6.6 TRENDS IN DENSE FOG FREQUENCY IN THE MIDWESTERN UNITED STATES

Nancy E. Westcott*
Illinois State Water Survey
Champaign, Illinois
and
Department of Geography
University of Illinois

## 1. INTRODUCTION

A preliminary examination of trends in the annual frequency of dense fog in the central Midwestern United States has been made employing hourly surface observations for the period 1948-1996. During this period, fog frequency decreased at many sites around the Great Lakes and increased in the central and western region of Iowa and Missouri. This occurred during a time when others have observed for the United States, an increase in specific humidity (Gaffen and Ross, 1999), and a decrease in general visibility, both of which might be thought to lead to enhanced fog frequency. Sulfate particles that form in the 0.1 to 1.0 micron range, an efficient size for visible light scattering, are hygroscopic, and are believed to be the dominant contributor (50-75 %) to visibility reduction (Trijonis, 1986) and an important source of fog nuclei (Roach et al., 1976). Vinzani and Lamb (1985) showed a decrease in horizontal visibility at many Illinois sites and Sloane (1982,1984) showed an increase in the number of smoke / haze days between 1948 and 1985 in the eastern United States sites. Changes in fog frequency also occurred during a time when cloud cover (e.g. Henderson-Sellers, 1992; Plantico, et al., 1990) and minimum temperatures (e.g. Karl, et al., 1994) increased, perhaps signaling a decrease in nighttime cooling rates. Whether changes in some or all of these factors can be associated with changes in fog frequency is under investigation.

## 2. DATA AND ANALYSIS

Nearly 50 years (1948-1996) of hourly observations of horizontal visibility from 40 National Weather Service first order stations were used in this study (Figure 1). Surface Airways Hourly observations consist of standard surface variables, visibility, cloud height and type, sky cover, and prevailing weather. The basic fog unit examined is the fog day. A fog day is identified at a site when a specific observation of fog was made in conjunction with at least 1 hour of $\leq$ 400 m horizontal visibility within a calendar day.

Shorter duration fogs are often found in the warm season (April-September) characterized by shorter nights. During the cold season (October-March) long-lasting fogs have been found to be more common, probably associated both with the advection of warm moist air from the passage of frontal systems (Westcott and Isard, 2001). Thus, the data are examined separately by warm and cold season.

*Corresponding authors address: Nancy E. Westcott, Atmospheric Environment Section, Illinois State Water Survey, 2204 Griffith Dr, Champaign, IL 61820;
e-mail: nan@uiuc.edu.

## 3. RESULTS

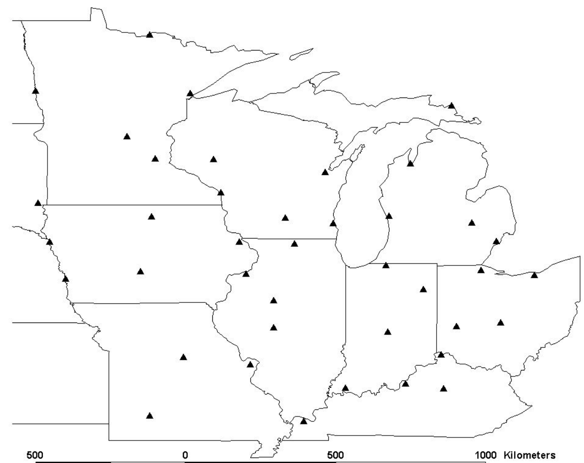


Figure 1. National Weather Service Surface Airways hourly sites employed in analysis.

### *3.1 Dense Fog Days and Trends*

The average spatial pattern of fog days was analysed in a simple way. The occurrence of dense fog was tallied by day for each of the 40 stations over the period of record. Average fog day frequencies are shown for two periods: 1948-1957 (Figures 2a and 3a), and 1987-1996 (Figures 2b and 3b). During the warm season in the period, 1948-1957, the annual average number of fog days varied from 2-3 in the western and southern portion of the central Midwest to more than 20 days per year at Duluth, and Sault Sainte Marie (Figure 2a). Sites near Lake Michigan had on the order of 10 days per year. These events lasted on average, 2 to 3 hours per day. A decrease in number of fog events was found in the northeastern portion of the region, particularly at Sault Sainte Marie (Figure 2b, 2c). An increase in frequency was found at many sites in Iowa, Missouri and Illinois.

During the cold season, the number of fog days was more uniform over the Midwest. Eight to 10 fog days per year were observed annually in the southern tier of states, and in the northern Great Lakes region around 15 days (Figure 3a, 3b). The average duration of fog on a day was 3 to 4 hours. An increase in fog days was found in the cold season in the southwestern region, and a decrease in the northwest and Great Lakes region.

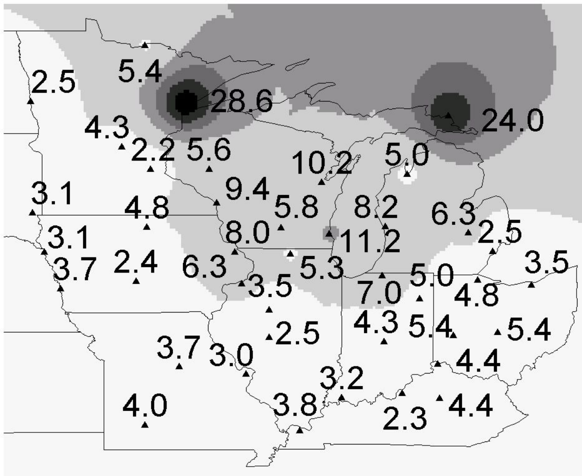


Figure 2a. Annual average number of dense fog days at National Weather Surface Airwaves stations during the warm season for the period 1948-1957 (Shading in increments of 5 fog days.

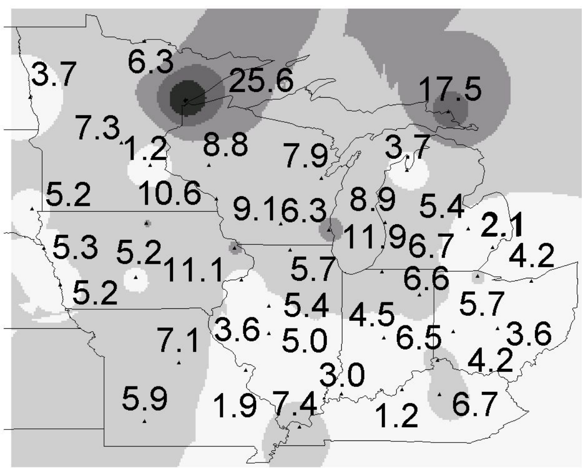


Figure 2b. Annual average number of dense fog days during the warm season for the period 1987-1996.

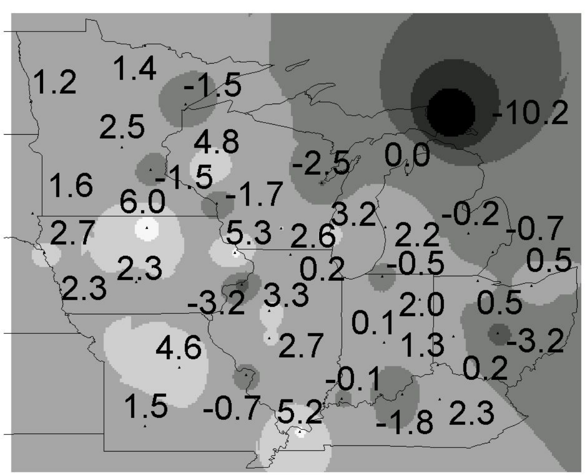


Figure 2c. Trend (days per 48 years) in dense fog days during the warm season for the period 1948-1996. Shading of trend in increments of 2 (per 48 years).

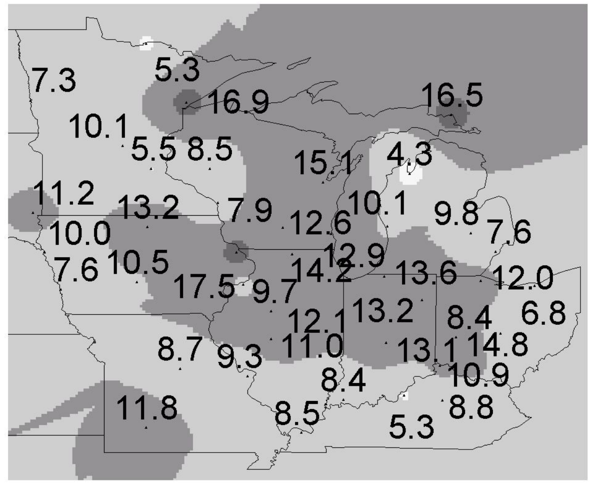


Figure 3a. Annual average number of dense fog days at National Weather Surface Airwaves stations during the cold season for the period 1948-1957.

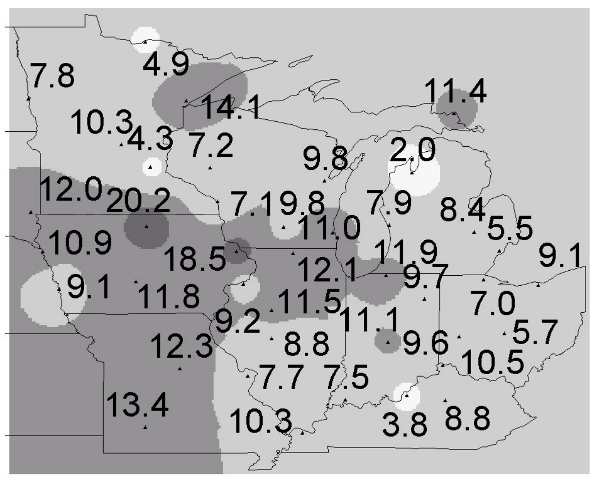


Figure 3b. Annual average number of dense fog days during the cold season for the period 1987-1996.

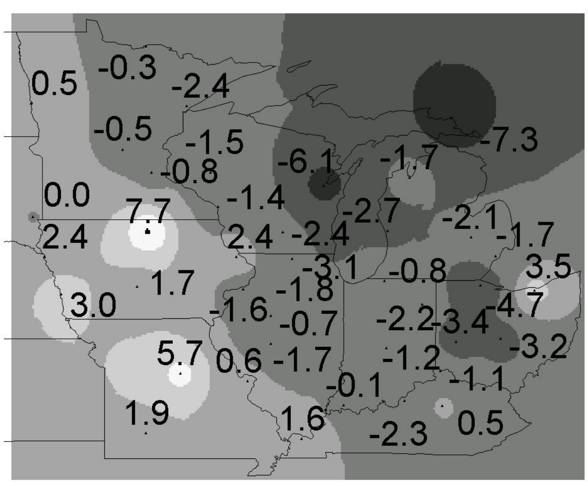


Figure 3c. Trend in dense fog days during the cold season for the period 1948-1996.

The trend in fog day frequency was computed for both seasons (Figure 2c, 3c). The trend in frequency is somewhat consistent between seasons, with a decreasing trend in the northeastern quadrant and an increasing trend in the southwest. The decrease in fog days extended further west and south during the cold months than during the warm season.

### *3.2 Trends in Meteorological Parameters*

The trend in maximum relative humidity was examined assuming that if fewer (more) periods with high humidities occurred in a given year, the seasonal mean relative humidity would be lower (higher) and there would be fewer (more) instances of dense fog. Maximum relative humidity was found to be positively correlated with fog day frequency at most sites during both warm and cold seasons. The median correlation with maximum relative humidity was 0.24 in the cold season and 0.28 in the warm season. Examining individual sites, it often was observed that years with high values of maximum relative humidity correlated well with years with many fog days, and low values of maximum humidity with fewer fog days. Examining the spatial distribution of trends in maximum relative humidity, some coherent patterns were observed (Figures 4, 5). In areas where fog frequency declined, the trend in maximum relative humidity was generally small. However, no consistent relationship was found between relative humidity and fog frequency trends.

At individual sites, the underlying trend in relative humidity did not always match the trend in fog frequency. For instance, at Sault Sainte Marie, located on the eastern end of Michigan's Upper Peninsula and Lake Superior, a decrease in relative humidity corresponding to a decrease in fog days was found during the cold months. The correlation between fog day and maximum relative humidity was 0.46. During the warm months when fog also decreased in frequency, there was no similar decrease in relative humidity. At many of the sites located in Iowa and Missouri, where fog frequency was observed to increase during both the warm and cold seasons, the trend in relative humidity often decreased.

There are several possible explanations for the inconsistency between fog frequency and relative humidity trends: 1) Seasonal values simply may not be representative of instances of discrete weather events. This could be true during the summer in the more southern states where there are fewer instances of dense fog. 2) The relative humidity measurements could be in error during some of this time period. Measurements often are poor for relative humidities near 100%. During many hours when dense fog was observed, it was found that for many sites, the measured relative humidity was often less than 95%, and in many instances was less than 90%. This was particularly true during the period 1965-1985 when lithium chloride hygrothermometers were in use. Note in Figure 6, the lower relative humidity values for that time period. When values near sunrise and sunset were eliminated from the analyses, as suggested by Gaffen and Ross (1999), the results were similar to those including all values. 3) Relative humidity is a function of temperature. Ackerman (1987) found relative humidity to be generally lower at an urban site in Chicago than at an outlying rural location, but no strong difference in actual vapor content was found between the sites. At Green Bay, WI (Figure 6), the trend in minimum temperature was observed to increase when fog frequency decreased. This suggests that urban influences may affect trends in humidity and fog frequency at some sites. However, during the cold season, relative humidity increased during this period and in the warm season showed no trend at Green Bay. 4) Other factors, such as cloud cover, wind, and temperature may be important in determining fog frequency. Examination of the spatial patterns of hourly data showed no one parameter or set of parameters that could explain the changes in fog frequency.

### *3.3 Discussion*

The hourly sites generally are located at airports near urban areas. During the past 50 years, many of the counties in which these urban areas are located have increased considerably in population, Green Bay included. Urban effects can result from increased surface friction resulting in changes in wind speed or direction, and the urban landscape can result in increased surface

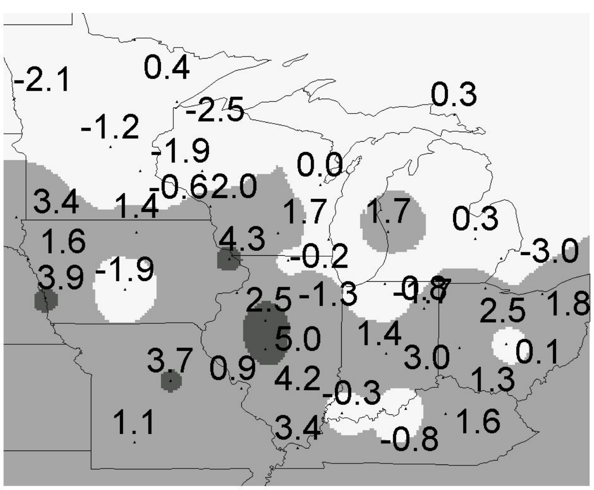


Figure 4. Trend in maximum relative humidity during the warm season for the period 1948-1996.

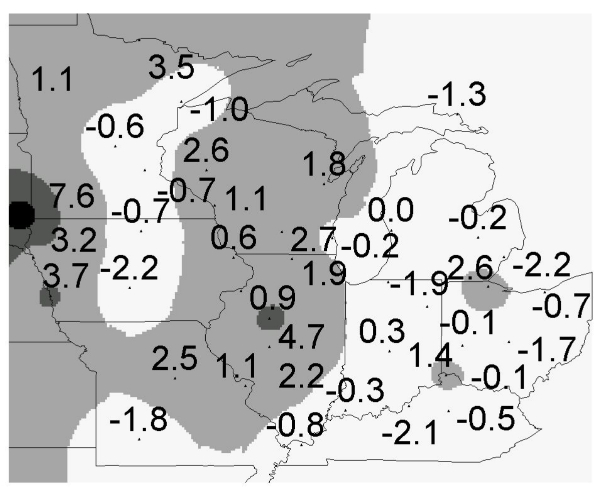


Figure 5. Trend in maximum relative humidity during the cold season for the period 1948-1996.

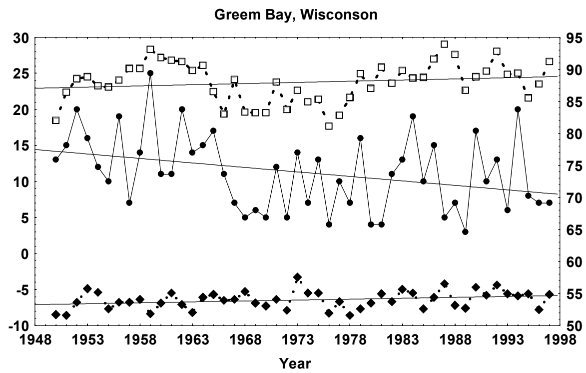


Figure 6. Trends in dense fog day frequency (close circles), maximum relative humidity (open squares), Minimum temperature (closed diamonds) during the cold season 1948-1996.

temperatures. Wind speed has declined to some degree at every site. Further, horizontal visibility has decreased at most sites during both seasons. This suggests some degree of anthropogenic influence at many of these locations. However, there are many sites where there are population increases, but no accompanying humidity or temperature changes. The actual impact of increasing urbanization on the fog conditions at these sites is unclear.

The location of a site with respect to the urban area could result in differing effects on fog frequency. Sachweh and Koepke (1997) reported a decrease in fog in Munich (1961-1990), and during the same period, a greater decrease in fog frequency, at Nymphenburg, an adjacent suburb that was urbanizing. At Riem, a rural site on the outskirts of Munich, there was an increase in fog frequency. Their study suggested that station location with respect to the urban area is very important in determining fog frequency.

Station moves, instrument replacement, changes in surroundings could affect the climate records. Only four of these 40 stations changed from one location to another during the past 50 years. However, many of these stations moved slightly within their current setting. What these small scale moves involved is unclear. Further, increases in humidity could result from increased irrigation or construction of a nearby reservoir. These local changes could obscure a regional signal. (Elliot, 1995).

## 4. CONCLUSIONS

The complexity of conditions that affect fog development and environmental changes near the observation sites suggest that further analyses of trends in fog frequency should include more exact station location information and possibly be performed on a station-by-station basis.

## 5. Acknowledgements

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