RADAR RAINFALL ESTIMATES VERSUS STATION RAINFALL DATA

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ABSTRACT

This study investigates the Arkansas-Red Basin River Forecast Center's P3 radar precipitation estimator accuracy with select Oklahoma Mesonet gauge locations. The data collected comes from the NEXRAD radars located within ARBFC's forecast area as well as rainfall measurements recorded by the Oklahoma Mesonet stations. Radar estimation errors were analyzed from a temporal and spatial standpoint to determine if errors developed specific trends in estimation accuracy. Greater radar estimation accuracy was observed at locations close to radar sites and at locations that were climatologically wetter. The fall season was also shown to have the smallest margin of radar estimation errors.

1. INTRODUCTION

Having accurate rainfall estimates is important to forecasters, among others, because even in locations where dense gauge networks exist, rainfall events can be highly localized and occur in between rain gauges. Thus, these rainfall events would be missed and/or under-represented. With flooding being the second-deadliest weather-related cause of death in the United States (The Weather Channel, 2019), having a detailed, accurate areal rainfall estimates enables forecasters to issue flood warnings and advisories in a timely matter. This study investigated how accurately radar rainfall estimation products compare with surface rain gauges at specific Oklahoma Mesonet locations. By selecting stations at various distances from radar sites performance of radar rainfall estimates at different distances were determined. Additionally, performance due to various monthly rainfall amounts, due either to climatological region or seasonality, were conducted.

2. LITERATURE REVIEW

Radar estimates have a multitude of difficulties with accuracy due to weather, terrain, or obstacles in the radar's view. Even in flat terrain and under normal conditions, radar estimates are complicated by factors of the radar itself. One cause is due to the higher the center of the radar beam is above the Earth's surface the further away the beam is from the radar site. Another cause is that the further that the beam travels from the radar, the greater volume of precipitation it interacts with leading to errors in rainfall estimation (Steiner et al., 1999).

A previous study looked at 30 storm events over a single watershed in northern Mississippi and observed that during 80% of these storms the radar estimate was less than the gauge amounts; in 45% of the storms the underestimation was at least 20%, and in 30% of the storms the underestimation exceeded 30% (Steiner et al., 1999). Continuing with the trend of underestimation, radar estimates have a larger margin of error during the summer, ranging from -28% to +8%, compared with winter, ranging from -18% to -2% (Prat and Nelson, 2015). Fortunately, errors in radar estimation are not

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necessarily insurmountable, simple methods like mean field bias correction and range dependent adjustment can significantly reduce the radar estimation error (Goudenhoofdt and Delobbe, 2009).

3. DATA SOURCES

3.1 *Radar Data*

Radar rainfall estimates data are collected and compiled by the Arkansas-Red Basin River Forecast Center (ABRFC) from the NEXRAD WSR-88D radars in ABRFC's forecast area, which include: KAMA, KDDC, KFDR, KPUX, KGLD, KVNX, KTLX, KINX, KSRX, and KICT. The ABRFC includes the Arkansas River watershed above Pine Bluff, Arkansas, and the Red River watershed above Fulton, Arkansas. The combined watersheds cover over 538,000 square kilometers and encompasses all of Oklahoma. For estimating rainfall over its forecast area, ABRFC created its own precipitation estimator called P3. The P3 uses the hourly digital precipitation product from each radar in ABRFC's area, and hourly rain gauge reports from Oklahoma Mesonet rain gauges and CoCoRaHs rain gauges in order to create a gridded radar rainfall estimation product, which is in a 4km x 4km grid (ABRFC).

3.2 *Mesonet Data*

The Oklahoma Mesonet is comprised of 120 automated surface observing stations across the state of Oklahoma, with at least one station in every county in Oklahoma, and is jointly operated by the University of Oklahoma and Oklahoma State University. The remote stations send meteorological and agricultural data every five minutes to an operations center, located at the Oklahoma Climatological Survey, for data quality assurance, product generation, and dissemination. Each Oklahoma Mesonet site has two tipping bucket rain gauges, with one gauge serving as primary measurement and one as a backup. The rain gauges have a resolution of 0.25 mm. Neither of the rain gauges are equipped with a heater for melting frozen precipitation, so frozen precipitation is measured as liquid equivalent after melting occurs (McPherson et al., 2007). The data files used for this study are the Mesonet Time Series (MTS) files, which are space delimited files that contains 5-minute UTC observations for one station for a given day (Mesonet). The rainfall is measured in millimeters and the total rainfall for each day for a station is loaded into the next day's respective 00Z file.

4. METHODOLOGY

Eight Oklahoma Mesonet locations were selected across Oklahoma at varying distances from the radar sites and therefore within different radar coverages. The coverages are qualified by the availability of radar beam coverage at specific above ground altitudes and defined by NOAA's Radar Operation Center as follows: 4,000 feet/1219 meters (best coverage), 6,000 feet/1829 meters (better coverage), 10,000 feet/3048 meters (fair coverage), and max coverage out to the maximum radar range of 230 kilometers (Kobar, 2020). The locations were also selected to cover the climatologically wet (~1318 mm/yr) and dry (~464 mm/yr) areas of Oklahoma. Table 1 shows the following Oklahoma Mesonet stations that were selected as locations for comparing the ARBFC's radar rainfall estimation product with rainfall measured with rain gauges. This study assumes that the Oklahoma Mesonet rain gauge value is the true and accurate rainfall for the selected time period.

Using the measured rainfall data from the Oklahoma Mesonet and the radar estimated precipitation product data from ABRFC, this study compared the respective rainfall amounts at the selected Oklahoma Mesonet sites. Locations were picked to investigate errors related to distance from radar as well as climatological variances. Data from multiple different seasons were analyzed to determine how radar estimation performs during different seasons. The time period analyzed for this study was between 2010 to 2019. For comparison reasons, the Oklahoma Mesonet rainfall gauge measurements were considered to be the true rainfall measurements for calculating the radar estimation percent error for this study. Underestimations, or negative errors, is when the radar estimate is under the rainfall gauge measurements, and overestimations, or positive errors, is when the radar estimate is over the rainfall gauge measurements.

STID	Radar Name	Distance from Radar	Radar Coverage	Annual Rainfall
SHAW	KTLX	31 km	Best	1050.0 mm/yr
GUTH	KTLX	60 km	Best	923.5 mm/yr
HOLD	KTLX	89 km	Better	1080.8 mm/yr
HINT	KTLX	111 km	Better	815.6 mm/yr
CLOU	KSRX	143 km	Fair	1302.8 mm/yr
CAMA	KVNX	134 km	Fair	687.6 mm/yr
HUGO	KSRX	177 km	Max	1205.2 mm/yr
BOIS	KAMA	179 km	Max	471.4 mm/yr

Table 1: Oklahoma Mesonet locations with associated radar and rainfall information

The radar estimation percent error was calculated by:

$$\%\ error = \frac{P3\ estimates - gauge\ measurement}{gauge\ measurement} * 100\%, \quad (1)$$

While analyzing the data for this study very large errors were observed during several months at some of the locations picked, so additional data quality control was performed to remove the months were the Oklahoma Mesonet rainfall gauge data or ARBFC radar estimation data was missing or questionable. Out of the 960 months were rainfall data was collected and analyzed, 14 months were removed.

5. RESULTS

The ARBFC's P3 precipitation estimator has been analyzed for its accuracy compared to the Oklahoma Mesonet rainfall gauge data for eight-gauge locations during the 10-year period of 2010 to 2019. These errors were calculated by each month and then averaged out for all months during the 10-year period or annually. The results are broken down temporally and spatially.

5.1 *Temporal Analysis*

For the temporal analysis the radar estimation errors were analyzed for each month during the 10-year study period. The percent error was then averaged for each month at each location over the study period. Table 2 shows the station monthly radar rainfall estimation average errors for the eight locations. Across the eight locations and over the time period analyzed; fall had the lowest absolute average radar estimation error at -2.5%, next lowest was spring at +4.8%, then winter at +8.8%, and finally summer had the highest absolute average radar estimation error at +23.8%. Similar to Prat and Nelson (2015), radar estimates had a larger margin of error during summer compared to winter. Fall had the smallest range of errors of all seasons, ranging from -36.1% to +83.4%; winter with the second smallest, ranging from -27.6% to +109.2%; summer with the third smallest, ranging from -17.3% to +141.9%; and spring with the largest margin of errors ranging from -39.8% to +165.71% respectively.

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SHAW	27.0%	-8.7%	-15.8%	5.9%	-11.5%	0.5%	21.5%	11.2%	12.6%	12.8%	-9.1%	-1.7%
GUTH	77.9%	-24.8%	37.4%	-25.9%	-1.4%	37.2%	62.9%	35.1%	-13.5%	-27.6%	-6.1%	-3.3%
HOLD	-20.9%	-13.3%	-9.5%	1.4%	-22.8%	12.8%	-9.1%	8.2%	3.8%	-11.7%	-19.1%	-27.6%
HINT	66.1%	-21.6%	3.2%	45.6%	-17.2%	59.5%	-1.1%	2.6%	4.4%	-15.7%	-7.6%	25.0%
CLOU	-27.5%	-24.9%	-25.7%	3.0%	0.1%	-17.3%	0.0%	-12.4%	-9.8%	12.2%	-11.0%	-12.1%
CAMA	59.2%	36.9%	57.3%	13.0%	-39.8%	103.8%	18.0%	8.7%	-36.1%	8.0%	-15.8%	5.2%
HUGO	-11.0%	-13.7%	-12.5%	2.9%	-24.6%	41.7%	-13.0%	141.9%	4.0%	18.6%	-9.4%	-20.4%
BOIS	17.8%	109.2%	165.7%	22.5%	-35.8%	24.2%	32.0%	3.5%	-2.0%	-25.8%	83.4%	17.7%

Table 2: Monthly average rainfall errors from 2010-2019 across select Oklahoma Mesonet Stations.

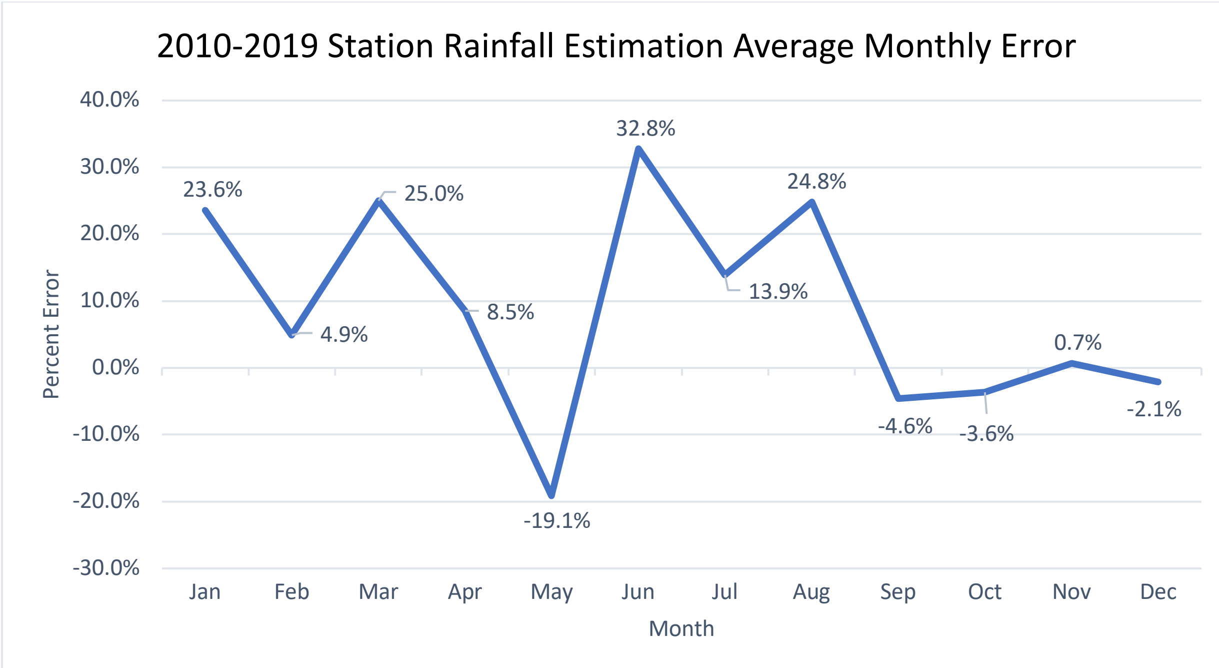

Figure 1: 2010-2019 station averaged monthly radar rainfall estimation errors.

Figure 1 shows the average radar estimation errors across all eight locations over the analyzed 10-year time period. November had the lowest average absolute error at +0.7% and June had the largest average absolute error at 32.8%. It is important to note that as shown in Table 2, BOIS had a few months of large average overestimation errors, as well as CAMA and HUGO, which skews the monthly error averages. For that reason, Figure 2 was created to show the median monthly estimation error in an attempt to show errors that are not as heavily impacted by those few large overestimations. The overall pattern in Figure 2 is similar to Figure 1, however the months with underestimations is more frequent and pronounced in Figure 2. In both Figures 1 and 2 the estimation tendency is drastic moving from May to June, going from the greatest underestimation errors in May to the greatest overestimation errors in June.

When considering all months across all locations analyzed for this study there was a bias towards underestimation for the radar rainfall estimations. Out of the 960 months where data was collected and analyzed across all locations, 545 of those months (about 57%) the radar underestimated the rainfall amounts. Figure 3 shows the number of months when the radar underestimated rainfall at each of the eight Oklahoma Mesonet stations. There was a greater incidence of underestimate months for the wetter locations with 59.2% of the months having radar underestimation, compared with the drier locations with 54.4% of the months being underestimates. BOIS is the only location that did not have a majority of radar rainfall underestimate months, 59 out of 120 months. BOIS had several instances of very large overestimation months as well. BOIS was also the driest of all locations that this study investigated.

5.2 *Spatial Analysis*

Table 3 shows the 2010-2019 annual average radar rainfall estimation error for each location grouped in their respective radar coverage levels. Table 3 also identifies which location is the

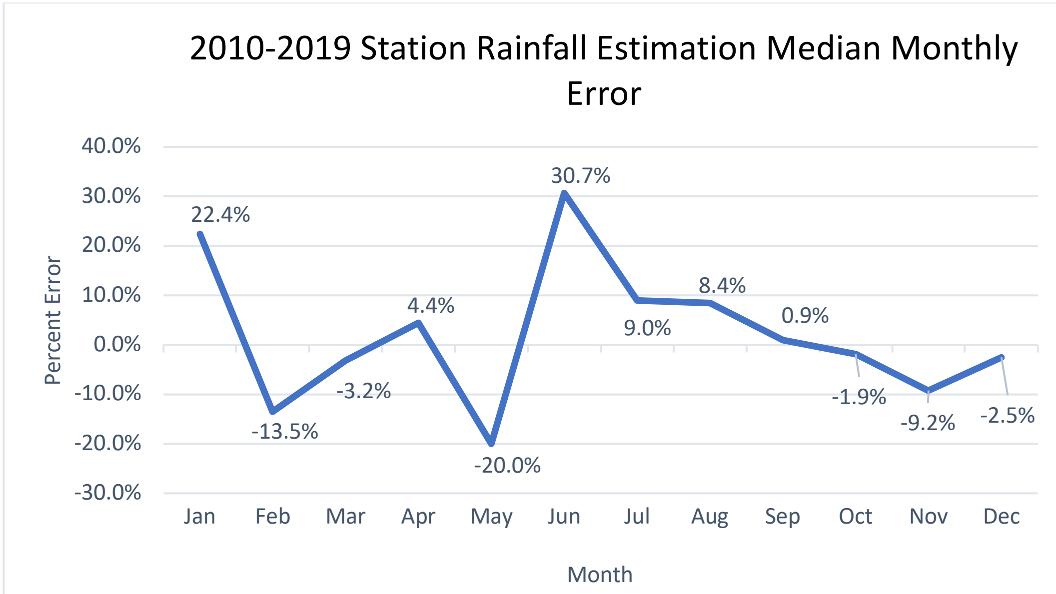

Figure 2: 2010-2019 station median monthly radar rainfall estimation errors

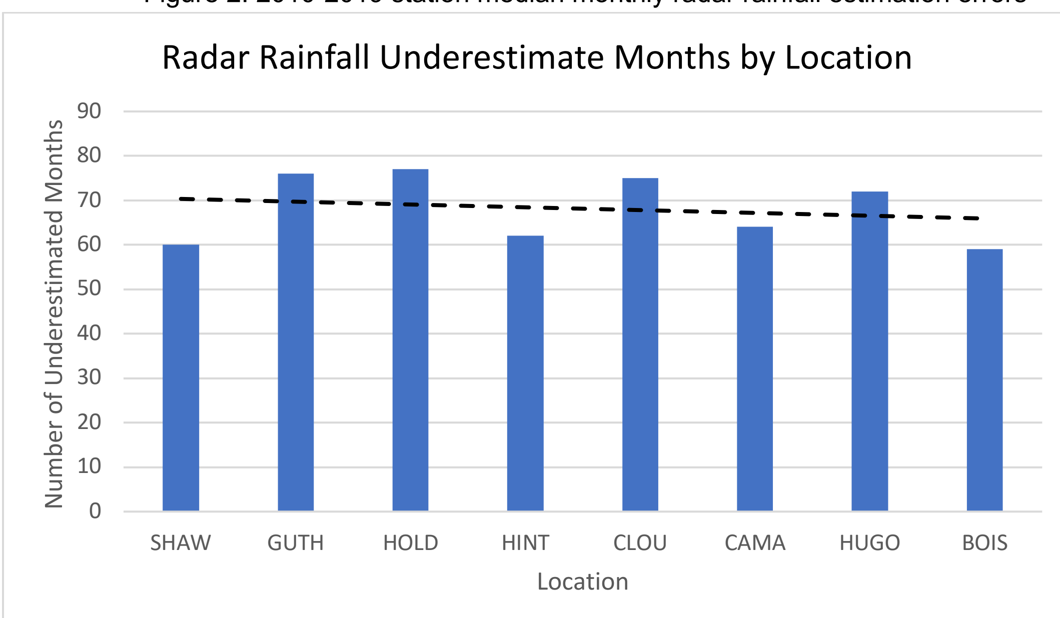

Figure 3: Radar rainfall underestimated months by Oklahoma Mesonet station. Locations are ordered in increasing distance from the radar site from left to right.

wet or dry site within that particular radar coverage. SHAW, the closest overall location to the radar and a wet site, had the lowest average absolute error for the study. Within each radar coverage level, the wet site of the pair had a lower average absolute error. Wet sites also had smaller annual margins of error, ranging from -26.7% to +20.6%, compared to dry sites, ranging from -38.3% to +36.4%, across all locations respectively.

By inserting a trendline in Figure 3 there is slight decrease in occurrence in the number of radar rainfall underestimation months with

Coverage	Site	Annual	Wet/Dry	mm/yr
Best	SHAW	3.7%	Wet	1050.0
	GUTH	12.3%	Dry	923.5
Better	HOLD	-9.0%	Wet	1080.8
	HINT	11.9%	Dry	815.6
Fair	CLOU	-10.5%	Wet	1302.8
	CAMA	18.2%	Dry	687.6
Max	HUGO	8.7%	Wet	1205.2
	BOIS	34.4%	Dry	471.4

Table 3: 2010-2019 annual average radar rainfall estimation error by Oklahoma Mesonet station. Grouped by radar coverage level and identifying the wet or dry site for that particular coverage level.

increasing distance from the radar site. The trendline for radar underestimate months has an R^2 value of 0.04. BOIS also had more months with very large radar overestimation errors compared with the other locations, as well as two months were the radar estimated precipitation and the gauge recorded none; again, more than any other location.

Average absolute radar rainfall errors increase with increasing distance. Figure 4 shows the average absolute radar rainfall estimate error by radar coverage level. There is a significant increase in the average absolute errors as the distance from the radar site increases. Average absolute radar rainfall errors for each radar coverage level ranged from “Best” at 8.0%, “Better” at 10.5%, “Fair” at 14.4%, and “Max” at 21.5%; a more than double increase in average absolute error from the closest radar coverage to the furthest. Furthermore, there were also more instances of very large radar overestimations with increasing distance from the radar sites, particularly drier locations.

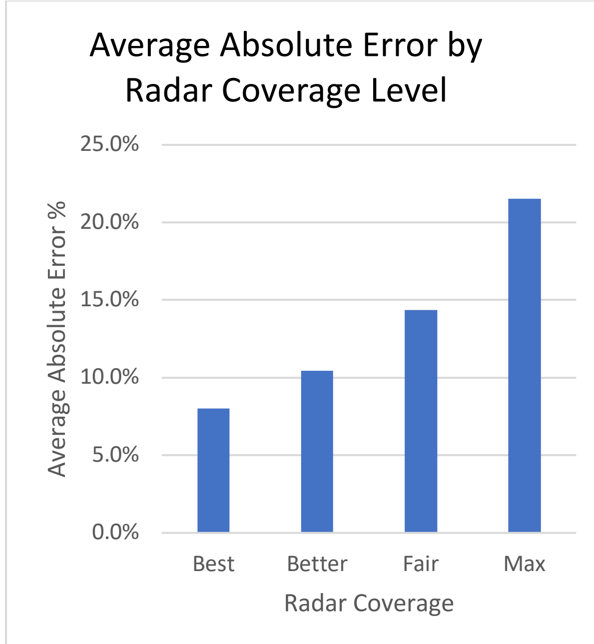

Figure 4: Average absolute radar rainfall estimate error by radar coverage. Distance from radar site increases from “Best” to “Max”.

6. DISCUSSION

While this study did show a slight bias to the number of months when the radar underestimated rainfall (57%), the incidence was not as high as the Steiner (1999) study at 80%. A reason for this could be that Oklahoma is on average drier than Mississippi as the drier rainfall estimates across all locations was skewed by a few of the locations having large overestimation errors, even though all locations studied except one had more months with underestimations. Future studies could investigate more locations in the Oklahoma Mesonet network to see if underestimates are more common. This does allow for some improvement in the ARBFC’s P3 precipitation estimator by correcting and eliminating the very large overestimation errors, for example when the radar estimated rainfall, but the gauge sites did not record any, that were especially common in the more distant locations from the radar site.

The large spike in underestimation errors during the month of May stands out from the other warm months that surround it. May is an active convective month throughout Oklahoma, as well as a high rainfall month for many locations, which may play a role in the sharp contrast of underestimation compared with the other warm months that surround May. The higher rainfall rates associated with convective precipitation could lead to a higher prevalence of radar rainfall underestimations. Future studies could investigate the correlation between high rainfall months, and heavy rainfall rates, and with how the radar handles those estimations.

7. SUMMARY

This study investigated how accurate the ARBFC's P3 radar rainfall estimator product was to select Oklahoma Mesonet rain gauge measurements were and sought to determine how distance from radar sites affected radar estimation accuracy, as well as how varying rainfall amounts and different seasons led to different margins of error. The major results from the study are as follows:

1. Locations that are closer to the radar sites, as well as wetter locations, generally have the lowest absolute radar rainfall errors. Additionally, average absolute errors increased linearly with increasing distance from radar sites.

2. Large radar overestimation errors are more common for locations farther from radar sites. Also, the large overestimation errors are more common for drier sites and generally occur during the winter.

3. Fall has the lowest margin of radar rainfall estimation errors, with spring having the largest margin of errors.

Future work should expand on the number of Oklahoma Mesonet locations, and time period, that were investigated to further confirm the findings found in this study as well as expand the data set in order to account for some of the averaging that was skewed in this study due to limited time and locations analyzed. Also, further researching into the instances when very large radar rainfall estimation errors occurred to understand if they are true errors or anomalies and to help identify areas to help improve the radar estimation product's overall accuracy.

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9. REFERENCES

ABRFC Precipitation Processing Methodology. Weather.gov,. https://www.weather.gov/abrfc/pcpn_methods (Accessed June 29, 2020).

Goudenhoofdt, E., and L. Delobbe, 2009: Evaluation of radar-gauge merging methods for quantitative precipitation estimates. *Hydrology and Earth System Sciences*, **13**, 195–203, doi:10.5194/hess-13-195-2009.

Kobar, J., NOAA, Personal email communications, June 08, 2020.

Mesonet MDF/MTS Files.. https://www.mesonet.org/index.php/site/about/mdf_mts_files (Accessed June 30, 2020).

McPherson, R. A., C. Fiebrich, K. C. Crawford, R. L. Elliott, J. R. Kilby, D. L. Grimsley, J. E. Martinez, J. B. Basara, B. G. Illston, D. A. Morris, K. A. Kloesel, S. J. Stadler, A. D. Melvin, A.J. Sutherland, and H. Shrivastava, 2007: Statewide monitoring of the mesoscale environment: A technical update on the Oklahoma Mesonet. *J. Atmos. Oceanic Technol.,* **24**, 301–321

Prat, O. P., and B. R. Nelson, 2015: Evaluation of precipitation estimates over CONUS derived from satellite, radar, and rain gauge data sets at daily to annual scales (2002–2012). *Hydrology and Earth System Sciences*, **19**, 2037–2056, doi:10.5194/hess-19-2037-2015. doi:10.5194/hess-19-2037-2015.

Steiner, M., J. Smith, S. Burges, C. Alonso, and R. Darden, 1999: Effect of bias adjustment and rain gauge data quality control on radar rainfall estimation. Water Resources Research, **35**, 2487-2503, doi:10.1029/1999wr900142.

The Weather Channel, 2019: The Top Cause of Weather Fatalities in Your Area May Surprise You | The Weather Channel. *The Weather Channel*,. https://weather.com/safety/news/2019-09-17-top-cause-weather-fatalities-nws-cwa-united-states-map (Accessed June 18, 2020).