6A.2 FOG OCCURRENCE, DISTRIBUTION, AND COVERAGE THROUGH GIS ANALYSIS

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1. INTRODUCTION

The occurrence and prediction of fog have been significant operational issues for quite some time, particularly with regard to forecasting, transportation (e.g., Leipper 1995, George 1960, and Garriott 1904), air quality (e.g., Pagowski et al. 2004), and even water-harvesting (Olivier 2004). Based on the fact that multiple fog development processes are common (e.g., Tardif and Rasmussen 2007), even within the same fog event or over time, accurate prediction can be elusive. These include fog evolution in time and space, the spread and/or dissipation of fog, onset and duration, intensity and variability, and a high dependence on the state and behavior of the local boundary layer as well as basic principles of cloud microphysics (e.g., COMET http://www.meted.ucar.edu/dlac/website/modules1.php).

Many of these fog prediction issues have been considered for more than 100 years by various authors through many types of investigations including some less rigorous. In addition, the evolution of fog with time (e.g., maintenance, dissipation, or coverage) suggests interaction between fog processes and local physiographic features that further complicates fog prediction in time and space. While many of these fog characteristics and behaviors are generally well studied in the United States on both local and/or regional scales (e.g., United States West Coast: Leipper 1994; Gulf Coast: Croft et al. 1997; East Coast: Tardif and Rasmussen 2008; Plains: Westcott and Kristovich 2009) and around the world (e.g., fog section of the Encyclopedia of Atmospheric Sciences, 2002; or Bendix 2002; and Cho et al. 2000); they are not well-predicted in short (0-6h) or longer range (6h to days) forecasts.

Impacts & Prediction

The significant impacts of fog occurrence have also been documented for specific fog events, various economies or activities, and their operational forecast including potential icing hazards (e.g., Cox 2007, Ellrod and Lindstrom 2006; Fuchs and Schickel 1995). A recent and extensive review by Tardif and Rasmussen (2007) provides insight to the myriad efforts that have been attempted to improve understanding of this important phenomenon and prediction of this significant and highly variable sensible weather element.

However, the full spatial distribution and character of fog have not been thoroughly investigated in many regions other than through satellite-based analyses (e.g., Bott and Trautmann 2002) or real-time satellite-derived forecast products. While these are valuable to operational forecasters, many are based on recognition of fog after it has formed and/or focus on its trends with time for the very short term (e.g., often less than three hours – see again Ellrod and Lindstrom 2006). Many forecasters also make use of studies that focus on individual site climatologies and conditional probability tables, or the nature of the prevailing synoptic conditions, in an attempt to name a fog type or process. These do not provide adequate information to assess or verify fog coverage in a region.

A recent and significant improvement upon these, in terms of methodology and outcomes, was the approach used by Tardif and Rasmussen (2007) to determine the typology of fog in the New York City area. Their results have provided a means to determine type and frequency according to observational sequences so as to specify occurrence features for the region of interest and are an important step towards an operationally useful conceptual forecasting model. This provides for an initial examination of the significance of contributions of both local physiographic features and fog processes throughout the year by location. The use of such information in a GIS framework (Ward and Croft 2008) might then allow for greater precision in the depiction of fog coverage (in terms of prediction) for a data sparse region.

The use of numerical modeling and their ensemble members (e.g., Roquelaure and Bergot 2008) has also been made to examine the features of a region as well as associated boundary layer micrometeorological and microphysical parameters and properties related to fog occurrence, distribution (in lieu of eventual non-simultaneous or asynchronous coverage), and intensity. These have

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provided insights for specific regions and synoptic settings but have not provided the fundamental operational support needed by forecasters – a means by which they may specify the potential occurrence and ultimate regional coverage of fog in advance (e.g., 0 – 6h, 6-12h, or 24h or more with verification). This lack of localized predictive information to specify fog occurrence at a location – or fog occurrence across a region – is detrimental to forecasters given the emphasis on digital forecast databases and their verification.

Other numeric and statistical guidance methods (e.g., the FOUS and MOS forecast equations) are also used by forecasters but their performance in prediction is often no better than a suite of current observations when compared with model or derived parameters available. In operational settings "reference-point" climatological information (e.g., a coastal versus an interior station) combined with model and statistical techniques may allow a more skillful forecast through a consensus approach. Thus forecasters who observe and relate the existing synoptic situation can more quickly and legitimately improve what are typically short-term forecasts of zero to six hours (anecdotally "local experience"). While successful, this approach does not provide an adequate understanding of fog's spatial distribution across a given region, or according to specific synoptic patterns and physiographic features, or the variation of fog with time.

Study Intent

Each of these would be of value towards improving the specificity of fog prediction and to identify the attributes of fog occurrence (versus null cases) and coverage, its spatial variations within synoptic regimes, and based on local physiography. In other words, these are related to the variance found within the population of fog events due to several competing and often confounding factors. Using information derived from the analytic fields associated with fog would assist a forecaster in predicting anticipated fog characteristics and behaviors, such as regional coverage (for verification purposes) and intensity (fog versus dense fog), with greater lead-times (i.e. of 24 hours or more).

Therefore, in an effort to better understand and forecast the spatial characteristics of fog as related to synoptic weather patterns and physiographic features, all fog occurrences, regardless of intensity or location, were examined within and around the New Jersey region for ten winter seasons of 1999 – 2000 through 2008 – 2009 (Dec-Feb). The winter season was selected for study as it produces the highest frequencies of fog that are often of long duration and have extensive coverage. These fogs have widespread impact in a very densely populated region with high transportation volume in all modes (i.e. vehicular, rail, aircraft, and marine).

The use of all fog reports, regardless of visibility restrictions (i.e. reported when visibility is reduced to below 6 miles, the criterion for reporting reduction to visibilities by the NWS), was intended to account for variations in fog intensity that may occur across the region, even if not officially recorded at all first-order sites, and to account for the limited number of surface observing stations across the study region. This criterion was deemed essential in order to "catch" as many fog events that may occur, even if only at one location, as fog may be occurring (unobserved or unreported) at other locations. This provides a more complete measure of the ultimate spatial coverage (and occurrence) of fog in the region and increases its probability of detection.

While this may appear initially to inflate the actual fog occurrence (frequency), coverage, and intensity; the intent was conservative in nature: to capture as many events as possible rather than to consider fog as an arbitrary function of station type and station density (or as a function of observational criteria). This study's goals were to (1) Determine the spatial characteristics of winter season fog – or more correctly, the role of the synoptic regime so as to (2) Determine (or infer) the spatial distribution and ultimate areal coverage of fog (i.e. to define whether it was localized, regional, or widespread), even if it occurred in an asynchronous manner; and use these to (3) Examine basic analytic fields associated with fog and dense fog occurrences versus null events.

These would then (4) Provide operational guidance for the improved specification of winter season fog occurrence and coverage; and allow for a direct GIS investigation and integration of data in order to (5) Predict the likelihood of fog occurrence locally, and its coverage, in real-time through the application of model data, synoptic regimes, and physiographic and other GIS database information.

2. DATA COLLECTION & METHODOLOGY

The study area was selected to include representative coastal, interior, and varying terrain and physiographic regions in and around New Jersey (Fig. 1) and, given the low density of official reporting stations, included sites from Connecticut, Delaware, New Jersey, New York, and Pennsylvania. This region is quite varied in terms of population density, land use, transportation modes, and represents an amalgam of distinct and overlapping climatic zones. Fourteen stations (Table 1) were selected based on data availability and fog data was collected using monthly climate "Summary of the Day" (CF-6) data for ten winter seasons (Dec-Feb) for the period 1999 – 2000 through 2008 – 2009. This provided a total of 902 potential "fog days" (i.e. 90 days for 8 seasons; 91 for two leap year seasons).

a. Fog Events

A fog day (or event) was designated to occur when any one of the 14 sites reported fog during any single observation on any day of the winter season regardless of fog "intensity" (or resulting visibility), duration, or occurrence elsewhere in the study region. Those fog days in which at least one site reported dense fog (visibility reduced to less than one quarter mile) were also examined to consider fog intensity (i.e. dense fog) and the characteristics of its distribution. The time of fog occurrence and its actual duration were not considered in order to focus efforts on the occurrence of fog across the region under a given synoptic regime and for purposes of verification of total inferred fog coverage.

Therefore, while the occurrence of fog is not necessarily contemporaneous between stations, it portrays the ultimate coverage (or verifying extent of fog) experienced in the area. This type of information is useful in the operational prediction (with a greater lead-time) of fog occurrence, its expected or ultimate verifying coverage of the forecast area regardless of time of occurrence, and its specific distribution as related to the prevailing synoptic weather pattern. These are important factors when assessing the likelihood of fog between observing sites.

The relatively broad definition of a fog event was used for several reasons: (1) to avoid replication of fog studies designed to provide single station climatologies (often for dense fog cases) without regard to fog occurrence or non-occurrence at nearby locations; (2) in order not to miss fog events that might occur between sites (e.g., when only one location reports fog) so as to improve the detection of fog events; (3) to better describe and infer the total coverage of fog across a region with regard to synoptic types and physiographic features (which may lead to better discernment of the spatial distributions of fog that may occur – or locations prone to fog); (4) to consider each of these aspects with regard to dense fog occurrences; and (5) to provide operational guidance to assist fog forecasting (beyond the zero to six hour time frame) through an examination of a few basic diagnostic fields and coverage patterns associated with fog and dense fog, versus null events (in which no fog was observed at the selected sites).

These criteria were intended to give a forecaster the specific knowledge needed to identify fog occurrence across forecast zones of interest (1, 2, and 3) and to help infer the fog coverage anticipated (even if not contemporaneous) (3), and with regard to causative processes and local effects as well as intensity and coverage (3 and 4). The criteria would potentially help improve fog prediction in advance (e.g., six to 24 hours or more) across the area based on model forecasts of synoptic features and diagnostic fields (5) based on various observed and/or derived parameters – including GIS database information.

This approach is supplemental and more comprehensive in that it provides an examination of the analytic fields associated with fog occurrences in an area and considers the same for non-occurrences of fog (null events). It is noted that while the study methodology here does not provide information on the specific fog processes, or their evolution with time, except through synoptic inference as related to local mesoscale factors and physiographic features; these are readily determined in an operational setting.

b. Occurrence, Time, and Distribution

Based on the criteria above, data collection resulted in a maximum of 90 days (except 91 days during 2003-2004 and 2007 – 2008, leap years) for any one winter season across fourteen stations. This provided for 12,628 possible observations of fog occurrence (i.e. 902 days for 14 stations). Using the event criterion, 721 of the 902 days possible, or 80%, were identified across the study area as fog events (with 329 of 902, or 36%, dense fog cases). In other words, fog was observed (by at least one location in the study region) an average of eight of every ten days each winter season and nearly half of those times (329 of the 721 or 47%) the fog was dense (or approximately 4 of 8 days when fog was observed). The frequencies of fog (and dense fog) occurrence are provided for each location by month and season in Table 2 (and are later examined according to their spatial distributions).

It is clear that fog is more common in association with higher elevations (e.g., MPO) and interior locations (e.g., RDG) and selected coastal regions (e.g., ISP and GED). Fog is least common in urban, near-coastal locations (e.g., LGA and CPK). Dense fog is favored in the highest terrain (MPO) and (although much less frequently) at the immediate coast (ISP); and is least common in the interior and urban center (CPK and LGA). It is also evident that significant variations may occur within any one winter season as well as between winter seasons and each location (e.g., approximately half of MPO fog events were dense during the winters of 2004-05 and 2006-2007). Many comparisons or characteristics can be made for each site and would assist local point forecasts and the development of operational conditional climatological forecasts.

These inter and intra seasonal variations may be more simply examined by viewing the week to week variations within each season of total fog reports, or the number of sites reporting fog each week for a standard winter season (Fig. 2). In the first case, it is clear that significant variations of fog reports occur within each season and are most likely due to the synoptic scale cycle of weather regimes occurring during the winter. Within each season a peak of fog occurrence is more often noted during late December and mid-January – the fifth and seventh weeks of the season – indicating the most stations and most days on which fog was observed in the study region.

This timing, while variable from season-to-season; is roughly coincident with both the minimum of insolation (fifth week) and the climatological minimum of air temperatures (seventh week) across the region. Clearly a variety of synoptic features and/or processes associated with fog occurrence (e.g., precipitation-induced fog, onshore flow) are also responsible for the timing of greater fog likelihood and these in turn may be modulated according to the ENSO and other atmospheric cycles from season-to-season. While of note, these frequencies do not provide information as to the distribution of fog in the region (i.e. urban, coastal, interior, higher elevation) or the types of fogs experienced as a function of location (local characteristics) or synoptic regime.

While the preceding analyses provide confirmation of what forecasters tend to be aware of operationally, they also quickly illustrate the vagaries of fog prediction in an operational setting. Multiple and conflicting or confounding signals often occur and points-out the need for improved understanding of fog occurrence as a function of location, synoptic setting, and behavior (intensity, coverage). To assist in this recognition, spatial plots of fog frequencies are also of value. An analysis of fog and dense fog occurrence across the study region is provided in Figure 3 (a, b). Given the low density of data points the Inverse Distance Weighted method was used to analyze isopleths (Chang 2004) for these maps as it provides a greater weighting to a station's value when closer in proximity to that site. The patterns of fog occurrence observed (i.e. maxima/minima) illustrate the significance of higher elevation and interior location (more frequent fog) versus urban and some coastal locations and these are comparable with the results of Tardif and Rasmussen (2007).

Fog occurrence minima occur over the New York Metropolitan region extending south and southwestward to northern Delaware (Fig. 3a). These are found in the vicinity of major urban areas in the region and may stretch across the Pine Barrens of southern New Jersey (although this could be an artifact of the analysis due to a lack of observing sites in that region). Maxima are found over interior sections of Pennsylvania, including higher elevation, and in true marine environments (i.e. coastal Long Island and coastal Delaware) where locations are more directly influenced by the ocean.

These patterns indicate gradients of higher to lower (well inland to the coast) and from lower to higher (i.e. inland/urban/near-coast to true marine locations) occurrences of fog across the study region. In the case of dense fog occurrence (Fig. 3b), the pattern is characterized by maxima first in high elevations followed by a much lower frequency moving towards the coast. The gradient from the coast to the inland minimum is ill-defined in comparison with the fog frequencies gradient in the prior analysis (Fig. 3a).

When the (Fig. 3a,b) plots are considered with regard to physiographic features and other characteristics of the region (as per Fig. 1), the urban minima are found within an urban corridor (a portion of the megalopolis running from Boston to Baltimore). This corridor, while characterized by major highways and industry, also contains and is bordered by the Watchung Mountains in north-central New Jersey, the Pine Barrens in southern New Jersey, and the mouth of the Chesapeake Bay near Delaware and Maryland. These regions create highly localized effects (e.g., topographic blocking of flow) that may also vary according to the prevailing synoptic regime.

For example, the interior regions of northeastern Pennsylvania contain terrain that may block flow and/or mixing of air as compared with southeastern Pennsylvania which is 'more open' versus coastal zones which are relatively flat such that air is easily mixed by any perturbation or disturbance in the atmosphere. However, based on the limited spatial extent of observing sites, there appears to be little relation between fog frequencies and physiography other than higher elevation and marine environments.

c. Synoptic Types: Occurrence & Event Distribution

In order to better understand the processes responsible for the winter season fog events identified (i.e. formation and the ultimate regional extent/coverage), the NCEP HPC Daily Weather Map Series (Daily Weather Map Series; as available online at www.hpc.ncep.noaa.gov/dwm/dwm.shtml) was used to classify the synoptic weather patterns occurring during each of the event and null days (no fog reported at study sites). Three basic synoptic patterns were considered for this study for ease of use (operationally) and simplicity: high pressure ("H"), low pressure ("L"), and frontal zones ("FRNT"). These were further classified into subtypes (Table 3) to indicate the location of synoptic features relative to the study area (e.g., Type "H" located "over" the study region) and to indicate other subtype features (e.g., "FRNT" = "Cold" front) to help characterize the effects (if any) that these may have had on fog frequency and coverage in the study region.

The basic types were selected as they most typically represent fog processes that are radiative (high pressure), advective (high or low pressure, fronts), a combination, or a more complex relationship (e.g., precipitation-induced, others). All partitioning of data to determine the frequency of each synoptic type and subtype was completed by simple visual inspection of the Daily Weather Map Series (DWM) for each event day and verified by the preparation of composite maps (not shown). It is important to recognize that although each event was defined by the observed DWM Series synoptic features at 1200 UTC, these may or may not have been proximate in time with the occurrence of fog at any given location in the study region (and fog may not have been reported at the same time by any given site in the study region).

The intent of this study was to identify the larger scale features occurring on the day during which fog was reported at one or more locations and relate those features to the total (or final) extent of fog coverage, whether synchronous or asynchronous, that was observed across the region. In effect, this provides an assessment of the fog threat across any given forecast zone for any day, time of day, and synoptic setting during the winter season. This avoids providing climatological estimates of fog occurrence at each location and instead allows for the operational determination of the potential coverage of a fog event (i.e. local, regional, or widespread) to be inferred for a forecast region.

Based on the synoptic partitioning the fog events classified revealed 332 of the 721 events were high pressure (H – 46%), 219 low pressure (L – 30%), and 170 frontal (FRNT – 24%). When examined with regard to the distributions within each basic synoptic type, high pressure over the study region was found less likely than high pressure located nearby to produce fog events. This highlights the significance of more than the simple radiative process for fog occurrence under high pressure. Dense fog events were more likely to occur for high pressure to the N-NE indicating possible coastal and terrain influences. Fog events under high pressure outnumbered those days without fog (i.e. the null events) by a 3:1 margin.

A review of the low pressure subtypes indicates the role and significance of advective and precipitation processes in fog occurrence (e.g., E-NE and W-NW) which may tend to minimize regional variations. Low pressure to the S-SE or over the region may imply too dry in the former and too moist in the latter situation. In low pressure cases with dense fog a slight preference is shown for systems to the E-NE of the study region and very few instances for those to the S-SE of the area. Fog events under low pressure outnumbered those days without fog (i.e. the null events) by a 7:1 margin.

In the case of frontal systems, cold fronts were clearly the preferred producer of fog when compared with the other subtypes. Warm fronts were not as prolific but did result in half as many events as cold fronts. In cold front cases showery precipitation and mixing processes, or simply cooling following frontal passage, are likely the key factors. Frontal systems were also much more likely to generate dense fog events. Fog events under low pressure outnumbered those days without fog (i.e. the null events) by a 10:1 margin. However, while such summations provide useful insight to an operational forecaster, they do not reveal the ultimate regional coverage of fog and dense fog events in the region nor do they consider the spatial variations of fog directly.

d. Fog Patterns by Synoptic Types

Fog and dense fog frequencies for each of the basic synoptic types (not shown) were plotted to reveal any preferred zones of fog occurrence. In each case variations from the predominant patterns identified previously (Fig. 3) were minimal. Plots of subtypes did reveal important variations. In cases of high pressure, fog occurrence frequencies tended to focus on the interior and southwestern portions of the study region (not shown) when the system was located from S-SW or OVER or N-NE. The frequencies were reduced for much of the region in cases of high pressure to the W-NW and S-SE.

Examination of low pressure subtypes (not shown) revealed a high frequency of occurrence for systems located to the E-NE and W-NW of the region with focus over higher terrain and interior sections. In cases of low pressure to the S-SW the focus was clearly shifted to the southwestern portion of the study region. For frontal cases, separation was made for cold, warm, and other subtypes (not shown). The most obvious signal appeared for warm frontal events in that a clear north-south gradient was observed and maxima found over higher terrain and at oceanic sites (i.e. ISP).

Further examination of synoptic types and subtypes considered null events in comparison to fog and dense fog events. This was accomplished by the use of analytic field composites generated using the Climate Diagnostics Center website. These findings are provided in the third section of this paper.

e. Event Coverage

To be more valuable, the above examinations require definition as to the extent of fog coverage. This must be inferred with regard to the prevailing synoptic weather pattern and without regard to individual site characteristics. From a practical point of view, an operational forecaster needs to assess whether a fog event will be isolated (or local) in nature, discontinuous (or regional), or occur at most locations (i.e. widespread). For the purposes of this study when less than four of the fourteen sites observed fog on the same day, or less than one-third (29%), the fog event was arbitrarily defined to be isolated or localized and patchy (LCL-FG). When four to ten stations observed fog, one-third to three-fourths (i.e. 29 to 71%), the fog event was defined as discontinuous across the region (REG-FG). For events in which more than ten sites reported fog, more than three-fourths (> 71%), the occurrence was considered widespread (WID-FG). These coverage definitions combined with analyses of synoptic regimes were selected to aid real-time forecast decisions to infer (or predict) fog coverage in the study region.

Therefore, all fog and dense fog events were analyzed with regard to the number of sites reporting fog (or dense fog) for any of the given event days during the study period (as defined above). Results (Table 4) indicated that high pressure fog events, although the most common in the study region (i.e. 46% of all fog events as per Table 3) produce predominantly LCL-FG events. This is not unexpected given that high pressure leads to subsidence and lends itself to radiational cooling at night but is a relatively dry air mass. The occurrence of REG-FG under high pressure is more dependent upon its location being over or to the south of the study region. This suggests a strong radiational component across the study region as well as the potential contribution of low level moisture from a return flow and/or in situ contributions. There were no cases of WID-FG for dense cases occurring with any high pressure regimes in this study's period of record and REG-FG was confined to cases with high pressure over or southwest of the region.

For low pressure systems, the second most commonly occurring synoptic type for fog (30% as per Table 3), the pattern of coverage was reversed from that of high pressure in that WID-FG events were most common, particularly with low pressure over or to the south of the study area. In fact, there were no occurrences of only LCL-FG for these subtype cases – all events led to either REG-FG or WID-FG occurrence. These imply that multiple fog production and/or maintenance processes could be occurring, such as precipitation-induced, advection, upslope, and onshore maritime flow – such that local influences are relatively unimportant during a given 24-hour period. Only in the case of low pressure to the east or northeast of the region was fog equally likely to be LCL-FG, REG-FG, or WID-FG. This could be related to the presence of a pressure trough extending westward behind the low pressure center, the occurrence of precipitation, or simply the peculiarities of the isobaric configuration associated with the system and its proximity to the study area on a case by case basis. When considering dense fog cases, low pressure was nearly twice as likely as high pressure to lead to REG-FG (and more often than frontal systems) and had the highest frequency of dense WID-FG production compared to high pressure and frontal systems.

Frontal systems (the least frequent of synoptic types in Table 3, 24%) were second only to low pressure in producing the most WID-FG with equal chances of LCL-FG or REG-FG across the study region. It is likely that in these cases the structure, flow, and movement of a frontal system limit the potential areal extent of fog given the focus along a boundary – or in a frontal zone – rather than a cyclonic circulation. For dense fog coverage, frontal systems were most likely to produce LCL-FG with only a small percentage resulting in WID-FG. When examined according to the specific subtypes, occluded fronts and stationary fronts were more likely to produce REG-FG or WID-FG and this may be related to the expansive nature of these systems and their associated precipitation during the winter season. However, these subtypes were among the smallest sample sizes in the dataset (as per Table 3). In contrast, warm fronts were dominated by a tendency towards WID-FG. This is not unexpected given the typically stable boundary layer found in advance of the feature during the winter season and which is often reinforced by precipitation falling through a cold boundary layer and cold onshore flow due to cool ocean waters. In the case of dense fog events, stationary and warm fronts were more likely to result in REG-FG with only warm and cold fronts capable of producing WID-FG in rare cases when they became stalled, slowed, or quasi-stationary with time or were associated with excessive precipitation.

f. GIS Integration

The incorporation of GIS mapping and statistical summation provide for a description of the fog occurrence population characteristics, features, and behaviors by season as well as the leading causative factors. These are based upon layer information (e.g., soil, land cover, population, et cetera) that provides 'local feature' parameters to be used in conjunction with atmospheric parameters. As specified in this study (for 14 observing locations) the information may be used to relate fog and dense fog occurrences through a multivariate analysis.

The analysis provides algorithms for individual locations that may then be used throughout a grid (Fig. 4), constructed for the study region, to identify and predict the likelihood of fog occurrence (intensity), and thus to map the anticipated total coverage in the region of interest. The approach is designed to assist forecasters operationally when predicting fog (or dense fog) at alternate locations and in data voids or data sparse regions. This provides a more precise plot of the spatial coverage patterns of fog that may be verified through satellite and other techniques so as to determine the POD, FAR, and CSI. These in turn may be evaluated with regard to MOS-output and/or numerical guidance available operationally.

3. ANALYSIS OF EVENTS

While the preferences identified for fog occurrence, intensity (i.e. dense fog), and extent (LCL, REG, WID-FG) from the preceding analyses were valuable, it was also important to examine the synoptic setting of the types and subtypes in order to understand and interpret the results – particularly if they were to be applied in an operational environment. Therefore two approaches were considered: (i) Diagnostic examination and interpretation of simple but relevant synoptic fields for the study region during fog event days; and (ii) Consideration of days on which fog was not observed (null events) within the study region. In the first instance, simple composites were generated for each synoptic subtype through the Climate Diagnostics Center website (http://cdc.noaa.gov/Composites) software, based on the NCEP Re-Analysis (Kalnay et al. 1996). In the second, a forecaster could improve both detection and specification of fog predictions with an increased ability to consider verification with knowledge of events, dense events, and non-occurrence.

Composite analyses included 500 mb contours, sea level pressure (mb), specific humidity at 1000 mb and 700 mb (kg/kg), and precipitable water (cm). The first two fields were prepared in order to establish the specific synoptic features, including advective and local processes, associated with the upper air and surface flow regime that might aid or inhibit fog occurrence and extent. This is particularly relevant at the surface based on contributions from local physiographic features. The specific humidity at low and mid levels was intended to assess the availability of low level, near-surface moisture, as well as moisture in the lower half of the atmospheric column. Dry air at 700 mb would raise the prospect of an 'open atmospheric window' for radiational cooling. Precipitable water offers an integrated measure of the moisture available in the atmospheric column that was present in association with fog events. Based on these analyses, forecasters could then apply any unique "footprints" or attributes found to be associated with fog (or dense fog) to predict occurrence, intensity, and coverage.

Based on the three winter seasons examined, composite maps were prepared for each synoptic subtype in order to identify and compare common features and find distinctions with regard to parameters that an operational forecaster could use based on observational data and/or numerical model guidance. Given the large number of composites generated, one subtype from each group (i.e. "H", "L", and "FRNT") was selected for presentation here to exemplify the operational technique being developed. The selection of these samples was based upon those with larger sample sizes that also had null and dense events available (in most cases) for comparison. The results for all subtype composites are summarized in Table 5 with approximations of values based on the generated contour field analyses. In each case, the surface and 500 mb features were examined as well as the coincident moisture fields (i.e. specific humidity and precipitable water). It must be understood that the mean fields necessarily contain temporal and spatial variabilities that could not be examined here given the event definition of fog (occurring for at least one site for any given day).

4. CONCLUSIONS

An examination of the occurrence, intensity, and coverage of fog and dense fog was made in the New Jersey-Metropolitan region. The intent was to provide greater operational support for the prediction of fog as well as to identify and develop methods that would allow for assessment of fog likelihood in areas where no reporting site exists. These were based on analysis of the temporal and spatial patterns observed in fog and dense fog frequency and coverage through a GIS framework.

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Figure 1. Study region.

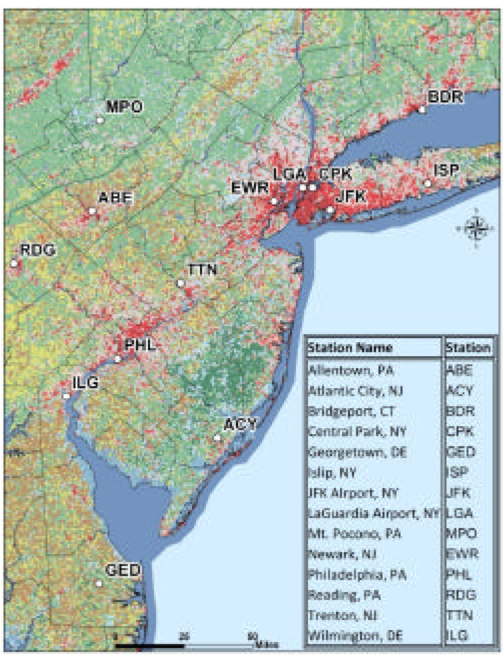

Figure 3. Fog and Dense Fog occurrences all winter seasons.

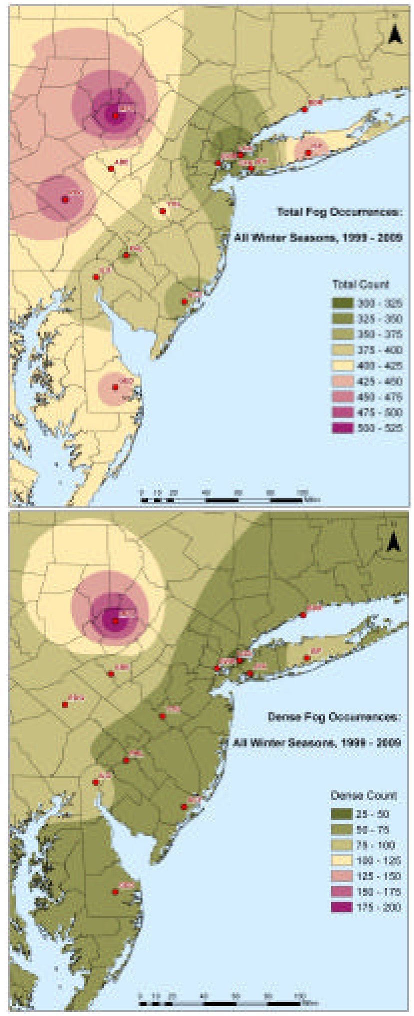

Figure 4. GIS grid development.