CW3E Event Summary: 28 February – 3 March 2024

Atmospheric River and Winter Storm Produce Heavy Snow Across Western US
- An atmospheric river (AR) and a slow-moving mid-level trough fueled a long-duration precipitation event over the Western US during 28 Feb – 3 Mar.

The AR:
- The AR made landfall over the Pacific Northwest late on 27 Feb, producing AR2 conditions (based on the Ralph et al. 2019 AR Scale) along the coast of southern Washington, Oregon, and far Northern California.
- After the initial landfalling AR weakened, a second pulse of moisture transport brought another period of AR conditions to Northern and Central California.
- The initial AR landfall and the second pulse of moisture transport combined to produce AR1–2 conditions in the foothills of the Sierra Nevada and played a key role in supporting very heavy snowfall accumulations.

Impacts:
- The heaviest precipitation (> 6 inches liquid equivalent) was observed in the Pacific Coast Ranges and Sierra Nevada.
- An estimated 4–10 feet of snow fell in the Northern and Central Sierra Nevada, with the highest totals near Lake Tahoe.
- About 2–4 feet of snow fell in the Olympic Mountains, Cascades, Klamath Mountains, and Southern Sierra Nevada.
- Low freezing levels also facilitated significant snowfall accumulations (> 12 inches) in the Willapa Hills, Oregon Coast Ranges, and Northern California Coast Ranges.
- This event provided a substantial boost to seasonal snowpack in the Sierra Nevada, with many stations reporting snow water equivalent (SWE) increases of 8–12 inches (~20–30% of the typical peak SWE) over a 5-day period.
- Heavy snowfall and high winds created extremely dangerous travel conditions, resulting in closures of I-80 and US-395.
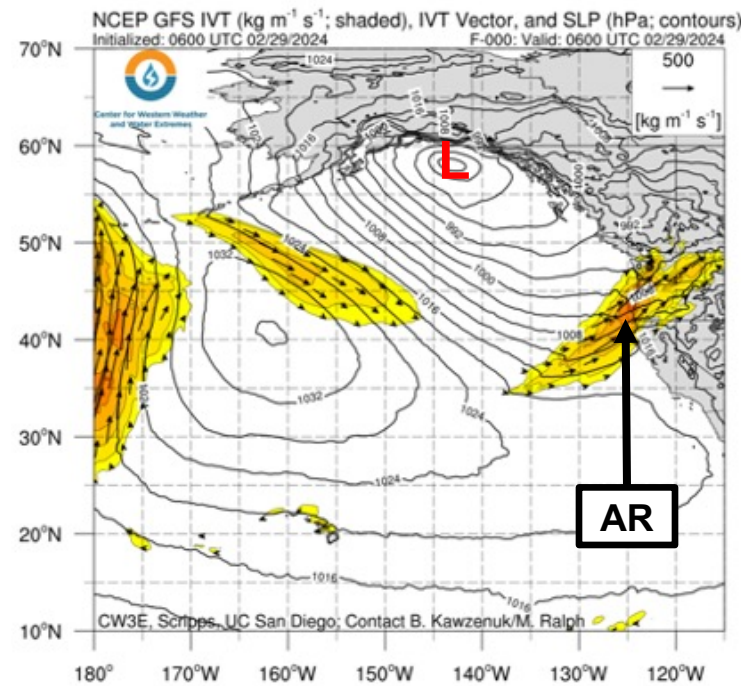
CW3E Event Summary: 28 February – 3 March 2024
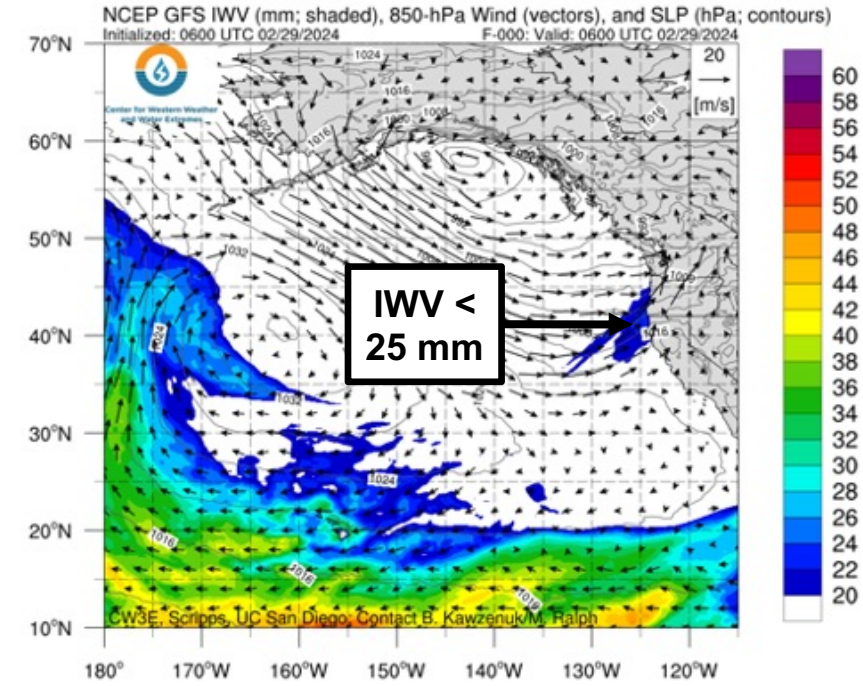
GFS Model Analyses: Valid 10 PM PT 28 Feb 2024

500-hPa Vorticity, Height, and Wind
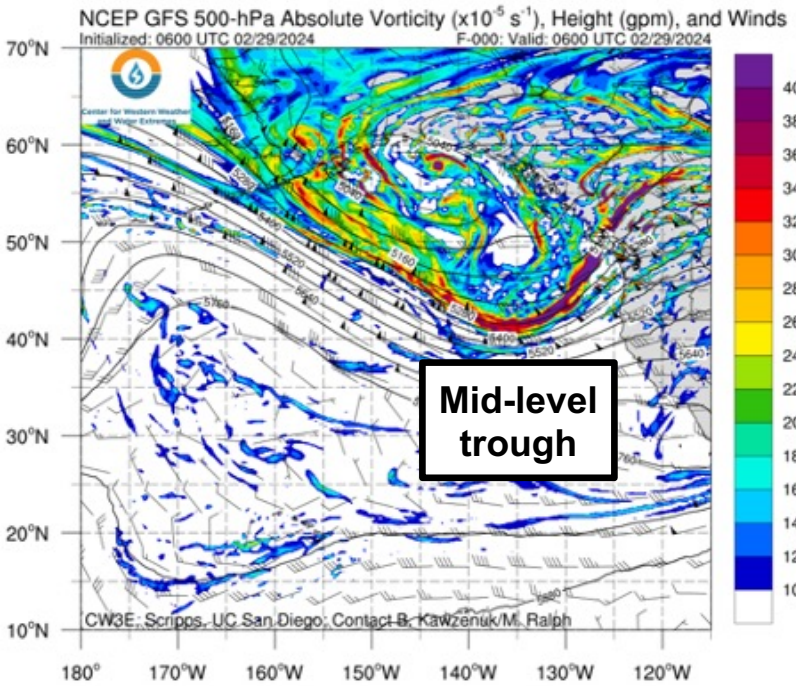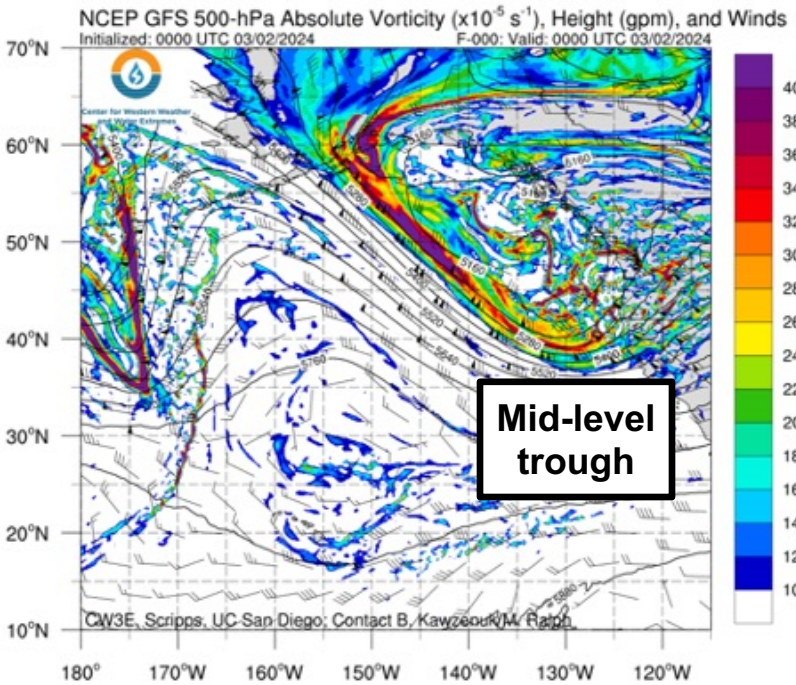
IVT and SLP

IWV and 850-hPa Wind

- The AR made landfall over the Pacific Northwest late on 27 Feb downstream of an amplifying mid-level trough.
- As the trough approached the West Coast of North America, the AR briefly intensified, with maximum IVT magnitudes approaching 700 kg m^{-1} s^{-1} along the coast of Oregon during the evening of 28 Feb.
- Unlike previous ARs that brought heavy rainfall to California in recent weeks, this AR was characterized by a lack of tropical moisture and relatively low precipitable water values (< 25 mm).

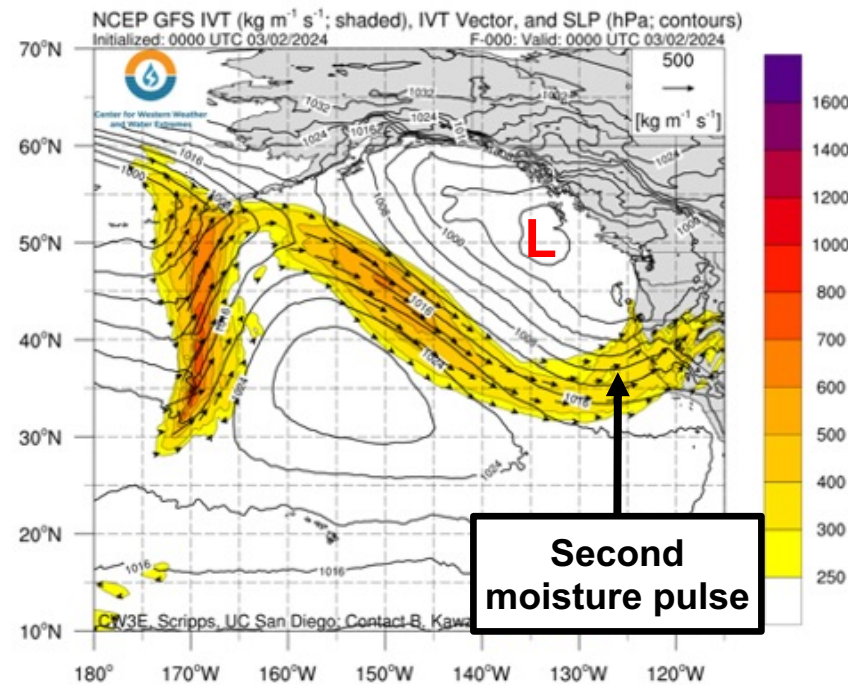# CW3E Event Summary: 28 February – 3 March 2024

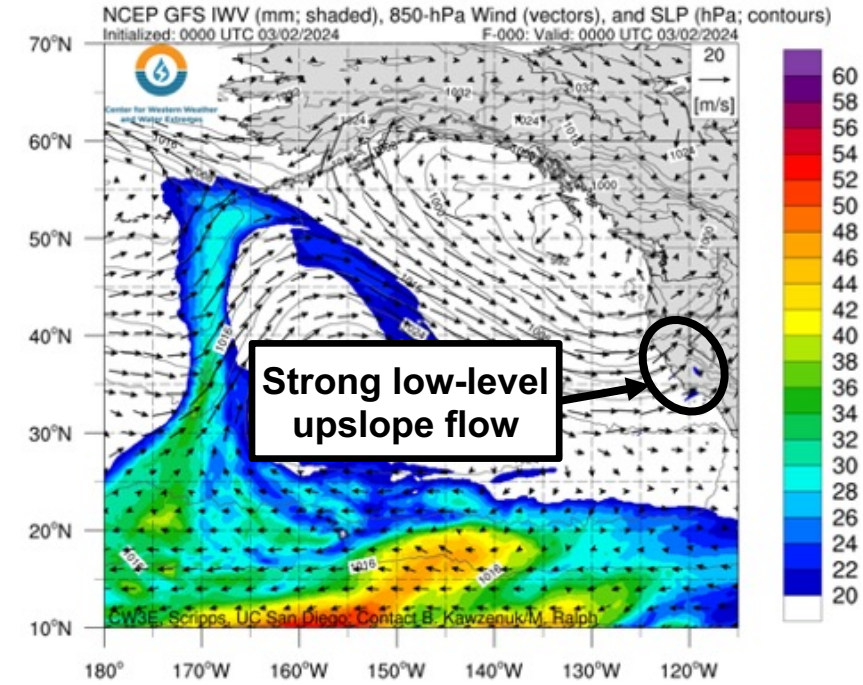**GFS Model Analyses:** Valid 4 PM PT 1 Mar 2024

500-hPa Vorticity, Height, and Wind

IVT and SLP

IWV and 850-hPa Wind

- As time progressed, the AR weakened, and the mid-level trough continued to deepen along the US West Coast, providing a focus for additional precipitation over the next several days.
- A second pulse of moisture transport developed on the southern periphery of the trough, bringing another period of weak AR conditions (IVT < 500 kg m^{-1} s^{-1}) to Northern and Central California on 1 Mar.
- This second pulse of moisture transport was primarily driven by strengthening low-to-mid-level winds.
- Despite the limited moisture, strong westerly-to-southwesterly upslope flow contributed to orographic enhancement of precipitation over the California Coast Ranges and Sierra Nevada.
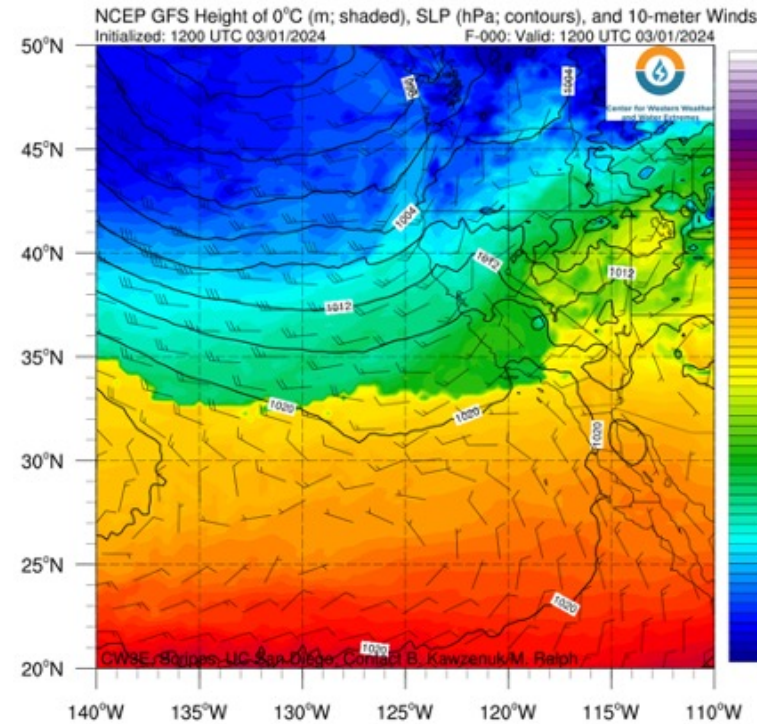
CW3E Event Summary: 28 February – 3 March 2024
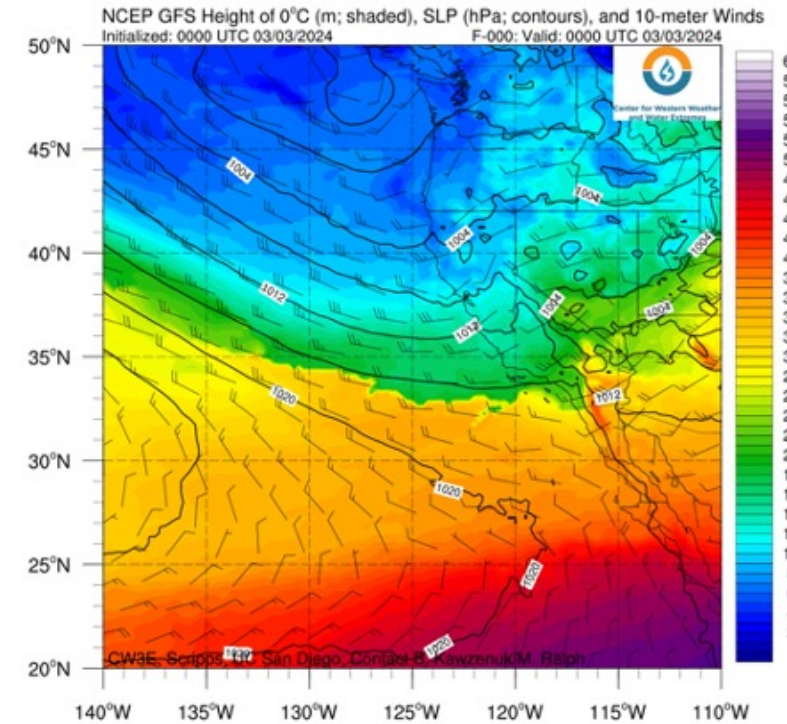
GFS Model Freezing Level Analyses
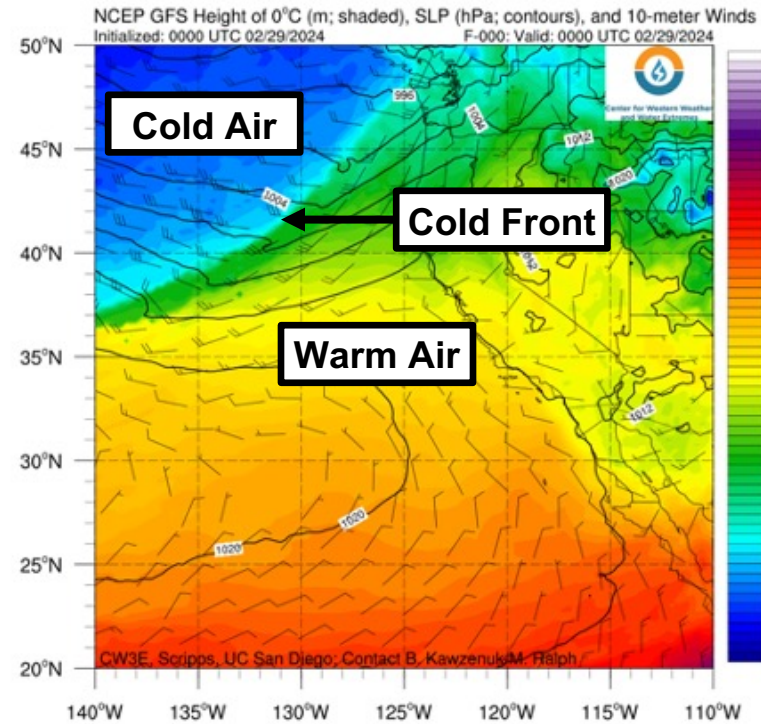

- One of the most notable aspects of this event was significant snowfall accumulations at intermediate elevations in Washington, Oregon, and Northern California.
- After the AR made landfall, the passage of a cold front and the continued deepening of the upstream mid-level trough facilitated a southward surge of cold air over much of the Western US.
- GFS model analyses suggest that freezing levels dropped below 3,000 feet over much of western Washington, western Oregon, and Northern California by the afternoon of 2 Mar.

# CW3E Event Summary: 28 February – 3 March 2024

GEFS AR Scale Analysis
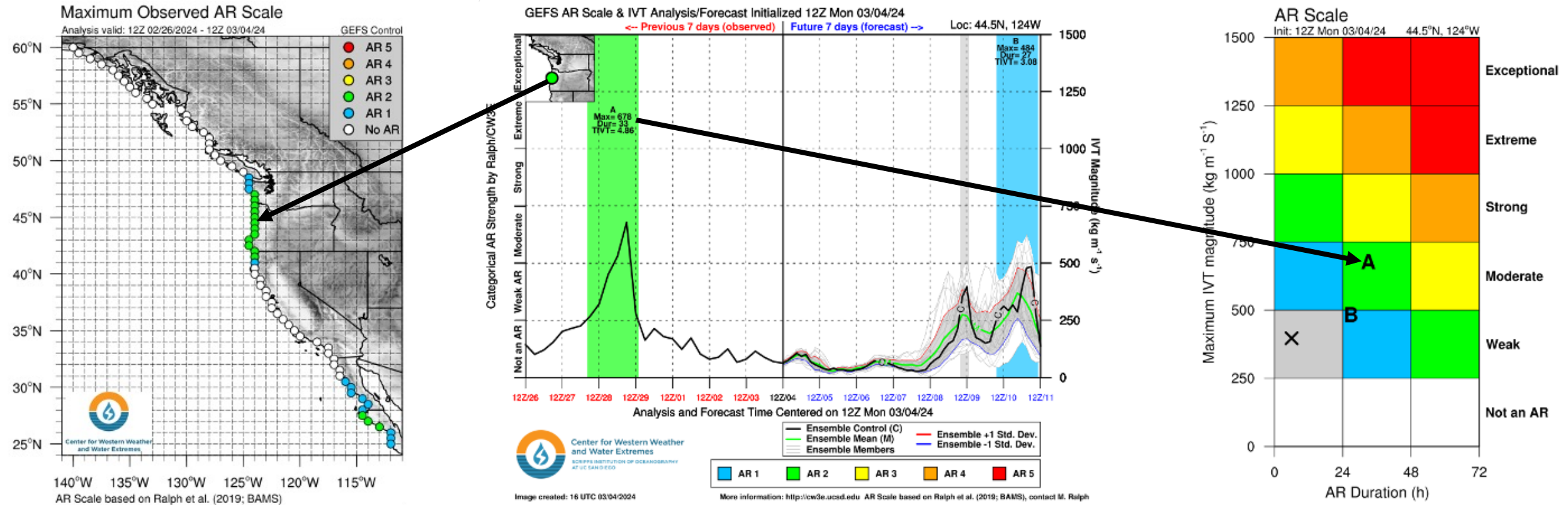
- Based on the GEFS analysis, the initial AR landfall produced AR2 conditions along the coast from Grays Harbor County, WA, to Humboldt County, CA.
- The GEFS analysis shows an estimated AR duration of 33 hours and maximum IVT of 678 kg m^{-1} s^{-1} in Lincoln County, OR.

CW3E Event Summary: 28 February – 3 March 2024

GEFS AR Scale Analysis
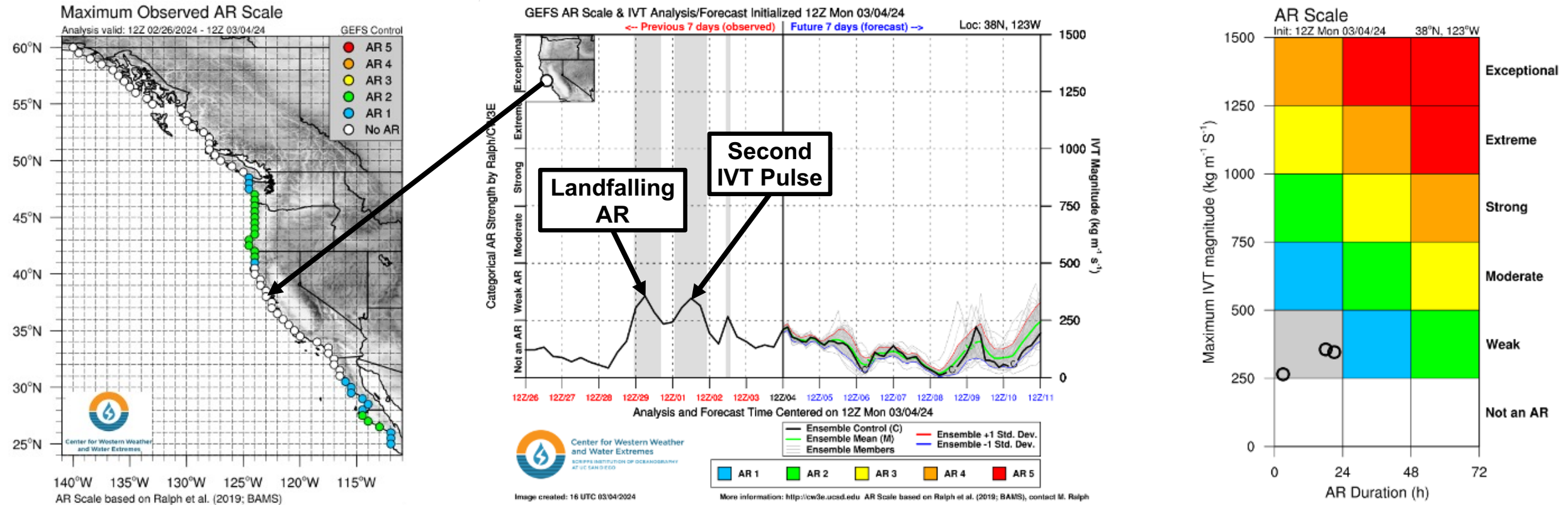
- The AR quickly weakened as it moved southward over CA, with only a brief period (< 24 hours) of AR conditions (IVT > 250 kg m^{-1} s^{-1}) occurring over the San Francisco Bay Area on 29 Feb.
- The second pulse of moisture transport brought another brief period of AR conditions to the Bay Area on 1 Mar.

# CW3E Event Summary: 28 February – 3 March 2024

GEFS AR Scale Analysis
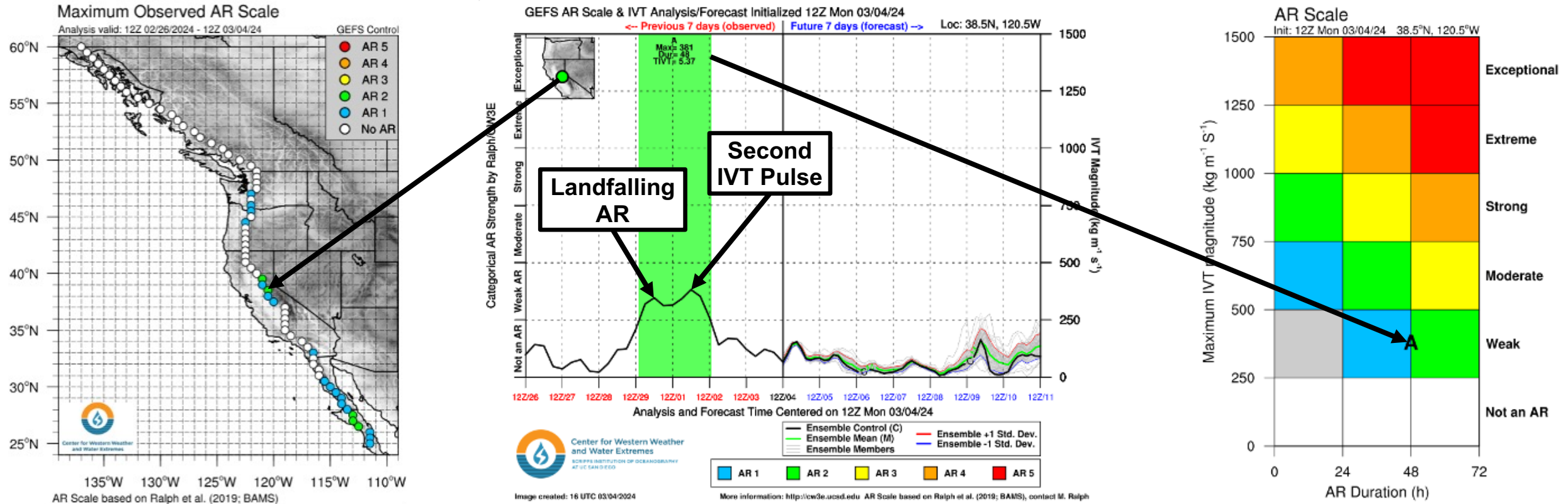
- Farther inland, the initial landfalling AR and the second pulse of moisture transport combined to produce AR1–2 conditions in the western foothills of the Northern and Central Sierra Nevada.
- The GEFS analysis shows an estimated AR duration of 48 hours and maximum IVT of 381 kg m^{-1} s^{-1} at 38.5°N, 120.5°W.
- Sustained moisture transport helped fuel the heavy snowfall in the Sierra Nevada during this event.

CW3E Event Summary: 28 February – 3 March 2024
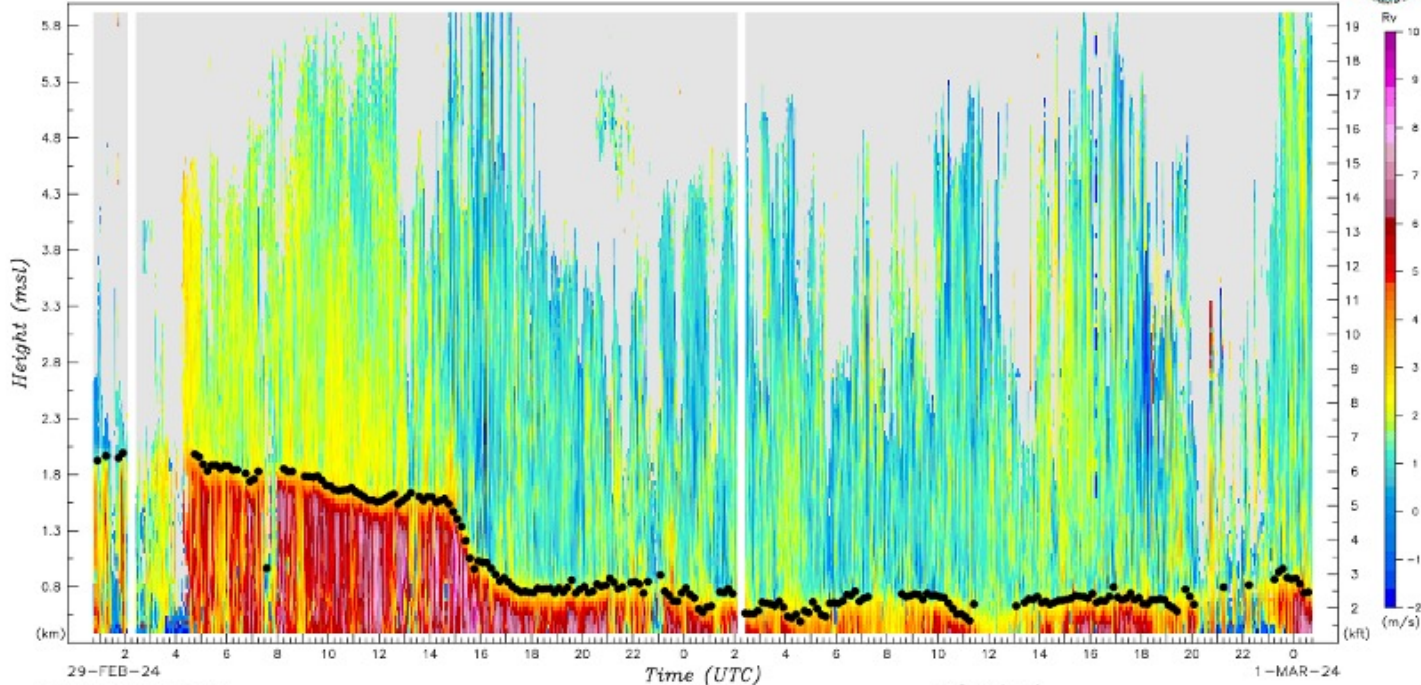
CW3E Observations: Radiosondes
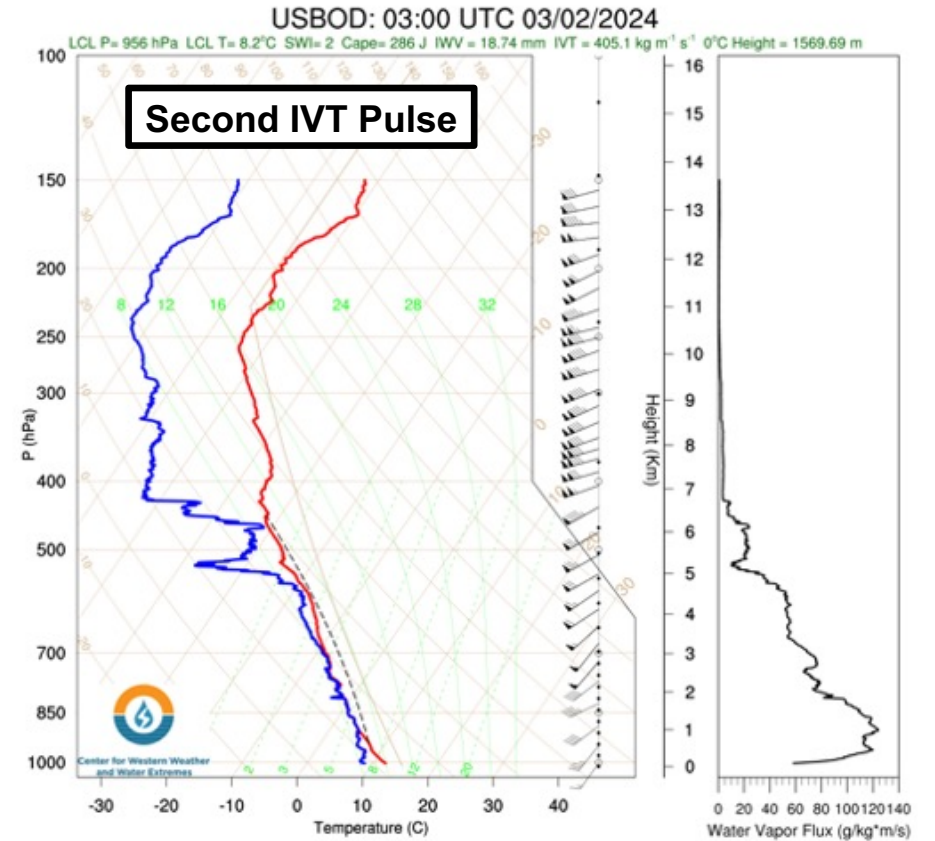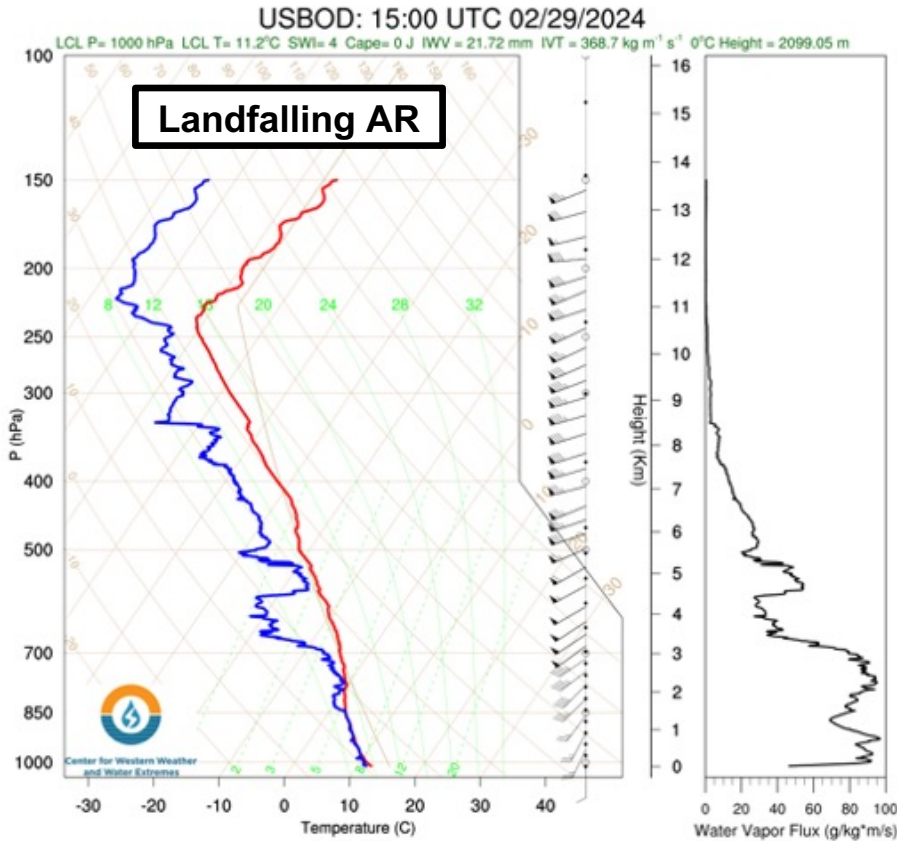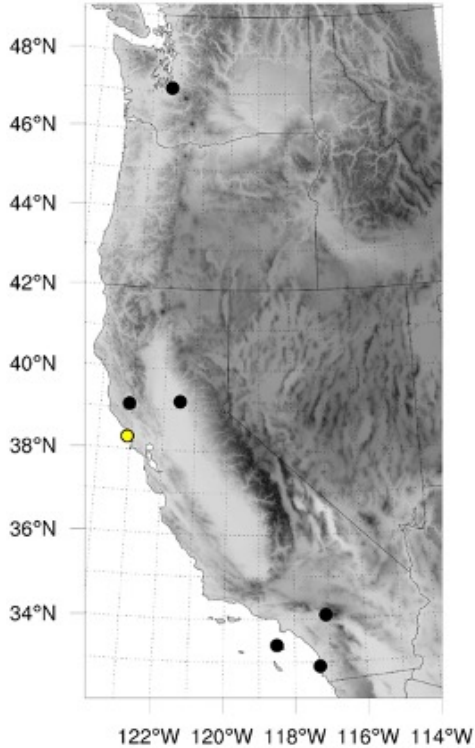
- The CW3E Field Team released radiosondes every 3 hours at Bodega Bay, CA (USBOD), from 06Z 29 Feb (10 PM PT 28 Feb) to 09Z 2 Mar (1 AM PT 2 Mar).
- Similar to the AR Scale analysis, the radiosonde data showed two distinct periods of weak AR conditions associated with the initial AR landfall and the second pulse of moisture transport on 1 Mar.

CW3E Event Summary: 28 February – 3 March 2024

Profiler Snow Level Radar: Happy Camp, CA

- The S-band snow level radar at Happy Camp, CA (located in the Lower Klamath subbasin), measured snow levels between 5,000 feet and 6,500 feet during the initial AR landfall.

- After the cold front passed through the region, snow levels dropped about 2,500 feet in a 3-hour period.

- Snow levels remained below 2,500 feet during most of the remainder of the event.

- Very low snow levels facilitated significant snowfall accumulations in the Klamath Mountains, as well as portions of the Willapa Hills in southwestern Washington, the Oregon Coast Ranges, and the Northern California Coast Ranges.

Profiler Snow Level Radar: Colfax, CA

- The S-band snow level radar at Colfax, CA (located in the North Fork American subbasin), measured snow levels between 5,500 feet and 6,000 feet at the onset of this event.

- After the initial AR landfall, snow levels dropped below 5,000 feet, allowing for significant snowfall accumulations at intermediate elevations in the Sierra Nevada.
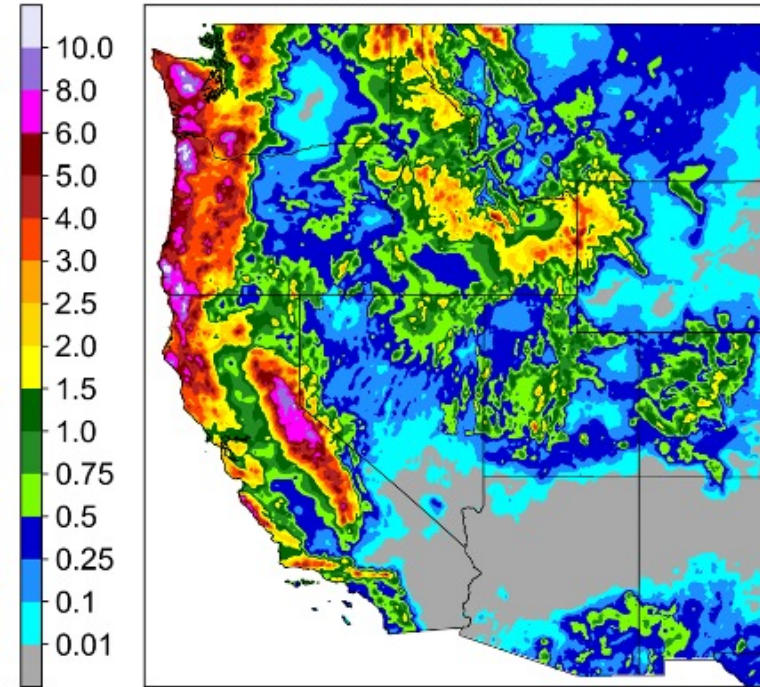
- A disdrometer recently installed by the CW3E Field Team at the Central Sierra Snow Lab successfully recorded rain at the onset of the event, with a transition to snow/sleet several hours later.

Storm-Total Precipitation

NWS Stage IV 120-h QPE
Valid: 4 AM PT 4 Mar 2024

[in]

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

NWS 120-h Snowfall Analysis
Valid: 4 AM PT 4 Mar 2024

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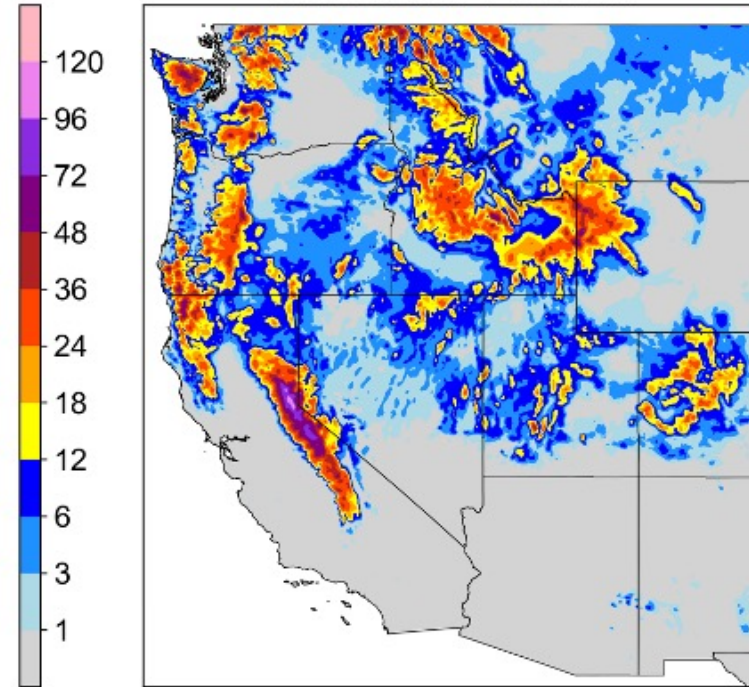
Data Courtesy: NOAA NWS National Operational Hydrologic Remote Sensing Center https://www.nohrsc.noaa.gov/

Sierra Ski Area Snowfall (Upper Mtn)

	3/1	3/2	3/3	3/4	Storm Total	Season Total	STD % Avg.	Season % Avg.
Tahoe North								
Sugar Bowl	20	32	35	38	125	391	121%	86%
Boreal	19	30	40	30	119	356	112%	80%
Palisades Tahoe	17	24	31	24	96	321	103%	74%
Homewood	19	27	26	26	98	260	97%	69%
Tahoe Donner	14	31	24	16	85	243	99%	71%
Northstar	17	27	26	16	86	281	98%	70%
Mt. Rose	20	36	28	8	92	322	122%	87%
Diamond Peak	10	30	18	7	65	181	95%	68%
Tahoe South								
Heavenly	10	20	24	4	58	194	77%	55%
Sierra at Tahoe	13	25	26	14	78	257	85%	61%
Kirkwood	12	19	21	10	62	290	92%	65%
Central Sierra								
Bear Valley	10	17	30	9	66	264	106%	76%
Dodge Ridge	4	16	32	19	71	294	137%	98%
Mammoth	1	19	17	2	39	270	93%	67%
China Peak	0	16	26	0	42	263	123%	88%

OPENSNOW

Credit: OpenSnow/B. Allegretto

- This storm produced widespread precipitation over the Western US, with the highest precipitation totals (> 6 inches) in the Coast Ranges of Washington, Oregon, and far Northern California, as well as the Northern and Central Sierra Nevada.
- An estimated 4–10 feet of snow fell in the Northern and Central Sierra Nevada, with the highest amounts near Lake Tahoe.
- An estimated 2–4 feet of snow fell in the Olympic Mountains, Cascades, Klamath Mountains, Southern Sierra Nevada, and the Rocky Mountains in central Idaho and northwestern Wyoming.
- Significant snowfall accumulations (> 12 inches) were also observed in portions of the Willapa Hills, Oregon Coast Ranges, and Northern California Coast Ranges.
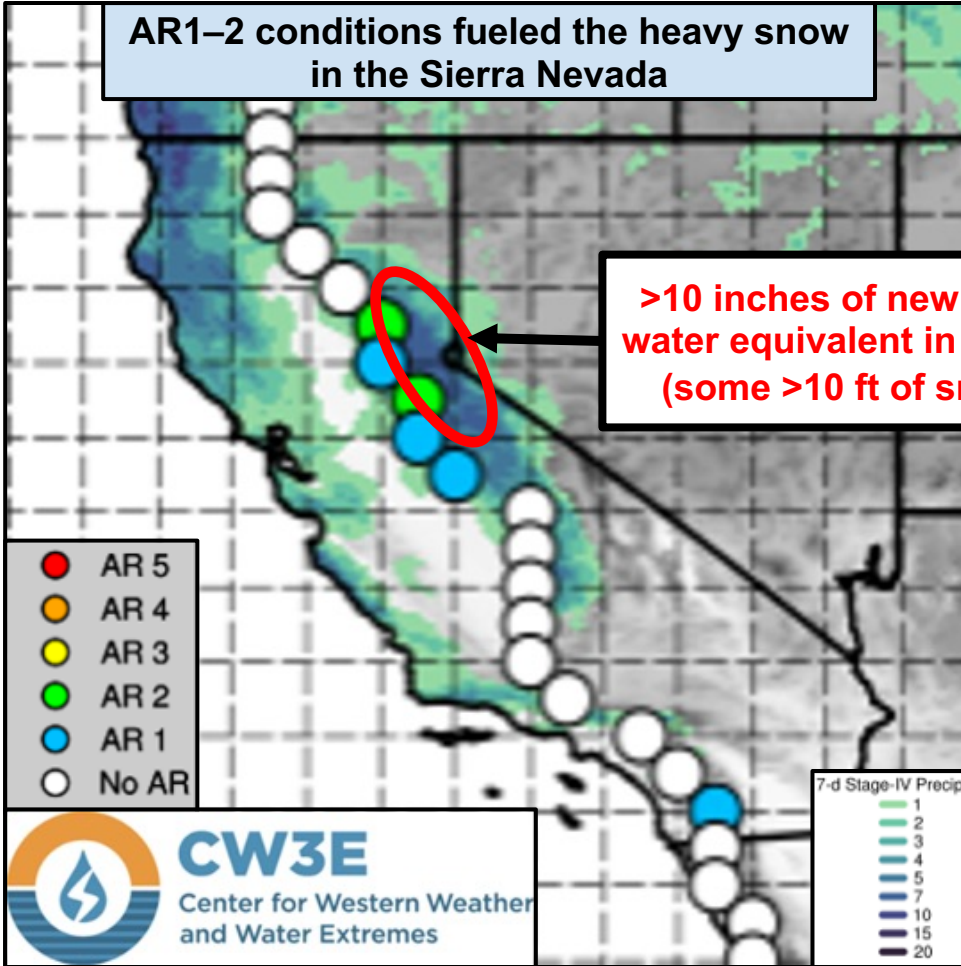
AR-Driven Snowfall

Maximum Observed AR Scale
Analysis valid: 12Z 02/28/2024 - 12Z 03/06/24   GEFS Control

AR1–2 conditions fueled the heavy snow in the Sierra Nevada

>10 inches of new snow water equivalent in 7 days (some >10 ft of snow)

AR 5
AR 4
AR 3
AR 2
AR 1
No AR

Credit: F. Martin Ralph, CW3E at UC San Diego Scripps Institution of Oceanography

7-day SWE Change: 28 Feb – 6 Mar

Credit: NOAA/NWS California-Nevada River Forecast Center
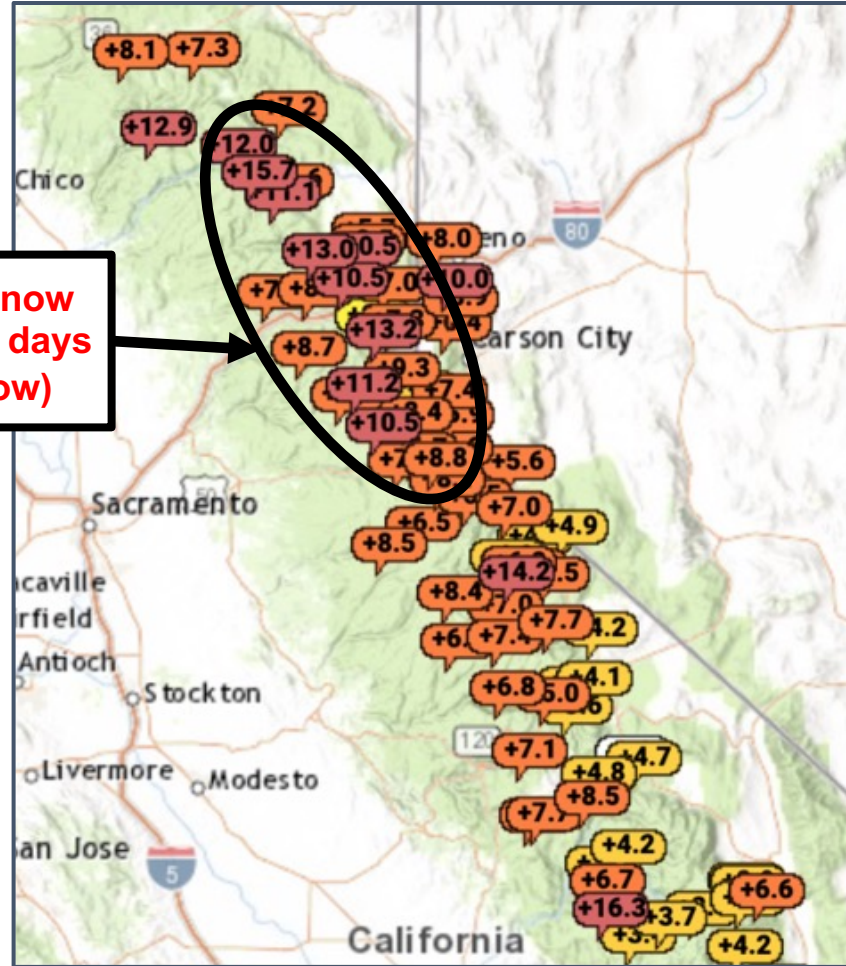
- The initial landfalling AR and the subsequent pulse of moisture transport combined to produce AR1–2 conditions in the western foothills of the Northern and Central Sierra Nevada.

- This moisture transport played a key role in driving heavy snowfall in the Sierra Nevada.

- Snow water equivalent (SWE) increased by more than 10 inches in some locations over a 7-day period.
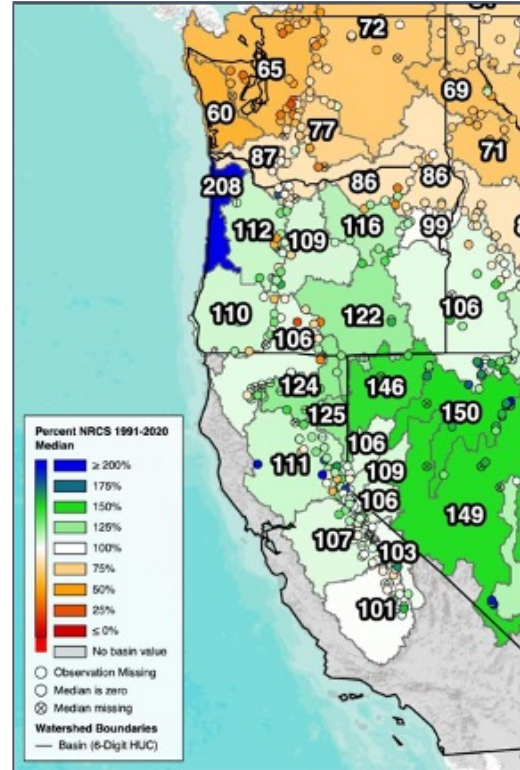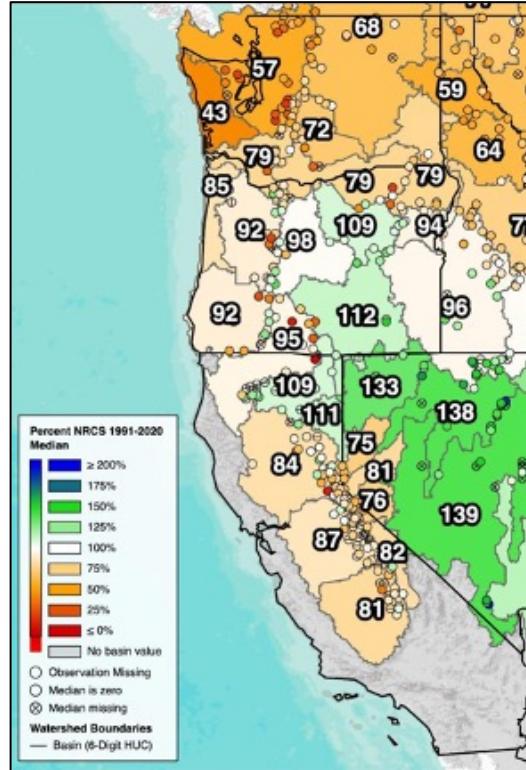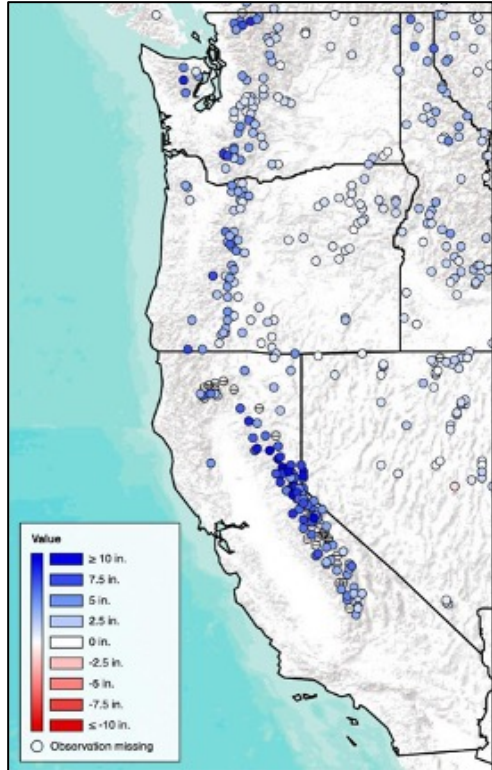
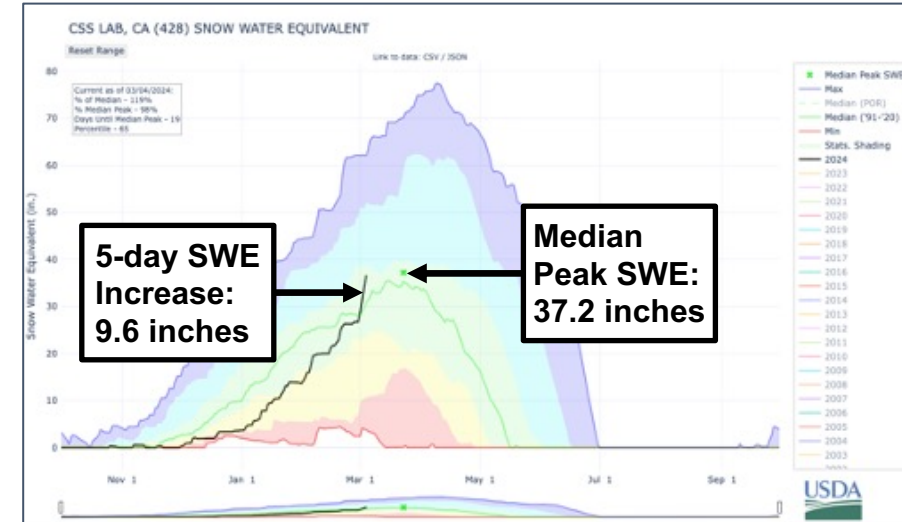# CW3E Event Summary: 28 February – 3 March 2024

Changes in Snowpack

5-day SWE Change
Valid: 28 Feb – 4 Mar

SWE Percent of 1991–2020
Median: 28 Feb

SWE Percent of 1991–2020
Median: 4 Mar

This event contributed 26% of the typical peak SWE at the Central Sierra Snow Lab

CSS LAB, CA (428) SNOW WATER EQUIVALENT

5-day SWE Increase: 9.6 inches
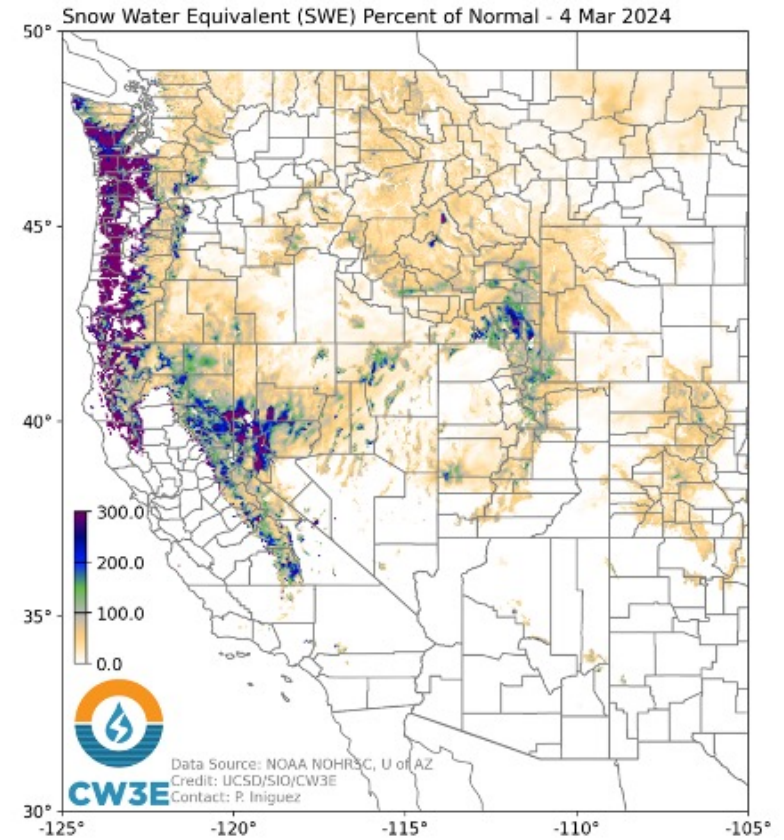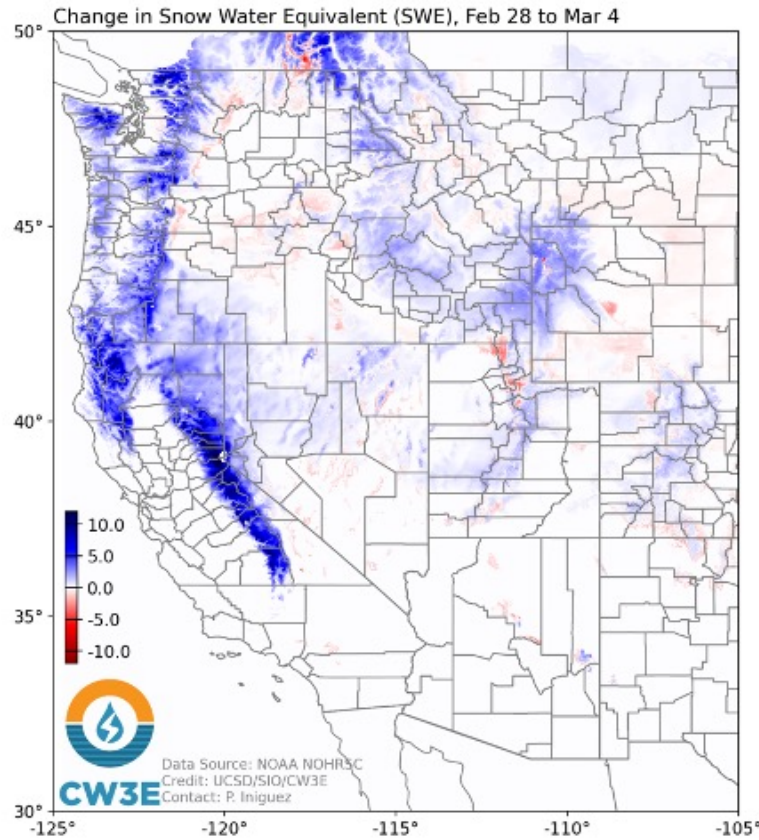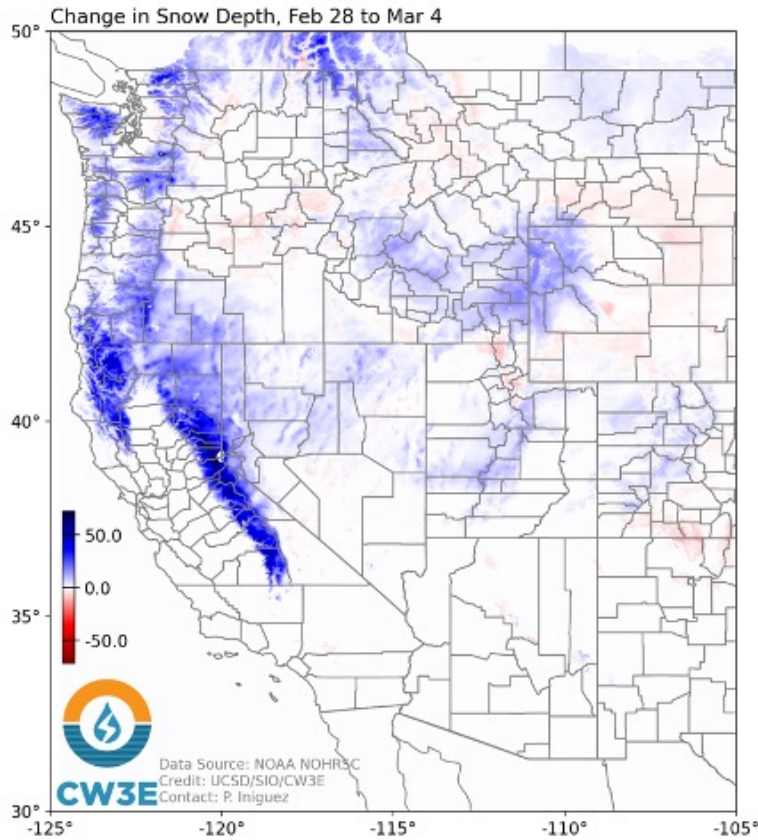
Median Peak SWE: 37.2 inches

Credit: USDA NRCS National Water and Climate Center

- This event produced substantial increases in snowpack in portions of the Olympic Mountains, Cascades, and Sierra Nevada.
- Many stations in the Northern and Central Sierra Nevada reported SWE increases of 8–12 inches between 28 Feb and 4 Mar.
- The 5-day SWE increase represented about 20–30% of the 1991–2020 median WY peak SWE in some locations.
- Snowpack conditions improved from 75–87% to 101–111% of the 1991–2020 median in basins surrounding the Sierra Nevada.
- Large improvements in snowpack were also observed in western Oregon, especially in the northern Oregon Coast Ranges.

Changes in Snowpack

- Gridded products show similar changes in snowpack over the Western US during this 5-day period, with SWE increases of 5 inches or more in parts of the Olympic Mountains, Cascades, Klamath Mountains, and Southern Sierra Nevada, and 10 inches or more in the Northern and Central Sierra Nevada.
- By 4 Mar, snowpack was running well-above normal in portions of the Coast Ranges in Washington, Oregon, and Northern California, as well as in western Nevada, and slightly above-normal at intermediate elevations in the Sierra Nevada.
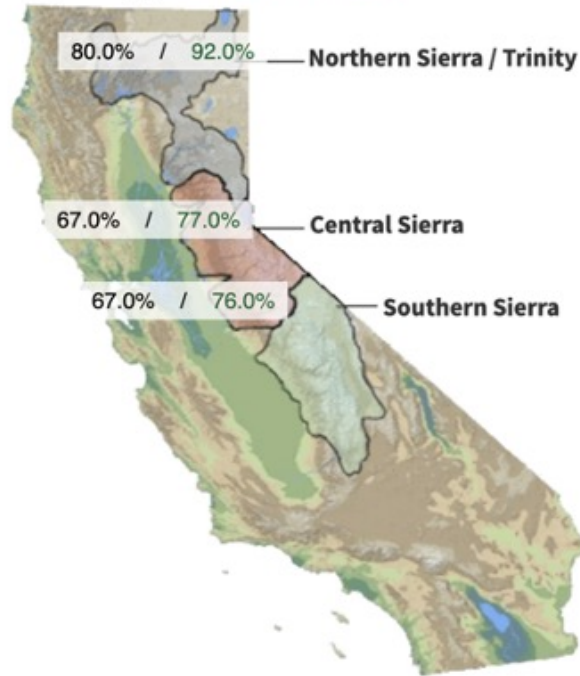
CW3E Event Summary: 28 February – 3 March 2024

Snowpack and Reservoir Conditions
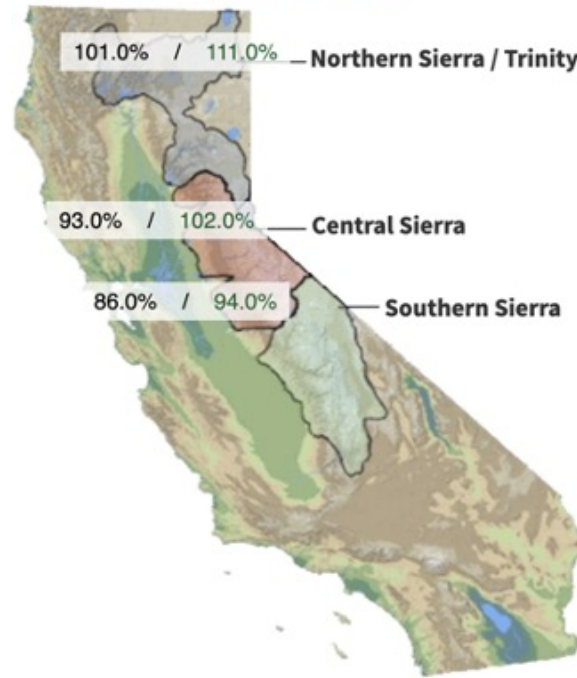
Credit: California Department of Water Resources
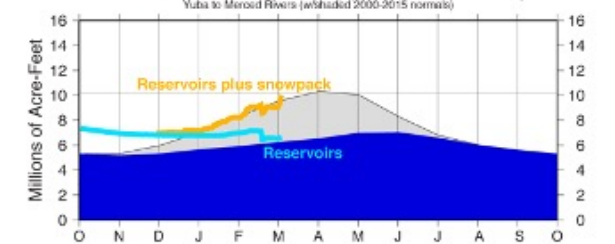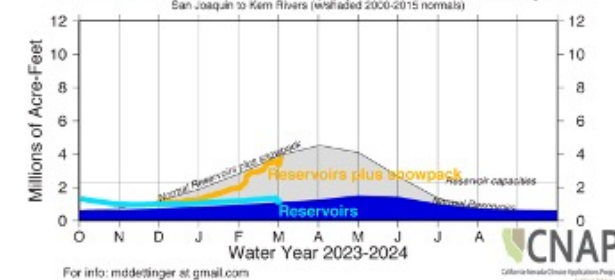
- Snowfall from this event brought California's snowpack from 80% of normal to 104% of normal statewide.
- As of 4 Mar, each of the three Sierra Nevada regions were reporting > 90% of normal snowpack.
- The increase in snowpack from this event will be beneficial for water supply as we begin to approach the spring snowmelt season.

Hydrologic Impacts
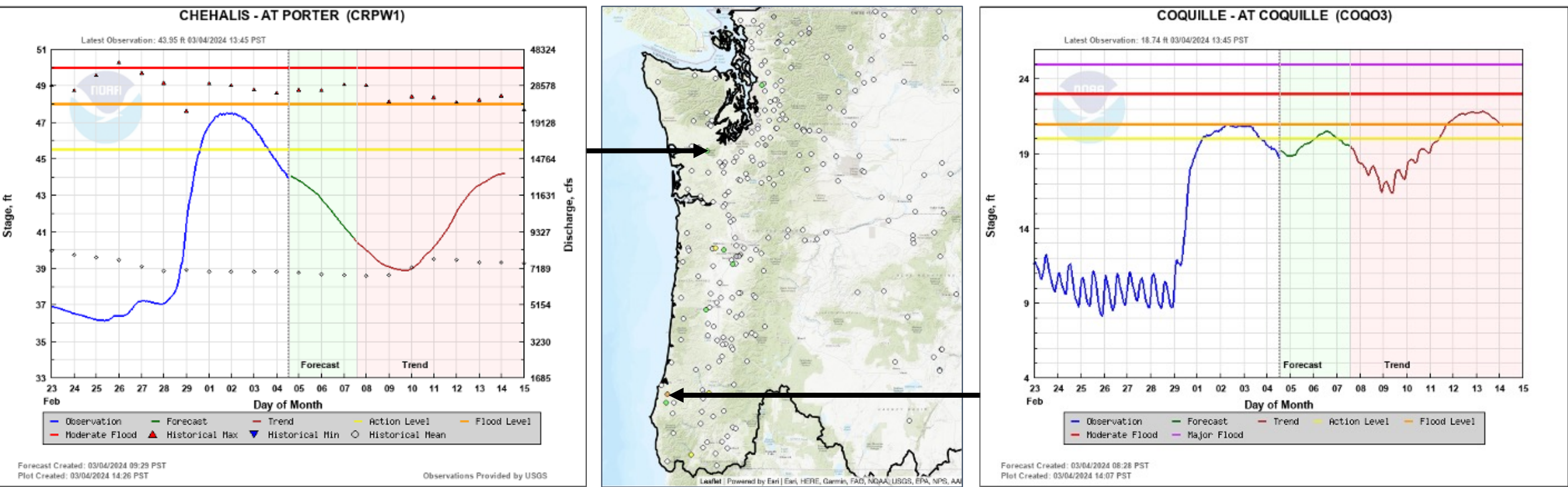
Credit: NOAA/NWS Northwest River Forecast Center

- Hydrologic impacts were relatively minor during this event due to moderate rainfall intensities and much of the precipitation falling as snow.
- Rainfall on 28–29 Feb caused isolated riverine flooding in coastal Washington and Oregon, including the Chehalis River (at Porter, WA) and the Coquille River (at Coquille, OR).
- Subsequent precipitation after the initial AR landfall caused river levels to remain elevated for several days.

CW3E Event Summary: 28 February – 3 March 2024

Impacts

Wind Gust Reports (mph)
Valid: 29 Feb 2024 - 4 Mar 2024

Palisades Tahoe
Ski Base: 145 mph

0.9 S Mammoth
Mountain: 130 mph

Data Courtesy: NWS Reno and NWS Sacramento

Elevation (m)

- Heavy snow and high winds created extremely dangerous travel conditions in the vicinity of the Sierra Nevada, resulting in multi-day closures of portions of Interstate 80 and US-395.

- Hurricane-force wind gusts (≥ 74 mph) were common along the Sierra crest.

- Wind gusts greater than 120 mph were reported at Palisades Tahoe and Mammoth Mountain.

- Blizzard conditions forced ski resorts in the Tahoe area to close or remain open in limited capacity on 3–4 Mar.

US-395 Near Crestview
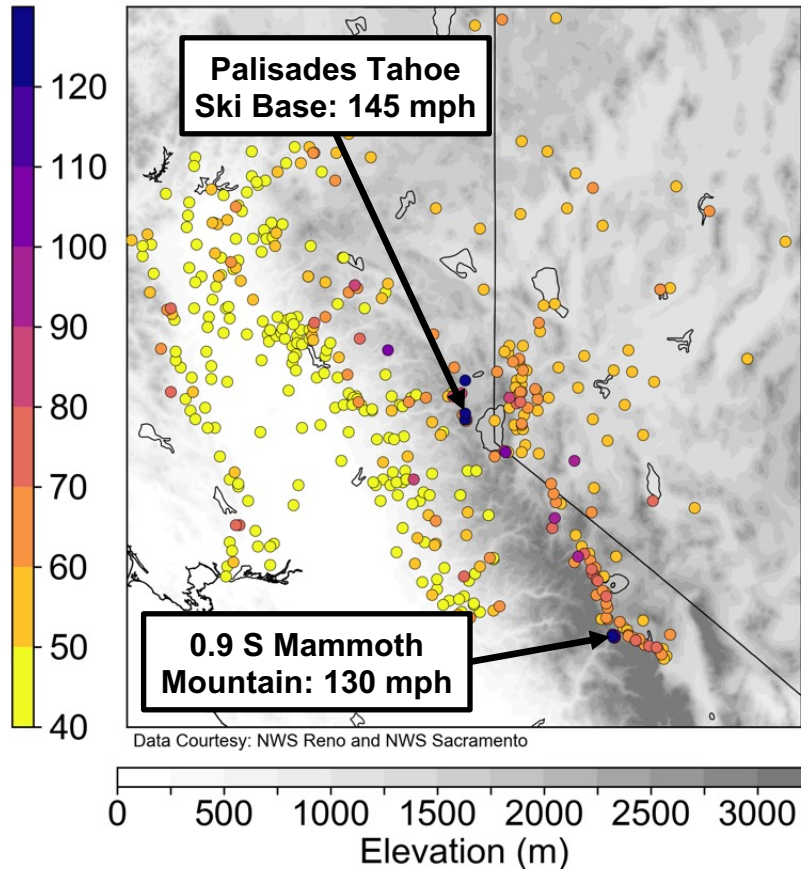

Credit: Caltrans District 9

US-395 Near Bartlett

Credit: Caltrans District 9
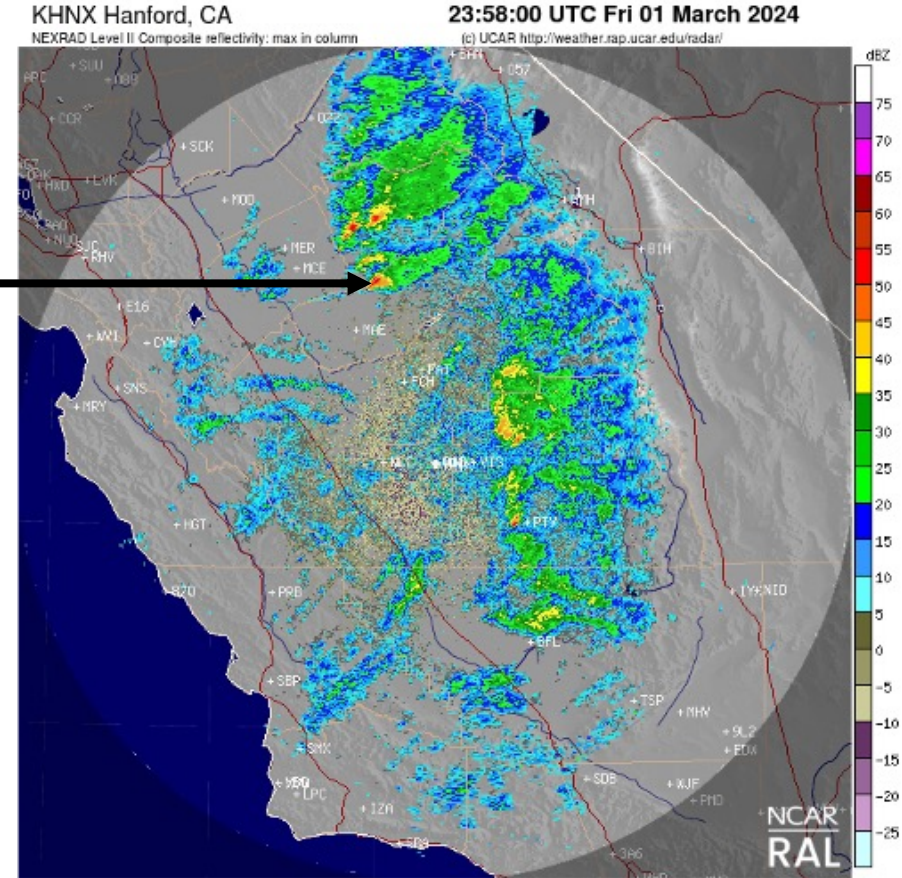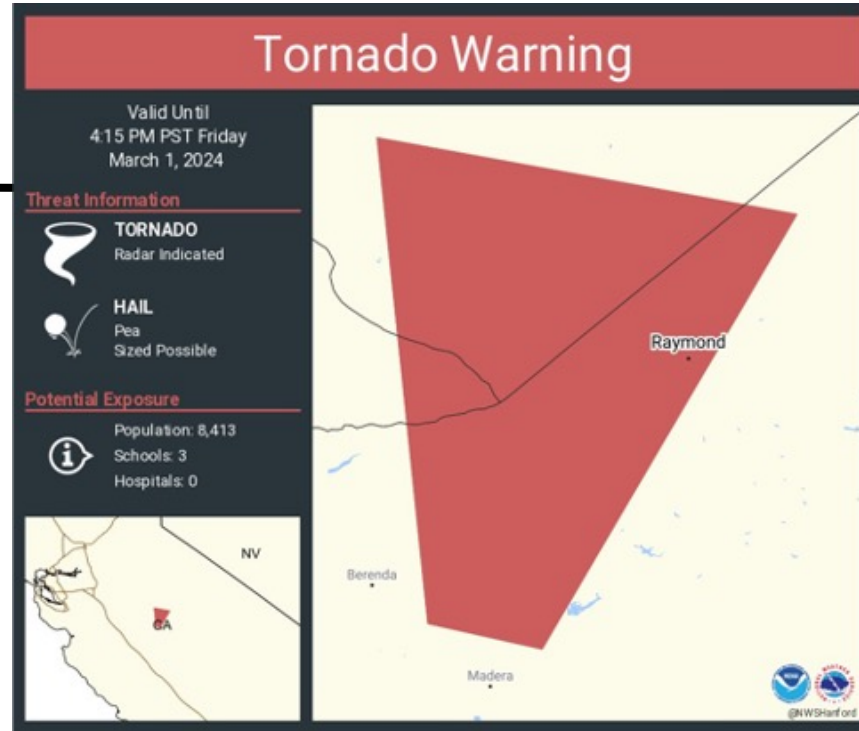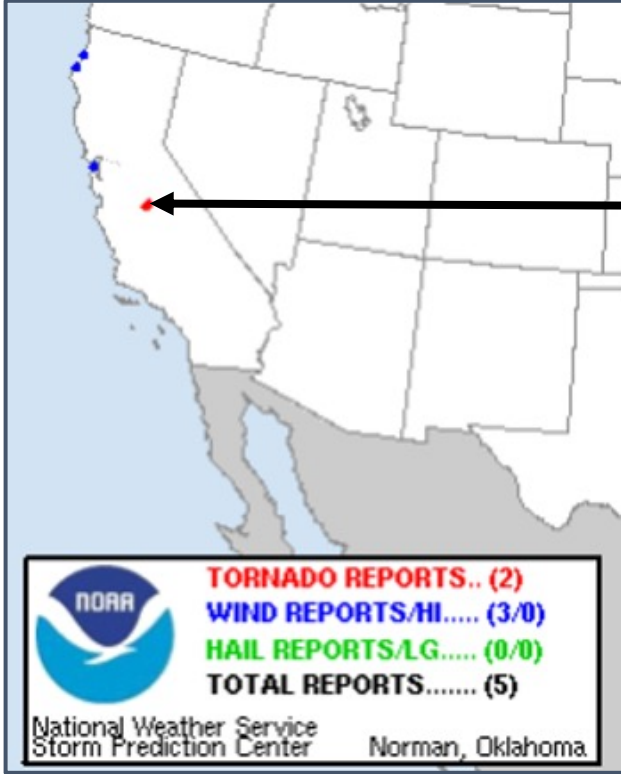
I-80 Between Colfax and NV State Line
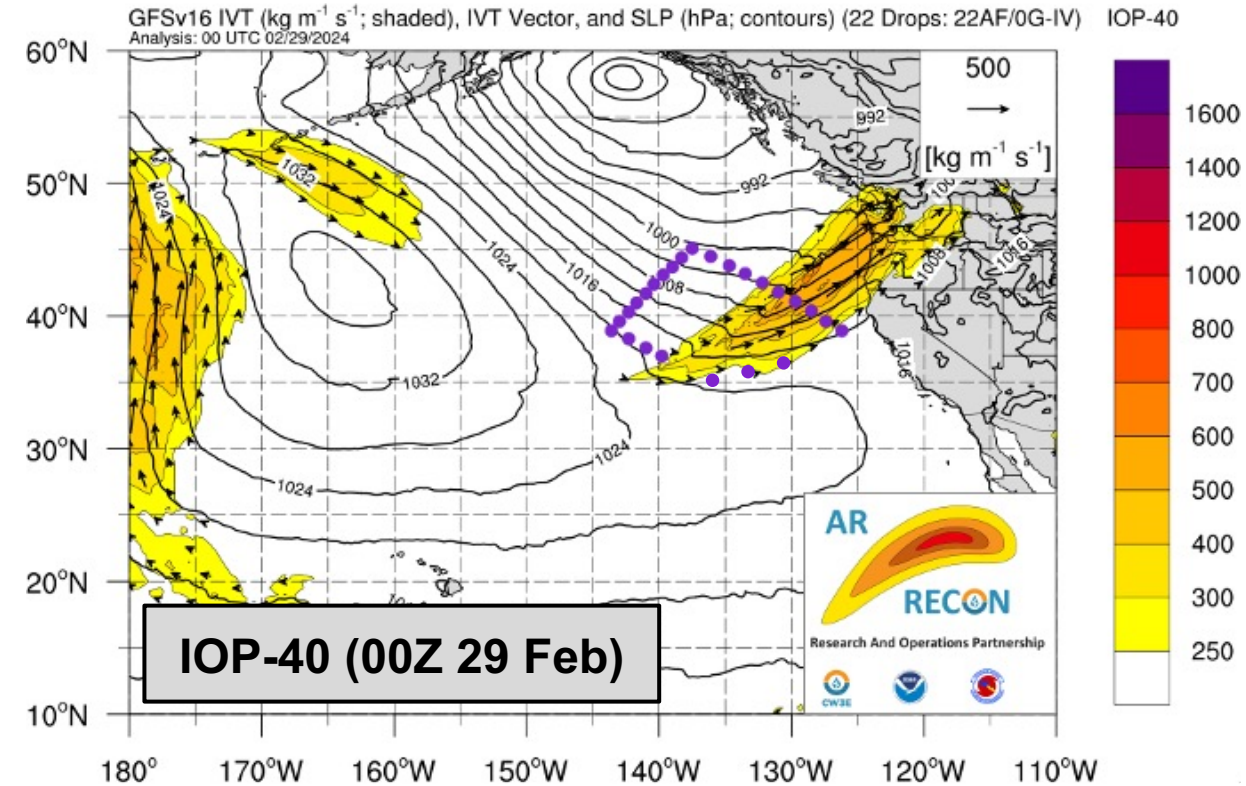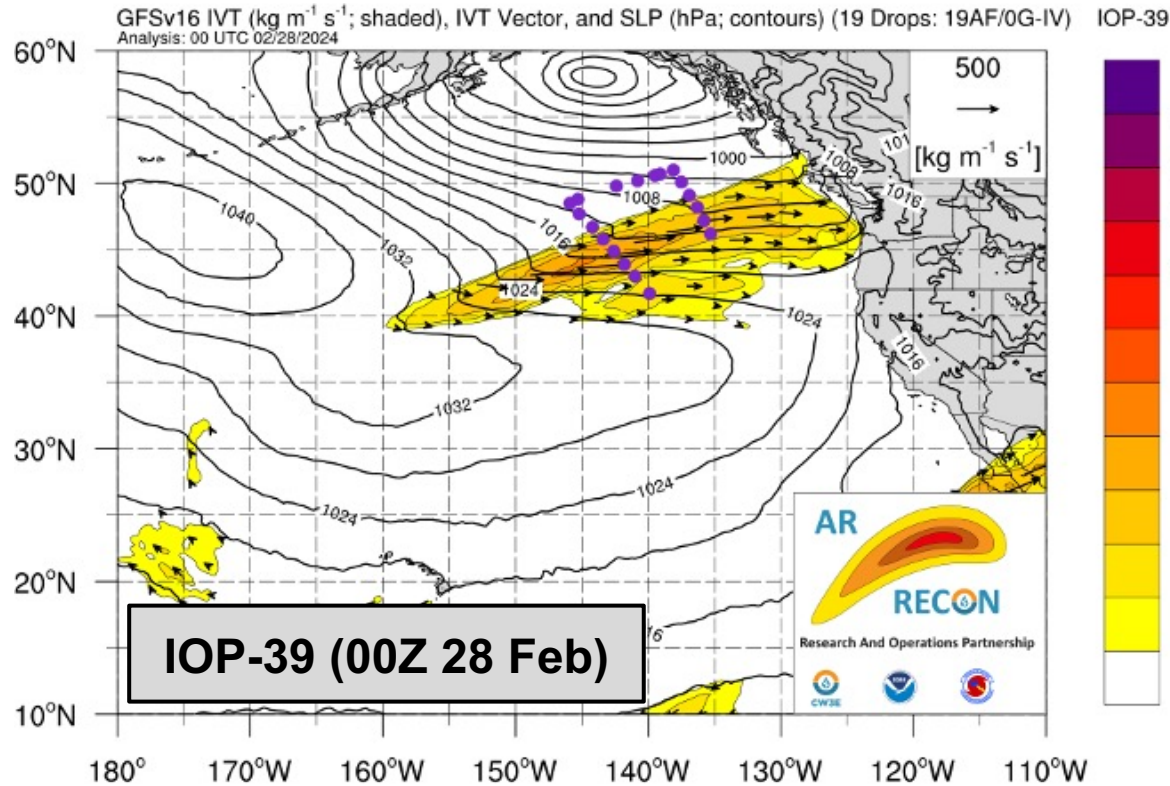

Credit: Caltrans District 3

Impacts

- Scattered convection over the Central Valley prompted NWS Hanford to issue multiple severe thunderstorm and tornado warnings on 1 Mar and 2 Mar.
- One tornado caused minor damage to a local elementary school in Madera County during the afternoon of 1 Mar.

Atmospheric River Reconnaissance

IOP: Intensive Observation Period

- As part of the CW3E-led AR Recon field campaign, members of the US Air Force 53rd Weather Reconnaissance Squadron provided operational support by sampling this AR prior to and during landfall, enhancing atmospheric observations over the Northeast Pacific.
- A total of 44 dropsondes were released during these two IOPs, providing atmospheric data within the AR and its associated atmospheric structures (i.e., mid-level trough, jet) for real-time assimilation into the global forecast models *and* future research.