CW3E Post-Event Summary: Upper Colorado River Basin Snowfall

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SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

Analysis of the Meteorological Conditions that led to a Snowy October in the Upper Colorado River Basin

- Numerous systems over a 2 week span at the end of October resulted in heavy snowfall over the Upper Colorado River Basin
- Moisture associated with the snowfall was supplied via an inland penetrating AR over the Pacific Northwest that resulted in flooding and road closures in mid to late October in Washington and Oregon
- Tower, a SNOTEL site #825 east of Steamboat Springs in the Yampa River watershed, received ~12% of it's annual maximum SWE in a short time-span
- Impacts were also experienced east of the Continental Divide, where Denver recorded its 12th snowiest and 4th coldest October since 1872

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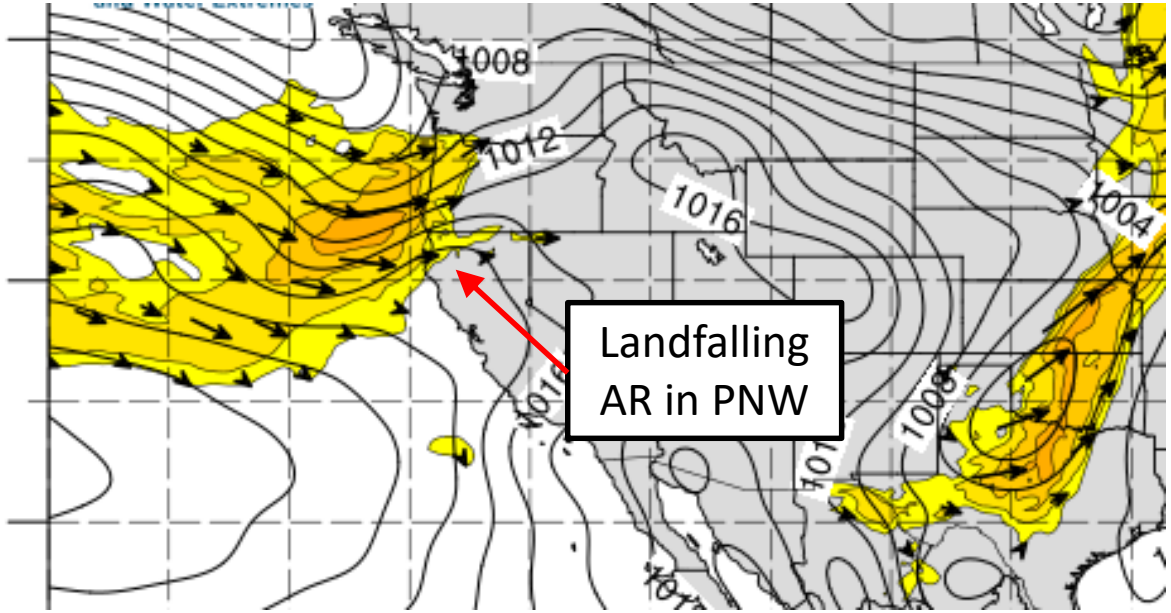
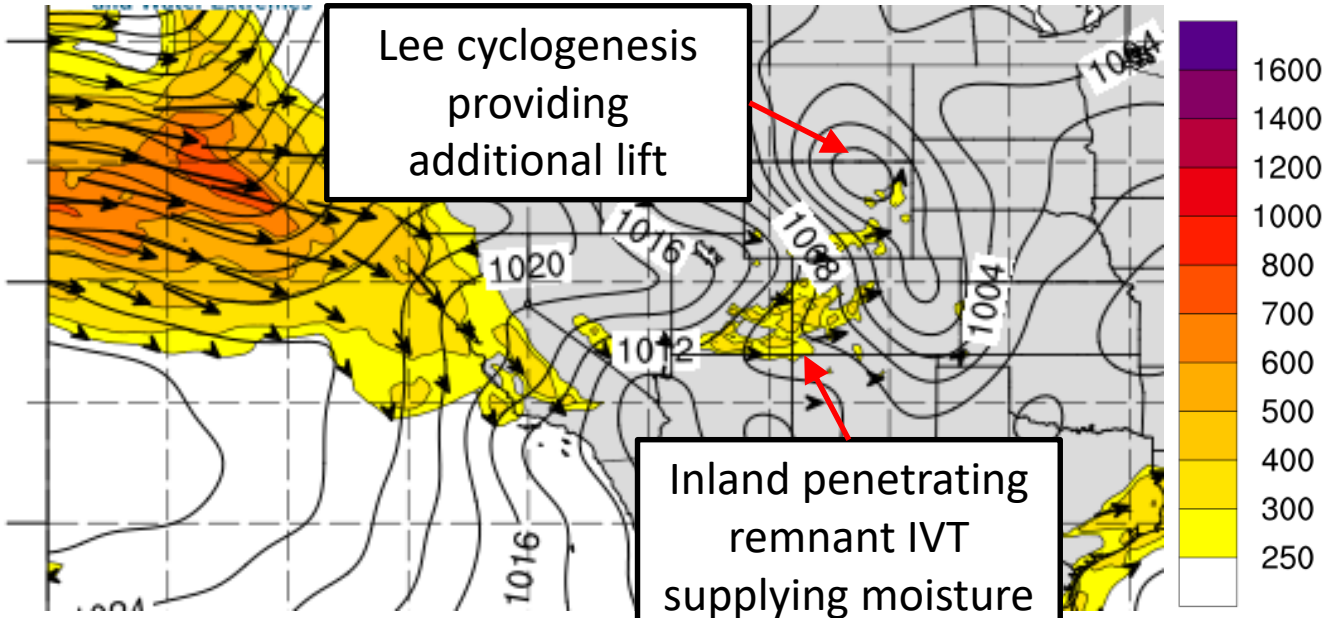
- **The first, and heaviest, snow event occurred between 19 and 22 October**
- **Moisture associated with this event was supplied by an inland penetrating Atmospheric River that initially impacted the Pacific Northwest and brought impressive precipitation accumulations to Washington and Oregon (For a post event summary on the PNW AR visit: https://cw3e.ucsd.edu/cw3e-post-event-summary-16-22-october-2019/)**
- **Strong cyclogenesis occurred in the lee of the Rockies of western WY and CO, providing additional lift for heavy precipitation over the Upper Colorado River Basin**

NCEP GFS Analysis IVT and Sea-level Pressure Valid 6 UTC 19 Oct. 2019



NCEP GFS Analysis IVT and Sea-level Pressure Valid 6 UTC 20 Oct. 2019



vfall

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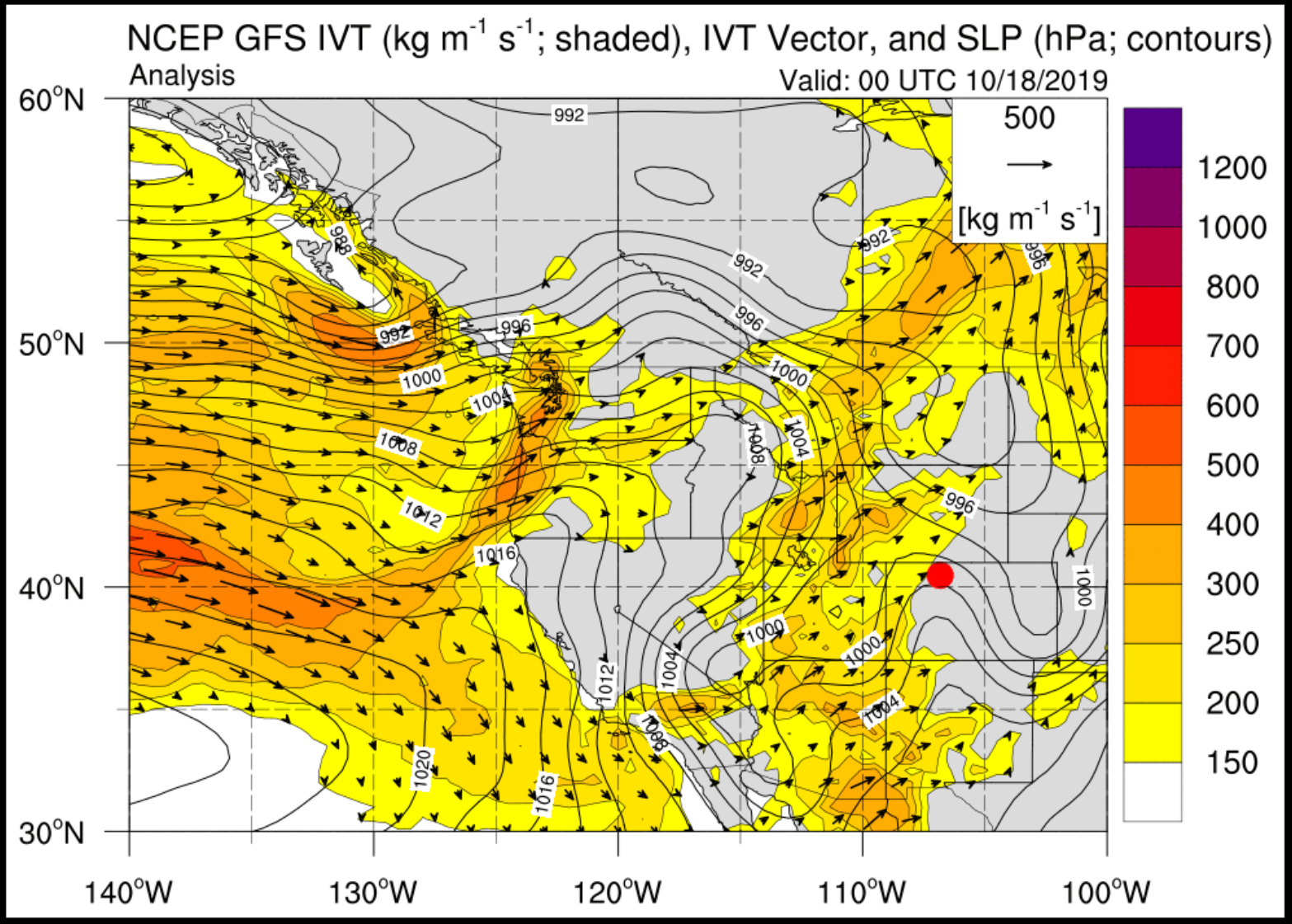

- **A loop of NCEP GFS Analysis derived IVT illustrates the numerous pulses of inland penetrating moisture transport into the intermountain west and over locations such as Steamboat Springs, CO (Red Dot on Map)**
- **This period of landfalling ARs over the PNW and heavy snow in the upper Colorado River Basin exemplifies the upstream connection between landfalling ARs on the U.S. West Coast and winter weather over the inland Rockies**

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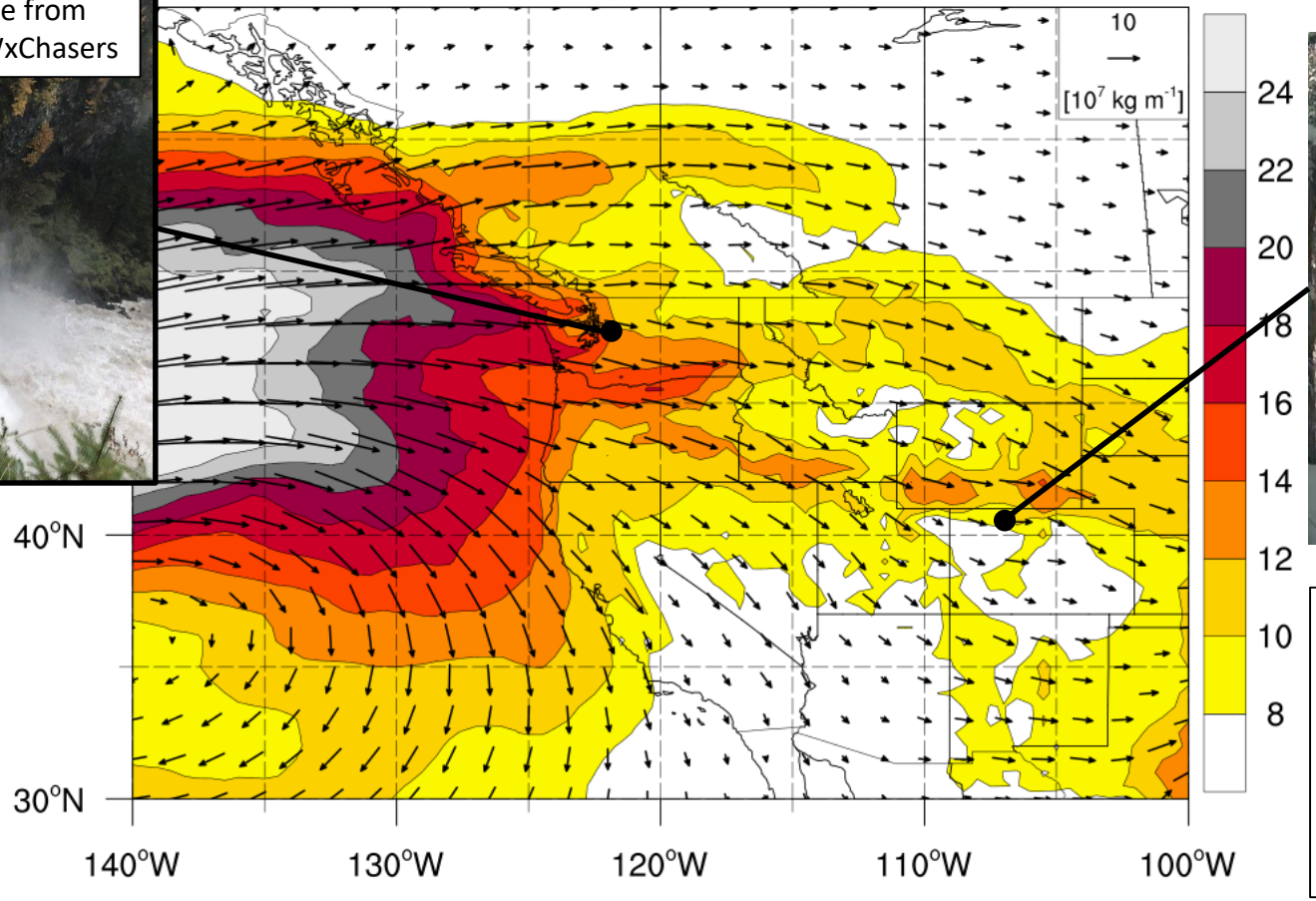
An examination of GFS analysis derived time-integrated IVT between 18 and 25 October further highlights how the landfalling ARs in the Pacific Northwest resulted in inland penetrating moisture transport to the inner mountain west, which supplied moisture for the heavy snowfall in the Upper Colorado River Basin

The Snoqualmie River near Snoqualmie Falls reached it's 14th highest crest of record on 22 Oct. 2019

NCEP GFS Analysis Time-Integrated IVT Valid: 00 UTC 18 through 18 UTC 25 October



The Powder Cam at Steamboat Resort on Sunshine Peak shows nearly 18 inches of snow before Halloween

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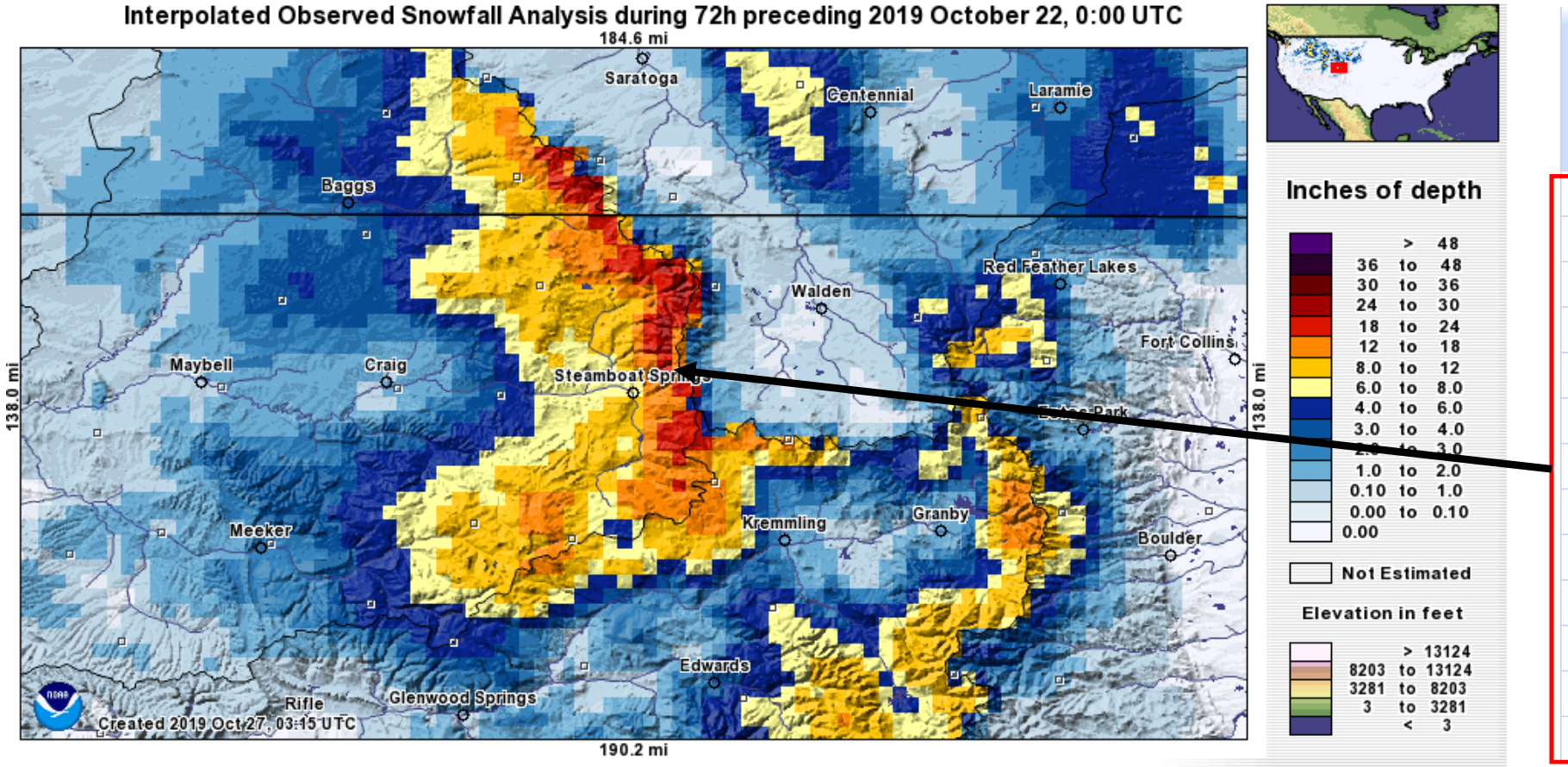
- This system resulted in 72-hour snowfall totals of >18 inches over the high elevations east of Steamboat Springs, and by 30 Oct snow depth had reached 32 in. at the Tower SNOTEL site
- A large portion of the Upper Colorado River Basin in Northwestern Colorado and southern Wyoming received >6 in. of Snow
- SNOTEL site #825, at 10.5 Kft, received a SWE increase from .1 to 6.5 in. (12% of max SWE) between 18 & 22 Oct.



Date	Snow Water Equivalent (in) Start of Day Values	Median Snow Water Equivalent (1981-2010) (in) Start of Day Values
2019-10-18	0.1	1.4
2019-10-19	0.5	1.5
2019-10-20	0.9	1.7
2019-10-21	3.7	1.9
2019-10-22	4.6	2.0
2019-10-23	4.9	2.1
2019-10-24	5.4	2.3
2019-10-25	5.3	2.4
2019-10-26	5.4	2.5
2019-10-27	5.4	2.6
2019-10-28	5.7	2.8
2019-10-29	6.0	2.8
2019-10-30	6.5	3.0

Snowfall Maps Available at nohrsc.noaa.gov/interactive/html/map.html

A SWE value of 6.5 on 30 Oct. is 217% of the 30-year median value

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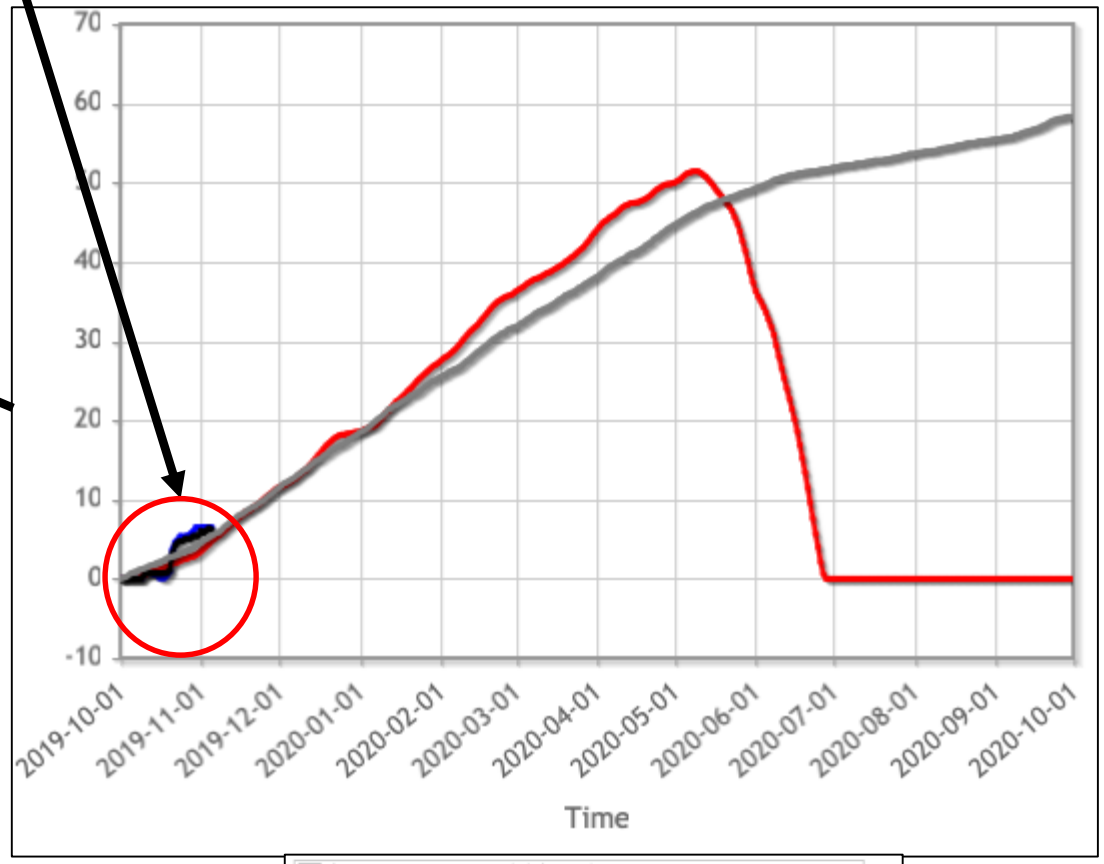
After the multiple events that brought snowfall to the Upper Colorado River Basin, SNOTEL Tower Site 825, east of Steamboat Springs, had received ~12% of it's normal annual maximum snow water equivalent, a majority of which fell during the October 22nd event



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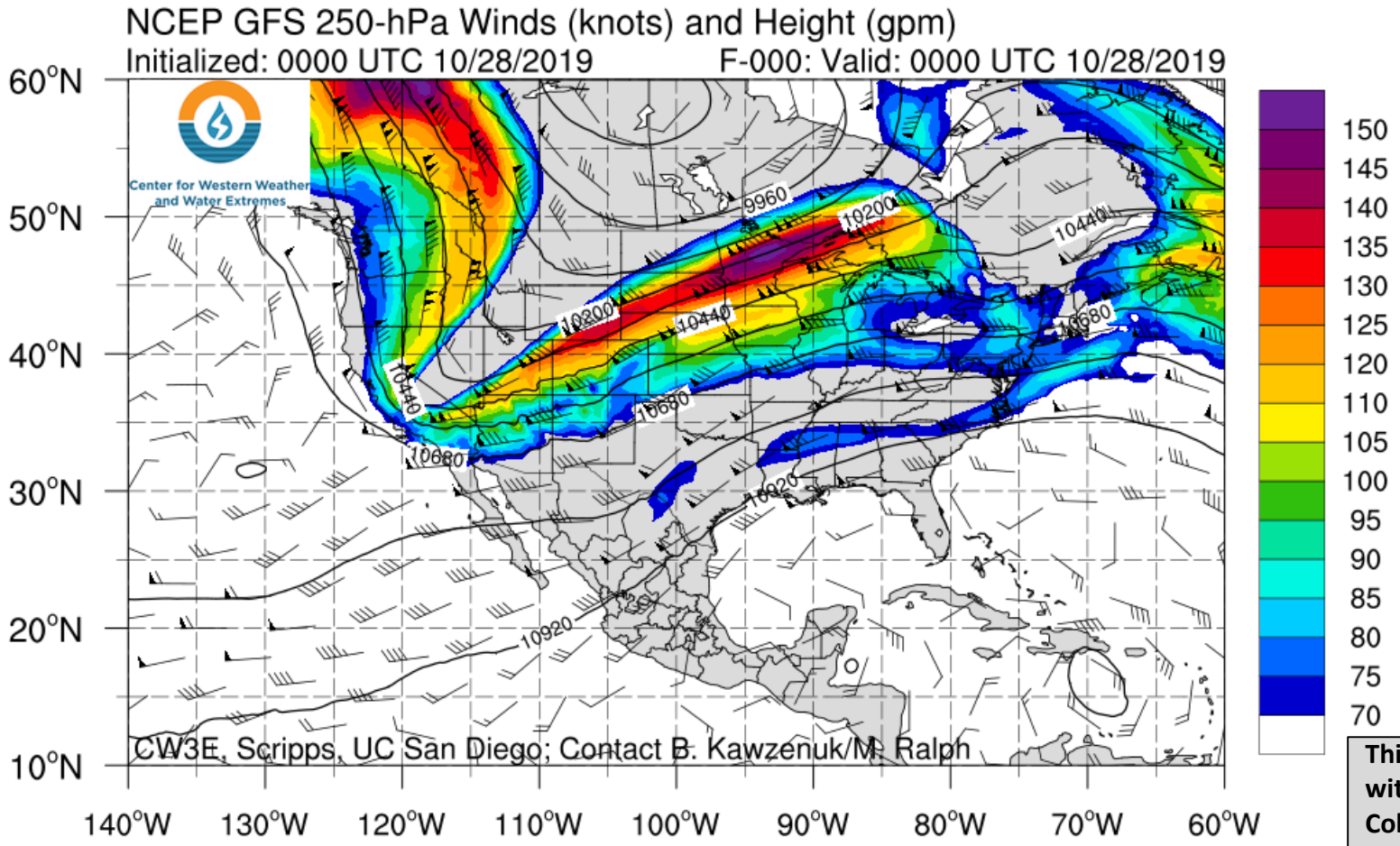
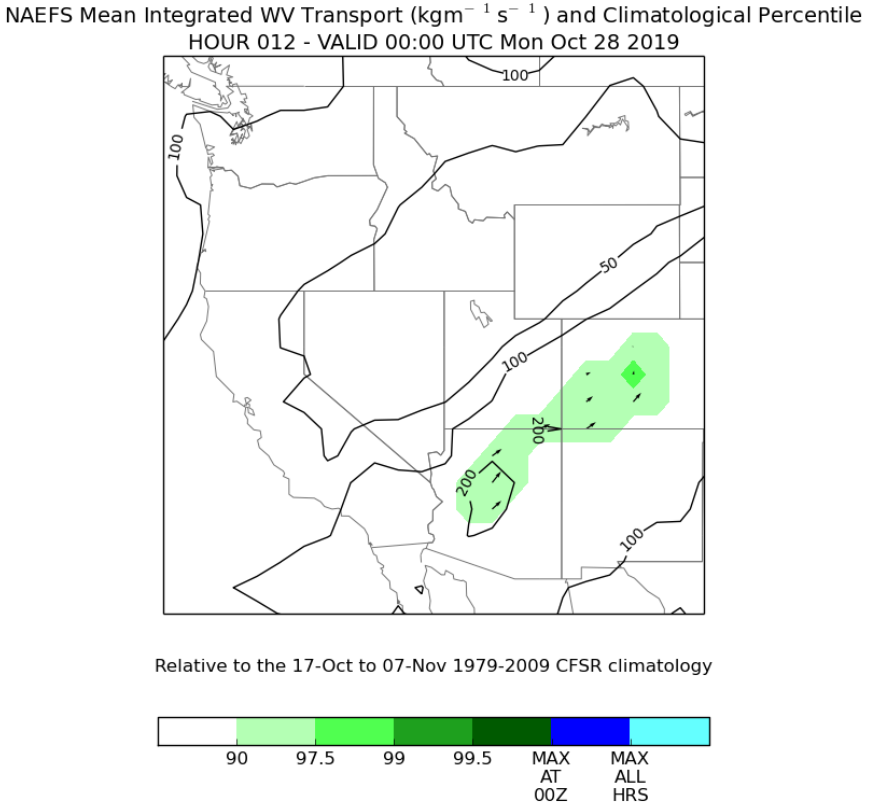
- **Additional Heavy snowfall during a 27–30 October period was associated with a series of low pressure systems that moved across the Four Corners region, which brought additional anomalous water vapor transport to**
- **At 00 UTC (6 PM MST) 28 October, central Colorado was located near the equatorward entrance region of a 250-hPa jet streak, a favorable region for quasi-geostrophic forcing for ascent**





This forecast plot illustrates how the integrated vapor transport was within the 90–99th percentile over central/northern AZ and western Colorado on 28 Oct. (Based on a 3-week climatological reference surrounding 28 Oct. within the NAEFS Dataset)

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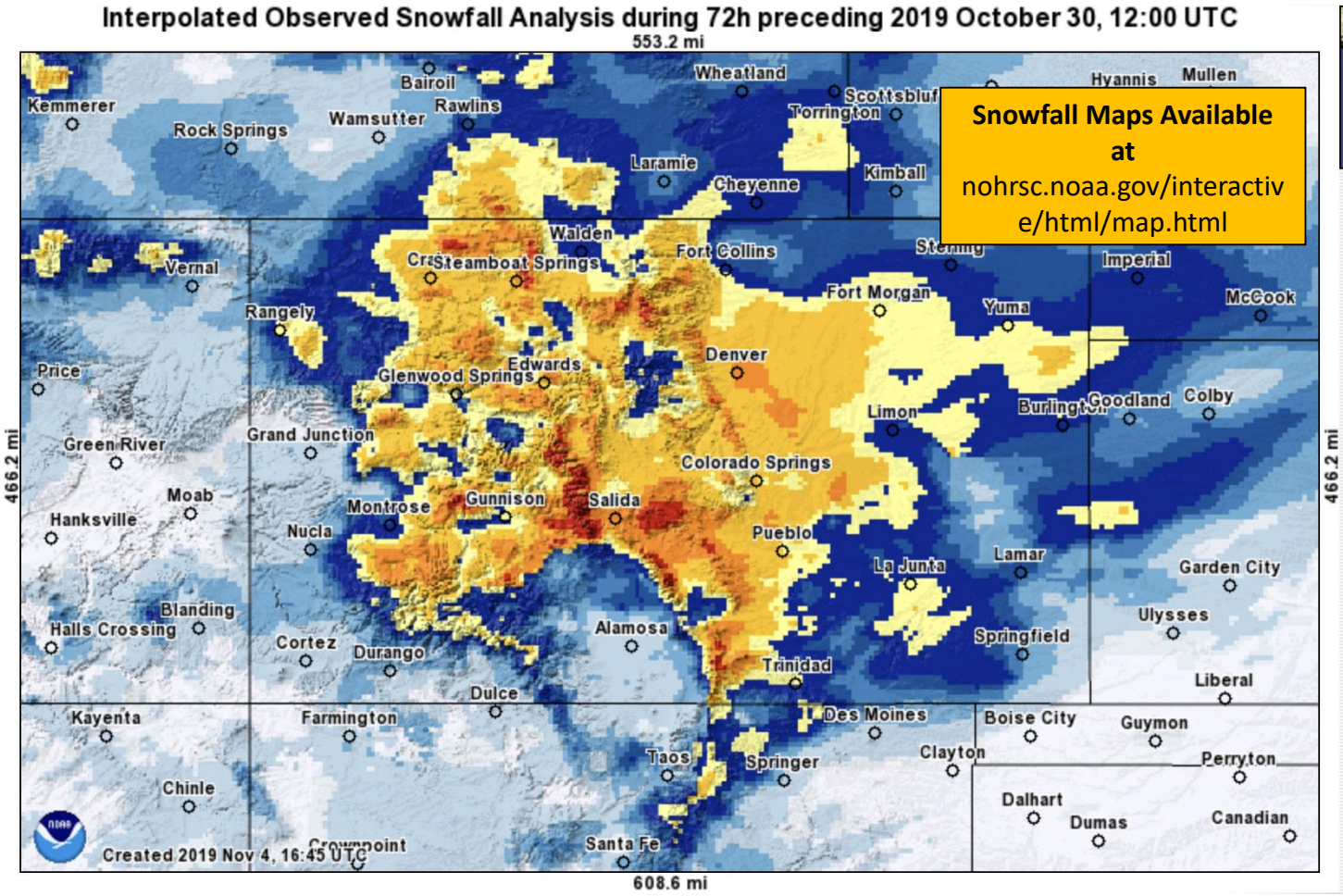
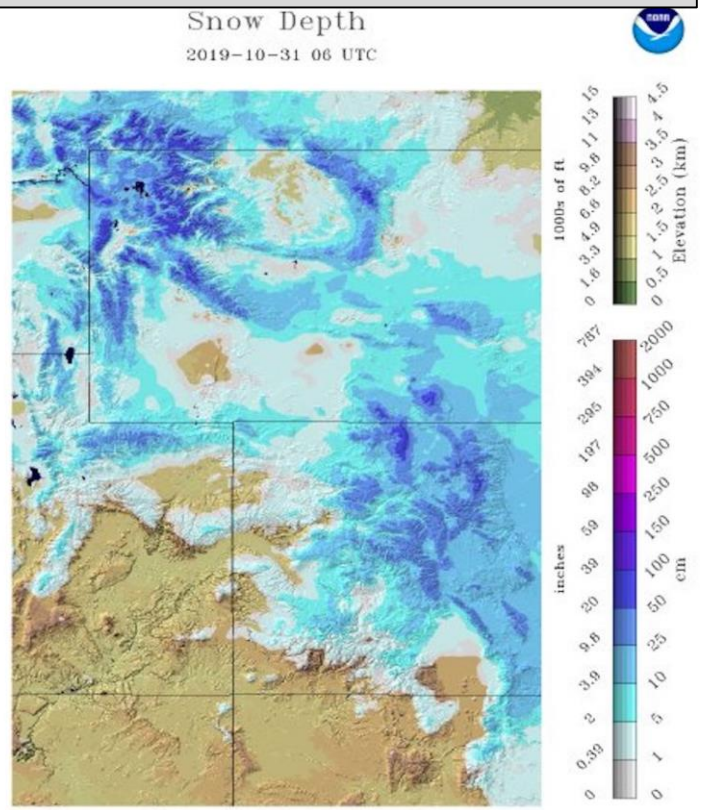
- The additional snowfall near the end of October contributed to a large portion of Colorado having a snow depth >6 inches
- The largest snow depths of >18 inches are over the higher elevations east of Steamboat springs and surrounding the upper Arkansas River Valley with the highest depths of up to 36 inches west of Salida, CO, and over the Continental Divide





Numerous locations in northwestern WY and Southern MT have a snow pack ~20 inches through 31 October, due in part to the inland penetrating ARs

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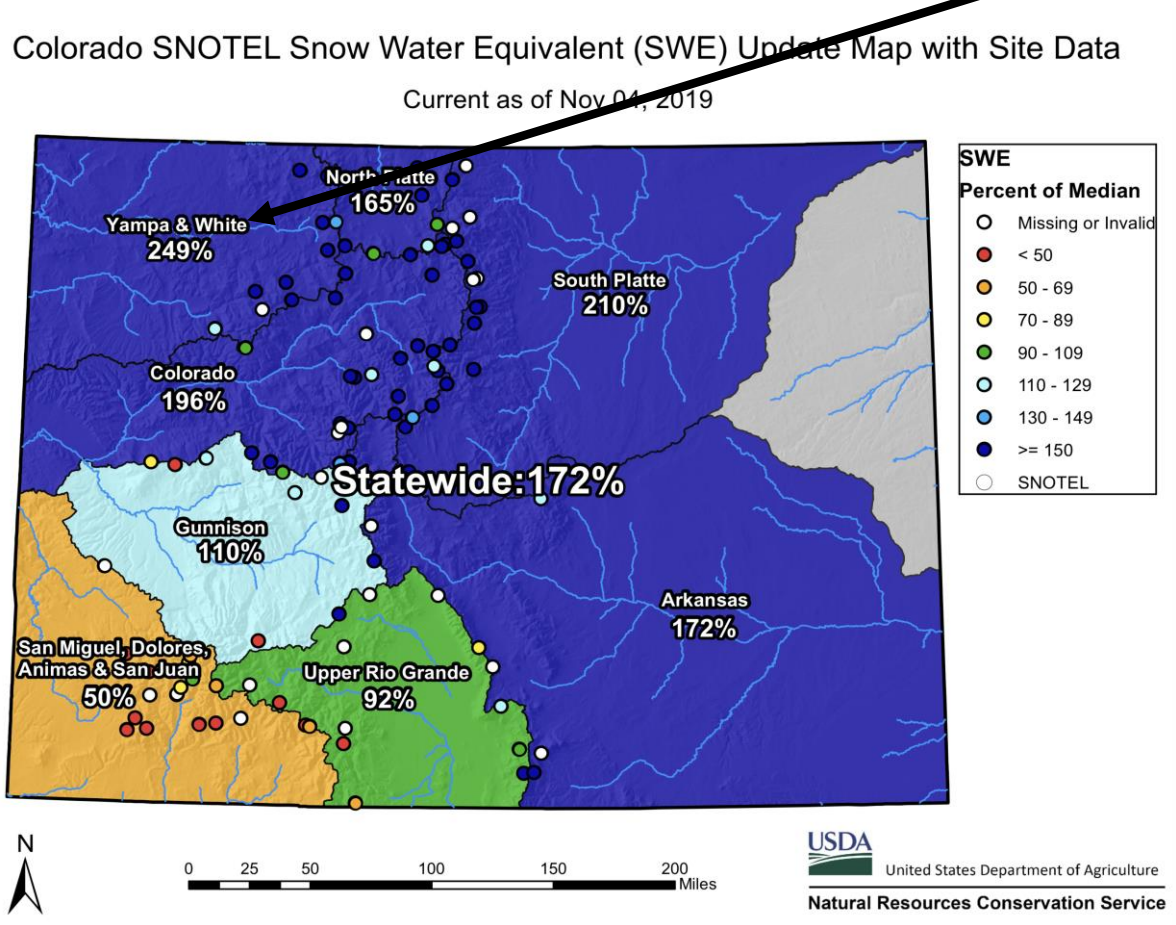
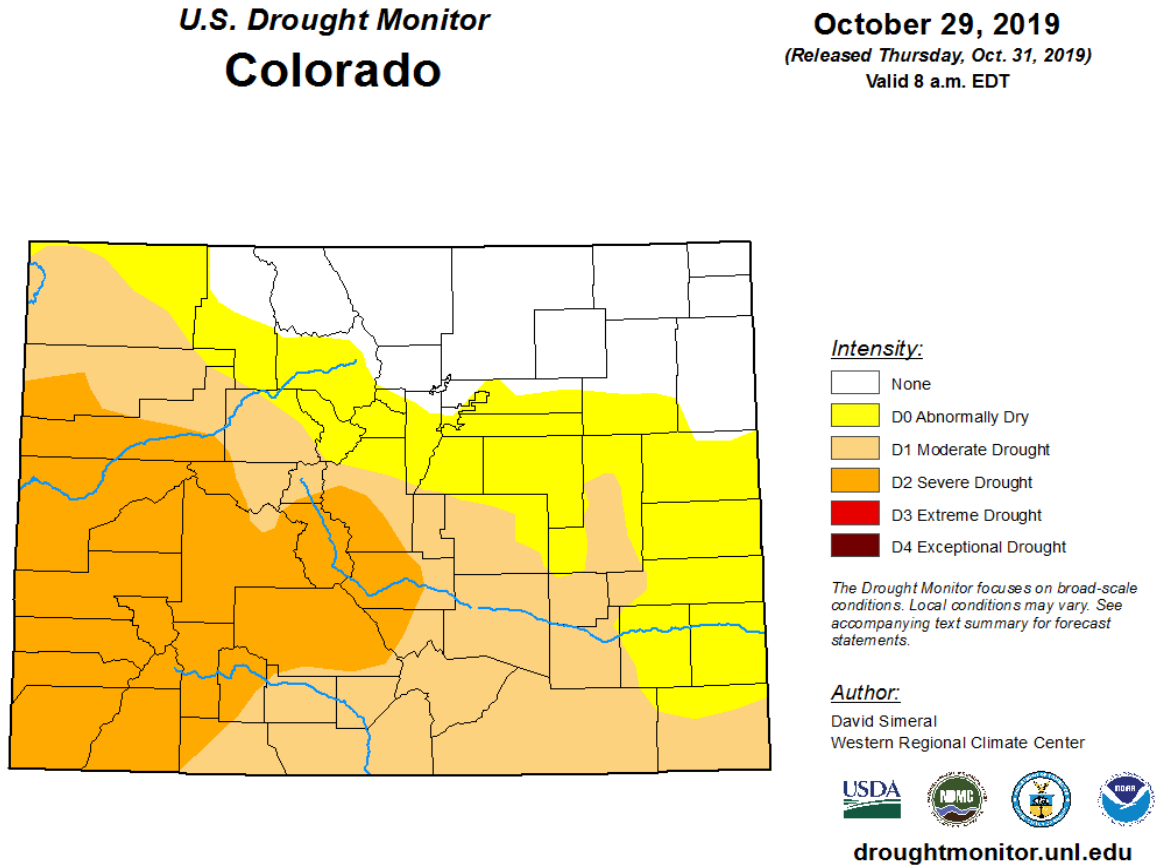
- As of early November, snow water equivalent (SWE) was significantly above the long-term (1981–2010) median throughout much of CO
- The Yampa & White River Watershed, both Tributaries of the Colorado River, received 249% of the year-to-date average



Source: USDA | National Resources Conservation Service, https://www.wcc.nrcs.usda.gov



Source: National Drought Mitigation Center, https://droughtmonitor.unl.edu

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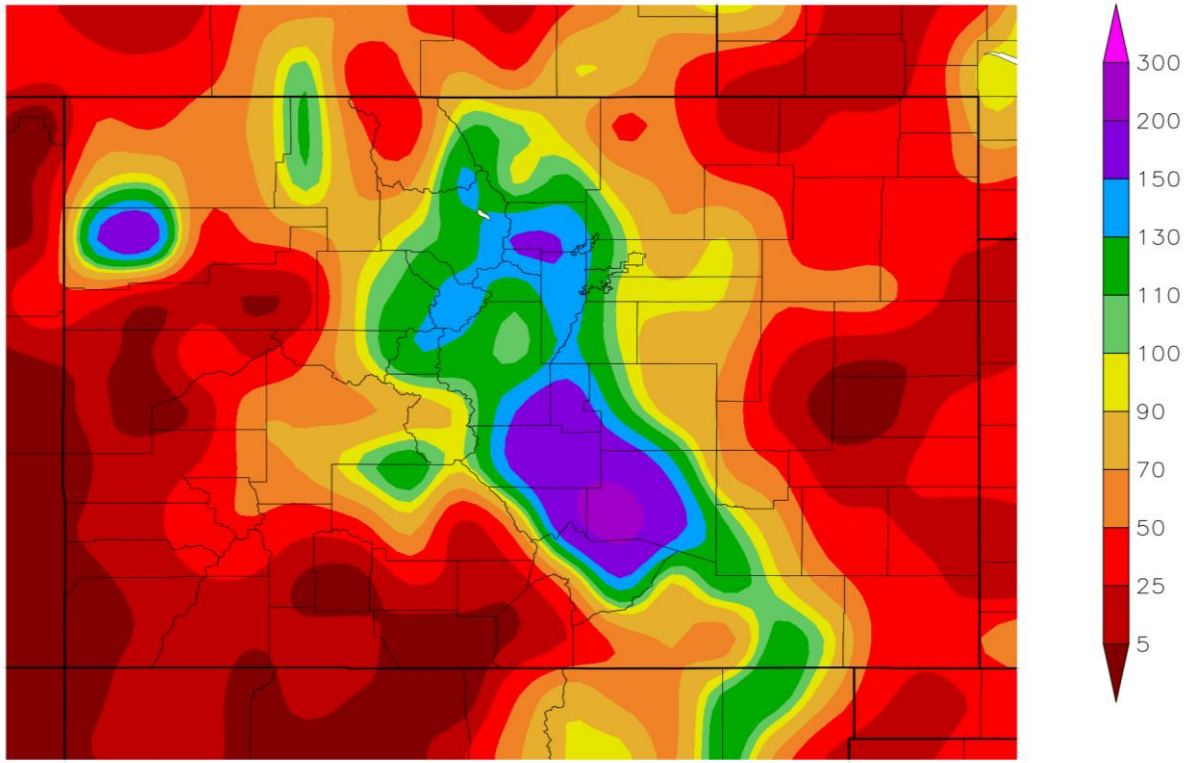
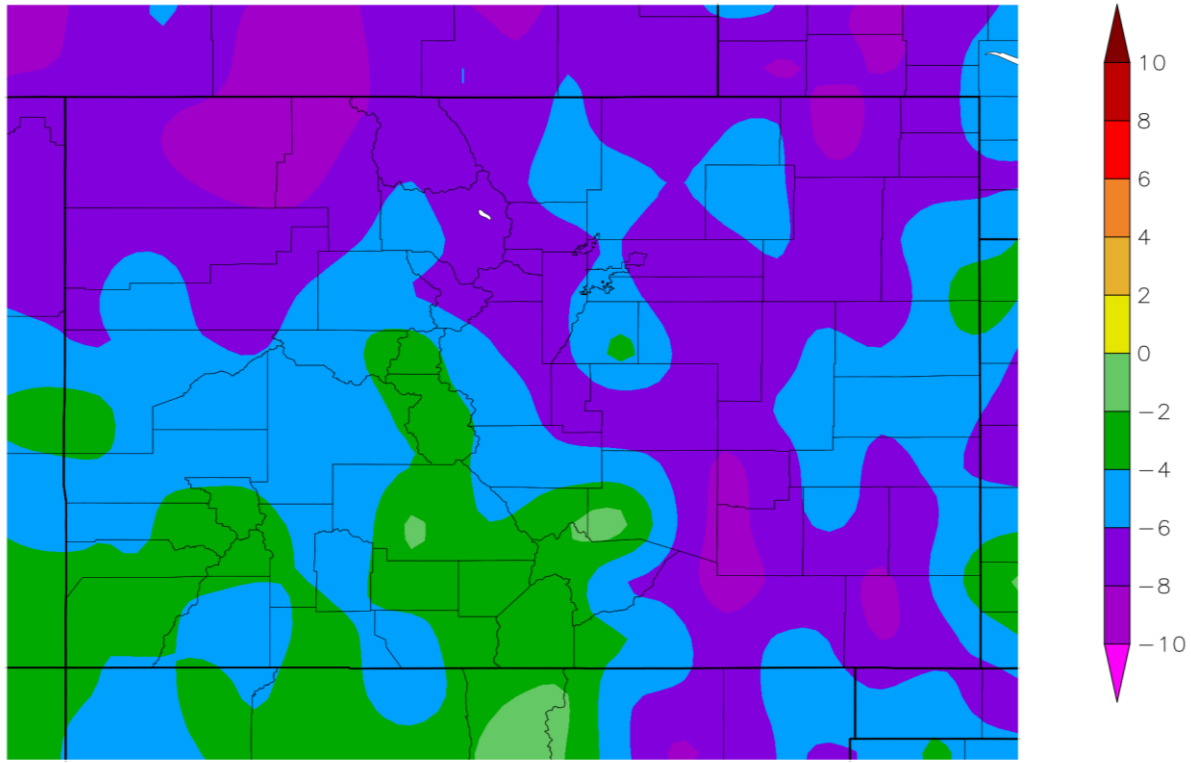
- **Total October precipitation was above normal for a large portion of the Upper Colorado River Basin and just east of the Front Range, but significantly below normal in southwestern and eastern Colorado**
- **October temperatures were below normal across the entire state, especially over northern and eastern Colorado (temperature anomalies between –4°F and –10°F)**

Percent of Normal Precipitation (%)
10/1/2019 – 10/31/2019



Departure from Normal Temperature (F)
10/1/2019 – 10/31/2019



Source: High Plains Regional Climate Center, https://hprcc.unl.edu

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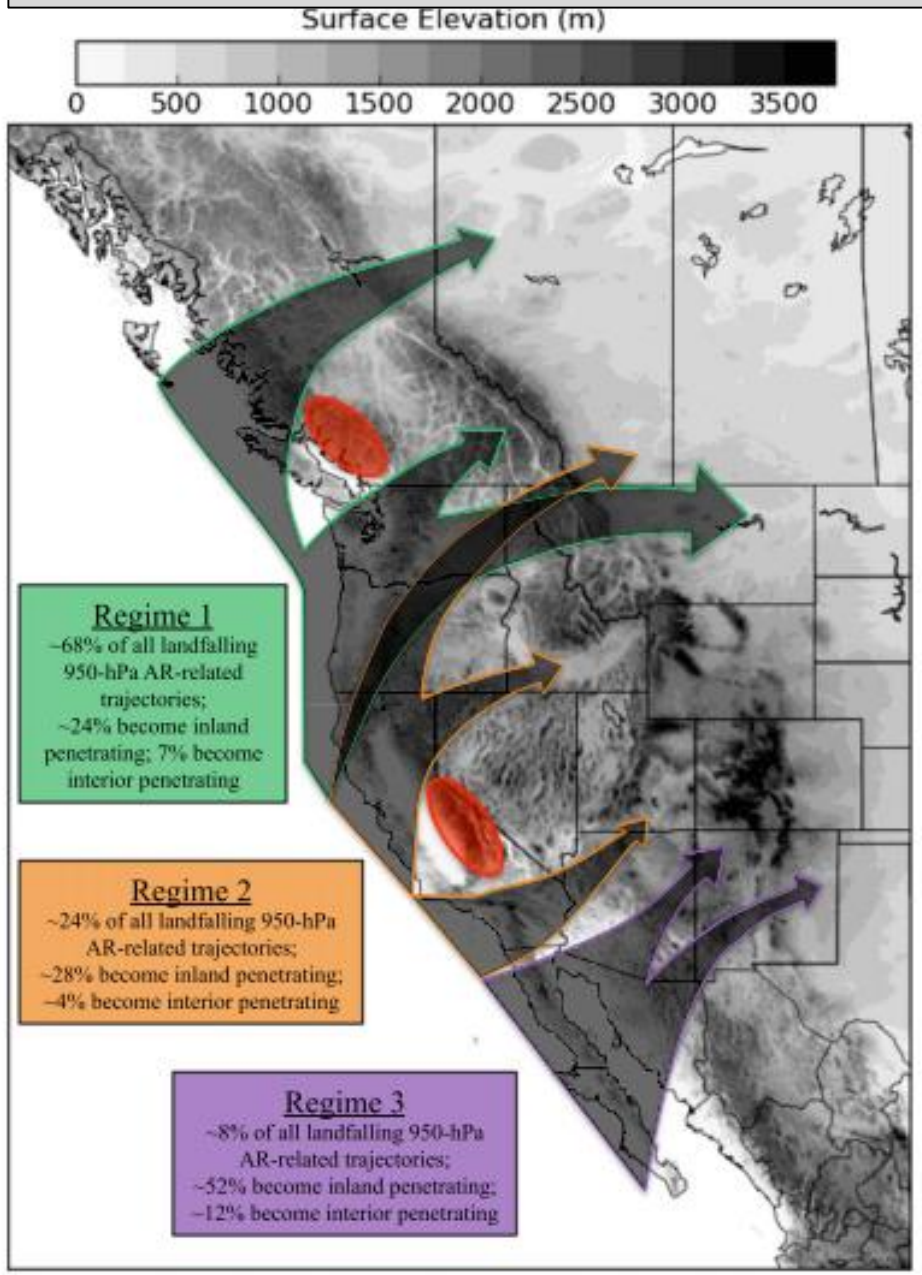

The Inland Penetration of Atmospheric Rivers over Western North America: A Lagrangian Analysis

J.J. Rutz, J. W. Steenburgh and F.M. Ralph
Mon. Wea. Rev., 2015

- **Work by Rutz et al. 2015 identified that westerly to northwesterly oriented ARs that make landfall over the Pacific Northwest have the potential to penetrate inland through gaps of lower terrain and bring AR conditions and impacts to the Intermountain West**
- **While landfalling ARs are very common over the Pacific Northwest, only a small proportion become inland penetrating**
- **~24% and ~7% of ARs that make landfall over the Pacific Northwest become inland and interior penetrating respectively, a proportion much lower (~1/2 as much) than ARs that make landfall over the Mexican Baja (Regime 3; Purple)**
- **For more information on the inland penetration of ARs visit:** https://cw3e.ucsd.edu/wp-content/uploads/2015/06/rutz_etal_mwr_2015.pdf