Synoptic Analysis of Two 14-day Extreme Precipitation Events in the Northwestern United States

ERIKA PRUITT*

National Weather Center Research Experiences for Undergraduates Program
Norman, Oklahoma,
University of Illinois at Urbana-Champaign
Urbana-Champaign, Illinois

TY DICKINSON AND MELANIE SCHROERS
University of Oklahoma
Norman, OK

ABSTRACT

Stakeholders would benefit from knowing more in advance when extreme weather events will happen. Therefore, information on a sub-seasonal to seasonal timescale will be needed, but the skill is very low, and research is needed to improve it. Research has already been done for broad regional information of 14-day extreme precipitation events. This study looked at two case studies of extreme precipitation events out of the northwestern region, one in 2015 and the other in 2018. ERA5 data, PRISM, and Wyoming soundings, was used to find synoptic drivers that caused the two events to occur. It was found that the 2015 event in the West Coast region happened due to the position of the trough over the Pacific Ocean, creating an atmospheric river. For the 2018 event in the Mountain West region, the ridge was the main cause of the event, as it assisted in bringing a supply of moisture in from the Pacific Ocean. In both cases, the jetstream played a role in determining if an area will get a lot of moisture to create the extreme events. Both of these events also had the same supplier for moisture, the Pacific Ocean. It was also found that these events were not just one system precipitating for over 14 days, but rather from three different systems. This study will be useful for stakeholders, who can use the information from these case studies to better mitigate risk from future events.

1. Introduction

Long duration extreme precipitation may not be a common disaster, but it can bring heavy impacts when these events occur. It can bring hazards such as flooding, one of the costliest of all natural disasters. These extreme precipitation events bring damage to not only properties, but also have taken an average of 88 lives per year (US Department of Commerce 2020). These events also have the potential to affect water resources, and the environment. These issues can be reduced if we could understand forecasting at the Subseasonal to Seasonal (S2S) time frame (Vitart et al. 2017). Weather forecasting, 0 to 14 days, is skilled enough that model errors do not impact the results heavily. In contrast, S2S forecasts, between 14 days to two months in advance, have much lower skill, so having model errors will have a bigger impact, as it will be too large to ignore (Jennrich et al. 2020). Stakeholders would benefit from forecasting information as far out as two weeks to two months. This creates a need to increase the forecasting skill within the timescale. This information can help them improve social responses and awareness of extreme weather.

S2S prediction systems can predict extreme weather like heat waves, cold spells, heavy precipitation events, and tropical and extratropical cyclones. The focus of this project is to investigate 14-day extreme precipitation events to understand their drivers, in order to improve the skill for S2S forecasting. The database of 14-day extreme precipitation comes has 15 different regional clusters, from all around continental United States from 1915-2018 (Dickinson et al. 2021). There are a total of 851 extreme weather events within the database.

In this study we will analyze two different case studies of 14-day extreme precipitation events to obtain a deeper understanding of the synoptic drivers. Both events are located on opposite sides of the Rocky Mountains, so differences can also be found in the synoptic drivers that formed the events. One is in the Mountain West (MW) region and the other is in the West Coast (WC) region. The West Coast (WC) has wet seasons between Novem-

---

**Corresponding author address:* Erika Pruitt, University of Illinois at Urbana-Champaign
E-mail: epruit3@illinois.edu

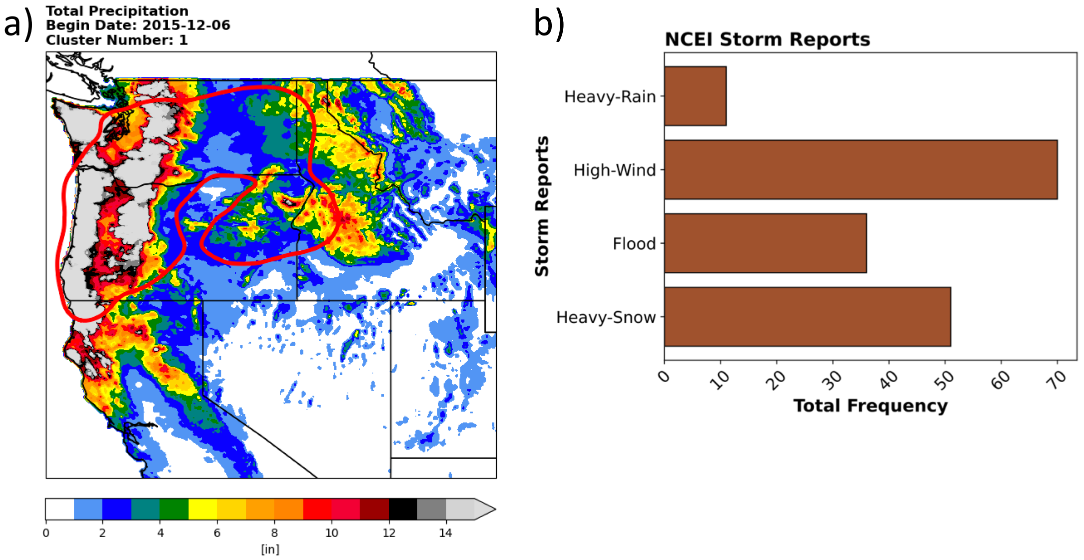

FIG. 1. a) Spatial total Precipitation amounts during event within the West Coast, with the event polygon seen in red b) Total count of NCEI Storm reports during the West Coast event.

ber and March. During these wet seasons, the extreme events can bring impacts like, heavy precipitation, flooding and high winds. In the Mountain West (MW) region, the wet seasons are around the months of June to October. Both regions have their differences in terms of climate, frequency of extreme precipitation, and even different drivers for their extreme precipitation (Schroers and Martin 2022). Understanding these differences and synoptic drivers will also be useful in further understanding S2S extreme weather.

2. Methods

a. Data

The Parameter Elevation Regressions on Independent Slopes Model (PRISM) was used to find precipitation data from the 14-day extreme events, since it can provide this information from 1981 until present day throughout the the continental United States (CONUS), (PRISM Climate Group, Oregon State University 2004). It can also provide a high 4-km resolution and can be used in areas with no direct observation.

For synoptic variable analysis, the European Centre for Medium-Range Forecast (ERA5) was used. The average, minimum and maximum temperatures, 500hPa and 300hPa geopotential height, and precipitable water, u-v winds and snowfall can be analyzed using this data (Copernicus Climate Change Service (C3S) 2017). ERA5 runs on an hourly temporal resolution but, for these case studies, the data was averaged into daily values. Lastly, vertical profile data from the University of Wyoming atmospheric soundings were used in the synoptic analysis (UWYO, Atmospheric Soundings 2016). This can be run by selecting the date, time and station of interest. For the West Coast and Mountain West event, the domain of the northern Pacific Ocean and northwestern CONUS will be used. The northern Pacific Ocean will be used due to its importance for western United States weather.

The two case studies that were studied came from the database by Dickinson et al. (2021). To be classified as a 14-day extreme event, the precipitation measurements needed to stay above a 99th percentile, the duration needed to be greater than or equal to seven days of rain, and lastly it needed to cover at least 200,000km2 of area

b. Case Studies

After looking at the 851 14-day extreme precipitation events, the two selected were an event of 2015 between December 6th to December 19th and an event of 2018 between February 3rd to February 16th. These two events were located on opposite sides of the Rocky Mountains and were characterized by different synoptic drivers.

1) EVENT 1: DECEMBER 6TH-19TH 2015

This extreme rain event occurred during the wet season of Oregon, Washington, northern California, and western parts of Idaho. As shown in the red polygon in figure 1a, the event impacted parts mainly in Oregon and Washington. There was a total of $36.51 million in property damages (NOAA-NCEI 2020) during the event owing to heavy

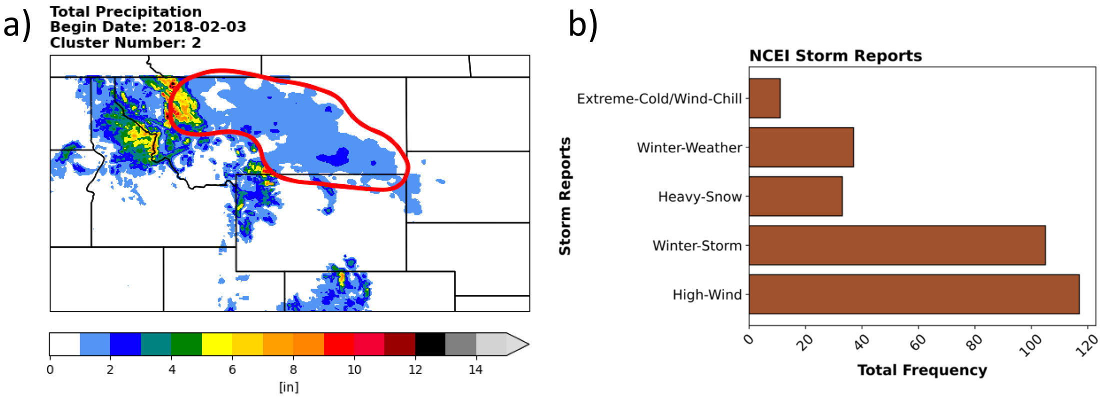

Fig. 2. Same as 1 but for the Mountain West Event

precipitation, high winds, and flooding (figure 1b). After a further look into this event, the snow reports came from the mountainous regions, making this an extreme rain event. The maximum precipitation for the entire event was up to 47.55 inches with 11.84 inches as the max daily precipitation Dickinson et al. (2021). Compared to the Pacific Northwestern average rainfall of about 84 inches a year, 47 inches is fairly large for one event (Western Regional Climate Center 2016).

Other than high property damages, many affected communities also saw massive flooding, mudslides, power outages, road closures and even contamination due to overflowing sewage systems during this event. There were other reports of an EF1 tornado in Battle Ground, Washington bringing in winds as high as 77mph (NOAA-NCEI 2020). This event also took three lives and injured two.

2) EVENT 2: FEBRUARY 3RD-16TH 2018

This extreme event occurred during the dry season of Montana and northern Wyoming. In the red polygon in figure 2a shows where the extreme event took place. It resulted in a total of $10 million in property damages with many reports of high wind and winter storm, seen in figure 2b (NOAA-NCEI 2020). Besides high property damages, this event also resulted in up to 58 inches of snow, icy roads, power outages and brutally cold wind chills as low as -58ºF. Temperatures during this time were also as low as -40ºF in some areas as well. After a further look into this event, it was found to be a record-breaking snow event. The maximum liquid equivalent precipitation for the entire event was up to 10.96 inches with 1.96 inches as the max daily precipitation (Dickinson et al. 2021). Western Montana can see up to 300 inches of snowfall annually while other parts can see up to 50 inches annually (Montana Kids 2020).

c. Analysis

Many of the ERA5 variables and the skew-ts' will be useful in understanding drivers for both events. PRISM will be used to analyze daily averages of precipitation throughout each event to help estimate the total number of systems that occurred during the events. An additional variable, snowfall, was used for the event in the Mountain West region, to obtain snowfall totals. To find the equation for snowfall totals, downloaded variables like the snowfall liquid equivalent and the snow density deemed helpful. We used the following equation to convert the snowfall from liquid equivalent to meters:

$$snow_{meters} = \frac{\rho_{water} * snowfall_{le}}{\rho_{snow}} \tag{1}$$

3. Results

a. Event 1: West Coast 2015

While looking at daily total precipitation throughout this event in figure 3, it was also found that at least three systems passed over during this event. Using PRISM, the cities could be broken up to find total precipitation amounts throughout the event. Using this, three peaks were found, which will be classified as systems that rolled over during the event. These systems were on December 9th, 13th and 18th with December 9th having the most precipitation, then December 18th, and lastly the December 13th system.

1) VERTICAL PROFILE

For this event, both the Spokane, WA (OTX) and Medford, OR (MFR) stations were used. figure 5a shows the soundings for MFR during the December 13th system and figure 5b shows the soundings for OTX during the December 9th system. Both soundings featured extremely moist profiles througnout the entire troposphere. Looking

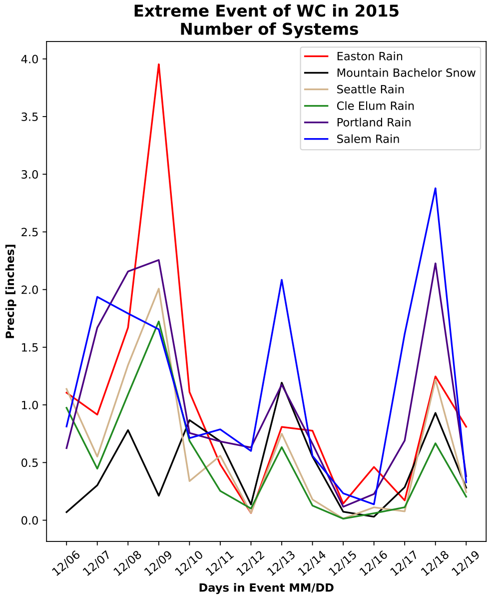

FIG. 3. Line graph for the precipitation in inches for six cities throughout West Coast event. Each peak represents a system

up to 300hPa, the winds are measured as high as 100 knots, coming from the WSW as seen in figure 5a. Since these winds are coming from WSW, this will be an onshore flow, with the moisture coming from the Pacific Ocean. Between both stations, MFR soundings showed that there was a lot of moisture coming in during each system. This could be because Medford is much closer to the coastal area where the most precipitation fell. In all soundings for each system, the temperature line stayed above 0ºC near the surface, meaning they were each rain events.

2) UPPER-LEVEL ANALYSIS

There is a consistent geopotential height dipole over the Pacific Ocean throughout before the entirety of the event. Within December 9th in figure 6a, there is a strong ridge with a stardardized anomaly of above 1.8, under the dipole. The trough moves in a counterclockwise motion while the ridge moves in a clockwise motion. Both flows contribute to making the noticeable atmospheric river (AR) seen in the narrow corridor of precipitable water, being advected into the region (figure 6b). The red arrows represent the movement of the wind, and the length represents the movement of the winds at 500hPa, and the length represents the strength of the winds in those areas. The AR is represented by the line of blue with the anomaly above 1.8, with long red arrows pointing inland. The area between the large ridge and trough, are the possible creators of the AR. This same line of moisture was seen for each system, the 500hPa jetstream shows this same area also having as much as around 73m/s (141 knots) average wind speeds (figure 6c). As seen by the positioning of the jet, this region is located in the left exit part of the jetstream. This region is a region of ascent, creating a rising motion that can support precipitation.

Looking at the precipitable water for December 13th (figure 6d), and for December 18th (figure 6e), there is a difference in the amount of moisture being advected, due to the stronger dipole over the Northern Pacific seen within the first system. Therefore, the first system produced more precipitation than the second system. In figure 6f, the ridge is standardized anomaly drops below 0.6. Even with the dissipating ridge, the trough still provides enough to supply the northwestern region (figure 6e).

3) SURFACE-BASED ANALYSIS

With each system, the temperature becomes cooler. Figure 7a is the surface temperature for December 9th. During this system, the area of the extreme event is above freezing, which can also explain why this system had the most total precipitation than the other systems. Figure 7b, shows the surface temperature for the system on December 18th. By this time, the freezing line (dotted line) had pushed much further south, dropping the temperatures by up to 10ºF in parts of Oregon a week prior. Throughout each system, the surface temperatures along the coastal area seemed to stay above 32ºF. This is also the area that received the most amount of precipitation during the event (figure 1a).

b. Event 2: Mountain West 2018

While looking at daily total precipitation throughout this event (figure 4), it was also found that at least three systems passed over during this event. Using PRISM, the cities could be broken up to find total precipitation amounts throughout the event. Three peaks in precipitation amount were found, which will be classified as systems that rolled over during the event. These systems were on February 5th, 9th, and 15th with February 9th having the most precipitation, then February 5th, and lastly February 15th.

1) VERTICAL PROFILE

For this event, the station located in Great Falls, Montana (TFX) was used to analyze the vertical profile. During this event the atmosphere was very moist, as seen in the skew-T in figure 8a. The moist content lowers towards the end of the day during the last system on February 15th. Temperature line stays under 0ºC which also supports that there was only snow produced during the time of these systems. The temperature profile was between -10ºC and -20ºC for much of the vertical column during each system (figures 8a, 8b, and 8c). Being between those temperatures signifies the dendritic growth

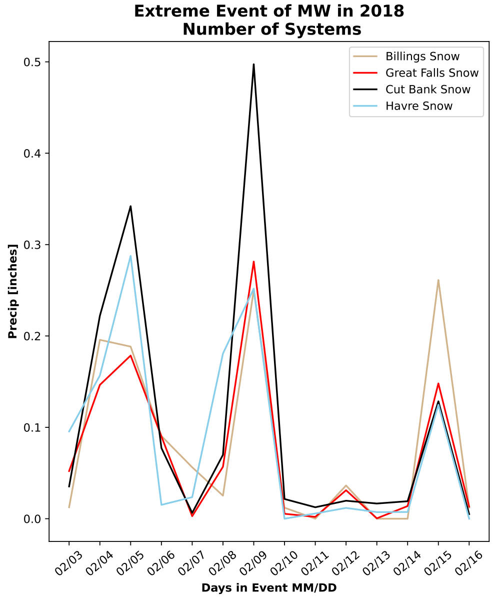

FIG. 4. Same as a but for the Mountain West Event

zone where snowflakes, grow efficiently, supporting large snowfall totals.

2) UPPER-LEVEL ANALYSIS

Looking at the geopotential heights at 300hPa, there is a noticeable strong ridge that has above a 1.8 standardized anomaly (figure 9a). Therefore, it is possible that the ridges position is influencing the moisture going into the Montana. The precipitable water before the second system on February 9th, is seen in figure 9b. We also see, a huge surge of moisture that gets pushed into the area on February 9th. This same flow is seen before the other systems as well, as shown in figure 9c and figure 9d. Figure 9d shows the flow before the third system, February 15th, and it shows the storm dissipating as there is less moisture being advected in before the system. Thus, it follows that this system also had the least amount of precipitation out of the other systems.

In the overall flow for each system, the red arrows have a much longer magnitude, meaning high winds during that time. Looking more at the jetstream at 500hPa, the winds were consistently between 36 to 45 m/s (figure 9e). The jet stream helps clarify that the moisture is coming from the Pacific Ocean and is most likely riding along the path of the ridge. Looking at the jetstream and geopotential heights for February 15th, it can be easily seen that the ridge is slowly moving more northernly, which causes the trough to be pushed southernly (figure 9f and 9g). The movement of the ridge is likely the reason for the arctic temperatures that occurred as well as what ended the series of systems that occurred during this extreme event.

3) SURFACE-BASED ANALYSIS

From looking at the upper-level analysis, cooler temperatures are expected due to the sinking of the trough. The average surface temperature throughout the three systems can be found in figures 10a, 10b, and 10c. As expected, the freezing line moves southernly after each system. Figure 10b shows the system of February 9th. When compared to the other systems, this day was the coolest and produced the most snowfall. Temperatures hit as low as below -10ºF in some areas and even lower than -22ºF in northern regions of Montana.

4. Discussion

For both events, the location of the jetstream and the constant supply of moisture were huge influences. The event within case study 1, occurred during the winter of an El Nino, and the jet position was anomalously poleward compared to a typical El Nino. The typical effects of an El Nino makes northwestern CONUS experience drier and warmer weather. But due to the large ridge over the Pacific Ocean, it drove the moisture into the West Coast area, bringing in an AR. In contrast, within case study 2, the event occurred during the winter of a La Nina. The path of the jetstream mimicked a similar expected path for a La Nina. The high over the Pacific Ocean continuously supplied this region which resulted in such heavy snowfalls.

Within both events, there was a total of three systems that occurred. This information will be useful in realizing that 14-day extreme precipitation events are likely composed of a combination of multiple moderate to heavy-precipitation systems in relatively close succession. From what was gathered so far, it also seems that there is no specific order on which system will be stronger than the others. In both case studies, the strongest system was not always the first one, nor was the weakest system the last one.

5. Conclusion

Extreme precipitation events like the two different case studies, are uncommon, but can be very impactful. Being able to have reliable forecasts at the S2S timescale will be beneficial. Stakeholders will be able to use info to help in a wide range of sectors like water management, health, etc. This info will also help prepare for the increase in frequency, duration, and power of future extreme events due to climate change (Clarke et al. 2022; Dickinson et al. 2021). Using ERA5 variables University of Wyoming soundings, Dickinson et al. (2021). 2021 database and PRISM precipitation, the synoptic analysis for two northwestern 14-day extreme precipitation events was conducted.

The largest influences of these extreme events in the northwesten CONUS were the jetstream's position, magnitude, and gradients, and the magnitude advection. Although ENSO conditions may exist, they are not the only drivers for these events. From the studies, it was also found that extreme events may be a combination of multiple precipitation systems impacting the region. Overall resulting in extreme precipitation that have major impacts in areas affected. Future case studies may investigate other variables such as vertical velocity and divergence to compliment the present findings. Overall, this study helped to provide leverage in other case studies since this is only two events out of the 851 events.

Acknowledgments. The author would like to thank Ty Dickinson, Melanie Schroers, and all other members of the $PRES^2iP$ team for assisting and providing a foundation with this research. I would also like to thank the Oklahoma REU program for gaining this wonderful opportunity to work alongside all of those who helped. This research was funded through the National Science Foundation Grant SF AGS-156041919.

References

Clarke, B., F. Otto, R. Stuart-Smith, and L. Harrington, 2022: Extreme weather impacts of climate change: an attribution perspective. *Environmental Research: Climate*, **1 (1)**, 012 001.

Copernicus Climate Change Service (C3S), 2017: ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate. *Copernicus Climate Change Service Climate Data Store (CDS).*

Dickinson, T. A., M. B. Richman, and J. C. Furtado, 2021: Subseasonal-to-Seasonal Extreme Precipitation Events in the Contiguous United States: Generation of a Database and Climatology. *Journal of Climate*, **34 (18)**, 7571–7586.

Jennrich, G. C., J. C. Furtado, J. B. Basara, and E. R. Martin, 2020: Synoptic Characteristics of 14-Day Extreme Precipitation Events across the United States. *Journal of Climate*, **33**, 6423–6440.

Montana Kids, 2020: Montana climate infomation. URL https://montanakids.com/facts_and_figures/climate/Climate_Information.htm.

NOAA-NCEI, 2020: Storm Events Database. URL https://www.ncdc.noaa.gov/stormevents/.

PRISM Climate Group, Oregon State University, 2004: URL http://prism.oregonstate.edu.

Schroers, M., and E. Martin, 2022: Synoptic connections and impacts of 14-day extreme precipitation events in the united states. *Journal of Applied Meteorology and Climatology*, **61 (7)**, 877 – 890.

US Department of Commerce, N., 2020: Thunderstorm hazards: Flash floods. NOAA's National Weather Service, URL https://www.weather.gov/jetstream/flood.

UWYO, Atmospheric Soundings, 2016: University of wyoming atmospheric soundings. URL https://weather.uwyo.edu/upperair/sounding.html.

Vitart, F., and Coauthors, 2017: The Subseasonal to Seasonal (S2S) Prediction Project Database. *Bulletin of the American Meteorological Society*, **98 (1)**, 163–173.

Western Regional Climate Center, 2016: Western regional climate center. URL https://wrcc.dri.edu/.

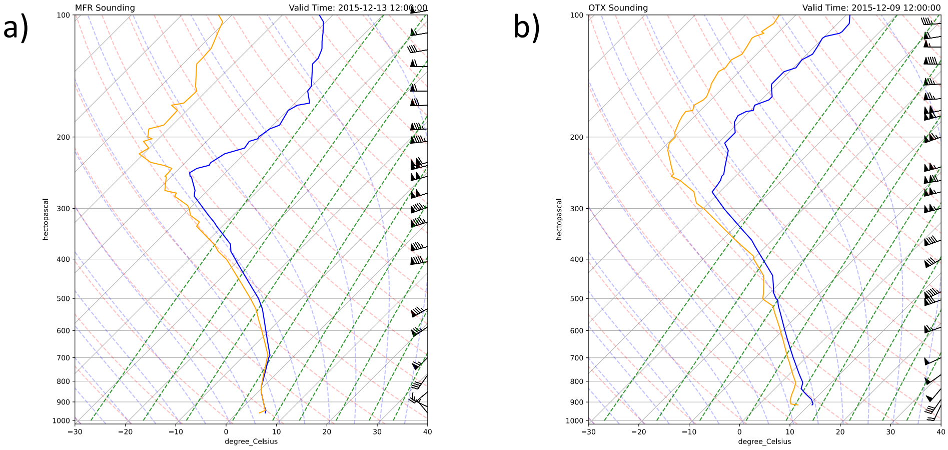

FIG. 5. Skew-T for both Medford, OR (MFR) and Spokane WA (OTX)

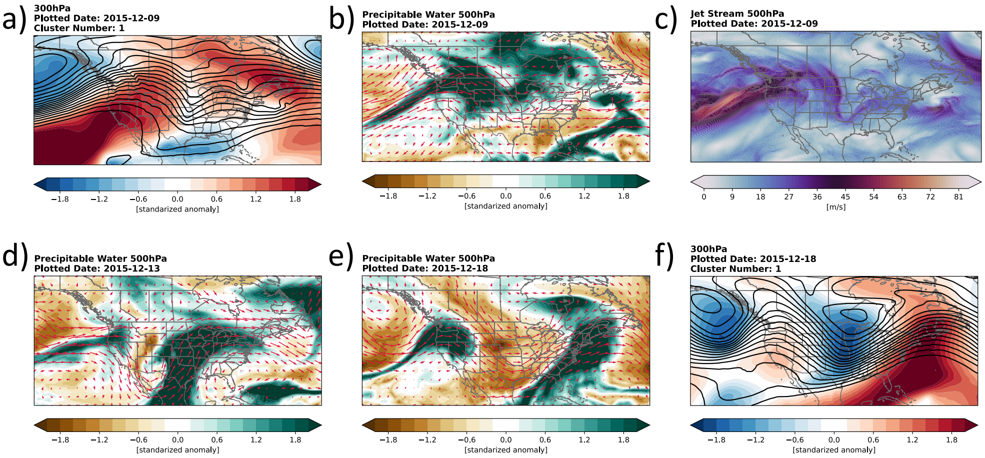

FIG. 6. Upper level analysis of West Coast Event: (a) and (f) 300 hPa geopotential height standardized anomaly fields with the raw 300 hPa geopotential heights overlaid (black lines), (b), (d) and (e) 500 hPa precipitable water standardized anomaly field with wind directions overlaid (red arrows) and (c) 500 hPa jetstream in m/s. Date of map seen in figure title.

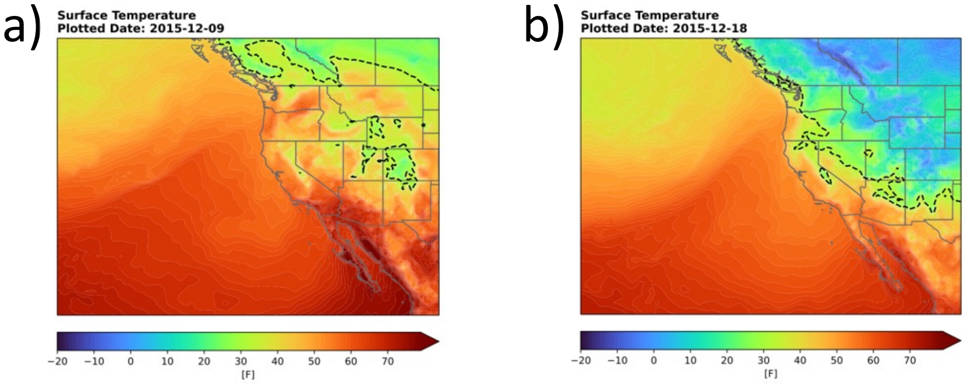

FIG. 7. Surface temperature for each system in Fahrenheit during West Coast event with freezing line (black dotted lines). Date of map seen in figure title.

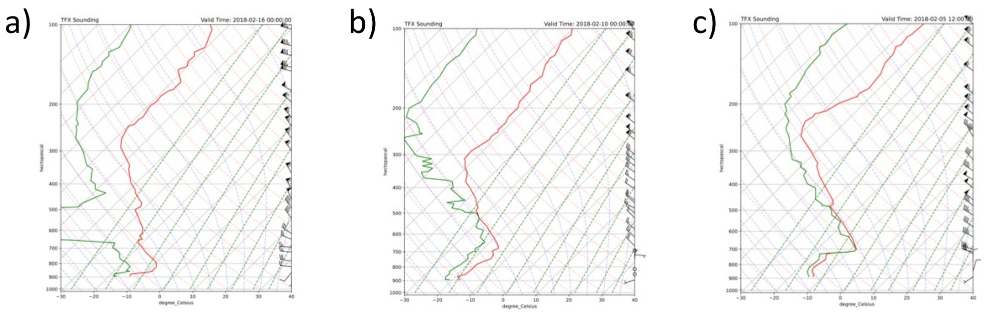

FIG. 8. Skew-T for Great Falls, MT (TFX)

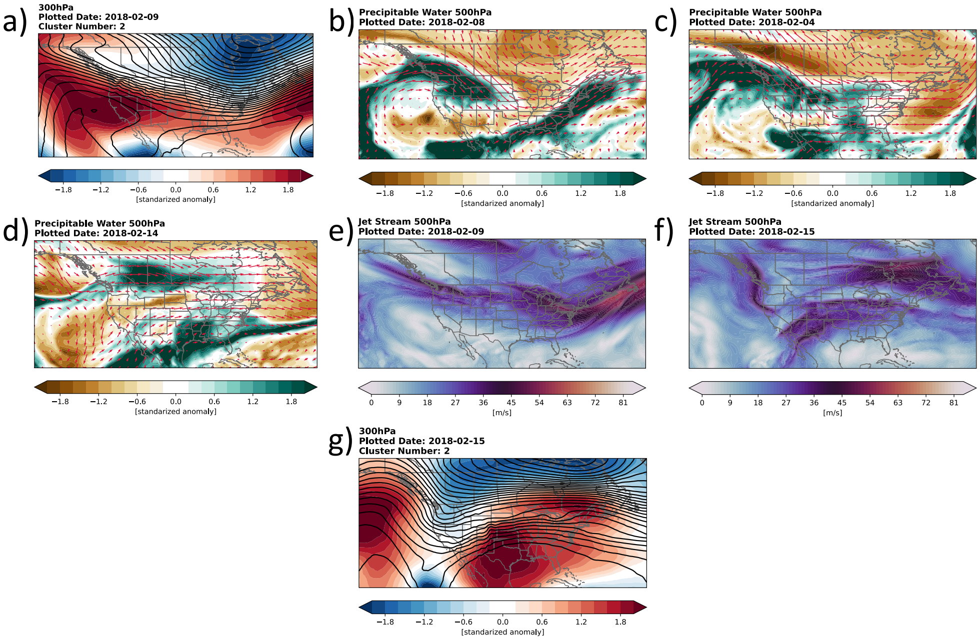

FIG. 9. Upper level analysis of Mountain West Event: (a) and (g) 300 hPa geopotential height standardized anomaly fields with the raw 300 hPa geopotential heights overlaid (black lines), (b), (c) and (d) 500 hPa precipitable water standardized anomaly field with wind directions overlaid (red arrows) and (e) and (f) 500 hPa jetstream in m/s. Date of map seen in figure title.

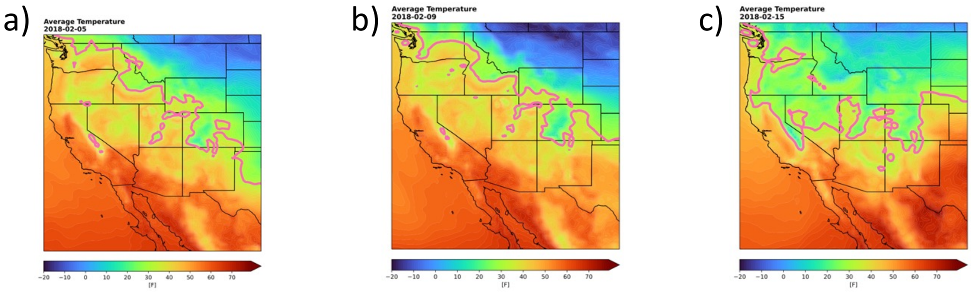

FIG. 10. Same as 5 but for the Mountain West Event and freezing line (pink lines).