P2.4 Synoptic Conditions Associated with Dense Fog in the Midwest

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1. INTRODUCTION

Widespread, dense fog can exert tremendous hardship to persons in the central United States through disruption of commerce and danger to personal safety. Both ground and air transportation can be severely impacted. During winter, it is not unusual for airline flights to be postponed or cancelled because of dense fog. Low highway visibility can slow or delay ground transportation throughout the year and result in accidents. Data obtained from the Illinois Department of Transportation indicates that between 1974 and 1996, some 4000 collisions occurred annually in Illinois under foggy conditions, resulting in an average of 30 deaths per year.

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 dense and widespread fogs of the central U.S. were largely related to fronts (e.g. Stone, 1936; George, 1951; Byers, 1959). In instances of pre-warm frontal fogs and post cold frontal fogs, precipitation was thought to play a role in fog formation. During the last few decades, radiation fog and coastal advection fog events have been extensively studied in other regions, but little research has been conducted on fog in the central U.S, and little reference is made with respect to fog forming in association with fronts. Continental fogs have been often associated with advection of warm moist air over cold or snowy surfaces or with radiational cooling (e.g. Roach, 1995). The purpose of this study is to document some of the conditions associated with dense fogs of the Midwest region.

2. DATA AND ANALYSIS

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Most widespread and long-lasting dense fog events occur during the cold season months of October through March (Westcott and Isard, 2001). This study will examine 561 cold season events that occurred at Peoria, IL for the period 1948-1996. 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 3.2km [2 miles]) or 12 hours with visibilities equaling or exceeding 1.6 km [1 mile].

The spatial dimensions of the 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.

Daily (0700 LST) snow depth observations for the region were used to evaluate the possible impact of snow on fog events at Peoria. Snow melt was estimated by subtracting snow depth on the day with fog from the previous 0700 LST observation.

The synoptic setting was examined for 302 dense fog events occurring during the 25-year period, 1970-1994. The 3-hr surface charts were primarily employed to discern the location and type of fronts, and the position of highs and lows with respect to Peoria, IL, at the time closest to the first observation of dense fog.

Hourly observations of precipitation were derived from the Surface Airways data for the time period of 1 hour before to 1 hour after the first observation of dense fog. Events designated as having precipitation refer only to precipitation during that period.

3. SHORT vs. LONG DURATION FOG EVENTS

In an attempt to determine the conditions that are most relevant for long-lasting dense fog events, the fog events have been categorized by the duration of the event. Duration categories are 1-2 hours, 3-5 hours and =6 hour events. Examining indicators of the dimensions (total number of stations with dense fog and number of stations adjacent to Peoria with dense fog), and severity (horizontal visibility, minimum ceiling), one can see that there are clearly differences between the long and short duration events (Table 1).

As might be expected, the long duration events tend to be characterized by lower visibilities and ceilings, and encompass a larger horizontal area (more sites) than do the short duration events. An important difference between the events is that the longer events often form during the late night / early morning hours and the short duration events after sunrise. Both long and short duration events tend to dissipate most frequently in the morning hours (0800 LST) within a few hours after sunrise. (Sunrise varies from about 0545 to 0715 LST between October and March.) The difference in begin times suggests that the conditions that set up the cooling and moistening regime for dense fog may be different for short and long duration events.

Table 1. Median characteristics of long (>5 hr), medium (3-5 hr) and short (1-2 hr) duration dense fog events at Peoria, October – March 1948-1996.

	Duration Category		
	Long	Medium	Short
Visibility at onset, m	200	200	300
Ceiling at onset, m	30	30	30
Speed at onset, m/s	3.1	3.1	2.6
Begin Time*, LST	0100	0600	0800
End Time*, LST	0800	0800	0800
Number of Total Sites	18	12	9
Number of Adjacent Sites	5	3	2
Number of Fog Events	197	128	236

* Median computed based on the day extending from 13:00 LST to 12:00 LST.

4. SNOW

Fog during the cold season is often described as occurring when warm air passes over cold surfaces or snow (e.g. Hidore and Oliver, 1993; Roach, 1995). During the 1948 -1996 period, 109 of the 558 October to March fog events (20%) were associated with snow on the ground at Peoria, and an additional 33 events were associated with snowmelt. While snow in Peoria occurred during April, fog associated with in-situ snow was only observed from November to March. By month, 4% of the fog events in November were associated with in-situ snow or snowmelt, 33% in December, 40% in January, 33% in February, and 23% in March. Looking only at the months of December through March, 33% of the 420 events were associated with snow on the ground or snowmelt, as opposed to 25% for the October to March period. The proportion of events occurring with and without snow was similar for the long, medium and short duration fog events. This suggests that the presence or absence of snow alone at the location with dense fog has little effect on the duration of the fog event.

Snow (not considering snowmelt) was present somewhere in the Midwest region, within 800km of Peoria, in the December to March time period for all the medium and long duration events. A snow field was present within 200 km of Peoria 73 and 59% of the time, respectively, for the long and medium duration events. Snow was present within about 50 km of Peoria for only about 37% of the long and medium duration events.

When snow was present, however, it was usually to the north, northeast or northwest of Peoria (76% of events). Snow surrounded Peoria during about 20% of the dense fog events, leaving just 4% of the cases with snow in the other 3 directions.

For snow to cool the overlying air for fog formation, it must be present at Peoria or the advection of moist air must be from the north. When snow was north of Peoria, the wind had a northerly component in about 32% of the cases and a southerly component in the remaining cases. Similarly, when snow surrounded Peoria, the wind was from the north in about 29% of the cases and from the south in 71% of the fog events.

These results suggest that snow does not play a predominant role in cooling overlying air for the development of the dense midwestern fogs, at least in regions where snow is intermittent during most winters. This study does not address the issue of the surface cooling the moist air as it moves northward from the gulf.

5. SYNOPTIC CONDITION

While fog is a boundary layer feature, its presence is often determined by synoptic conditions, by moistening the air or surface with preceding or concurrent precipitation, inducing areas of light winds, or perhaps in promoting clearing and thus radiational cooling. George (1951) and Byers (1959) indicated that long-lasting fogs in this region usually are associated with fronts, pre-warm frontal, post-cold frontal, or associated with a frontal passage. It was thought that these fogs were formed from the evaporation of overrunning warm precipitation and subsequent recondensation in the cold stable air below, or from the mixing of warm and cold saturated air along a frontal boundary. In the decades since, radiation fog (e.g. Meyer and Lala, 1989) and coastal advection fog (e.g. Croft et al., 1997 and Leipper, 1994) have been extensively studied in regions outside of the Midwestern U.S. Little attention has been given to fog in the Midwest or to frontal fogs.

Ten categories were developed to accommodate the synoptic conditions found on days with dense fog at Peoria for the period, 1970-1994. These include:

1) Highs: often with a low in Canada, off the East Coast or in the southwestern U.S., or with a cold front in the high plains states.

2) Behind a cold front (front to the east or south of Peoria, usually in eastern IL or IN)

3) Behind a warm front (front to the north of Peoria, often in south or central WI)

4) Between some combination of fronts, lows or troughs with the primary synoptic condition ambiguous.

5) Low (sometimes ahead of a cold front, a warm front or both)

6) Warm sector, ahead of a cold front and behind a warm front.

7) Ahead of Cold / Stationary Front, generally to west or northwest, within a state (from central WI, central IA to northwest MO).

8) Ahead of Warm / Stationary Front, generally across southern Illinois.

9) Ahead of both a Cold Front and Stationary Front

10) Front over Peoria, or just to the north, west or south)

Table 2 presents the distribution of dense fog events by duration and synoptic category. Note the similarity in percent frequency between the duration classes. There is a relatively large sample of events from each duration category that occur under conditions of high pressure, when lows are present, and when fronts are present.

More short than long duration events occur under the influence of high pressure or behind a cold front, and with fronts in close proximity to the station reporting fog (Peoria). More long than short-lived events are found in the warm sector or ahead of a warm / stationary front. It should be noted that for the very long-lasting fog events, fog persisted under various evolving synoptic conditions.

Overall, about 25% of the events occur under high pressure and about 65 % of the events occur in association with a front or low. The events occurring under conditions of high pressure were fairly equally distributed by month. More events were found to occur in conjunction with low pressure centers or fronts in the months of December to March.

Table 2. Percent Frequency of Synoptic Category for all events and by Duration Category for October-March of 1970 – 1994

Synoptic Category	Duration Category			
	All %	> 5 hr %	3 – 5 hr %	< 3 hr %
High Pressure Cen.	26	22	28	28
Behind CF	5	1	4	9
Behind WF	2	2	5	<1
Between Features	9	12	5	9
Low pressure Cen.	23	26	16	24
Low, no fronts	*(15)*	*(18)*	*(9)*	*(15)*
Low, fronts	*(8)*	*(8)*	*(7)*	*(9)*
Warm Sector	3	5	5	-
Ahead of CF/SF	9	8	12	7
Ahead of WF/SF	8	13	5	6
Ahead of CF & WF	1	1	1	<1
Front close to PIA	15	11	18	16
Number of Events	302	101	76	125

The events associated with high pressure systems and with lows or fronts were examined according to the time of onset of dense fog. (The "Between Feature" category was excluded from this analysis as the dominating synoptic condition was ambiguous).

For high pressure events (Fig. 1), the peak time of onset was midnight (73% between midnight and 0400 LST) for long-duration events, 0500 LST (67% between 0200 and 0600 LST) for the medium duration events and 0700 LST (66% between 0600 and 0900 LST) for the short duration events. This suggests that the long duration events occurred under more favorable cooling or moistening conditions. Very few events were initiated between 1100 and 2100 LST.

For events occurring in the presence of a low or an approaching or nearby front, a broader distribution of initial time of occurrence was found (Fig. 2). The peak in time occurrence was still earliest for the long duration events and latest for the short duration events.

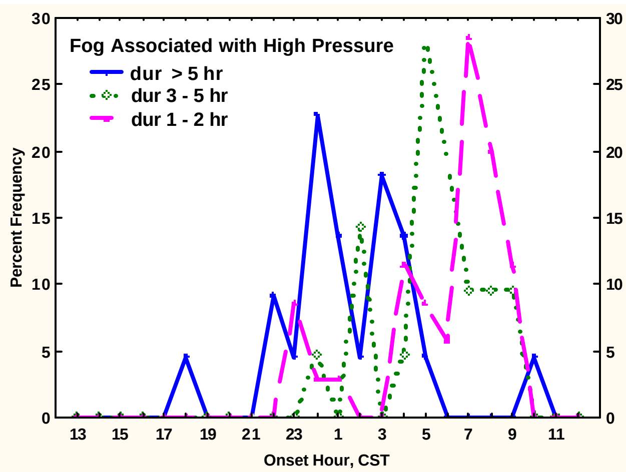

Figure 1. Percent frequency of onset times for October – March 1948-1996 dense fog events occurring under conditions of high pressure.

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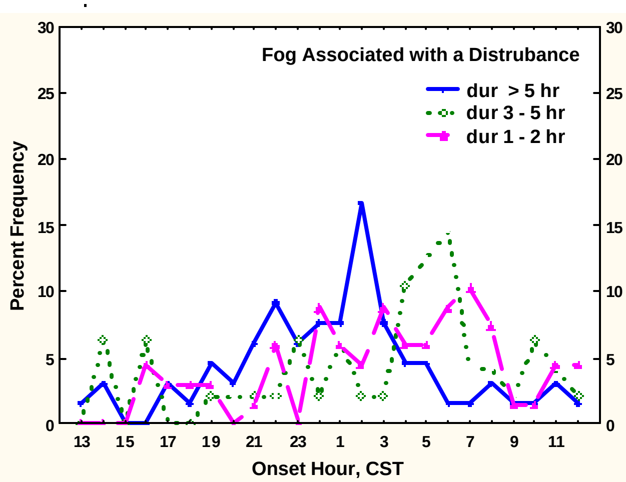

Figure 2. Percent frequency of onset times for October – March 1948-1996 dense fog events occurring with the presence of a low pressure system, approaching or nearby front.

6. PRECIPITATION AT DENSE FOG ONSET TIME

Light precipitation (usually light drizzle or light rain) often (41% of cases) occurs within +/- one hour of the first dense fog observation. Precipitation was primarily observed in the months of November through March and was associated with low pressure systems and/or fronts. The onset times of fog events that had precipitation were relatively evenly distributed throughout the 24 hour period. Dense fog events without precipitation occurred primarily in the late night to near dawn hours. Precipitation occurred in about 15% more short duration events than long duration events.

Tables 3 and 4 present the percent frequency of cases where precipitation is observed with dense fog formation by synoptic category, for the long-lived and short-lived events, respectively. Precipitation occurring when dense fog is first observed is observed for about 37% of the long-lived cases. These cases usually are associated with lows, warm sector events, or ahead of cold or warm fronts. When only considering those events associated with lows and/or fronts, precipitation is observed in 50% of the long-lived cases.

Table 3. Percent within each synoptic category with precipitation (ppt) and without precipitation (no_ppt) at time of first dense fog for long-lived fogs for October-March 1970 – 1994.

Synoptic Category	# > 5 hr	% ppt	% no_ppt
High	22	5	95
Behind CF	1	-	100
Behind WF	2	-	100
Between Features	12	33	67
Low	26	58	42
Low, no fronts	*(18)*	*(56)*	*(44)*
Low, fronts	*(8)*	*(63)*	*(37)*
Warm Sector	5	80	10
Ahead of CF/SF	8	50	50
Ahead of WF/SF	13	62	38
Ahead of CF & WF	1	-	100
Front close to PIA	11	9	91
Total	101	37	64

Precipitation near onset time is observed in about 50% of the short-lived dense fog cases (Table 4). The events occurring in conjunction with precipitation most commonly occur when fronts are close to Peoria, when low pressure systems are present, and ahead of warm/stationary fronts located in central or southern Illinois. When only considering those events associated with lows and/or fronts, precipitation is observed in 75% of the short-lived cases.

Note that for dense fog events that occur when a front is close to Peoria at the time of the onset of fog, the longer-lived ones tended to occur with no precipitation (Table 3) but precipitation was observed near the time of onset for the short duration events (Table 4).

Table 4. Percent within each category with precipitation (ppt) and without precipitation (no_ppt) at time of first dense fog, for short- lived fogs for October-March 1970 – 1994.

Synoptic Category	# < 3 hr	% ppt	% no_ppt
High	35	6	94
Behind CF	11	27	73
Behind WF	1	100	-
Between Features	11	64	36
Low	30	77	23
Low, no fronts	*(19)*	*(68)*	*(32)*
Low, fronts	*(11)*	*(91)*	*(9)*
Warm Sector	-	-	-
Ahead of CF/SF	9	56	44
Ahead of WF/SF	7	86	14
Ahead of CF & WF	1	100	-
Front close to PIA	20	75	25
Total	125	50	50

When only fog events associated with lows and/or fronts are considered, the events with precipitation near onset time tend to be more widespread, with the median number of total sites with fog being 15 as opposed to 12 for fog events with no precipitation. The events with precipitation also tend to peak in the months of December and January, whereas the ones without precipitation in October and December. The events with precipitation have two peaks in onset time, one between 22:00 and 02:00 and one between 08:00 and 11:00 LST. Events associated with an approaching warm front (with or without a low) often occur from December to March, frequently with precipitation, and begin at any time during the day.

The onset time of those events without precipitation have a single peak between the hours of 2 and 6 LST, as is the case for events occurring under the influence of high pressure, suggesting that perhaps radiational cooling is important. Events associated with an approaching cold front (with or without a low) tend to begin during this same early morning period, and often occur in the months of October to December without precipitation.

It is clear that light rain or drizzle often occurs near the onset time of fogs associated with lows and/or an approaching front. It is not obvious, however, whether precipitation is responsible for the development of dense fog as suggested by early researchers (e.g. George, 1951; Byers, 1959), or whether it simply occurs concurrently with the onset of dense fog, possibly even scavenging fog droplets and leading to the dissipation of fog. In those cases where light drizzle is not observed at the surface, it also is not known whether precipitation has occurred aloft and has evaporated prior to reaching the surface. The possibility does exist that light rain may play some role in the morphology of dense fog, but what that role might be is beyond the scope of this study.

7. SUMMARY AND CONCLUSIONS

Dense fog events occurring during the cold season months of October to March have been examined. They were separated into categories by duration. The short duration events (< 3 hours) tended to include fewer stations in a given event, had slightly higher minimum ceilings and slightly longer minimum horizontal visibilities (less dense fog) than the long duration events (> 5 hours), as might be expected. Importantly, the long duration events tended to form earlier in the night than did the medium and short duration events. The three fog groups tended to end in the few hours after sunrise.

Often it has been stated that fog in the Midwest occurs as warm moist air advects over cold, usually snowy surfaces. Here it was found that in only 25% of the cases of fog in the October to March period, and 33% of the December to March cases formed when snow was present or melting at Peoria. Further, the proportion of long and short events was similar whether snow was present or not. This suggests that snow does not play the predominant role in cooling the overlying air for the development of dense Midwestern fogs, at least in regions where snow is intermittent during most winters.

Dense fog can occur under a variety of synoptic conditions during the cold season. About 25% of the events occurred under the influence of a high pressure system and about 65% in the presence of a low pressure center, an approaching front, or with a nearby front. While the exact processes resulting in fog are unclear, this study verifies the results of early scientists (e.g. Stone, 1936; George, 1951; Byers, 1959) that for the Midwest, fronts and lows do play a role in setting up the conditions leading to dense fog.

Long and short duration events were similarly distributed among the differing synoptic types. More short duration events formed behind cold fronts and more long duration events formed in the warm sector environment or in advance of a warm or stationary front to the south.

The differences in onset times for long and short-lived fog events were pronounced for high pressure events, with the long duration events forming around midnight and the short duration events in the hours near sunrise. Most likely the difference in timing is related to conditions responsible for the effectiveness of radiational cooling (e.g. clear nighttime skies). There was also a shift in onset times for fogs associated with fronts or lows, but with much broader peaks, dependent upon the timing of the synoptic event and perhaps less so on the effectiveness of radiational cooling.

Precipitation is often observed at the time of onset of fog. For events with a low and/or an approaching front about 50% of the long duration cases and 75% of the short duration cases have precipitation near the time of onset of fog. What role precipitation may have in the morphology of fog, however, remains unclear.

8. Acknowledgements

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