P10.4 Environmental Conditions Associated with Dense Fog in Illinois

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1. INTRODUCTION

Dense and widespread fogs in the central United States were initially examined in the early and mid-1900's. Many of these studies suggested that these fogs were largely related to fronts (e.g. Stone, 1936; George, 1951; Byers, 1959). More recently, it is often assumed that continental fogs are either associated with advection of warm moist air over cold or snowy surfaces or with radiational cooling (e.g. Roach, 1995). Attempts at forecasting fog have been directed at forecasting radiation fogs (e.g., Baker et al., 2002) and coastal fogs (e.g., Leipper, D.F., 1994: Croft et al., 1997), or are observationally based (e.g. Herzegh et al., 2004; Leyton and Fritsch, 2004). A physically-based operational forecast model for inland fogs remains elusive. The goal of this study is to document some of the conditions under which dense fog develops in the Midwestern United States and specifically at Peoria, IL.

2. DATA AND ANALYSIS

Most widespread and long-lasting dense fog events occur during the cold season months of October through March (Westcott and Isard, 2001). This study examines cold season dense fog events that occurred at Peoria, IL during the period 1970-1994. The primary database is the Surface Airways Hourly Observations of horizontal visibility, ceiling, wind, and prevailing weather. Dense fog events are defined as those where the horizontal visibility is 400 m or less and an observation of fog has been recorded. Following the definition of Meyer and Lala (1989), each dense fog event was separated from other events by at least 6 hours with no fog reported (horizontal visibility exceeding 3.2 km [2 miles]) or 12 hours with visibilities equaling or exceeding 1.6 km [1 mile].

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For this study, only dense fog events are considered that form during the nighttime hours of 21:00 to 05:00 LST, and are associated with either high pressure, or with disturbances, that is with a low, an approaching front, or a front near Peoria. The synoptic typing was based on 3-hourly surface charts and was reported on in Westcott (2004). Of a possible 165 nighttime events, 139 are included here. Thirty-one percent (43) of these events are associated with high pressure and the remainder with disturbances. Post-cold frontal events, post-warm frontal events, and events in which the dominant synoptic feature was ambiguous were excluded.

The horizontal dimensions of dense fog events were estimated by considering the total number of Surface Airways stations in the Midwest that reported dense fog on days when dense fog was observed at Peoria, and also the number of stations adjacent to Peoria reporting dense fog. A maximum of 57 Surface Airways stations were examined over the Midwest and there were 8 possible "adjacent" stations within about 200 km of Peoria. The number of stations varied slightly over the 50-year period, so that these numbers are only approximations. The 19:00 LST rawinsondes from Peoria, IL also were examined.

3. CONDITIONS AT AND BEFORE FOG ONSET

Typically, one looks for fog on clear nights with low wind speeds where radiational cooling will reduce the surface air temperature to the dew point temperature. For the nighttime cold season dense fog events, about 68% occurred at temperatures above freezing. Approximately 30% of the high pressure dense fog events, and about 85% of the events associated with disturbances occurred at temperatures above freezing (Figure 1). The higher temperatures at dense fog onset for the disturbance events suggests that warm air advection occurred sometime before and/or during the disturbance fog events.

Friedlein (2004) found that about 95% of dense fog events in the autumn, winter and spring at O'Hare Airport in Chicago, IL. occurred at temperatures above the seasonal average low temperature. Figure 2 shows the difference between the temperature at dense fog onset and the average (1948-1996) daily low temperature. About 89% of nighttime dense fog events occurred at temperatures above the average daily low temperature. The median difference was 2.6°C for high pressure events and 9°C for the disturbance events. While many of the dense fogs associated with high pressure occurred at temperatures below freezing, about 50% of the long duration (>5 hr) events occurred at temperatures above freezing and only 3 of the shorter duration high pressure events occurred at temperatures above freezing.

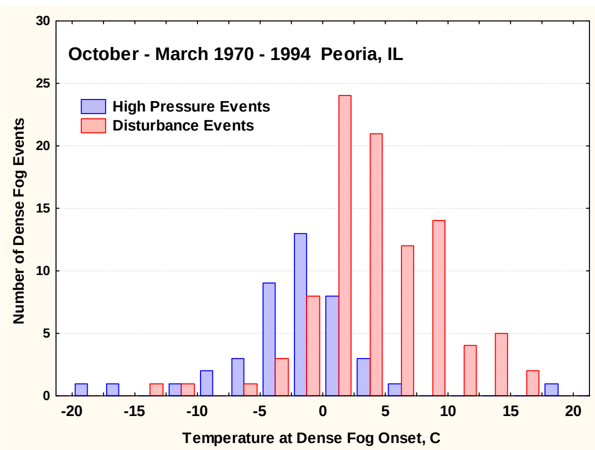

Figure 1. Temperature at the time of dense fog onset (°C), for cold season nighttime dense fog events at Peoria, IL.

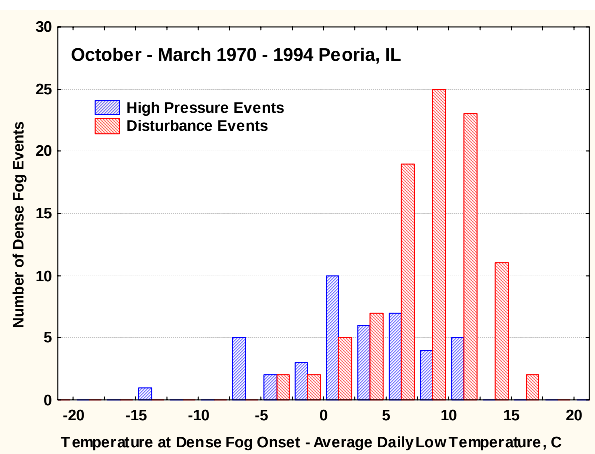

Figure 2. Difference between temperature at the time of dense fog onset (°C) and the average daily low temperature, for cold season nighttime dense fog events at Peoria, IL.

In the hours prior to fog onset, cooling is often expected. The median temperature change in the 3 hours prior to the onset of dense fog is -0.6°C for high pressure events and 0.0°C for disturbance events (Figure 3). Cooling is expected during the night. When temperature change is normalized by the average 3-h cooling rate for the cold season at each hour, the median temperature change is 0.2°C for high pressure events and 0.9°C for disturbance events (Figure 4). Thus, while cooling is often observed for both high pressure and disturbance events, the cooling rate is often less than expected, particularly for the disturbance events.

Low wind speeds are typically expected for radiation fogs. Meyer and Lala (1989) found that 87% of their dense radiation fogs had wind speeds

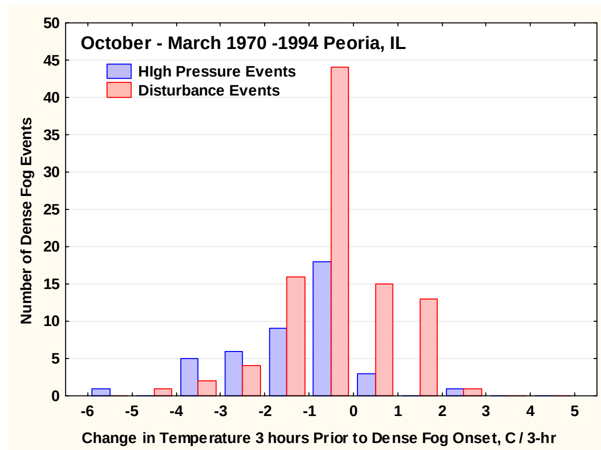

Figure 3. Temperature change in the 3 hours prior to dense fog onset (°C), for cold season nighttime dense fog events at Peoria, IL.

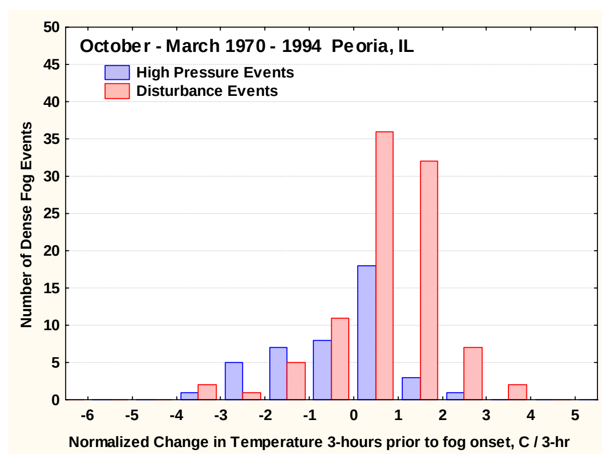

Figure 4. Normalized temperature change in the 3 hours prior to dense fog onset (°C), for cold season nighttime dense fog events at Peoria, IL.

of ≤ 2.1 m/s and 98 % ≤ 3.1 m/s. Here, a median wind speed of 2.6 m/s was found for high pressure events and 3.1 m/s was found for disturbance events (Figure 5). For the high pressure events, 32% would not meet the 2.1 m/s speed criteria, and 42% of the disturbance events would not meet the 2.1 m/s speed criteria for dense fog at the time of dense fog onset. The average (1948-1996) nighttime cold season wind speed at Peoria is 4.4 m/s. About 86% of the high pressure and 83% of the disturbance events had wind speeds lower than the climatological average. All of the fog events had speeds <7.0 m/s at dense fog onset.

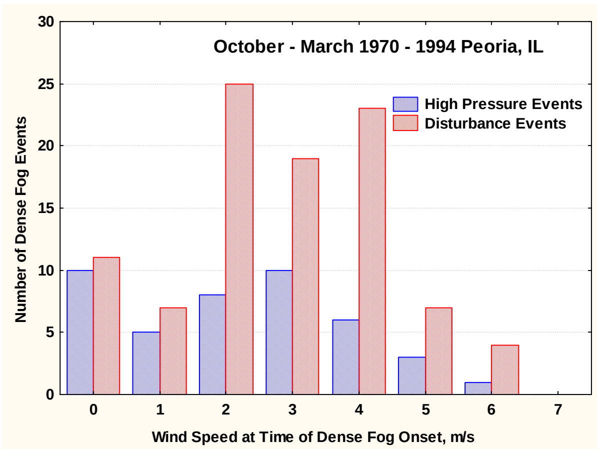

Figure 5. Wind speed (m/s) at the time of dense fog onset, for cold season nighttime dense fog events at Peoria, IL.

Parameters derived from the 19:00 LST Peoria, IL rawinesondes were also examined. The depth of the moist layer was estimated as the level where the difference between temperature and dew point temperature first exceeded 2°C. The amount of water in the lower atmosphere was estimated by computing precipitable water in the surface to 900 hPa layer. The moist layer, though not the same as the fog layer, may be related to the depth of the fog layer. The inversion height is simply the first level where temperature increases with height. The height of the dry layer was estimated as the level where the difference between temperature and dew point temperature first exceeded 15°C. Croft et al. (1993) suggested that the presence of a dry layer results in more intense radiational cooling that is conducive to fog formation. The wind speed and wind direction at the surface, 950, 900, 850 and 700 hPa also were considered. The median values for these variables are presented in Table 1.

The events associated with disturbances tend to have a deeper moist layer, a higher inversion base, and a higher dry layer base than the dense fog events associated with high pressure. Further the wind speeds tend to be stronger, and have a more southerly component than for the high pressure events. These results and the results based on the surface observations suggest that advection plays a larger role in the disturbance – related dense fog events than for the high pressure events. Further as light precipitation often occurs at the time of dense fog onset for disturbance events, precipitation may contribute to moistening of the atmosphere in many disturbance events (Westcott, 2004).

Table 1. Median values of parameters derived from Peoria 19:00 LST rawinsondes for dense nighttime fog events.

	High Pressure	Disturbance
900 hPa Precipitable Water, cm	1.0	1.3
Top of Moist Layer, hPa	907	808
% with ≤2° t-td difference	81 %	92 %
Base of Inversion, hPa	950	937
% with Inversion <700 hPa	100 %	98 %
Base of Dry Layer, hPa	850	750
% with >15° t-td difference	98 %	77 %
700 hPa Wind Speed, ms^{-1}	10	14
850 hPa Wind Speed, ms^{-1}	8	9
900 hPa Wind Speed, ms^{-1}	7	9
950 hPa Wind Speed, ms^{-1}	5	7
Surface Wind Speed, ms^{-1}	2	4
700 hPa Wind Direction, °	296	246
850 hPa Wind Direction, °	274	228
900 hPa Wind Direction, °	257	217
950 hPa Wind Direction, °	239	172
Surface Wind Direction, °	220	140
% Cases with rain near onset	2 %	57 %
Number of cases	43	95

Because higher wind speeds are sometimes observed at fog onset for high pressure events and because temperature sometimes increases prior to the onset of dense fog, advection probably occurs in some high pressure dense fog events. Thus, high pressure events cannot be equated with radiation fog events. Conversely, some disturbance events may be radiation fogs as some disturbance events occur with light winds, decreasing temperatures, and a dry layer aloft.

4. LONG VS SHORT DURATION EVENTS

Unfortunately, the surface and sounding parameters presented, were found to have little value when attempting to predict whether dense fog would last for an hour or two, or would last for 6 hours or more. It is not surprising that the sounding parameters have little predictive value, as fog often forms early in the morning when conditions aloft may have changed significantly.

Observations related to fog dimensions were examined to determine if they might provide some guidance as to dense fog event duration (Table 2). Horizontal visibility and ceiling height at the time of dense fog onset, and the minimum ceiling height and visibility during a fog event were examined. Ceiling height is defined as the height of the lowest sky cover layer that is more than ½ opaque. The maximum number of stations experiencing dense fog during a fog event also was examined.

Table 2. Median dimensions for nighttime (21:00 – 05:00 LST) high pressure and disturbance dense fog events at Peoria, IL, October-March 1970-1994. Bold type indicates that difference in medians are statistically significant at better than 0.05 with Mann-Whitney U Test.

High Pressure Events	> 5 hr N=20	< 3 hr N=12
Max Number of Sites	**15**	**7.5**
Max Number of Adjacent Sites	**3**	**1.5**
Visibility At Onset, m	**190**	**400**
Minimum Visibility, m	**100**	**400**
Ceiling at Onset, m	**30**	*
Minimum Ceiling, m	**0**	*
Disturbance Events	N=45	N=31
Max Number of Sites	**17**	**8**
Max Number of Adjacent Sites	**4**	**1**
Visibility At Onset, m	310	400
Minimum Visibility, m	**100**	**400**
Ceiling at Onset, m	30	30
Minimum Ceiling, m	**0**	**30**

* Ceiling unlimited for one half of the sample of high pressure short duration dense fog events.

These results show that once dense fog has formed, it is more likely to persist if the horizontal visibility is 200 m (1/8th mile) or less and the ceiling height is 30 m (200 ft) or less. Further the more widespread events tend to last longer than dense fog events that encompass only a few stations. This is true for dense fog events forming under the influence of high pressure and for those forming under the influence of a disturbance.

7. SUMMARY AND CONCLUSIONS

Dense fog events occurring during cold season nights have been examined for the period 1970 - 1994. They were separated into two broad synoptic categories: those occurring under the influence of a high pressure system, and those in the presence of a disturbance, such as a low pressure center, an approaching front, or a nearby front. It was found that the distributions of: temperature at the time of dense fog onset, the temperature at onset with respect to the daily mean temperature, and the temperature change in the 3-hours prior to the onset of dense fog differed for the two synoptic categories. Relative to the high pressure events, dense fog associated with disturbance events tended to form at warmer temperatures and temperatures above freezing, at temperatures warmer than the average daily low temperature, and the normalized temperature would increase prior to the onset of dense fog.

These surface observations suggest that advection plays more of a role in the disturbance events than for the high pressure events. Results from the rawinsonde analysis further confirm this. Dense fog events associated with disturbances tend to have stronger wind speeds and winds with a more southerly component, a deeper moist layer, a higher inversion base, and a higher dry layer base than for the high pressure events.

These surface and sounding parameters did not prove to be useful in differentiating between short (1-2 hour) and long (>5 hr) duration dense fog events. Parameters relating to the density and extent of the area affected by fog were considered to attempt to distinguish between long and short duration dense fog events. For both high pressure and disturbance associated events, the long duration events tended to encompass more stations reporting dense fog, and were characterized by lower horizontal visibilities at fog onset and during the fog event. The minimum ceiling observed at dense fog onset was lower for events associated with high pressure, and the minimum ceiling observed during the event was lower for both high pressure and disturbance events.

8. Acknowledgements

The author wishes to thank for reviewing this manuscript. The views expressed herein are those of the author and do not necessarily reflect those of the Illinois State Water Survey.

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