day SWE Change: Valid 10–15 Dec



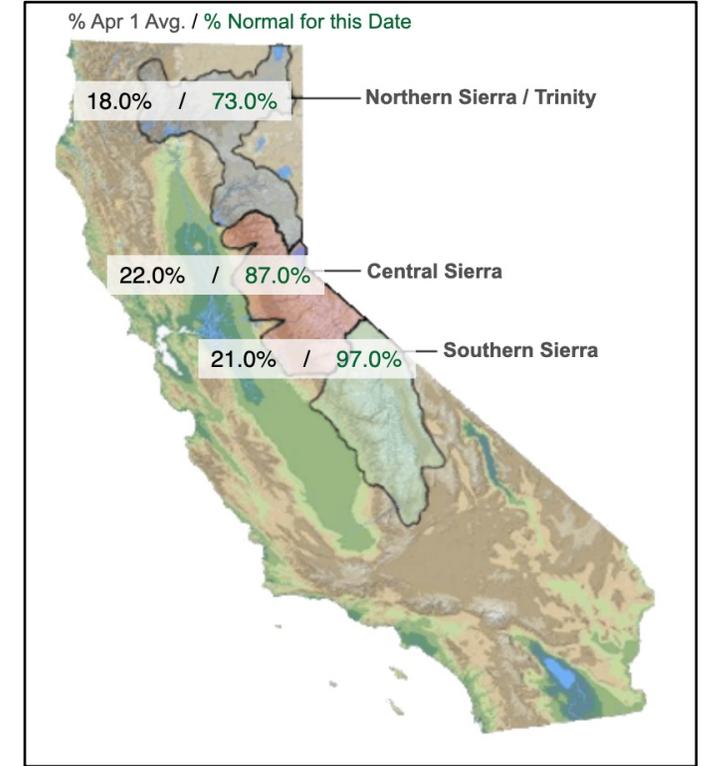
Source: NOAA/NWS CNRFC

California Snowpack: 10 Dec



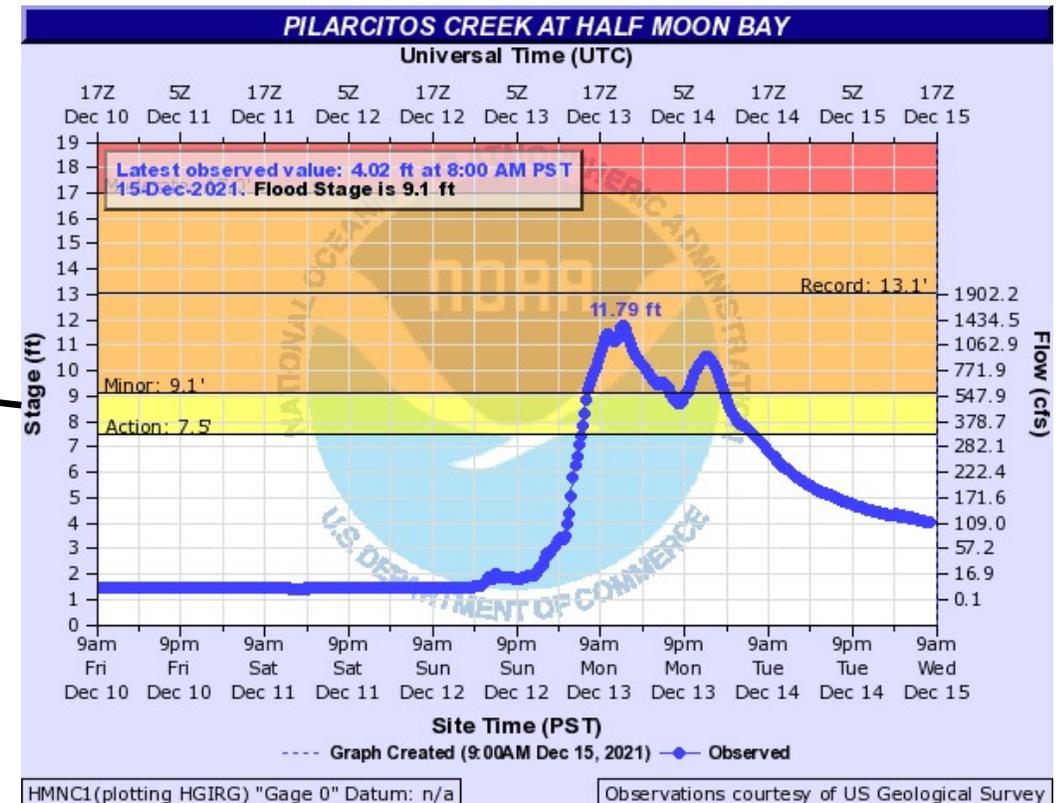
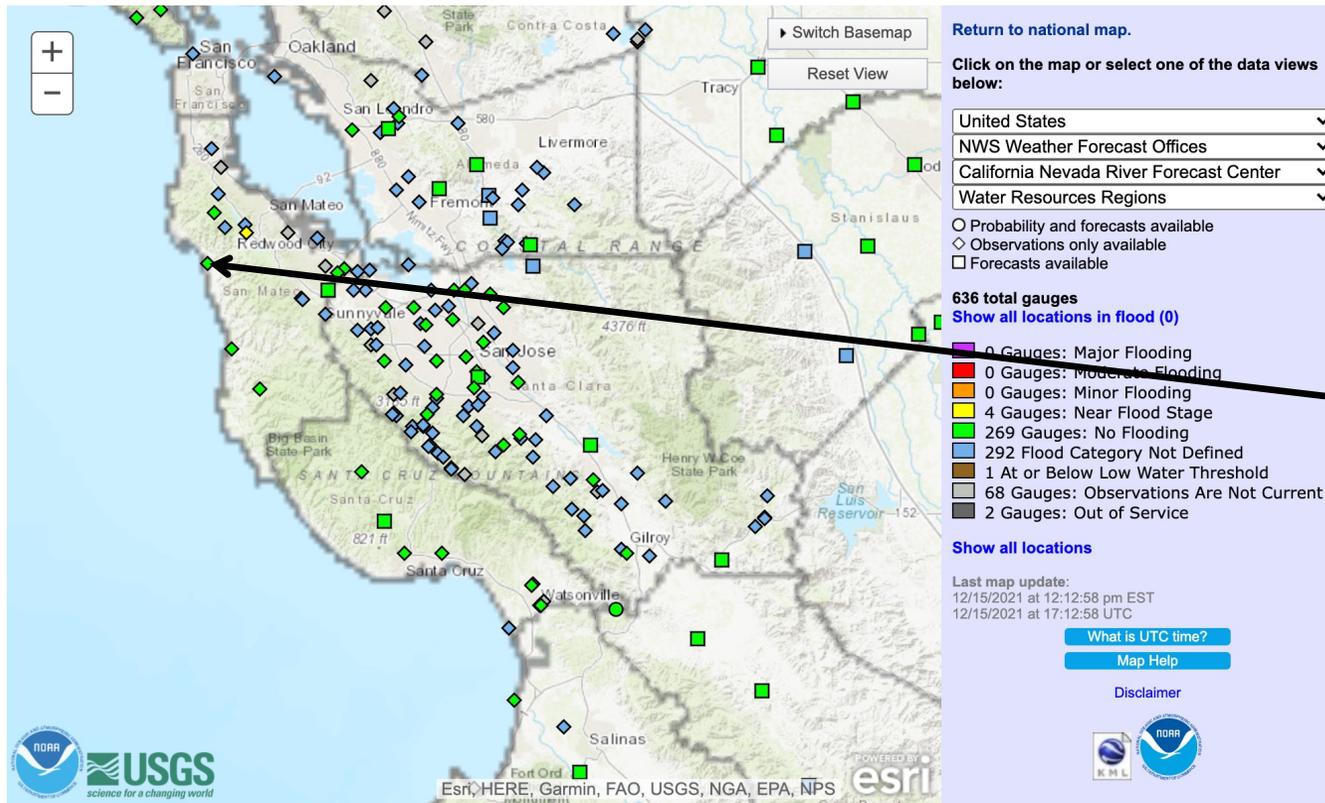
Source: California Department of Water Resources

California Snowpack: 15 Dec



- This event provided a significant boost to seasonal snowpack in California
- Most snow monitoring stations in the Sierra Nevada recorded large SWE increases (> 5 inches) between 10 and 15 Dec
- Prior to this event, seasonal snowpack was running well below normal, especially in the Northern Sierra Nevada, where snowpack was less than 10% of normal
- Between 10 and 15 Dec, statewide snowpack increased from 19% of normal to 83% of normal

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Source: NOAA/NWS Advanced Hydrologic Prediction Service

- Intense rainfall over the Santa Cruz Mountains during the morning of 13 Dec caused minor flooding in San Mateo and Santa Cruz Counties
- Pilarcitos Creek at Half Moon Bay rose above flood stage (9.1 ft) during the morning of 13 Dec, reaching a peak stage of 11.79 ft
- The San Lorenzo River at Big Trees (not shown) rose nearly 13 ft in a 24-hour period, reaching a peak stage of 16.06 ft, just below flood stage (16.5 ft)

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California SR 92



Source: CAL FIRE CZU

California SR 38



Source: Caltrans District 8

Silverado Canyon



OC Public Works @OCpublicworks · 21h
#Rain update: Heavy rain causing a lot of water & mud across roadways in #SilveradoCanyon. Crews clearing mud from Kitterman Bridge to restore access. #OCCanyonFlood



1.9K views 0:01 / 0:14

14 25

Source: OC Public Works

Del Mar, CA



Sources: Richard Cronwell and CBS 8

- Heavy rainfall caused flooding and slides in the Bay Area and in Southern California
- A section of Highway 92 east of Half Moon Bay, CA, was closed due to flooding
- Highway 38 was closed between Yucaipa, CA, and Big Bear, CA, due to rockslides and debris flows
- Multiple debris flows were reported in the Bond Fire burn scar in Silverado Canyon
- Strong wind gusts also downed trees and caused power outages throughout the state
- Several automated weather stations in the San Bernardino Mountains and the Peninsular Ranges recorded wind gusts > 70 mph