

CW3E Event Summary: 19-26 February 2023

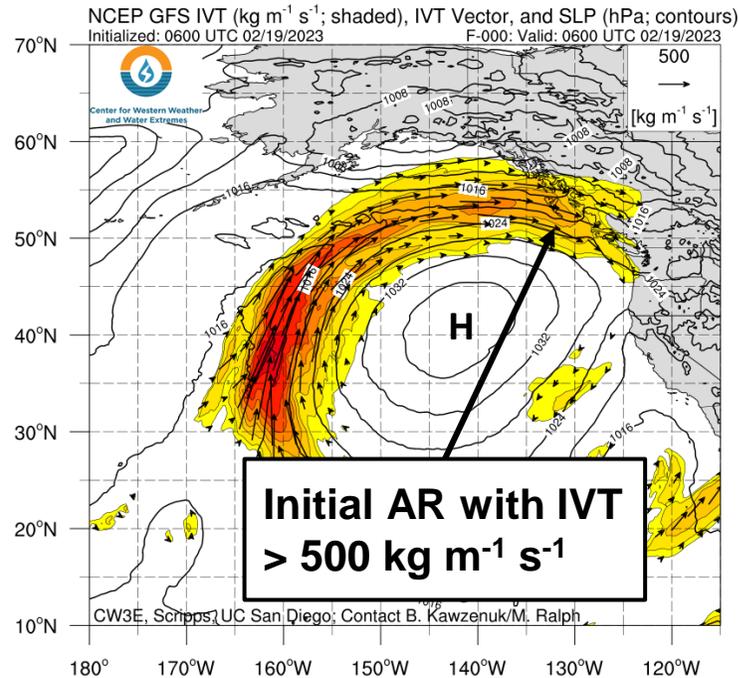
Active Weather Pattern Brings Heavy Rain and Low-Elevation Snow to Western US

- An atmospheric river (AR) made landfall over the Pacific Northwest on 19 February
- AR 1/AR 2 conditions (based on the Ralph et al. 2019 AR Scale) were observed across much of coastal Washington
- The storm produced more than 6 inches of storm-total precipitation in Western Washington and up to 2 feet of snow in the Washington Cascades
- As the AR propagated south along the US West Coast and dissipated, an upper-level shortwave trough and associated area of low pressure formed over British Columbia
- As this trough deepened along the US West Coast, unsettled weather with low-elevation snow continued
- A second AR formed in association with the trough and made landfall over Central California on 24 February
- This storm featured strong upper-level dynamics and a favorable moisture flux direction for heavy orographic precipitation along the Transverse Ranges of Southern California
- The heaviest storm-total precipitation, >10 inches, fell in the western Transverse Range with accumulations >6 inches elsewhere in the Transverse Ranges and the southern Sierra Nevada.
- More than 36 inches of snow fell throughout the Transverse Ranges with >72 inches in parts of the southern Sierra Nevada
- Very low freezing levels and ample moisture allowed for snow in locations that rarely see snow accumulations
- The combination of heavy rainfall and high antecedent soil moisture and streamflow conditions led to riverine and urban flooding

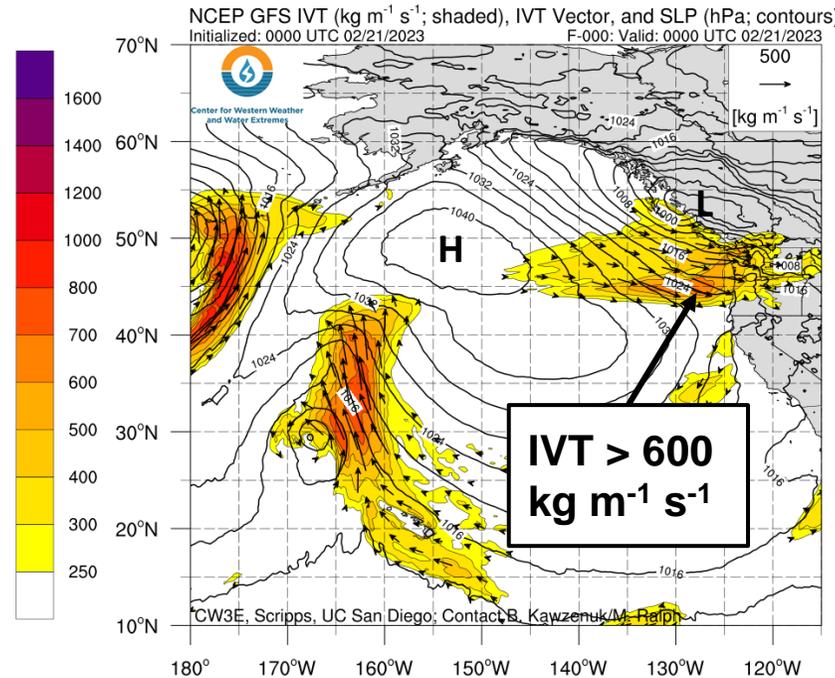
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GFS IVT, and IWV Analysis – Pacific Northwest

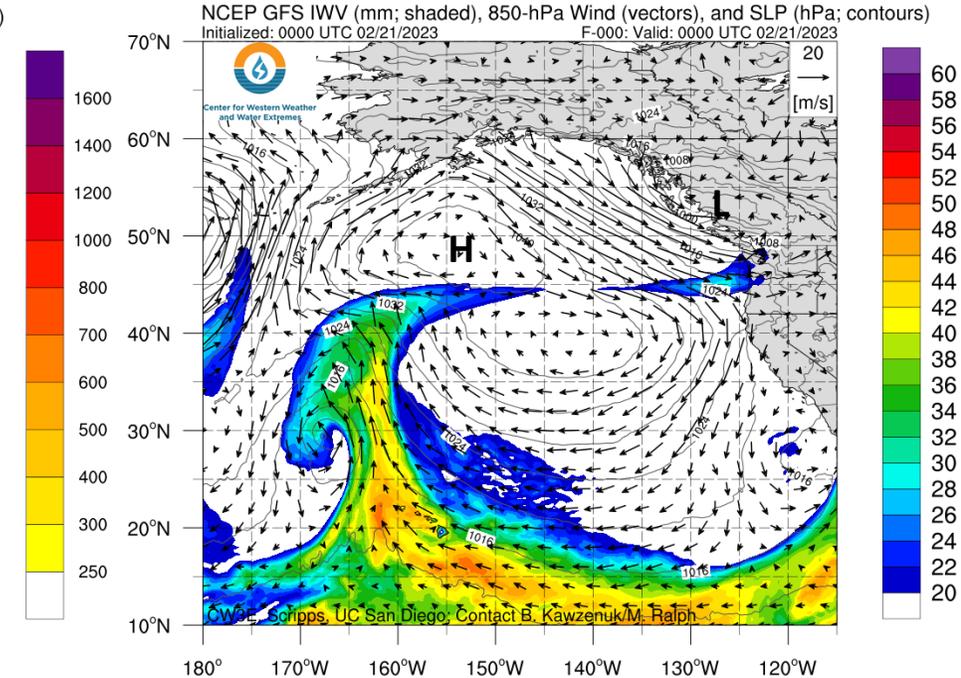
(A) Valid 10 PM PT 18 Feb



(B) Valid 4 PM PT 20 Feb



(C) Valid 4 PM PT 20 Feb



- High pressure continued its presence in the Eastern Pacific forcing moisture over the top of the ridge leading to an initially unfavorable direction of IVT for heavy orographic precipitation in the Pacific Northwest (Figure A)
- As the storm progressed, an upper-level shortwave trough formed over British Columbia (Figure B), orienting mid-level IVT to a more westerly direction
- Available moisture remained modest, near 20mm along the Oregon and Washington coast (Figure C)

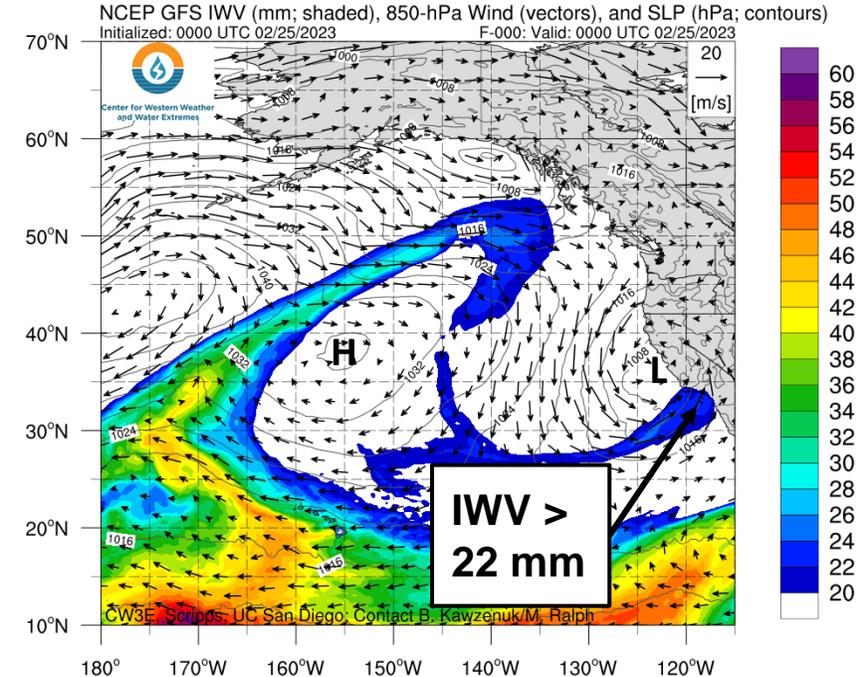
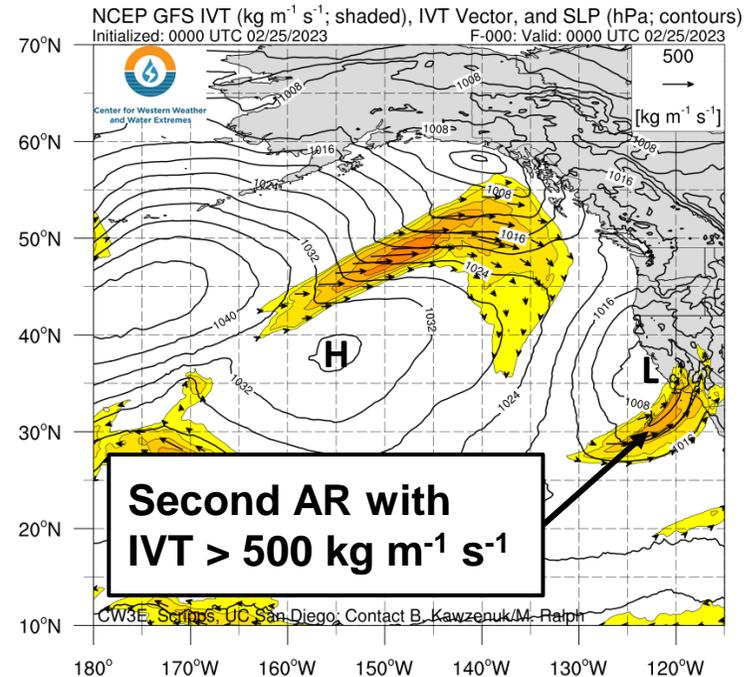
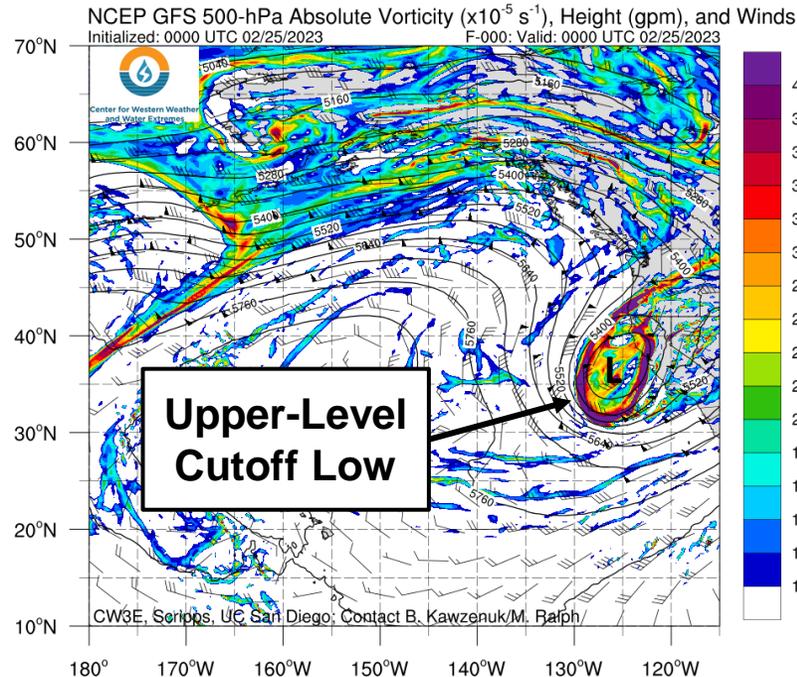
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GFS 500-hPa, IVT, and IWV Analysis – Southern California

(A) Valid 4 PM PT 24 Feb

(B) Valid 4 PM PT 24 Feb

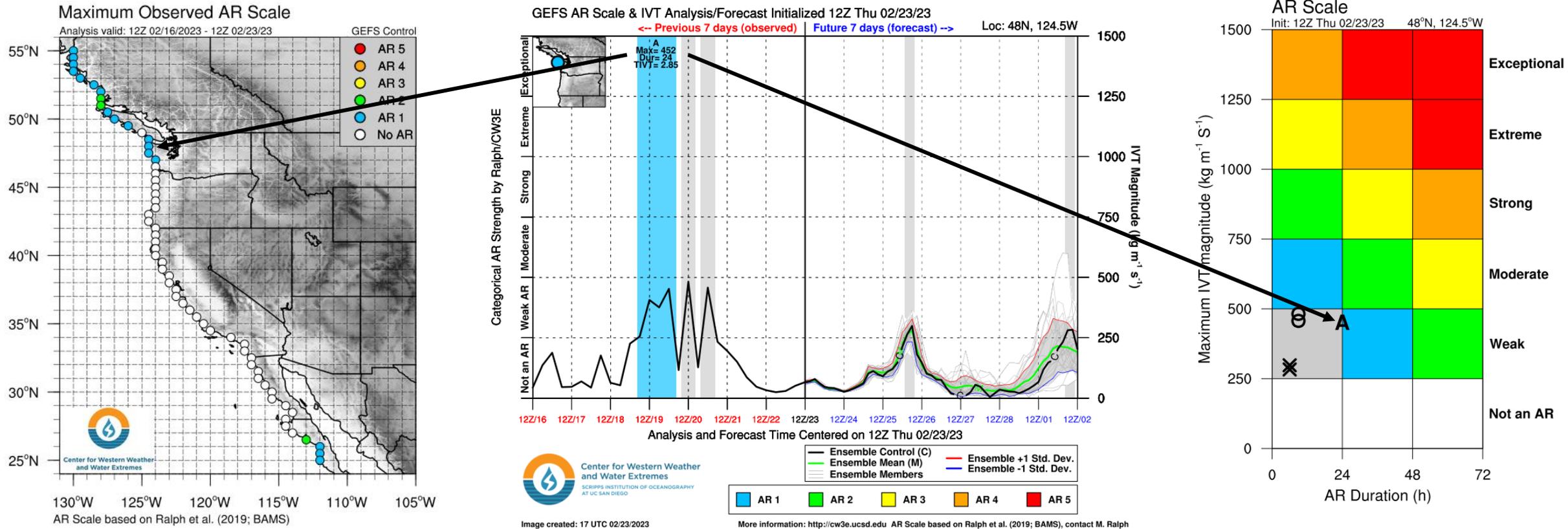
(C) Valid 4 PM PT 24 Feb



- As the initial AR propagated south along the US West Coast and dissipated, a shortwave trough and area of low pressure formed over British Columbia, cutoff from the main flow, and moved south into Southern California (Figure A)
- A second AR formed in association with this cutoff bringing IVT > 500 $\text{kg m}^{-1} \text{ s}^{-1}$ into Southern California and modest moisture values near 22mm along the coast (Figs B and C)
- This storm featured strong upper-level dynamics and a favorable moisture flux for heavy orographic precipitation along the Transverse Ranges of Southern California

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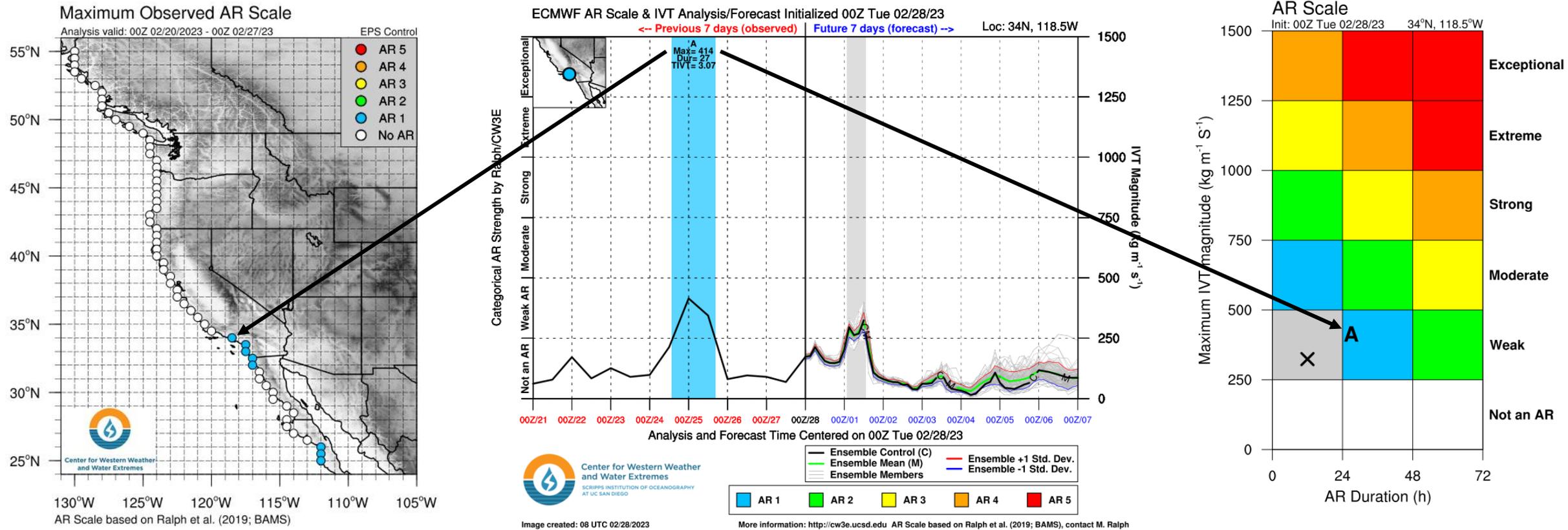
GEFS Control AR Scale Analysis – Pacific Northwest



- The initial AR in the PNW produced weak AR 1 conditions over coastal Washington
- Three distinct IVT pulses were observed during the AR at this location, but only the initial pulse was above $250 \text{ kg m}^{-1} \text{ s}^{-1}$ for more than 24 hours
- A maximum IVT value of $452 \text{ kg m}^{-1} \text{ s}^{-1}$ and an AR duration of 24 hours were observed at 48°N , 124.5°W (near Quillayute, WA)

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ECMWF EPS Control AR Scale Analysis – Southern California

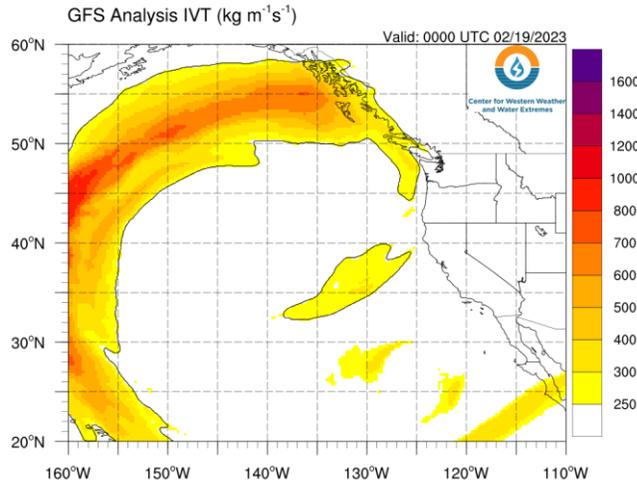


- The second AR produced weak AR 1 conditions over Southern California
- A maximum IVT value of $414 \text{ kg m}^{-1} \text{ s}^{-1}$ and an AR duration of 27 hours were observed at 34°N , 118.5°W (near Santa Monica)

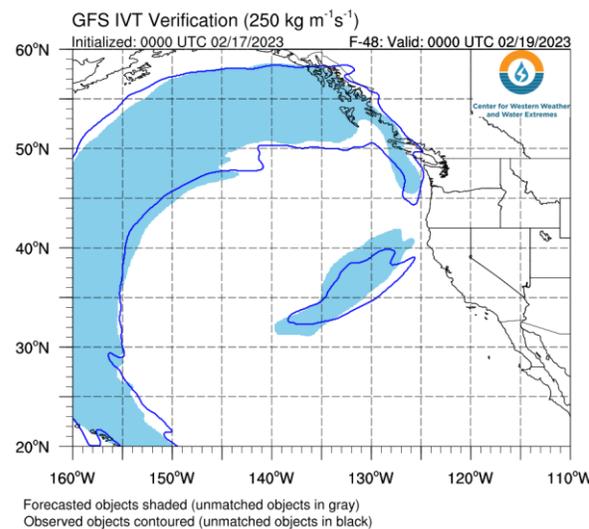
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GFS AR/IVT Pacific Northwest Forecast Verification: Valid 00Z 19 February

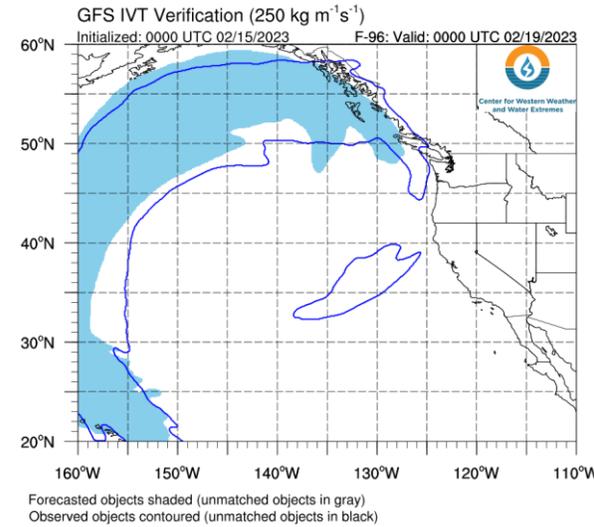
Model Analysis



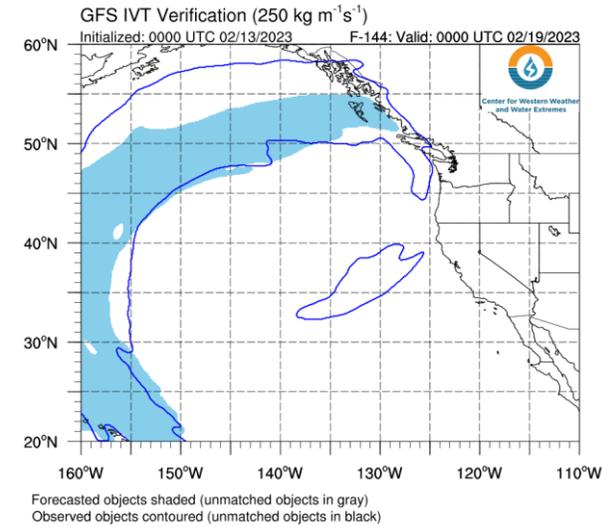
48-h Forecast



96-h Forecast



144-h Forecast



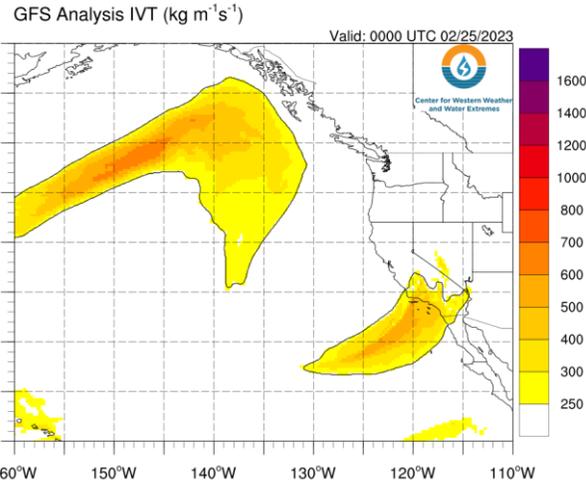
*Forecast objects shaded (unmatched objects in gray)
Observed objects contoured (unmatched objects in black)
Objects defined based on $\text{IVT} > 250 \text{ kg m}^{-1} \text{s}^{-1}$*

- Using the Method for Object-Based Diagnostic Evaluation (MODE) with a $250 \text{ kg m}^{-1} \text{s}^{-1}$ IVT threshold shows the location of the core of the initial AR in the Pacific Northwest was well forecasted at a 48-hour lead time but the nose of the AR was a bit west as compared to the analysis
- Examination of the 96-hour forecast shows that the AR was further north and did not yet make landfall in northwestern Washington
- A closer look at the 144-hour forecast shows a much smaller northerly extent of AR conditions and a much further north landfall

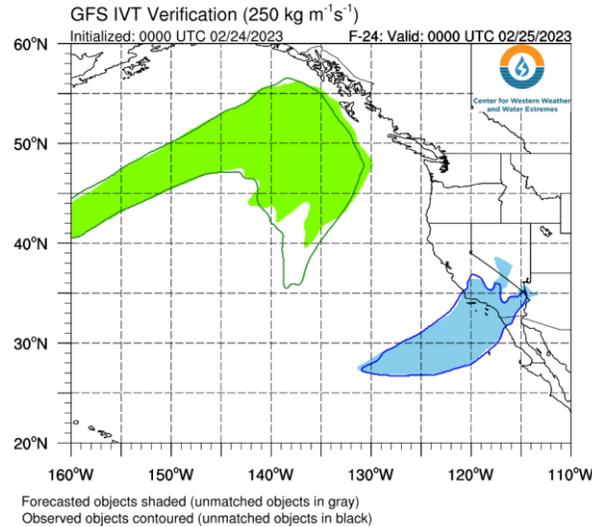
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GFS AR/IVT Southern California Forecast Verification: Valid 00Z 25 February

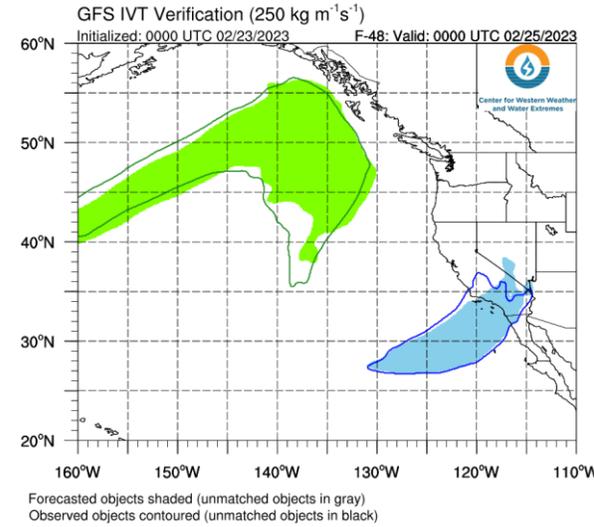
Model Analysis



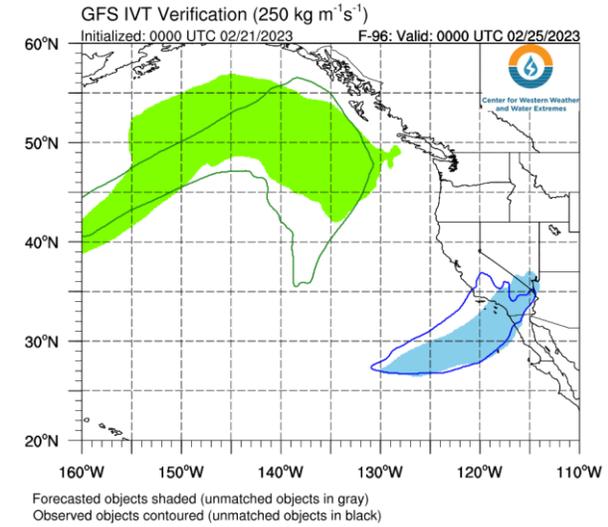
24-h Forecast



48-h Forecast



96-h Forecast



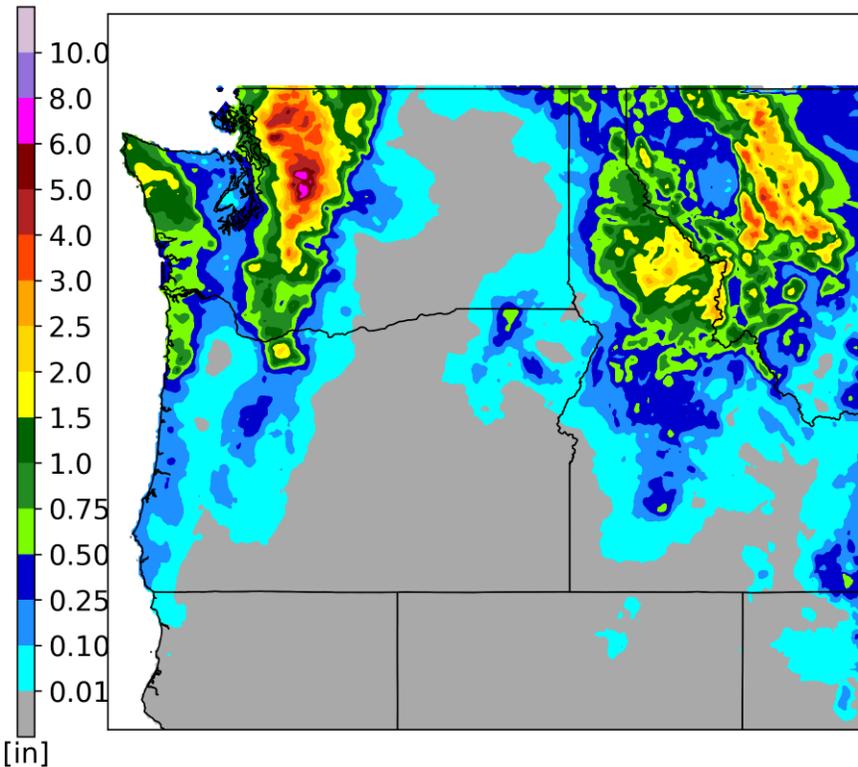
*Forecast objects shaded (unmatched objects in gray)
Observed objects contoured (unmatched objects in black)
Objects defined based on $IVT > 250 \text{ kg m}^{-1} \text{ s}^{-1}$*

- Using the Method for Object-Based Diagnostic Evaluation (MODE) with a $250 \text{ kg m}^{-1} \text{ s}^{-1}$ IVT threshold shows the location of the core of the second AR in Southern California was well forecasted at a 24-hour lead time.
- The northern portion of the AR over land was missing from the 48-hour lead time indicating a faster propagation of the AR over Southern California
- Examination of the 96-hour forecast shows that the AR was not as wide as what was observed and again had a faster propagation over Southern California. In addition, inland penetration was forecast to extend into Southern Nevada

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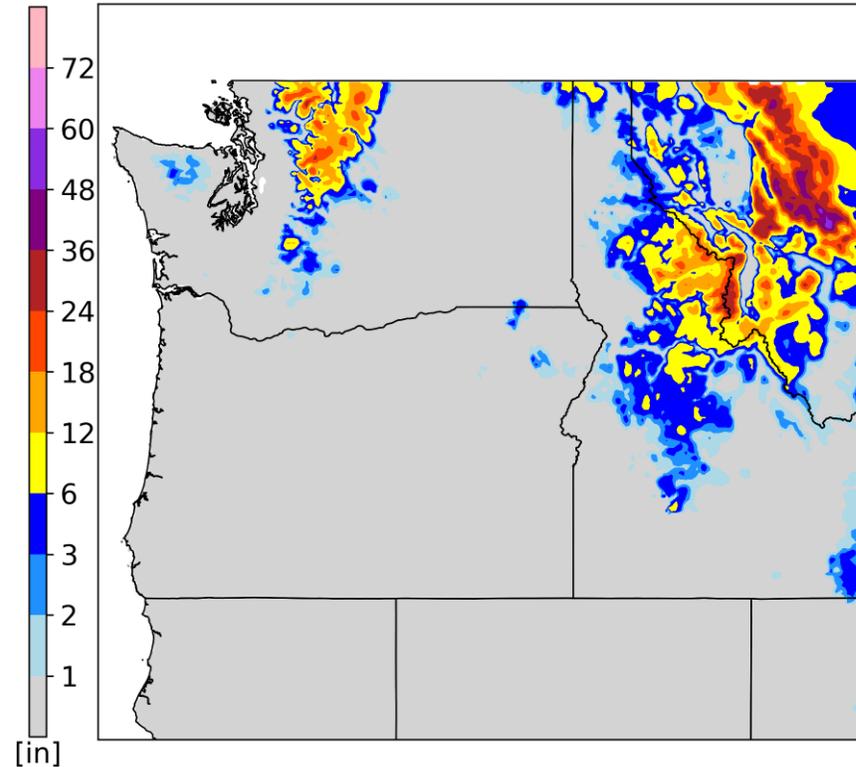
NCEP Stage IV 72-h QPE

Valid: 4 AM PT 18 Feb - 4 AM PT 21 Feb



NOHRSC 72-h Snowfall Analysis

Valid: 4 AM PT 18 Feb - 4 AM PT 21 Feb

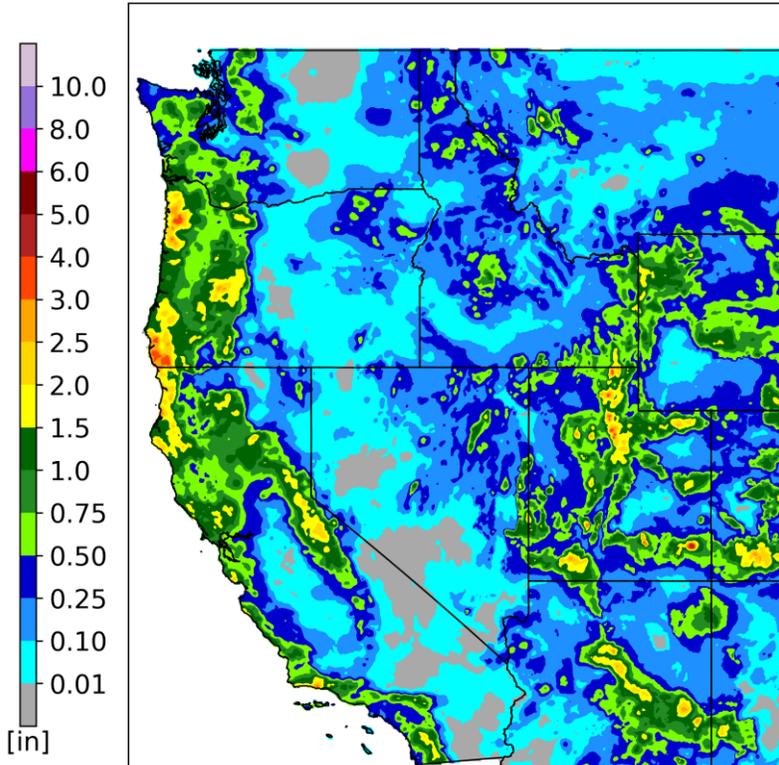


- The initial AR produced moderate-to-heavy precipitation throughout western Washington with the heaviest precipitation (>6") in Cascades
- Up to 3 feet of snow fell in the northern Washington Cascades
- Moisture transport associated with the initial AR penetrated quite far inland with portions of the Northern Rockies receiving 1-3 feet of snow during this period

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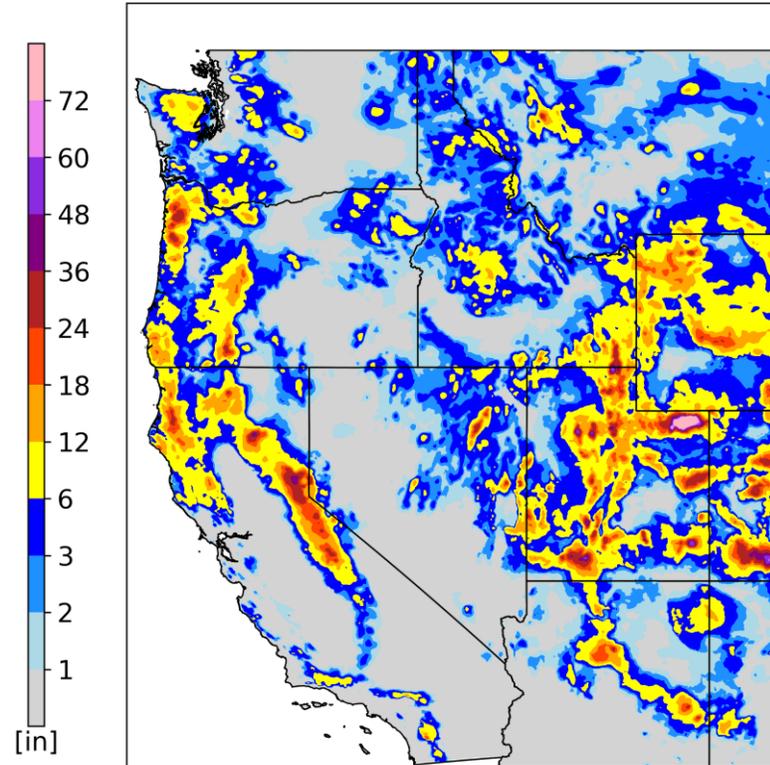
NCEP Stage IV 72-h QPE

Valid: 4 AM PT 21 Feb - 4 AM PT 24 Feb



NOHRSC 72-h Snowfall Analysis

Valid: 4 AM PT 21 Feb - 4 AM PT 24 Feb

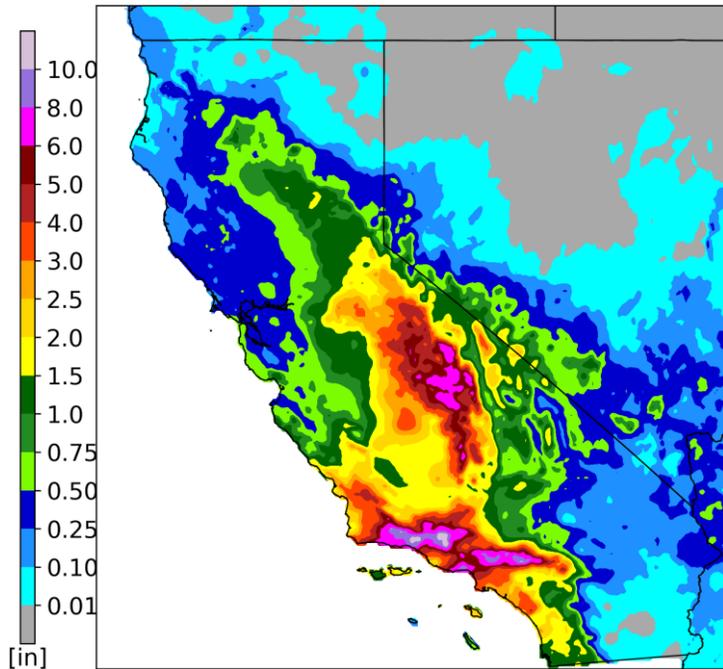


- As the AR propagated south along the US West Coast and dissipated, an upper-level shortwave trough and associated area of low pressure formed over British Columbia
- As this trough deepened and moved south along the US West Coast, unsettled weather with low-elevation snow continued
- Additional widespread precipitation accumulations >1 inch were seen along the US West Coast with the largest accumulations in southern coastal Oregon where up to 4 inches fell
- More than 12 inches of snow fell in the Cascades, Northern California Coast Ranges, Sierra Nevada, and the Upper and Lower Colorado Basins. The heaviest snowfalls in CA, >24 inches, accumulated in the Northern Sierra

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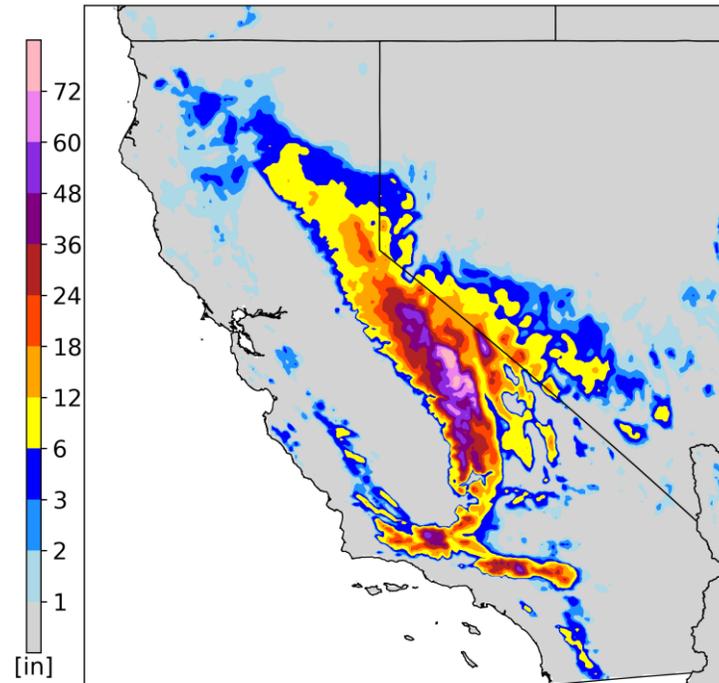
NCEP Stage IV 48-h QPE

Valid: 4 AM PT 24 Feb - 4 AM PT 26 Feb



NOHRSC 48-h Snowfall Analysis

Valid: 4 AM PT 24 Feb - 4 AM PT 26 Feb

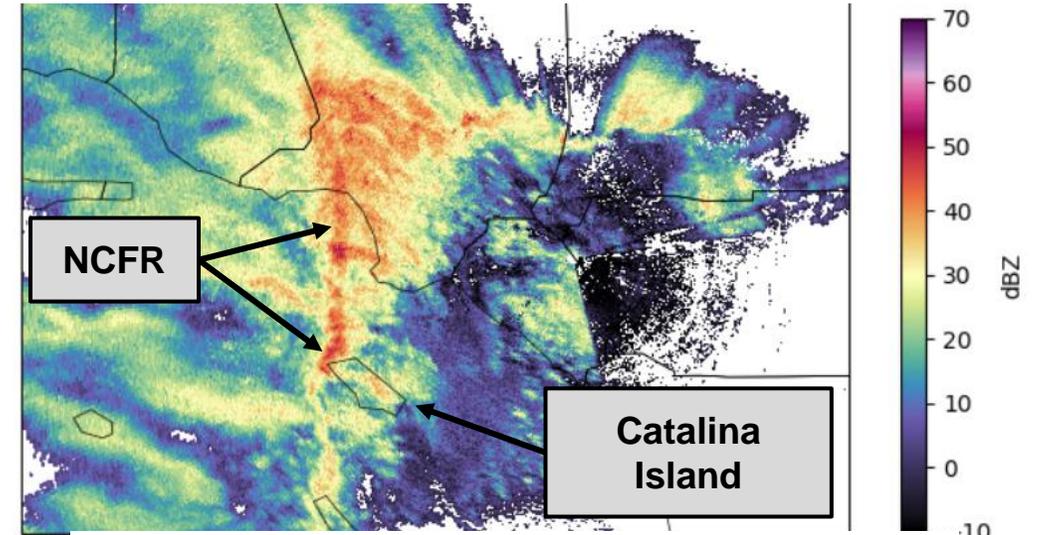
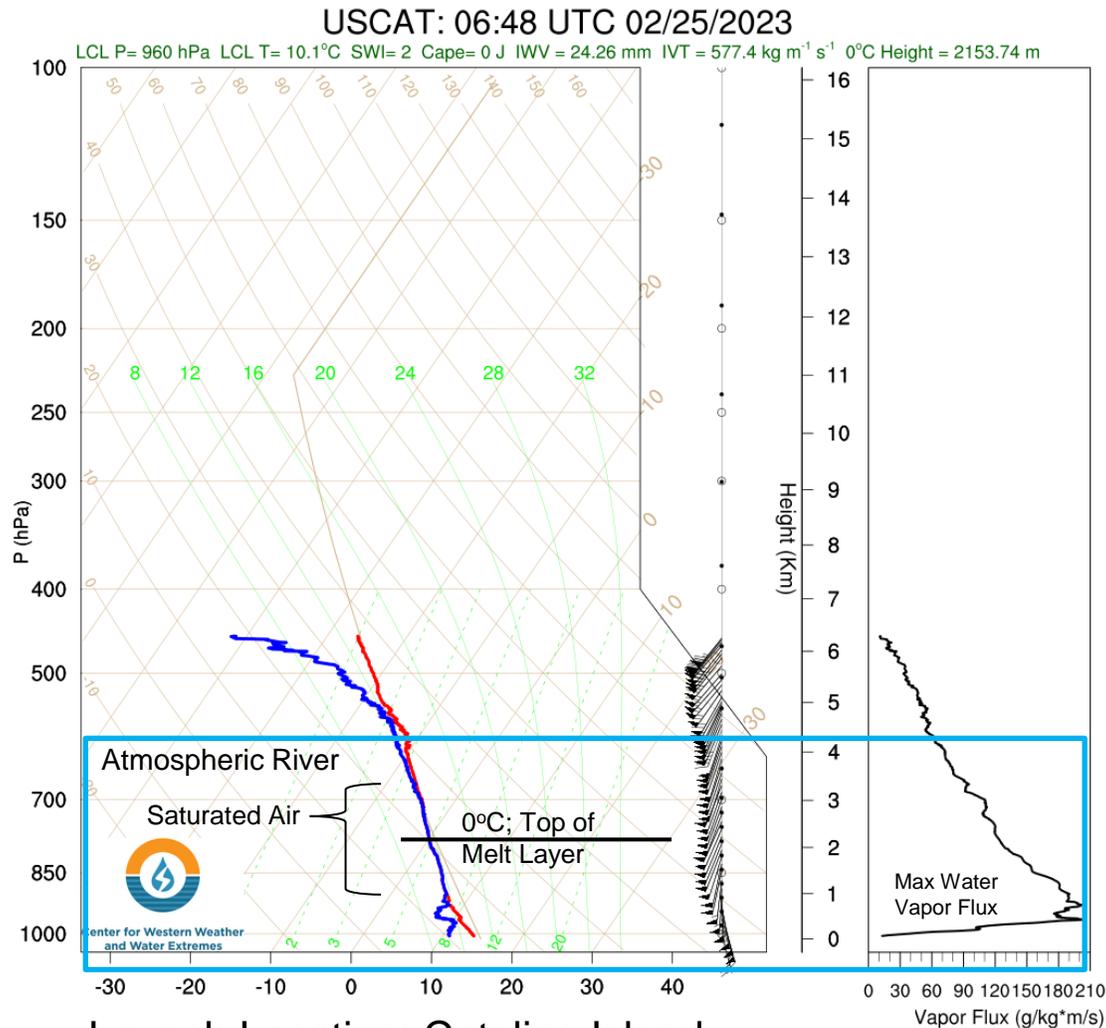


- The second AR produced heavy precipitation in the central and southern Sierra Nevada and in the Transverse Ranges of California with widespread storm-total precipitation >1 inch throughout California
- The heaviest storm-total precipitation, >10 inches, fell in the western Transverse Range with >6 inches elsewhere in the Transverse Ranges and the southern Sierra Nevada
- More than 3 feet of snow fell throughout the Transverse Ranges with >72 inches in parts of the southern Sierra Nevada
- Hanford (2.70 inches on 24 Feb) recorded its wettest day since records began in 1899. Burbank (4.61 inches on 24 Feb) recorded its wettest February day and its 5th wettest day overall since records began in 1939

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CW3E Radiosonde Launches

- CW3E launched radiosondes from both Catalina Island and Seven Oaks Dam between 12Z 24 Feb and 18Z 25 Feb
- Highest IWV and IVT values at Catalina were ~24mm and ~577 kg m⁻¹ s⁻¹, respectively, which coincided with the passage of an NCFR around 0645 UTC (10:45 PM PT). The freezing level height was ~2150 m (~7,050 ft)

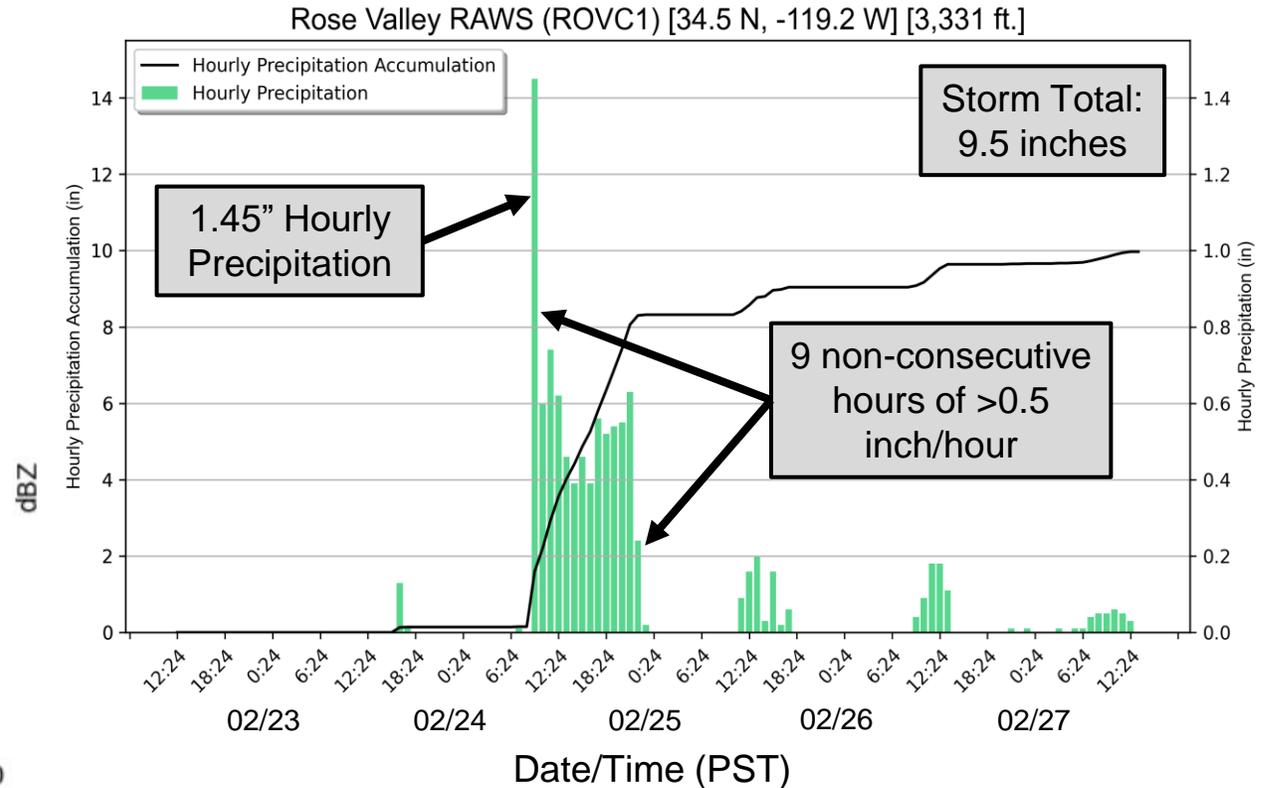
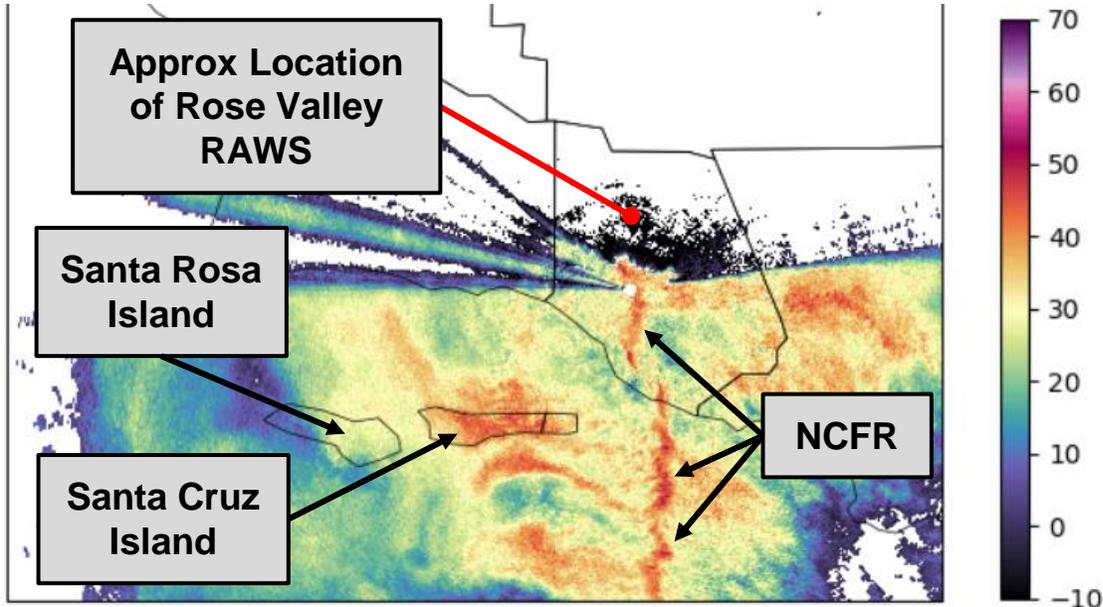


KSOX NEXRAD Radar
Valid 10:45 PM PT 24 Feb

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Precipitation Analysis

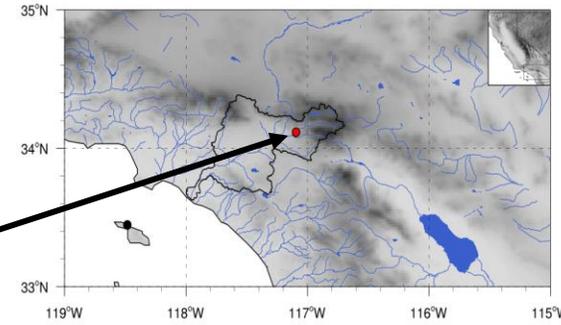
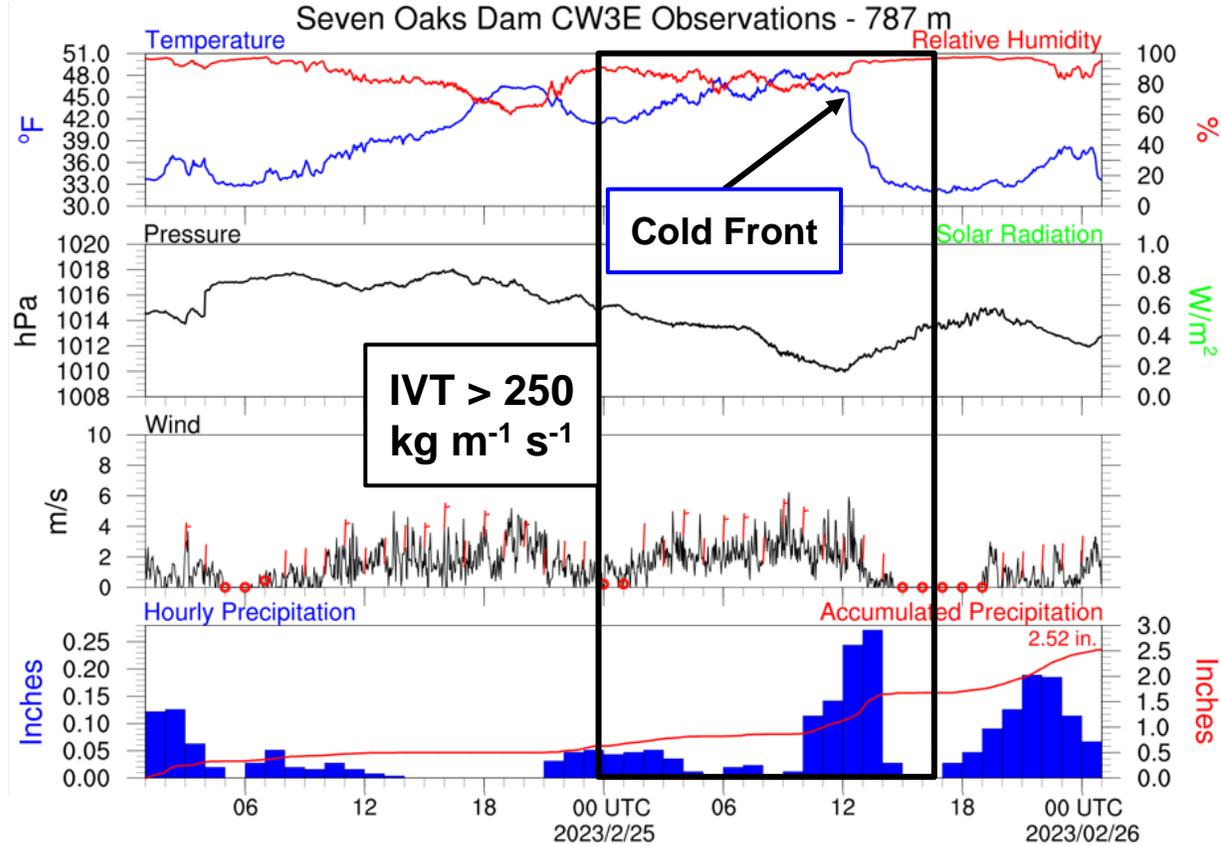
KVIX NEXRAD Radar
Valid 9 PM PT 24 Feb



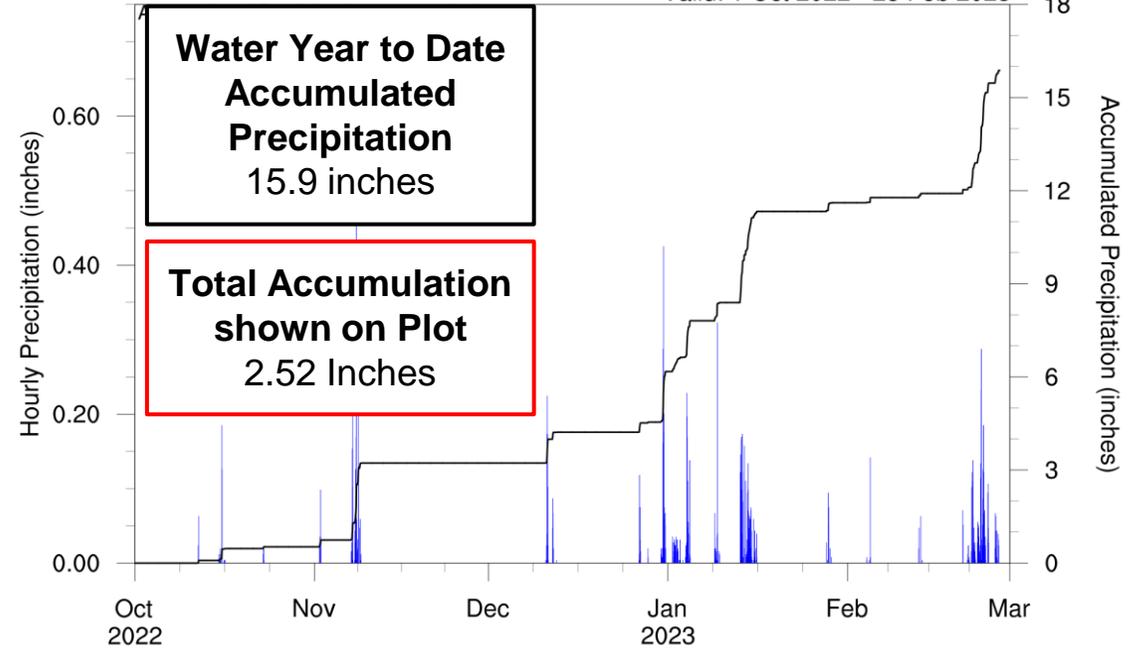
- A narrow cold frontal rainband (NCFR) associated with the AR produced heavy precipitation over the western Transverse Range
- The Rose Valley RAWS weather station observed 9.5 inches during the storm period with 8.2 inches falling between 9 AM - 11 PM PT 24 Feb (17 UTC 24 Feb – 7 UTC 25 Feb)
- Rainfall rates during this time exceeded half an inch per hour for 9 non-consecutive hours
- Maximum hourly rainfall observed during the heaviest precipitation was 1.45 inches

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CW3E Meteorological Observations (Seven Oaks Dam)



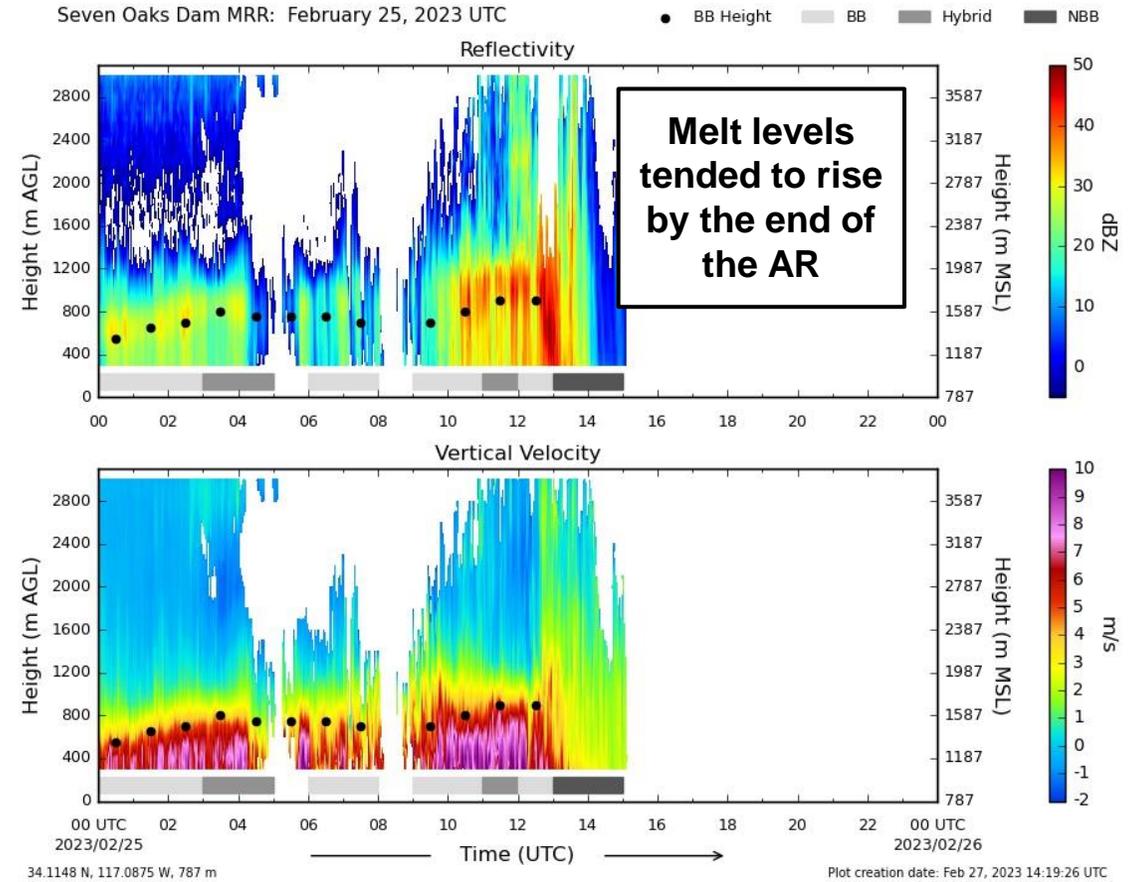
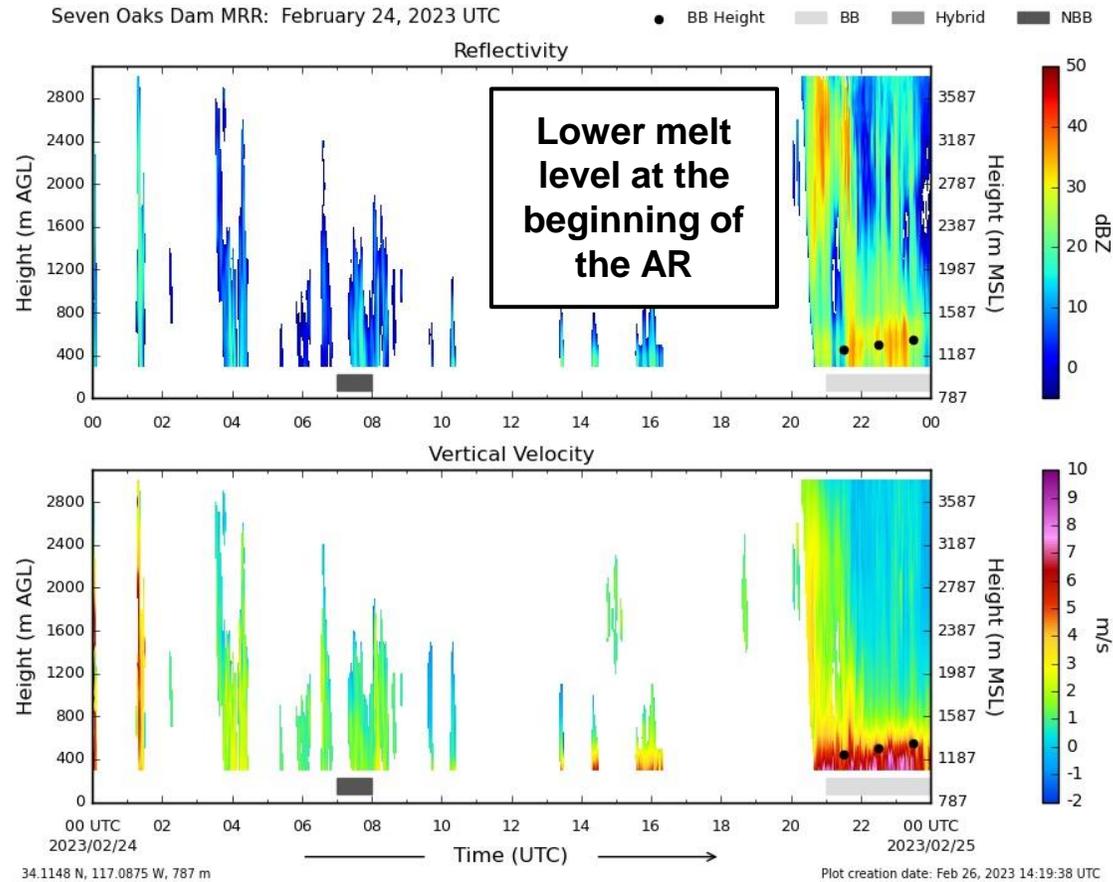
Water Year to Date Seven Oaks Dam Precipitation
Valid: 1 Oct 2022 - 28 Feb 2023



- CW3E's surface meteorology station at Seven Oaks Dam captured the cold air at the surface and precipitation with the thick black line on the plot indicating the approximate time of AR passage
- The AR and cold frontal passage was associated with 1.8 inches of precipitation and a >10°F decrease in temperature

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CW3E Snow Level Observations (Seven Oaks Dam MRR)

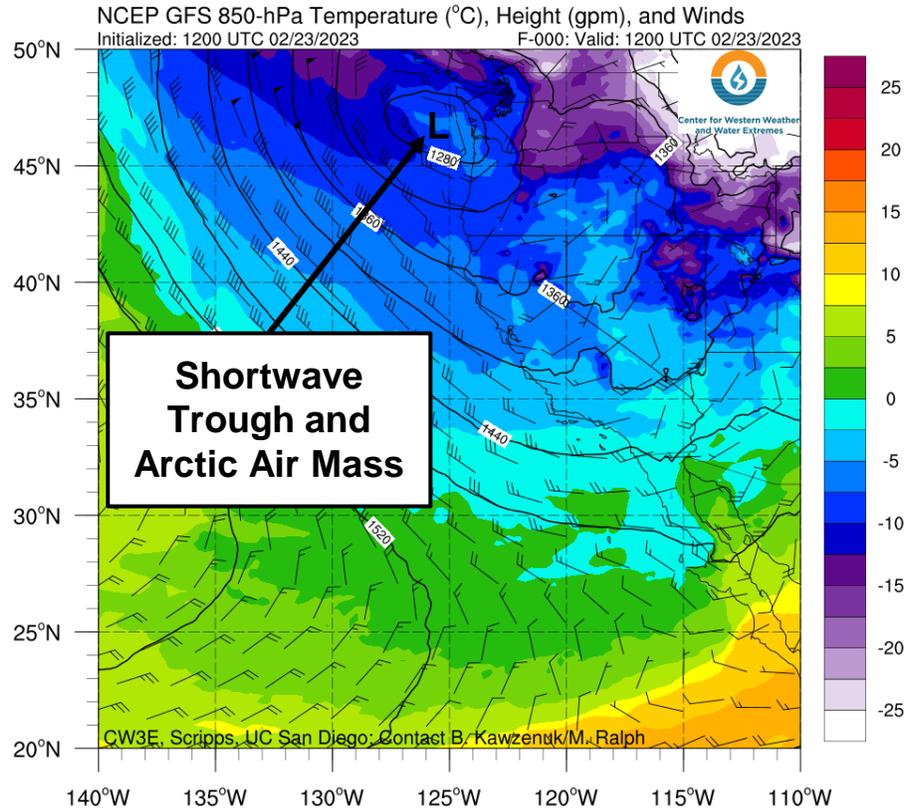


- Cold air was brought in from the north with the upper-level shortwave trough
- Snow levels at CW3E's MicroRain Radar (MRR) at Seven Oaks Dam in the San Bernardino Mountains started near 3,900 ft and rose to 5,300 ft by the end of the AR

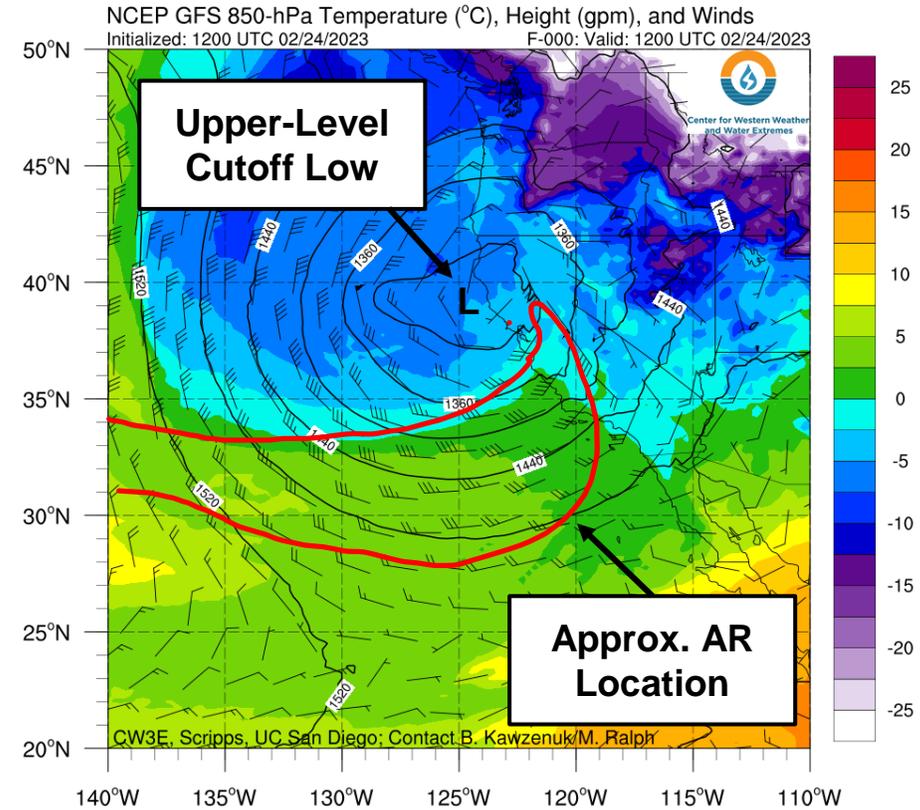
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Cold Air Analysis – GFS 850 hPa Air Temperatures

(A) Valid: 4 AM PT 23 Feb (F00)



(B) Valid: 4 AM PT 24 Feb (F00)

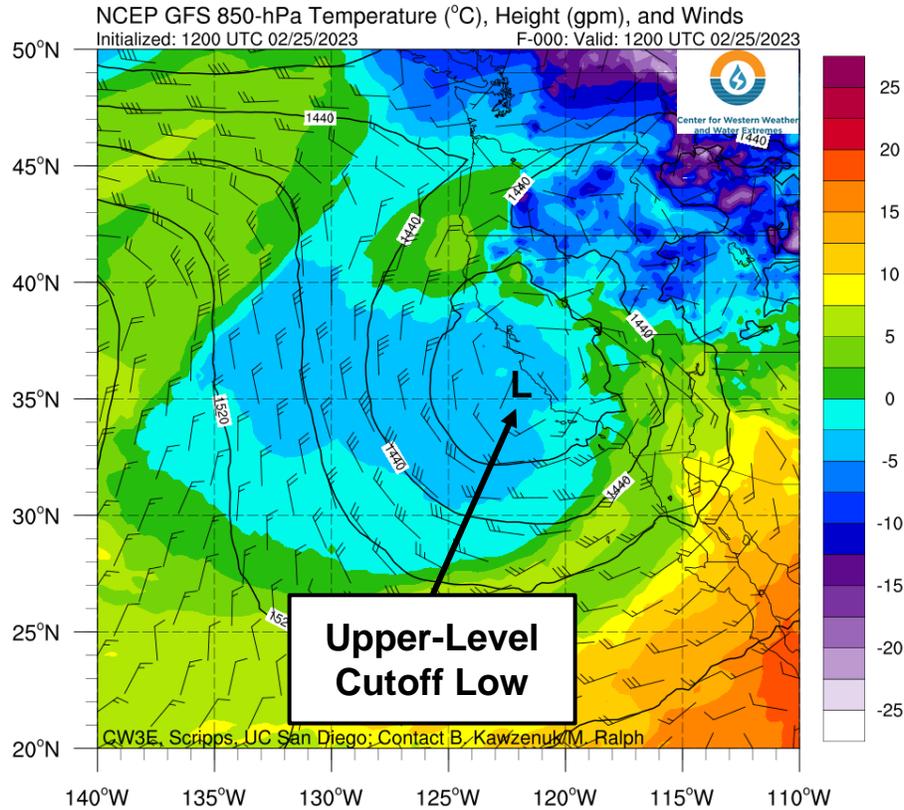


- The shortwave trough initially formed over the Pacific Northwest on 22 Feb
- The area of low pressure cut off from the main flow later on 23 Feb and featured a very cold arctic air mass (Figure A)
- This arctic air mass then moved offshore (Figure B) allowing it to gather moisture as it moved south along the US West Coast
- The second AR formed along the southern periphery (warm sector) of the shortwave trough (Figure B and see slide 3)

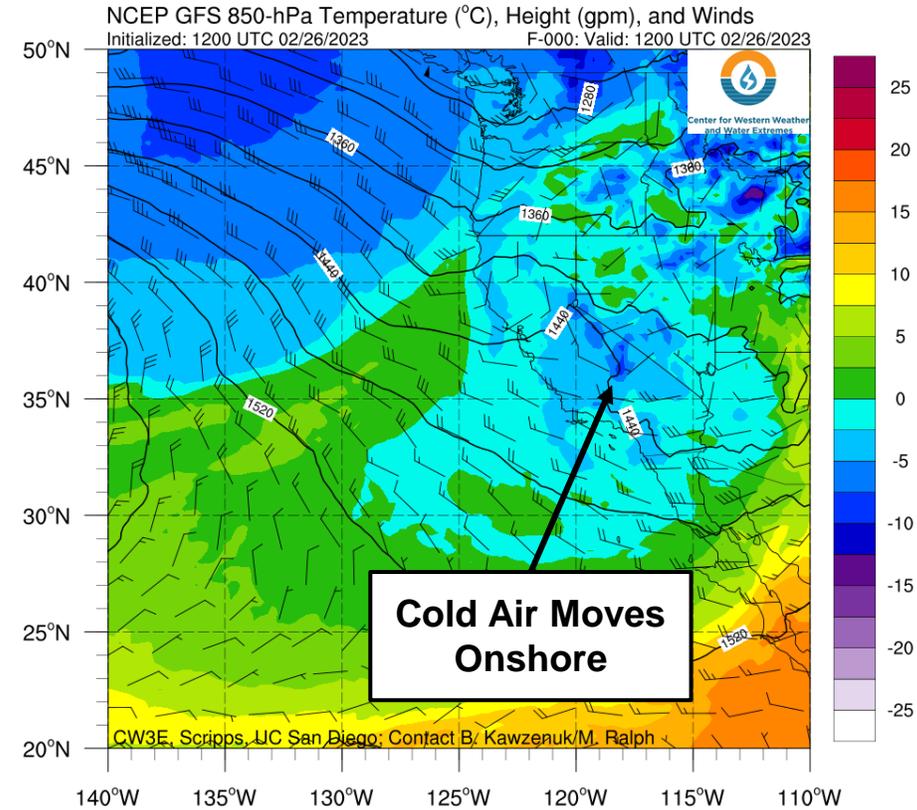
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Cold Air Analysis – GFS 850 hPa Air Temperatures

(A) Valid: 4 AM PT 25 Feb (F00)



(B) Valid: 4 AM PT 26 Feb (F00)



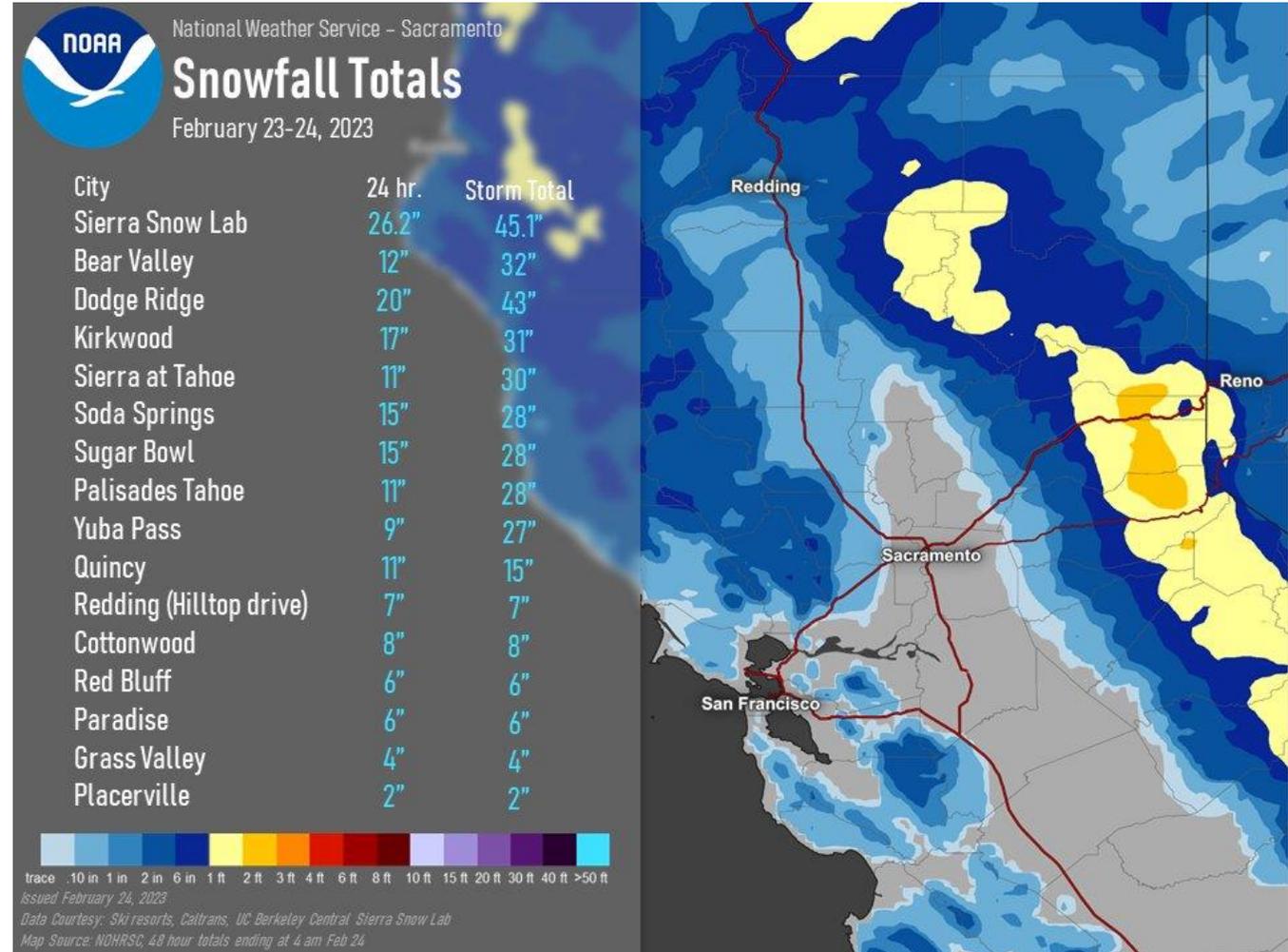
- At 12Z 25 Feb the cold air mass and cutoff low was centered just offshore of Central California (Figure A)
- This was also when the cold frontal passage occurred at Seven Oaks Dam (See slide 13)
- By 12Z 26 Feb the cutoff low moved onshore in Southern California transporting the cold air mass into the US West

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NWS Snowfall Totals Around California



Snowfall Valid: 2/23 – 2/26

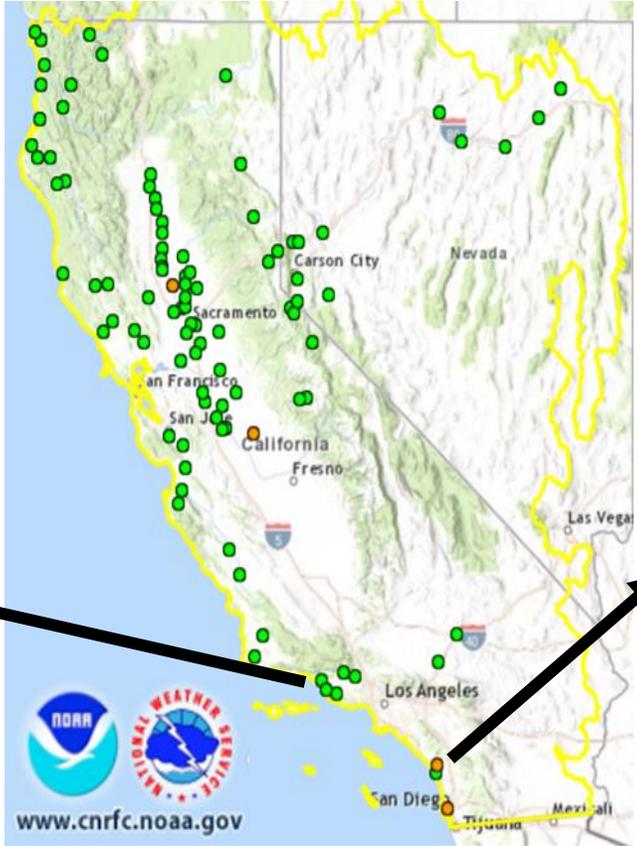
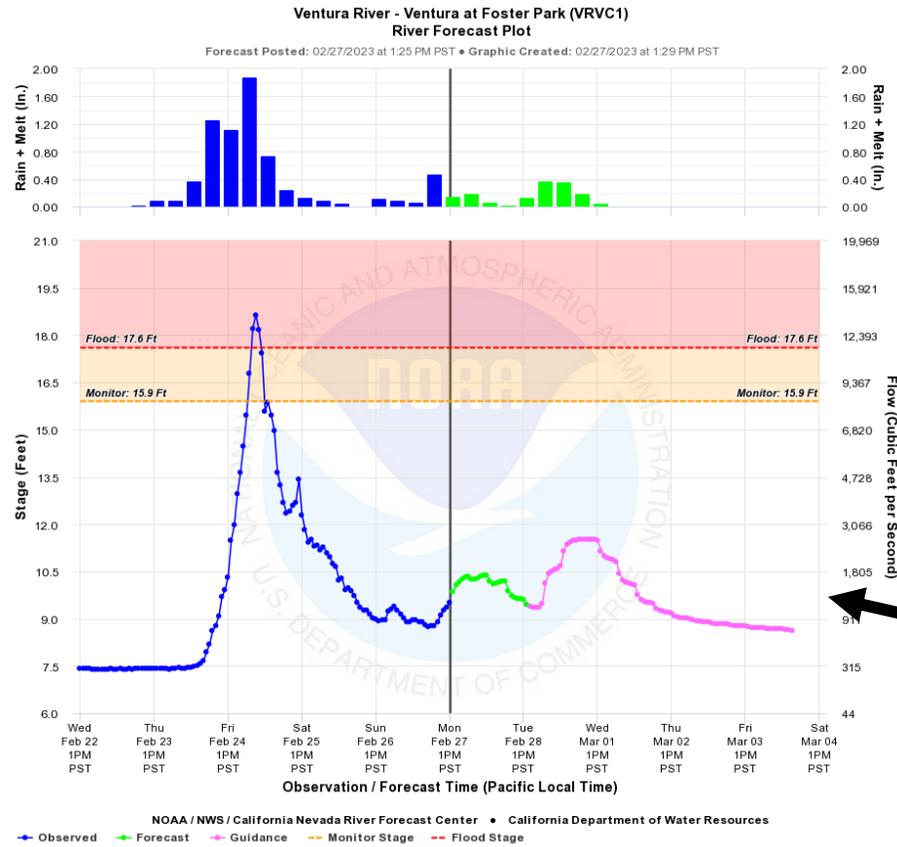


Snowfall Valid: 2/23 – 2/24

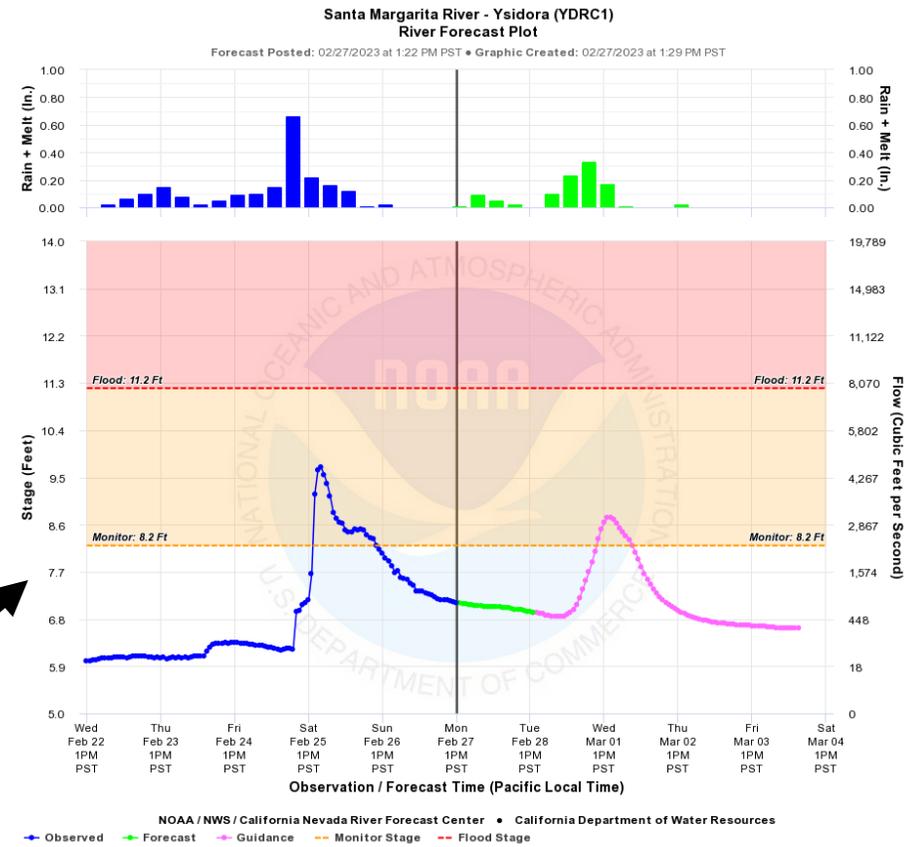
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Streamflow Response – Southern California

Ventura River at Foster Park



Santa Margarita River - Ysidora



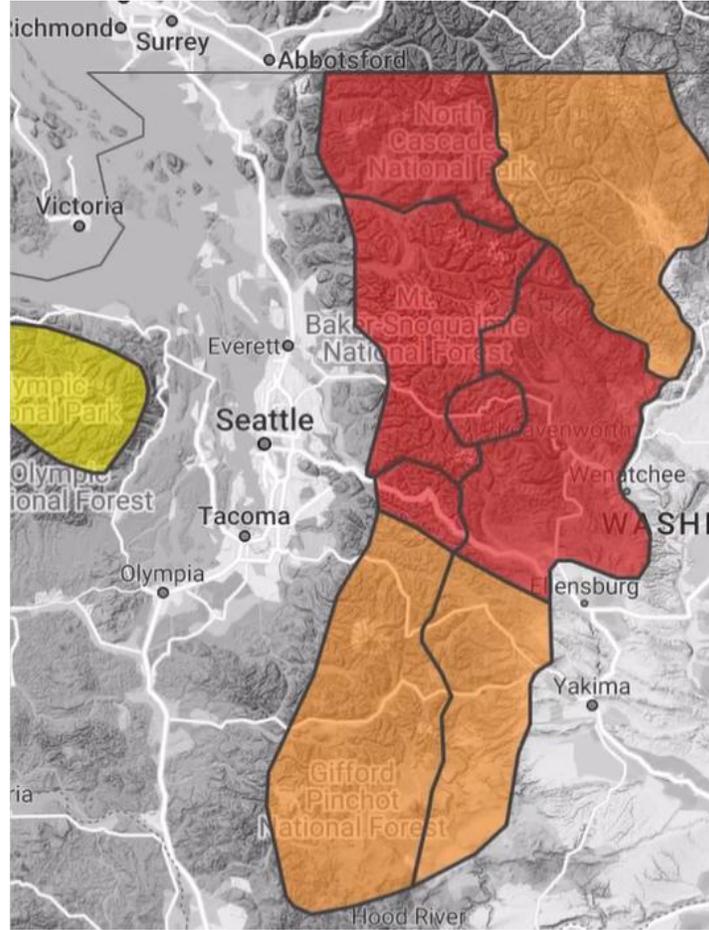
- The Ventura River at Foster Park exceeded flood stage around 5 PM PST on 24 Feb
- The Santa Margarita River - Ysidora rose above monitor stage around 3 PM PST on 25 Feb

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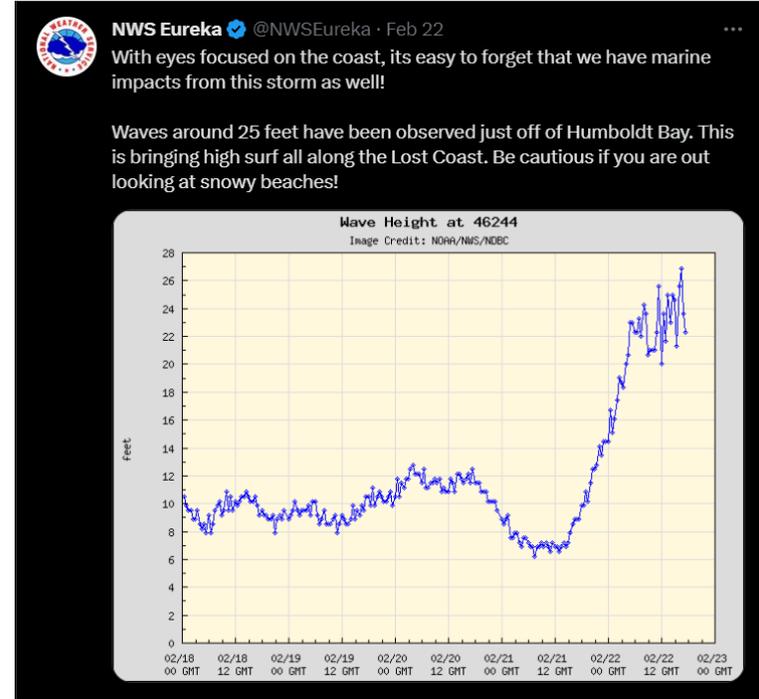
Impacts Photos – Pacific Northwest



Heavy snow in coastal Oregon resulted in downed trees, which complicated snow removal along US 101 near Otis, OR
Oregon DOT



Avalanche forecasts from 2/19 for the Northern Cascades highlighted “Considerable” to “High” danger in the area
Northwest Avalanche Center



Waves forecast > 25 ft off coast of NorCal
NWS Eureka

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Impacts Photos – Southern California Geohazards



Road washout along HWY 1 near Lompoc, CA
Caltrans District 5



Hillside collapse along SR-39 in the Angeles National Forest
Caltrans District 7

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Impacts Photos – Southern California



Highway closures in Santa Clara and Santa Cruz counties due to snow and downed trees
Caltrans District 4



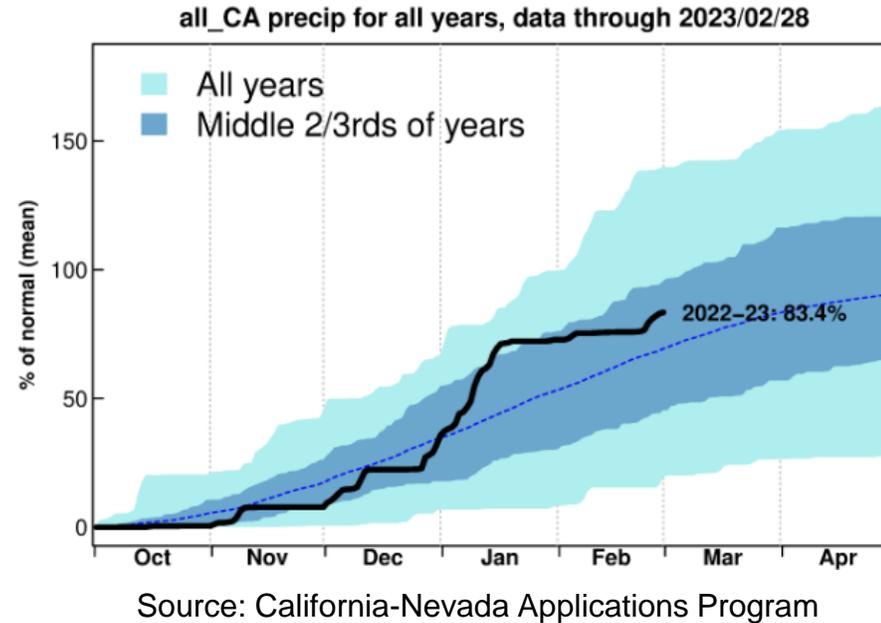
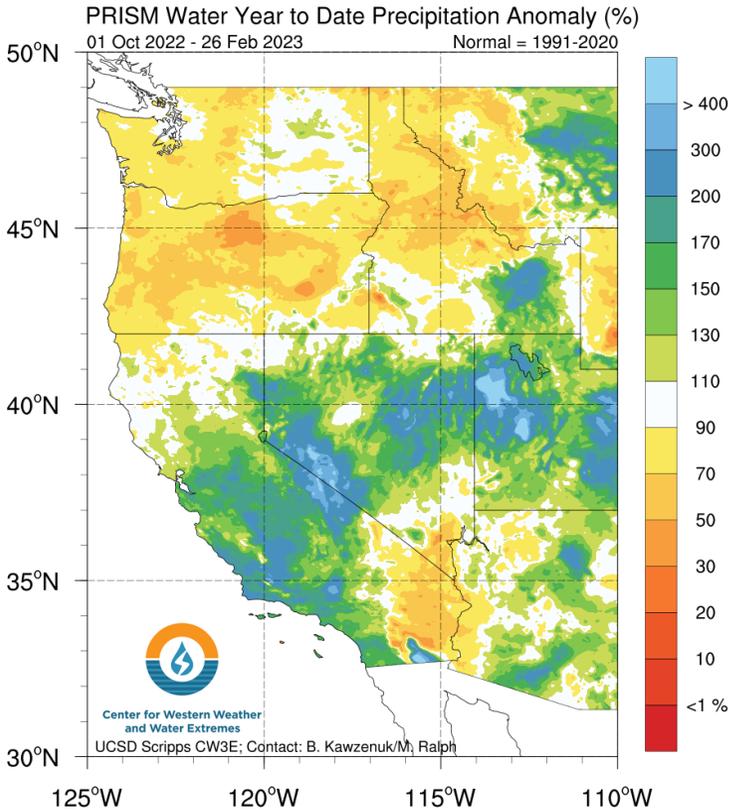
Deep snow along SR 168 E near Big Pine, CA
Caltrans District 9



Heavy snow and ice near Tejon Pass
CHP Fort Tejon

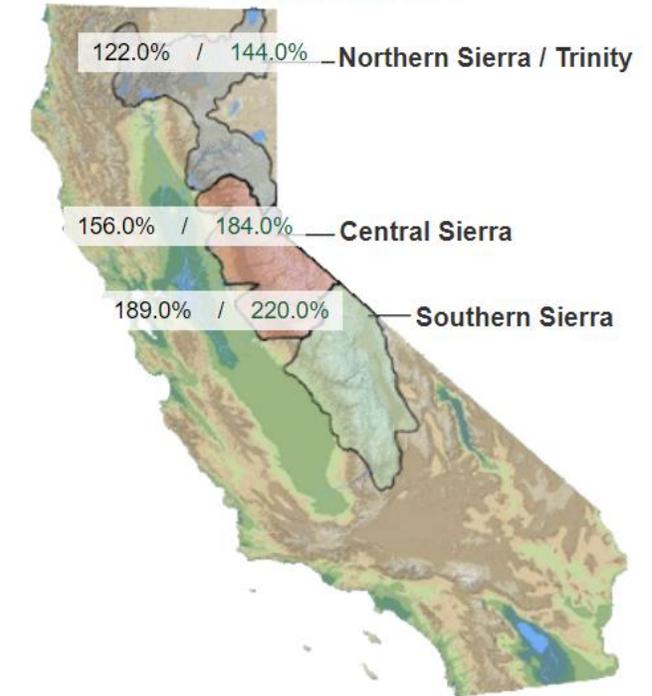
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Water Year 2023 California Precipitation and Snowpack



Data For: 26-Feb-2023

% Apr 1 Avg. / % Normal for this Date

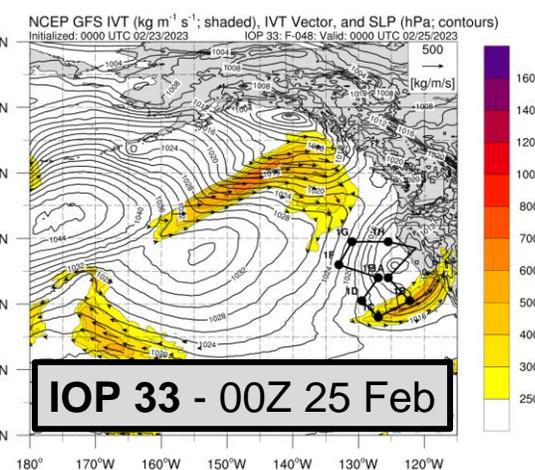
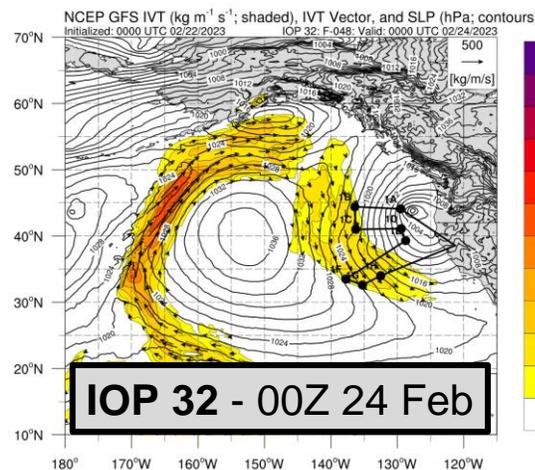
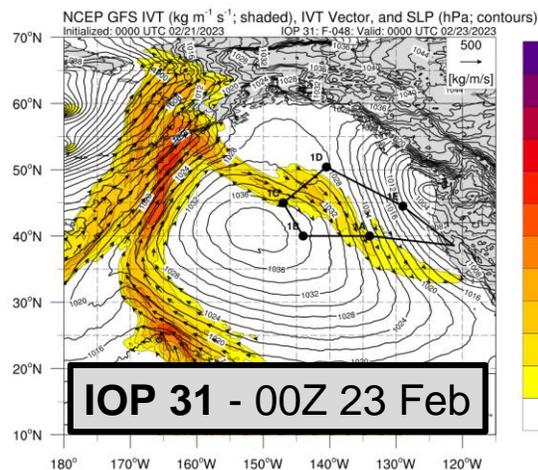
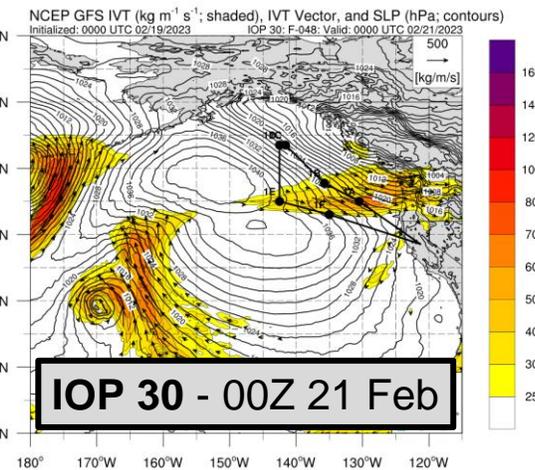
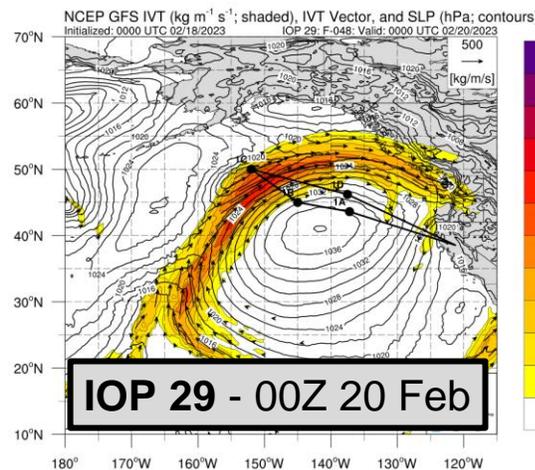
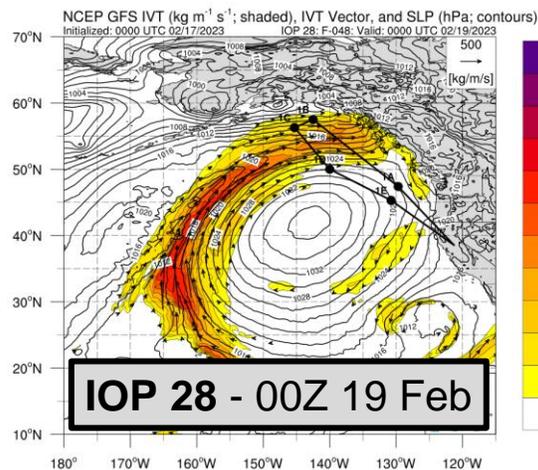
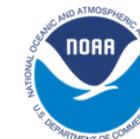


Source: California DWR

- PRISM is indicating normal to much above normal water year precipitation to date for most of California except for the southern desert region with much of Oregon and western Washington remaining between 50 and 90% of normal
- Based on the 8-Station index, California has received 83.4% of normal precipitation
- California's snowpack continues to be above normal, especially in the Southern Sierra, where snowpack is 189% of 1 April normal and 220% of normal as of 28 Feb

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Atmospheric River Reconnaissance – Planned Missions



- During this time period the 53rd Weather Reconnaissance Squadron continued to provide observational support over the North Pacific as part of CW3E's Atmospheric River Reconnaissance field campaign
- CW3E planned 6 IOPs (150 planned dropsondes) with a total of 144 successful dropsondes providing additional observations for global forecast models and collecting valuable data for future research
- IOP = Intensive Observation Period