CW3E Event Summary: 30 November – 6 December 2023

Atmospheric Rivers Produce Heavy Precipitation and Flooding in Washington and Oregon

- A series of low-pressure systems and three atmospheric rivers (ARs) brought heavy snow and rain to much of the Pacific Northwest during 30 Nov – 6 Dec.
- While the first AR was associated with a cold system, the second and third ARs were characterized by the transport of very warm, moist air from the subtropical North Pacific into the midlatitudes.
- The third and strongest AR produced AR3/AR4 conditions (based on the Ralph et al. 2019 AR Scale) over coastal WA/OR, as well as AR2 conditions in portions of the interior Pacific Northwest.
- These storms produced 10–20 inches of total precipitation in the Olympic Mountains, Cascades, and OR Coast Ranges, as well as 4–8 inches of precipitation in the lowlands of western WA and OR.
- The cold storms (including the first AR) produced 1–3 feet of snow in the Cascades during 30 Nov – 2 Dec.
- Snow levels remained below 4,000 feet through the first AR, then rose above 7,000 feet during the second and third ARs, resulting in significant rain-on-snow.
- High reservoir inflows prompted dam operators to increase releases to ~3,000 cfs at Howard Hanson Dam after the third AR.
- Heavy rain falling on moist soils and fresh snowpack during the third AR led to widespread riverine flooding across western Washington and northwestern Oregon.
- The Skagit and Stillaguamish Rivers reached major flood stage on 5 Dec.
- Significant flooding was observed in multiple locations, requiring road closures, sandbagging, and multiple water rescues – to include a helicopter rescue by the US Coast Guard due to rapidly rising waters near Rosburg, WA.
- There were also numerous landslides and debris flows in Washington and Oregon, requiring the shutdown of various roadways, including a post-fire debris flow within the boundaries of the 2020 Holiday Farm Fire in Oregon.

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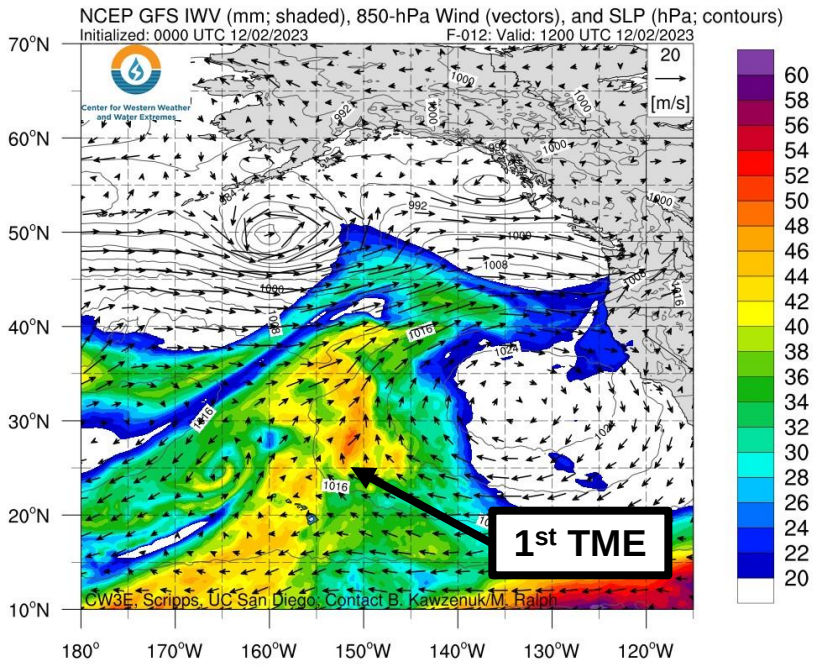
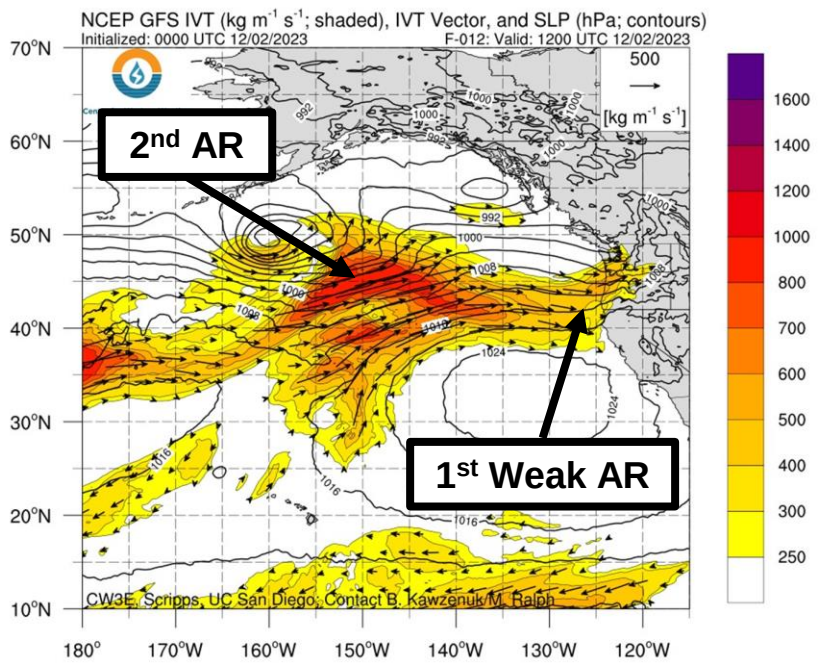
1st AR

GFS Analyses of First AR: Valid 4 AM PT 2 December 2023

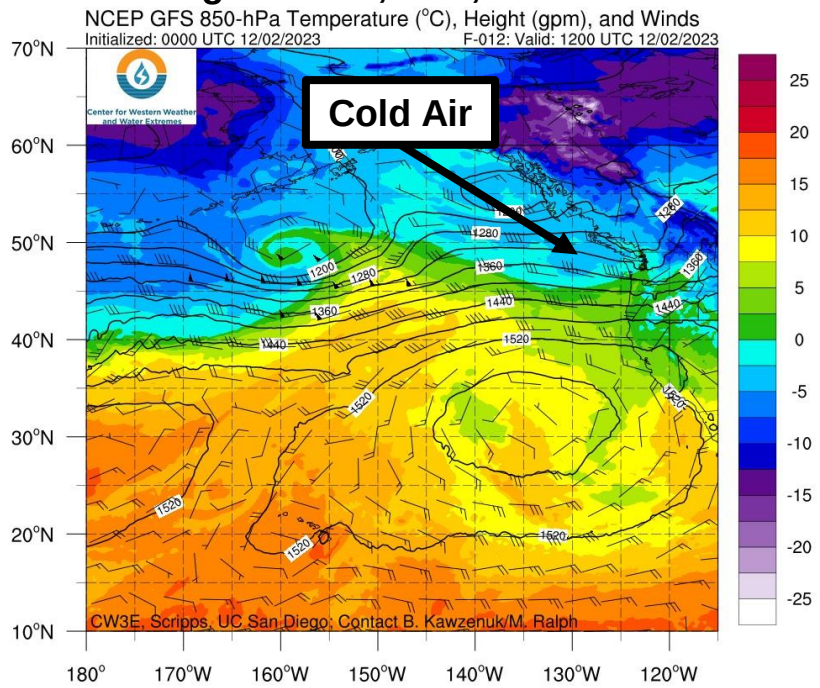
IWV and 850-hPa Wind



IVT and SLP



GFS Height of 0°C, SLP, and 10m Winds



- The 1st AR was supported by a narrow region of moisture extending onshore over the Pacific Northwest with IWV values >20 mm in this region, with a relatively short period of maximum IVT > 500 kg $m^{-1}s^{-1}$ in the core of the AR as it made landfall.
- The 2nd AR was supported by a more robust TME extending north from Hawaii with IWV values > 40 mm. At this time, the AR was intensifying to the south of Alaska, with IVT > 900 kg $m^{-1}s^{-1}$ in the core.
- Freezing levels during the first AR remained relatively low, between 2,000–4,000 feet in the mountains of the Pacific Northwest due to a broad region of cold air and 850-hPa temperature below 0°C to the north and east of the AR core.

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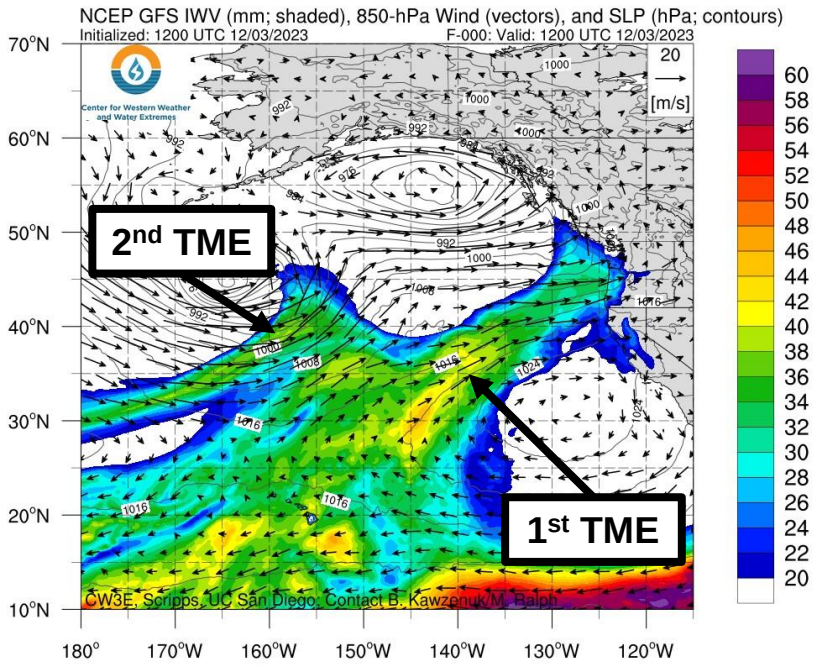
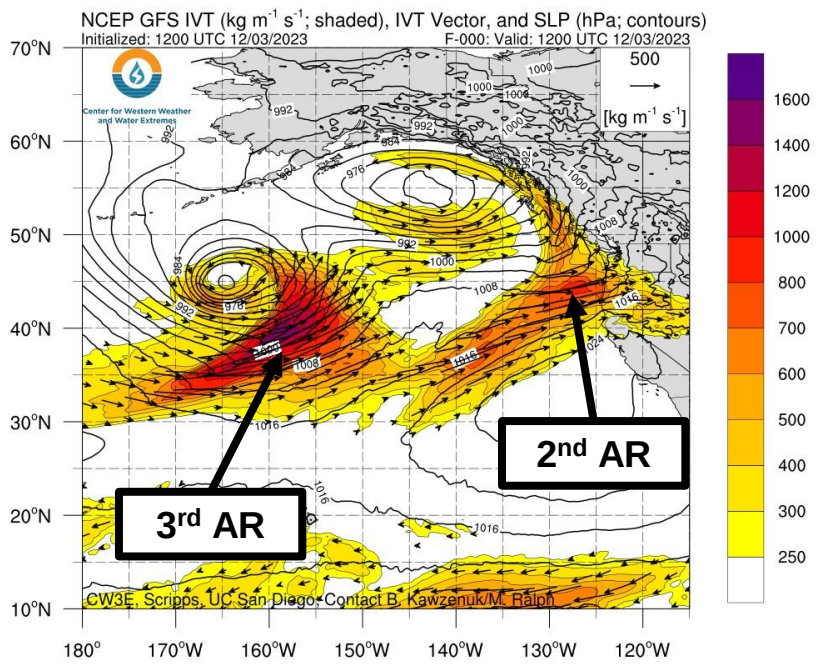
2nd AR

GFS Analyses of Second AR: Valid: 4 AM PT 3 December 2023

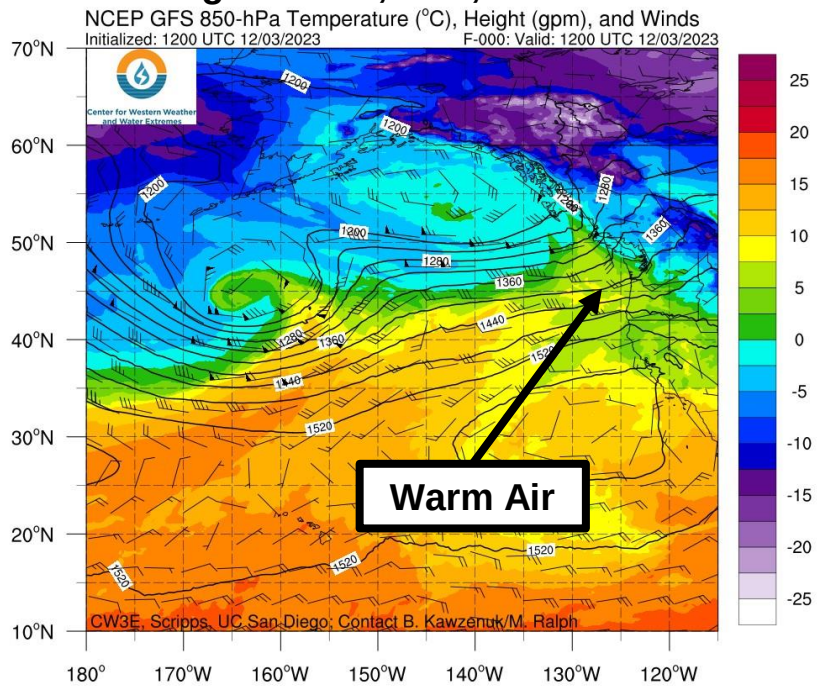
IWV and 850-hPa Wind



IVT and SLP



GFS Height of 0°C, SLP, and 10m Winds



- The robust TME positioned to the north of Hawaii shifted to the east, bringing substantial moisture to the Pacific Northwest, with IWV values > 40 mm. This moisture fueled the 2nd AR of the sequence, with IVT > 800 kg $m^{-1}s^{-1}$ in the core of the AR as it made landfall in association with a strong surface cyclone positioned in the Gulf of Alaska.
- A secondary TME with IWV > 34 mm was positioned in the central North Pacific at this time, providing moisture for the 3rd AR in this sequence south of Alaska with IVT > 1,400 $m^{-1}s^{-1}$ in with a strong surface cyclone offshore of the Aleutian Islands.
- A broad region of warm, moist air between 2–7°C at 850-hPa along the leading edge of the 2nd AR resulted in dramatic increases in freezing levels over the Pacific Northwest to ~8,000 feet, resulting in primarily rain during this AR.

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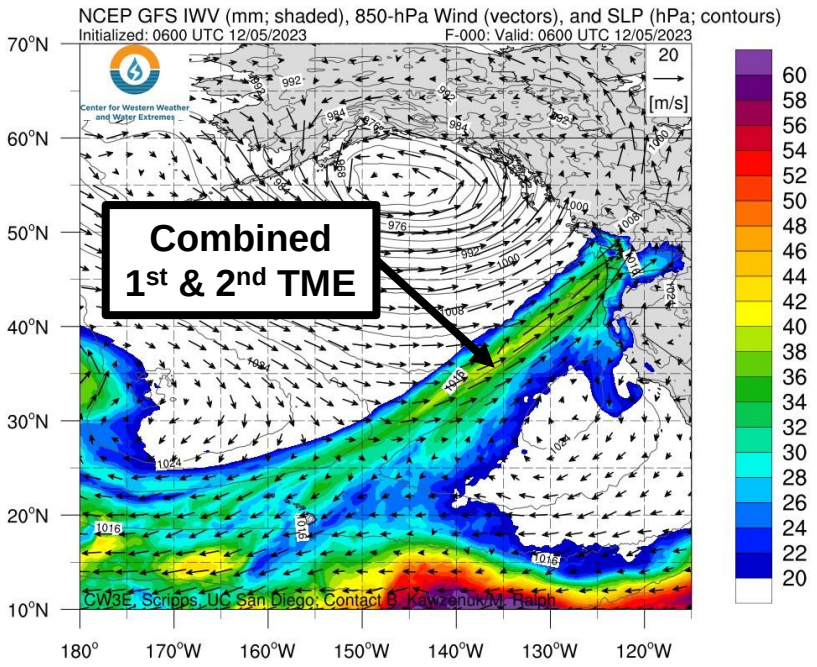
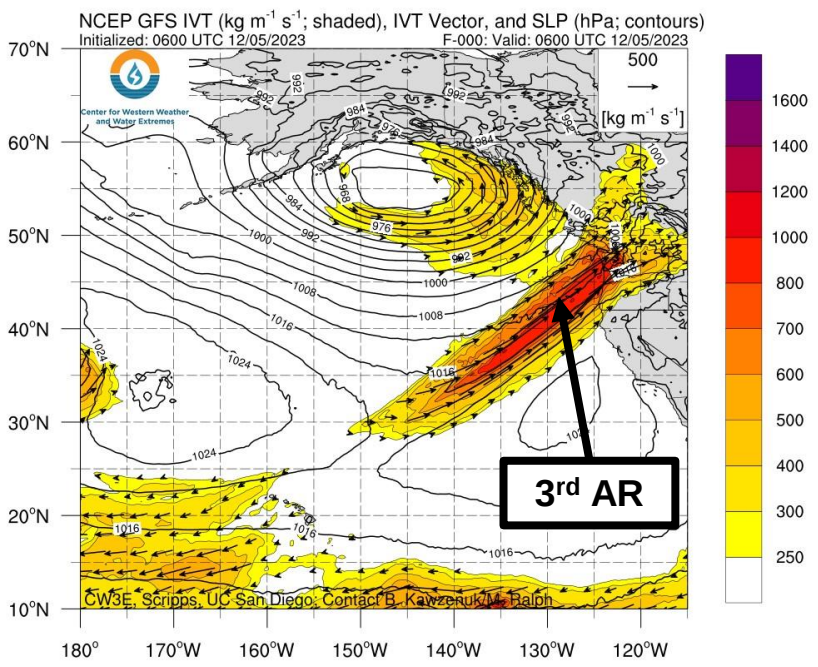
3rd AR

GFS Analyses of Third AR: Valid: 10 PM PT 4 December 2023

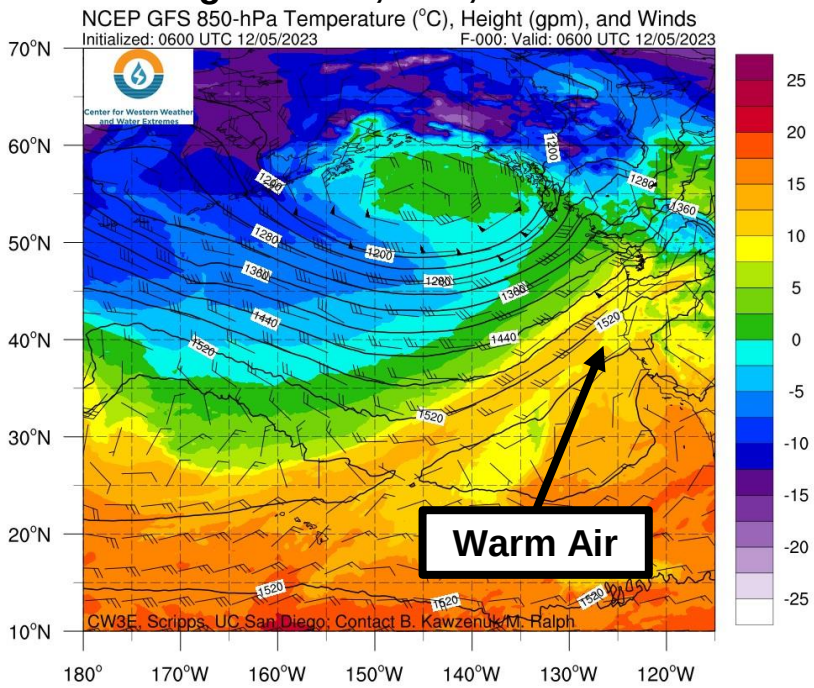
IWV and 850-hPa Wind



IVT and SLP



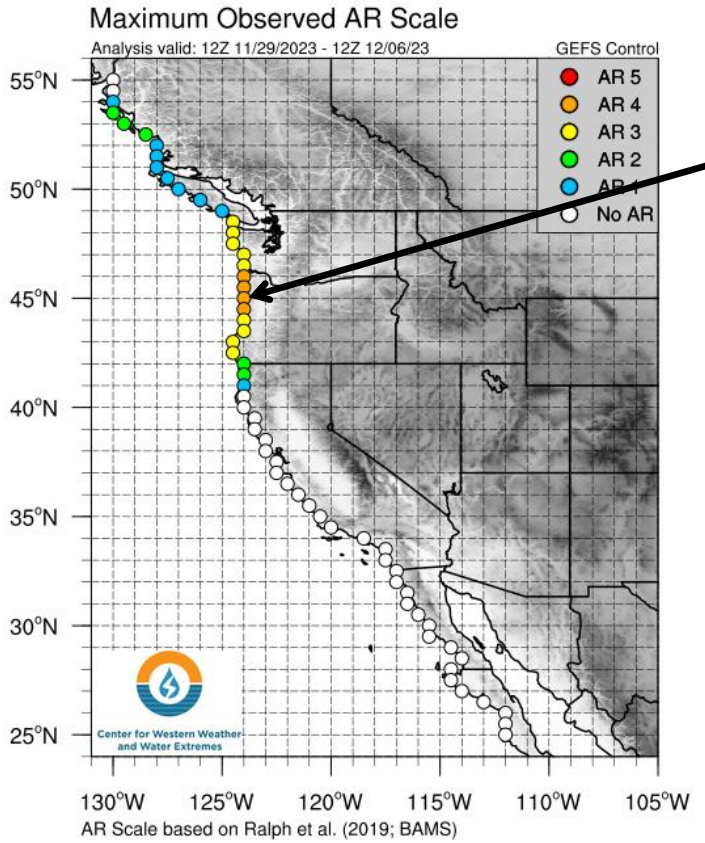
GFS Height of 0°C, SLP, and 10m Winds

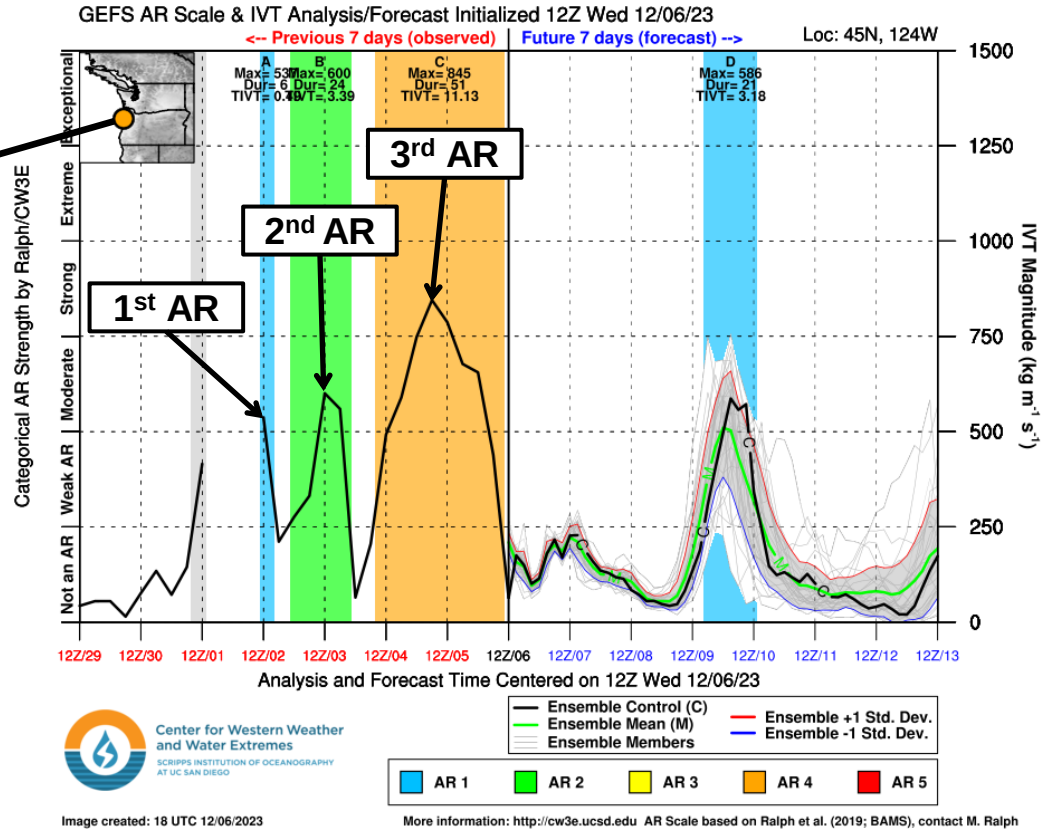


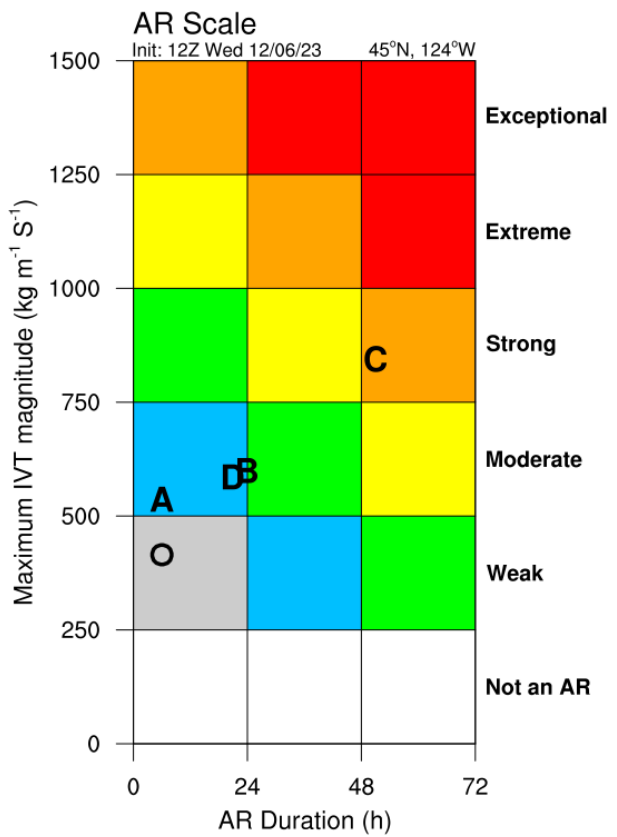
- The 2nd TME positioned in the central North Pacific shifted to the east and caught up with the 1st TME that was positioned closer to the US West Coast, resulting in a narrow corridor of IWV > 30 mm extending from Hawaii to the Pacific Northwest.
- The 3rd AR made landfall over the Pacific Northwest with IVT > 1,000 kg $m^{-1}s^{-1}$ in the core of the AR, in association with a robust surface cyclone positioned in the Gulf of Alaska.
- A broad region of warm moist air was also present along the leading edge of the 3rd AR, with 850-hPa temperatures between 5–10°C over the Pacific Northwest, limiting the potential for low freezing levels during the storm.

CW3E Event Summary: 30 November – 6 December 2023

GEFS AR Scale Analysis (Coast)



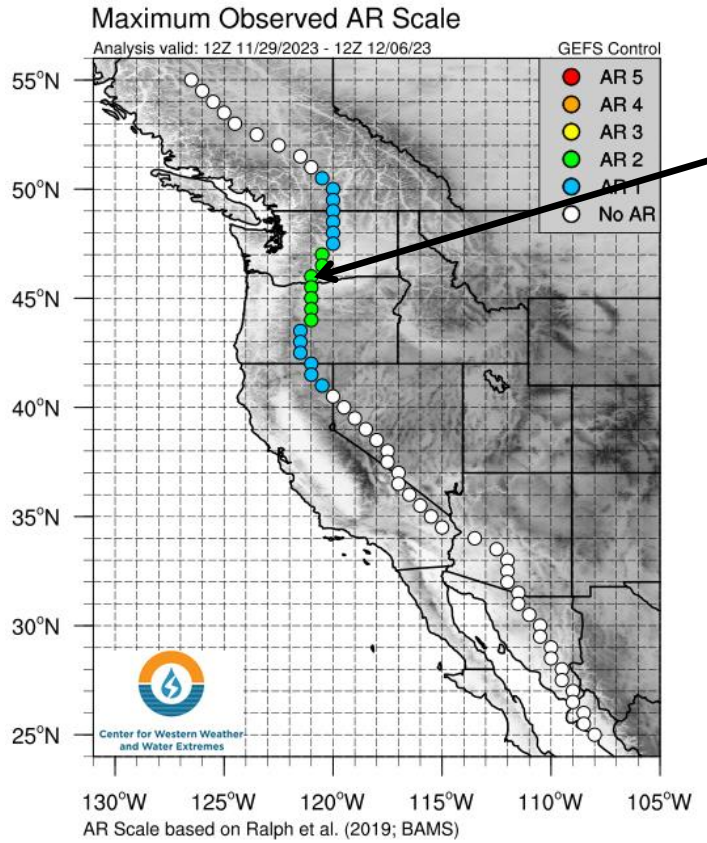


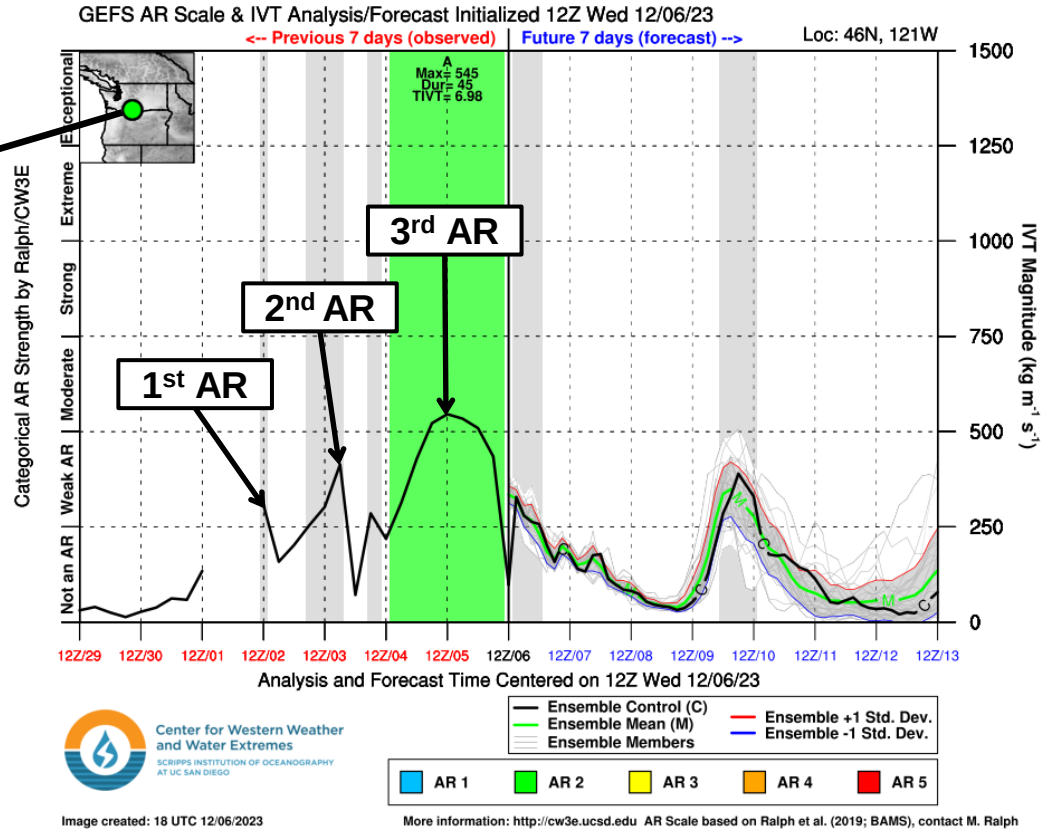


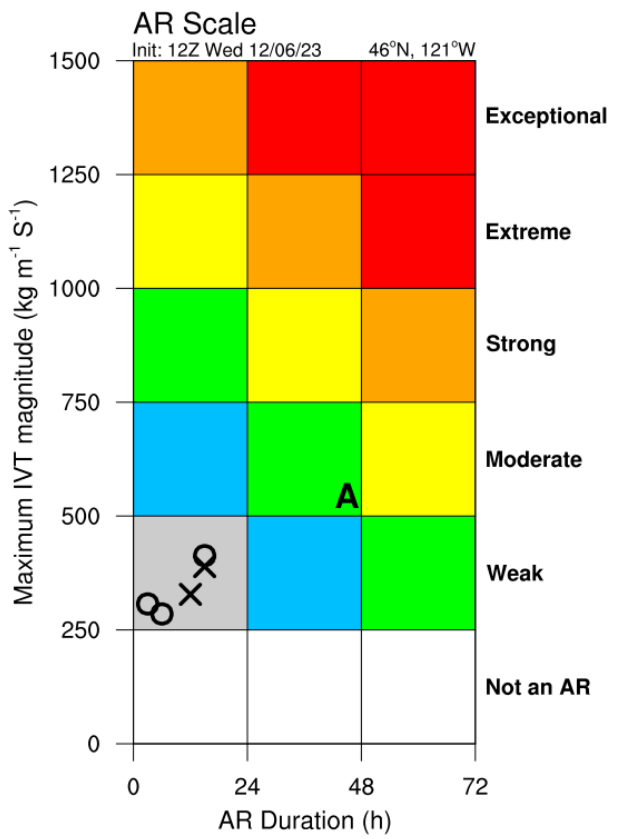
- GEFS AR Scale analysis shows three distinct periods of AR conditions associated with the three ARs over northern coastal OR.
- The first AR produced AR1 conditions over northern coastal OR with max IVT > 500 kg m^{-1} s^{-1}.
- The second AR produced AR2 conditions over much of coastal OR with max IVT > 600 kg m^{-1} s^{-1}.
- The third and strongest AR produced AR3/4 conditions over coastal OR and WA with max IVT > 900 kg m^{-1} s^{-1} and AR conditions lasting more than 48 consecutive hours in some locations.

CW3E Event Summary: 30 November – 6 December 2023

GEFS AR Scale Analysis (Inland)







- Inland penetration of the third AR resulted in AR2 conditions over portions of the interior Pacific Northwest.
- AR conditions persisted for nearly 48 consecutive hours east of the Cascades near the WA/OR border.

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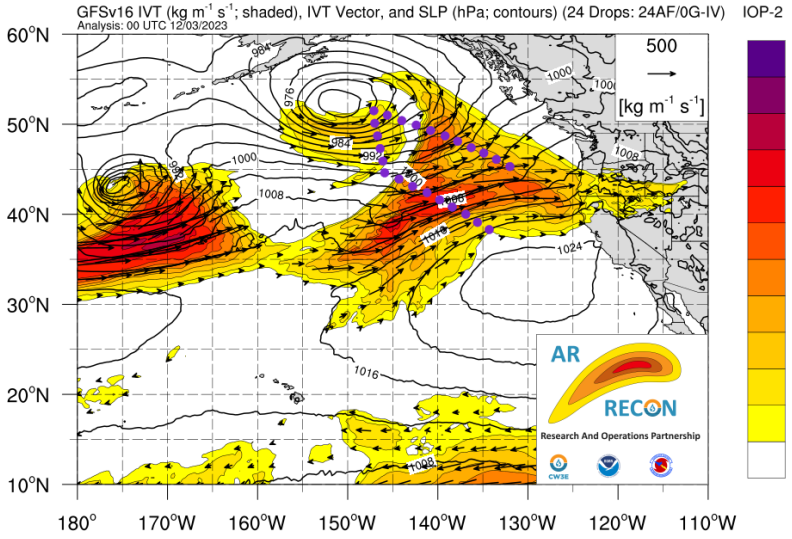
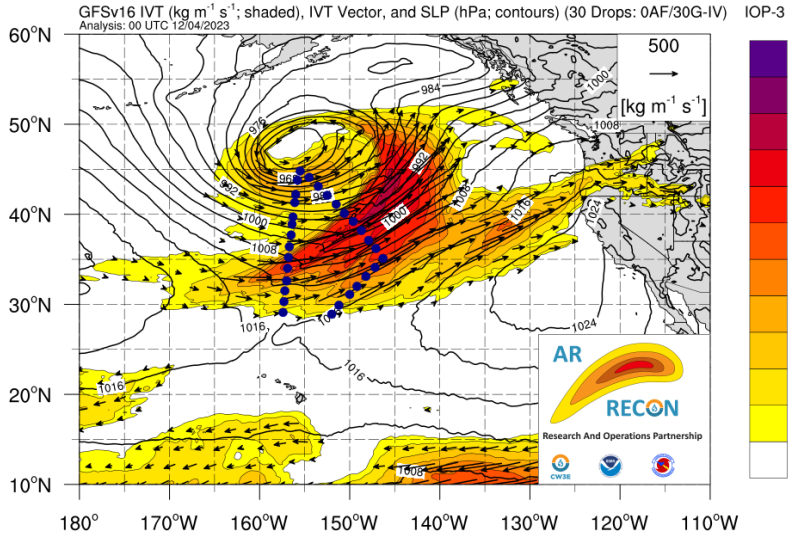
Atmospheric River Reconnaissance Flights

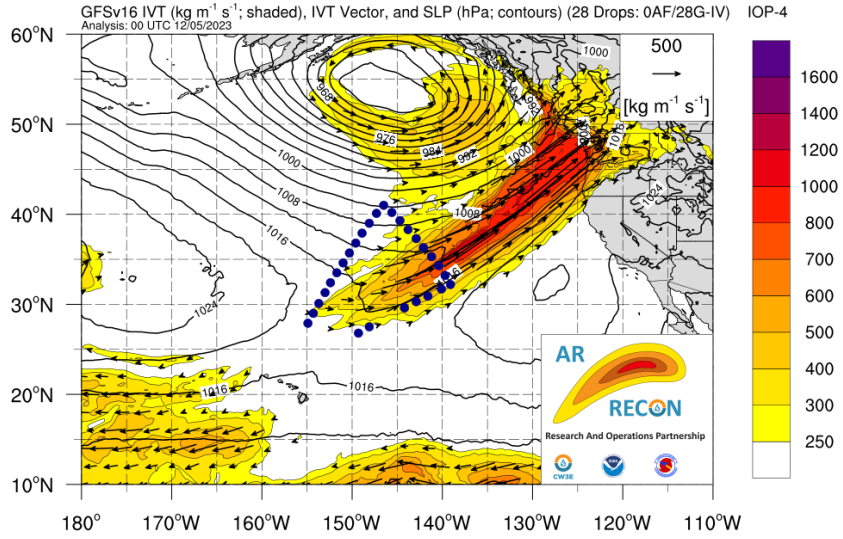
IOP-2 (00Z 3 Dec)



IOP-3 (00Z 4 Dec)



IOP-4 (00Z 5 Dec)



IOP = Intensive observation period

- During this storm sequence, NOAA and the 53rd Weather Reconnaissance Squadron provided observational support over the North Pacific as part of CW3E's AR Recon field campaign.
- 82 successful dropsondes were deployed across three missions, providing additional observations for global forecast models and collecting valuable data for future research.
- The Air Force C-130 targeted the second AR and nearby essential atmospheric features during IOP-2.
- The NOAA-GIV targeted the third AR and nearby essential atmospheric features during IOP-3 and IOP-4.

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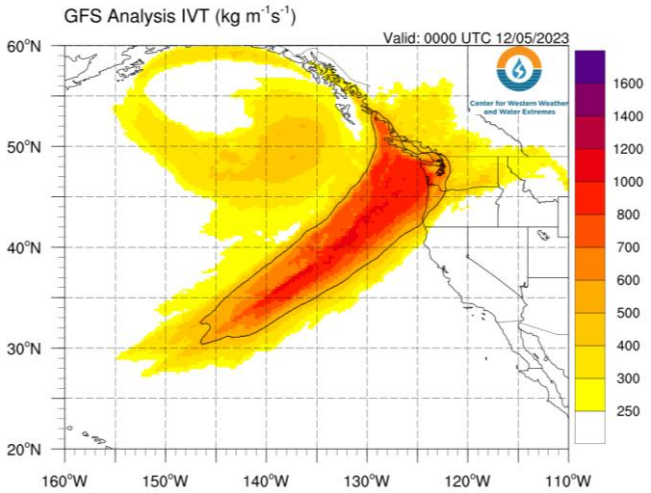
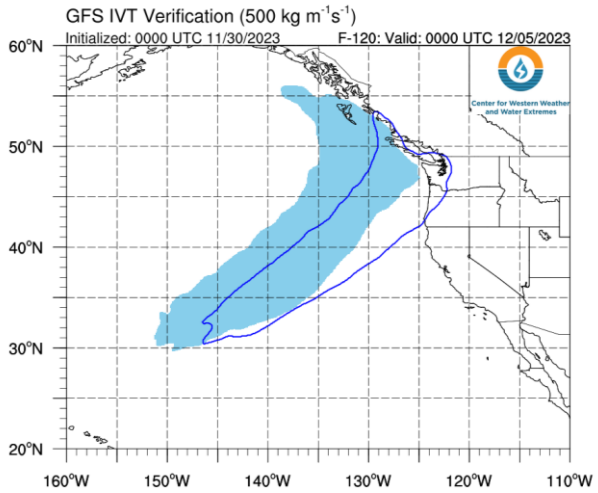
AR/IVT Forecast Verification of Third AR

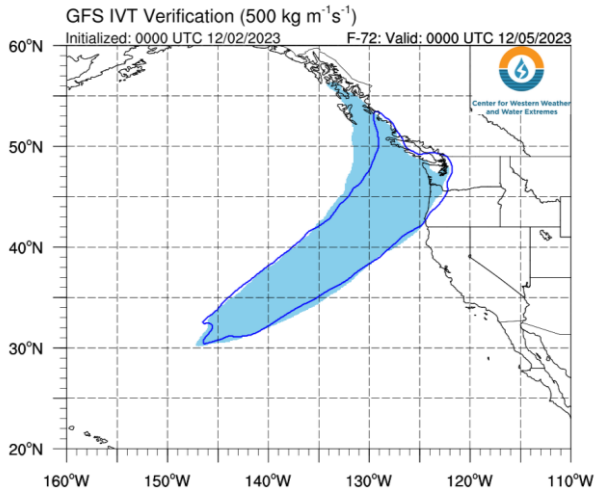
GFS Model Analysis:
Valid 4 PM PT 4 Dec

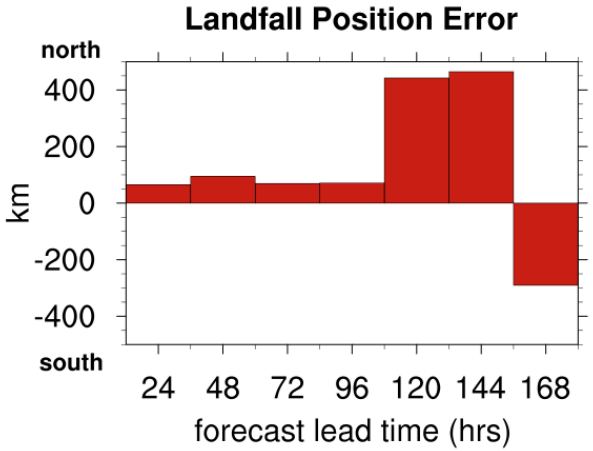


120-h GFS Forecast:
Initialized 4 PM PT 29 Nov



72-h GFS Forecast:
Initialized 4 PM PT 1 Dec





Forecast objects shaded (unmatched objects in gray)
Observed objects contoured (unmatched objects in black)
Objects defined based on IVT > 500 kg m^{-1} s^{-1}

- Using a 500 kg m^{-1} s^{-1} IVT threshold, the Method for Object-Based Diagnostic Evaluation (MODE) shows that the forecast location of the third AR was too far north and west in the GFS model at a 5-day lead time.
- The forecast orientation of the AR at landfall was also more southerly than in the GFS analysis.
- GFS forecasts of the third AR were much more accurate at shorter lead times, but the 3-day forecast still showed the AR making landfall too far northwest with a more southerly orientation compared to the GFS analysis.
- AR landfall position errors decreased from > 400 km to < 100 km between the 5-day and 4-day forecasts.

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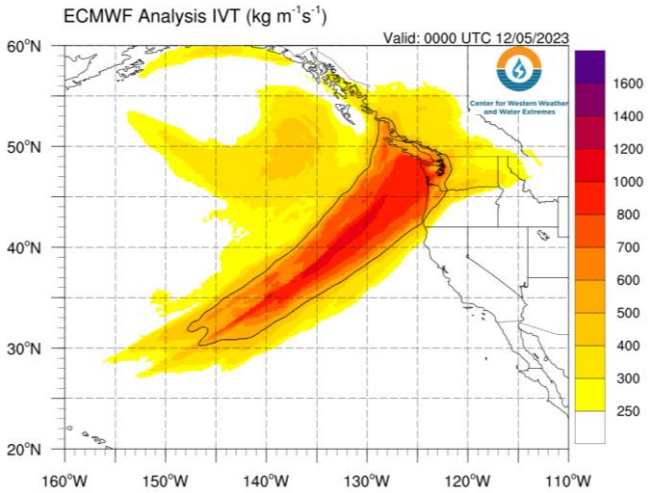
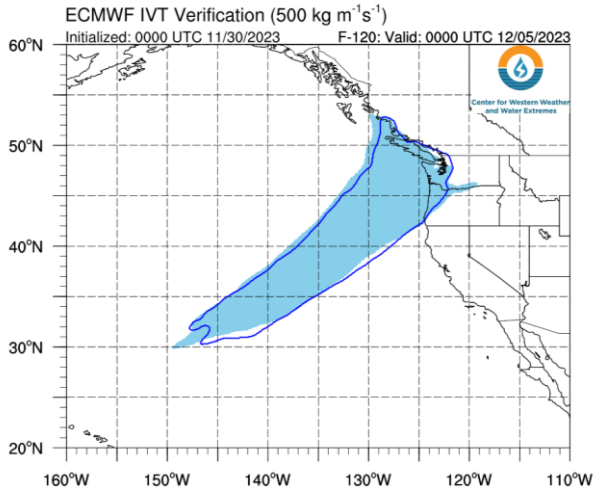
AR/IVT Forecast Verification of Third AR

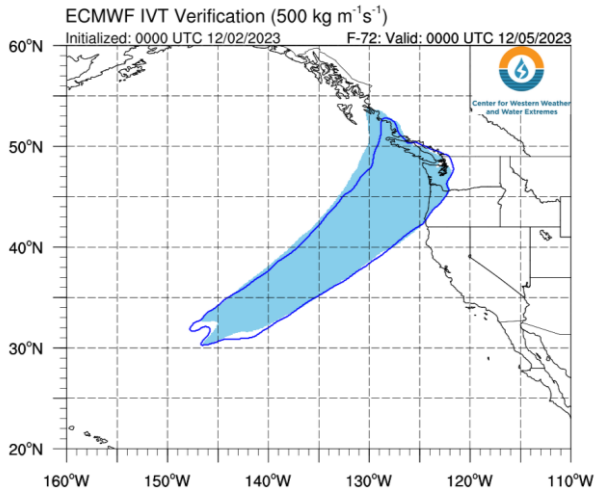
ECMWF Model Analysis:
Valid 4 PM PT 4 Dec

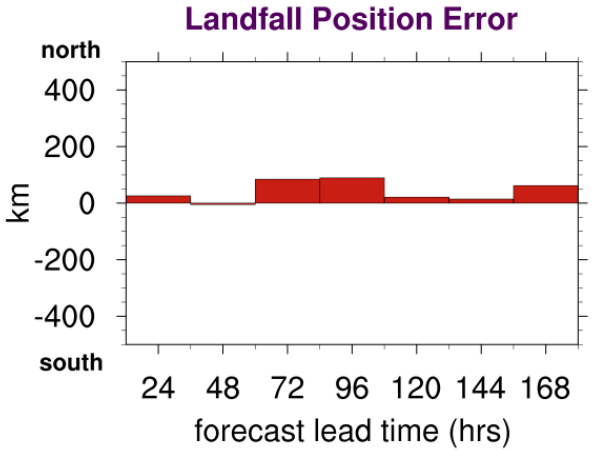


120-h ECMWF Forecast:
Initialized 4 PM PT 29 Nov



72-h ECMWF Forecast:
Initialized 4 PM PT 1 Dec





Forecast objects shaded (unmatched objects in gray)
Observed objects contoured (unmatched objects in black)
Objects defined based on IVT > 500 kg m^{-1} s^{-1}

- Using a 500 kg m^{-1} s^{-1} IVT threshold, the Method for Object-Based Diagnostic Evaluation (MODE) shows that the forecast location and orientation of the third AR was well forecast by the ECMWF model at both 3-day and 5-day lead times.
- The orientation of the AR at landfall in the 3-day forecast was slightly more southerly than in the ECMWF analysis.
- AR landfall position errors were consistently < 100 km between at lead times ≤ 7 days.
- Interestingly, the landfall position error was smaller in the 5-day forecast compared to the 3-day forecast.

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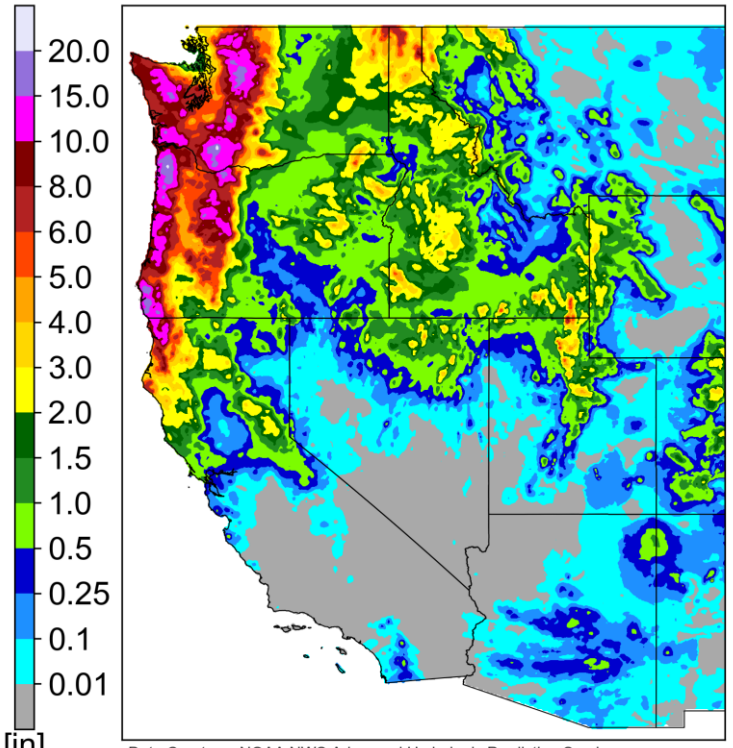
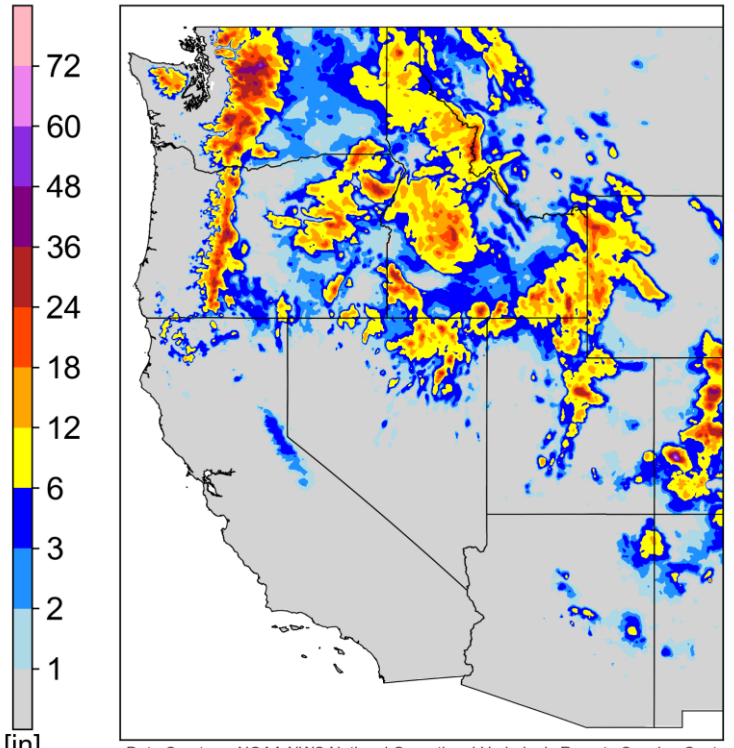
Observed Precipitation

NWS Stage IV 7-day QPE
Valid: 4 AM PT 7 Dec 2023



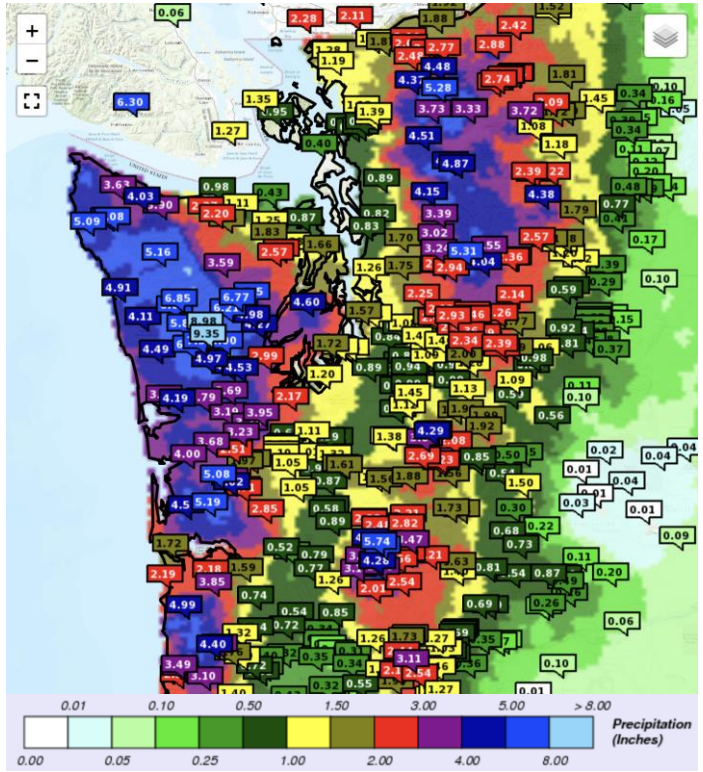
Data Courtesy: NOAA NWS Advanced Hydrologic Prediction Service, https://water.weather.gov

NWS 72-h Snowfall Anaysis
Valid: 4 AM PT 3 Dec 2023



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

24-h QPE: Valid 4 AM PT 5 Dec



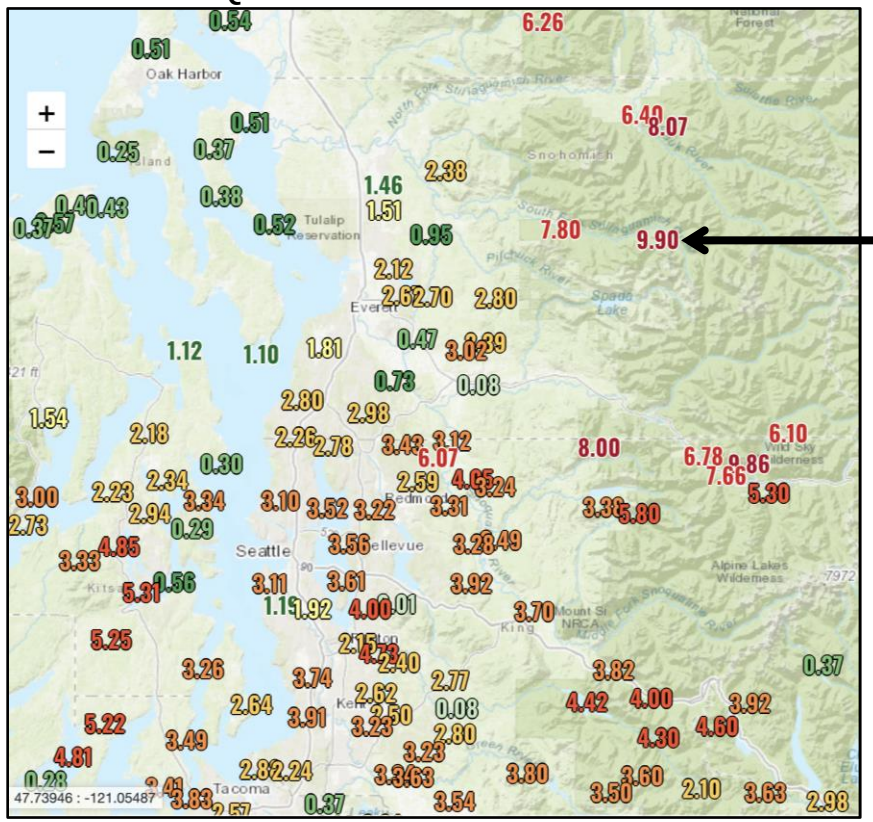
Source: NOAA NWS NWRFC

- These storms produced a combined 10–20 inches of precipitation in the Olympic Mountains, Cascades, and OR Coast Ranges, and 4–8 inches precipitation in the lowlands of western Washington and Oregon.
- An estimated 1–3 feet of snow fell in the higher terrain in the Cascades during the cold storms between 30 Nov and 2 Dec.
- The heaviest precipitation occurred during the third AR landfall, with numerous locations in the Olympic Peninsula reporting > 5 inches in a 24-hour period ending the morning of 5 Dec.
- Inland penetration of the third AR also facilitated heavy precipitation in northeastern Washington and northern Idaho.

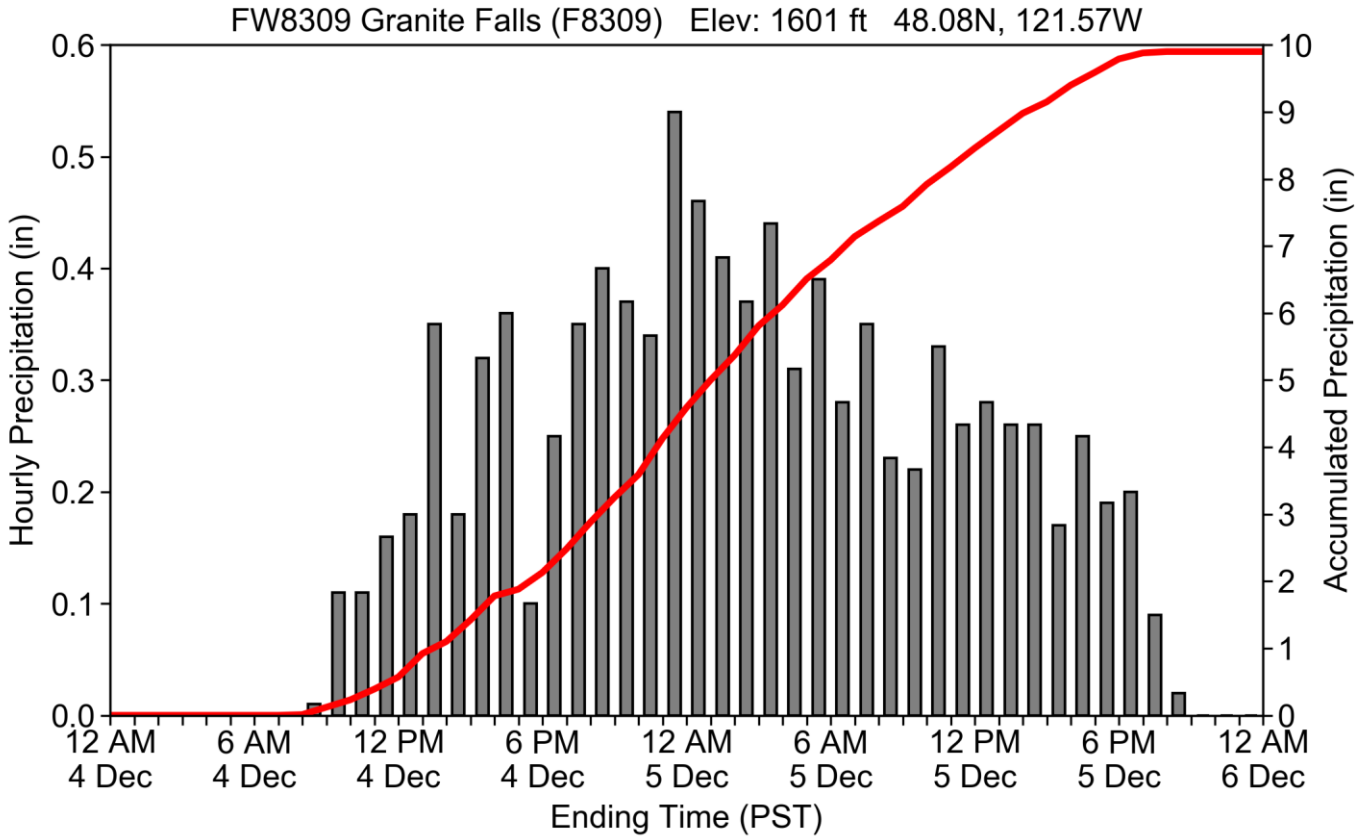
CW3E Event Summary: 30 November – 6 December 2023

Observed Precipitation

48-h QPE: Valid 12 AM PT 6 Dec



Source: NOAA/NWS Western Region Headquarters

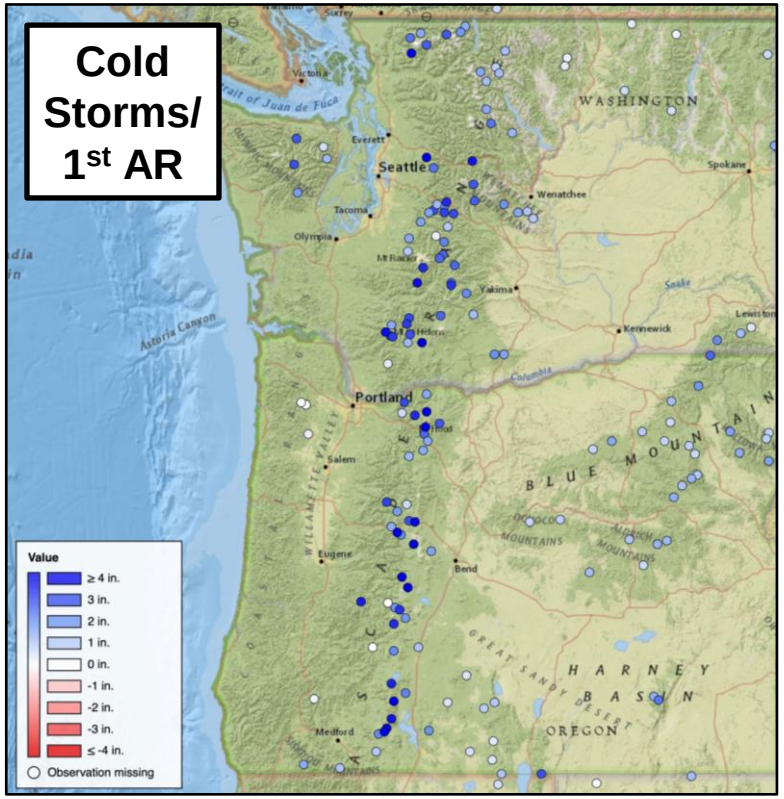


- The third AR produced heavy rain in the Seattle metro area and in the foothills of the Cascades in King and Snohomish Counties.
- A Citizen Weather Observer Program (CWOP) station located east of Granite Falls, WA, recorded precipitation rates > 0.25 inches/hour for 21 consecutive hours and 9.9 inches of total precipitation on 4–5 Dec.
- Some of the most severe flooding occurred on the Stillaguamish River downstream of this location.

CW3E Event Summary: 30 November – 6 December 2023

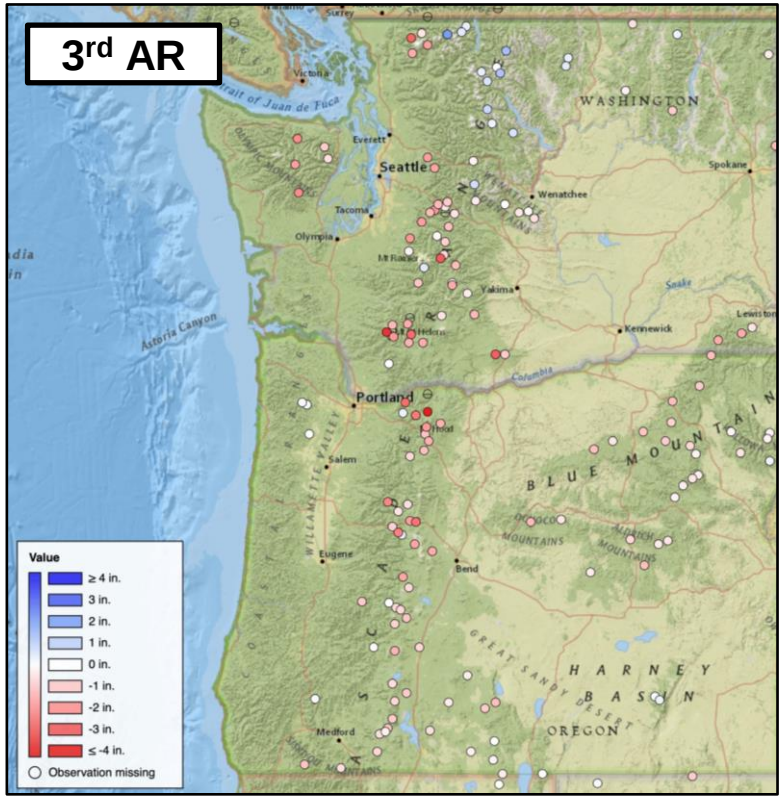
Changes in Snowpack: Snow Water Equivalent (SWE)

3-day SWE Change: 30 Nov – 3 Dec



1-day SWE Change: 3–4 Dec

2-day SWE Change: 4–6 Dec



Source: USDA NRCS National Water and Climate Center

- SNOTEL stations in the Cascades recorded SWE increases of 2–5 inches during the cold storms between 30 Nov and 2 Dec.
- Warmer temperatures and rain-on-snow during the second AR led to moderate losses in snowpack in the Oregon Cascades.
- Very high freezing levels and heavy rain during the third AR resulted in substantial losses in snowpack throughout the Cascades.
- Melting snowpack contributed to flooding on the western side of the Cascades, particularly during the third AR.

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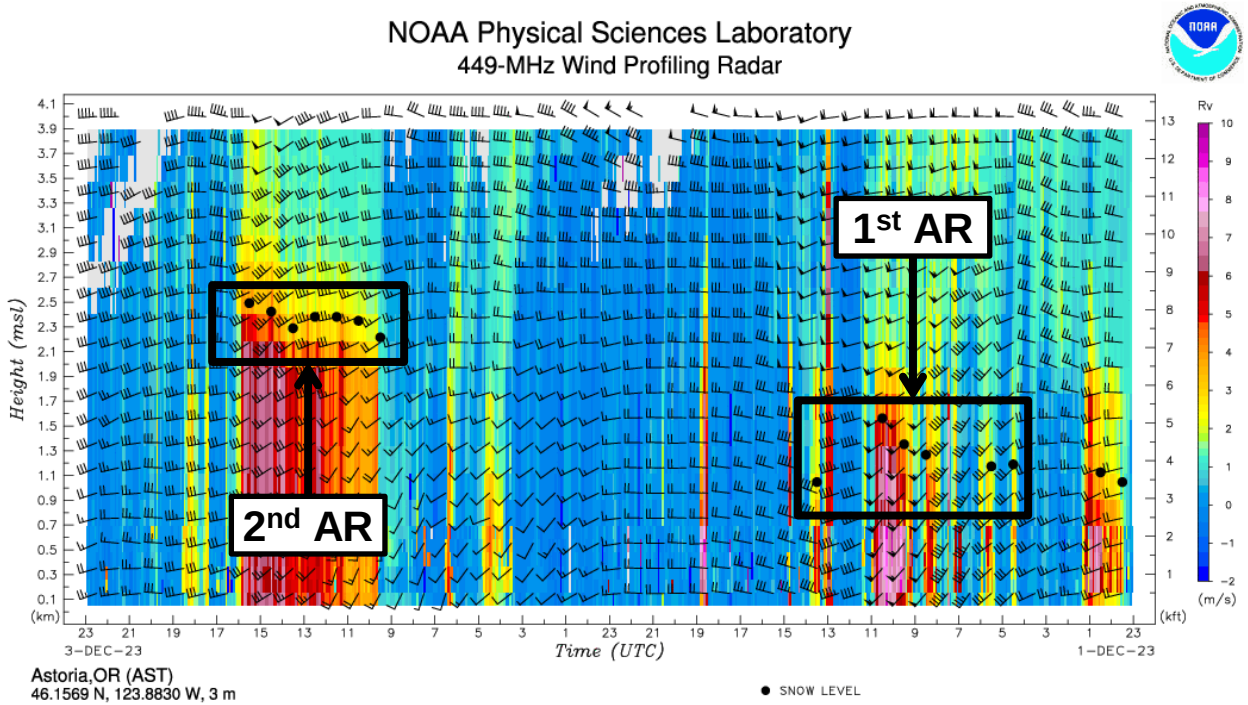
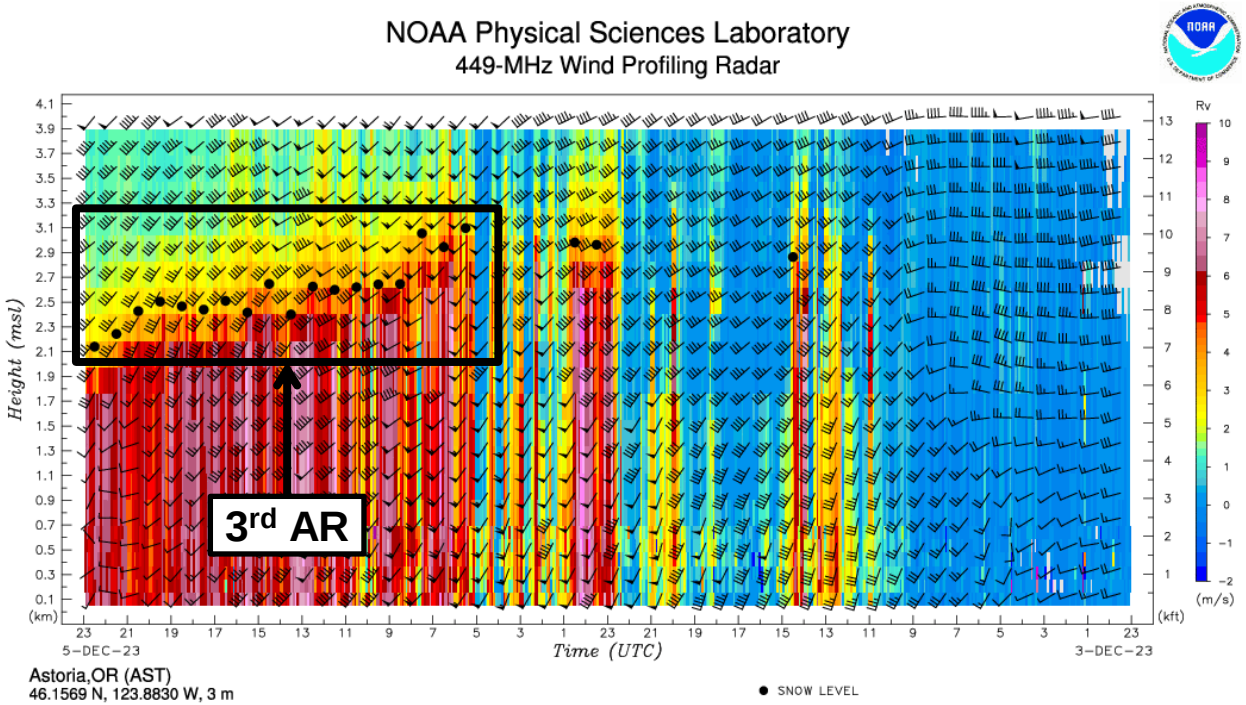
Wind Profiler Snow Level: Astoria, OR





Astoria,OR (AST)
46.1569 N, 123.8830 W, 3 m

● SNOW LEVEL

Time (UTC)	2230	2130	2030	1930	1830	1730	1630	1530	1430	1330	1230	1130	1030	0930	0830	0730	0630	0530	0430	0330	0230	0130	0030	2330
Snow Level (m)	none	none	none	none	none	none	none	2492	2423	2289	2381	2381	2349	2215	none	none	none	none	none	none	none	none	none	none
Snow Level (ft)	none	none	none	none	none	none	none	8173	7947	7507	7809	7809	7704	7265	none	none	none	none	none	none	none	none	none	none
Sfc Temp (C)	12.20	12.38	12.49	12.34	12.39	12.35	11.40	8.61	8.27	8.35	8.12	7.87	7.66	7.47	7.27	7.30	7.22	6.94	7.09	7.03	7.37	7.99	9.21	9.70

Time (UTC)	2230	2130	2030	1930	1830	1730	1630	1530	1430	1330	1230	1130	1030	0930	0830	0730	0630	0530	0430	0330	0230	0130	0030	2330
Snow Level (m)	none	none	none	none	none	none	none	none	none	1047	none	none	1562	1352	1267	none	none	1174	1190	none	none	none	1125	1047
Snow Level (ft)	none	none	none	none	none	none	none	none	none	3434	none	none	5123	4434	4155	none	none	3850	3903	none	none	none	3690	3434
Sfc Temp (C)	10.24	10.45	10.18	9.04	9.24	9.81	9.57	9.25	9.10	8.64	10.56	10.22	10.66	11.11	11.10	10.91	10.78	10.78	10.77	10.46	9.62	8.66	9.29	10.21

Astoria,OR (AST)
46.1569 N, 123.8830 W, 3 m

● SNOW LEVEL

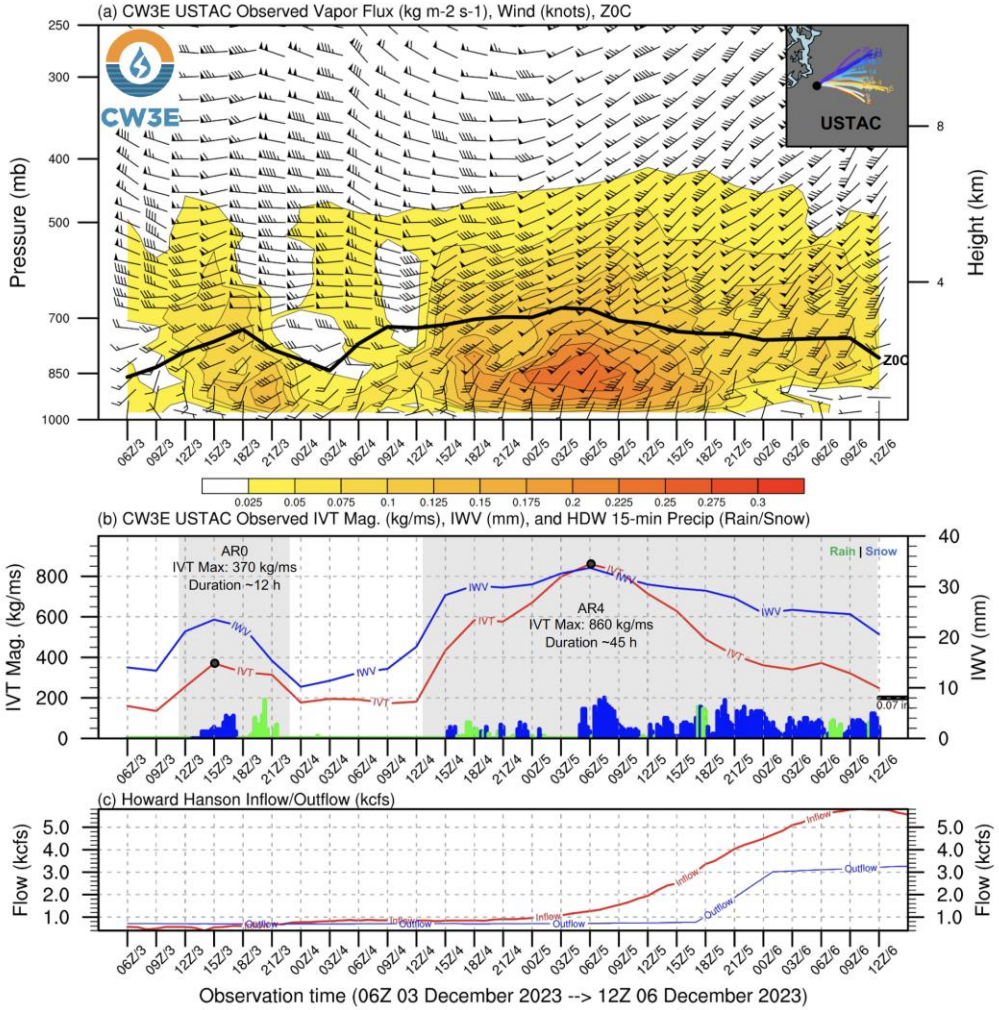
Time (UTC)	2230	2130	2030	1930	1830	1730	1630	1530	1430	1330	1230	1130	1030	0930	0830	0730	0630	0530	0430	0330	0230	0130	0030	2330
Snow Level (m)	2140	2243	2427	2504	2466	2439	2510	2416	2647	2401	2625	2599	2620	2643	2646	3055	2944	3098	none	none	none	none	2981	2963
Snow Level (ft)	7019	7357	7960	8213	8088	7999	8232	7924	8682	7875	8610	8524	8593	8669	8678	10020	9656	10161	none	none	none	none	9777	9718
Sfc Temp (C)	9.74	10.63	11.05	10.99	10.84	10.87	10.94	12.27	13.43	13.79	13.97	14.12	14.31	14.62	14.53	14.75	14.46	14.49	14.43	14.63	14.85	14.53	14.50	14.58

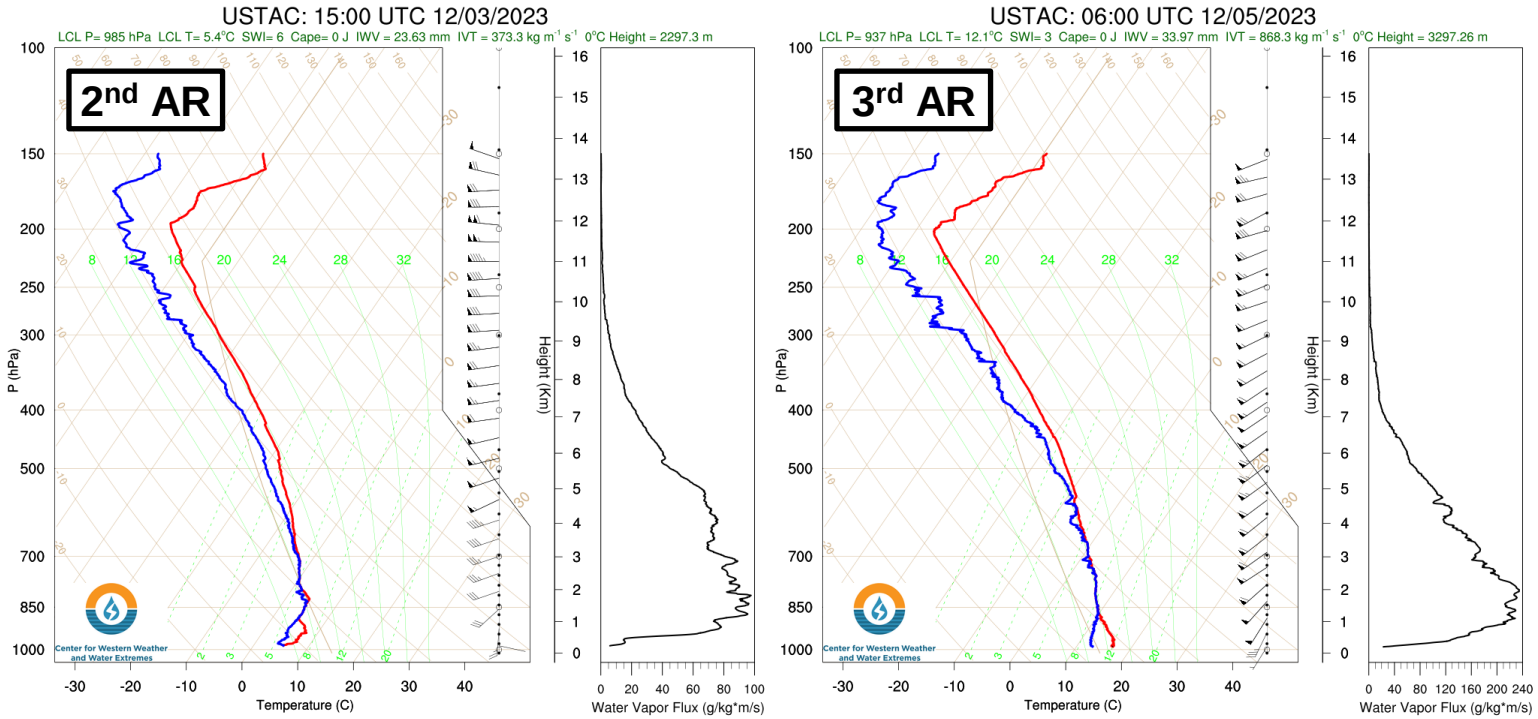
Time (UTC)	2230	2130	2030	1930	1830	1730	1630	1530	1430	1330	1230	1130	1030	0930	0830	0730	0630	0530	0430	0330	0230	0130	0030	2330
Snow Level (m)	none	none	none	none	none	none	none	none	2864	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none
Snow Level (ft)	none	none	none	none	none	none	none	none	9393	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none
Sfc Temp (C)	14.50	13.97	14.10	14.40	14.12	13.77	13.49	13.27	13.21	11.26	9.56	9.28	8.95	8.51	8.25	6.71	7.43	8.85	8.64	8.42	8.86	9.96	10.91	11.52

- The wind profiler at Astoria, OR, measured snow levels between 3,400 and 5,200 feet during the first AR.
- Snow levels rose after the first AR and remained above 7,000 feet during the second AR.
- Snow levels continued to rise after the second AR, reaching ~10,000 feet at the start of the third AR.
- As time progressed, snow levels began to drop again, but remained above 7,000 feet during much of the third AR.

CW3E Event Summary: 30 November – 6 December 2023

CW3E Observations in the Duwamish Watershed

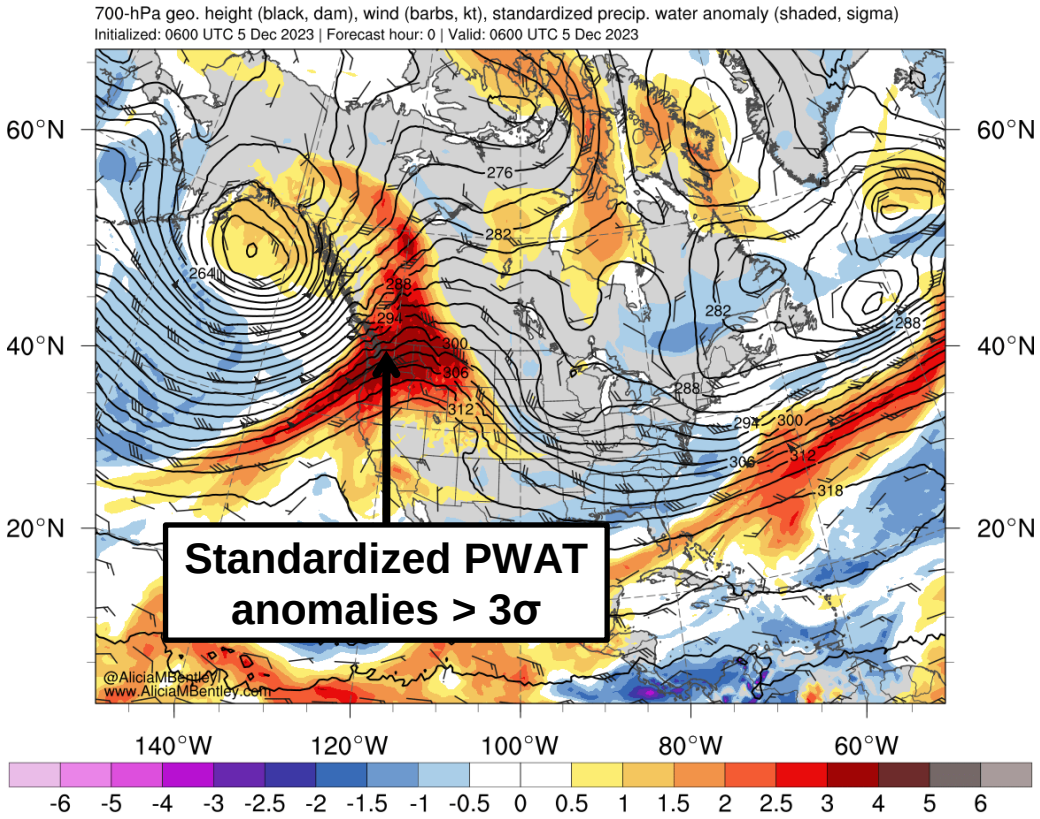




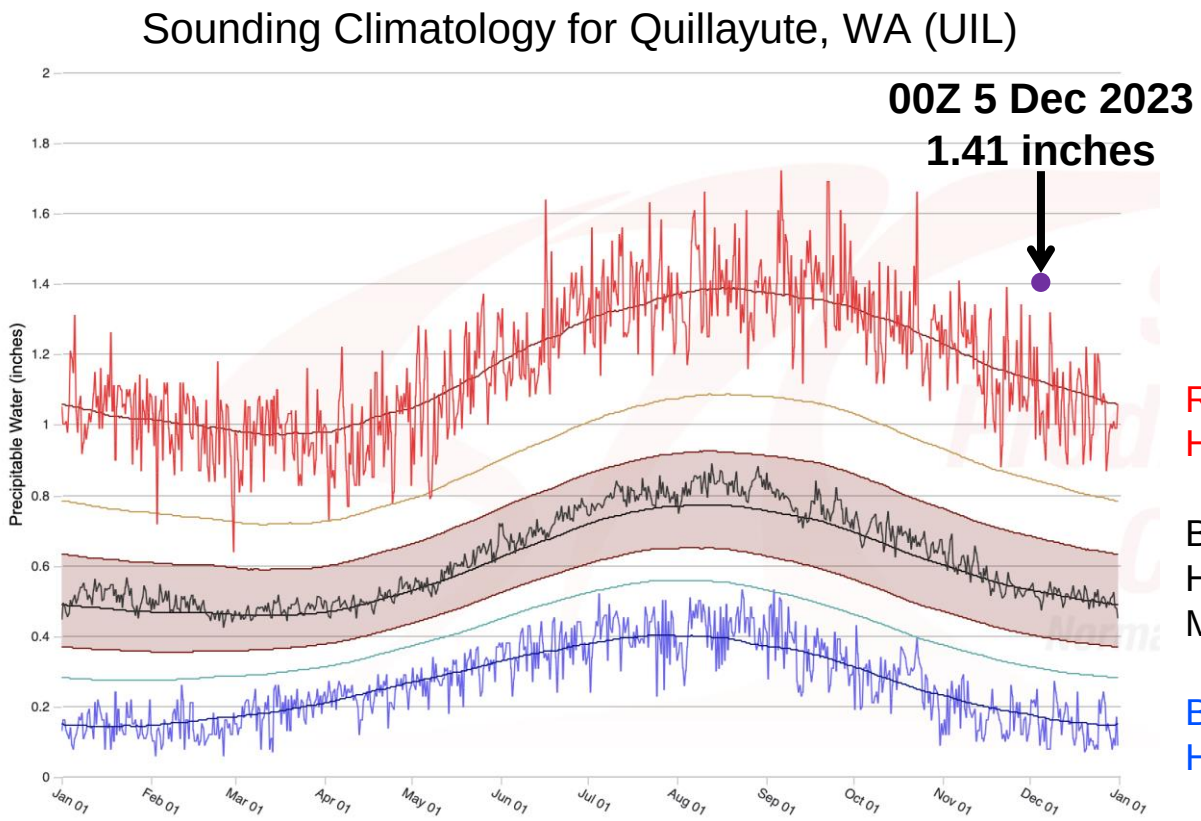
- The CW3E Field Team launched radiosondes at Tacoma, WA (USTAC) for 78 consecutive hours during the second and third ARs.
- A max IVT of 373.3 kg m^{-1} s^{-1} and ~12 hours of AR conditions were observed during the second AR.
- A max IVT of 868.3 kg m^{-1} s^{-1} and ~45 hours of AR conditions (i.e., an AR3 on the AR Scale) were observed during the third AR.
- Heavy rain during the third AR led to large increases in both inflow (up to ~6,000 cfs) and water releases (up to ~3,000 cfs) at Howard Hanson Dam.

CW3E Event Summary: 30 November – 6 December 2023

Precipitable Water Analysis



Source: Alicia Bentley's Real-Time GFS Maps



Red Line: Historical Max

Black Line: Historical Median

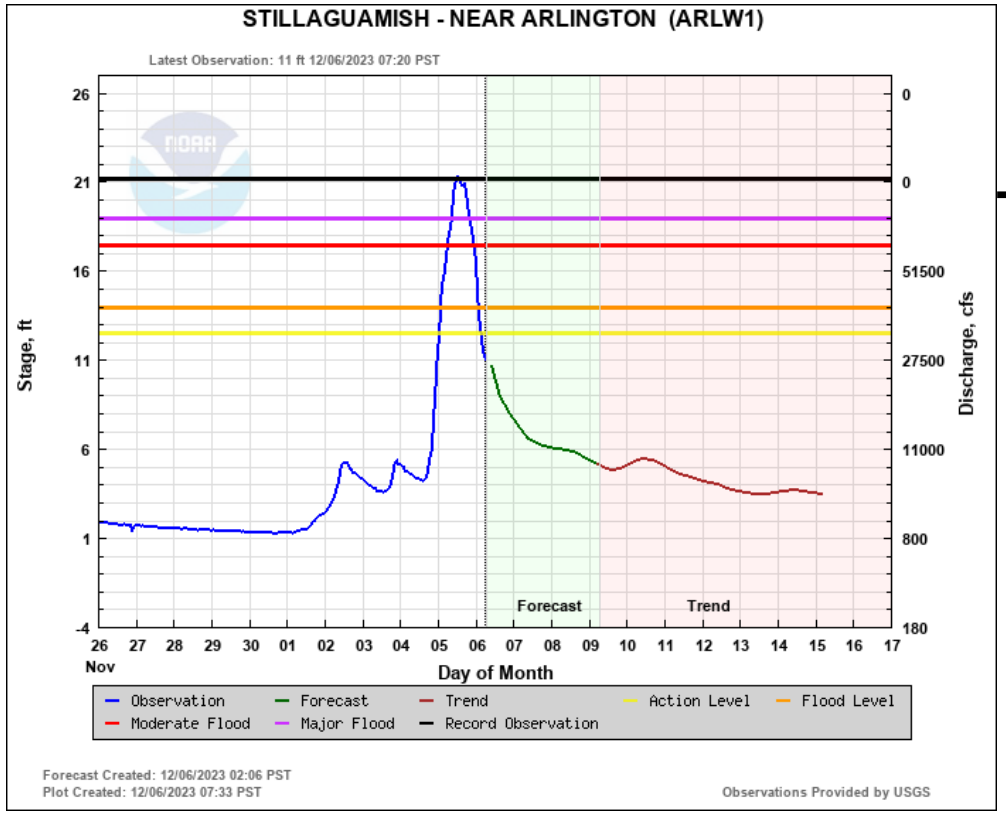
Blue Line: Historical Min

Source: NOAA/NWS Storm Prediction Center

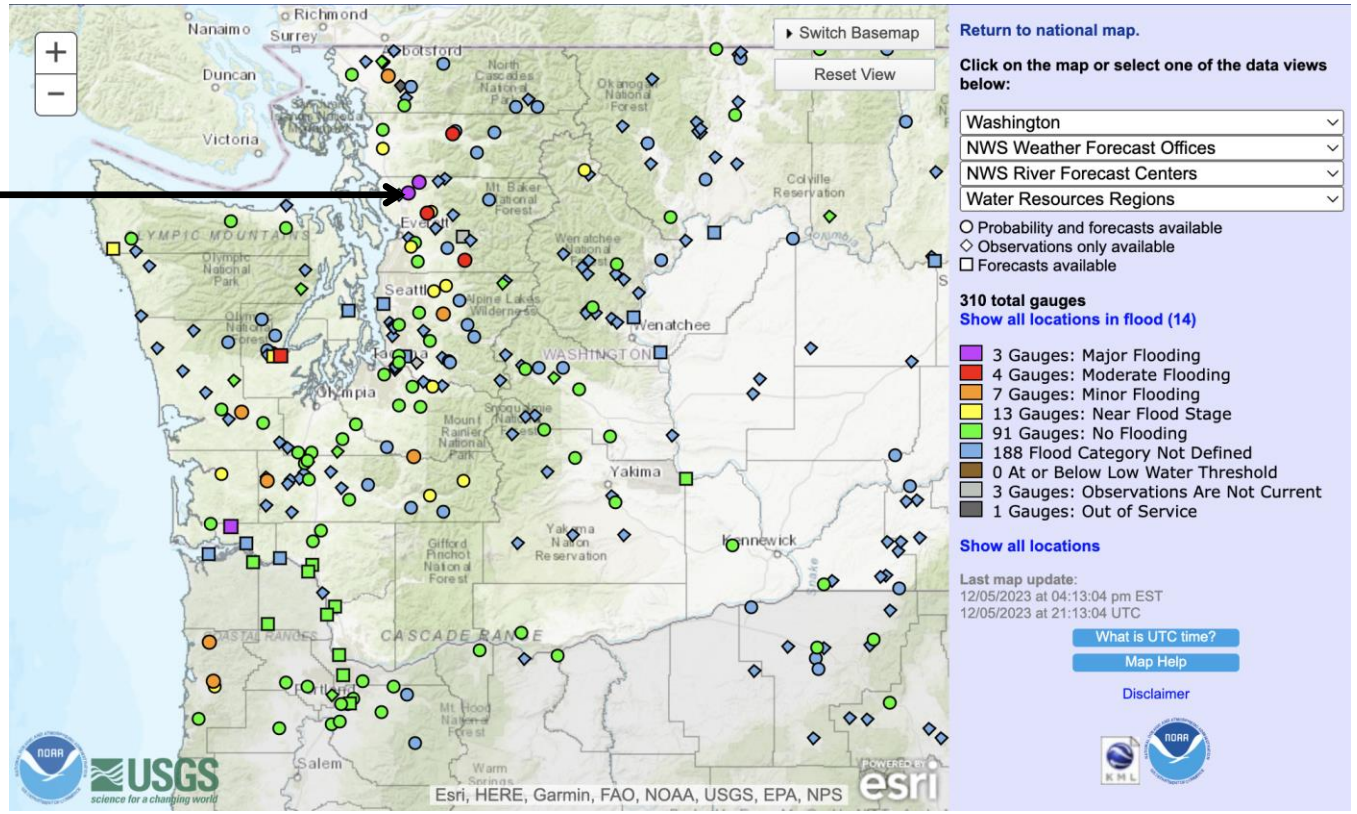
- GFS analyses show precipitable water values > 3 standard deviations above climatology over much of the Pacific Northwest during the third AR.
- Quillayute, WA (UIL) recorded its highest ever Dec precipitable water (1.41") during the 00Z 5 Dec sounding.
- Spokane, WA (OTX) recorded its 2nd highest Dec precipitable water (0.96") during the 12Z 5 Dec sounding.

CW3E Event Summary: 30 November – 6 December 2023

Hydrologic Impacts



Source: NOAA/NWS Northwest River Forecast Center

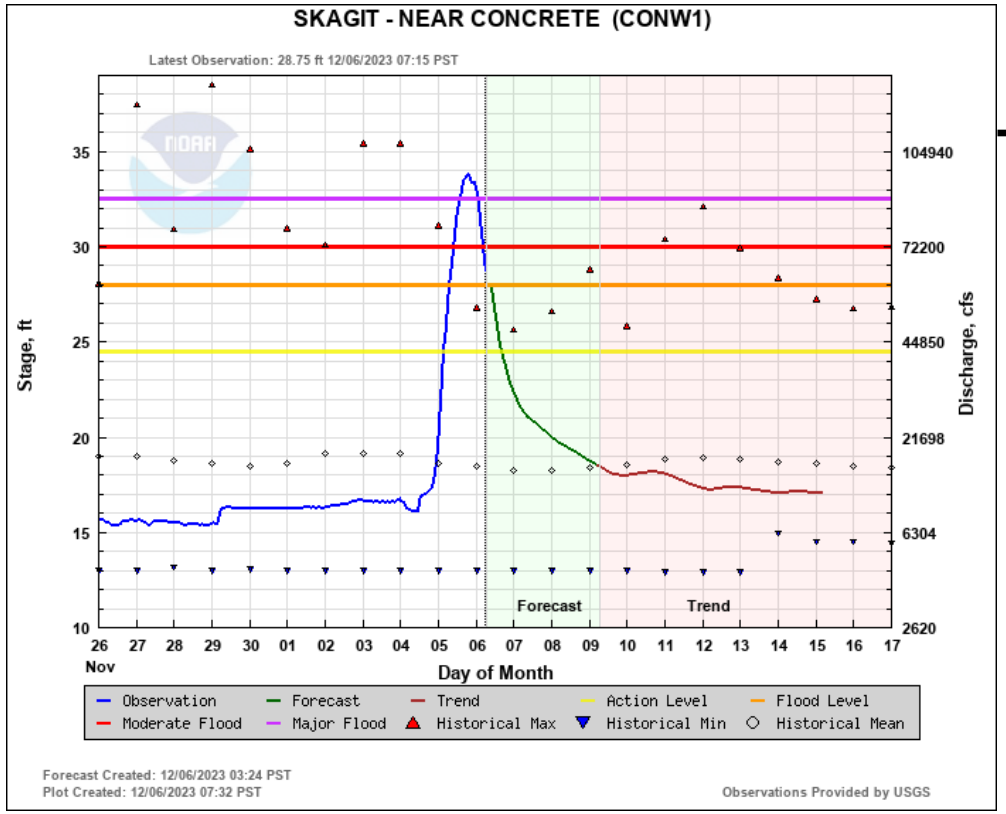


Source: NOAA/NWS Advanced Hydrologic Prediction Service

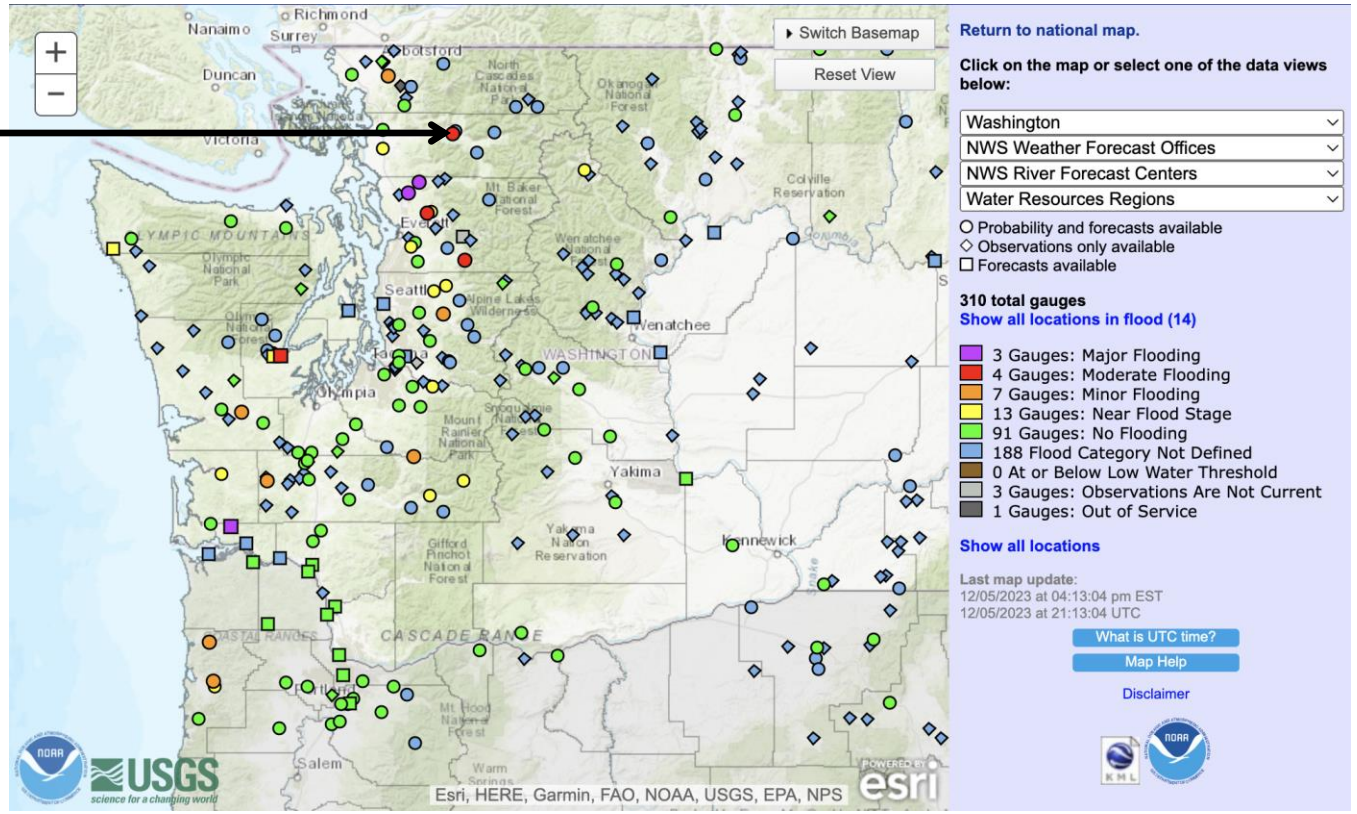
- Heavy rain falling on moist soils and fresh snowpack during the third AR caused widespread riverine flooding in western Washington and northwestern Oregon.
- The Stillaguamish River at Arlington, WA, rose about 17 feet in 24 hours, reaching major flood stage (19.0 feet) on 5 Dec.
- Preliminary data suggests that this stream gage set a new record for peak stage (21.34 feet).

CW3E Event Summary: 30 November – 6 December 2023

Hydrologic Impacts



Source: NOAA/NWS Northwest River Forecast Center

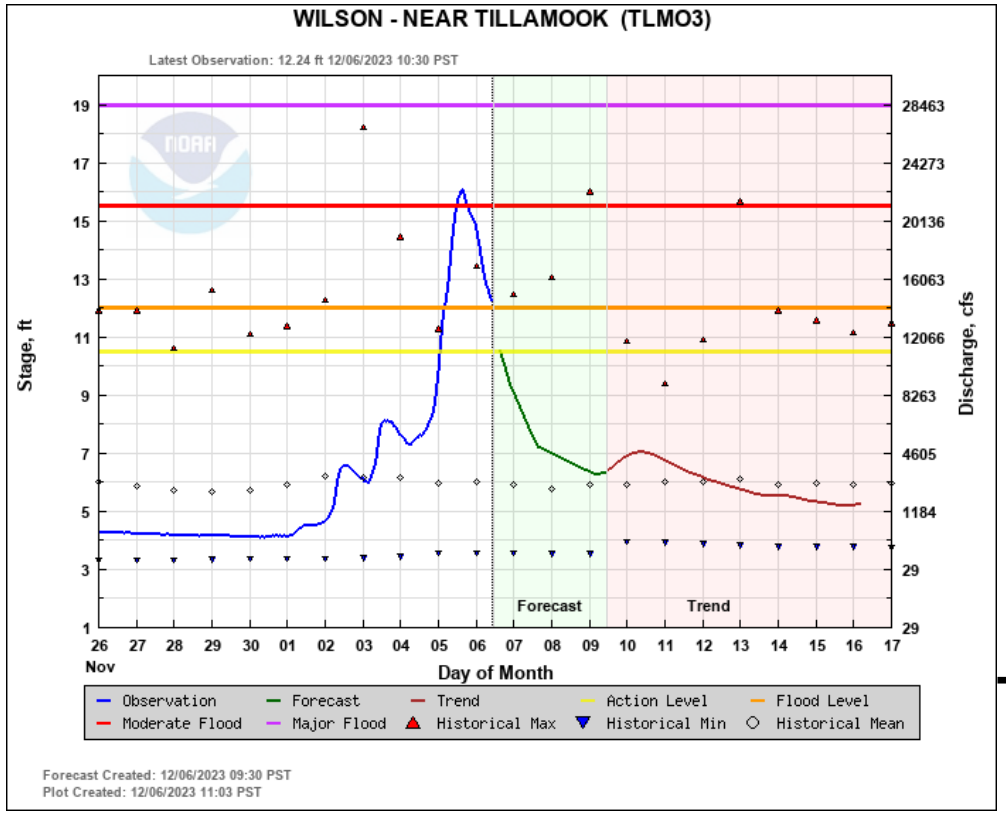


Source: NOAA/NWS Advanced Hydrologic Prediction Service

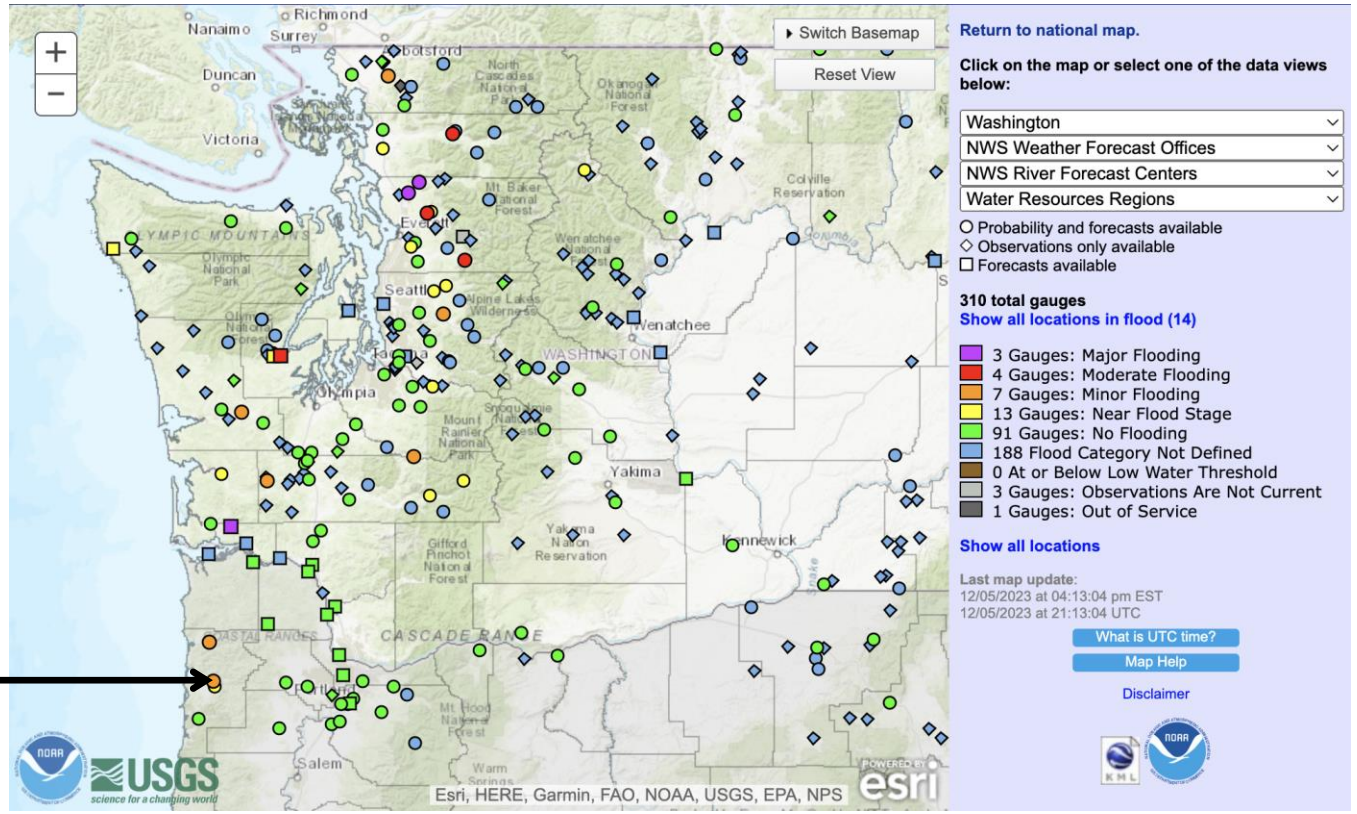
- The Skagit River near Concrete also exceeded major flood stage (32.5 feet).
- The river rose more than 16 feet in 24 hours, reaching a peak stage of 33.83 feet during the evening of 5 Dec.

CW3E Event Summary: 30 November – 6 December 2023

Hydrologic Impacts



Source: NOAA/NWS Northwest River Forecast Center



Source: NOAA/NWS Advanced Hydrologic Prediction Service

- The Wilson River near Tillamook, OR, exceeded moderate flood stage (15.5 feet), reaching a peak stage of 16.07 feet just before midnight on 5 Dec.
- Note the three distinct peaks in observed streamflow (blue line) at this location corresponding to precipitation from the first (2 Dec), second (3 Dec), and third (5 Dec) ARs.

CW3E Event Summary: 30 November – 6 December 2023

https://twitter.com/SouthSnoFire/status/1732469284398657828

Firefighters place sandbags to prevent flooding near Stanwood, WA along the Stillaguamish River (12/6)
South County Fire

Homes flooded as the Stillaguamish River exceeds its banks near Granite Falls, WA (12/5)
Snohomish County Department of Emergency Management

https://www.facebook.com/photo/?fbid=758834266285843&set=pcb.758835079619095

https://twitter.com/wsdot_north/status/1732284051401461896/photo/1

Roadway blocked due to debris flow in the North Cascades National Park near Ross Dam on North Cascades Highway (12/5)
Washington Department of Transportation - North

CW3E Event Summary: 30 November – 6 December 2023

https://twitter.com/wsdot_sw/status/1732225173141754295/photo/3

A significant roadway failure occurred after floodwaters undermined WA State Route 503 near Cougar, WA (12/5)
Washington Department of Transportation - Southwest

A USCG rescue helicopter hoisted 5 people to safety after flooding inundated homes and vehicles near Rosburg, WA (12/5)
US Coast Guard Pacific Northwest

https://twitter.com/USCGPacificNW/status/1732196260692779384

https://twitter.com/OregonDOT/status/1732144913020747944

Water and debris over the roadway along US 101 Northbound near Neskowin, OR (12/5)
Oregon Department of Transportation

CW3E Event Summary: 30 November – 6 December 2023

A landslide consisting of >30 cubic yards of soil and vegetation was reported near the Oregon Health & Science University in Portland, OR (12/6)
Portland Bureau of Transportation

https://twitter.com/PBOTinfo/status/1732459556146737488

CW3E Event Summary: 30 November – 6 December 2023

A landslide along the banks of the Coos River led to debris and downed utility poles on Oregon State Route 241 (12/4)
Oregon Department of Transportation

https://twitter.com/OregonDOT/status/1731826695332671710

CW3E Event Summary: 30 November – 6 December 2023

Post-fire debris flow in the Willamette National Forest near Cougar Dam (12/3)
Willamette National Forest - US Forest Service

Hillslope failure along a walking path in Seattle, WA (12/5)
Seattle Parks

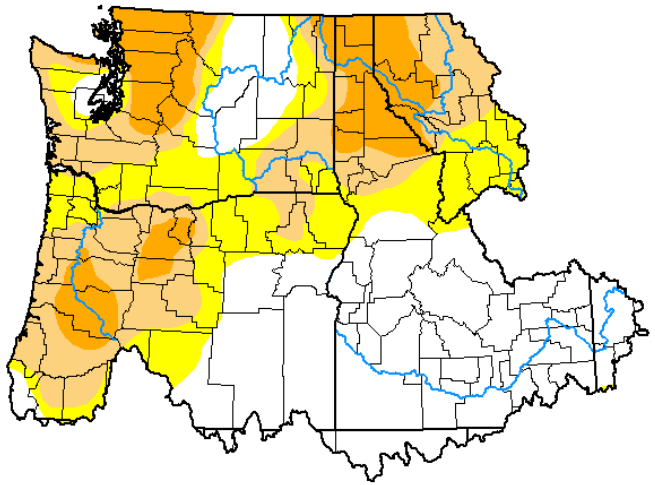
Debris flow near Neskowin, OR (12/5)
Oregon Department of Transportation

CW3E Event Summary: 30 November – 6 December 2023

Drought Conditions

U.S. Drought Monitor

Northwest RFC



November 28, 2023

(Released Thursday, Nov. 30, 2023)

Valid 7 a.m. EST

Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	43.27	56.73	36.15	13.89	0.00	0.00
Last Week 11-21-2023	45.76	54.24	37.44	13.44	0.00	0.00
3 Months Ago 08-29-2023	33.36	66.64	51.75	22.45	4.22	0.00
Start of Calendar Year 01-03-2023	14.75	85.25	48.70	23.61	8.20	0.49
Start of Water Year 09-26-2023	36.71	63.29	49.77	28.60	7.45	0.00
One Year Ago 11-29-2022	3.67	96.33	60.53	23.52	9.04	0.49

Intensity:

- None
- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

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:

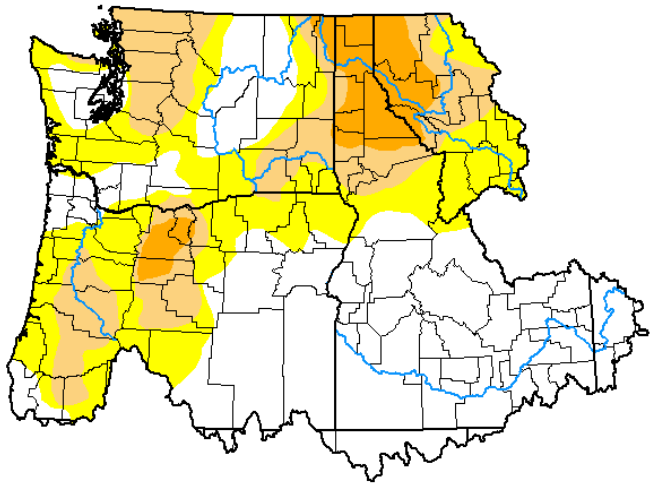
David Simeral

Western Regional Climate Center

droughtmonitor.unl.edu

U.S. Drought Monitor

Northwest RFC



December 5, 2023

(Released Thursday, Dec. 7, 2023)

Valid 7 a.m. EST

Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	48.83	51.17	24.51	7.05	0.00	0.00
Last Week 11-28-2023	43.27	56.73	36.15	13.89	0.00	0.00
3 Months Ago 09-05-2023	34.98	65.02	50.75	22.45	4.22	0.00
Start of Calendar Year 01-03-2023	14.75	85.25	48.70	23.61	8.20	0.49
Start of Water Year 09-26-2023	36.71	63.29	49.77	28.60	7.45	0.00
One Year Ago 12-06-2022	5.40	94.60	55.95	23.50	9.04	0.49

Intensity:

- None
- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

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

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- Precipitation from these storms helped provide drought relief to much of western Washington and Oregon.
- Areas that were previously experiencing severe drought are now experiencing moderate drought.
- Additional precipitation from the third AR as well as another AR that made landfall this weekend (10 Dec) will likely result in further improvement in drought conditions by this week's drought monitor update.