JP1.1 SPATIAL COHERENCE OF RAINFALL VARIATIONS USING THE OKLAHOMA MESONET

K. Margret Sturgis* and Renee A. McPherson
Oklahoma Climatological Survey, Norman, Oklahoma

David J. Karoly and Michael B. Richman
University of Oklahoma, School of Meteorology, Norman, Oklahoma

1. INTRODUCTION

Jointly owned by the University of Oklahoma (OU) and Oklahoma State University (OSU), the Oklahoma Mesonet has provided valuable meteorological measurements since the early 1990's. With over 110 stations located across the state of Oklahoma, the Mesonet is a state-of-the-art network that measures several hydrological, agricultural, and meteorological variables (Brock et al. 1995; McPherson et al. 2006).

Each of the automated observing stations of the Oklahoma Mesonet monitors and gathers data regarding temperature, dew point (and relative humidity), incoming solar radiation, soil temperatures, wind speed and direction, and rainfall. Rainfall is measured using a tipping-bucket rain gauge. This type of instrument measures rainfall by collecting rain in a bucket, tipping, and accumulating the number of tips. Each tip of the bucket indicates 0.01 inches (0.254 mm) of rainfall fell. The number of tips, along with the volume of the bucket, is utilized in calculating the amount of rainfall. The Oklahoma Mesonet began recording rainfall in 1994.

Previous studies have been conducted using Oklahoma Mesonet data. There have been spatial analyses of temperature, wind, and other variables. However, rainfall has not been studied extensively on a spatial scale. Rainfall impacts run-off, irrigation practices, drought mitigation, and traffic flow. Therefore studying rainfall patterns and the spatial distribution of rainfall is beneficial for many aspects of society, including agriculture, transportation, and business.

**Corresponding author address:* K. Margret Sturgis, Oklahoma Climatological Survey, Univ. of Oklahoma, Norman, OK 73072-7316; e-mail: kmsturgis@ou.edu.

This study proposes to conduct spatial analyses of rainfall patterns in Oklahoma using the rainfall data from the Mesonet from January 1, 1994 to December 31, 2003. The overall goal of this research is to determine if the density of the Oklahoma Mesonet is sufficient to measure rainfall patterns at different time scales. Particular emphasis will be placed on examining the spatial coherence of rainfall variations for 24-hour rainfall totals.

2. DATA

2.1 *Overview and Methodology*

As numerous states and areas of the United States plan for new mesoscale surface observing networks, a primary question arises: "How densely spaced should the stations be to measure most mesoscale phenomena in the region?" When considering the Oklahoma Mesonet, spatial coherence is important in determining if the density of Mesonet sites is sufficient to capture the majority of rainfall variations across an area.

For this study, a rotated principal component analysis was conducted on precipitation data from the Oklahoma Mesonet sites for 24-hour total accumulations. The dataset consists of rainfall data from January 1, 1994 to December 31, 2003. Principal component analysis was utilized due to the nature of rainfall and the abundance of data available for this study. If the rotated principal component loadings exceeded 0.4 (~20% of the variance), then the region was considered spatially coherent.

2.2 *Principal Component Analysis (PCA)*

One method to determine the most important features of a dataset is principal component analysis (PCA). PCA is a data reduction technique that minimizes a large dataset into a smaller dataset that not only contains fewer components but also retains the variability recorded between the original data. PCA is comprised of 1) calculation of a matrix, 2) computation of eigenvectors, 3) calculating principal component loadings, and 4) either analyzing the loadings or rotating them and analyzing the results graphically. One advantage of PCA is that it is an eigenvectorial method that encourages the understanding of the variance between observations through analysis of the resulting patterns in the "loadings" and "scores." For rainfall data, principal component loadings describe the regions of coherent rainfall in a study area while scores indicate how much rain fell across a spatially coherent region.

For this study, a correlation matrix is employed. A correlation matrix describes the correlations amongst the given variables and illustrates that the observations vary with each other (Elmore and Richman 2001). After the matrix has been computed, an eigenanalysis can be performed on the correlation matrix. The corresponding eigenvectors (loadings) are important because they describe the amount of variability between the variables in the correlation matrix. The eigenvectors also provide a method to plot and interpret the eigenanalysis. The interpretation of the eigenanalysis by the author is the key step in a principal component analysis.

When the principal components are rotated (i.e., to maximize the variance of the components), the results are similar to that of a cluster analysis. A rotation of principal components means the eigenvectors are rotated onto a new set of coordinates in order to enhance the physical interpretability of the principal components. Stated similarly by Gong and Richman (1995), the goal of principal component analysis is to find which observations lie within a given referenced cluster. Rotation implies enhanced interpretability, but it does not mean the results will be able to be interpreted (Elmore and Richman 2001).

A commonly used rotation method is the VARIMAX rotation. VARIMAX rotation is a rigid, orthogonal rotation that maximizes the interstation variance (Walsh and Richman 1981; Horel 1981; Richman 1981; Richman 1985). Elmore and Richman (2001) commented that the use of the VARIMAX rotation provided easy interpretability of rotated principal components.

2.3 *Quality Assurance of the Data Set*

Rigorous quality assurance (QA) procedures are performed for all meteorological variables gathered at Oklahoma Mesonet sites (Shafer et al. 2000; Fiebrich et al. 2005). Basic QA procedures include the following: 1) laboratory testing and calibration, 2) intercomparisons on-site, 3) manual inspections and 4) automated routines. For example, 24-hour accumulated rainfall is compared to the 24-hour radar-estimated rainfall total for any given site. If the rainfall estimate is at least 0.5 inches and the corresponding Mesonet site reports less than 25% of that rainfall, then a report is sent to the QA manager for manual inspection (Reader 2004). This type of QA procedures are carried out on a daily, monthly, tri-monthly, and yearly timeframe (Reader 2004).

Besides the basic QA procedures performed, the rainfall dataset used in this study also has been scrutinized using a double-mass analysis. The double-mass analysis compared the total number of tips from a Mesonet rain gauge and the totals for the nearest five Mesonet sites. Consistency amongst the Mesonet sites resulted in a nearly 1:1 ratio of accumulated rainfall over a long period of time. If the data were not consistent, then a plot of the two accumulations demonstrated a substantial deviation from the 1:1 ratio.

The double-mass analysis revealed over 145,000 observations out of over 100 million were not correct and consequently were removed from the dataset (Reader 2004).

3. RESULTS

To understand the distribution of rainfall across Oklahoma, a plot of rainfall averaged over 30 years is shown in Figure 1. The map shows that the rainfall across Oklahoma increases from west to east. The eastern half of Oklahoma receives, on average, twice as much rainfall than the western half. Likewise, eastern Oklahoma is affected the most by extreme rainfall events. The panhandle region of Oklahoma typically experiences drier weather, and in the springtime, is located mostly behind the dryline. On the other hand, southeastern Oklahoma is typically more moist, being closer to the Gulf of Mexico and experiencing southeasterly winds during much of the spring and summer.

For the 24-hour rainfall accumulations, the first four principal components were calculated and explained approximately 64% of the total variance. The variances and eigenvalues for the four components are shown in Table 1.

Figure 2 depicts the first rotated PC loading (top image) and the associated PC scores (bottom) for the 24-hour rainfall accumulations. Daily rainfall is spatially coherent across the northeast portion of Oklahoma. The highest scores denote extreme events that occurred primarily during the warm-seaon (April - October). The rainfall events that affected the PC loadings were primarily heavy rainfall events that occurred across northern Oklahoma.

The second, third, and fourth rotated PC loadings (top) and PC scores (bottom) are described in Figures 3, 4, and 5, respectively. The second component illustrates a moisture gradient in Oklahoma from NW to SE. Rainfall is spatially coherent across southeast Oklahoma. There is also a sharp gradient in the spatial coherence from southwest to northeast across central Oklahoma. The principal component scores show that generally, when there heavy rainfall in southeast Oklahoma, the northwest region of Oklahoma is dry. A plot of the third rotated PC loadings indicate a region of spatial coherence across southwestern Oklahoma, whereas the fourth rotated PC loadings plot demonstrate spatial coherence across far northwestern Oklahoma, including the Oklahoma Panhandle. This principal component may be representative of mesoscale convective complexes, which tend to move southeast out of southwestern Kansas into northwestern Oklahoma.

The first and fourth PC scores indicate that the rainfall events that affected the PC loadings the greatest occurred during the warm-season months of April through October. In both cases, the rainfall events generally were caused by localized heavy rainfall or slow-moving thunderstorms. On the other hand, the second and third PC scores indicate extreme rainfall events that occurred throughout the year. The majority of rainfall events in the second PC were severe weather events, whereas the third PC experienced mainly heavy rainfall events.

4. CONCLUSIONS

Overall, four principal components were analyzed in studying the spatial coherence of 24-hour rainfall accumulations across Oklahoma. Each component represented different regions of spatial coherence, resulting from different physical mechanisms. These causes and their seasonality will be discussed in this poster. In addition, results for different time scales will be presented.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Brock, F. V., K. C. Crawford, R. L. Elliott, G. W. Cuperus, S. J. Stadler, H. L. Johnson, and M. D. Eilts, 1995. The Oklahoma Mesonet: A technical overview. *J. Atmos. Oceanic Technol.* 12: 5 – 19.

Elmore, K. L., and M. B. Richman, 2001: Euclidean distance as a similarity metric for principal component analysis. *Mon. Wea. Rev.,* **129,** 540-549.

Fiebrich, C. A., D. L. Grimsley, R. A. McPherson, K. A. Kesler, and G. R. Essenberg, 2005: The value of routine site visits in managing and maintaining quality data from the Oklahoma Mesonet. *J. Atmos. Oceanic Technol.*, **23,** 406-416.

Gong, X., and M. B. Richman, 1995: On the application of cluster analysis to growing season precipitation data in North America east of the Rockies. *J. Climate Appl. Meteor.,* **8,** 897-931.

Horel, J. D., 1981: A rotated principal component analysis of the interannual variability of the Northern Hemisphere 500 mb height field. *Mon. Wea. Rev.,* **109,** 2080-2092.

McPherson, R. A., and Coauthors, 2006: Statewide monitoring of the mesoscale environment: A technical update on the Oklahoma Mesonet. *J. Atmos. Oceanic Technol.,* accepted.

Reader, A., 2004: Depth-Duration Frequency of precipitation for Oklahoma using the Oklahoma Mesonet. M. S. Thesis, School of Meteorology, University of Oklahoma, 107 pp.

Richman, M. B., 1981: Obliquely rotated principal components: An improved meteorological map typing technique. *J. Appl. Meteor.,* **20,** 1145-1159.

Richman, M. B., and P. J. Lamb, 1985: Climatic pattern analysis of three- and seven- day summer rainfall in the central United States: Some methodological considerations and a regionalization. *J. Climate Appl. Meteor.,* **24,** 1325-1343.

Shafer, M. A., C. A. Fiebrich, D. Arndt, S. E. Fredrickson, and T. W. Hughes. 2000. Quality assurance procedures in the Oklahoma Mesonetwork. *J. Atmos. Oceanic Technol.*, **17**, 474-494.

Wilks, D. S., 1995: *Statistical Methods in the Atmospheric Sciences*. Academic Press, 467 pp.

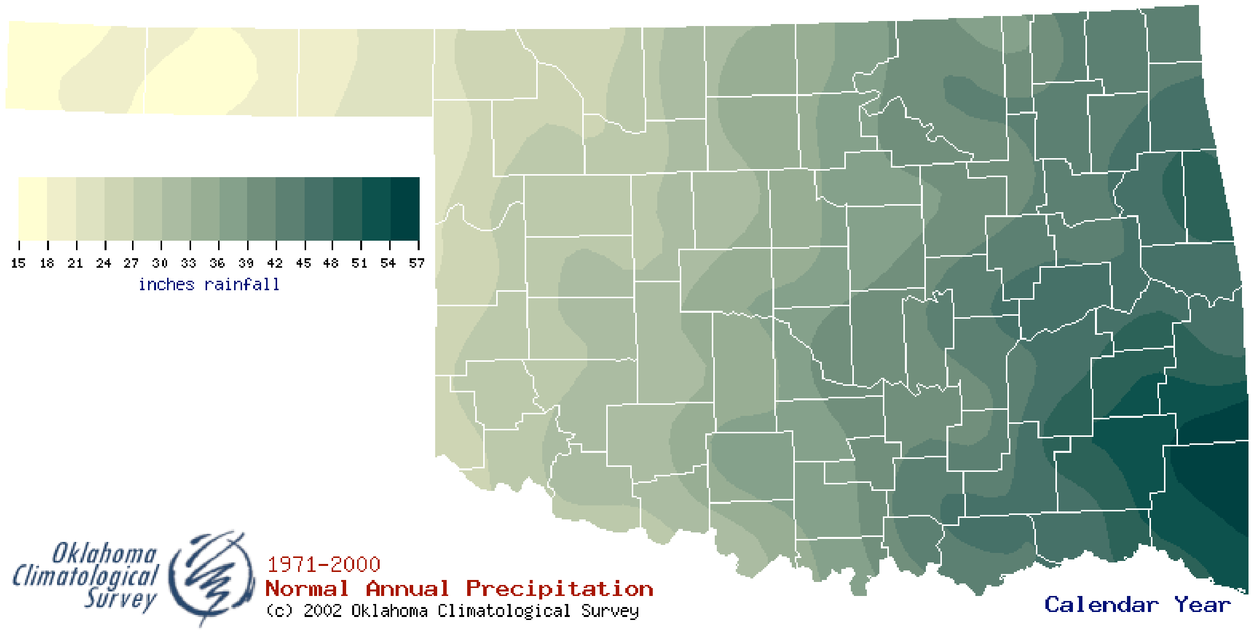

Figure 1: Annual rainfall for the Oklahoma Mesonet sites over a thirty year period. Rainfall amounts are in inches.

Table 1: The four rotated principal components and their corresponding eigenvalues and variance explained. The right column displays the cumulative variance.

Principal Components	Eigenvalues	Variance	Cum. Variance
1	43.17	42.74	42.74
2	10.83	10.72	53.46
3	5.65	5.59	59.05
4	4.76	4.71	63.76

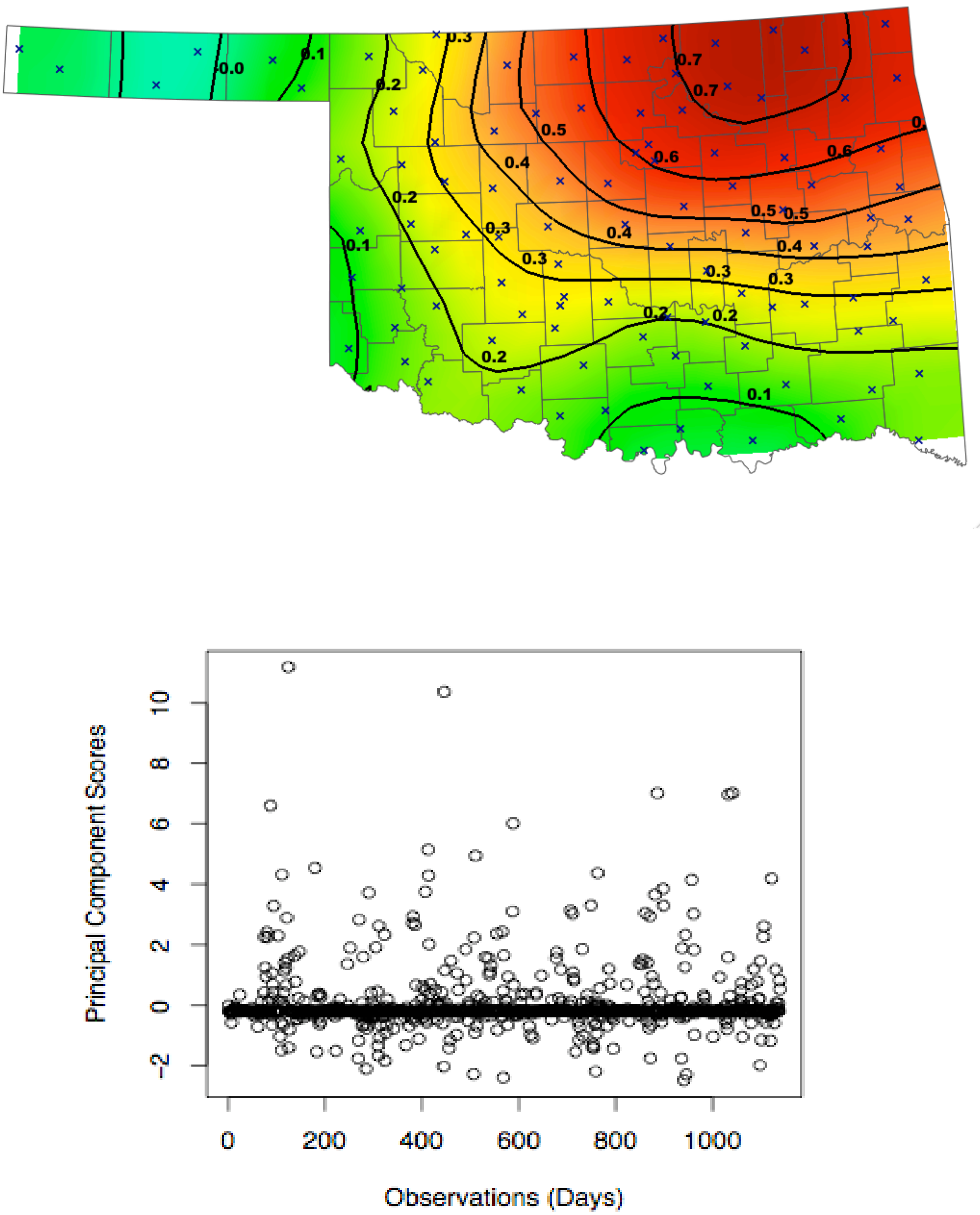

Figure 2: Loadings (top) and scores (bottom) for the first principal component, rotated using the VARIMAX orthogonal rotation, for daily rainfall totals from 104 Oklahoma Mesonet sites. Data cover the period from 1 January 1994 to 31 December 2003. Days missing daily rainfall totals from *any* single Mesonet site are not displayed.

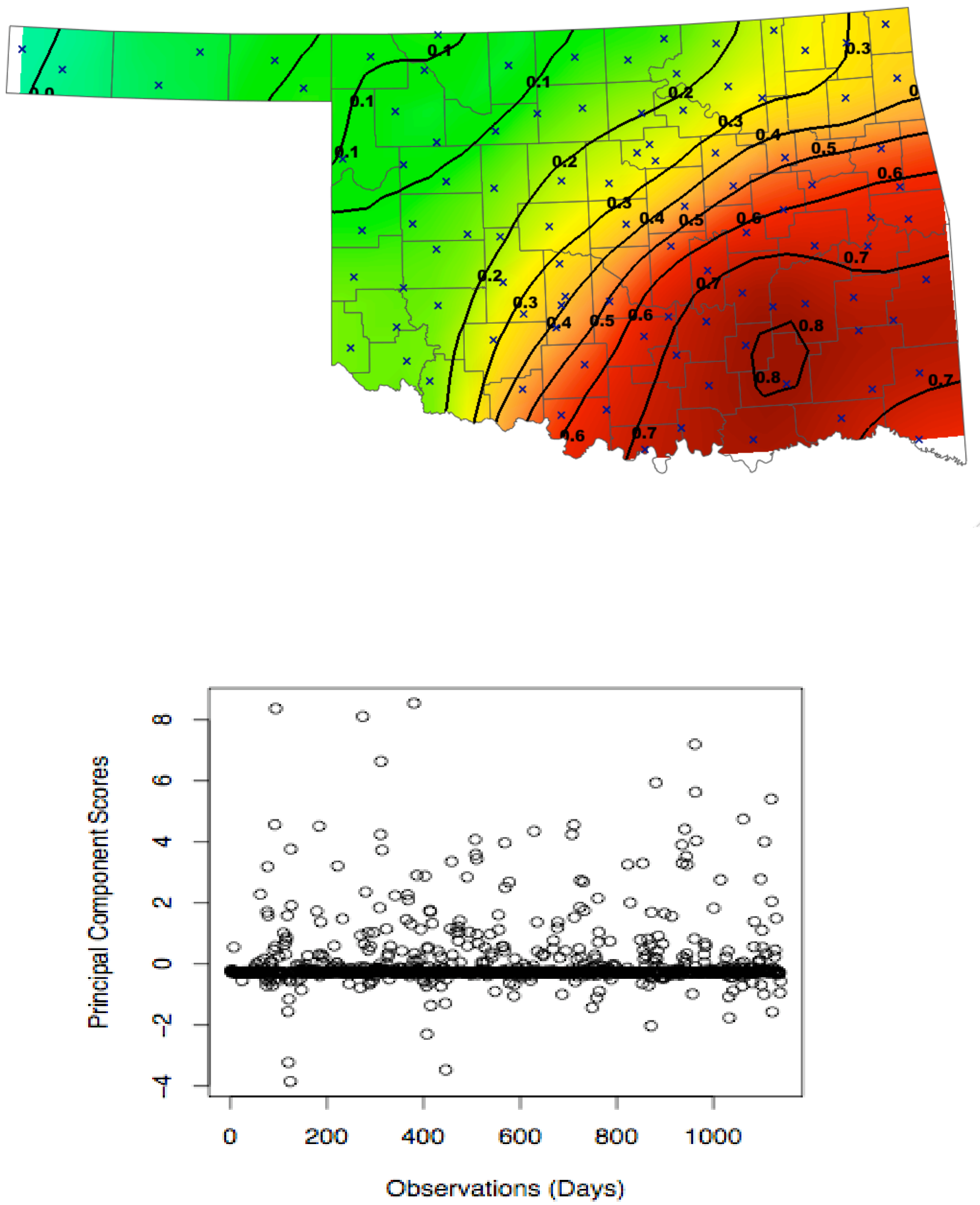

Figure 3: Loadings (top) and scores (bottom) for the second principal component, rotated using the VARIMAX orthogonal rotation, for daily rainfall totals from 104 Oklahoma Mesonet sites. Data cover the period 1 January 1994 to 31 December 2003. Days missing daily rainfall totals from *any* single Mesonet site are not displayed.

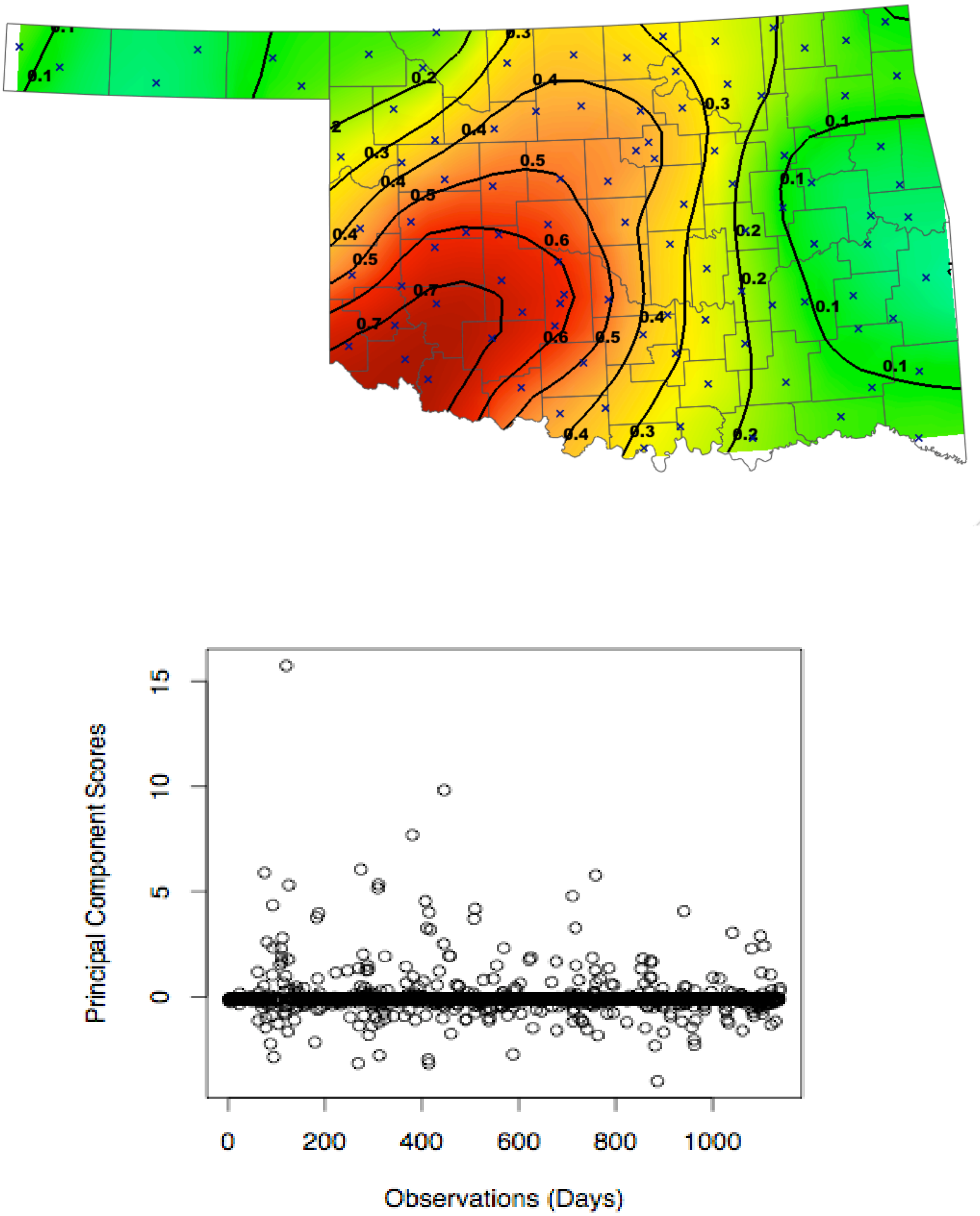

Figure 4: Loadings (top) and scores (bottom) for the third principal component, rotated using the VARIMAX orthogonal rotation, for daily rainfall totals from 104 Oklahoma Mesonet sites. Data cover the period from 1 January 1994 to 31 December 2003. Days missing daily rainfall totals from *any* single Mesonet site are not displayed.

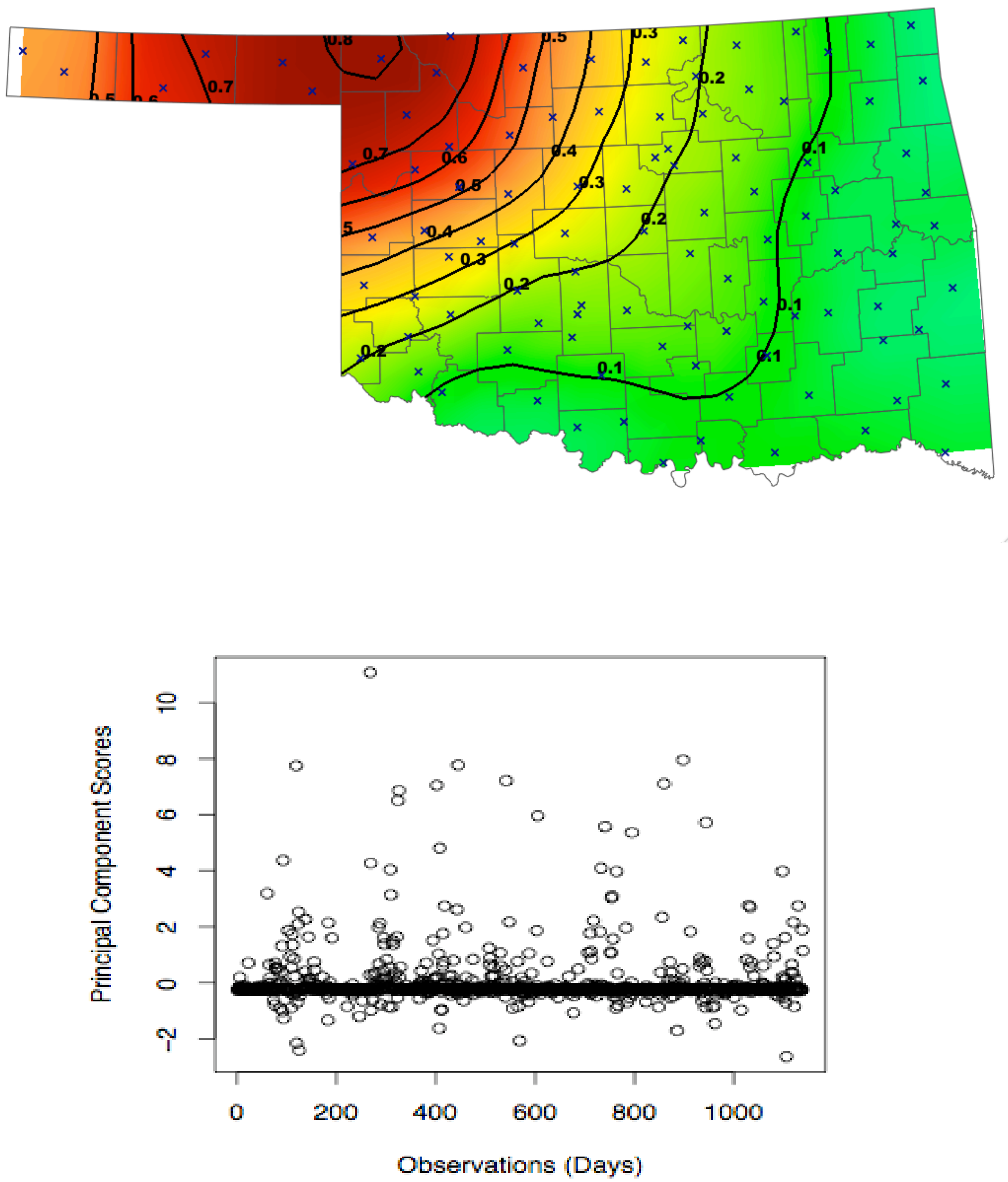

Figure 5: Loadings (top) and scores (bottom) for the fourth principal component, rotated using the VARIMAX orthogonal rotation, for daily rainfall totals from 104 Oklahoma Mesonet sites. Data cover the period from 1 January 1994 to 31 December 2003. Days missing daily rainfall totals from *any* single Mesonet site are not displayed.