

CW3E Event Summary: 10–16 November 2021

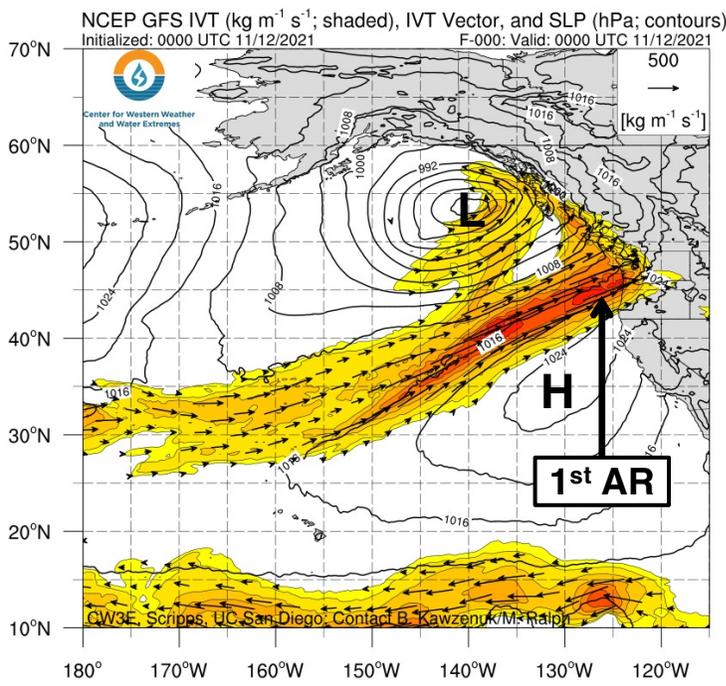
Atmospheric Rivers Produce Heavy Rainfall, Flooding, and Landslides in the Pacific Northwest

- Multiple strong atmospheric rivers (ARs) impacted the Pacific Northwest between 10 Nov and 15 Nov
- The first AR produced AR 3/AR 4 conditions (based on the Ralph et al. 2019 AR Scale) in coastal Oregon and southern coastal Washington
- The second AR produced AR 4 conditions in coastal Washington and northern coastal Oregon
- The intensification of a mesoscale frontal wave (MFW) led to a secondary pulse in moisture transport that prolonged the duration of the 2nd AR and brought borderline AR 5 conditions (max IVT > 1000 kg m⁻¹ s⁻¹; AR duration > 48 hours) to Tillamook County, OR
- Parts of the Olympic Peninsula and Washington Cascades received more than 15 inches of total precipitation from these ARs
- Heavy rain falling on moist soils led to widespread flooding and mudslides, particularly in northern Washington and southern British Columbia following the second AR landfall
- Strong winds and flooding during the second AR also created dangerous travel conditions, downed numerous trees, and caused widespread power outages in western Washington

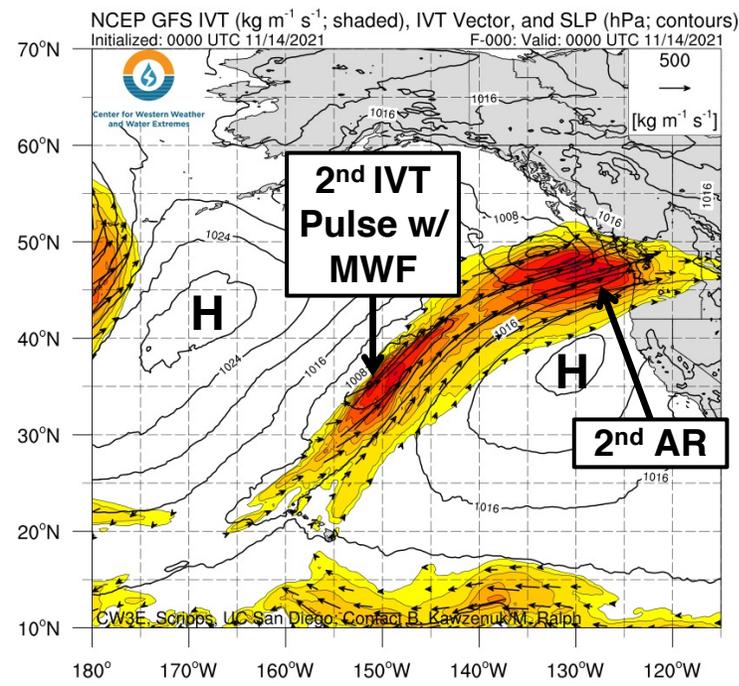
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GFS IVT Analyses of the two ARs

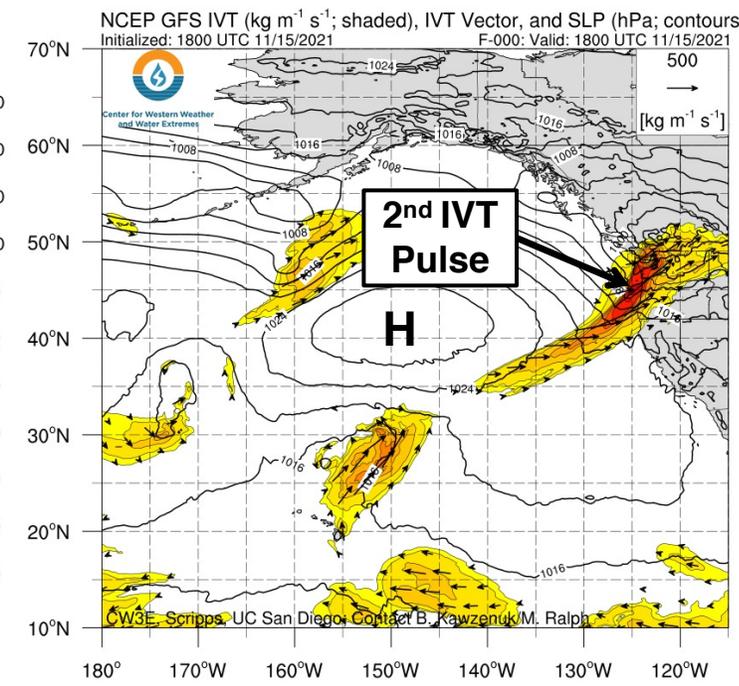
A) Valid: 4 PM PST 11 Nov



B) Valid: 4 PM PST 13 Nov



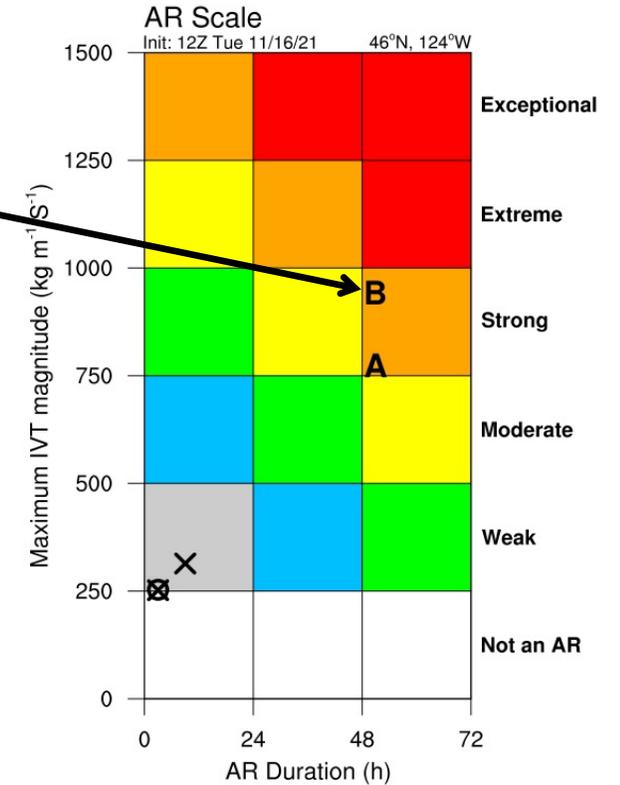
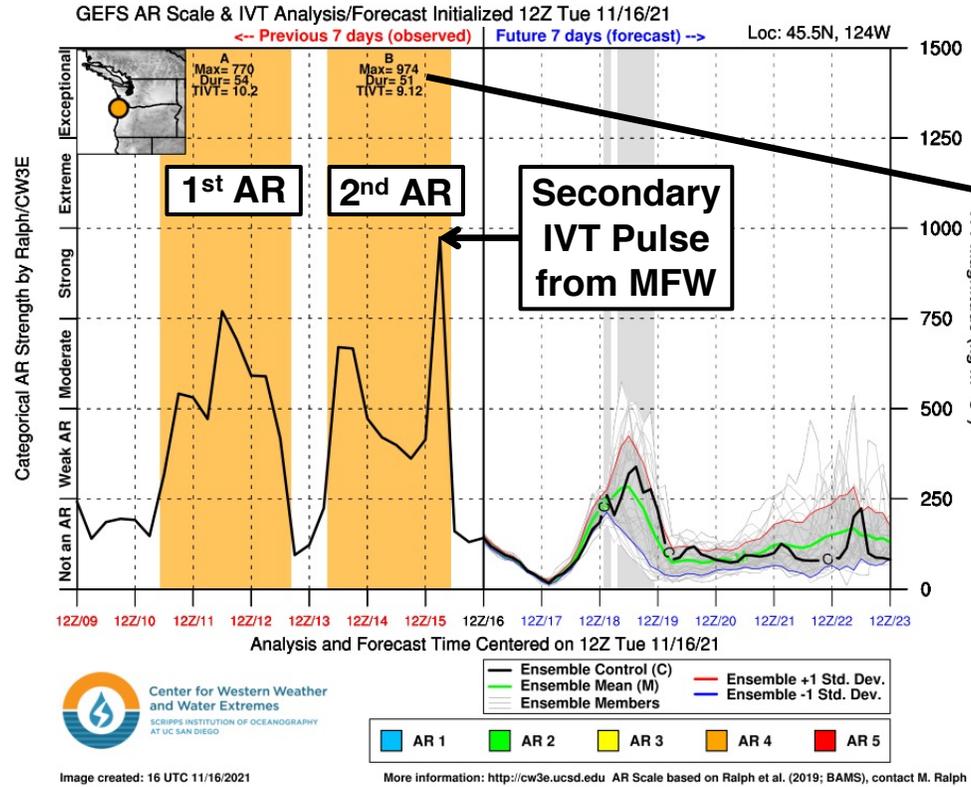
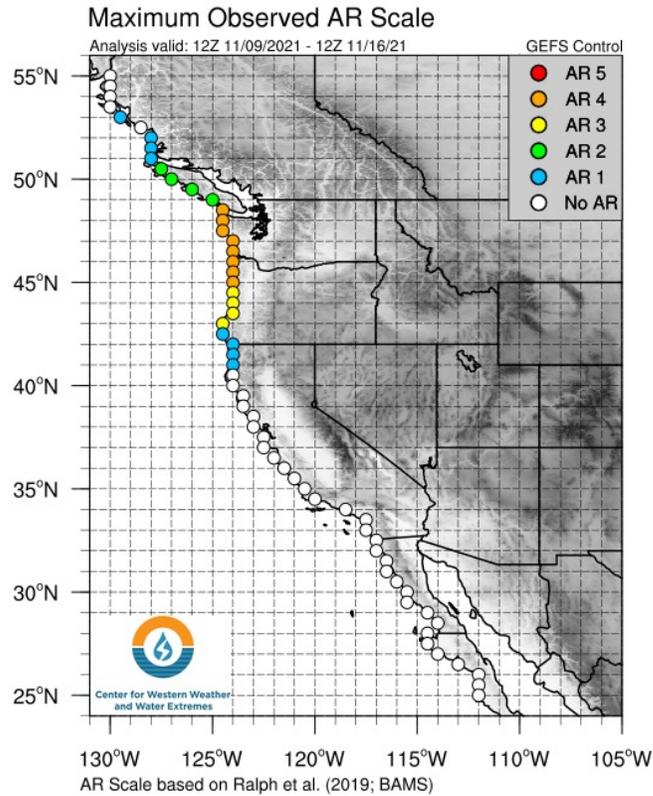
C) Valid: 10 AM PST 15 Nov



- Two ARs developed over the Northeast Pacific Ocean and impacted the US West Coast from 10 Nov through 15 Nov
- The first AR made landfall in the Pacific Northwest on the morning of 11 Nov (Figure A) in association with a surface cyclone
- The second AR made landfall early on 13 Nov (Figure B) in nearly the same location as the first AR
- A mesoscale frontal wave (MFW) formed into a secondary cyclone at $\sim 150^\circ\text{W}$ on 13 Nov, which created a 2nd pulse of enhanced IVT magnitudes ($> 800 \text{ kg m}^{-1} \text{ s}^{-1}$) and prolonged the overall duration of AR conditions over the coastal Pacific Northwest (Figures B and C)

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GEFS AR Scale & IVT Analyses of the two ARs

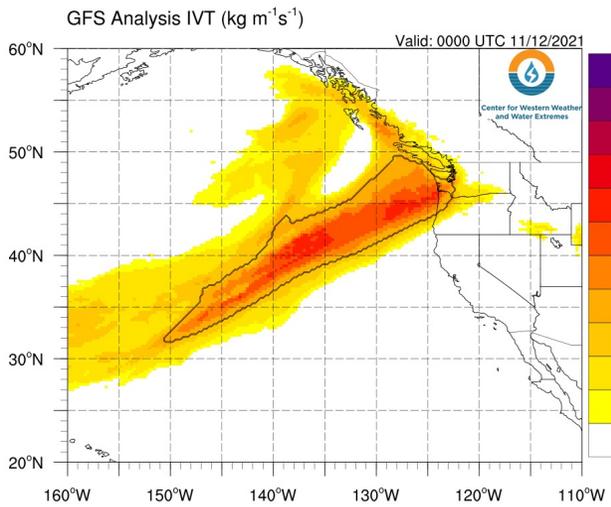


- Back-to-back ARs produced AR 4 conditions (based on the Ralph et al. 2019 AR Scale) along the Northern Oregon coast
- The first AR produced a maximum IVT of $770 \text{ kg m}^{-1} \text{ s}^{-1}$ and a total duration of 54 hours, while the second AR brought a maximum IVT of $974 \text{ kg m}^{-1} \text{ s}^{-1}$ and a total duration of 51 hours over coastal Tillamook County, OR
- The maximum IVT during the 2nd AR was the result of an MFW that produced enhanced IVT and a secondary pulse of AR conditions
- The hydrologic impacts produced by these ARs were exacerbated by the short break between AR 4 conditions, leaving little time for rivers and streams to recede and soils to dry out

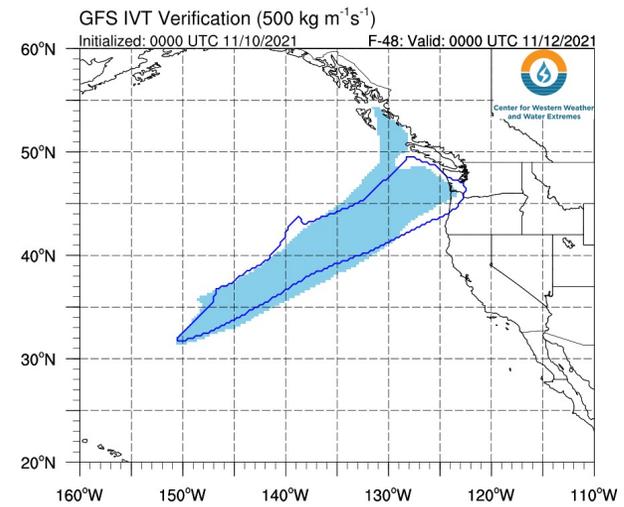
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GFS AR/IVT Forecast Verification: Valid 00Z 12 Nov

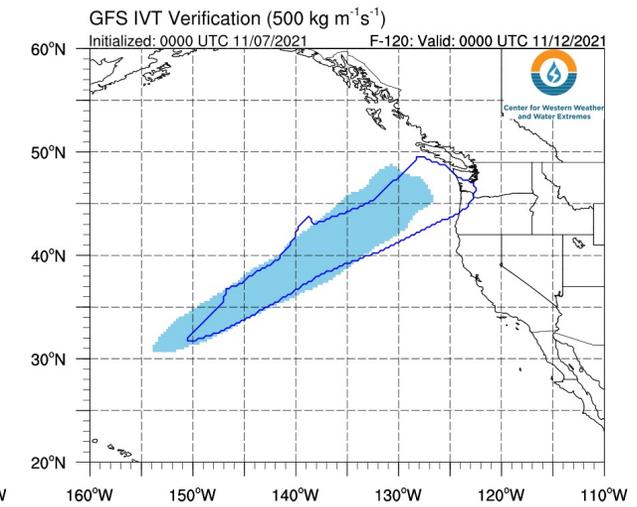
Model Analysis



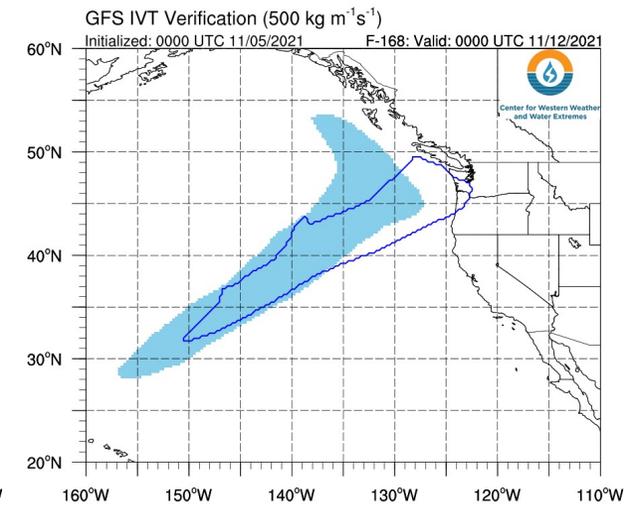
48-h Forecast



120-h Forecast



168-h Forecast



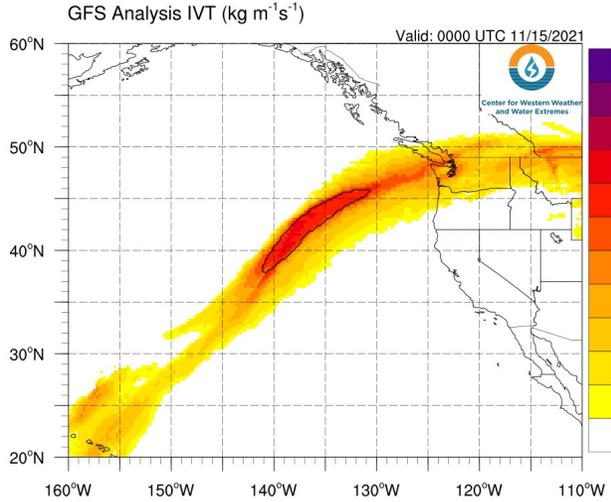
*Forecast objects shaded (unmatched objects in gray)
Observed objects contoured (unmatched objects in black)
Objects defined based on $IVT > 750 \text{ kg m}^{-1} \text{ s}^{-1}$*

- Using the Method for Object-Based Diagnostic Evaluation (MODE) with a $500 \text{ kg m}^{-1} \text{ s}^{-1}$ IVT threshold shows the locations of the core of the first AR was well forecasted at a 48-hour lead time with a westward shift of the AR and not as much of an inland extension compared to the analysis
- Examination of the 120-hour and 168-hour forecasts shows that each forecast of moderate AR conditions ($IVT > 500 \text{ kg m}^{-1} \text{ s}^{-1}$) was shifted too far offshore, highlighting how the GFS was too slow in each forecast but trended closer towards the correct position of the first AR as lead time decreased

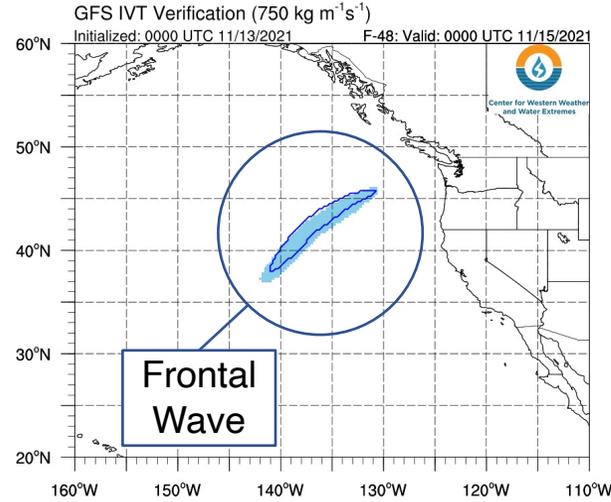
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GFS AR/IVT Forecast Verification: Valid 00Z 15 Nov

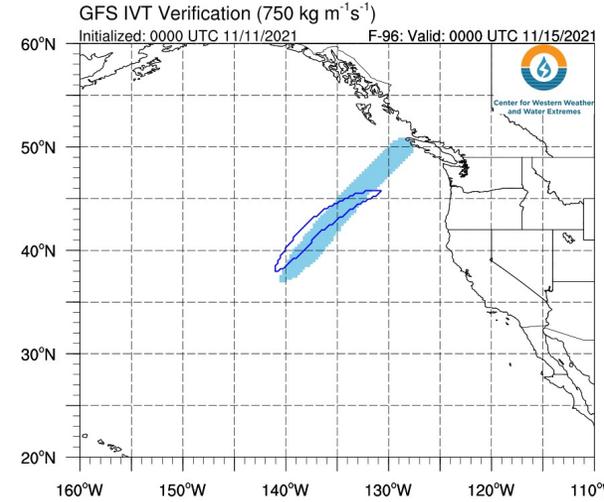
Model Analysis



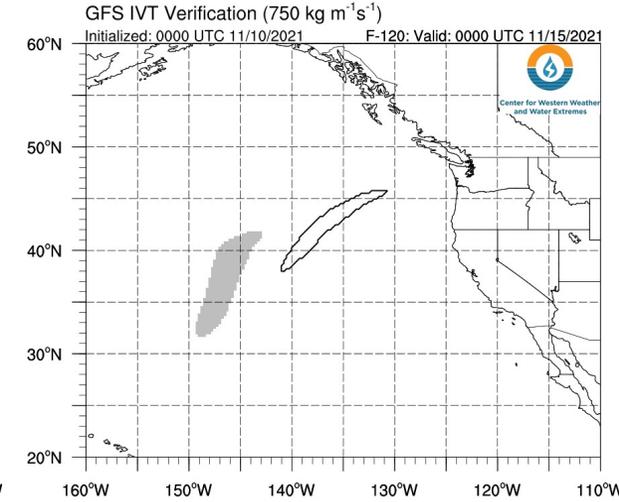
48-h Forecast



96-h Forecast



120-h Forecast

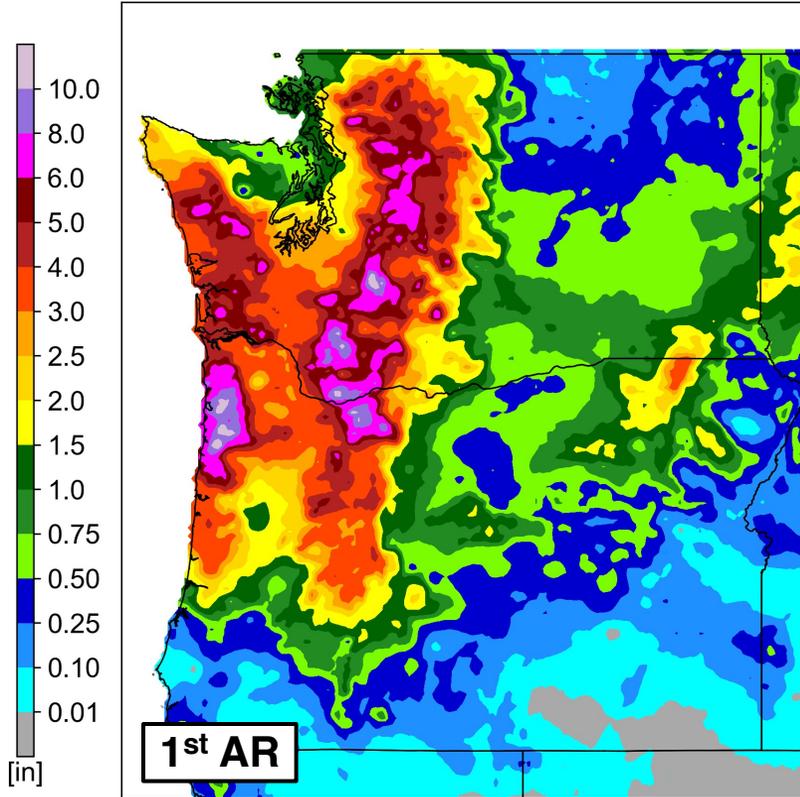


*Forecast objects shaded (unmatched objects in gray)
Observed objects contoured (unmatched objects in black)
Objects defined based on $IVT > 750 \text{ kg m}^{-1} \text{ s}^{-1}$*

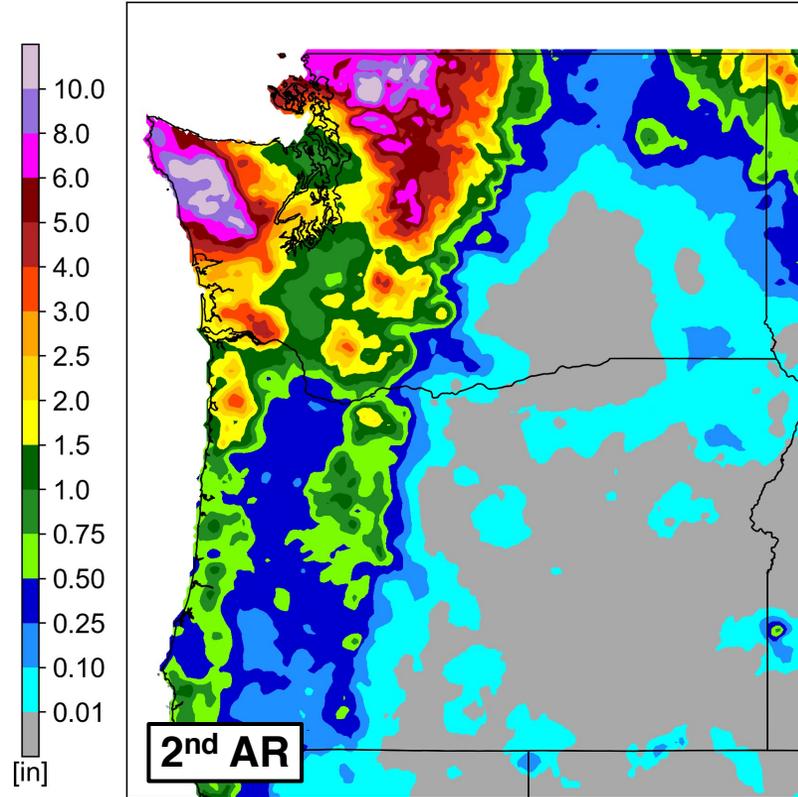
- Examination of the $750 \text{ kg m}^{-1} \text{ s}^{-1}$ object valid at 00 UTC 15 November highlights the poor forecasts of the MFW that formed over the Eastern Pacific at lead times > 48 hours
- In general, the GFS nearly perfectly captured the location and magnitude of the wave and enhanced IVT at a 48-hour lead time
- The 96-hour forecast by the GFS correctly identified IVT magnitudes $> 750 \text{ kg m}^{-1} \text{ s}^{-1}$ over the Eastern Pacific, but there was no evidence of a wave in the IVT plume and the plume was extended too far to the northeast, making landfall over British Columbia
- The 120-hour forecast also highlighted the potential for strong AR conditions, but the location and structure of the feature was too far to the southwest

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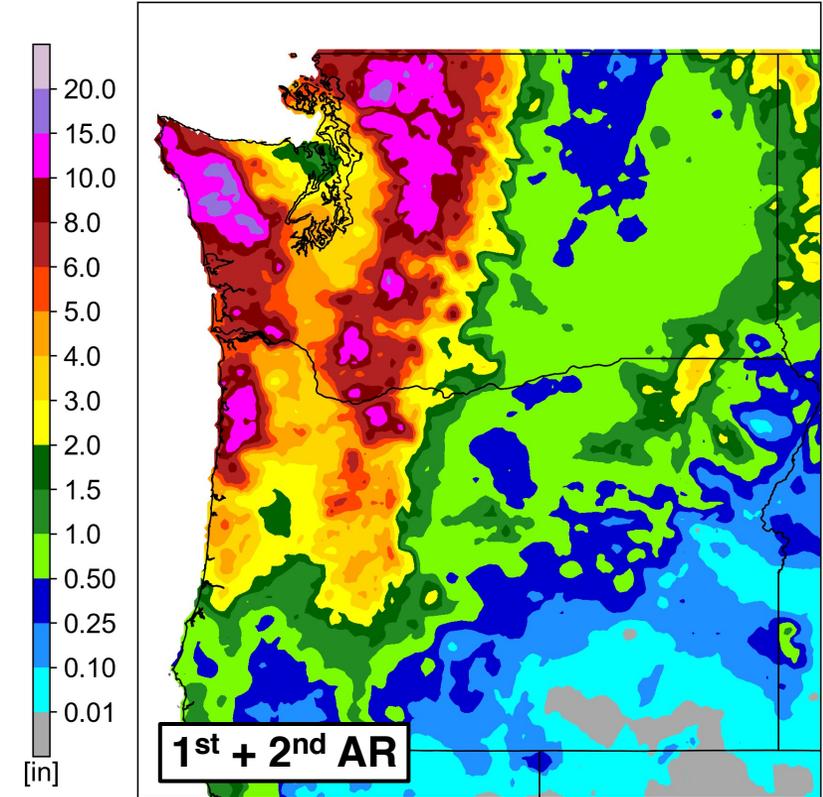
NCEP Stage IV 72-h QPE
Valid: 4 AM PT 10–13 Nov



NCEP Stage IV 72-h QPE
Valid: 4 AM PT 13–16 Nov

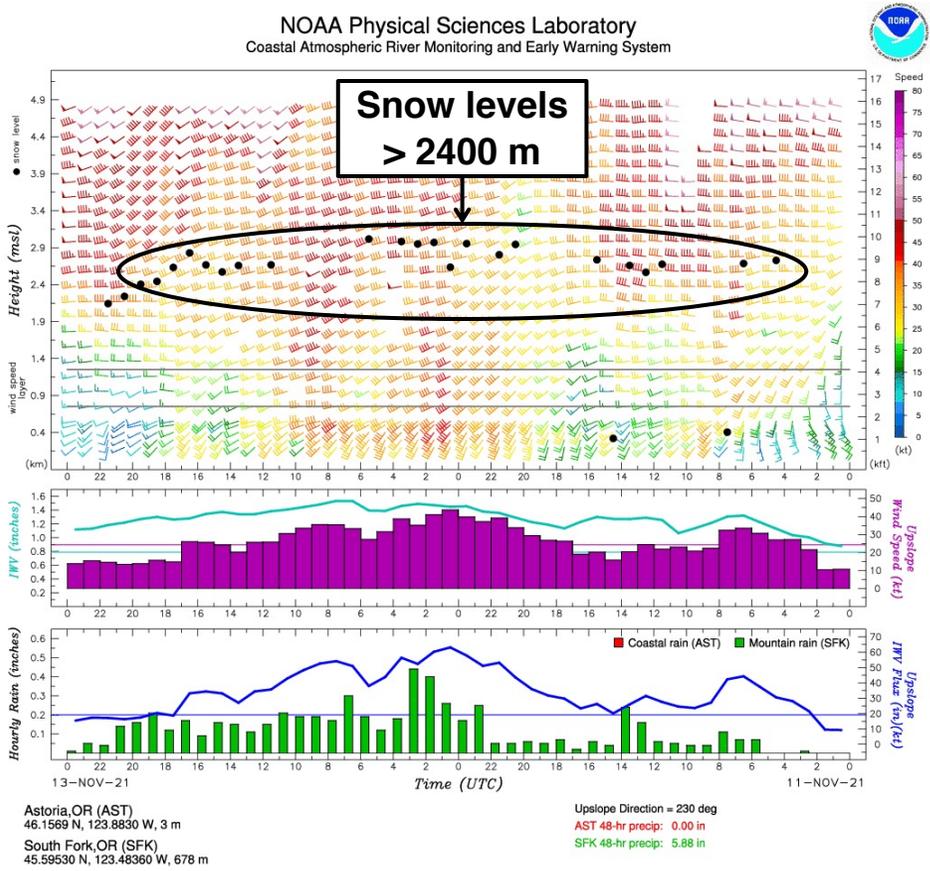


NCEP Stage IV 6-day QPE
Valid: 4 AM PT 10–16 Nov

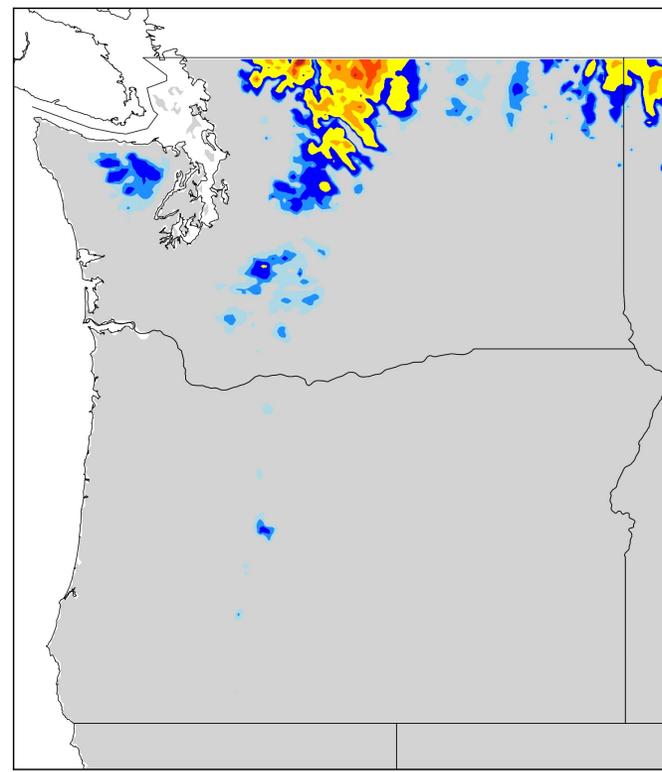


- The first AR produced widespread heavy precipitation in western Washington and Oregon, with the highest precipitation amounts (> 8 inches) in the northern Oregon Coast Ranges and the Cascades between Mt. Rainier and Mt. Hood
- Due to its more northerly track, the second AR primarily affected Washington, bringing more than 10 inches of precipitation to parts of the Olympic Peninsula and North Cascades
- Some locations in the Olympic Peninsula and the North Cascades received an estimated 15–20 inches of total precipitation from these two ARs

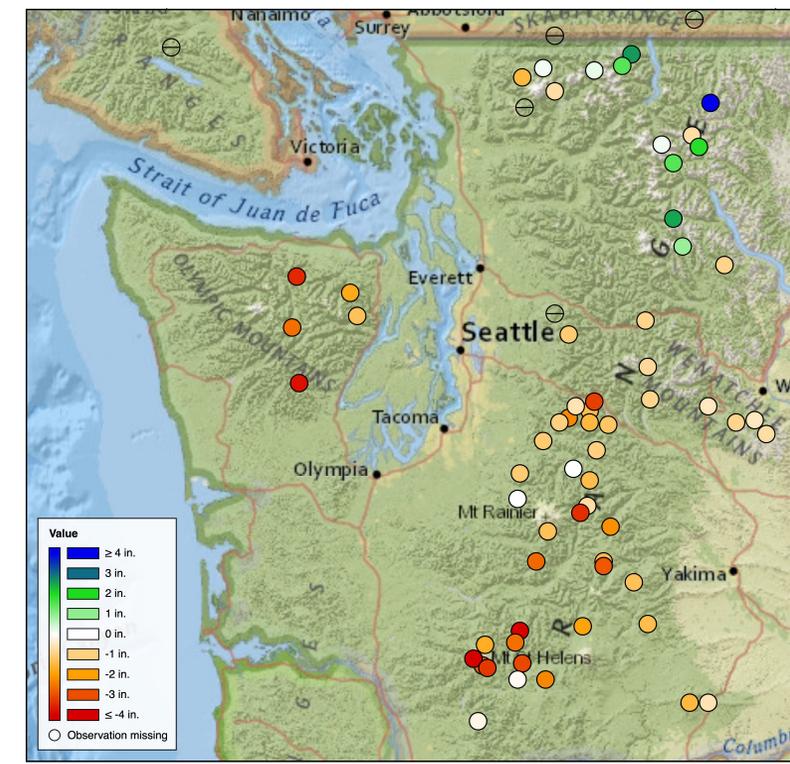
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72-h Interpolated Snowfall Valid: 4 AM PT 13–16 Nov



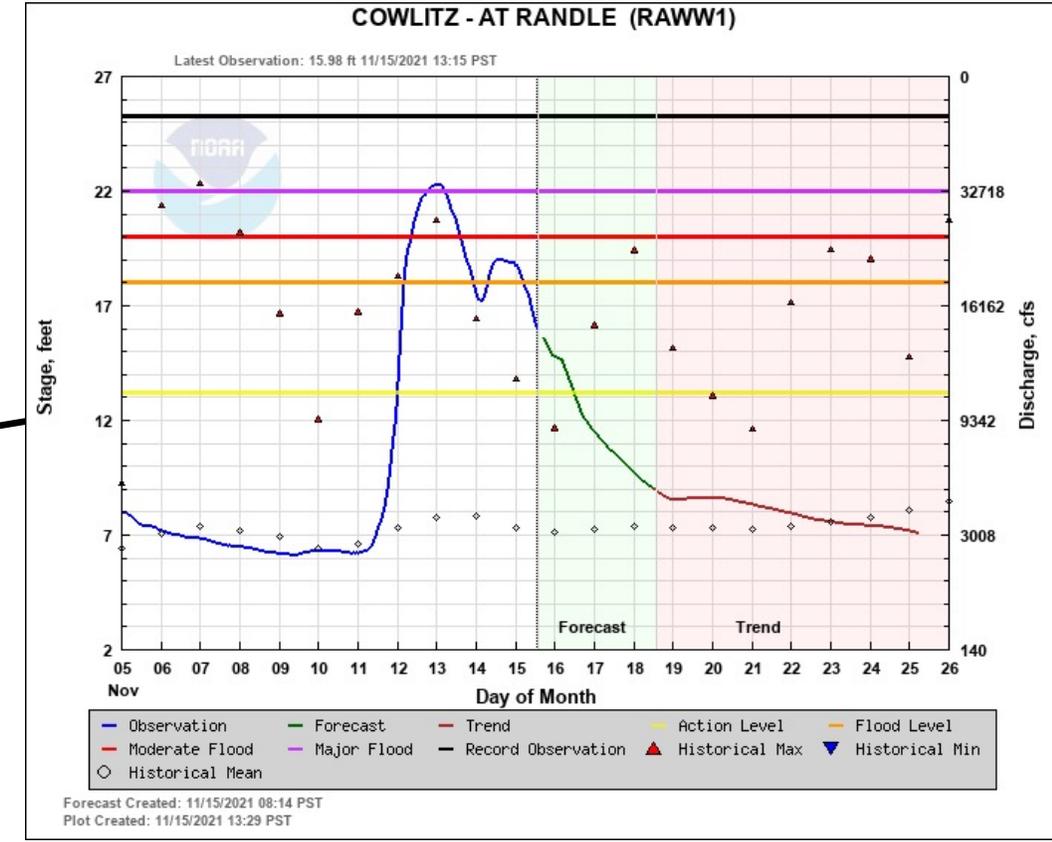
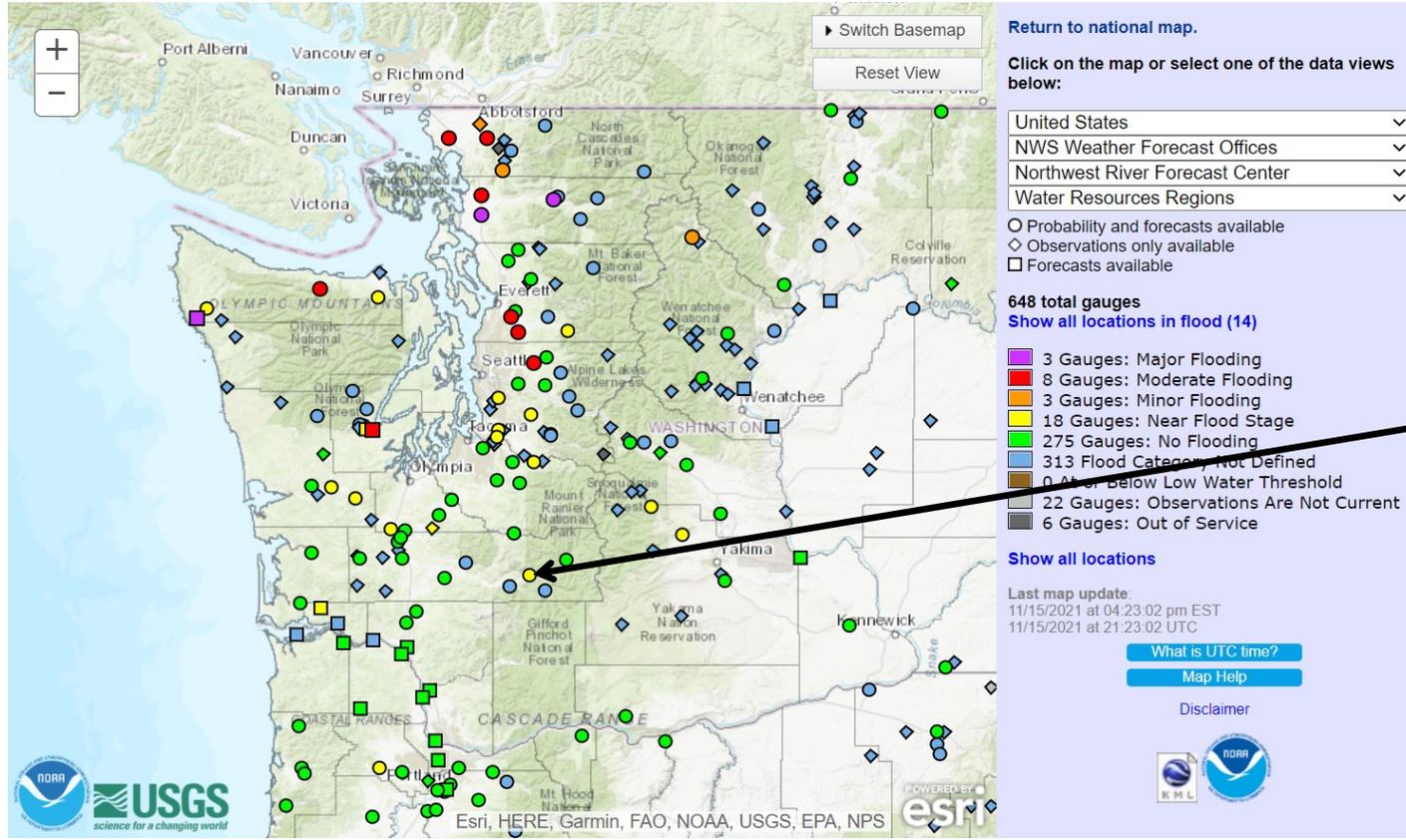
6-day SWE Change Valid: 10–16 Nov (First of Day)



Source: NRCS Water and Climate Center

- High freezing levels limited snowfall accumulations, especially during the first AR
- Some areas in the North Cascades (primarily above 8,000 ft) received more than 12 inches of snow from the second AR
- Most SNOTEL sites below 6,000 ft reported significant losses in snow water content and snow depth between 10 Nov and 16 Nov
- Heavy rainfall on existing snowpack likely increased surface runoff and exacerbated the flooding at lower elevations

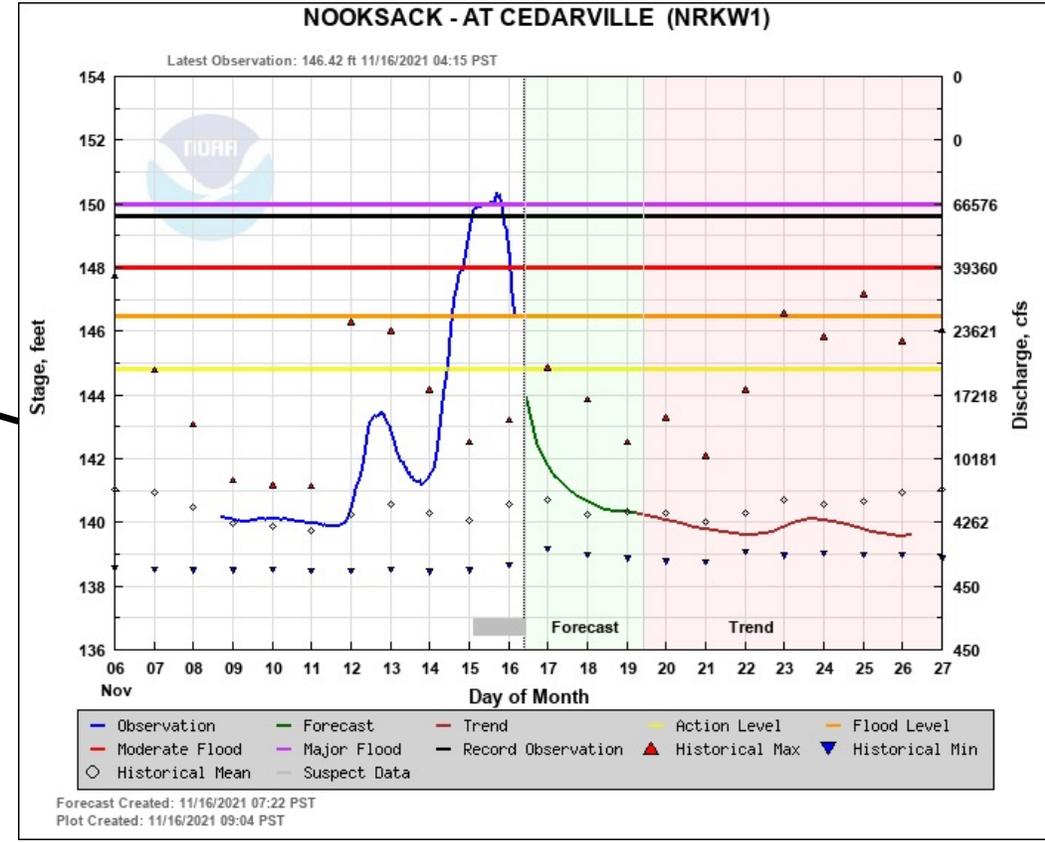
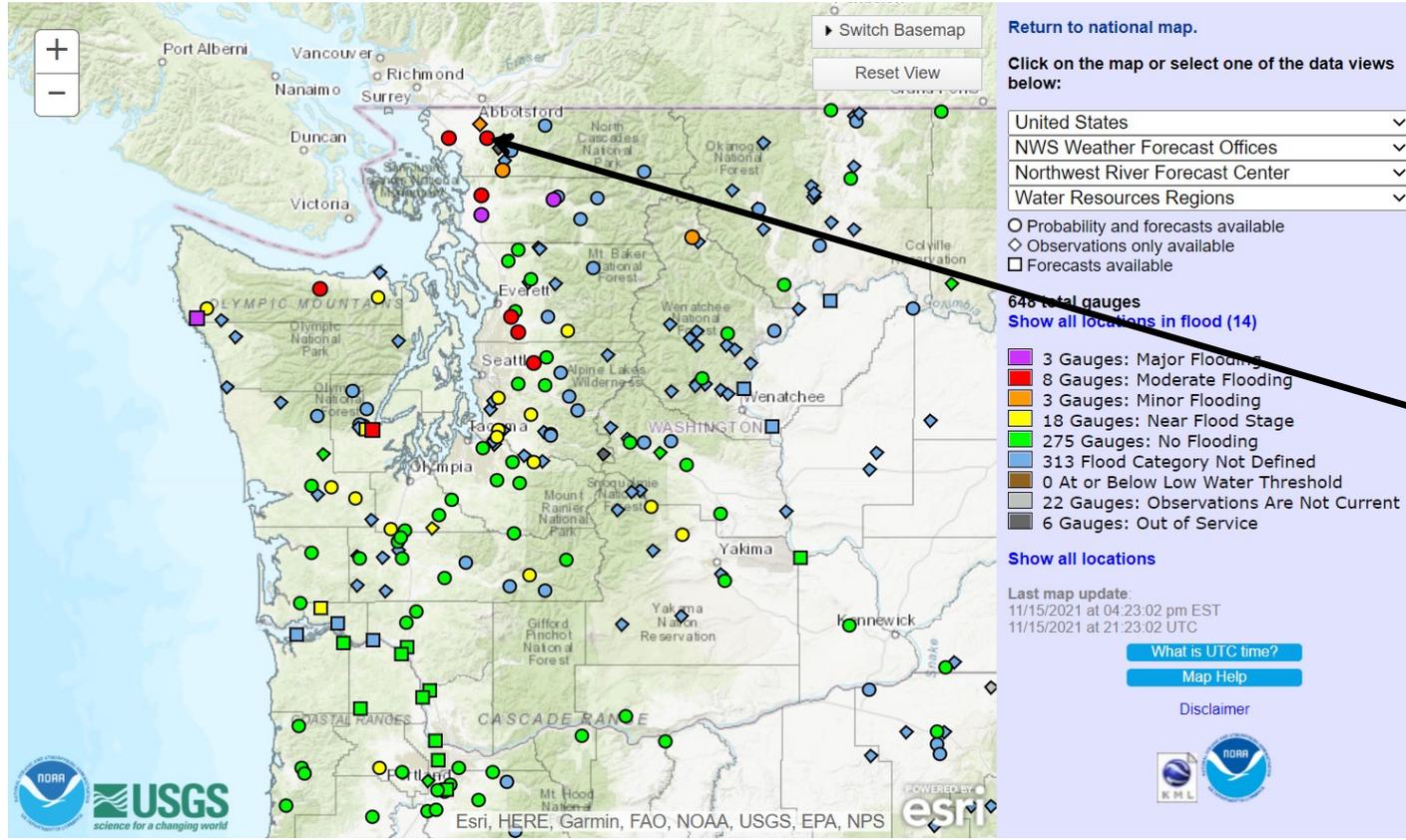
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Source: NOAA/NWS Northwest River Forecast Center

- The combination of high soil moisture levels and heavy rain produced widespread riverine flooding in western Washington
- The most severe flooding from the first AR occurred in King and Lewis Counties
- The Cowlitz River (at Randle, WA) rose above major flood stage (22 ft) on 12 Nov, reaching a peak stage height of 22.28 ft
- This is the 8th highest stage height observed at this location since records began in 1994

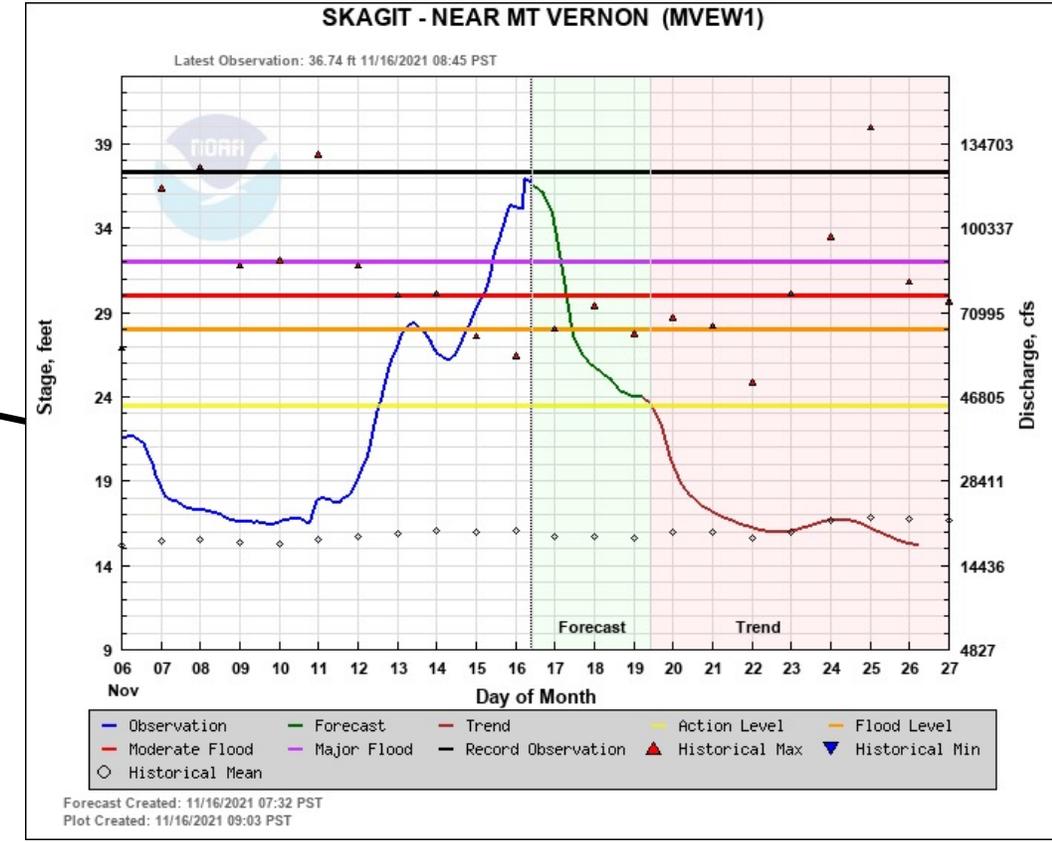
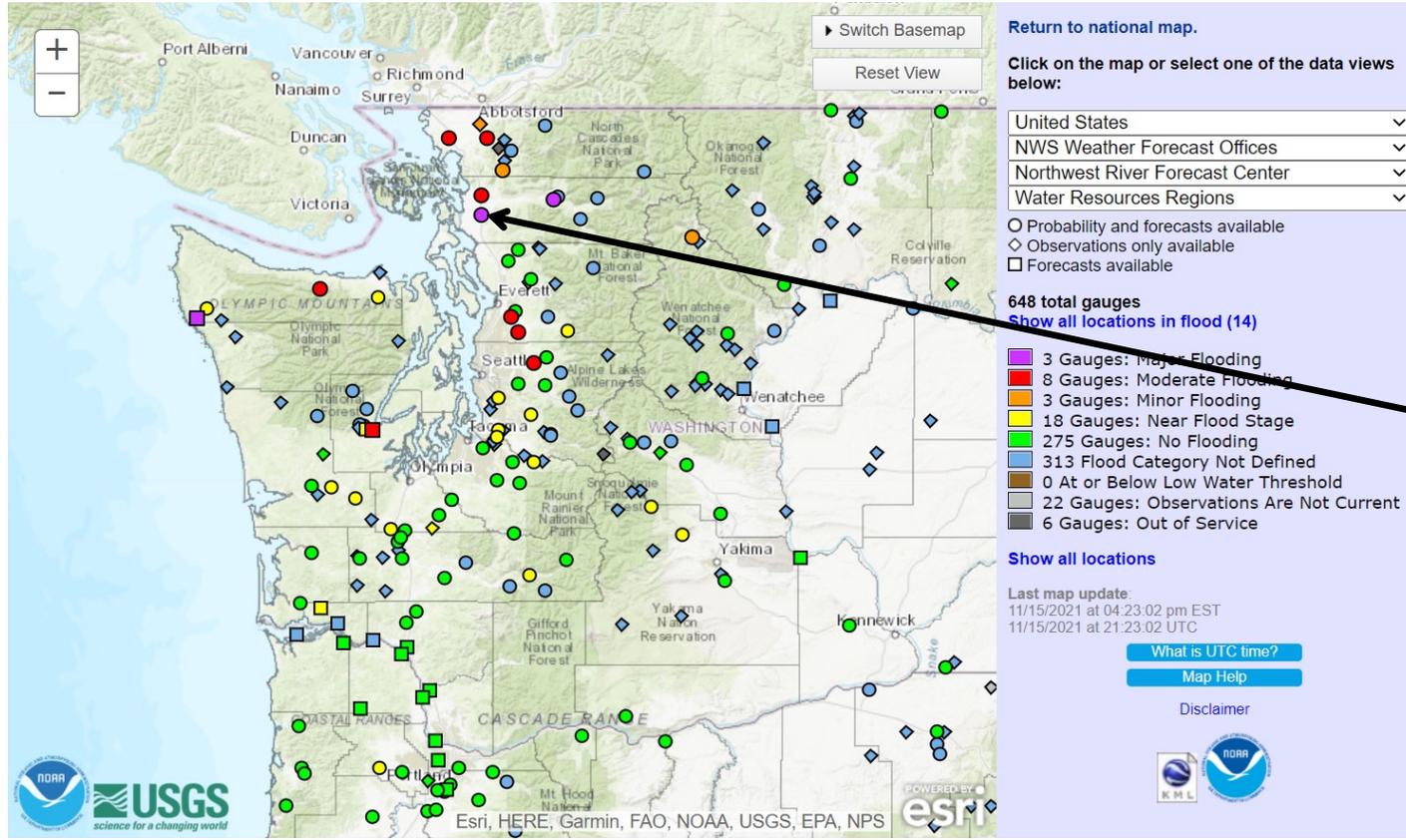
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Source: NOAA/NWS Northwest River Forecast Center

- The most severe flooding from the second AR occurred in Whatcom and Skagit Counties
- The Nooksack River (at Cedarville, WA) rose above major flood stage (150 ft) on 15 Nov
- The peak stage height of 150.35 ft was the highest river level ever recorded at this location (records began in 2004)

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Source: NOAA/NWS Northwest River Forecast Center

- The Skagit River (near Mt Vernon, WA) also rose above major flood stage (32 ft) on 15 Nov, but debris carried by the floodwaters destroyed the stream gauge before the river reached its crest
- Manual observations taken during the morning of 16 Nov showed a peak stage height slightly above 37 ft, which would be the 3rd highest river level ever recorded at this location (records began in 1906)

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Everson, WA



Source: Whatcom County Sheriff

Sumas, WA



Source: Washington State DOT

Bellingham, WA



Source: Washington State DOT

Lytton, BC

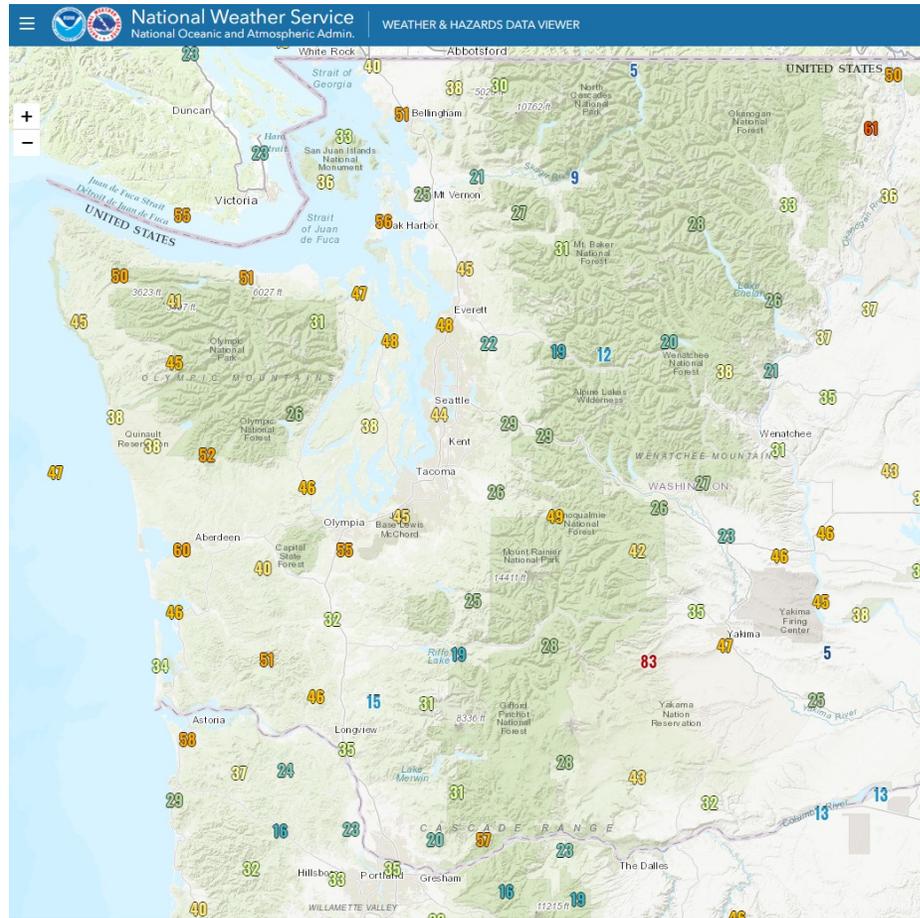


Source: BC Transportation

- Severe flooding and numerous slides caused significant damage in northern Washington and southern British Columbia
- Portions of Everson, WA, Sumas, WA, and Abbotsford, BC, were completely inundated with floodwaters
- It is estimated that at least 500 residents in Whatcom County have been displaced due to flooding
- Mudslides closed sections of Interstate 5 in both directions near Bellingham, WA
- Sections of Highway 1 near Lytton, BC, and Highway 5 near Hope, BC, were completely washed out by mudslides
- All rail service to/from Vancouver, BC, was suspended, and the TransMountain oil pipeline was temporarily shut down
- At least one person died in a mudslide on Highway 99 near Pemberton, BC, and hundreds of others were rescued from their homes and vehicles

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24-h Maximum Wind Gust:
Valid 11:59 PM PT 15 Nov



Source: NWS Western Region

- The second AR also brought high winds to much of western Washington, where numerous stations recorded wind gusts > 50 mph and some higher elevation locations experienced gusts > 80 mph
- These high winds resulted in widespread power outages as Puget Sound Energy reported more than 167,400 customers were without power at some point during the event
- Ground and air travel was made difficult by the high winds where numerous trees blocked roadways, trucks were blown over, and significant turbulence was observed

Deception Pass, Whidbey Island, Washington



SIGMET for Severe Turbulence

WHISKEY 3
Valid Until
0434 UTC Tuesday
November 16, 2021

Hazard Information
Severe Turbulence
SFC-140

ARTCCs Affected
ZSE

EXPERIMENTAL Not every SIGMET will be posted here. Feedback welcome!

See www.aviationweather.gov for the latest SIGMETs.