Graph-based representation and analysis for storm events

Weibo Liu, Xingong Li, and David Rahn

Department of Geography and Atmospheric Science, University of Kansas

Abstract

Large amounts of time series of spatial snapshot have been collected or generated for monitoring and investigation of environmental systems. Those time series data provide the opportunity of tracking and analyzing dynamic geographic phenomena such as land use/land cover change, hurricanes, and storms. This research develops computational efficient methods and tools for the representation, and spatiotemporal characteristics of storm events based on a spatiotemporal graph model. We explore the storm events using 5-min radar reflectivity product from 2010 to 2014 during the warm seasons. This dataset covers the state of Kansas, state of Oklahoma, and north part of Texas. In order to derive the evolution of storm objects, we mainly use the location/topology, distance of storm objects and movement direction to determine filiation relations. Then, a directed spatiotemporal graph model is proposed to better represent, store, and analyze patterns and characteristics of storm events. Some statistical results are obtained, such as storm number per year/month, storm duration, initiation/termination time, movement speed and direction. Furthermore, maximum reflectivity path is used to generalize the storm event graphs, and then kernel density estimation is applied to reveal the spatial distribution and hotspots of storm events, which confirms theory, numerical simulations, and other observed case studies.

Objectives

- Develop event-based computational approaches to facilitate the identification, representation and analysis of storms in space and time.
- Use the spatiotemporal graph model to represent and analyze the storm events.

Data

The data used in this study are the final reflectivity product (N0R) provided by Iowa Environment Mesonet. This dataset has 1 km spatial resolution, and 5-minute temporal resolution. The storm events were extracted and analyzed from 2010 to 2014 during the warm seasons (April to September). The study area is shown in Figure 1.

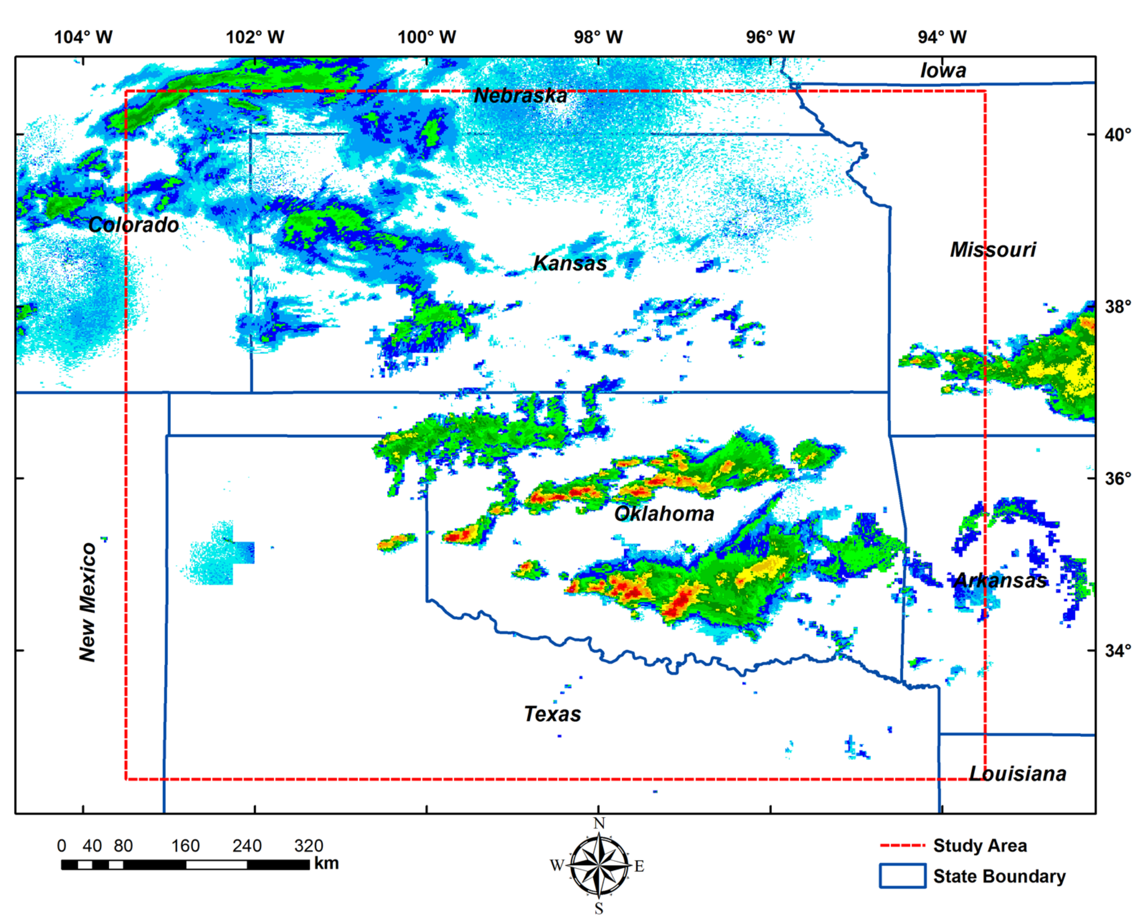


Figure 1

Storm Event Extraction

An event is defined as an individual occurrence or episode that has a definite start and end. There are two major steps to extract the storm events. The first step is to delineate a single storm object (Figure 2). A storm object in a single snapshot image is defined as a contiguous region, where the reflectivity (>=35 dBZ) and the area (>=20 km²) exceed a certain threshold. The second step is to build the filiation relations (Figure 4). The following criteria are used to associate the storm objects between consecutive snapshots: spatial overlap/topology (Figure 3), centroid distance of storm objects, and movement direction.

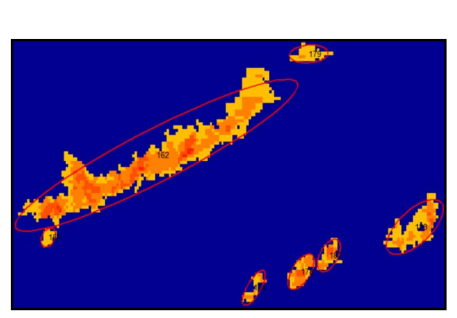


Figure 2

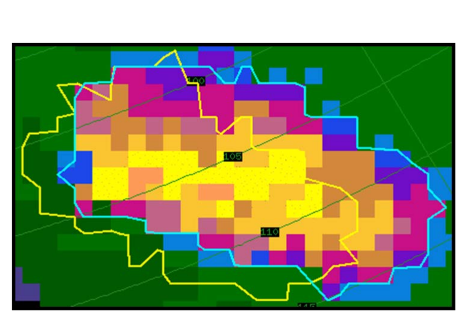


Figure 3

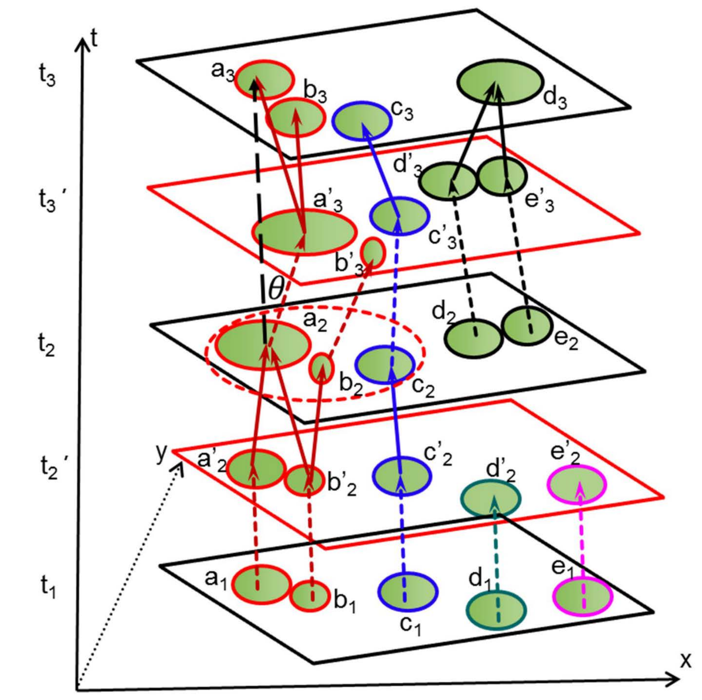


Figure 4

Six filiation relationships:

- Generation;
- Continuity;
- Split;
- Merge;
- Combinatorial;
- Dissipation.

Graph-based Storm Event Representation

It is natural to use a directed spatiotemporal graph model (Figure 5: 3D, Figure 6: 2D) to depict the evolution, change, and interaction of storm events. The nodes in the graph represent the spatially contiguous storm objects at each time step. The directed edges in the graph denote the spatial and temporal linkages (i.e., filiation relations) among storm objects at two adjacent snapshots where direction indicates the time sequence. A generalization of an event can be achieved by using the maximum reflectivity path (Figure 7) between the starting and ending storm objects of the event using the classic Dijkstra's shortest path algorithm on the graph.

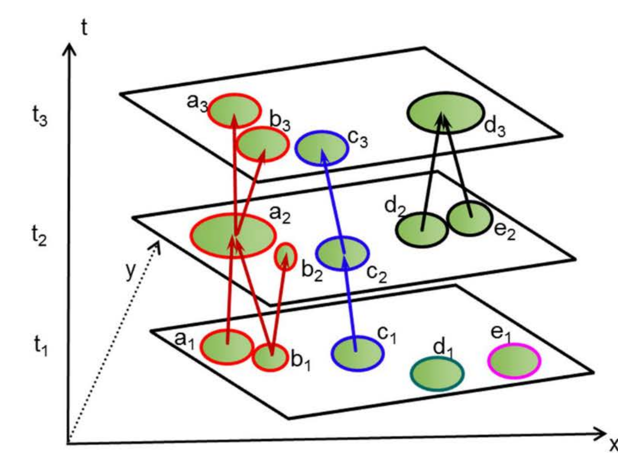


Figure 5

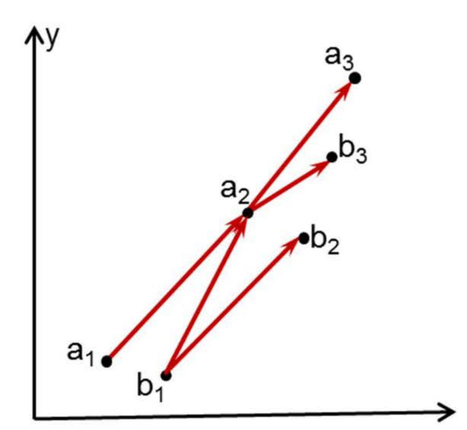
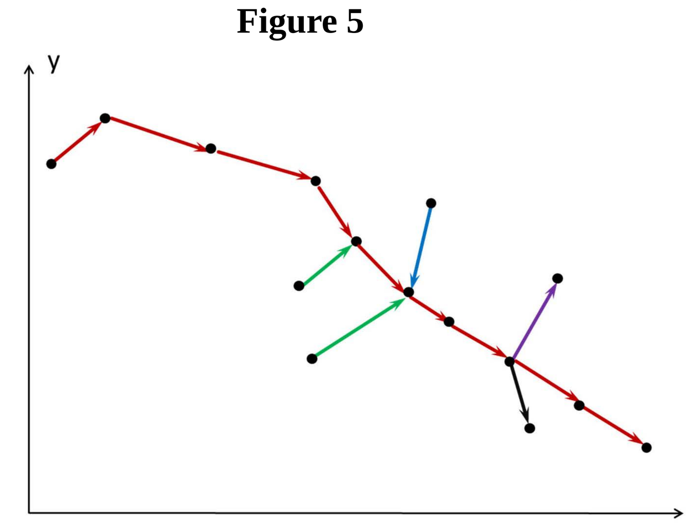


Figure 6



$$W_i = \max(R) - R_i + \min(R)$$

Figure 7

Implementation

A prototype system (Figure 8) was developed using MATLAB to process the reflectivity data, delineate storm objects, track storm events, visualize, verify, and analyze the events. There are four primary components in the work flow (Figure 9): the spatiotemporal database generation from raw NEXRAD snapshots, storm object identification, storm event tracking and event graph generation, and storm event visualization and analyses based on graph theory/algorithms.

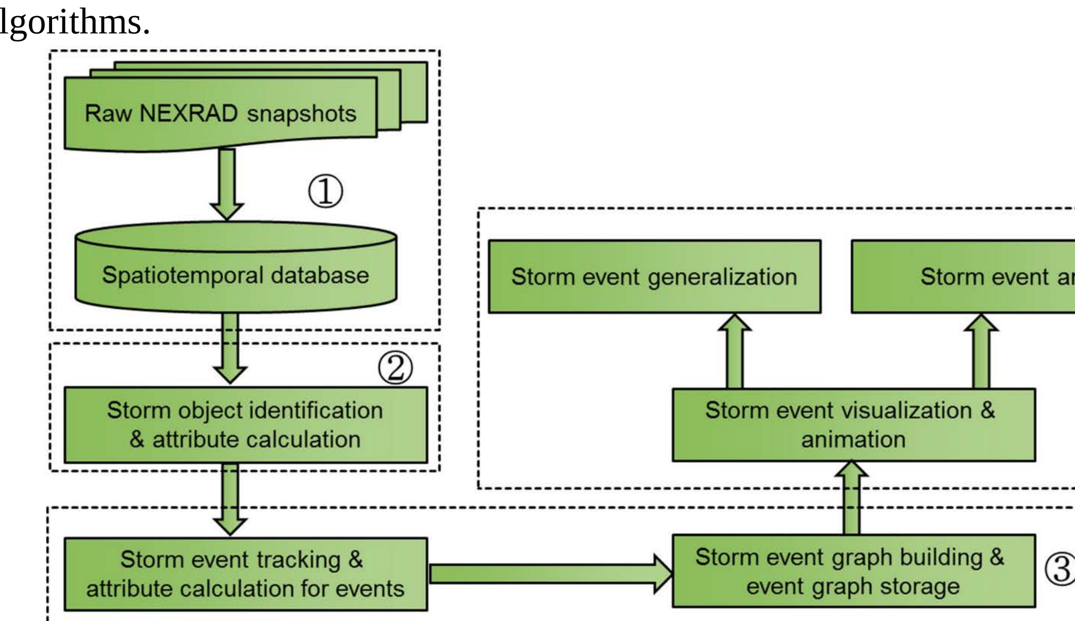


Figure 9

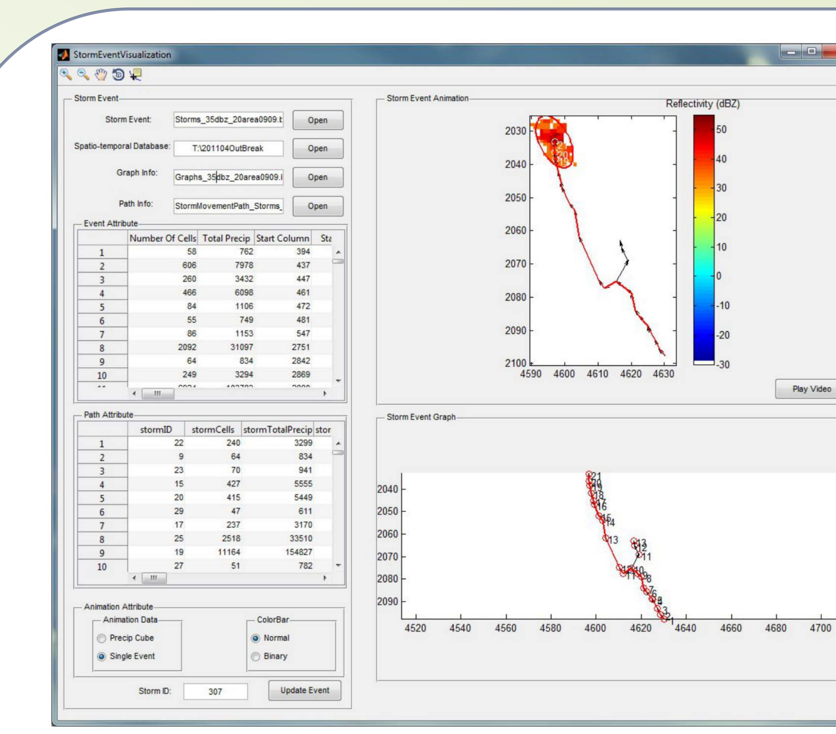


Figure 8

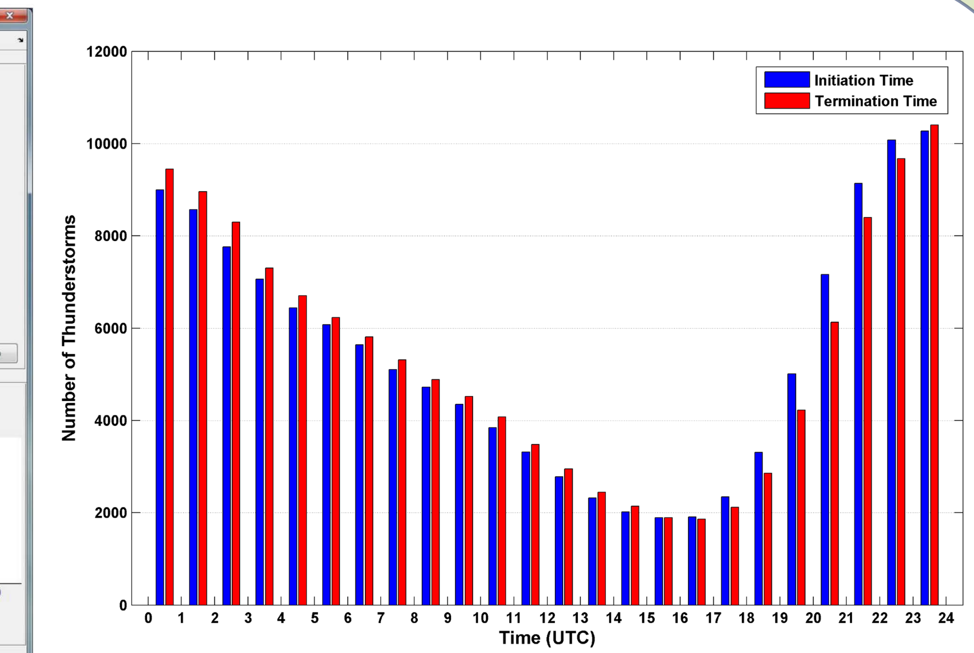


Figure 10

Storm Event Analysis

A number of statistical results are obtained, such as initiation/termination time (Figure 10), storm number per year (Figure 11), per month (Figure 12), storm duration (Figure 13), movement speed and direction (Figure 14), which verify the accuracy of the model. Furthermore, maximum reflectivity path is used to generalize the storm event graphs, and then kernel density estimation is applied to reveal the spatial distribution and hotspots of storm events (Figure 15).

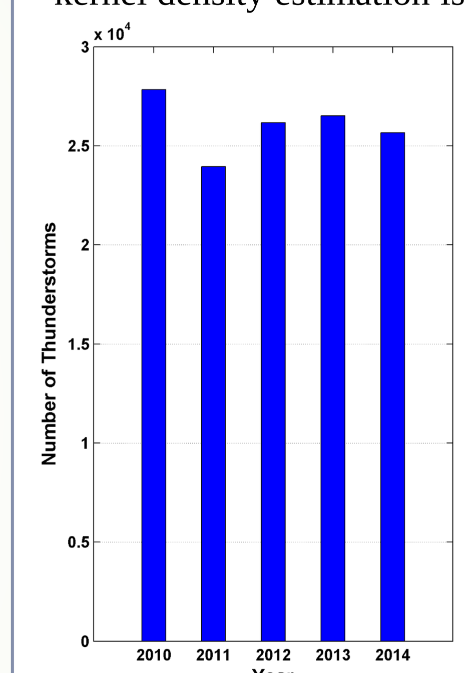


Figure 11

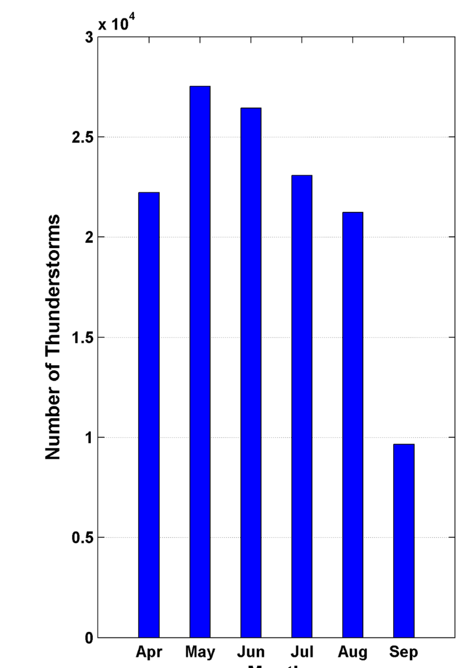


Figure 12

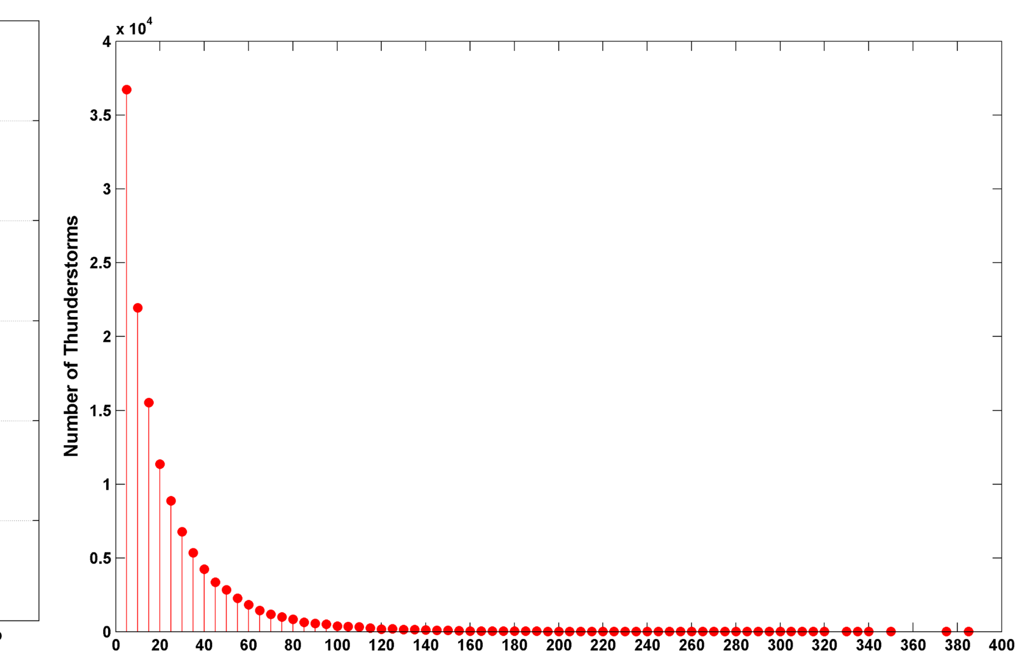


Figure 13

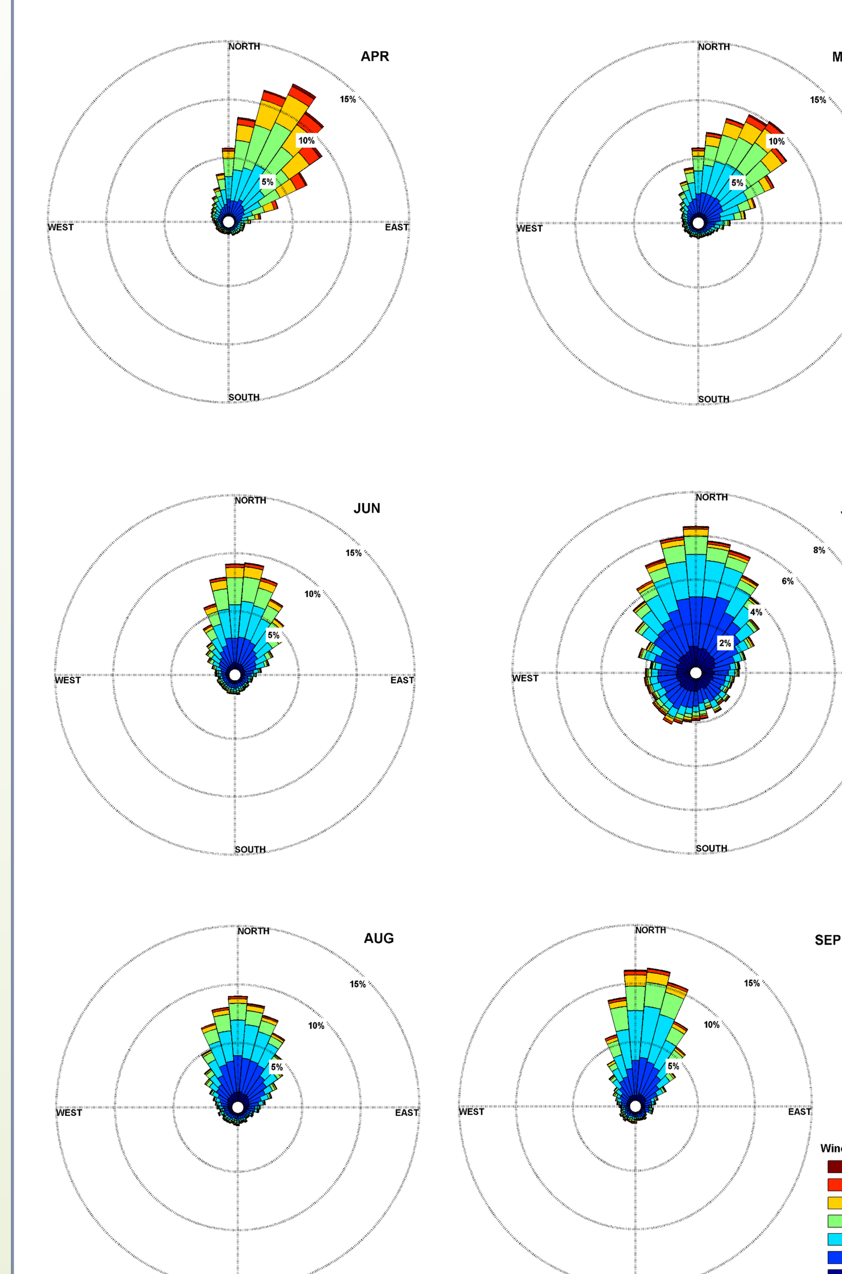


Figure 14

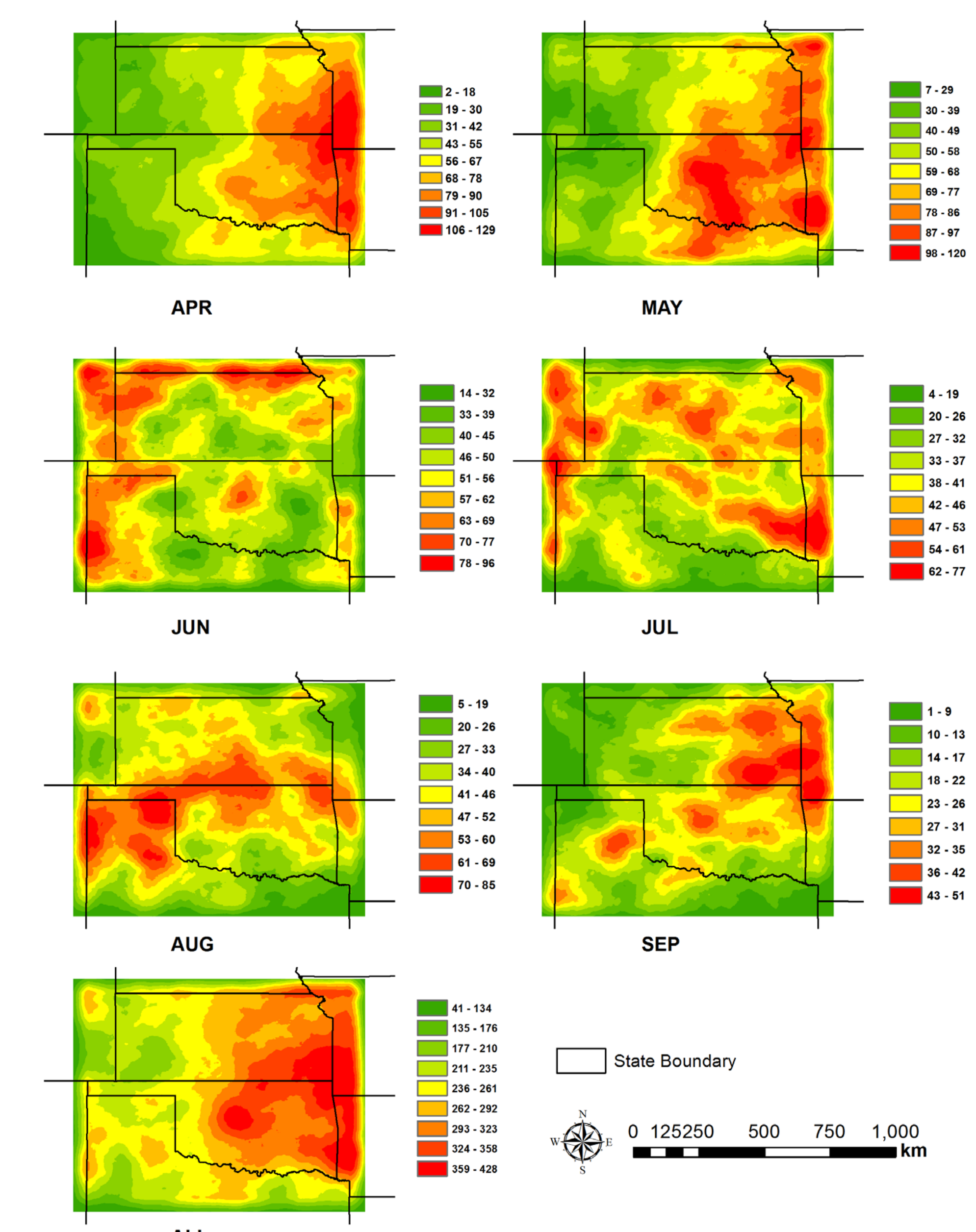


Figure 15

Conclusions & Future Work

- Further analyses based on graph theory such as event similarity comparison.
- Possible applications: urban heat island, land use/land cover.