FORECASTING SIGNIFICANT FOG IN SOUTHERN ALABAMA

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Abstract

Forecasting the areal extent of dense fog is of great importance to the aviation, ground and marine communities as it can result in delayed operations, damage and injury causing losses of millions of dollars each year. Therefore, fog forecasts for large areas are critical to many users and often result in the issuance of special weather statements after significant fog has formed or is expected to occur.

Despite the use of numerical model output and sophisticated mesoscale models, improved forecasting of fog and its areal extent remain elusive. Attention has instead focused on the development of site specific climatologies, checklists and fog typing forecast schemes. Given the National Weather Service's modernization efforts and mesoscale emphasis, improved forecasts of fog formation and its areal extent are needed.

A methodology is presented to improve these forecasts by considering fog impacts, climatology and physiographic factors in relation to the dynamic-synoptic regime. To illustrate the method and assess its usefulness a case study is presented for 6–8 March 1994 for the central gulf coast. The hindcast dynamic-synoptic analysis indicated that periods of significant fog developed first as a localized radiative event and then developed into a widespread advective-radiative event with upslope and sea fog contributions. Reductions in visibility were often quite varied across the region during the event.

An appreciation of the fog's formation and evolution through application of the method described would have provided more specific predictions of the fog's mesoscale distribution and formation mechanisms. The results of this study would suggest that further efforts concentrate on the development of forecast techniques that would better evaluate the formation and areal extent of dense fog.

1. Introduction

Although dense fog is not thought of as an exciting or dynamic phenomenon, its impact is often costly and can be deadly. Of the over 1500 references to fog that have appeared in the literature during the last 30 years (Leipper 1994), less than 100 appear for fog forecasting. Even fewer detail specific impacts of fog (e.g., Martin and Suckling 1987). It is necessary to fully understand these impacts on the local user community in order to establish users' forecast needs. Forecasting the occurrence of fog, its duration and its extent is not straight forward despite the availability of operational output from numerical weather prediction models. This is because fog occurrence is often a function of local, regional and dynamic-synoptic conditions which cannot be adequately represented in those models. This has led to the development of fog forecasting techniques which include climatologies (including conditional and synoptic climatologies; e.g., Sutton 1994), empirical rules (e.g., Bacinschi and Filip 1976), statistical investigations (e.g., Gimmestad 1993), checklists and graphical aids (e.g., Johnson and Graschel 1992), satellite imagery (e.g., Gurka 1978; and Ellrod et al. 1989), numerical modeling (e.g., Barker 1977; Forkel and Zdunkowski 1986; and Bergot and Guedalia 1994) and operational models (e.g., Burroughs and Alpert 1993).

Fog forms when the temperature and dewpoint of the air become the same or nearly the same (generally within 3 degrees; Huschke 1959). It is ultimately attributable to mechanical and/or thermal cooling of air, and/or its rapid humidification through evaporation either from the underlying surface or rainfall (George 1960). Therefore, it is clear that knowledge of the physiography of a region or location is important in forecasting the occurrence, duration and areal extent of fog. However, the large number of fog studies implies large variations in the process of fog formation and its local frequency despite the fact that radiative and advective processes are common to all. More than ten types of fog identified by George (1960) are merely derivatives or hybrids of radiative and advective fogs and many are region-specific. These types are named according to their dynamic-synoptic process of development (e.g., advection-radiation fog) and/or local characteristics (e.g., sea fog) and have been used in many studies. Johnson and Graschel (1992) have identified four types of sea fog in the northwestern Gulf of Mexico related to the return flow phenomenon (i.e., the onshore advection of modified continental polar air). Yet all fog types may ultimately be characterized as one of the following: radiative, advective or combinatorial (after George 1960).

However, determining the type of fog for a specific reference site is much less important than forecasting its development, significance and extent according to sound dynamic-synoptic reasoning and local topographic variations. It is clear that a single station climatology of fog, although useful in the development of a forecast checklist, is limiting, as are all site specific climatologies. Local climatologies do not adequately reflect fog extent and can be biased with regard to the causative factors involved (e.g., advective-radiative versus sea fog). Synoptic climatologies lack the appropriate information to describe the mesoscale variations of fog. Instead, the approach advocated

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here is to combine a site specific climatology with knowledge of local physiography and impacts to help forecast the areal extent and distribution of fog, particularly when it does not occur at the climatology site. This approach is crucial for the proper and timely issuance of special weather statements within various forecast zones.

To illustrate how these ideas may be applied, fog impacts are first considered to determine the level at which fog restricts normal operations and activities. This assessment provides just cause to forecast the areal extent and distribution of fog. Then, observations from the Mobile Regional Airport (MOB) are used to determine the site-specific climatology of fog. In turn, these are related to both the dynamic-synoptic setting and local physiography.

2. Fog Impacts

Climatology for the period 1949–1990 (NCDC/NOC 1992) indicates that the Mobile site (located at Bates field since 1947) experiences fog an average of 150 days each year. The greatest frequency of fog occurs during the cool season (Fig. 1). Although useful in summarizing the location's propensity for fog, the values do not provide information essential to operational forecasting. The frequencies listed do not consider duration, extent or visibility restrictions, or the fact that fog may not be carried in an observation unless visibility is reduced to six miles or less (DOC/NOAA 1988). More importantly, the frequencies do not consider fog impacts. A more specific climatology which includes an assessment of impacts on aviation, ground and marine operations and activities, is necessary in order to establish thresholds at which fog becomes a significant hazard.

a. Aviation

Almazan (1992) reported that 41 percent of aircraft delays in 1990 were weather related, with 17 percent being avoidable (e.g., based on more accurate forecast information, unnecessary flight scheduling and routing changes could have saved time and fuel). These resulted in losses of approximately 1.7 billion dollars. These losses occur when critical thresholds of clouds and/or visibilities (including heavy fog) and various weather conditions are encountered or predicted to occur. For most aviation interests IFR and LIFR are the most significant conditions to consider because they lead to delays and cancellations (LIFR is ceilings less than 500 feet and/or visibilities less than 1 statute mile; DOC/NOAA 1994). At the Mobile Regional Airport, Delta Airlines (the airport's largest carrier) indicated that two flights were diverted or canceled in 1993 due to adverse weather conditions (Delta Airlines 1994). This resulted in estimated losses of up to twenty-five thousand dollars. As the occurrence of heavy fog is critical to runway operations (1/4 mile or less halts most air traffic according to Flight Service Station personnel), temporary closure of an airport may also cause significant losses to local carriers (e.g., overnight package services), impose limitations on helicopter use in medical emergencies, and delay transports to offshore oil platforms (Johnson and Graschel 1992).

b. Ground

Fog often plays a role in traffic accidents when visibility is reduced below a "safe driving distance" and when conditions vary considerably over very short distances. Chain reaction collisions, such as the October 1973 event in New Jersey involving 65 vehicles (Houghton 1985), can occur under these conditions. Fog can also result in costly delays to trucking and delivery companies which must operate in many adverse

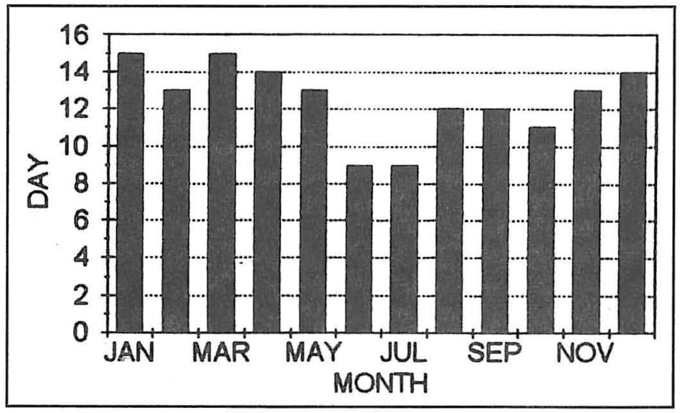

Fig. 1. Mean number of days of fog by month for MOB (Mobile, Alabama) based on the period 1949–1990.

weather conditions. There are no specific criteria for visibility in fog which define safe versus unsafe driving conditions. This would be difficult to define given the varying abilities of vehicles and drivers. Further, safe driving and stopping distances are difficult to assess based on variations in road and travel conditions. For example, when roads are wet, safe stopping distances may be three to twelve times greater than under dry conditions (Alabama Department of Public Safety 1993). Therefore at speeds of 30 and 60 miles per hour the stopping distance may be as much as one-fifth to three-fifths of a mile. This does not include the possibility of skidding nor does it consider whether another vehicle is ahead of the driver. Therefore, visibilities under one-half mile make automotive travel hazardous at low and high speeds.

In 1992, the state of Alabama reported fog as the primary factor in 0.8% of all traffic accidents. Of 1,590 crashes involving 2,952 vehicles, 402 injuries and 11 fatalities on Interstate 10, three percent cited fog as the primary cause. Although this percentage is extremely low, it belies the direct and indirect dollar impact of fog to the public, private and commercial sectors. To determine a portion of the economic significance of fog (Garmon et al. 1995), cost estimates recommended by the National Safety Council (National Safety Council *Estimating the Cost of Accidents* 1992) were combined with the crash statistics (provided by the Alabama Department of Transportation). Interstate 10 crashes in Alabama resulting from dense fog resulted in losses estimated to be in excess of one million dollars and were the focus of a study commissioned by the state's Department of Transportation (Parsons and Brinkenhoff and KBN Engineering 1994).

c. Marine

Marine operations, whether cargo shipping or recreational, may be severely hampered by fog and often have a large impact on the local and national economy (Kotsch 1983). When shipping operations are halted less cargo is moved and less income is made. When fog persists for several days losses of up to twenty-five thousand dollars a day per ship become burdensome. Based on an average of four ships using the Port daily, losses would be $100,000 a day. In addition, daily operating costs and delays to other ports increase losses. The Port of Mobile handles over 1500 port calls and 35 million tons of imports and exports each year (statistics provided by the Alabama State Docks 1994). When fog lowers the visibility to one-quarter mile the Port of Mobile is closed (Port of Mobile Harbor Master's Office 1994). However, accidental collisions and groundings of ships resulting in injury or loss of life have occurred with visibilities above this criteria. The sinking of the Andrea Doria south of Long Island, New York in July 1956 following its collision with another vessel in dense fog is an example (Houghton 1985).

3. Significant Fog Climatology

For heavy fog an operational forecaster would issue a special weather statement for a non-precipitating hazard according to National Weather Service procedures (DOC/NOAA 1992). For issuance of a special weather statement visibilities of 1/4 mile or less are necessary but need not be widespread in their occurrence. However, considering each of the impacts examined above, it is apparent that visibility of less than 1/2 mile may be a more appropriate threshold for general statements about fog (see Garmon et al. 1995). This is because ground transportation sets the threshold criteria for impacts of fog-reduced visibility. This first impact distance criteria is equivalent to the international definition of fog (visibility less than one kilometer; i.e., less than 3/5 mile; Huschke 1959) and has been used in other studies (e.g., "dense fog" as defined by Leipper 1994).

Data for significant fog (which we define as fog-reduced visibility of less than one kilometer) were tabulated and plotted for Mobile (MOB) for a 10 year period (1981–1990). Significant fog occurrence by time of day (Fig. 2) within each season (i.e., the standard meteorological seasons; e.g., the winter season being the months of December, January, and February) and for each month (not shown) were examined. The results indicated that the radiative component of fog formation is likely the predominant factor as most significant fog was observed during the predawn hours regardless of season. However, given the obvious preference for fog during the cool season (i.e., 95% of all significant fog events occur from September through May), advective factors are likely to be important as well.

In order to provide forecasters with insight to the formation of significant fog at Mobile Airport, the distributions of temperature, dew point, wind direction and wind speed measured at MOB were plotted for the fall (Sep–Nov), winter (Dec–Feb) and spring (Mar–May) seasons (Figs. 3a, b and c). It should be noted that the apparent peak of significant fog observations at wind speeds of three knots in Fig. 3 is likely an artifact of observation criteria (i.e., the observer must "choose" between reporting calm winds or 3 knots). Boundary layer wind observations are also useful in fog prediction as they provide informa-

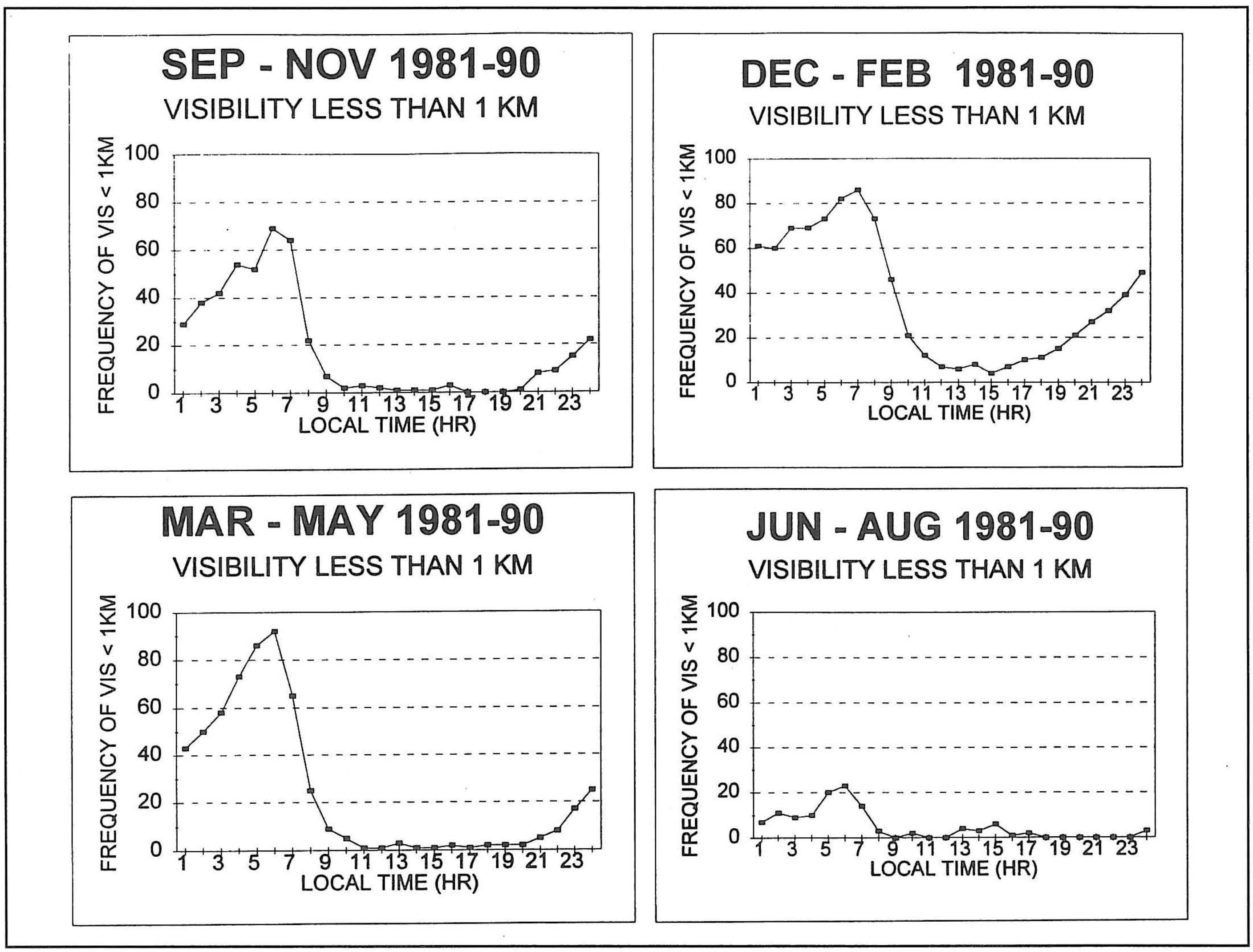

Fig. 2. Frequency (i.e., total number of occurrences) of significant fog (defined as visibility less than one kilometer) by season and hour of day at the MOB Regional Airport for the period 1981–1990.

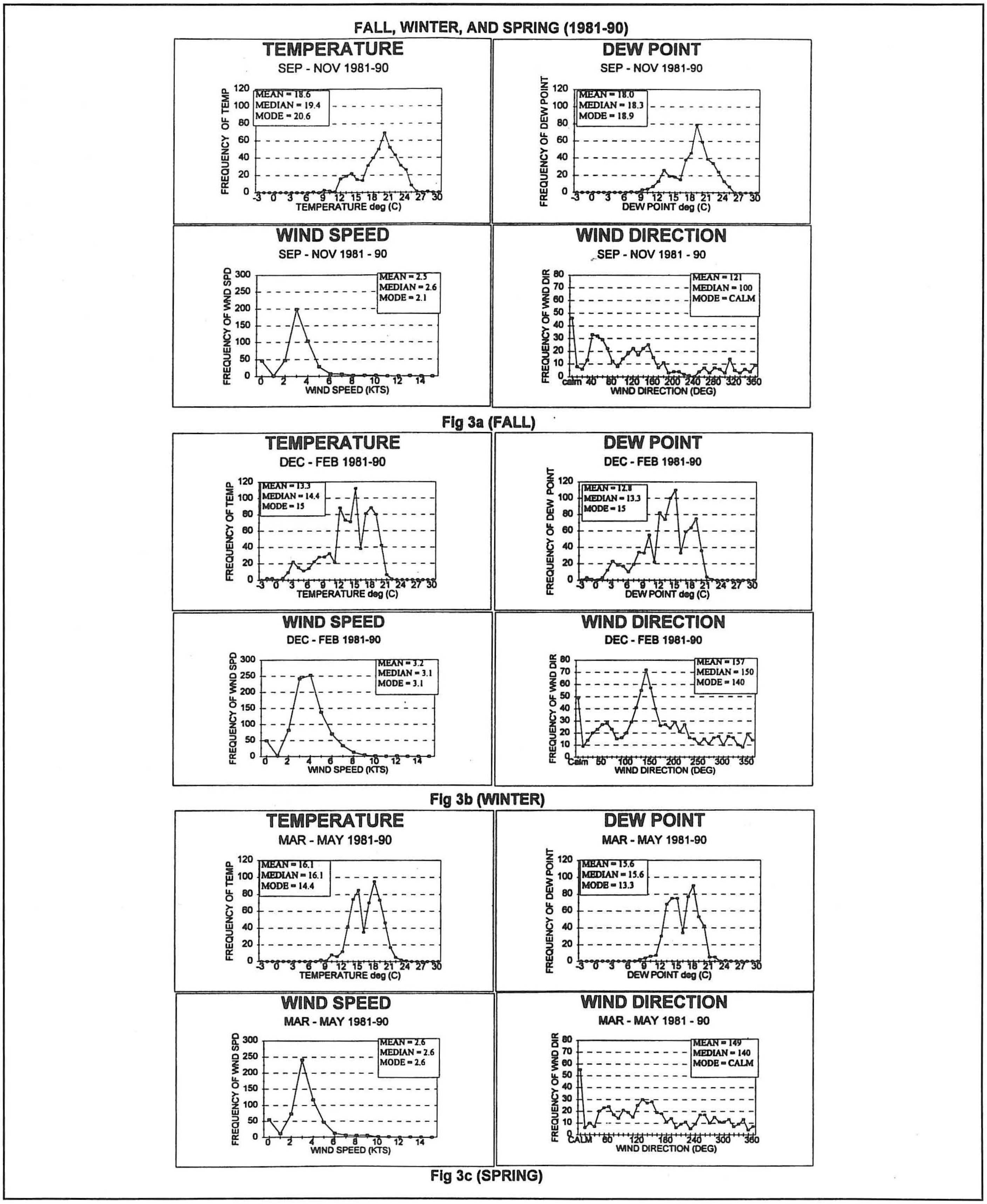

Fig. 3. Frequency (i.e., total number of occurrences) distributions of wind direction (degrees), windspeed (knots), temperature (°C) and dew point (°C) observed simultaneously with significant fog by hour of day for the: (a) fall (Sep–Nov), (b) winter (Dec–Feb) and (c) spring (Mar–May) seasons at the MOB Regional Airport for the period 1981–1990. Note: the apparent peak of significant fog observations with wind speeds of three knots is likely an artifact of observational criteria as described in the text.

tion on low-level mixing and advection. However, as the emphasis of the present study was to determine the local conditions associated with fog, and given the lack of real-time data, boundary layer winds were not examined.

The summer season was excluded from further study given the low frequency of significant fog during that time of year (Fig. 2). The plots provide operational forecasters information that may be used in the development of a significant fog forecasting checklist for Mobile (see Garmon et al. 1995) that is consistent with Funke (1951). Such a checklist can be used with numerical model output and knowledge of local physiography to make forecasts of the areal extent of significant fog.

4. Physiography and Dynamic Considerations

Both numerical and descriptive weather prediction model output are routinely available to operational forecasters (e.g., c/v MOS forecasts). However, neither these nor local climatological studies adequately portray the regional variations that are crucial in local forecasting. Thus physiographic features must be considered in association with the dynamic-synoptic situation when forecasting the areal extent and distribution of significant fog. Such features help to provide insight to the root causes of fog development, its spread and its duration. They also provide information on the local variation of fog that numerical models are unable to simulate (e.g., Bergot and Guedalia 1994), are not designed for (Burroughs and Alpert 1993) or are only beginning to account for (e.g., Golding 1993).

The focus of the present study was to define those conditions associated with significant fog occurrence in an attempt to identify mesoscale characteristics. By examining these conditions and relating them to dynamic and physiographic factors, the mesoscale occurrence and distribution of significant fog may be inferred. This is important when forecasting fog, particularly when fog is not expected to occur at the forecast office (i.e., the reference climatological forecast site).

For example, the Mobile National Weather Service Office (Fig. 4) is located to the northwest of Mobile Bay and 12 miles due west of the junction of the Mobile River and Mobile Bay. The site is approximately 10 miles west of the downtown area of Mobile, 30 miles north of the Gulf of Mexico and has an elevation of 221 feet (66 meters) above mean sea level (Funke 1951; and DOC 1954). The terrain slopes gradually upward to the north, downward to the south and sharply downward to the east and southeast of the site. This allows for the dynamic uplift of air (and upslope flow) when the winds are east through southwest. Downslope flow occurs for winds from the west through northeast. There is considerable variation in topography (i.e., hilly) and the presence of many water bodies and low-lying areas that dictate local weather conditions under both calm and low advective flow regimes (i.e., weak boundary layer and synoptic scale motion). The waters of Mobile Bay and the northern Gulf of Mexico provide significant humidification and moderation throughout the year. During the spring season the waters of Mobile Bay are fed by cold discharge waters from the Mobile River.

5. Operational Application

a. Significant fog forecasting methodology

Based on the foregoing discussion, a significant fog forecasting methodology is suggested and detailed below. The method first requires knowledge and understanding of the nature of the local impact of fog. These allow for the establishment of a threshold visibility below which the local economy is adversely affected by fog. Once determined, those conditions observed to be associated with significant fog at a reference site are collected. These are examined to identify the frequency and types of fog experienced at the reference site. These provide a forecaster with a climatological viewpoint of fog occurrence. This viewpoint can be easily related to the synoptic setting by the forecaster and provides insight to the fog formation process.

An assessment of the dynamic-synoptic environment of the forecast area with regard to local physiography is then made. This requires fundamental knowledge of the slope and aspect of topographic features, the shapes of valleys and ridges and coastlines, and the distribution of land and water in the forecast area. This step is crucial in identifying the likely mesoscale variations of significant fog occurrence and distribution for a variety of atmospheric conditions. A forecaster may then correctly ascertain the type of fog development that is expected and its distribution within the forecast area. The forecaster may also readily identify how the type of fog, as well as its distribution, may change with time within the forecast area. To illustrate the significant fog forecasting methodology, a case study of significant fog occurrence is examined based on the previously established impact and visibility criteria.

b. Case study: 6–8 March 1994

The significant fog event of 6–8 March 1994 was examined in hindcast to assess and predict the areal extent and distribution of significant fog. The results are presented here in the context of an operational forecaster assessing the local conditions. Based on ten years of data (1981–1990) fog is observed in Mobile in March an average of 15 days (Fig. 1). It is significant (i.e., visibility less than one kilometer) 30% of the time in the spring season and 52% of all significant events during the spring occur in March (based on data from 1981–90, not shown). Significant fog occurs most frequently in the spring season between 2100 and 1000 local time (Fig. 2) and between 2000 and 1100 in March (based on data from 1981–90, not shown). This implies a strong radiative component. Significant fog conditions at Mobile during the spring season are associated with winds of less than 7 knots with an easterly through southerly component (Fig. 3c) and temperatures and dew points ranging from 9 to 22°C (48 to 72°F). In conjunction with local physiography this indicates to a forecaster that upslope flow (Fig. 4) and the advective process will be important factors throughout the forecast region. This provides a forecaster with clues as to where fog may be more dense or more persistent and indicates that significant fog may occur under a wide variety of synoptic situations.

Prior to initial fog development, surface synoptic charts (not shown) indicated a weak surface pressure gradient along the Gulf Coast with higher pressure over the central Gulf of Mexico and the Ohio Valley on 5 March 1994. Surface winds were from the west-southwest and upper air charts indicated a west-northwesterly flow of up to 75 knots with weak troughing over the area. By the morning of 6 March, the surface pressure gradient had weakened further and winds had become calm after acquiring a slight easterly component. Weak ridging and a westerly flow of 40 knots were observed at 500 mb. Although an initial examination might have suggested that a return flow event from the Gulf of Mexico was occurring, it was clear from observations (not shown) that fog formation was radiative and regional in nature. Although forecasts issued prior to the event were not available for review, it was determined that special weather statements and dense fog advisories were issued by local NWS offices between 0130 and 0425 local time on 6 March 1994 as visibilities fell below two miles.

By the morning of 7 March, higher pressure over the Atlantic Ocean had built westward along the Gulf Coast and provided a sufficient pressure gradient for the mixing of drier air for dissolution of fog over much of the area. Only very localized areas of fog were observed (e.g., along the "Bayway" portion of I-10, Fig. 4) and were generally not significant. Wind flow at 500 mb was northwesterly at 20 knots. Surface winds became easterly, then southeasterly, and thus provided a weak upslope flow of warmer and moister air from Mobile Bay and coastal sections over a cold ground surface. This in combination with a continuous warming and humidification of the air mass across the Central Gulf Coast during 7 March indicated that a return flow event was developing. However, whether the subsequent fog formation was sea fog, upslope fog or advective-radiative in nature is debatable.

By the morning of 8 March, widespread significant fog was observed with surface winds having an easterly and southeasterly component. Winds at 500 mb were westerly at 30 knots and became southwesterly during the day. Although a combination of radiative and advective effects (including upslope and sea fog) were responsible, the strong onshore flow which developed led to the large areal extent and determined the distribution of significant fog. However, the low wind speeds reported at the land sites at the time of significant fog occurrence (as compared to buoy observations) indicate several causative factors with varying contributions depending on location. Special weather statements were issued between 0000 and 0430 local time on 8 March by local NWS offices. As the surface pressure gradient became stronger during the morning, in response to a low pressure system developing to the west of the Mobile area, the significant fog quickly dissipated.

6. Conclusions

The forecasting method presented is intended to provide forecasters with an operational conceptual model for use in predicting the occurrence and distribution of fog. The method requires an understanding of local impacts, the establishment of a visibility threshold and the determination of those conditions associated with fog occurrence at a reference site. These are then used in conjunction with knowledge of the dynamic-synoptic setting, local physiography and changes in atmospheric conditions in time and space. As an illustration, the hindcast case study presented indicated that periods of significant fog developed in the Mobile area first as a localized radiative event and then developed into a widespread advective-radiative event with upslope and sea fog contributions.

An appreciation of the fog's formation and evolution through application of the method described could have provided for a more detailed diagnostic assessment of where and when fog would occur. It thus would have also provided greater specificity, allowed for a less geocentric forecast (i.e., one centered at the forecast site) and limited the econocentric nature of the forecast (e.g., focusing only on aviation transportation). The hindcast presented indicates that a focus on the forecast of fog types can be a limitation which may blind a forecaster to the extent and nature of significant fog occurrences within the forecast region of responsibility. This is particularly true when several fog types may occur simultaneously as a function of the mesoscale variations found within a forecast region. Therefore, it is suggested that fog typing be used as a starting point to identify the types of formation processes expected to occur. Then, based on the local physiography and the anticipated dynamic-synoptic situation, a forecaster may predict the areal extent, distribution and duration of fog.

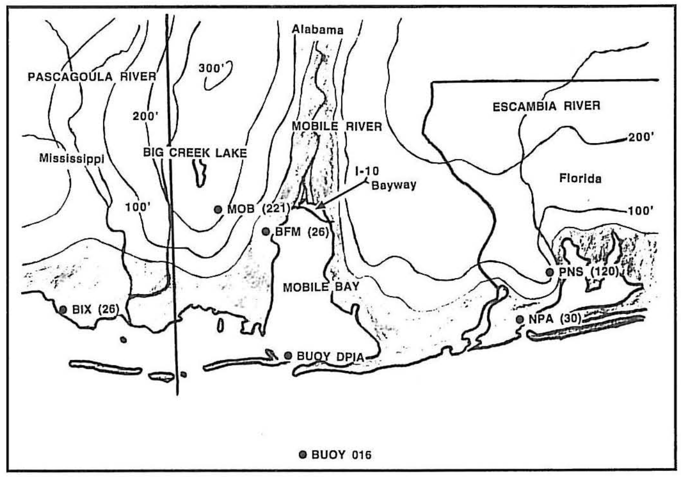

Fig. 4. Smoothed topography (intervals of 100 feet) for the central gulf coast (MS, AL, and northwest FL). Shading indicates elevations less than 50 feet. Location and elevation (feet MSL) of sites and physiographic features are given where BFM = Brookley Field, AL; BIX = Biloxi, MS; Buoy DPIA = Dauphin Island; MOB = Mobile Regional Airport, AL; NPA = Navy Pensacola, FL; and PNS = Pensacola, FL. State borders and the "Bayway" portion of Interstate 10 (I-10) are also shown.

Although the method accomplished its desired goal it would be more desirable to summarize this information for more rapid assimilation by the forecaster by developing forecast techniques to evaluate fog extent and duration more directly (e.g., the approach by Sutton 1994). Mesoscale modeling and the use of satellite imagery may help to address these but may be limited in their success for a variety of reasons. It is therefore suggested that an alternative approach be used in which several reference climatology forecast sites are used to evaluate the extent and location of significant fog. This would provide for improved assessment and forecasting of the variations of fog by requiring forecasters to develop conceptual mesoscale models for operational use. Such an approach would facilitate the development of forecast checklists for any forecast region and provide specificity on the mesoscale across and within all forecast zones.

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References

Almazan, J. A., 1992. *National Aviation Weather Program Plan.* Department of Commerce/NOAA, FCM - P27 - 1992.

Alabama Department of Public Safety, 1993. *Alabama Driver's Manual*, 56 pp.

Alabama State Docks, 1994. Personal communication, Terry Curow. Port of Mobile Traffic Office.

Bacinschi, D., and L. M., Filip, 1976. Forecasting nomogram for meteorological visibility. *Meteorology and Hydrology*, Bucharest, 1: 33–38.

Barker, E. H., 1977. Maritime boundary-layer model for the prediction of fog. *Boundary Layer Meteorology*, Holland, 11(3): 267–294.

Bergot, T., and D. Guedalia, 1994. Numerical forecasting of radiation fog. Part I: Numerical model and sensitivity tests. *Monthly Weather Review*, 122(6): 1218–1230.

Burroughs, L. D., and J. C. Alpert, 1993. Numerical fog and visibility guidance in coastal regions. *NOAA Technical Procedures Bulletin*, No. 398, 8 pp.

Delta Airlines, 1994. Personal communication, M. Heying, Chief Technical Meteorologist, February.

DOC/NOAA, 1988. *Federal Meteorological Handbook No. 1, Surface Observations*, April 1988.

DOC/NOAA, 1992. *National Weather Service Operations Manual*, Chapter C-44, September 1992.

DOC/NOAA, 1994. *National Weather Service Operations Manual*, Chapter D-21, July 1994.

Ellrod, G., E. Maturi, and J. Steger, 1989. Detection of fog at night using dual channel GOES-VAS imagery. *Preprints 12th Conference on Weather Analysis and Forecasting*, Amer. Meteor. Soc., pp. 515–520.

Forkel, R., and W. Zdunkowski, 1986. Two-dimensional numerical model for fog forecasting. *Annelen der Meteorologie*, Offenbach, 23: 46–47.

Funke, P. W., 1951. *Forecasting advection fog at Mobile, Alabama.* Eastern Air Lines, Inc., Meteorology Department, Atlanta, Georgia, December 1951, 32 pp.

Garmon, J. F., D. L. Darbe, and P. J. Croft, 1995. A checklist for forecasting widespread significant fog along the central gulf coast. In preparation for submittal as a Technical Memorandum.

George, J. J., 1960. *Weather forecasting for aeronautics.* Academic Press Inc. New York, New York, 673 pp.

Gimmestad, C., 1993. A statistical forecasting method for fog at Olympia, Washington. *NOAA/NWS Western Region Technical Attachment*, No. 93-15, 6 pp.

Golding, B. W., 1993. A study of the influence of terrain on fog development. *Monthly Weather Review*, 121: 2529–2541.

Gurka, J. J., 1978. Use of enhanced VIS imagery for fog detection and prediction. *NOAA/National Environmental Satellite Services, Satellite Applications Information Note* 78/4, 6 pp.

Houghton, D. D., (ed), 1985. *Handbook of Meteorology.* John Wiley and Sons, New York, New York, 1461 pp.

Huschke, R. E., (ed), 1959. *Glossary of Meteorology.* American Meteorological Society, 638 pp.

Johnson, G. A., and J. Graschel, 1992. Sea fog and stratus: A major aviation and marine hazard in the northern Gulf of Mexico. *Preprints Symposium on Weather Forecasting*, Atlanta, Georgia January 5–10, 1992, Amer. Meteor. Soc., pp 55–60.

Kotsch, W. J., 1983. *Weather for the mariner.* Naval Institute Press, Annapolis, Maryland, 315 pp.

Leipper, D. F., 1994. Fog on the U.S. west coast: A review. *Bulletin of the American Meteorological Society*, 75(2): 229–240.

Martin, M. D., and P. W. Suckling, 1987. Winter fog and air transportation in Sacramento, California. *Climatological Bulletin*, Ontario, Canada, 21(3): 16–22.

National Safety Council, 1992. *Estimating the cost of accidents, 1992.*

NCDC/NOC, 1992. *International Station Meteorological Climate Summary.* CD-ROM ver 2.0, USAFETAC OLA, June 1992.

Parsons and Brinkenhoff and KBN Engineering, 1994. *Report to the Alabama Department of Transportation.*

Port of Mobile Harbor Master's Office, 1994. Personal communication, Captain Dave Kerry, January.

Sutton, M., 1994. An analysis of meteorological conditions during dense fog events at Shreveport, Louisiana 1983–1992 Part 1: Overview. Unpublished manuscript prepared at the National Weather Service Office in Shreveport, Louisiana, 21 pp.

DOC, 1954. *Terminal Forecasting Reference Manual.* Bates Field Mobile, Alabama. U.S. Department of Commerce, Weather Bureau, February 1954, 8 pp.