Developing a Visual Drought Index

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Sectoral Applications Research Program

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A NOAA RISA TEAM

Suggested Citation: Bertrand, Darrian, Gina Fujan, Mark Shafer, Henry Reges, and Nolan Doesken, 2017. Developing a Visual Drought Index. Southern Climate Impacts Planning Program, 34 pp. [Available online at http://www.southernclimate.org/documents/Visual_Drought_Index.pdf].

Cover Photos: Gary McManus, Oklahoma Climatological Survey. Photos are from a farm pond near Buffalo, Oklahoma, taken in May 2009 (upper left), August 2010 (upper right), March 2012 (lower left), and October 2012 (lower right).

Developing a Visual Drought Index

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November 2017

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Introduction

Drought is a meteorological phenomenon that frequently affects ecosystems and populations across the United States. Since 1980, there have been 24 billion-dollar drought disasters in the U.S. (NOAA 2017). There is not a standard definition of drought, but drought indices can be used to quantify drought for different time frames (Wilhite and Glantz 1985). For example, the U.S. Drought Monitor (USDM, Svoboda et al. 2002) tracks drought conditions across the country and produces weekly severity maps, with categories of D0 (abnormally dry) to D4 (exceptionally dry). A unique quality of the USDM is their engagement with their users through weekly discussions about the accuracy of drought severity locally. In addition, the National Drought Mitigation Center offers a Drought Impact Reporter where individuals can submit reports of their local drought impacts (NDMC 2017).

Engaging with citizens to gain information about local drought conditions and impacts is important for improving the accuracy of drought indices and identifying local-scale drought, but what does drought actually look like across the country? This project was designed to create a visual drought severity scale by using photos that citizens took of their landscape, and compare the scale to established drought indices to determine if the scale is accurate and executable. This concept of a visual assessment of drought severity is similar to the Enhanced Fujita Scale that is used to assess tornado damage. Drought indices used for comparison include the USDM, the Palmer Drought Severity Index (PDSI), and the Standardized Precipitation Index (SPI).

Methodology

The goal of this work was to create a Visual Drought Index based on photos that citizens across the country took of their landscape during Field Photos Weekends, which is a project developed by the NOAA RISA's Southern Climate Impacts Planning Program, CoCoRaHS, and the Earth Observation and Modeling Facility (EOMF) and supported with funding from NOAA's Sectoral Applications Research Program (SARP). The campaign started in September of 2012 and is still active today. It originally took place over the following three weekends: Labor Day, President's Day, and Memorial Day. In 2016, Independence Day was added into the mix of weekends in order to better capture all of the seasons. These holiday weekends were chosen on the basis that there would be a higher chance that citizens would be out in nature and able to take pictures at a similar time all across the nation. Since its inception, the project has collected more than 8,000 landscape photos.

In order to construct the Visual Drought Index and determine if it was a feasible and reliable representation of actual drought severity, several steps were taken. The photos were gathered from the Field Photos Weekend database, categorized by region and land cover type by event, and compared to the USDM and other established drought indices.

Field Photos Data

The first step was to compile all photos from the beginning of the Field Photos Weekend project, September 2012, to September 2016. Because of the large quantity of photos, the photos were downloaded by employees at EOMF and given to the Field Photos team. The provided data included a file for each Field Photos Weekend event that contained any information that was entered by participants when the photos were originally uploaded to the EOMF server. The fundamental part of the metadata in this file was the latitude and longitude. These data were essential for reorganizing the photos in the next step.

The photos were then sorted according to whether they were "good," "useful," or "not useful." "Good" photos were defined as images that showed the overall landscape. They had to be clear and could not include any large obstructions in front of the landscape. "Useful" photos still included much of the overall landscape, but could contain some small obstructions. Finally, "not useful" photos were categorized as those that were too blurry, and/or were concealed by some obstruction.

Categorizing the photos

Each useable photo was then separated by land cover type, including grassland, cropland, forest, waterbody, and desert. Once the photos were divided into land cover categories, it was concluded that only the photos from the Memorial Day and Labor Day events should be included in the analysis. This was decided in order to avoid any issues with dormant vegetation or snow concealing the ground in some locations during the President's Day events and the short duration of the Independence Day events (not added until 2016). Then, the remaining photos in each land cover category were placed into six climate regions designated by the USDM. This included the Northeast, Southeast, Midwest, High Plains, South, and West. There were over 3,000 photos submitted across the country for Memorial Day and Labor Day events, and approximately 2,000 photos were labeled as "good" or "useful."

Finally, for each Memorial Day and Labor Day event from 2012 to 2016, each photo was classified by the visual appearance of drought severity, following the USDM's categories of no drought to exceptional drought (D4), by region and land cover type. For example, Figure 1 shows the Visual Drought Index using Memorial Day and Labor Day photos under the grasslands land cover type in the South, where each row represents a drought category ranging from no drought to exceptional drought. None of the photos in this region were categorized as D4, or exceptional, drought; therefore, the last row of the figure was left blank. In the Northeast region, there were only two drought categories of no drought and D0 (abnormally dry) represented in the photos. The other regions' Visual

Drought Indices are located in Appendix A. A list of photos used in the Visual Drought Index Guide is included in Appendix B. This analysis was subjective, because the scale was based on our own judgment and experience.

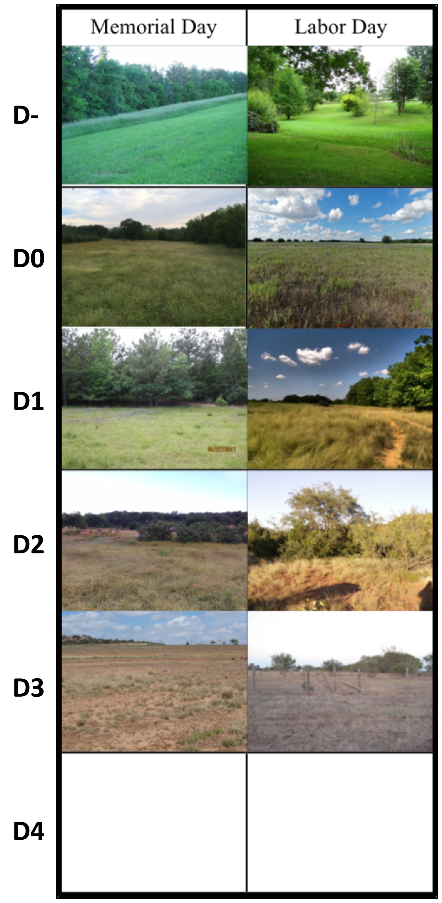


Figure 1. Visual Drought Index from the Memorial Day (left) and Labor Day (right) photos with grasslands land cover type in the South.

Comparing the Photos to Drought Indices by Region and Event

In order to assess the performance of the visual drought severity scale, the categorized photos were then compared to actual USDM, PDSI, and SPI values at the time and location of each photo across the country. These indices were selected because they are widely used and established drought indices, and the PDSI and SPI is used as input to the USDM. The analysis was conducted through ArcMap software. U.S. Drought Monitor shapefiles were downloaded from the U.S. Drought Monitor Map Archive (http://droughtmonitor.unl.edu/Maps/MapArchive.aspx). The PDSI and SPI data were downloaded at a climate division scale from the National Centers for Environmental Information (NCEI).

For the USDM comparison, a simple difference was taken between the value assigned to the photo and the actual USDM value in order to determine the performance of the Visual Drought Index. For this analysis, visual products were then created in ArcMap to display the performance across the country. For PDSI and SPI, a correlation analysis was conducted for each event. This process was not as straightforward as the USDM analysis. Both indices range from negative values that indicate drought conditions to positive values that represent wet conditions, while the Visual Drought Index only includes positive values with increasing drought severity that are associated with the USDM's scale. Therefore, data manipulation was required for this part of the analysis. First, all positive PDSI and SPI values were replaced with a zero for no present drought conditions because we were only concerned with the dry range of the scale. Then, the Visual Drought Index values were inverted in order to comprise of negative values that would correspond with the PDSI and SPI values. Then, a correlation analysis was conducted between the Visual Drought Index and the other drought indices through Microsoft Excel's correlation function for each region in order to determine if there were any trends between the scales:

$$Correl(X,Y) = \frac{\Sigma(x-\bar{x})(y-\overline{y})}{\sqrt{\Sigma(x-\bar{x})^2}\sqrt{\Sigma(y-\bar{y})^2}}$$

Correlation coefficients could not be calculated in instances where either the Visual Drought Index value or the PDSI/SPI value was the same for the entire region, because this created a situation in which the denominator was zero.

Results

Visual Drought Index vs. U.S. Drought Monitor

There were a total of 12 analyses conducted for the comparison of the Visual Drought Index versus the actual USDM values. These included an analysis for each Memorial Day and Labor Day event, all Memorial Day events, all Labor Day events, and all events. All products were created with ArcMap software, and graduated circles display the location of each photo and the performance of the Visual Drought Index, with performance declining with increased circle sizes. Red colors indicate that the Visual Drought Index value was less severe than indicated by the USDM and blue colors indicate that the Visual Drought Index value was more severe than the USDM.

(a) Memorial Day

The participation of Field Photos Weekend declined after the first Memorial Day event that took place in 2013, so there were much less data from 2014 to 2016. The Memorial Day 2013 analysis included widespread results with no striking pattern of performance level. Photos that were taken in the northwest U.S. and some locations in the Northeast region were assigned a drought value that matched the USDM values. These areas had very green landscapes with no drought conditions (Fig. 2). On the other hand, the largest differences between the Visual Drought Index and USDM were located in the Southeast region and the desert land cover types in the southwest U.S.

Figure 2. Photo taken in Maryland for the 2013 Memorial Day Field Photos Weekend

The Southeast region's dissimilarities were due to the values assigned to the waterbody land cover types. Outside human factors can affect water levels, which created difficulty in deciding whether lower water levels were due to these factors or drought conditions. The desert landscape was a particularly challenging land cover type for assigning a drought category value. There was little vegetation, aside from cacti and some shrubbery, in these photos and we were unfamiliar with this region, being natives of eastern

Oklahoma. There were many cases where we believed that the photographed landscape did not appear to have drought conditions, yet the USDM value was D3 for severe drought (Fig. 3). We acknowledge that results for desert photos were likely biased by our own experiences and perceptions.

Figure 3. Photo taken in Arizona during the 2013 Memorial Day Field Photos Weekend

Figure 4 demonstrates the overall spatial patterns of the performance of the Visual Drought Index compared to the USDM for all Memorial Day events. Performance for individual years, 2013-2016, are shown in Appendix C, Figures 1C-4C. At first glance, results seem to have a checkerboard appearance across the map. However, there are some regions that largely deviate in performance. For example, the Visual Drought Index estimated much less severe drought conditions in the Southeast region and desert land cover type in Arizona than specified by the USDM. Performance of the Visual Drought Index was best in the Northeast region and a large portion of the Midwest, with the exception of the northwest area of the Midwest. Locations with the largest difference between scales was Colorado, which were often photos of a mountainside.

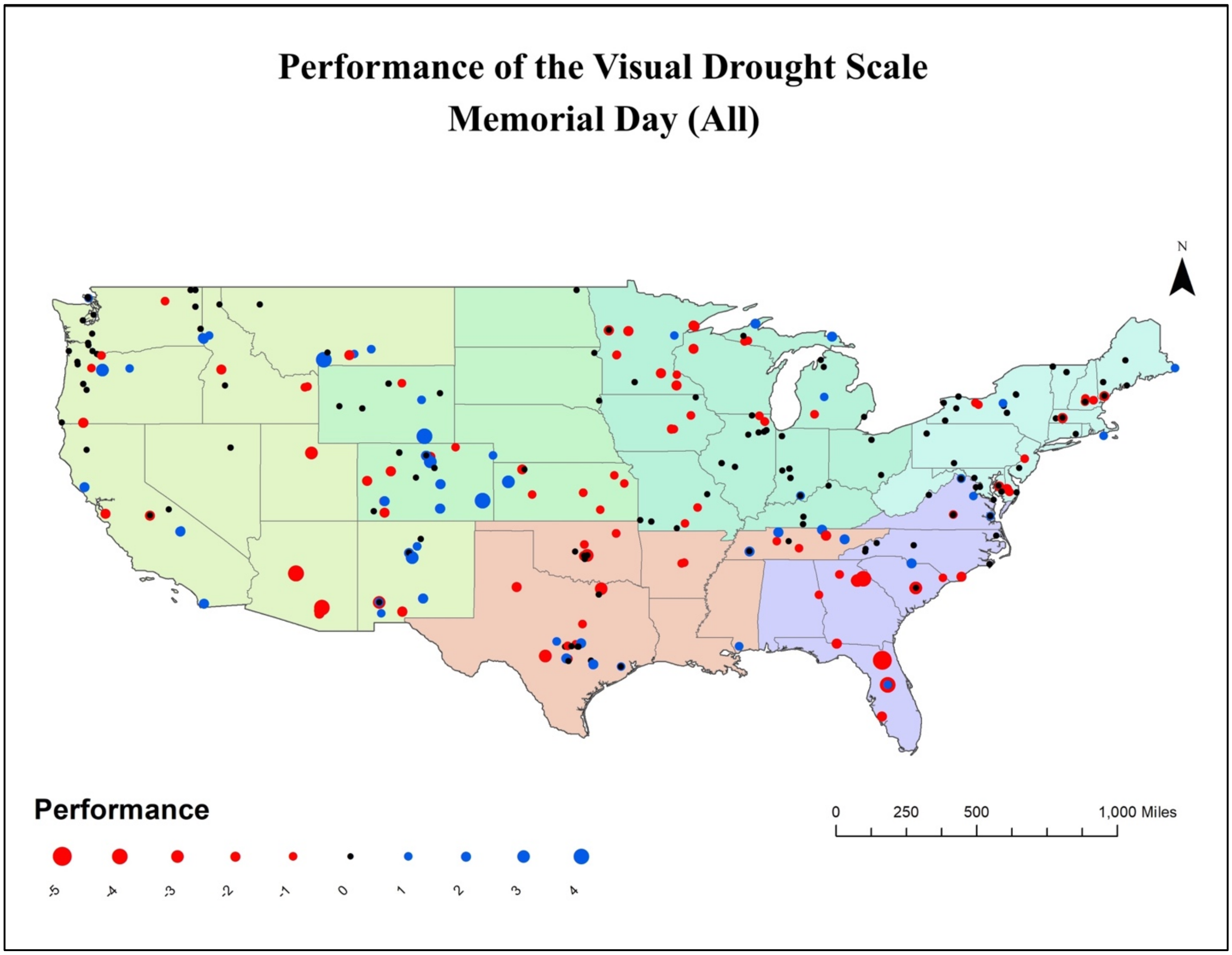


Figure 4. Performance of the Visual Drought Index compared to the USDM for all Memorial Day events; larger circles represent a larger difference between scales; red (blue) colors indicate that the Visual Drought Index category was less (more) severe than the USDM.

(b) Labor Day

Similar to the Memorial Day photos, there was a large decline in engagement with Field Photos Weekend submissions for Labor Day events after 2014. However, results for Labor Day events held many spatial patterns. For example, the Visual Drought Index value was much less severe in widespread areas of the Midwest and Southern regions in 2012 and 2013 (Appendix C, Figures 5C-6C). This indicates that we perceived that drought conditions were not as critical by the visual appearance of the landscape. During these years, there was also a noticeable pattern in the northwest U.S. in which the Visual Drought Index values were more severe than indicated by the USDM. In addition, the mountainous areas of Colorado were also classified as being less severe than the USDM. Many mountainous photos were difficult to categorize due to many photos being taken on the mountainside, where shrubs were the only vegetation present in the rocky landscape. Overall, the performance of the Visual Drought Index in the Northeast region and many east-coast states was relatively good, with many locations having a perfect match between scales and others only ranging one value apart.

An assessment of all Labor Day events brought differing results. Whereas earlier in the year when the Visual Drought Index had a relatively satisfactory performance in the Northeast region, the fall timeframe of the Labor Day events included many instances of the scale falling either above or below the USDM values. This indicates that it may be more difficult to visually identify drought conditions during the fall season in this region. The Midwest region continued to have several occurrences of a perfect match between the Visual Drought Index and the USDM values (Fig. 5). Another pattern that remained was a lower severity of drought conditions for the Visual Drought Index versus the USDM in the Desert Southwest and a higher severity in the mountains of Colorado. On the other hand, the Visual Drought Index improved in the Southeast region during Labor Day events, versus the large differences between scales during Memorial Day events.

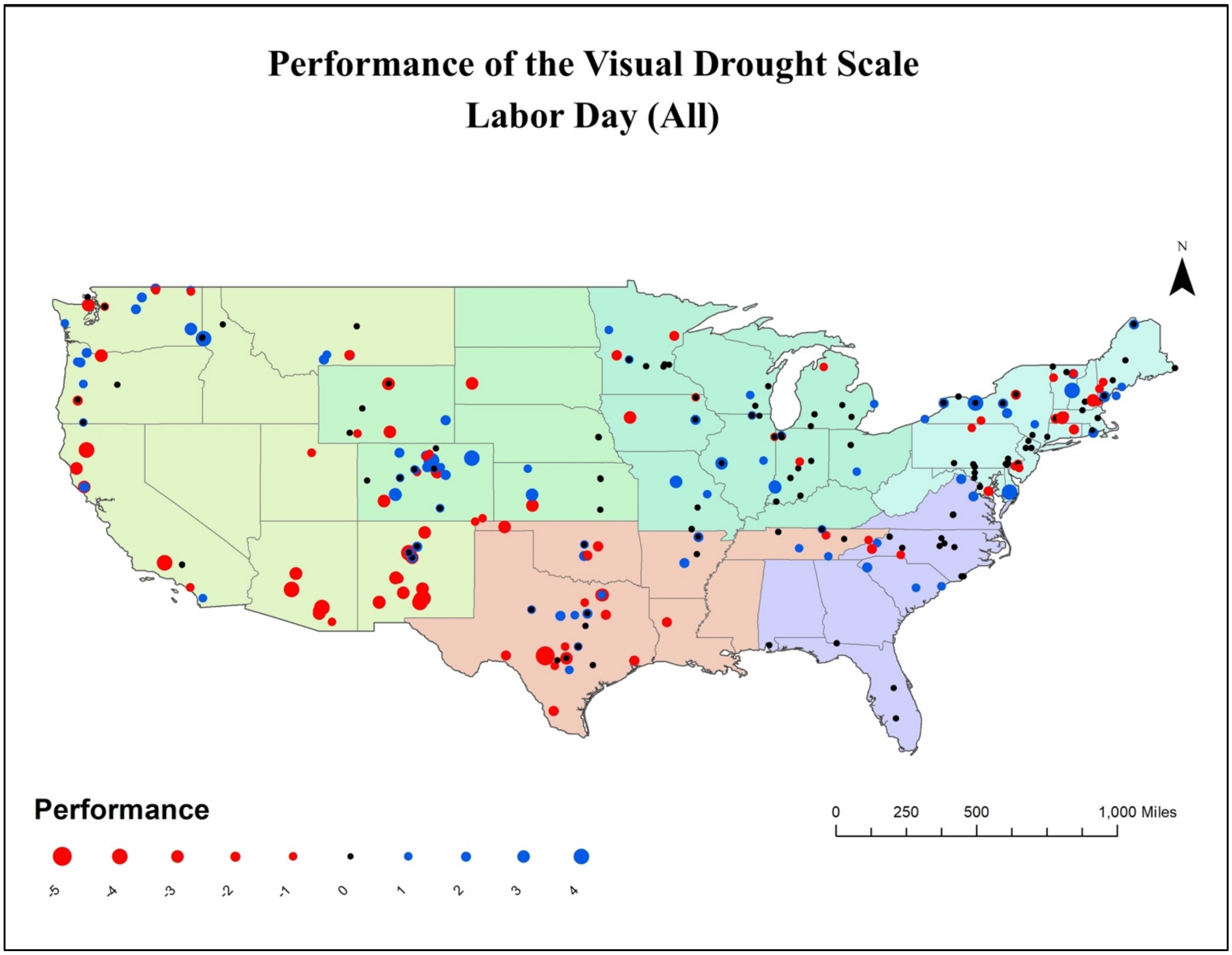


Figure 5. Performance of the Visual Drought Index compared to the USDM for all Labor Day events; larger circles represent a larger difference between scales; red (blue) colors indicate that the Visual Drought Index category was less (more) severe than the USDM.

(c) All Events

Finally, a view of all Memorial Day and Labor Day events provided an overall picture of the Visual Drought Index performance. All regions had a mixture of results, with an overestimation and underestimation of drought severity compared to USDM values covering the country. As mentioned previously, there were localized areas that experienced the largest problems, such as the Desert Southwest and portions of the Southeast region. Furthermore, areas with a higher number of matches between Visual Drought Index values and USDM values included the eastern Midwest region and portions of the Northeast. As seen in Figure 6, there were also large areas with little or no participation with the Field Photos Weekends. For example, only a handful of photos were submitted in the northern High Plains and the central West regions.

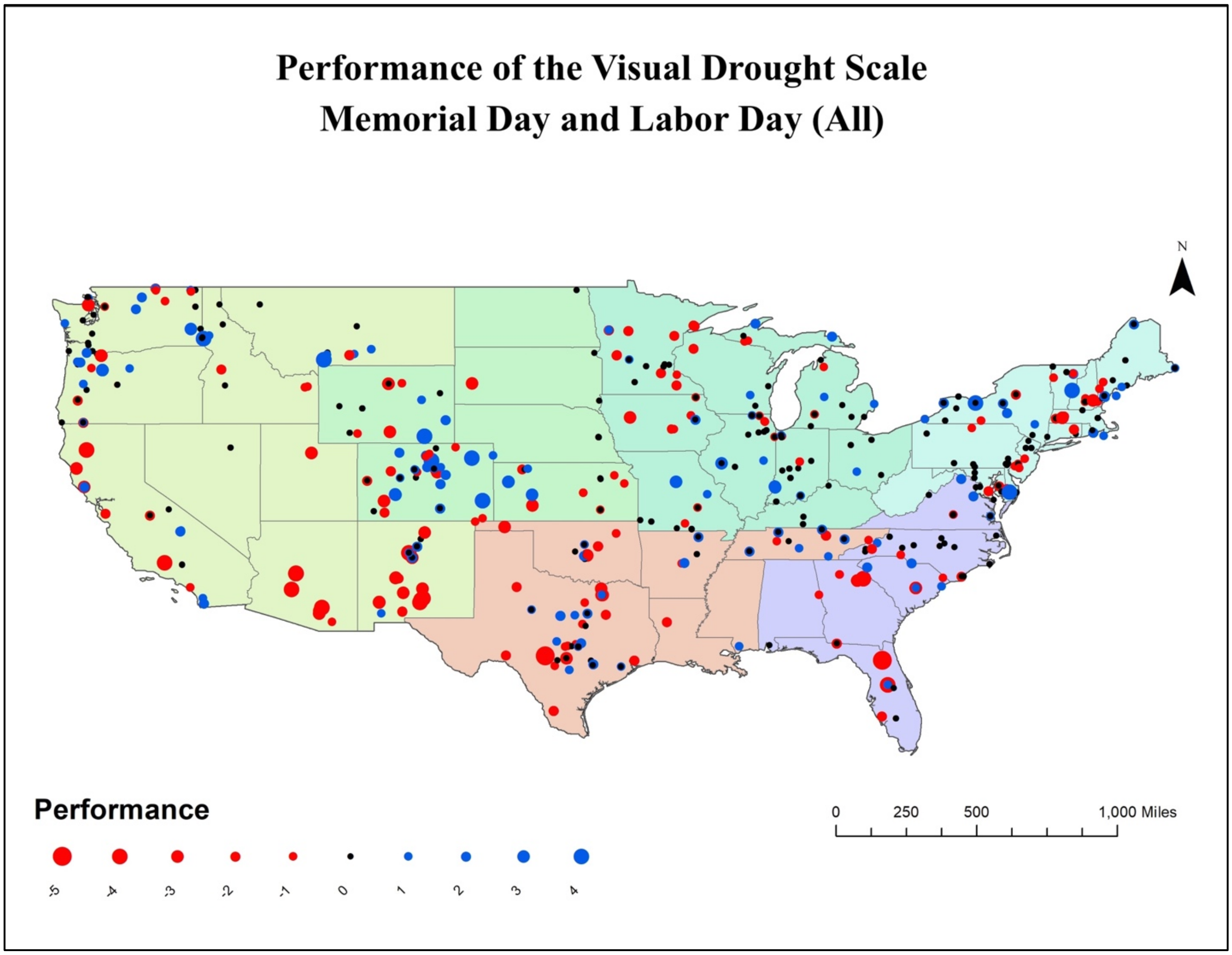


Figure 6. Performance of the Visual Drought Index compared to the USDM for all Memorial Day and Labor Day events; larger circles represent a larger difference between scales; red (blue) colors indicate that the Visual Drought Index category was less (more) severe than the USDM.

Visual Drought Index vs. PDSI and SPI

Another aspect of this project was to compare the Visual Drought Index to other established drought indices. For this comparison, a correlation analysis was conducted for the PDSI and 1-month SPI against the Visual Drought Index values. 1-month SPI was used to capture more rapidly-varying conditions as opposed to the slower-response PDSI. Tables 1 and 2 display the resulting correlation coefficients for PDSI and SPI with values greater than 0.5 highlighted to display the instances of a moderately strong linear relationship. "NA" values were placed in the table for cases in which correlation coefficients that could not be calculated.

Results differed from the USDM analyses in many ways. For example, the Visual Drought Index performed relatively well for the Northeast when compared to the USDM values; however, there were weak linear relationships between the Visual Drought Index and both the PDSI and the SPI. This was also evident in the Midwest, where there was only one event with a moderately strong correlation coefficient. On the other hand, the South and West regions held the most events with correlation coefficients above 0.5, which were the regions that greatly underestimated drought conditions compared to the USDM in our previous analysis.

Table 1. Correlation coefficients of the Visual Drought Index versus the PDSI; values greater than 0.5 are highlighted.

Correlation Coefficients of the Visual Drought Index vs. the PDSI						
Event	Northeast	Southeast	South	Midwest	High Plains	West
MD-13	-0.24	0.43	0.55	-0.02	0.39	0.74
MD-14	-0.06	NA	0.64	-0.14	0.56	0.72
MD-15	NA	-0.54	0.25	NA	-0.26	0.46
MD-16	0.03	NA	0.02	-0.26	0.68	-0.72
LD-12	0	-0.18	0.52	0.12	0.38	0.05
LD-13	-0.14	-0.21	0.46	0.09	0.06	0.13
LD-14	0.05	0.13	0.5	NA	NA	0.41
LD-15	-0.02	-0.25	NA	-0.13	0.22	-0.22
LD-16	-0.22	-0.62	0.04	NA	0.56	0.26

Table 2. Correlation values between the Visual Drought Index and the SPI; values greater than 0.5 are highlighted.

Correlation Coefficients of the Visual Drought Index vs. the SPI						
Event	Northeast	Southeast	South	Midwest	High Plains	West
MD-13	0.37	0.53	0.72	-0.03	0.86	0.51
MD-14	NA	NA	-0.37	0.53	-0.07	-0.16
MD-15	NA	-0.64	0.26	0.25	NA	0.22
MD-16	-0.04	NA	-0.29	0.41	0.65	-0.74
LD-12	0.06	-0.14	0.31	0.03	-0.27	-0.07
LD-13	-0.23	-0.23	-0.24	0.18	-0.27	NA
LD-14	-0.33	NA	-0.59	-0.19	NA	NA
LD-15	NA	-0.21	0.56	-0.07	0.18	0.52
LD-16	-0.19	-0.32	-0.26	0.11	0.2	0.07

Discussion and Conclusions

A functional visual drought severity scale would be an important contribution in the drought community, for anyone could potentially look at their landscape and be able to estimate their area's drought conditions. This is a challenging goal, and this project sought to determine if such an index is feasible at this time. The foundation of this research was from the Field Photos Weekends campaign, in which citizens from across the U.S. were encouraged to take photos of their landscape during specific holiday weekends and submit them to the online platform. The number of photos taken was vital to our project, because a thorough spatial representation of the entire country was necessary for a sufficient analysis. However, participation declined over the years. For example, the first Field Photos Weekend event was during the Labor Day weekend of 2012. For this event, there were over 600 photos submitted, while less than 300 were submitted in 2016. This potentially affected the results of the performance of the Visual Drought Index to the USDM and other drought indices, because there were an insufficient number of photos to make a general statement during some events.

Results were also dependent on the initial steps of subjectively categorizing photos. These values were assigned based on our judgment and experiences. Another aspect to consider is the content of the photos. For example, waterbody land cover types often included a photo of a pond or lake that could be affected by human use, reducing the water depth. In cases where a waterbody with lowered water depth was shown, the Visual Drought Index value was placed in a more severe drought category, but it is possible that the cause of the lowered water depth was from an outside factor (Fig. 7). In these instances, we could only use our judgment because we did not have this outside information. Another example of photo content occurred when multiple photos were taken in one location but the photos were categorized as different landscape types (for example, grasslands in one direction, forest or water body in another). In these cases, different values may have been assigned because each photo was categorized independently, even though they were in the same location.

Figure 7. Photo taken in Oregon from the 2015 Memorial Day Field Photos Weekend event, showing a reduced water level from outside factors

At the time of this project, there was too much variability between the Visual Drought Index values and the USDM to recommend this scale for public use. However, the grasslands land cover type shows potential, with the highest volume of photos and the largest range in drought categories. With more localized drought research and more participation with the Field Photos Weekends, we hope that the scale will improve in the future.

Appendix A: Visual Drought Index Guide

Grasslands (May)

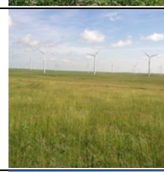
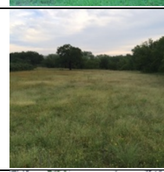
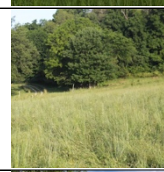
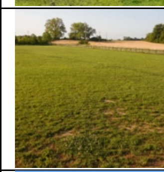
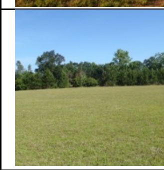
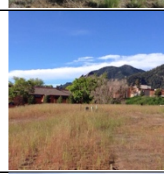
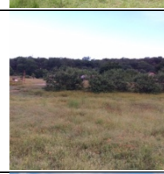
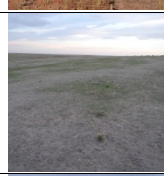
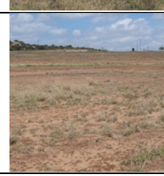
	West	High Plains	South	Midwest	Northeast	Southeast
None						
D0						
D1						
D2						
D3						
D4						

Figure 1A. *Visual Drought Index from the Memorial Day (May) for grasslands land cover type; rows represent drought categories, ranging from no drought to exceptional drought (D4).*

Grasslands (September)

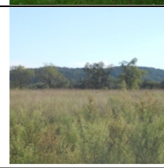
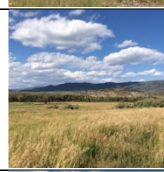
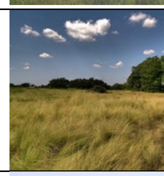
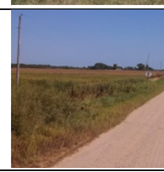
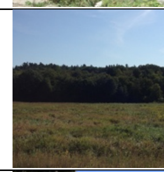
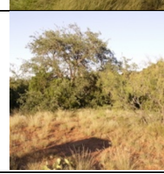
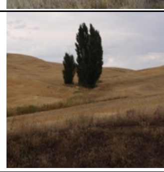
	West	High Plains	South	Midwest	Northeast	Southeast
None						
D0						
D1						
D2						
D3						
D4						

Figure 2A. *Visual Drought Index from the Labor Day (September) for grasslands land cover type; rows represent drought categories, ranging from no drought to exceptional drought (D4).*

Croplands (May)

	West	High Plains	South	Midwest	Northeast	Southeast
None						
D0						
D1						
D2						
D3						
D4						

Figure 3A. *Visual Drought Index from the Memorial Day (May) for croplands land cover type; rows represent drought categories, ranging from no drought to exceptional drought (D4). Many crops in late May are newly emergent and therefore less likely to show stress from extreme drought.*

Croplands (September)

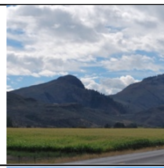
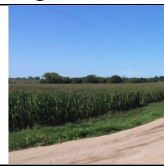
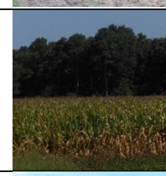
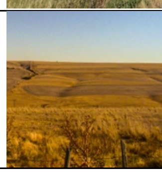
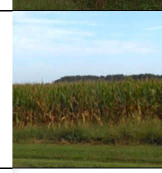
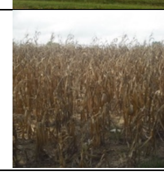
	West	High Plains	South	Midwest	Northeast	Southeast
None						
D0						
D1						
D2						
D3						
D4						

Figure 4A. *Visual Drought Index from the Labor Day (September) for croplands land cover type; rows represent drought categories, ranging from no drought to exceptional drought (D4).*

Forest (All Seasons)

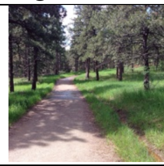
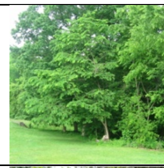
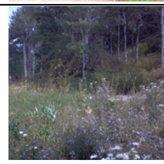
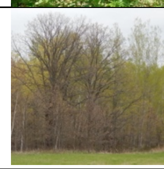
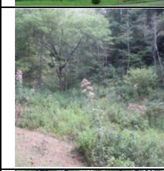
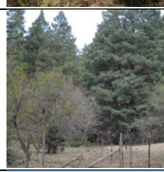
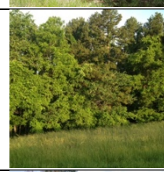
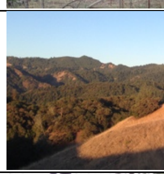
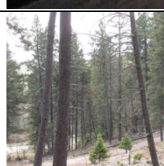
	West	High Plains	South	Midwest	Northeast	Southeast
None						
D0						
D1						
D2						
D3						
D4						

Figure 5A. *Visual Drought Index for forest land cover type; rows represent drought categories, ranging from no drought to exceptional drought (D4). Forest response to drought is slower than for crop or grassland types and showed little discernible difference between Memorial Day (May) and Labor Day (September) photos; consequently these were grouped together.*

Water Body (All Seasons)

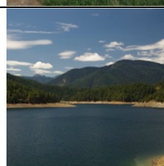
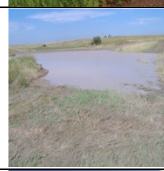
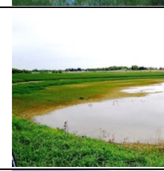
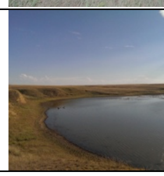
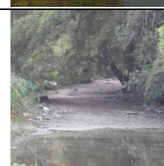
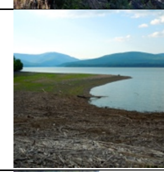
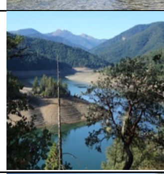
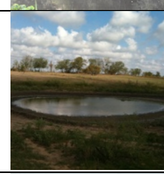
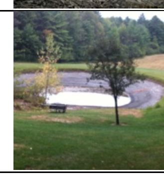
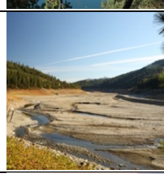
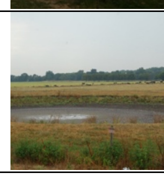
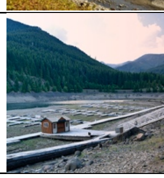
	West	High Plains	South	Midwest	Northeast	Southeast
None						
D0						
D1						
D2						
D3						
D4						

Figure 6A. *Visual Drought Index for water body land cover type; rows represent drought categories, ranging from no drought to exceptional drought (D4). Water Body response to drought is slower than for crop or grassland types and showed little discernible difference between Memorial Day (May) and Labor Day (September) photos; consequently these were grouped together.*

Desert (All Seasons)

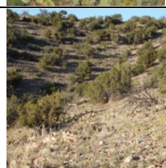
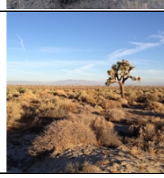
	West	High Plains	South	Midwest	Northeast	Southeast
None						
D0						
D1						
D2						
D3						
D4						

Figure 7A. *Visual Drought Index for desert land cover type; rows represent drought categories, ranging from no drought to exceptional drought (D4). Desert response to drought is slower than for crop or grassland types and showed little discernible difference between Memorial Day (May) and Labor Day (September) photos; consequently these were grouped together. Desert land cover type is only present in large areas the Western United States.*

Appendix B: Photos used in Visual Drought Index Guide

Type	Region	VDI Category	USDM Category	No. of Photos	State	Year	Station ID
Cropland-May	High Plains	D-	D-	4	KS	2016	KS-MN-12
Cropland-May	Midwest	D-	D-	12	IL	2016	----
Cropland-May	Northeast	D-	D-	5	MD	2015	MD-DR-9
Cropland-May	South	D-	D-	3	OK	2013	OK-CN-2
Cropland-May	Southeast	D-	D-	1	NC	2013	NC-PS-5
Cropland-May	West	D-	D0	3	ID	2013	ID-MD-1
Cropland-May	West	D0	D0	2	ID	2013	ID-MD-1
Cropland-May	West	D1	D0	1	OR	2016	OR-MN-16
Cropland-Sep	High Plains	D-	D-	5	NE	2014	----
Cropland-Sep	Midwest	D-	D1	16	IL	2013	IL-CS-3
Cropland-Sep	Midwest	D0	D1	9	IL	2013	IL-CS-3
Cropland-Sep	Midwest	D1	D0	5	IL	2013	IL-CP-34
Cropland-Sep	Midwest	D2	D-	3	IL	2015	----
Cropland-Sep	Northeast	D-	D-	9	NY	2015	NY-WN-18
Cropland-Sep	Northeast	D0	D0	1	NJ	2012	NJ-GL-22
Cropland-Sep	Northeast	D1	D2	1	DE	2014	DE-SS-3
Cropland-Sep	Northeast	D2	D-	1	DE	2016	DE-SS-3
Cropland-Sep	Northeast	D3	D-	2	MD	2012	MD-CV-7
Cropland-Sep	South	D-	D-	2	AR	2013	AR-PS-56
Cropland-Sep	Southeast	D-	D-	1	AL	2013	AL-BW-3
Cropland-Sep	West	D-	D0	5	WA	2016	WA-OK-5
Cropland-Sep	West	D0	D1	1	WA	2014	WA-OK-5
Cropland-Sep	West	D1	D0	2	MT	2015	----
Cropland-Sep	West	D2	D1	1	ID	2013	----
Desert	West	D-	D2	27	AZ	2013	AZ-PN-50
Desert	West	D0	D0	16	NM	2015	NM-SN-45
Desert	West	D1	D0	4	NM	2015	NM-SN-45
Desert	West	D2	D1	2	NM	2013	NM-SN-45
Desert	West	D3	D3	3	CA	2014	CA-LA-31
Forest	High Plains	D-	D-	30	CO	2015	----
Forest	High Plains	D0	D-	6	CO	2014	CO-PT-05
Forest	High Plains	D1	D-	11	CO	2015	----
Forest	Midwest	D-	D-	50	IN	2014	IN-OW-9
Forest	Midwest	D0	D-	2	MN	2013	MN-CN-6
Forest	Midwest	D1	D1	1	MN	2015	MN-LK-4
Forest	Northeast	D-	D0	77	ME	2016	ME-YK-46

Forest	Northeast	D0	D0	3	VT	2012	VT-CL-5
Forest	Northeast	D1	D-	1	ME	2012	ME-AR-4
Forest	South	D-	D-	13	TN	2014	TN-MT-77
Forest	South	D0	D0	15	TX	2013	TX-FY-43
Forest	South	D1	D-	6	TN	2015	TN-MT-77
Forest	South	D2	D1	4	TX	2014	TX-WO-45
Forest	Southeast	D-	D-	23	NC	2015	NC-YN-4
Forest	Southeast	D0	D0	8	NC	2014	NC-MS-5
Forest	Southeast	D1	D-	2	SC	2013	----
Forest	West	D-	D2	42	WA	2015	----
Forest	West	D0	D0	10	OR	2013	OR-DS-29
Forest	West	D1	D3	19	NM	2013	NM-OT-35
Forest	West	D2	D2	4	CA	2015	CA-SN-4
Forest	West	D3	D3	2	NM	2013	NM-OT-35
Forest	West	D4	D2	2	CA	2013	----
Grassland-May	High Plains	D-	D-	27	CO	2014	CO-RT-51
Grassland-May	High Plains	D0	D0	25	KS	2013	KS-BU-26
Grassland-May	High Plains	D1	D-	18	CO	2014	----
Grassland-May	High Plains	D2	D-	3	CO	2015	----
Grassland-May	High Plains	D3	D0	9	KS	2013	KS-LG-2
Grassland-May	High Plains	D4	D0	3	CO	2013	CO-PW-28
Grassland-May	Midwest	D-	D0	52	IL	2013	IL-CK-143
Grassland-May	Midwest	D0	D-	11	IN	2016	IN-HR-5
Grassland-May	Midwest	D1	D-	2	MI	2016	----
Grassland-May	Northeast	D-	D-	46	NY	2013	NY-ER-60
Grassland-May	Northeast	D0	D-	13	NY	2016	----
Grassland-May	South	D-	D0	38	TN	2013	TN-MT-77
Grassland-May	South	D0	D2	21	TX	2015	TX-KR-15
Grassland-May	South	D1	D-	16	TN	2016	TN-HR-2
Grassland-May	South	D2	D2	1	TX	2015	TX-KR-15
Grassland-May	South	D3	D3	2	TX	2013	TX-DK-2
Grassland-May	Southeast	D-	D0	18	VA	2013	VA-PN-2
Grassland-May	Southeast	D0	D-	11	VA	2015	VA-SF-5
Grassland-May	Southeast	D1	D3	7	FL	2013	FL-GD-5
Grassland-May	West	D-	D-	29	WA	2013	----
Grassland-May	West	D0	D0	10	NM	2015	NM-RA-40
Grassland-May	West	D1	D0	30	NM	2015	NM-SF-50
Grassland-May	West	D2	D2	4	NV	2013	NV-EL-7
Grassland-May	West	D3	D2	11	NM	2014	NM-SF-50
Grassland-May	West	D4	D4	11	CA	2015	CA-MA-5

Grassland-Sep	High Plains	D-	D2	17	WY	2013	WY-WH-13
Grassland-Sep	High Plains	D0	D1	36	CO	2013	CO-JF-413
Grassland-Sep	High Plains	D1	D-	22	CO	2014	CO-RT-51
Grassland-Sep	High Plains	D2	D0	12	CO	2016	CO-EL-13
Grassland-Sep	High Plains	D3	D-	4	CO	2015	----
Grassland-Sep	Midwest	D-	D-	50	IN	2014	IN-VN-2
Grassland-Sep	Midwest	D0	D0	17	IL	2013	IL-WL-23
Grassland-Sep	Midwest	D1	D1	2	MN	2013	MN-PP-4
Grassland-Sep	Northeast	D-	D-	44	MD	2012	MD-FR-9
Grassland-Sep	Northeast	D0	D-	14	ME	2016	ME-CM-110
Grassland-Sep	Northeast	D1	D1	21	MA	2015	MA-HS-2
Grassland-Sep	Northeast	D2	D0	1	VT	2012	VT-CL-5
Grassland-Sep	South	D-	D-	37	TN	2014	TN-FN-5
Grassland-Sep	South	D0	D-	22	AR	2013	AR-SH-6
Grassland-Sep	South	D1	D3	28	OK	2014	----
Grassland-Sep	South	D2	D1	7	TX	2013	----
Grassland-Sep	South	D3	D3	3	TX	2013	TX-MCL-12
Grassland-Sep	Southeast	D-	D-	22	FL	2013	FL-GD-5
Grassland-Sep	Southeast	D0	D-	6	SC	2016	----
Grassland-Sep	Southeast	D1	D0	5	VA	2015	VA-SF-5
Grassland-Sep	West	D-	D0	18	WA	2012	WA-SG-15
Grassland-Sep	West	D0	D0	28	NM	2015	NM-SF-50
Grassland-Sep	West	D1	D0	35	OR	2013	OR-LA-54
Grassland-Sep	West	D2	D0	26	NM	2015	NM-SF-50
Grassland-Sep	West	D3	D0	4	WA	2013	WA-WM-6
Water Body	High Plains	D-	D-	36	SD	2013	SD-LN-22
Water Body	High Plains	D0	D0	2	KS	2016	----
Water Body	High Plains	D1	D-	2	KS	2015	KS-NS-17
Water Body	Midwest	D-	D-	57	MI	2014	----
Water Body	Midwest	D0	D-	3	MI	2013	MI-MT-5
Water Body	Midwest	D1	D-	3	IN	2015	IN-MD-25
Water Body	Midwest	D2	D-	2	IL	2012	----
Water Body	Northeast	D-	D-	60	PA	2012	----
Water Body	Northeast	D0	D0	4	VT	2012	VT-GI-3
Water Body	Northeast	D1	D0	2	NY	2012	NY-UL-8
Water Body	Northeast	D2	D-	2	NH	2012	----
Water Body	South	D-	D-	65	AR	2013	AR-PS-56
Water Body	South	D0	D-	13	TN	2013	TN-BF-4
Water Body	South	D1	D1	1	TX	2015	TX-WM-195
Water Body	South	D2	D2	1	TX	2013	TX-LV-21

Water Body	South	D3	D2	1	TX	2013	----
Water Body	Southeast	D-	D-	43	FL	2013	FL-GL-2
Water Body	Southeast	D0	D3	12	FL	2013	FL-LK-10
Water Body	West	D-	D0	90	ID	2013	ID-MD-1
Water Body	West	D0	D1	2	OR	2015	----
Water Body	West	D1	D-	3	WA	2013	WA-CH-39
Water Body	West	D2	D2	1	OR	2015	OR-JS-18
Water Body	West	D3	D2	2	OR	2015	OR-JS-18
Water Body	West	D4	D1	4	OR	2015	OR-MN-16

CoCoRaHS station id indicated by state-county-number codes. See https://www.cocorahs.org/ for more details. Photos that were submitted to Field Photos Weekends but did not include the observer's station id are indicated by ----.

Appendix C: Comparison to U.S. Drought Monitor

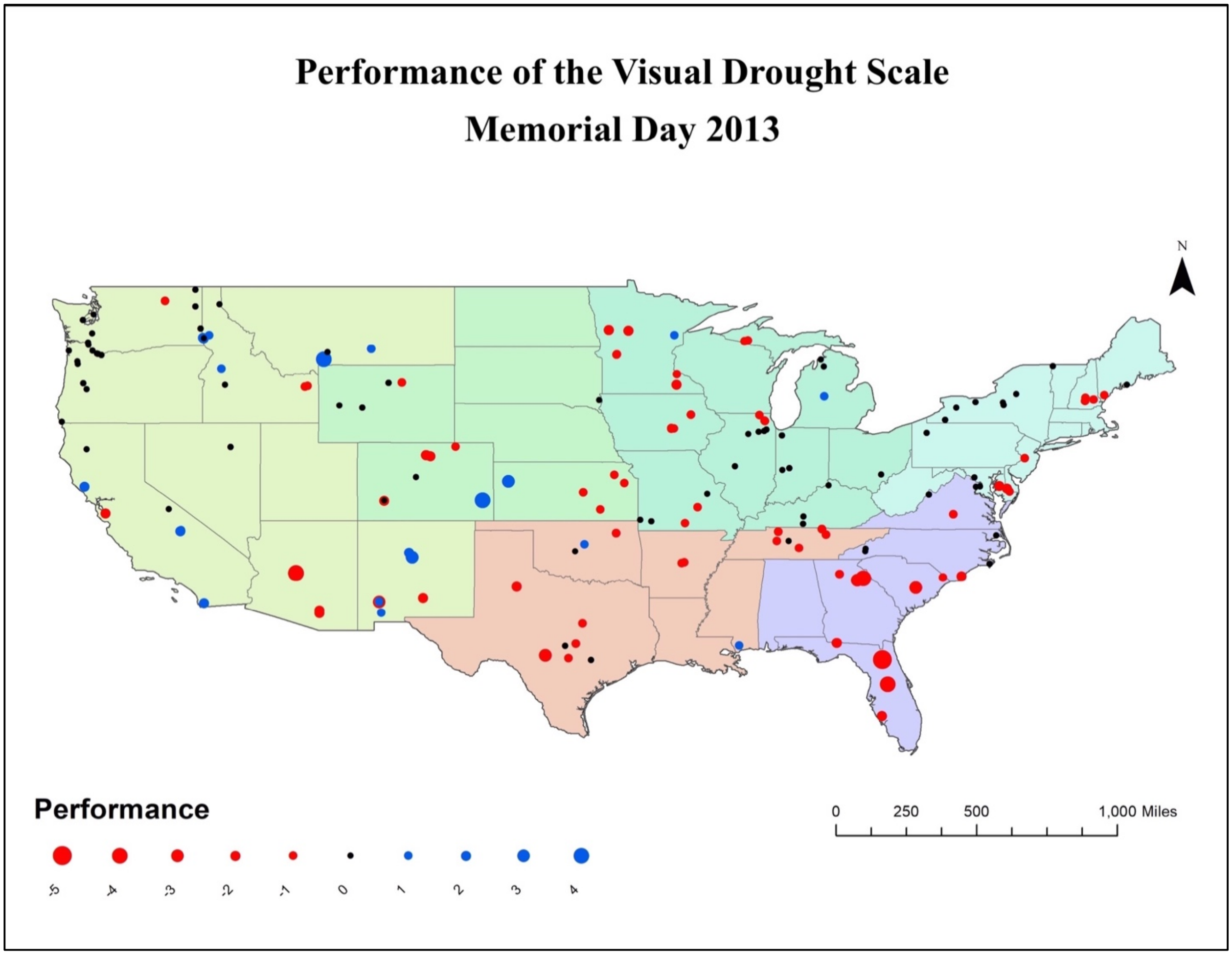


Figure 1C. Performance of the Visual Drought Index compared to the USDM for Memorial Day 2013; larger circles represent a larger difference between scales; red (blue) colors indicate that the Visual Drought Index category was less (more) severe than the USDM.

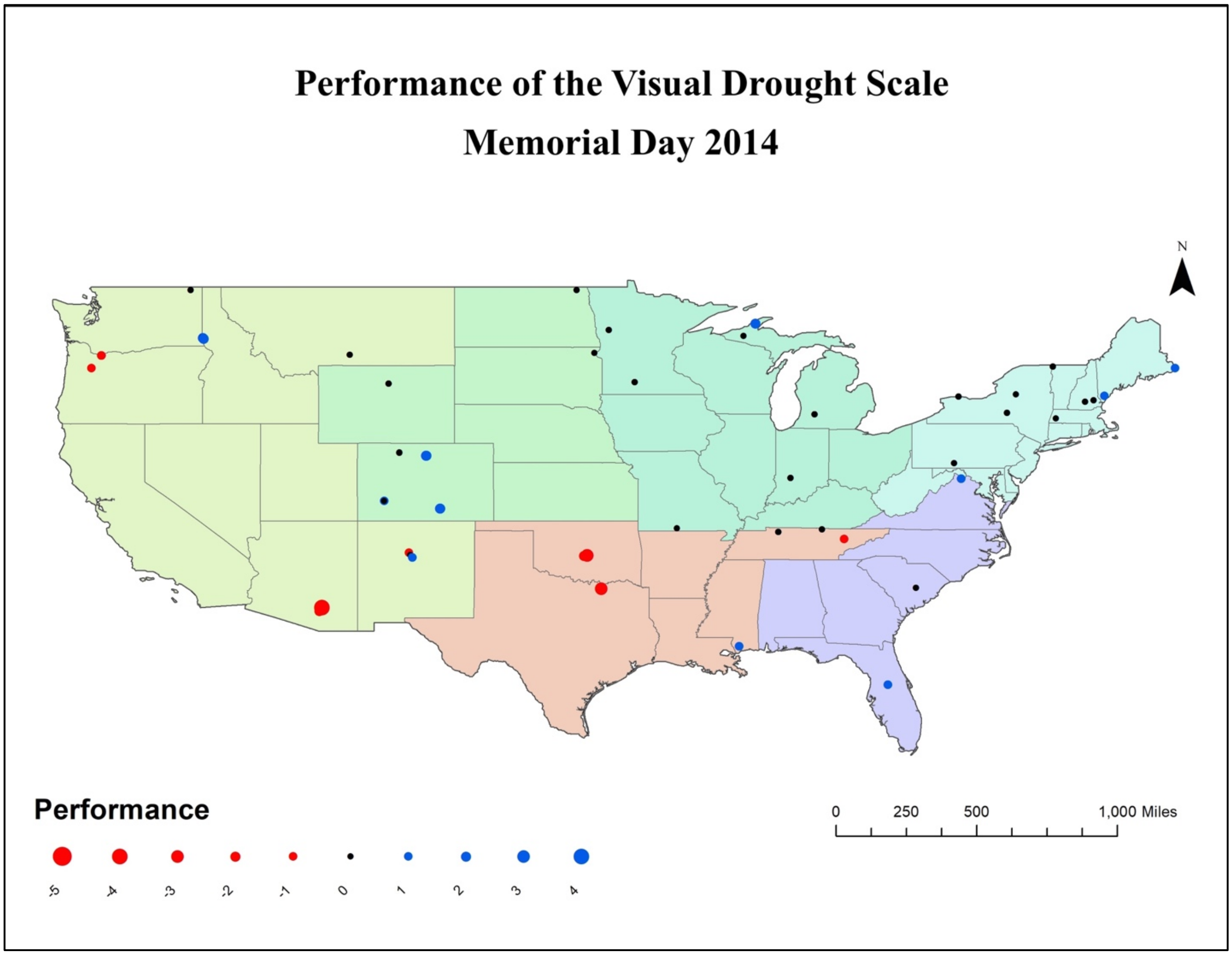


Figure 2C. Performance of the Visual Drought Index compared to the USDM for Memorial Day 2014; larger circles represent a larger difference between scales; red (blue) colors indicate that the Visual Drought Index category was less (more) severe than the USDM.

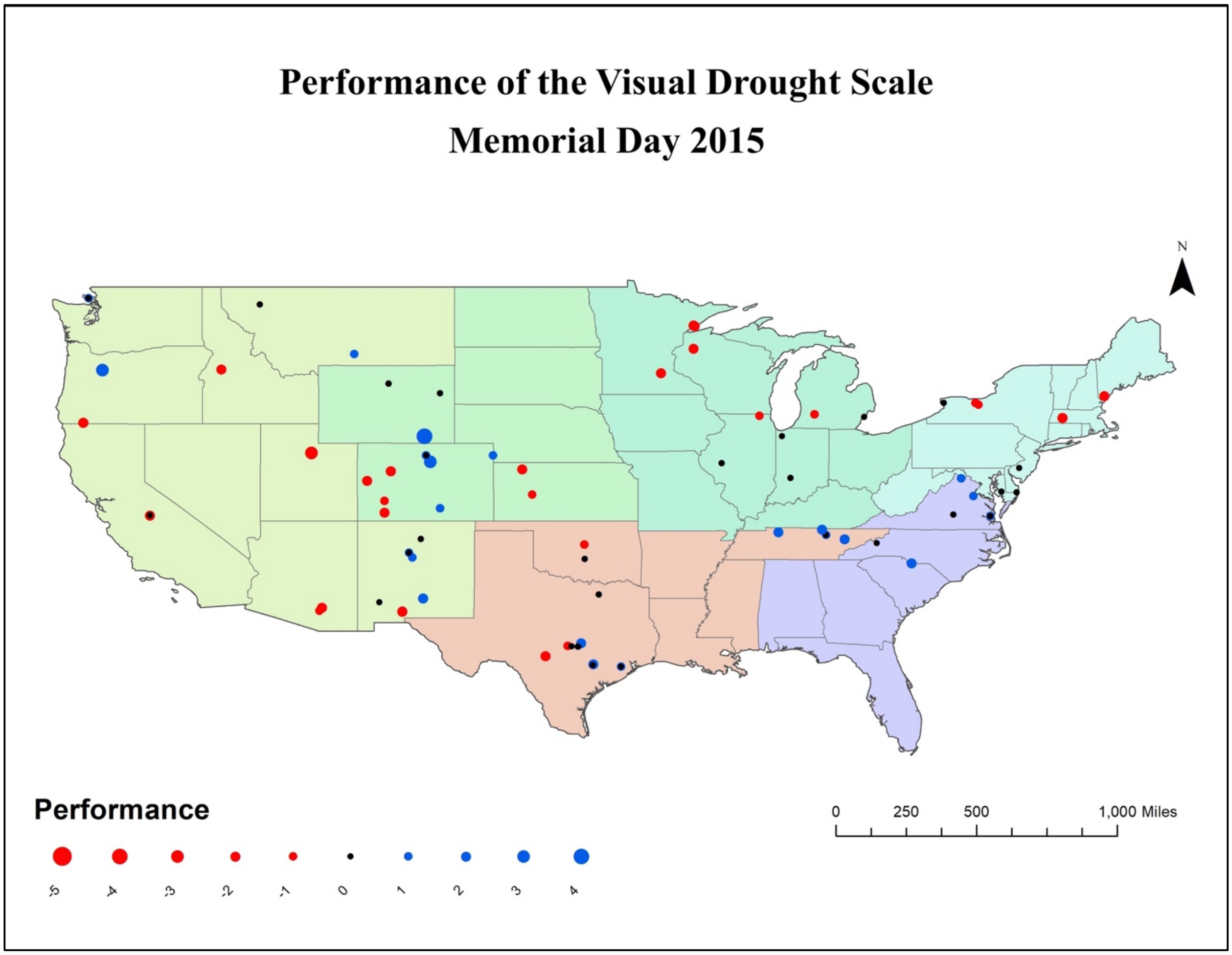


Figure 3C. Performance of the Visual Drought Index compared to the USDM for Memorial Day 2015; larger circles represent a larger difference between scales; red (blue) colors indicate that the Visual Drought Index category was less (more) severe than the USDM.

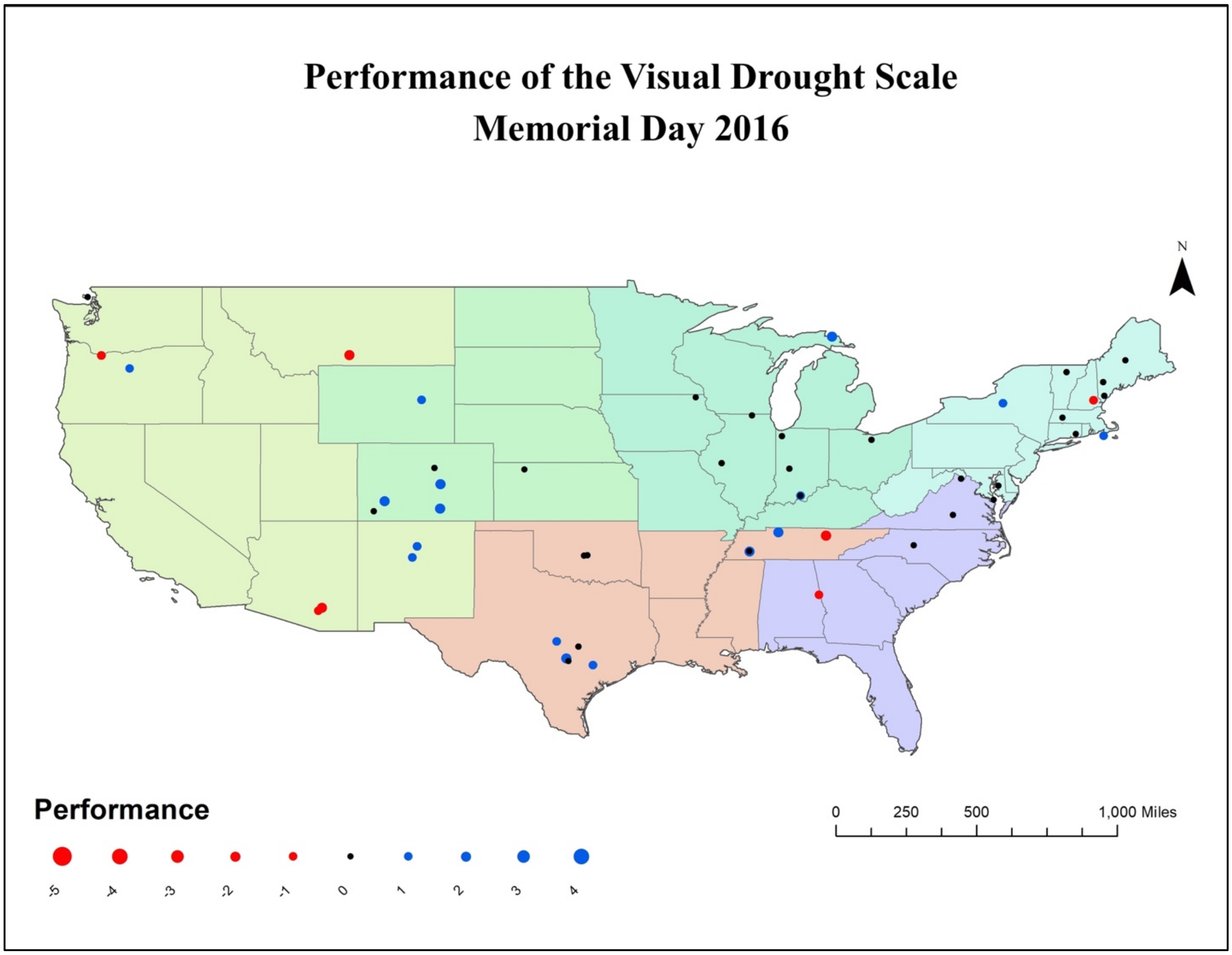


Figure 4C. Performance of the Visual Drought Index compared to the USDM for Memorial Day 2016; larger circles represent a larger difference between scales; red (blue) colors indicate that the Visual Drought Index category was less (more) severe than the USDM.

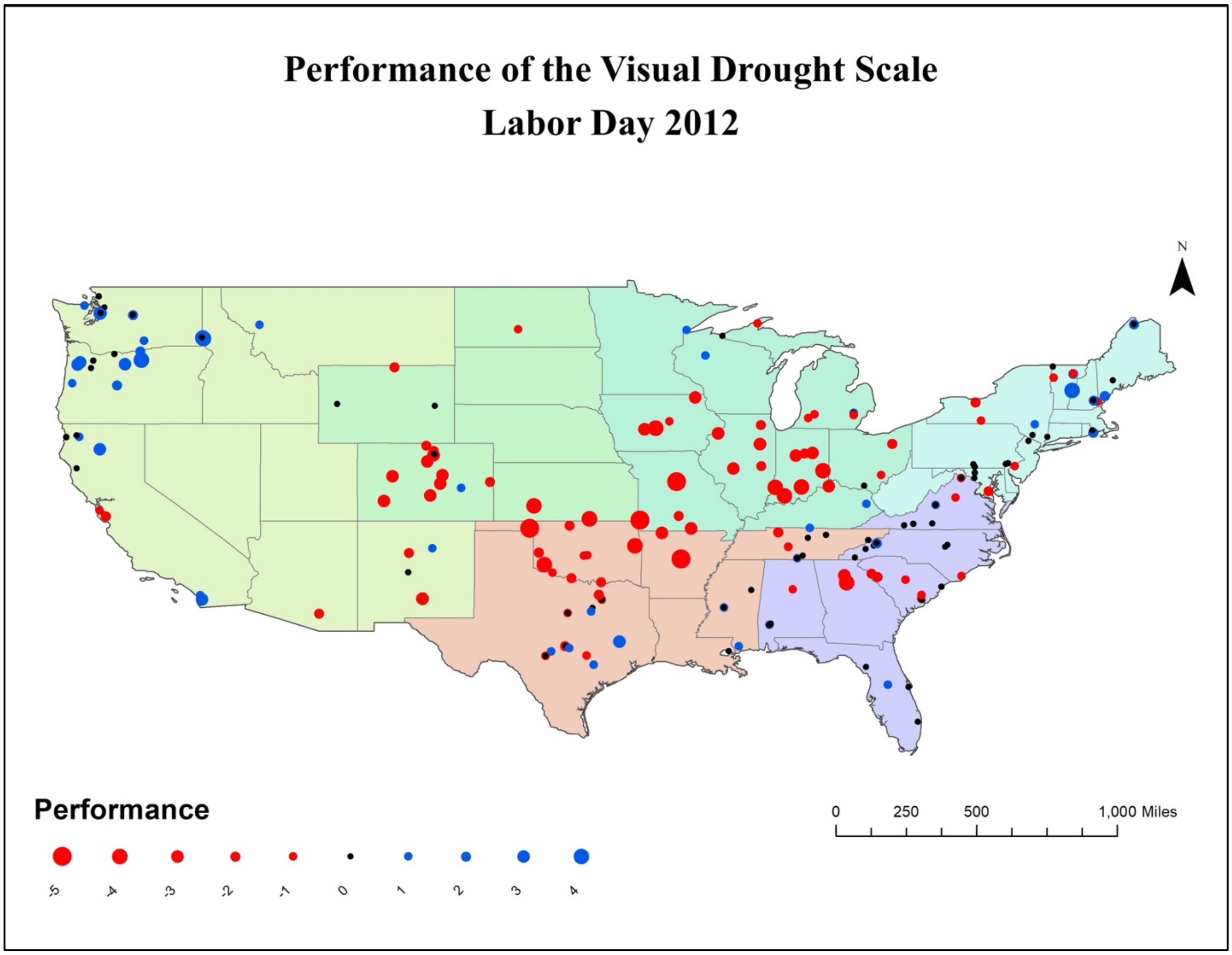


Figure 5C. Performance of the Visual Drought Index compared to the USDM for Labor Day 2012; larger circles represent a larger difference between scales; red (blue) colors indicate that the Visual Drought Index category was less (more) severe than the USDM.

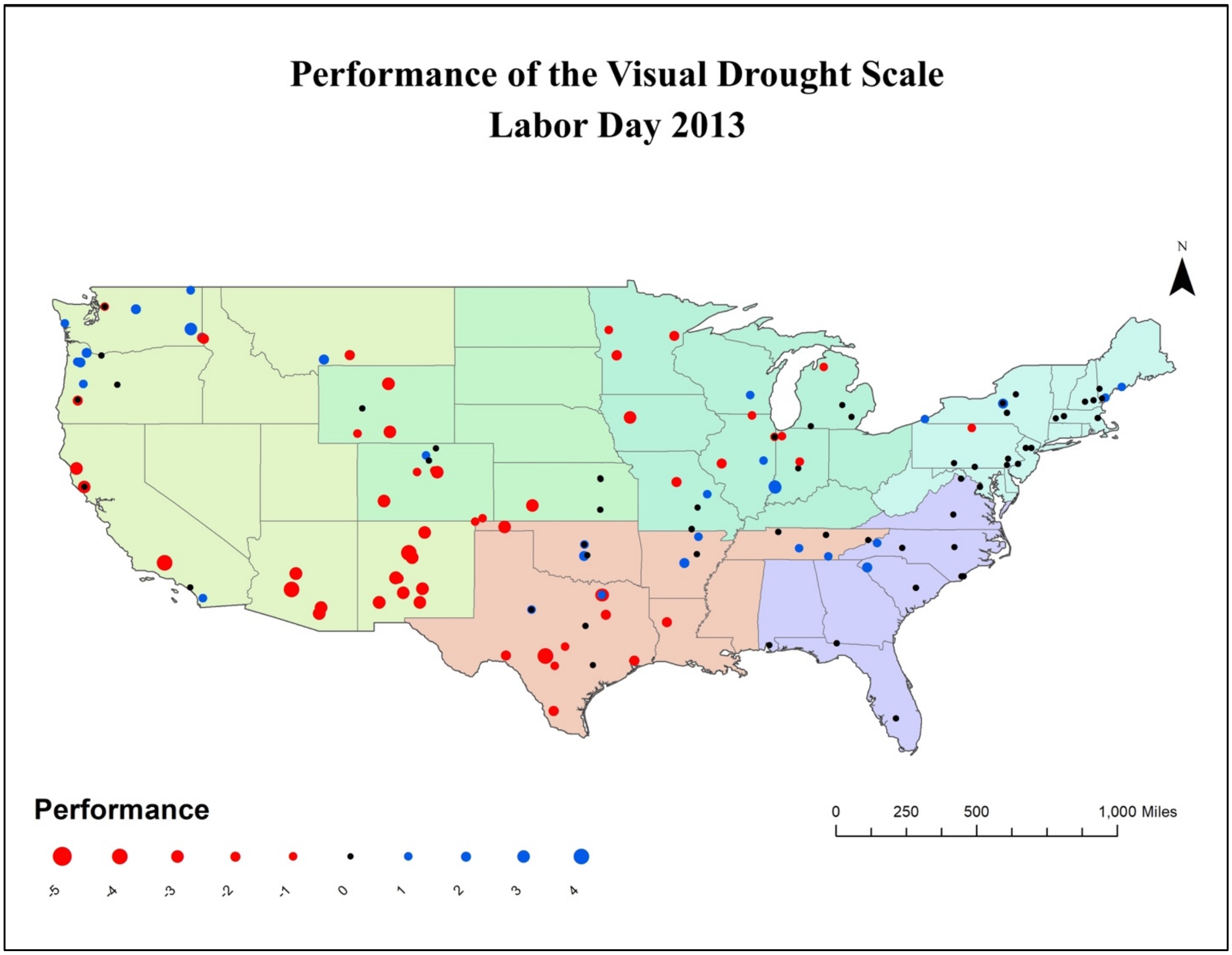


Figure 6C. Performance of the Visual Drought Index compared to the USDM for Labor Day 2013; larger circles represent a larger difference between scales; red (blue) colors indicate that the Visual Drought Index category was less (more) severe than the USDM.

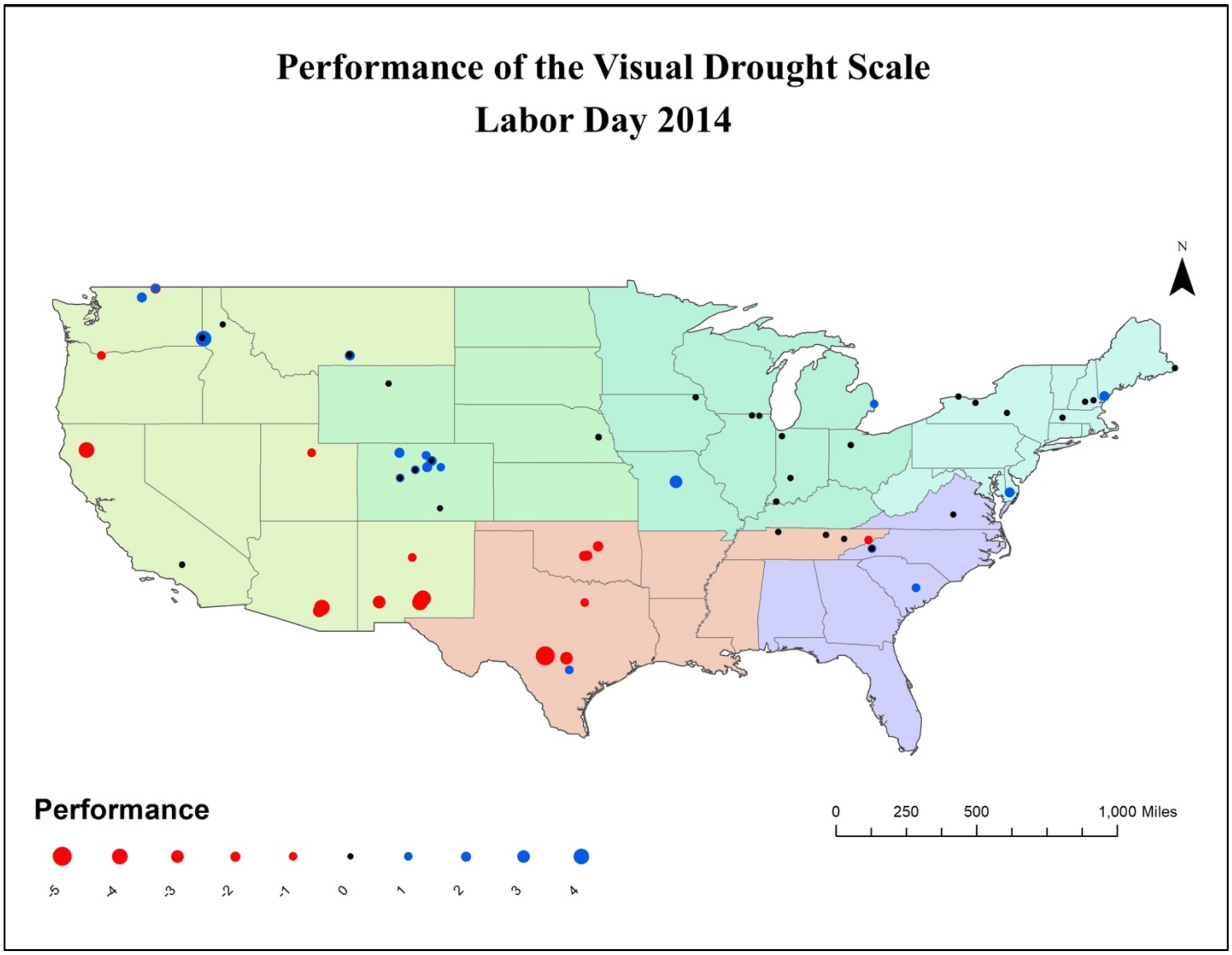


Figure 7C. Performance of the Visual Drought Index compared to the USDM for Labor Day 2014; larger circles represent a larger difference between scales; red (blue) colors indicate that the Visual Drought Index category was less (more) severe than the USDM.

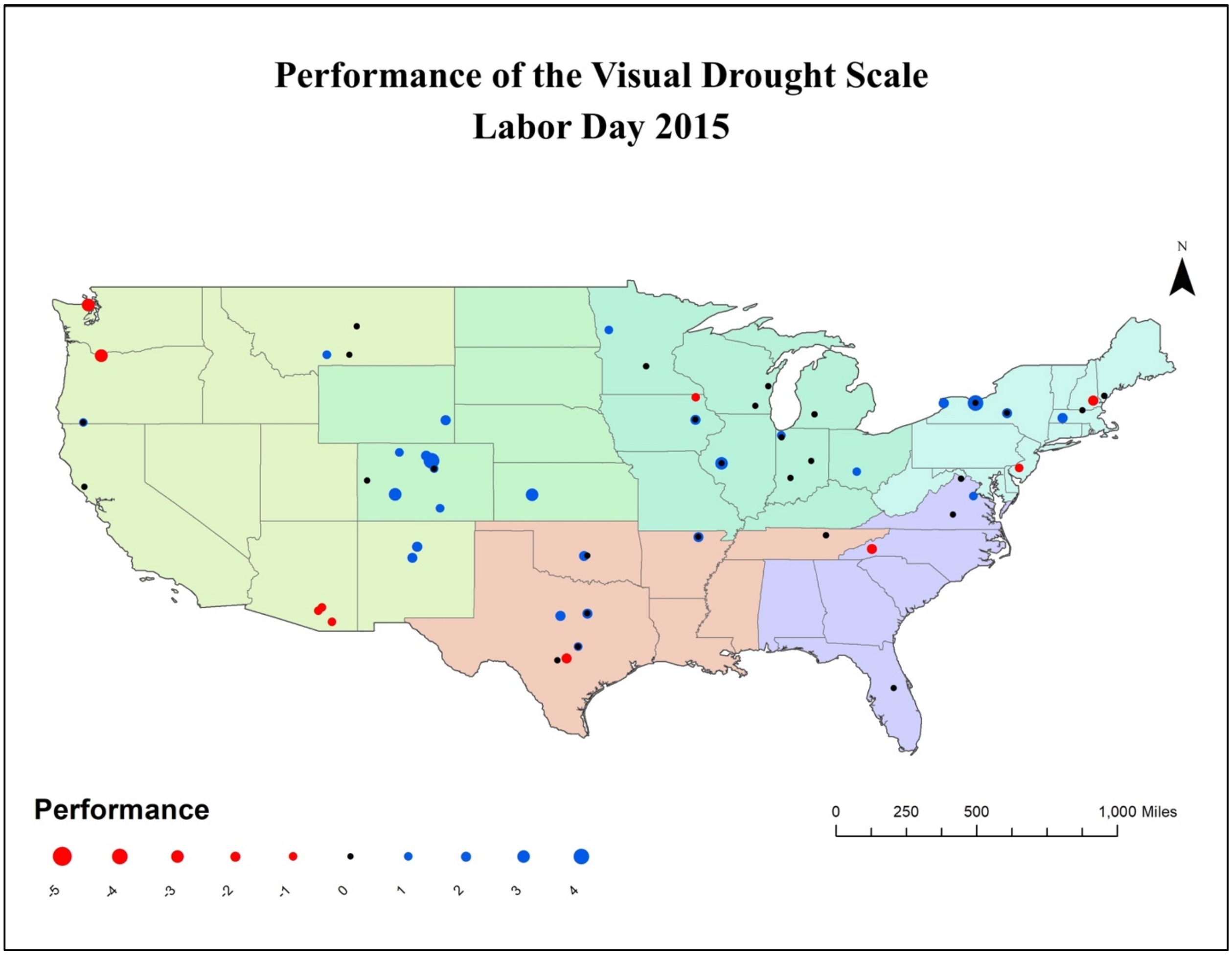


Figure 8C. Performance of the Visual Drought Index compared to the USDM for Labor Day 2015; larger circles represent a larger difference between scales; red (blue) colors indicate that the Visual Drought Index category was less (more) severe than the USDM.

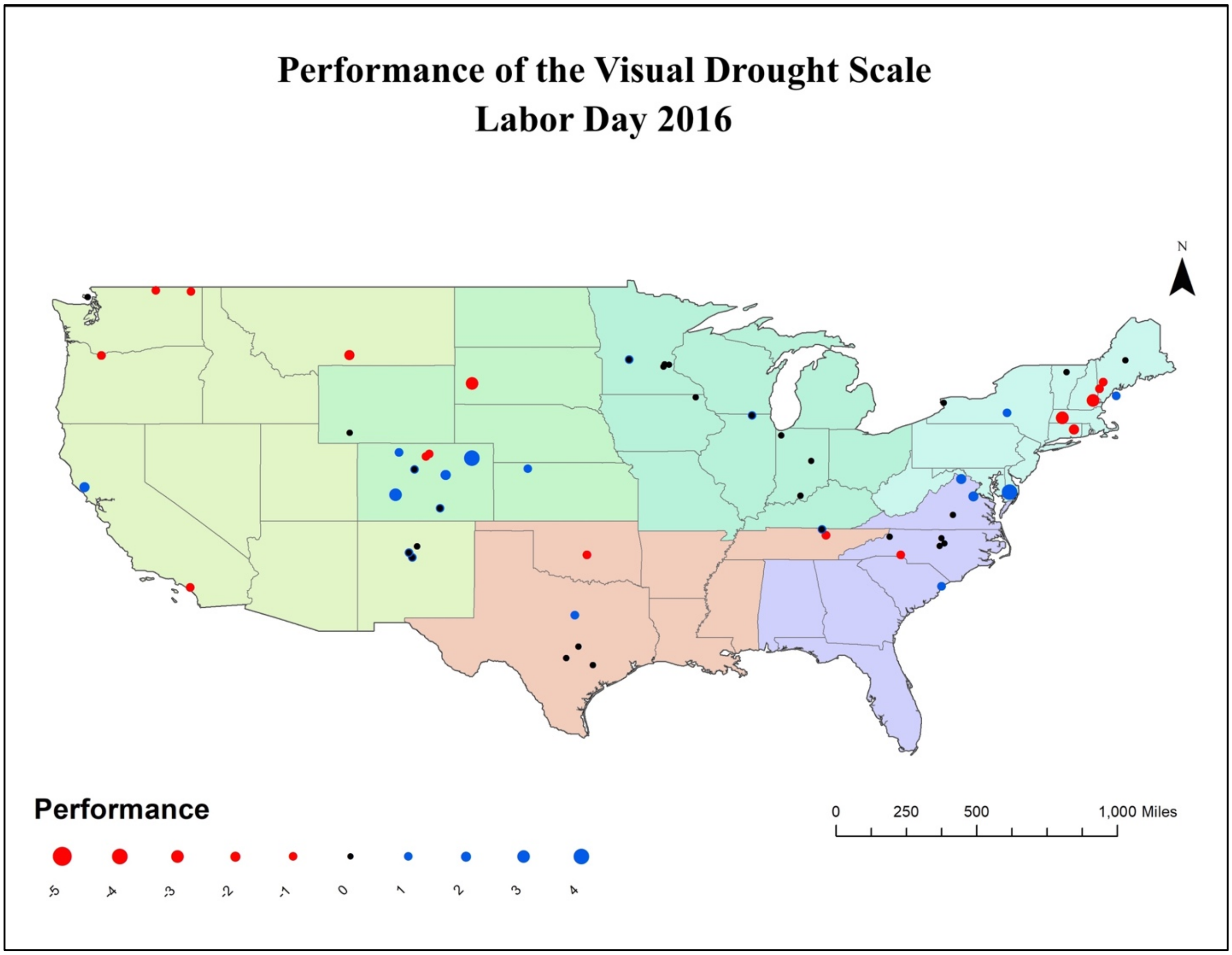


Figure 9C. Performance of the Visual Drought Index compared to the USDM for Labor Day 2012; larger circles represent a larger difference between scales; red (blue) colors indicate that the Visual Drought Index category was less (more) severe than the USDM.

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Acknowledgements

This project was supported by NOAA Climate Program Office's Sectoral Applications Research Program (SARP) under grant NA15OAR4310107. Participating organizations in this project included CoCoRaHS, the Earth Observation and Modeling Facility, ISeeChange, and the Southern Climate Impacts Planning Program. The project would not have been possible without the numerous landscape photos taken and submitted by CoCoRaHS observers and other participants through the Field Photos Weekends events between 2012 and 2017. We appreciate the dedication of these observers and citizen scientists throughout the world.

This publication is produced by the Southern Climate Impacts Planning Program (SCIPP) as authorized by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration Co-operative Agreement, NA13OAR4310183. Funding for the project was provided by NOAA Sectoral Applications Research Program (SARP) under Cooperative Agreement NA15OAR4310107.

Copies have not been printed but are available through the SCIPP website.