P 3.3 FOG DURING THE 2004-2005 WINTER SEASON IN THE NORTHERN MID-ATLANTIC STATES: SPATIAL CHARACTERISTICS AND BEHAVIORS AS A FUNCTION OF SYNOPTIC WEATHER TYPES

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1. INTRODUCTION

The occurrence and prediction of fog, while well studied in the United States (e.g., see Leipper 1994; Croft et al. 1997; or the "COMET-MetEd" online fog module) as well as around the world (e.g., see fog section by Croft in the Encyclopedia of Atmospheric Sciences, 2002; or Bendix 2002), has not been well quantified with regard to its spatial distribution or character (other than satellite-based studies, e.g., Bott and Trautmann 2002). Much of the focus has been with regard to individual sites and/or the nature of the prevailing synoptic conditions and, in some cases, the associated boundary layer and micrometeorological parameters as related to fog occurrence, intensity, and dissipation.

Some fog studies have also focused on the microphysical principles, associated dynamics and processes, and droplet characteristics. Other efforts attend to the forecast dilemmas and the use of conditional probabilities, statistical guidance, simulations, and similar approaches. In fact, the use of statistical guidance (e.g., the FOUS and MOS forecast equations) often prove operationally the significance of current observation in fog prediction rather than any model or derived parameters available. Thus climatological information and techniques often perform more skillfully than other methods such that forecasters who observe and relate the existing synoptic situation can often improve upon that skill level.

The significant impacts of fog occurrence have also been well documented for specific fog events, various economies and activities, and their operational forecast including potential icing hazards (e.g., Fuchs and Schickel 1995). However, little attention has focused on the impact of fog's spatial distribution, according to synoptic patterns, that would be of value to improve the specificity of prediction and to identify situations in which fog dispersal or mitigation techniques could be employed with some reasonable and economic success. These would also be of some consequence for both regional and local airport operations. While George (1960) wrote the seminal treatise and others have followed, little operational impact (and in some cases, improvement) has occurred.

In an effort to better understand and forecast the spatial characteristics of fog as related to synoptic weather patterns, all fog occurrences (regardless of intensity) were examined within the northern Mid-Atlantic region during the 2004-2005 winter season (Dec-Feb). The intent was to determine the summary synoptic and spatial characteristics of fog events in order to identify the significance of fog type – or more correctly, fog processes (and synoptic types), assess the role of local effects, determine the spatial distribution and coverage of fog (e.g., isolated, scattered, widespread) within fog event types, and – based upon these – provide information towards the improved prediction of fog occurrence and coverage in the study region.

2. DATA COLLECTION & METHODOLOGY

The study area was selected to include coastal, interior, and varying terrain regions from Connecticut, Delaware, New Jersey, New York, and Pennsylvania to help incorporate and identify impacts of physiographic influences on fog frequency, intensity, and distribution. In addition, some sites are from highly urbanized areas while others are more remote and/or in a mountain/valley or similar setting. The stations selected were National Weather Service (NWS) sites with data readily available online through various NWS Forecast Offices (e.g., see www.erh.noaa.gov). For the 14 stations selected (see Table 1 and Fig. 1) monthly climate summaries for the winter season (Dec-Feb) were accessed to determine the days on which fog was observed, regardless of its intensity or duration, and to record how often dense fog was observed.

The data set was therefore composed of a maximum of 90 days for any one of the fourteen station and allowed collection of all synoptic patterns producing fog within the study region during the 2004-2005 winter season. Using the criterion of fog occurrence at any one location, 75 of the 90 days

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possible (or 83%) were identified across the study area on which at least one of the 14 stations reported fog. The frequency of fog occurrence (Table 2) was highest for Islip (ISP), New York (61 days, or 68% of the days of the winter season examined) and lowest for Atlantic City (ACY), New Jersey (33 days, or 37%). While both sites represent coastal locations, the significance of their proximity to the ocean appears to be of limited importance in the overall occurrence of fog for the winter season studied (and without accounting for the traditional fog type classification schema).

When considered according to the frequency of fog at any one location when an event was observed at one or more locations across the study area (i.e., of the 75 days identified) the highest and lowest rates of occurrence were once again observed at ISP (81%) and ACY (44%), respectively. Further examination of these data spatially was completed by application of ArcMap GIS Software. Data were plotted and the Inverse Distance Weighted (or IDW) method was used for interpolations to analyze isopleths. The IDW method (Chang 2004) was used given the lack of point data which requires more weighting as one moves towards a station and less when moving away.

Examination of these basic frequencies spatially (Fig. 2) indicated a relative minimum of fog occurrence from southwestern Connecticut through central New Jersey into northern Delaware. Fog days became greater when moving into eastern Pennsylvania (topographic) and across eastern Long Island (maritime). The same examination for dense fog days (Fig. 3) indicated that although frequencies were slightly higher when moving southeastward towards the coast in the study area, the highest rate of occurrence for dense fog was well-inland at higher elevations (e.g., Mount Pocono, Pennsylvania MPO).

In order to better understand the factors responsible for the winter season fog events identified, the Daily Weather Map Series (DWM) (www.hpc.ncep.noaa.gov/dwm/dwm.shtml) was used to classify the basic synoptic weather patterns occurring during each of the 75 event days. Preliminary analysis focused on surface features in order to allow the events to "self-sort" themselves into the weather patterns associated with the occurrence of fog. In this manner, the fog processes of greatest significance could be inferred for each event across the study area and considered against the role of any given site's local effects. Three basic synoptic patterns (and subtypes) were considered for this study: high pressure ("A"), low pressure ("B"), and frontal zone ("C"). These were further classified into subtypes to indicate the location of the features relative to the study area.

It is noted that the "null case" (i.e., the non-occurrence of fog across the study area, or 15 days) was not considered in the determination of synoptic types nor was there any attempt to examine either the timing of fog occurrence or its duration. The intent was to identify spatial features and characteristics associated with those days producing fog during the winter season as a function of the synoptic pattern and as modulated by local effects. This type of information would be useful in prediction of fog occurrence, its expected coverage, and its specific pattern within a given synoptic weather pattern for a given forecast region.

3. ANALYSIS OF EVENTS

All fog events were classified according to the categories (or types) listed above using the DWM Series surface charts online and they are shown in Table 3. Of the 75 events, 34 were type "A" (45%, high pressure), 17 type "B" (~23%, low pressure), and 24 type "C" (32%, frontal zone). Within each synoptic type, the location of the feature of interest (e.g., high pressure over, to the S-SW of the study area, et cetera) was used to define subtypes. The intensity of their associated surface pressure systems (maximum and minimum isobars) and associated pressure gradients were derived relative to a common reference point in the study area (i.e., south-central New Jersey) in order to make comparisons and to quantify the synoptic characteristics as much as possible while allowing for the consideration of local effects by station (not shown).

For each synoptic type, 32% (or 11 of 34) of the high pressure fog events were dense fog events (i.e., at least one location reporting dense fog during a fog day), 59% (10 of 17) of the low pressure events, and 54% (13 of 24) of the frontal zone cases. For each of the synoptic types (and subtypes), summary statistics were generated to identify the highest and lowest pressure values, pressure gradients; the occurrence of precipitation at any time, the presence of snow cover, and the prevailing upper air pattern. These were reviewed and analyzed through box and whisker plots (not shown) in order to both verify and confirm the classifications used (as well as their consistency) and the resulting separation of fog events in the database. These helped to identify differences between them in hopes of determining the key factors controlling fog occurrence and coverage.

The highest pressure values were associated with type "A" (as would be expected for high pressure) and the pressure gradients averaged greatest for synoptic type "B" (low pressure). Pressure gradient values behaved similarly for type "A" and type "C" with their mean values (~0.01 mb per mile versus ~0.03 for type "B") and quartile distributions nearly equivalent suggesting that mixing may be of some common significance to these fog occurrences. Events were also ranked according to the pressure gradients and pressure values to determine any relationship between these and the number of stations reporting fog (and/or dense fog). These analyses indicated no seasonal variation or trend by synoptic type (nor by station or synoptic subtype) and little, if any, relationship between pressure, pressure gradient and the occurrence or coverage of fog (although the highest pressures for type "A" did see a general decline in the number of locations reporting fog as would be expected).

A summation of these analyses (Table 3) shows that the study area has a greater coverage of fog (i.e., more stations) when high pressure (type "A") is over and/or to the N-NE of the region than when high pressure is S-SE, SW, or W-NW of the study area. However, the occurrence of dense fog in these situations appears to be independent of the nuances of this synoptic weather type (except for W-NW in which no cases were reported and which had the greatest mean pressure gradient within the synoptic type). Although type "A" was the most frequent of all synoptic types, type "B" and "C" were more prolific and efficient at generating fog with greater coverage and intensity.

In cases of low pressure (type "B") fog coverage and occurrence is complete (100%) with a system to the S-SW (and with the highest mean pressure of the synoptic type) and least (though still higher than for type "A") when low pressure is to the W-NW (with the second lowest mean pressure gradient within the synoptic type). Dense fog is about twice as likely across the region when low pressure is to the E-NE (and the highest mean pressure gradient). Type "C" events had greatest coverage when the frontal zone was stationary and least when only a trough was present (with the greatest mean pressure gradient). Dense fog occurrence and coverage was much more likely for those events occurring with a warm front present yet very unlikely (there were no occurrences) for a trough or occlusion (with the lowest mean pressure).

The same analyses were completed for each synoptic type in order to provide information to help distinguish between the distribution of fog across the study area and the importance of local effects (and to better understand fog occurrence at each location). When summarized by synoptic type and location an assessment of the relative importance of various fog processes can be made. For example, type "A" should be dominated by radiative effects, "B" by advective and lift, and "C" by mixing processes. Both summary statistics and a plot of the same information would also provide evidence as to the greatest contributing factors to the occurrence and distribution of fog events during the winter season for the study area.

Plots of the number of fog events by station and (overall) synoptic type also provide insight as to the more likely distribution of fog. For example, with high pressure events the greater chances for fog appear in eastern Long Island, southern Delaware, and eastern Pennsylvania (low lying and similar soil types) with a corridor of lesser values (in a more urbanized zone) from northern Delaware to southwestern Connecticut. When dense fog cases are considered, the absence of any occurrences in the middle of the study region imply that local (urban and other) effects are more critical and more prominent than along the coast and at higher elevations.

While a lesser degree of variation in fog frequencies is noted within the low pressure type given synoptic scale processes, the occurrence of dense fog is clearly not favored across much of the region. The occurrence is relatively rare, except at MPO, and there is an inconsistent response in the coastal locations. The frontal zone type is similar to high pressure in the overall pattern and maximum values, but shows limited variation across the study region. However, there is clearly a difference for dense fog events in that they occur more often at all locations. In some cases the occurrence of dense fog is equivalent to the sum frequency of types "A" and "B" and could simply be indicative of focused, undisturbed, and/or maintained fog processes at work across the study area.

Further review of the spatial distribution of fog was made with regard to patterns of maxima and minima and the spatial coverage by event and synoptic types (see Figures 4a-c). Plots indicated that specific areas were favored (with nearly twice the frequency of fog) under high pressure events whereas for low pressure cases there was a northward preference (although frequency ranges were limited). The exceptions were regions of northeastern New Jersey (urban and low-lying) and east-central

Pennsylvania (terrain variations). Frontal events showed a preference well-inland and in the extreme eastern portion of the study area.

To further define the extent of fog events, when more than 10 of the 14 stations (i.e., more than 71% of all study region stations) reported fog, the event was arbitrarily defined to be widespread. The event was defined as scattered when 4 to 10 stations reported fog (i.e., 29% to 71% of stations) and as isolated (or localized) when less than 4 sites observed fog (i.e., less than 29% of stations). When examined according to these criteria, high pressure events, while the most common, experienced widespread fog only 29% of the time, scattered events 30%, and isolated fog 41% of the time.

Low pressure (and frontal) systems experienced widespread fog 69% (50%) of the time, scattered 12% (27%), and isolated 19% (23%). Applying the same definitions to dense fog events revealed that all (100%) high pressure dense fog events were isolated, 25% of low pressure events were scattered (and 75% localized), whereas for frontal events only 14% and 9% of the occurrences of dense fog were considered to be scattered and widespread with the remainder being localized (77%).

Therefore, while fog may be widespread for the study area (especially for low pressure and frontal events) the occurrence of widespread dense fog across the entire area is highly unlikely except in the case of frontal events. It is possible that if the same were examined by regions within the study area, additional useful forecast information might be obtained.

4. CONCLUSIONS

The spatial characteristics of fog as related to synoptic weather patterns were examined. All fog occurrences (regardless of intensity) were studied within the northern Mid-Atlantic region during the 2004-2005 winter season and indicated some preference of occurrence, location, and intensity. These reflected a variety of local effects which can help forecasters determine the spatial distribution and coverage of fog (e.g., isolated, scattered, widespread) for any fog event according to its synoptic type. Further review will focus on station specific features as well as a review of composite maps to identify the influences of local and synoptic scale forcing.

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Location Name	Station ID
Allentown, PA	ABE
Atlantic City, NJ (Pomona)	ACY
Bridgeport, CT	BDR
Central Park, NY	CPK
Georgetown, DE	GED
Islip, NY	ISP
John F. Kennedy Airport, NY	JFK
LaGuardia Airport, NY	LGA
Mt. Pocono, PA	MPO
Newark, NJ	EWR
Philadelphia, PA	PHL
Reading, PA	RDG
Trenton, NJ	TTN
Wilmington, DE	ILG

Table 1. Stations selected for use in study area as shown in Figure 1.

Station ID	# of Days w/ Fog	% of Study Period (90 days)	% of Events (75 days)	# of Dense Days	% of Dense Days/Events
ABE	48	53.3	64	7	14.6
ACY	***33***	***36.7***	***44***	9	27.3
BDR	38	42.2	50.7	***3***	7.9
CPK	38	42.2	50.7	5	13.2
EWR	39	43.3	52	5	12.8
GED	48	53.3	64	9	18.8
ILG	40	44.4	53.3	7	17.5
ISP	***61***	***67.8***	***81.3***	10	16.4
JFK	43	47.8	57.3	11	25.6
LGA	41	45.6	54.7	8	19.5
MPO	54	60	72	***24***	***44.4***
PHL	40	44.4	53.3	10	25
RDG	55	61.1	73.3	4	***7.3***
TTN	42	46.7	56	4	9.5

Table 2. Overall frequency of fog (and dense fog occurrences, in number of days) is listed for each station within the study region. The relative frequencies of fog (and dense fog) occurrence are as compared to the entire winter season (90 days) and given in percent. The relative frequency (percent) that each location was “involved” in a fog day event is also shown. Maxima and minima are underlined in each column.

Synoptic Type	# of Fog Events	% of All Events	# of Sites Reported	# of Possible Sites	% of Sites Reported/# Possible	# of Dense Fog Events	% All Dense	# of Site Reporting Dense	% of Dense Sites/# Possible
Type A	**34**	**45.3**	**212**	**476**	**44.5**	**11**	**32**	**20**	**4.2**
Over	14	18.7	97	196	49.5	6	17.6	9	4.6
S-SE	5	6.7	24	70	34.3	2	5.9	4	5.7
SW	4	5.3	18	56	32.1	1	2.9	3	5.4
N-NE	6	8	48	84	57.1	2	5.9	4	4.8
W-NW	5	6.7	25	70	35.7	0	0	0	0
Type B	**17**	**22.7**	**185**	**238**	**77.73**	**10**	**59**	**29**	**12.2**
W-NW	6	8	54	84	64.3	2	5.9	3	3.6
Over	3	4	34	42	81.0	2	5.9	3	7.1
S-SW	4	5.3	56	56	100	4	11.8	19	33.9
E-NE	4	5.3	41	56	73.2	2	5.9	4	7.1
Type C	**24**	**32**	**220**	**336**	**65.5**	**13**	**54**	**61**	**18.2**
Warm	5	6.7	58	70	82.9	4	11.8	32	45.7
Cold	11	14.7	97	154	63.0	7	20.6	15	9.7
Stationary	4	5.3	46	56	82.1	2	5.9	14	25
Trough	2	2.7	7	28	25	0	0	0	0
Occluded	2	2.7	12	28	42.9	0	0	0	0

Table 3. Summary statistics of fog and dense fog days (events) according to synoptic type and sub-type: Type A – High Pressure; Type B – Low Pressure; Type C – Frontal. The percent columns may add to slightly more or less than 100% due to rounding.

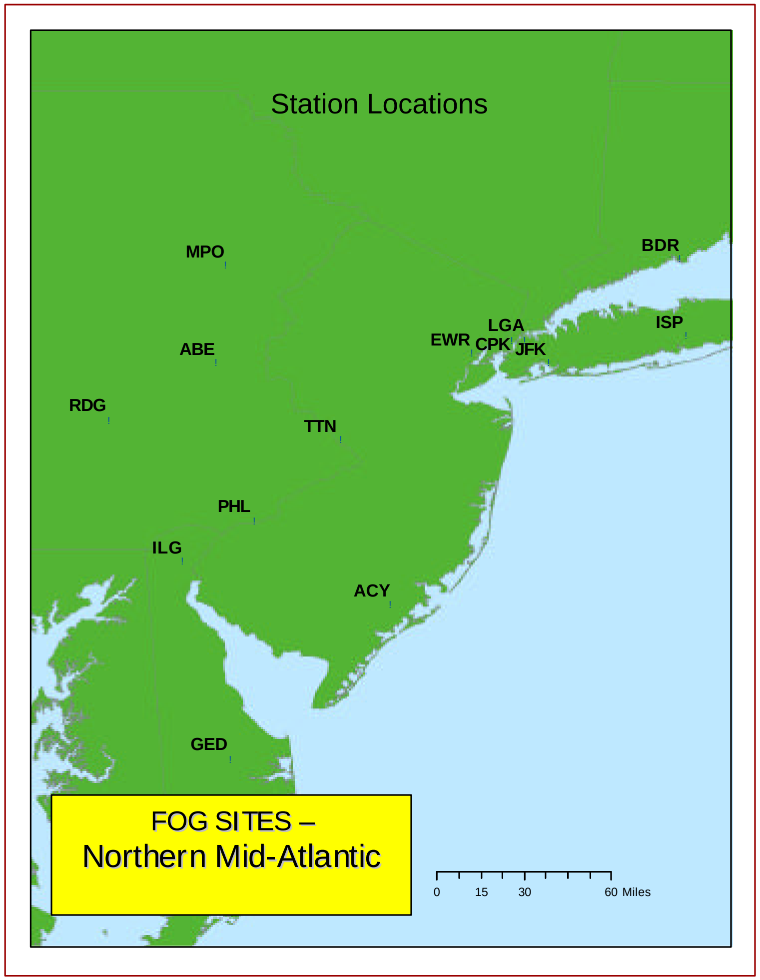

Figure 1. Distribution of stations in study area as specified in Table 1.

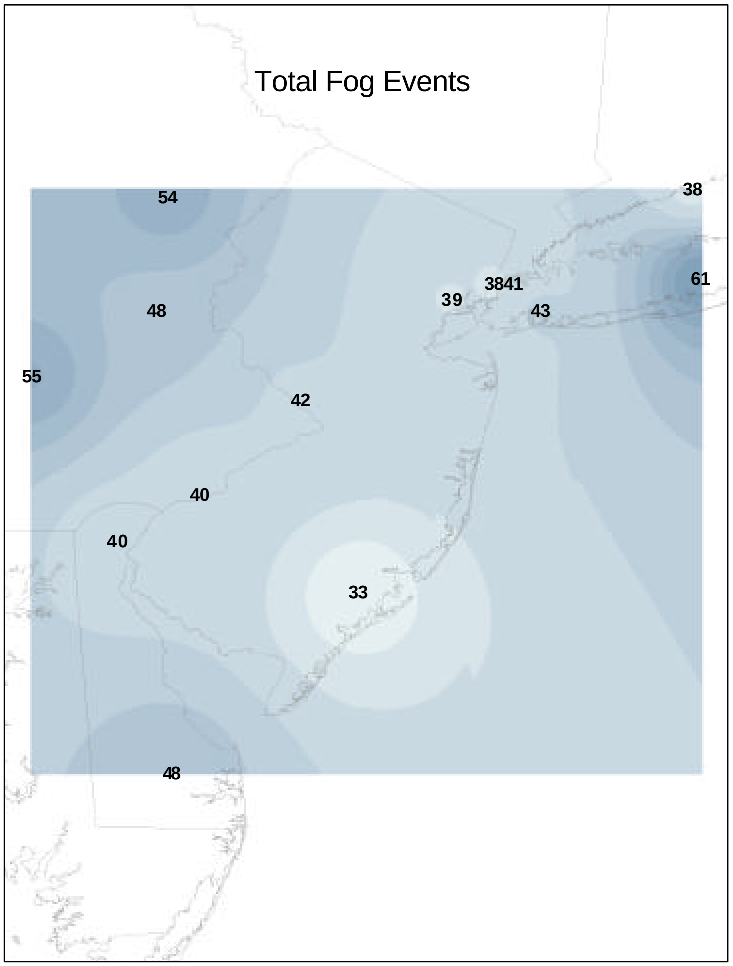

Figure 2. Distribution of fog events (total days observed of 90) across study area.

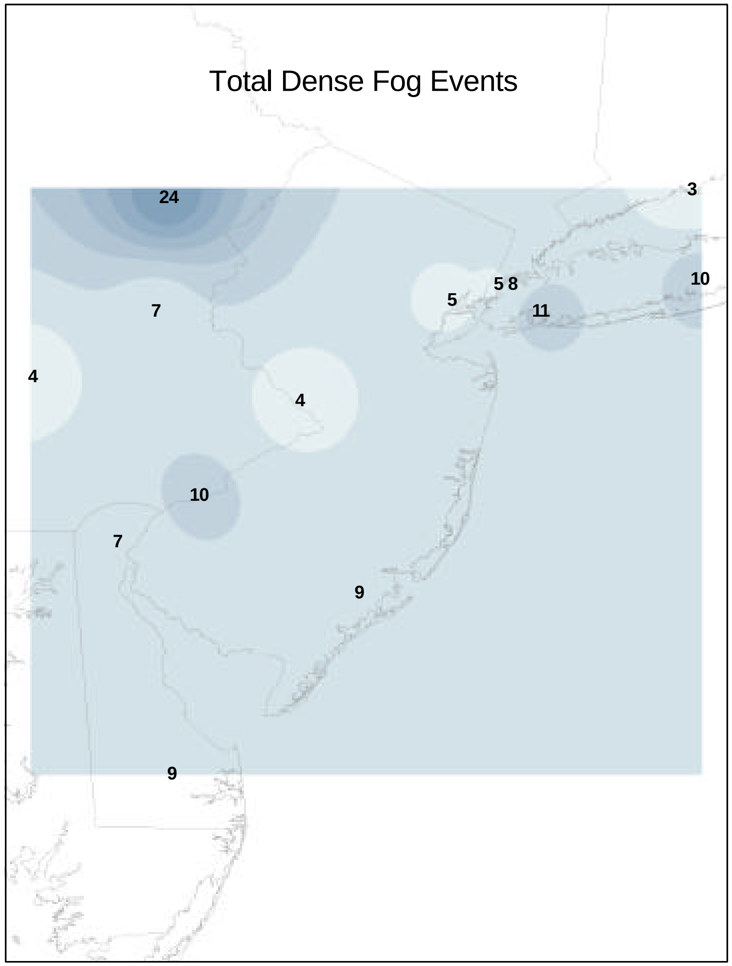

Figure 3. Distribution of dense fog events (total days observed of 90) across study area.

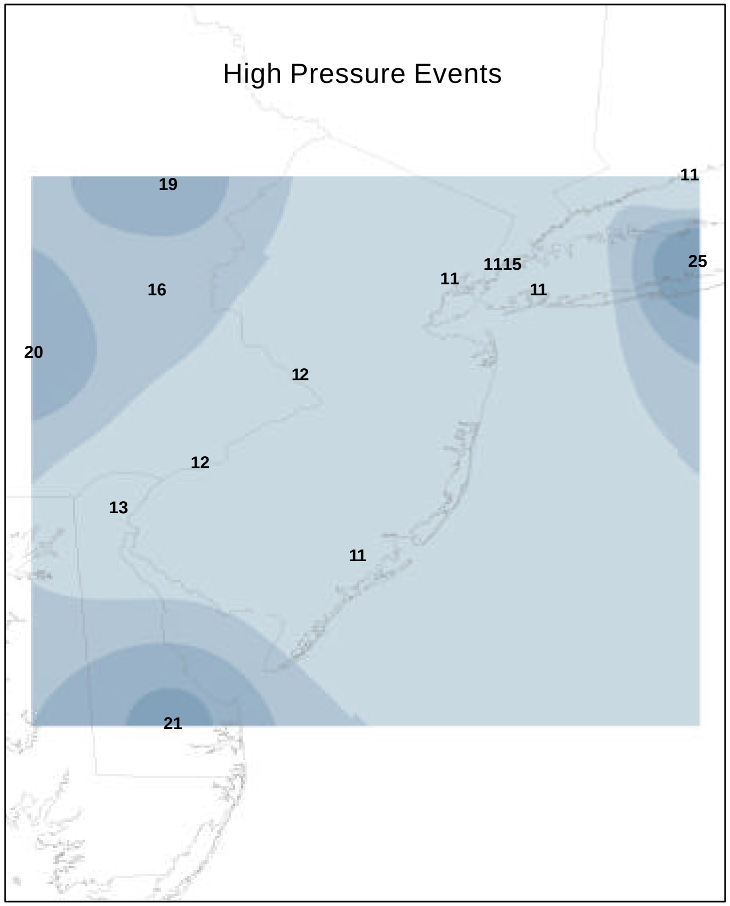

Figure 4a. Total frequency of fog occurrence for study area based on all high pressure events.

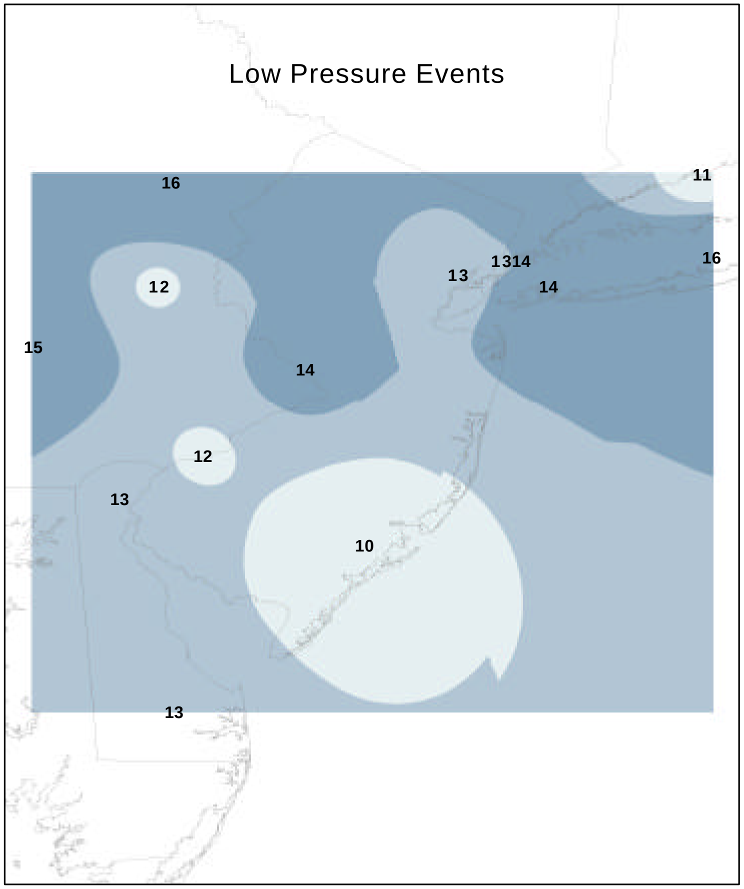

Figure 4b. Total frequency of fog occurrence for study area based on all low pressure events.

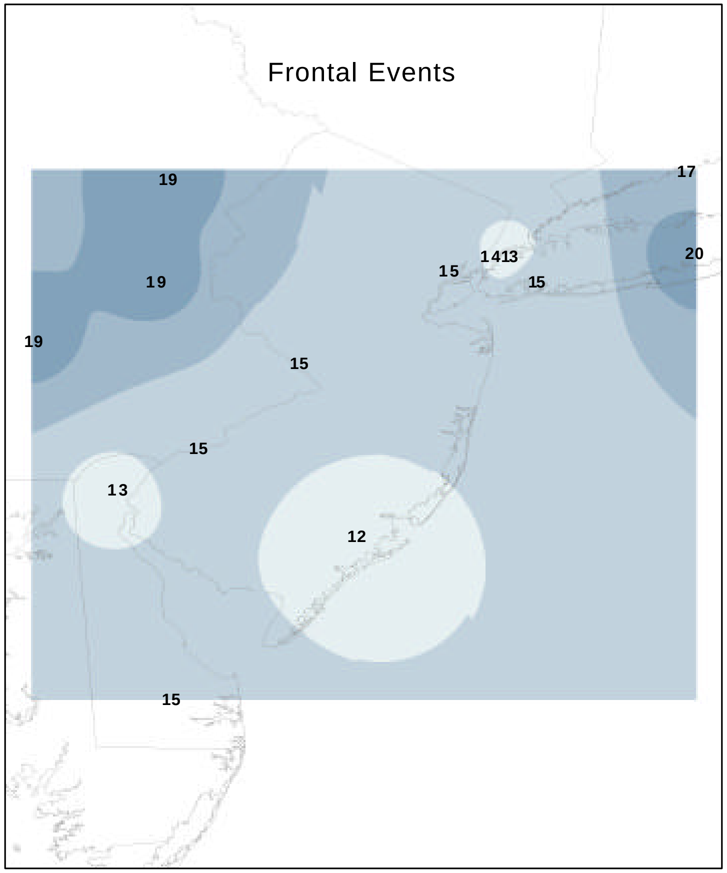

Figure 4c. Total frequency of fog occurrence for the study area based on all frontal fog events.