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July 2018 Mid-Atlantic Atmospheric River and Extreme Precipitation Event Captured by MERRA-2

Allie Collow and Mike Bosilovich

SUMMARY

Despite limited precipitation during the first part of July 2018, the month ended as one of the wettest Julys on record for the Baltimore/Washington D.C. area. Beginning on July 21, 2018, an atmospheric river, a narrow stream of enhanced water vapor transport, positioned itself over the region, resulting in record daily rainfall totals and extensive flash flood warnings as the entire months' worth of precipitation fell in a matter of days. This rainfall event was clearly captured by GMAO's Modern Era Retrospective analysis for Research and Applications, version 2 (MERRA-2), and given the nearly 40-year record of MERRA-2, can be placed in the context of past events and the overall climate for the region during July. Not only was the multi-day rainfall out of character using multiple metrics, but large-scale atmospheric features throughout July differed from the roughly 40-year climatology and there were even bigger differences in the state of the atmosphere between the first and second halves of July 2018.

BACKGROUND

Atmospheric rivers, narrow, highly concentrated filaments of atmospheric water vapor, are responsible for approximately 90% of the poleward transport of water vapor outside of tropics (Zu and Newell, 1998). Though most common along the west coast of the United States, atmospheric rivers can also impact the weather around the globe, including the east coast of the United States (Guan and Waliser, 2015). Climatologically, most atmospheric rivers are present over the ocean, but when landfall is made and proper synoptic or orographic conditions are met, the resulting extreme precipitation events can have catastrophic impacts on society, including extensive flooding (Lamjiri et al., 2017).

The Formation of an Atmospheric River

Figure 1 shows total precipitable water vapor (TPW) from MERRA-2 at 00:30z on July 22, 2018, within the time period when the most precipitation fell in the area around the Baltimore/Washington Airport (BWI), here defined as an area of roughly 25 km^2 surrounding the airport. The narrow filament of an atmospheric river extended from the Gulf of Mexico and converged into Maryland with near tropical values (exceeding 50 km m^{-2}) of TPW. In conjunction with the synoptic influence of a low pressure system moving up the eastern seaboard, this band of elevated TPW provided enough moisture to cause record breaking precipitation in the region on that day.

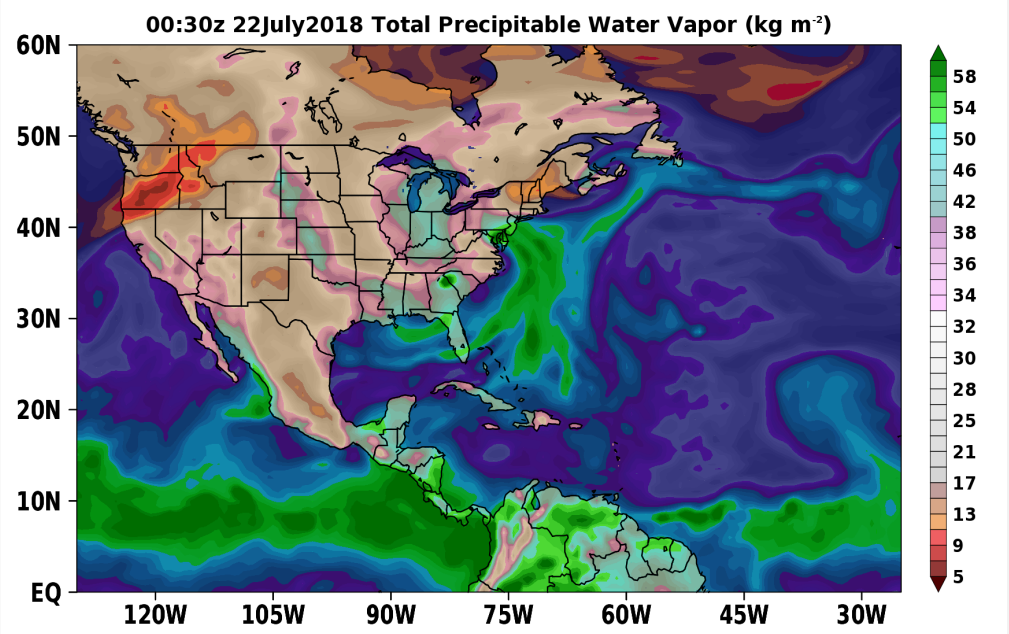

Figure 1. Total precipitable water vapor at 00:30z on July 22, 2018, from MERRA-2.

Throughout the multi-day precipitation event, a sub-tropical high pressure system was present over the Atlantic Ocean and a digging trough extended south into the Gulf of Mexico and north to the east coast. Both features helped guide the transport of water vapor into the Maryland area, as evident in the corresponding animation at https://gmao.gsfc.nasa.gov/researchbriefs/midatlARevent_July2018/midatlARevent_July2018.mp4. The sub-tropical high is a semi-permanent feature that is not out of the ordinary for this time of year. However, the southern extent and waviness

of the jet stream are typical of winter-like patterns and unusual for the summer months. The majority of the moisture originated from the Gulf of Mexico and Gulf Stream, but an additional pocket of moisture branched off of the Intertropical Convergence Zone (ITCZ) on July 19 and converged with the atmospheric river on July 21.

The first, most intense, round of precipitation on July 21 and into July 22 was accompanied by a low pressure system that made its way up the east coast. Subsequently, the atmospheric river took on a more southerly flow and lingered over the east coast before being pushed out by a high pressure system on July 26. The precipitation during the latter part of the event tended to be more convective in nature.

Extreme Precipitation in the Region

A map of the accumulated precipitation in the area spanning the week of July 19, 2018 through July 26, 2018 from the Integrated Multisatellite Retrievals for the Global Precipitation Measurement mission (GPM IMERG; Huffman, 2015) can be seen in Figure 2. The highest precipitation accumulations occurred along the strip extending from central Maryland through Pennsylvania, with localized maxima near BWI and to an even greater extent in Pennsylvania, north of Harrisburg. Within the BWI region, the total accumulation for this week of ~180 mm substantially exceeds the climatological average for the entire month of July (~100 mm). Similarly, the region north of Harrisburg also recorded accumulations of over double the monthly mean for July in just this one week.

Because GPM has only been in orbit since 2014, the satellite record is not long enough to provide a climatology with which to evaluate extreme precipitation events. However, a useful precipitation climatology can be constructed from MERRA-2, which has a data record between 1980 to present. Figure 3 shows the daily accumulated precipitation for the month of July 2018 in the immediate area of BWI and thresholds used to determine an extreme precipitation event. There are many definitions of an extreme precipitation event and thresholds used; in Figure 3, we use percentiles calculated for each day of the calendar year when at least 1 mm of precipitation occurs on a day within a window of +/- one week of the date in question for the climatology period of 1981 through 2010. There was hardly any rainfall during the first half of July 2018 but during the second part of the month, there were six days that easily exceeded both the 90th and 95th percentiles for

precipitation in the immediate BWI region. Furthermore, the July 22 rainfall nearly tripled the 99th percentile threshold and contributed a substantial portion of the July record breaking rainfall accumulations.

This multi-day extreme precipitation event can also be characterized using the RX5Day index developed by the CLIVAR Expert Team on Climate Change Detection and Indices (ETCCDI). RX5Day is defined as the highest 5-day accumulation of precipitation within a month. The RX5Day anomaly with respect to climatology for MERRA-2 in July 2018 can be seen in panel a of Figure 4. The spatial pattern is similar to the accumulations observed by GPM (Figure 2), with positive anomalies nearly everywhere east of 79 °W. The highest 5-day accumulation anomaly exceeded 180 mm and occurred in Pennsylvania, though a strip of exceptionally high rainfall totals is present through Maryland. A timeseries for RX5Day during the month of July for BWI from MERRA-2 is shown in Figure 4c.

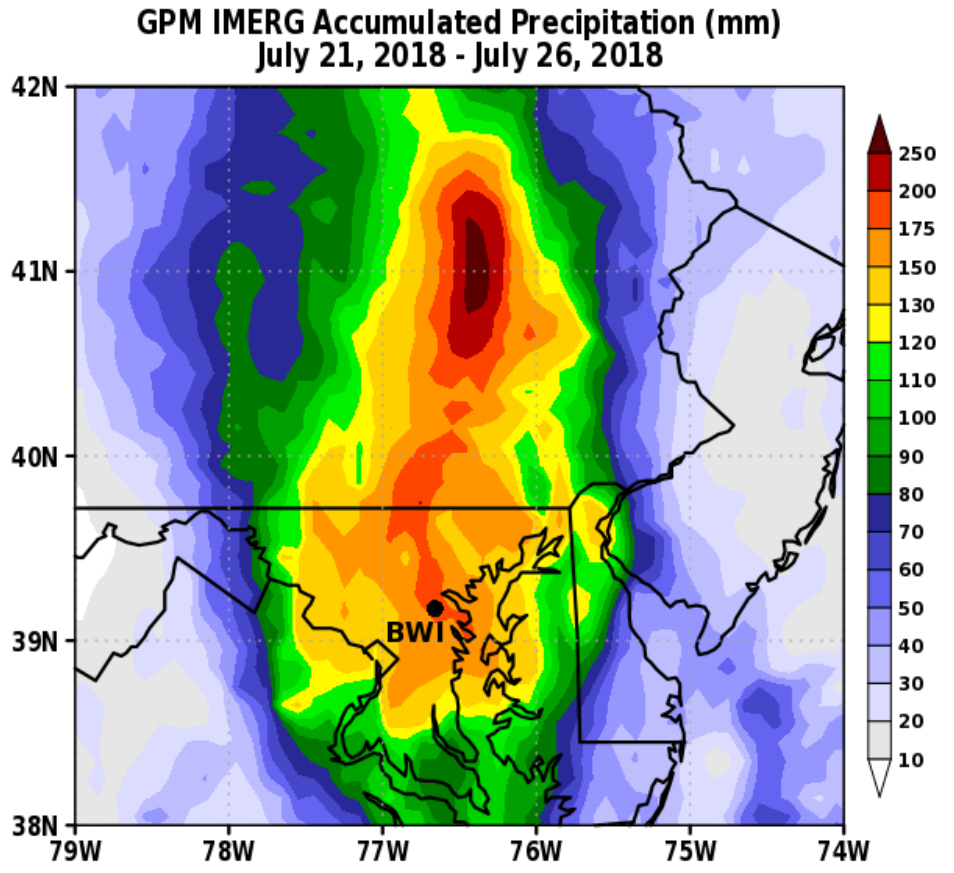

Figure 2. GPM IMERG accumulated precipitation between July 21 - July 26, 2018.

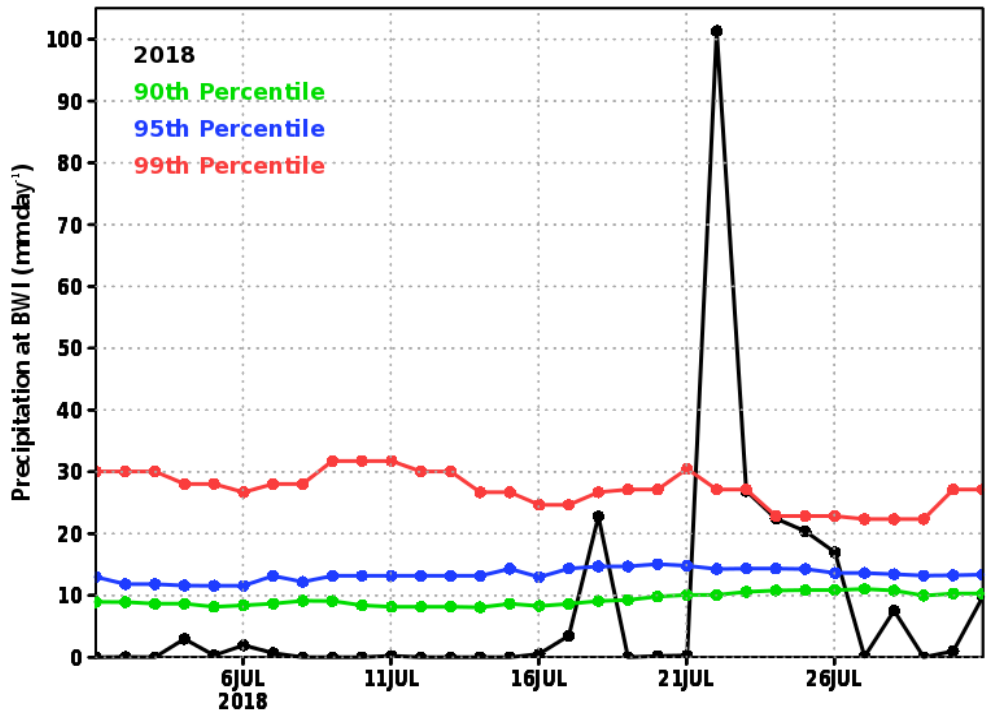

Figure 3. Daily precipitation for July 2018 (black line) and the climatology event thresholds as defined in the text.

On occasion, wet Julys total roughly 75 mm of precipitation during the 5-day period of maximum precipitation; this July more than doubled that amount, exceeding a record-breaking total 5-day accumulation of 180 mm.

A secondary definition of the RX5Day index includes the number of 5-day periods with at least 50 mm of precipitation. A spatial map of this version of the RX5Day for July 2018 can be seen in Figure 4b. This is a rolling index, or moving count, so each period can overlap one another. Most of the region with the highest accumulations experienced seven 5-day periods with at least 50 mm of precipitation, including BWI. As can be seen in Figure 4d, there is interannual variability in the number of 5-day periods with at least 50 mm of precipitation, but 2018 was the first time in the MERRA-2 record that exceeded a total of 5 in the immediate BWI region during the month of July.

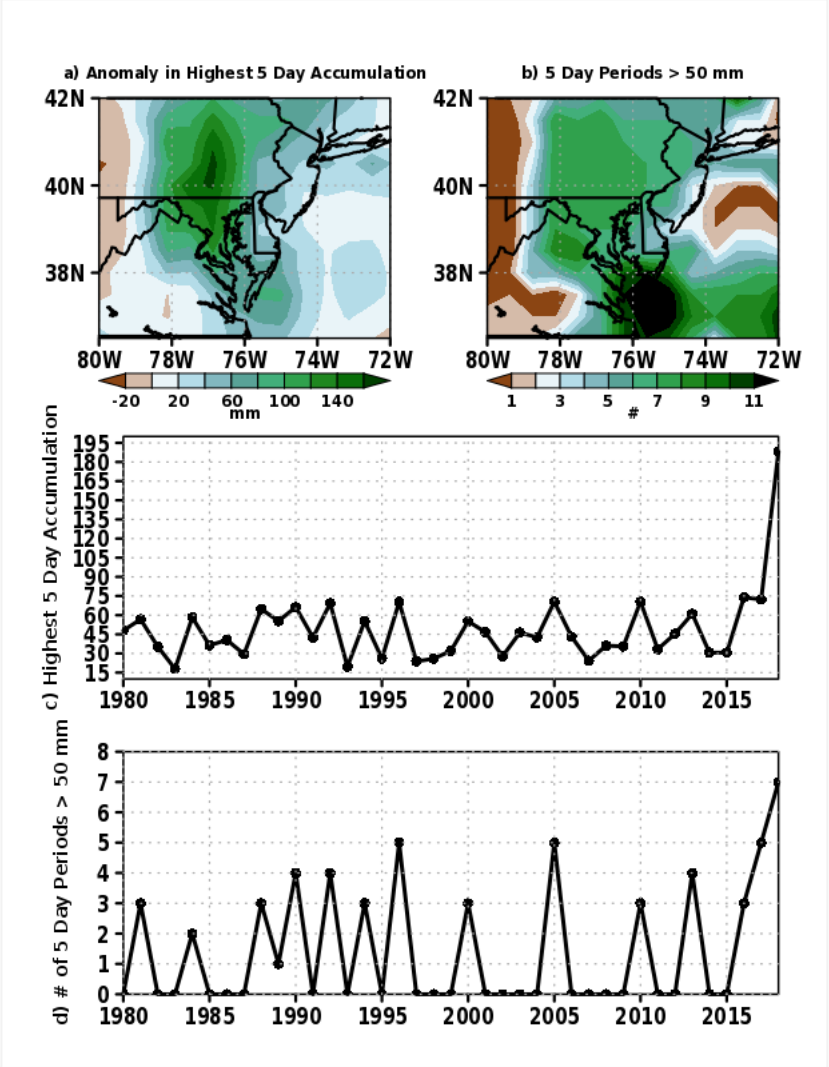

Figure 4. RX5Day calculations for July 2018. (a) RX5Day anomaly for July 2018. (b) Regional pattern of 5-day periods with precipitation over 50 mm. (c) timeseries of (a). (d) timeseries of (b).

The July 2018 Dichotomy

The synoptic weather patterns exhibited a sharp contrast between the first and second part of July 2018. During the first part of July, a high pressure system sat over the Northeast and Mid-Atlantic regions for multiple days. In contrast, during the second part of the month, sea level pressure (SLP) was substantially lower due to a persistent low

pressure trough observed in Figure 5a. These two distinct synoptic patterns resulted in relatively dry conditions in the beginning of July followed by frequent clouds and rain in the end of the month. Also noticeable in Figure 5a is the late July northward extension of the sub-tropical high that helped steer tropical moisture toward the Mid-Atlantic coast. This steering is evident in the difference of TPW for the first and second halves of July 2018 (Figure 5d). TPW was roughly 12 kg m^{-2} higher along the east coast in the second half of the month; however, the entire atmospheric river extended from the Gulf of Mexico north into Newfoundland and eastward over the Atlantic Ocean.

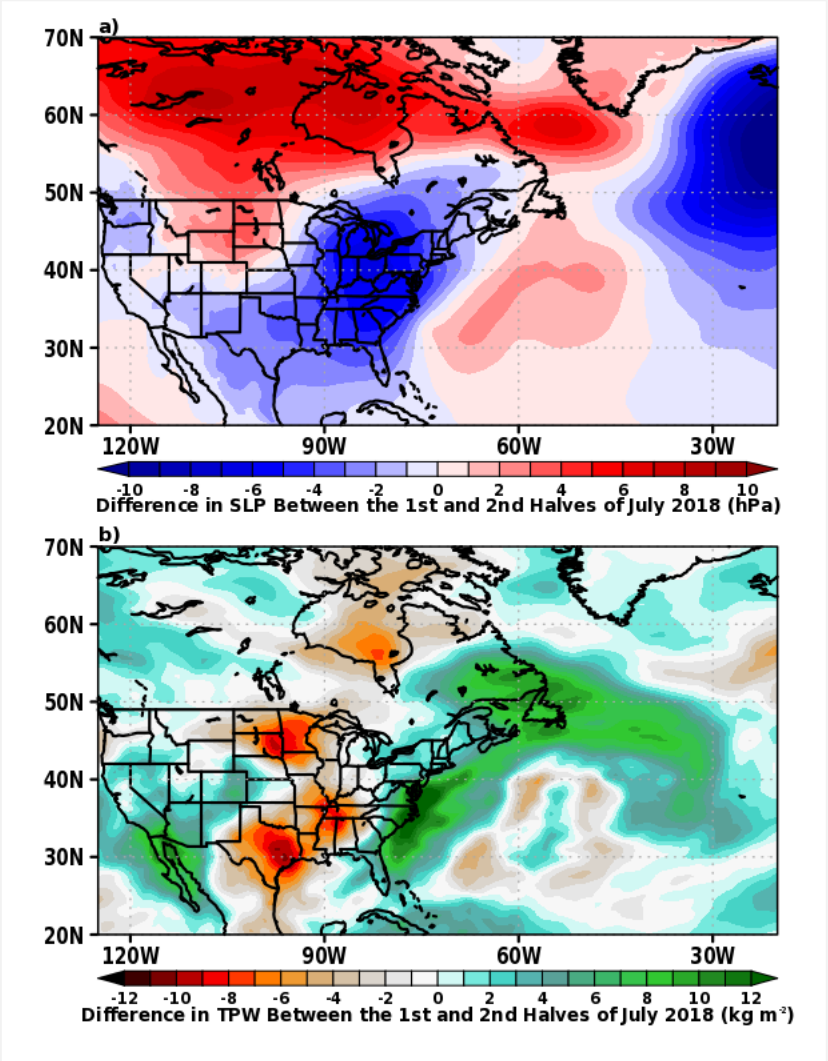

Figure 5. July 1-15 subtracted from July 16-31, 2018 for (a) sea level pressure and (b) total precipitable water vapor).

Monthly Anomalies within the Atmosphere

Despite the dichotomy between early and late July 2018 atmospheric parameters, features relating to large accumulations of precipitation are present in the monthly mean with respect to climatology (Figure 6). Positive anomalies in SLP and 500 hPa height were present in the Gulf of Alaska, which helped force the 'ridge in the west – trough in the east' pattern. This pattern aided the synoptic set up for precipitation along the east coast (Figure 6a). Furthermore, as indicated by the positive anomalies in SLP and 500 hPa height over the Atlantic Ocean, the Azores High was positioned further north than usual. This positioning allowed for moisture from the tropics to be transported into the Mid-Atlantic region. However, the TPW positive monthly mean anomaly was located off the east coast and over the Gulf Stream in contrast to the positioning observed in the sub-monthly differencing (Figure 6c). Despite this, there was an anomalous flow of water vapor integrated within the atmosphere, with values exceeding 200 kg m^{-1} s^{-1}, directed into Maryland due to the anomalous circulation within the atmospheric column (Figure 6d).

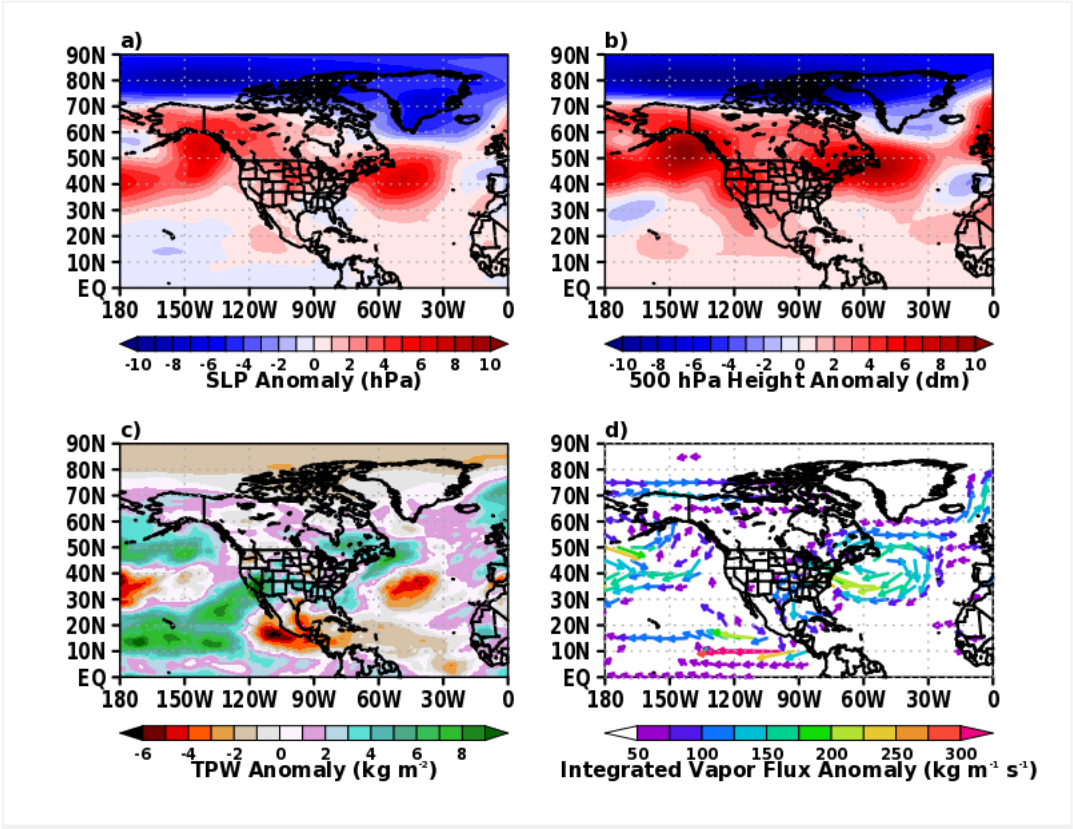

Figure 6. MERRA-2 monthly (a) SLP anomaly, (b) 500 hPa height anomaly, (c) TPW anomaly, and (d) vertically integrated water vapor flux anomaly.

In summary, the ideal conditions within the atmosphere led to synoptic features and an atmospheric river that resulted in daily and multi-day precipitation records in the Mid-Atlantic region during late July 2018. Precipitation indices here were focused on BWI due to the proximity to Goddard Space Flight Center, however the largest accumulations and flooding occurred to the north in Pennsylvania. There is still more that can be explored with respect to this event using MERRA-2 data; more can be learned about the formation of the observed atmospheric river and why this precipitation event was so unique.

References

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