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DENSE FOG CLIMATOLOGY FOR THE BLUE RIDGE FOOTHILLS AND PIEDMONT AREAS OF THE BLACKSBURG, VA COUNTY WARNING AREA FOR THE PERIOD 1973 -2008

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ABSTRACT

WFO Blacksburg issues Terminal Aerodrome Forecasts (TAFs) for five airports. Dense fog with visibilities of a half mile or less producing VLIFR conditions is a frequent forecast problem at individual airports. In addition, dense fog occasionally becomes widespread enough to necessitate a Dense Fog Advisory. Historical dense fog data is available for each of the five airports. The locations of three of the airports, Roanoke, Lynchburg, and Danville, represent a climatological region with similar geographical characteristics on the east side of the Appalachian Mountains. Thirty six years of fog data (1973 through 2008) from these airports were studied to produce a climatology of dense fog events. Although a quarter of a mile or less visibility is the threshold for a dense fog advisory, we found that we needed to use visibilities of a half mile or less in order to get a large enough sample for the study. A dense fog event was then defined as one in which 2 of the 3 airports recorded dense fog of a half mile or less for at least 2 hours during the same period. A period of two hours or longer would have a major impact on aviation and ground travel, and with the similar topography and relative close proximity of the three airports, the dense fog was then probably extensive enough to warrant a dense fog advisory. 176 separate events were identified in the 36 year period.

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1. INTRODUCTION

The purpose of this study is to develop a climatology of dense fog for the foothills and piedmont region of Blacksburg's County Warning Area (CWA), and use it to help recognize synoptic patterns that are conducive to the formation of dense fog. The foothill and piedmont region was separated from the remainder of the CWA because the topography of the CWA is characterized by two separate regions. There is mainly mountainous terrain over the northwestern half of the CWA along and west of the Blue Ridge mountain range, with some elevated valleys. The mean annual number of days with dense fog in the Blacksburg CWA is highest west of the Blue Ridge Mountains, at greater than 50 days, but an axis of greater than 40 days extends into the foothills and piedmont of southwest Virginia and northwest North Carolina (Peace Jr. 1968). The southeastern CWA is comprised of the foothills and piedmont, east of the Blue Ridge Mountains. There is a gradual increase in elevation from southeast to northwest from the piedmont to the Blue Ridge foothills, and then a rapid increase in elevation further northwest into the mountains. Elevations start at around 500 feet in the Piedmont, rise to around 1000 feet in the foothills, and then increase rapidly to mountainous terrain of 2500 to 5000 feet in the Blue Ridge and Appalachian Mountains of southwestern Virginia (VA), southeastern West Virginia (WV), and northwestern North Carolina (NC). In addition, the availability of historical fog data across the CWA was limited to first order airports as defined by the National Climatic Data Center. There are three airports that were judged to be in close enough proximity and elevation to be representative of the area; Roanoke, Lynchburg and Danville (Fig. 1).

The total economic losses associated with the impact of the presence of fog on aviation, marine and land transportation can be comparable to that of other severe weather like tornadoes, winter storms and hurricanes. (NOAA Economics 2008) This local dense fog climatological study will provide forecasters an improved understanding of the frequency and type of dense fog events in the piedmonts of southwest Virginia and northwest North Carolina. (Croft et al. 1997) This is expected to help forecasters in two areas. The first is for Terminal Aerodrome Forecasts (TAFs) at Roanoke, Lynchburg and Danville. Dense fog would bring either Low Instrument Flight Rules (LIFR) of visibilities less than a mile, or Very Low Instrument Flight Rules (VLIFR) of visibilities less than a half mile (NWSI 10-813 November 19, 2007). The second area this study is expected to help forecasters with is the issuance of dense fog advisories for widespread fog with visibilities of a quarter of a mile or less (NWSI 10-515 NOVEMBER 1, 2005).

2. DATA

Data were gathered for all dense fog events for the airports of Roanoke, Lynchburg and Danville during the period of January 1973 through December 2008. The climate database in the TAF monitor program, Aviation Forecast Preparation System (AvnFPS), was used to find the periods of dense fog at each site. For the purposes of this study, one half mile visibility or less was used to define dense fog. There were two reasons for this. First, a half mile or less corresponds closely to VLIFR conditions. Second, although a quarter of a mile or less visibility is the threshold for a dense fog advisory, we found that we needed to use visibilities of a half mile or less in order to get a large enough sample for the study. A dense fog event was then defined as one in which 2 of the 3 sites recorded dense fog of a 1/2 mile or less for at least 2 hours during the same period. A period of two hours or longer would have a major impact on aviation and ground travel, and with the similar topography and relative close proximity of the three airports, the dense fog was then probably extensive enough to warrant a dense fog advisory. 176 separate events were identified in the 36 year period.

There was a wide range in the annual distribution of dense fog events. In four of the 36 years of the study there were no dense fog events at all, and nearly half (17) of the years had three events or less. In comparison, eight of the years had 10 or more dense fog events, with a maximum of 18 events identified in 1982. Dense fog events were found in every month. The distribution by month is characterized by a minimum in the spring and summer months (just 25 events in the April through August period), then a sharp increase in the number of events to a peak in November, with high numbers through the winter months (December, January, February) when there is a minimum of solar radiation. (Slemmer 2004; Fig. 2a).

3. METHODOLOGY

There are three types of fog that were identified from the dense fog events. The fog types were determined using the characteristics comparison table from the COMET® Distance Learning Aviation Course (DLAC) on fog, (Bol 2001), and reviewing the surface and upper air data, including soundings at Greensboro and Blacksburg (available at Blacksburg only after 1995).

Synoptic and upper air patterns, along with the presence and timing of any precipitation, were utilized to help classify the categories of dense fog events. Details of the start and end times of the fog events and whether there was precipitation with the fog can be found in the Appendix.

The types of fog identified in this study are radiation (or ground) fog, advection fog, and frontal/precipitation fog. Further, for radiation fog, three distinct synoptic patterns were determined based on review of surface data and upper air patterns, and the timing of synoptic frontal features with any associated precipitation. Dense radiation fog events that developed within 24 hours of a warm frontal passage were categorized as Post Warm Front, and events that developed within 12 hours of a cold frontal passage were categorized as Post Cold Front. Dense radiation fog events under synoptic high pressure (and no frontal passage within 24 hours) were labeled as No Front events.

Therefore, for the purpose of this study, we have five categories of dense fog events. The categories are: Advection Fog (23 events), Frontal/Precipitation Fog (41 events), Radiation Fog/No Front (39 events), Radiation Fog/Post Cold Front (34 events), and Radiation Fog/Post Warm Front (39 events) (Fig. 2b). The distribution of fog type by month shows that Advection, Frontal/Precipitation, and Radiation/Post Warm Front fog all occurred only in the cooler months, (September through April), while Radiation/Post Cold Front and Radiation/No Front occurred in the warm season, (May through August), as well as the cooler months (Fig. 2c).

In an effort to show the synoptic pattern of each category, composite maps of various meteorological fields were generated using the Earth System Research Laboratory (ESRL) 6-Hourly Composites web page which uses the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data. This was accomplished by assigning an actual start, middle and ending time of the dense fog in each of the cases in a category to the nearest 6-hour synoptic time, (00, 06, 12, 18 UTC). The maps generated then represented a composite for a particular field around the start, middle and end times of the dense fog for each category.

4. CATEGORIES

4.1. ADVECTION FOG (23 events)

Advection fog develops when warm, moist air moves over a colder underlying surface. The surface could be cold ground, snow cover, water or ice. The fog forms primarily by boundary layer dynamic and adiabatic processes including advection of moisture and temperature. It often occurs with light or moderate low-level winds (up through 850 mb) that are less than 10 ms^{-1}, but can also occur with winds stronger than 10 ms^{-1}. Rapid development can occur as the preconditioned air mass moves over a cooler surface.

Low-level factors to look for with advection fog include: air parcel trajectories originating over a moisture source sufficient to establish a moist boundary layer condition, the depth of the surface-based moist layer increases as a result of mechanical turbulence and convective mixing of buoyant moist air, and cold air damming with large-scale anticyclonic winds and subsidence providing a capping inversion so the boundary layer can saturate.

In identifying the 23 advection fog events, Greensboro NC (GSO) soundings were utilized to determine the low level temperature and dewpoint profiles, and the presence of cold air damming. The low-level winds in the soundings helped identify warm advection. Historical daily weather maps provided by the NOAA Central Library Data Imaging Project were utilized to determine the presence and location of any high or low pressure centers, and synoptic scale fronts. The surface observations at all three of the sites were used to determine if there was precipitation during the event. Many of the advection fog cases had drizzle reported during the event. Five of the advection fog events had light rain reported at one or more of the sites, but the daily weather maps indicated there was no warm front near the region.

Advection fog can last several days and may be advected over large areas and across great distances. The average length of the 23 advection fog events was 13.6 hours, the longest of all the fog categories. It tends to be deeper than radiation fog since it is often driven by synoptic scale factors, and it can form and advect into a region almost any time of day, although it has some tendency to develop in the evening hours as the boundary layer cools.

a) Synoptic Overview

Composite maps of mean sea level pressure were generated for the start, middle and end of the advection fog events (Fig. 3a). A start time was determined for each event by assigning the nearest 6 hour synoptic time (00, 06, 12, 18 UTC), in which one or more of the airports first reported dense fog. The ending time for each event was determined by assigning the nearest 6 hour synoptic time to the last observation of dense fog at any of the three airports. The middle point of each event was then assigned to the nearest 6 hour synoptic time to the average between the start and end times. The surface map at the start shows a high pressure centered off the mid-Atlantic coast, with low pressure over the western Great Lakes, a warm front across the Ohio Valley and into the southern Appalachians, and a cold front in the Mississippi Valley. By the middle of the advection fog events, the center of the high pressure was further east into the Atlantic, while the low pressure center and trailing cold front were moving slowly eastward. The warm front was north of the study area. By the end of the advection fog events, the high pressure was well east of the region and the cold front had progressed into the Tennessee Valley.

Composite maps of 925 mb relative humidity, 850 mb relative humidity, and surface winds for the day of the event (Figs. 3b, 3c and 3d) indicate shallow

low-level moisture over the study area, with near saturation to 850 mb, and very little change in the low-level moisture profile through the event. There were east to southeast surface winds of less than 4 ms^{-1} into the study area, with trajectories off the Atlantic. Winds above the boundary layer at 850 mb (not shown) were 8 to 12 ms^{-1} from the southwest, indicating warm advection. The upper pattern in the advection fog cases (not shown) had a progressive, full latitude Midwest trough, and a southeast U.S. upper ridge.

Representative GSO soundings for advection fog from November 30, 1977 (Fig. 4) show uniform southwest flow (warm advection) above a shallow saturated layer through the event. In this case, dense fog developed at Roanoke and Lynchburg around 30/00 UTC, developed at Danville at 29/14 UTC, and lasted until 29/18 UTC for all sites. The only precipitation reported was light drizzle.

There were 23 events identified as advection fog. This represents just 13% of the total, making advection fog the rarest form of widespread dense fog. Indeed, over half (19) of the years in the study period had no cases of dense advection fog. Advection fog occurred only in the cooler months (September through March), with a peak from November through January.

4.2. FRONTAL/PRECIPITATION FOG (41 events)

Frontal/precipitation fog is formed by precipitation falling into a cold stable layer and raising the dewpoint. The fog is formed primarily by diabatic processes - evaporational cooling/condensation. The evaporation/condensation process extends the cloud to the surface. The fog may develop during the precipitation, or after the precipitation ends. It is most common with cold air damming in the vicinity of warm or stationary fronts.

In identifying the 41 frontal/precipitation fog events, the surface observations at all three of the sites were used to identify the events with prolonged rainfall. All of the events identified as frontal/precipitation had rain or drizzle reported at each site that had dense fog. Historical daily weather maps were utilized to determine the presence and location of any high or low pressure centers, and synoptic scale fronts. In all of the frontal/precipitation events, a warm front was in the vicinity of the study area during the event. Greensboro NC (GSO) soundings were utilized to look for a deep saturated layer with a veering wind profile indicating warm advection and overrunning. The main factors in differentiating between frontal/precipitation fog and advection fog were whether or not there was precipitation, and how long it lasted, along with the presence of a warm front.

Frontal/precipitation fog may develop over large areas and across great distances, and can last a day or two. The average length of the 41 Frontal/Precipitation Fog events was 10.1 hours, the second longest of all the fog categories. The depth of the fog is normally greater than any other type. It can form any time of the day or night.

a) Synoptic Overview

Composite maps of mean sea level pressure were generated for the start, middle and end of the frontal/precipitation fog events (Fig. 5a). The surface map at the start shows a warm front extending eastward from a low pressure in the Ohio Valley, and across the area of study. A trailing cold front extends southward through the Tennessee Valley. By the middle of the frontal/precipitation fog events, the warm front had moved north of the area of study into northern Virginia, while the cold front had progressed eastward but remained west of the Appalachians. All of the area of study is in the warm sector. At the end of the frontal/precipitation fog events, the cold front had moved into the mountains just west of the study area.

Composite maps of 925 mb relative humidity, 850 mb relative humidity, and surface winds for the day of the event (Figs. 5b, 5c and 5d) indicate near saturation to 850 mb over the study area, with very little change through the event. Surface winds are light, generally less than 3 ms^{-1}, while 850 mb winds (not shown) are from the west-southwest at 11 to 14 ms^{-1}. The upper level pattern associated with frontal/precipitation fog (not shown) features a progressive, full latitude Midwest trough, with a strong Great Lakes short wave, and a weak southeast U.S. upper ridge.

Representative GSO soundings for frontal/precipitation fog from December 2, 1991 (Fig. 6) show a strong, slightly veering, south to southwest flow (warm advection) and a deep nearly saturated layer from the surface to 750 mb at the beginning of the event (02/00 UTC). By the middle of the event (02/12 UTC), the saturated layer extends from the surface to 600 mb. In this case, rain began before 01/12 UTC at Roanoke and Lynchburg, and the ceilings and visibility lowered to 0.5 mile or less and 100 feet after 02/00 UTC, then rose some during the day (after 02/12 UTC), before dropping back again after 03/00 UTC with more rain.

Frontal/precipitation events with widespread dense fog were more common than advection fog in the area of study. Forty one of the 176 events (22%) were from frontal/precipitation fog. Even though it was more common than advection fog, there were still 13 years in the study period with no frontal/precipitation fog events identified. The monthly distribution of frontal/precipitation fog was similar to advection fog, only occurring in the cooler months, (September through April), with a peak from November through February.

4.3. RADIATION FOG (112 events)

Radiative cooling is the most common process by which dense fog is formed over the study area. Radiation fog is produced over a land area when radiational cooling reduces the air temperature to its dewpoint. There were three types of radiation fog that affected the study area, based upon their distinct synoptic pattern.

One of the types, Radiation Fog/No Front, (RF/No), occurred under the influence of high pressure, with no frontal passage and no rainfall within 24 hours of the event. A ridge of high pressure was located over the southeastern U.S., and low level winds were light and from the southeast to south.

A second type, Radiation Fog/Post Cold Front, (RF/Cold), occurred within 12 hours after a weak cold front or surface trough passage. In these events, dense fog occurred with surface high pressure building into the region from the west with low level winds veering from the south before the event, to the southwest or west near the beginning of the event. GSO soundings indicated a moist layer below 700 mb rapidly dried out and radiative cooling left a very shallow saturated layer at the surface.

A third type, Radiation Fog/Post Warm Front, (RF/Warm), occurred within 24 hours after a warm frontal passage. Most of the RF/Warm events had rainfall reported *before* the dense fog developed, but no rainfall reported *during* the dense fog. GSO soundings were utilized to determine the progression and depth of the saturated layer, and all of the events identified as RF/Warm indicated a nearly saturated layer up to 700 – 500 mb, drying in the mid-levels before dense fog developed. Although the rainfall moistened and pre-conditioned the lower levels of the atmosphere, radiative cooling was determined to be the process by which dense fog developed.

All three types of radiation fog occur in the presence of a weak low-level anti cyclone with moist surface conditions under a capping inversion, and moderate vertical shear near the capping inversion. There is rapid nocturnal radiational cooling of the lower boundary layer.

Radiation fog tends to be short duration, less than 24 hours. The average length of the 112 radiation fog events was 8 hours. RF/No and RF/Warm both averaged around 8.5 hours, while RF/Cold had the shortest average length of all dense fog categories at 7.2 hours. Radiation fog tends to be confined to a shallow layer that mainly forms late at night or early in the morning. Surface winds are generally 5 ms^{-1} or less.

When considering all three types, this general category is by far the most common producer of widespread dense fog in the study area. There were 112 radiation fog events, representing 64% of the total. The three types of radiation fog and a description of their synoptic patterns follows.

4.4 RADIATION FOG/NO FRONT (39 events)

a) Synoptic Overview

Composite maps of mean sea level pressure were generated for the start, middle, and end of the RF/No events (Fig. 7a). The surface map at the start the RF/No events shows a large high pressure centered off the New England coast, and strong ridging into the southeastern U.S. A cold front extends from the western Great Lakes, southwestward into Texas. A warm front extends eastward into Pennsylvania from the low pressure. By the middle of the event, surface high pressure remains ridged strongly into the southeast U.S., while the surface low pressure and associated cold front has progressed slowly eastward. The RF/No events end as the low pressure and cold front move into the Ohio and Tennessee Valleys, and the surface high pressure over the southeast U.S. weakens.

Composite maps of 925 mb relative humidity, 850 mb relative humidity, and surface winds for the day of the event (Figs 7b, 7c, and 7d) indicate very shallow low level moisture, with greater than 80 percent saturation at 925 mb and greater than 70 percent saturation at 850 mb through the event. The 850 and 925 mb levels became increasingly saturated west of the Appalachians during the event. Surface winds are less than 4 ms^{-1} from the southwest, and 850 mb winds (not shown) are 8 to 12 ms^{-1} from the west-southwest. The upper pattern in RF/No events features a weakening Midwest trough, with a short wave lifting through the Great Lakes region.

Representative soundings from December 29, 1974 for RF/No (Fig. 8) show a shallow saturated layer near the beginning of the event at 29/00UTC, that transitions to a saturated layer from the surface to 850 mb by 29/12 UTC. There were light northeast surface winds near the beginning of the event at 29/00 UTC. Surface winds by 29/12 UTC were light despite a strengthening west flow above the boundary layer. In this case, dense fog began around 29/02 UTC, ended at 29/1930 UTC. Dense fog was reported at all three sites. There was no precipitation during the period.

Thirty nine of the 176 dense fog events were identified as RF/No. RF/No occurred in every month, except for February, with the peak months (27 events) extending from August through December. Similar to all radiation fog types, nearly half (17) of the years in the study had no widespread dense fog events identified as RF/No.

4.5 RADIATION FOG/POST COLD FRONT (34 events)

a) Synoptic Overview

Composite maps of mean sea level pressure were generated for the start, middle and end of the radiation fog/post cold front events (Fig. 9a). The surface map at the start of the RF/Cold events shows a weak low pressure over the Maryland/Delaware region, with a trailing cold front off of the mid-Atlantic coast. Weak high pressure is over the Gulf Coast region. In the middle of the event, the low pressure and cold front move further off shore, while the high pressure builds northward into the Tennessee valley. The RF/Cold events end when the high pressure is centered over the southern Appalachians.

Composite maps of 925 mb relative humidity, 850 mb relative humidity, and surface winds for the day of the event (Figs 9b, 9c, and 9d) indicate near saturated low levels at the start of the event, (greater than 90 percent at 925 mb and 80 percent at 850 mb), gradually drying out from the top down through the middle and into the end of the event with the relative humidity dropping to 60 percent at 850 mb near the end of the event. There is a light southwest surface wind of less than 3 ms^{-1}, and west-southwest 850 mb winds (not shown) of 7 to 8 ms^{-1}. The upper level pattern associated with RF/Cold events (not shown) features a weak short wave passing across the region in southwest flow aloft.

Representative soundings for RF/Cold from November 7, 1989 (Fig. 10) show a moist layer below 850 mb near the beginning of the event (07/00

UTC). There was drying above 950 mb, a shallow saturated layer under a steep inversion near the surface, and lighter surface winds near the peak of the event (07/12 UTC). The main change in airmass behind the front was drier air. In this case, dense fog began shortly after 07/00 UTC at Roanoke and Lynchburg, and after 07/03 UTC at Danville. The dense fog ended around 07/14 UTC at Roanoke, and 07/16 UTC at Lynchburg and Danville. Precipitation preceded the frontal passage at Lynchburg and Danville, but not Roanoke.

Thirty four of the 176 dense fog events were identified as radiation/post cold frontal passage. Radiation fog/post cold frontal passage fog occurred in every month, with minimums in the spring and summer months, (March through August), and a peak in the winter months (December through February). Similar to all radiation fog types, nearly half (16) of the years in the study had no widespread dense fog events identified as RF/Cold type fog.

4.6 RADIATION FOG/POST WARM FRONT (39 events)

a) Synoptic Overview

Composite maps of mean sea level pressure were generated for the start, middle and end of the RF/Warm events (Fig. 11a). At the start of the RF/Warm events, a warm front extends across northern Virginia just north of the area of study, and extends westward to a low pressure over Wisconsin. A cold front extends southward through the Mississippi valley. By the middle of the event, the low pressure has progressed eastward into northwest Michigan, with the trailing cold front into western sections of the Ohio and Tennessee Valleys. The warm front moved further north of the area of study. The RF/Warm events end when the cold front moves into the mountains of southwest Virginia.

Composite maps of 925 mb relative humidity, 850 mb relative humidity, and surface winds for the day of the event (Figs 11b, 11c and 11d) indicate near-saturated low levels at the start of the event, (greater than 80 percent at 925and 850 mb, gradually drying out from the top down through the middle and into the end of the event, with the relative humidity dropping to 65 percent at 850 mb near the end of the event. There are light south surface winds less than 4 ms^{-1}, and west-southwest 850 mb winds (not shown) of 7 to 8 ms^{-1}. The upper level pattern associated with RF/Warm events (not shown) features a full latitude Midwest trough, with southwest flow aloft over the mid-Atlantic region.

Representative soundings for RF/Warm from December 2, 1982 (Fig. 12) show drying levels above 900 mb near the beginning of the event, (02/00 UTC), and light winds with a steep saturated surface inversion at the peak of the event (02/12 UTC). There was rain at Roanoke and Lynchburg before the dense fog developed at all three sites in this event. Dense fog began as early as 02/00 UTC at Roanoke, and ended as late as 02/1730 UTC at Lynchburg.

Thirty nine of the 176 dense fog events were identified as the RF/Warm fog type. The monthly distribution of RF/Warm was similar to advection fog and frontal/precipitation fog: only occurring in the cooler months, with a peak from October through December.

Similar to all radiation fog types, nearly half (16) of the years in the study had no widespread dense fog events identified as RF/Warm type fog.

5. DISCUSSION

Although there were 176 dense fog events identified in a 36 year period, there was a wide variability in the annual occurrence, with no widespread dense fog events at all in four of the 36 years, (1985, 1987, 1988, 1992). In the four null years, three of them had moderate drought conditions on the annual Palmer Drought Severity Index, (PDSI) and one was neutral (NCDC 2008). Since soil moisture can change rapidly from month to month, a look at the monthly historical PDSI showed a range from one to three months in each of the null years with moderate to severe drought (NCDC 2010). More importantly, there were no months during the null years with moist conditions. In comparison, of the eight years with ten or more events, six (1973, 1974, 1975, 1978 and 1979) had several months with moist conditions and no drought. One, (1982 with 18 events), had no drought but only one moist month, and one (2006) had 4 months with moderate drought, but also 4 moist months (NCDC 2010). Further study of soil moisture and other environmental variables, such as percent of normal precipitation, may provide more indicators for widespread dense fog development. There were an average of about five events per year, and a median of four events, indicating that widespread dense fog events in the foothills and piedmont of southwest Virginia and northwest North Carolina are relatively rare. Widespread dense fog is also mostly a cool season phenomena. There were only twenty three (13%) widespread dense fog events identified in the spring and summer, (April through August time frame). All but one of the dense fog events from April through August were radiation fog. Nearly two thirds of all dense fog events, (115 of 176 or 65%), occurred during November through February, and over half of the events, (92 of 176 or 52%), occurred in the three month November through January period.

All-category composite maps (Figs 13, 14, 15, 16, 17, 18, 19) combined all categories at the middle of the events. These all-category composites showed that a key feature to look for in the surface synoptic pattern is a surface high pressure centered along or off the east coast (Fig. 13). This is the case in all but the RF/Cold type. However, the location of any warm frontal boundaries becomes less distinct in the all category composite. In a majority of the dense fog cases, (frontal/precipitation and RF/Warm combined), a surface warm front will be in close proximity to the study area. The composite maps from all categories also show a warm advection pattern, with veering winds from the surface to 850 mb (Figs. 14 and 15). This veering wind pattern, from southeast to south at the surface, to southwest at 850 mb, can be found in all of the individual category composites except for RF/Cold. Even though with the RF/Cold type there is weak cold advection, the relatively small number of this type means that signal is averaged out in the composites. Other key features to note at the surface from the all-category composites are that surface winds are light, 4 ms^{-1} or less (Fig. 14), but not necessarily calm. All-category composite surface winds are from a southerly direction. 850 mb winds are from the southwest, with the core of the strongest winds in either the Tennessee or Ohio Valleys, extending across the central Appalachians (Fig. 15). Wind speeds at 850 mb over the study area are around 10 ms^{-1}.

The synoptic pattern in the upper levels is similar in all of the dense fog categories, with a central U.S. trough and weak southeast U.S. ridge at 500 mb (Fig. 16). Otherwise, there are only subtle differences between the categories.

As for low level moisture, the composite of all categories at the middle of the event shows relative humidity of 90 percent at 925 mb across the study area (Fig. 17). The 850 mb relative humidity is greater than 70 percent (Fig. 18). The frontal/precipitation and advection fog categories both contribute greater than 80 percent relative humidity at 850 mb, while the radiation fog types are less than 70 percent. The all-category composite 700 mb relative humidity indicates drier air aloft, with only 40 to 45 percent relative humidity over the study area (Fig. 19). This drier air applies to all categories except for the frontal/precipitation fog (not shown).

In conclusion, sensitivity to the time of year and composites of the patterns that produce the different categories of dense fog events in the Blue Ridge foothills and piedmont areas of Blacksburg, Virginia CWA will result in a better anticipation of dense fog development.

ACKNOWLEDGEMENTS

The authors would like to thank Steve Keighton (Science and Operations Officer at WFO Blacksburg), Dave Radell (Eastern Region Scientific Services Division), and two anonymous reviewers in the Eastern Region, for their insight and review of the document. Also special thanks to Paul Jendrowski (Information Technology Officer at WFO Blacksburg) for help in developing the topographical map.

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DISCLAIMER

FIGURES

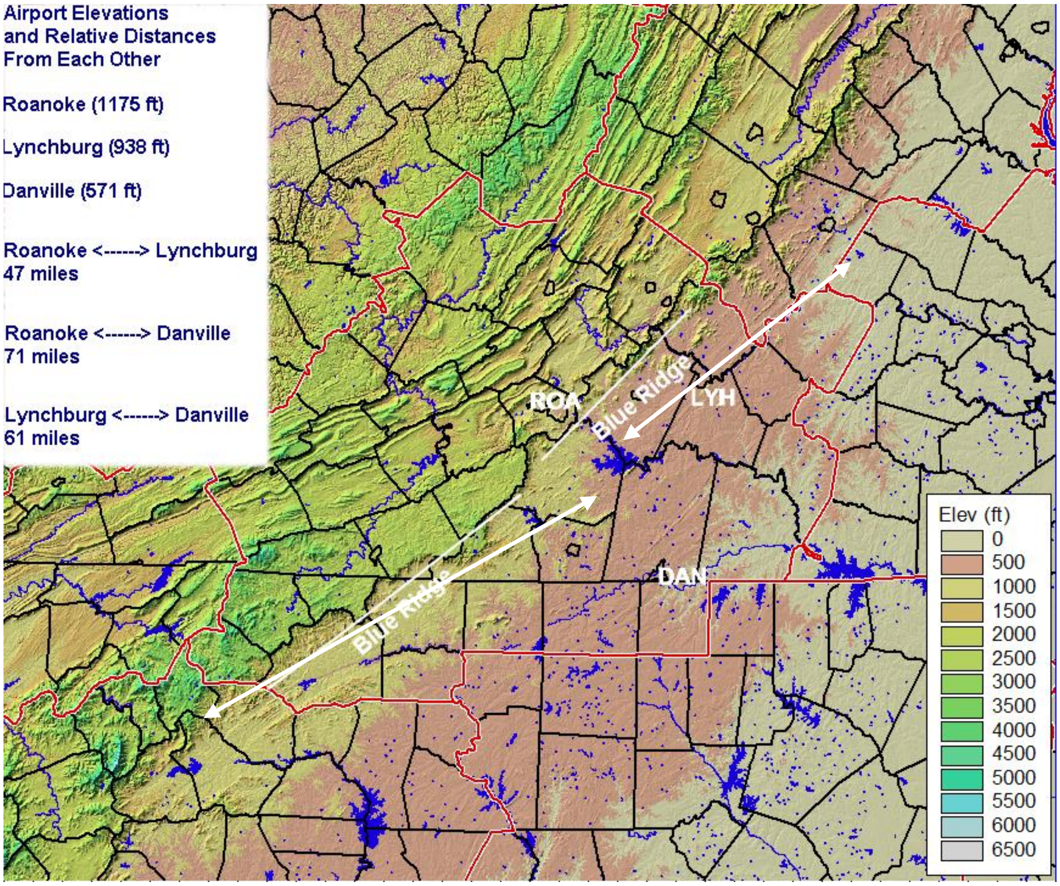

Figure 1. TAF sites KROA, KLYH and KDAN. White lines indicate the Blue Ridge Mountains.

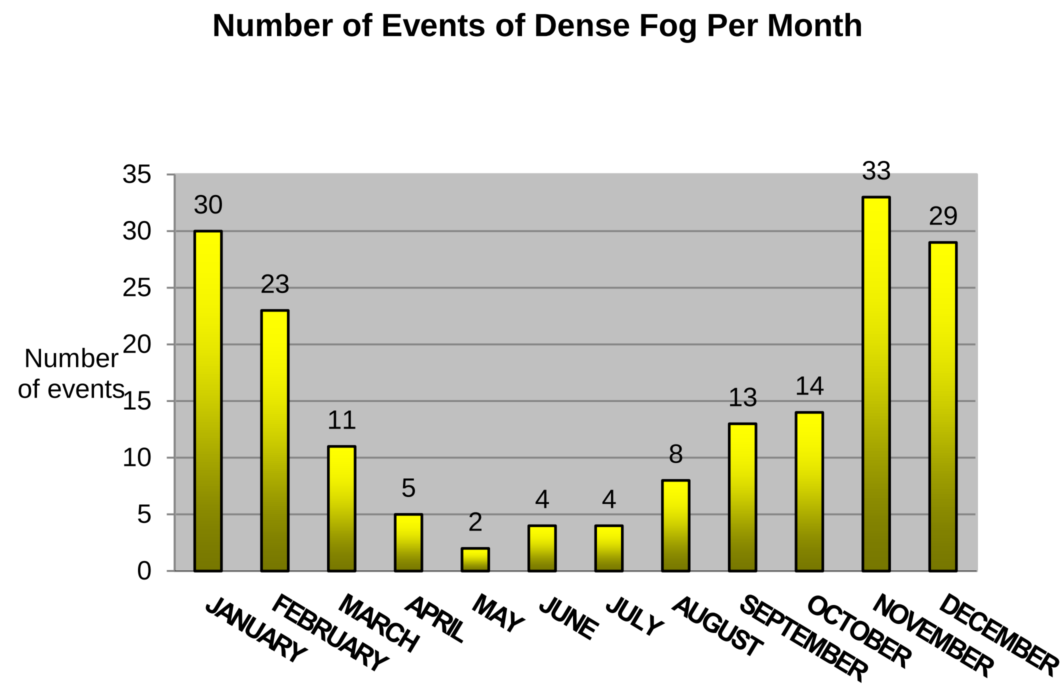

Figure 2a. Number of dense fog events per month over the study period.

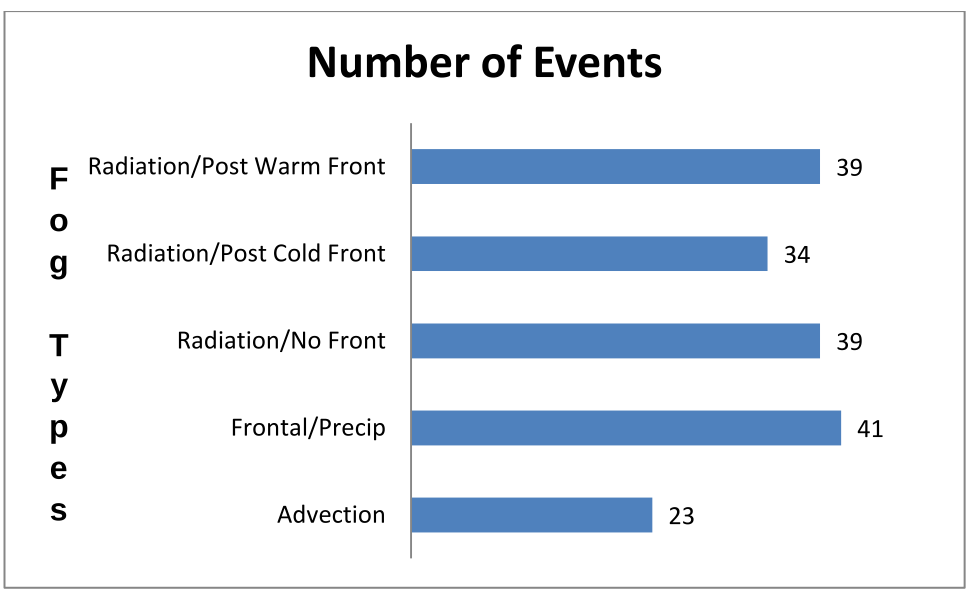

Figure 2b. Number of dense fog events by category for the period of study.

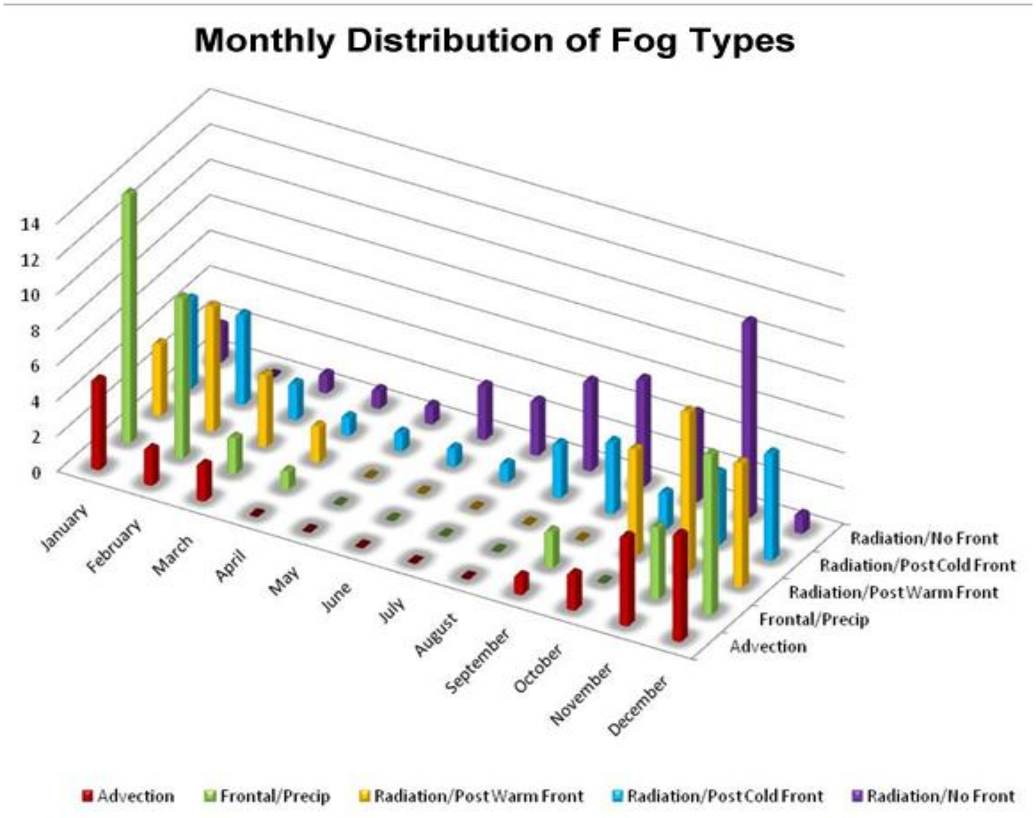

Figure 2c. Monthly distribution of fog type for the period of study.

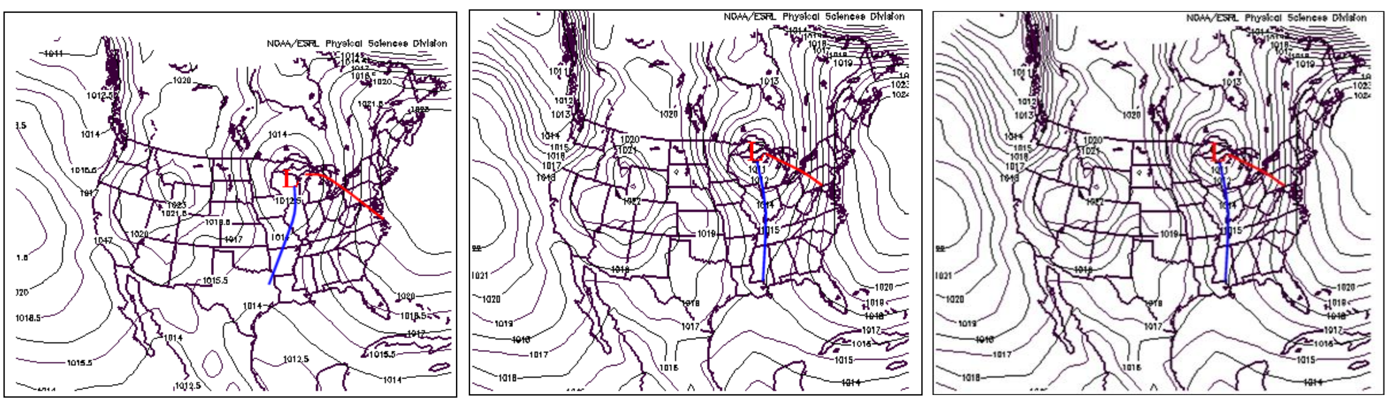

Figure 3a. Composite surface map of mean sea level pressure (mb) and overview of advection fog cases. From left to right: Start, middle, and end of event.

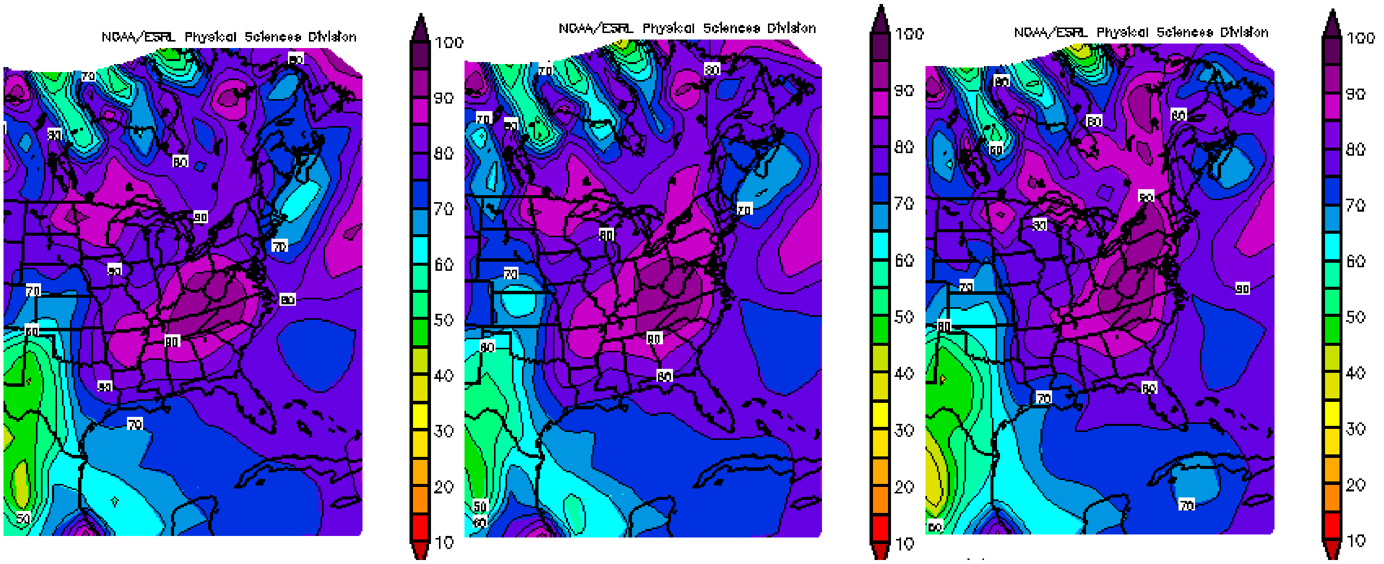

Figure 3b. Composite 925 mb relative humidity (%) overview of advection fog. From left to right: Start, middle and end of the event.

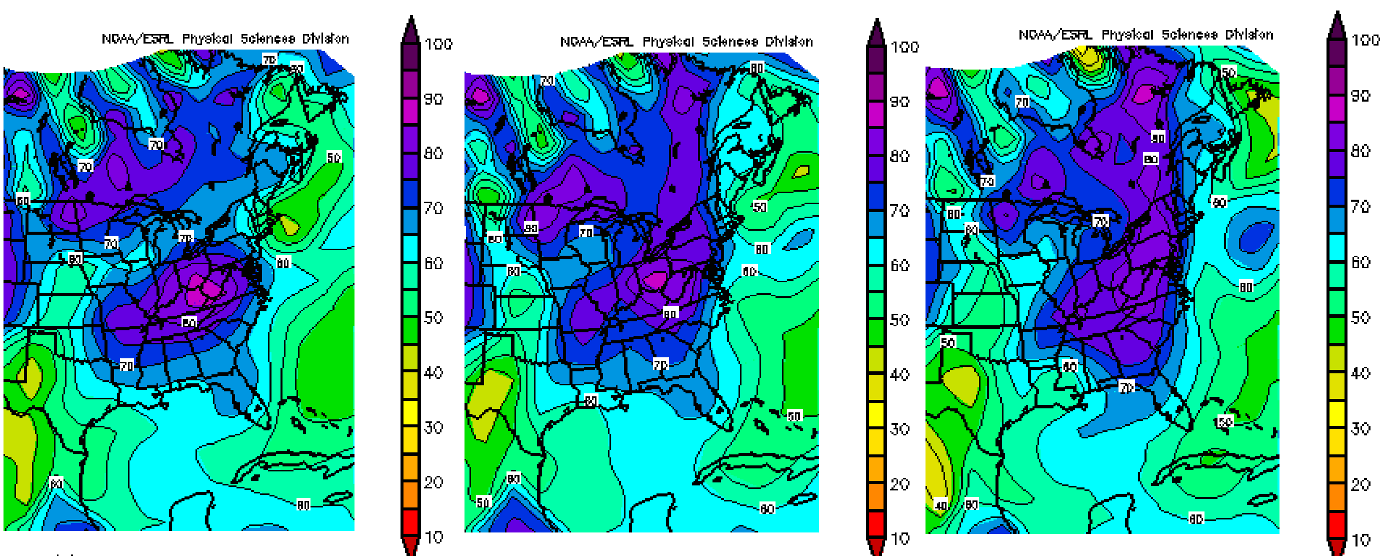

Figure 3c. Composite 850 mb relative humidity (%) of advection fog. From left to right: Start, middle and end of the event.

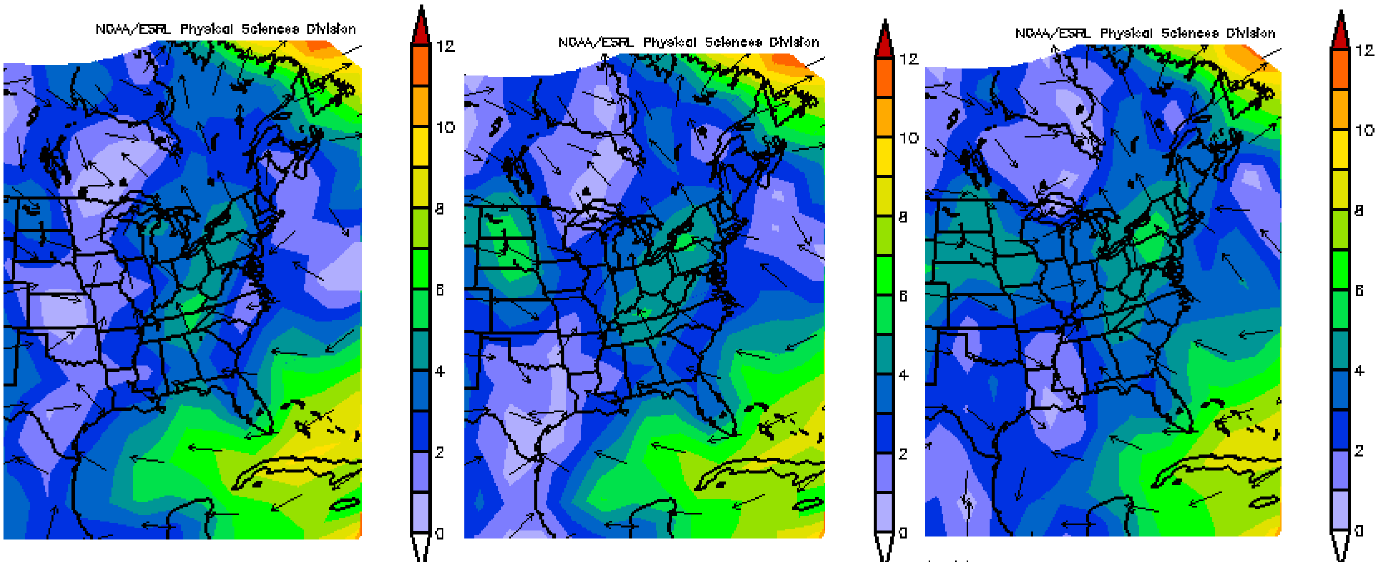

Figure 3d. Composite surface winds (ms^{-1}) of advection fog. From left to right: Start, middle and end of the event.

(a) GSO Sounding 00UTC 30 Nov 77 (b) GSO Sounding 12UTC 30 Nov 77

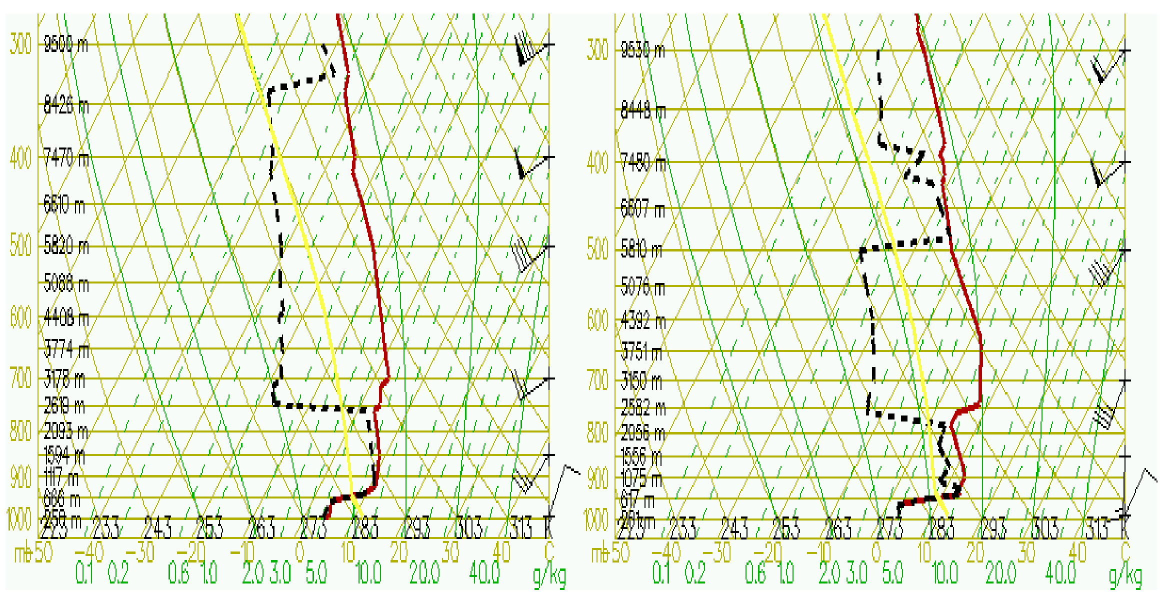

Figure 4. Advection Fog representative soundings at the (a) beginning and (b) during the peak, of the event. Images courtesy of Plymouth State Weather: (http://vortex.plymouth.edu/)

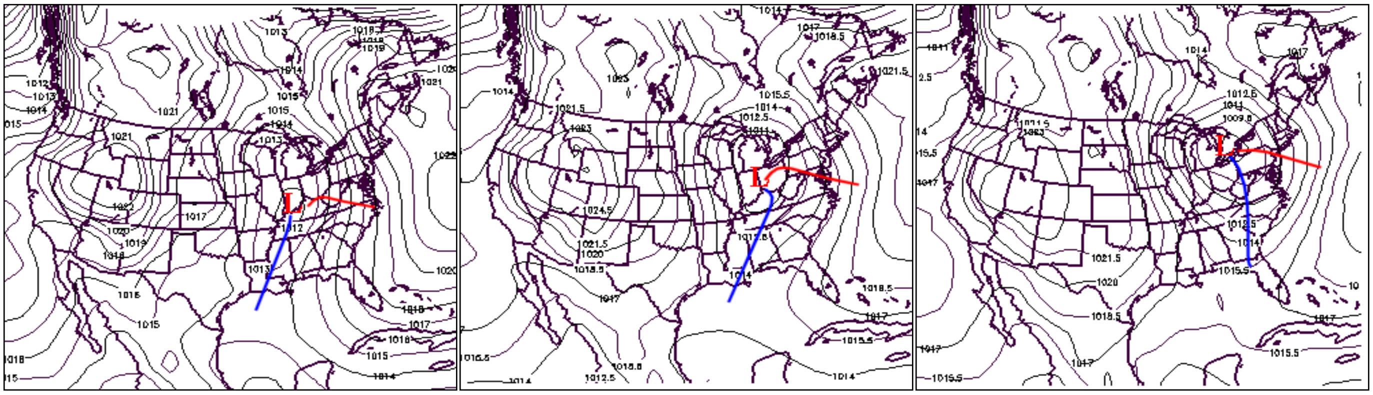

Figure 5a. Composite surface map of mean sea level pressure (mb) and overview of frontal/precipitation fog cases. From left to right: Start, middle, and end of event.

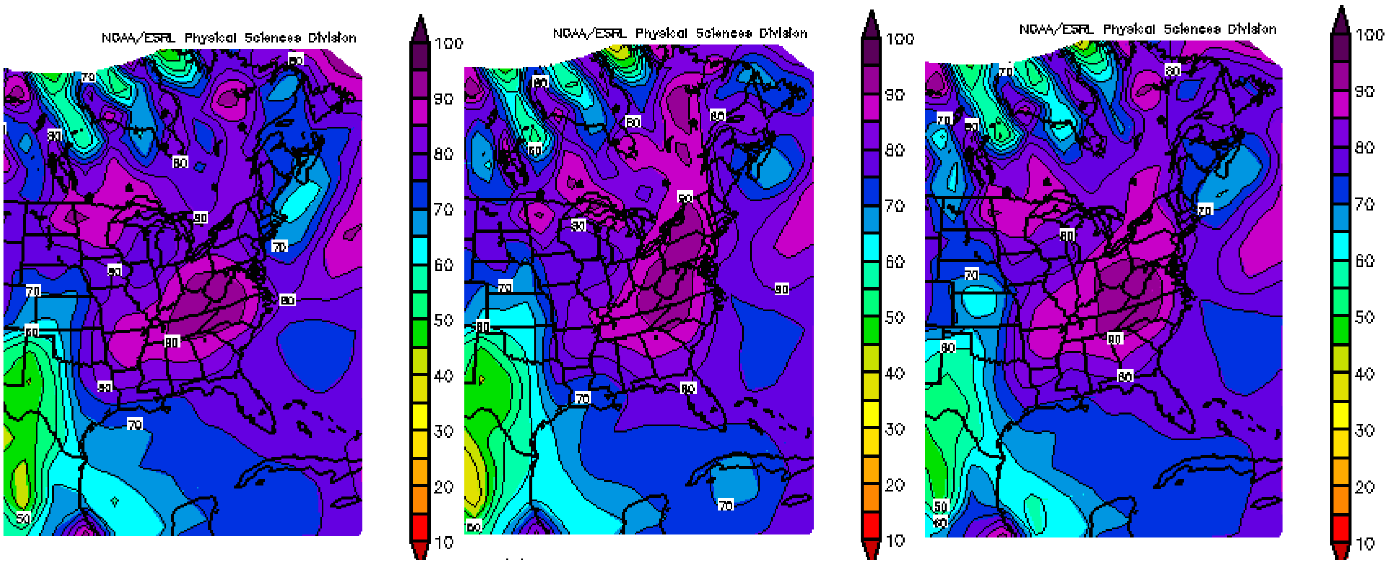

Figure 5b. Composite 925 mb relative humidity (%) overview of frontal/precipitation fog. From left to right: Start, middle and end of the event.

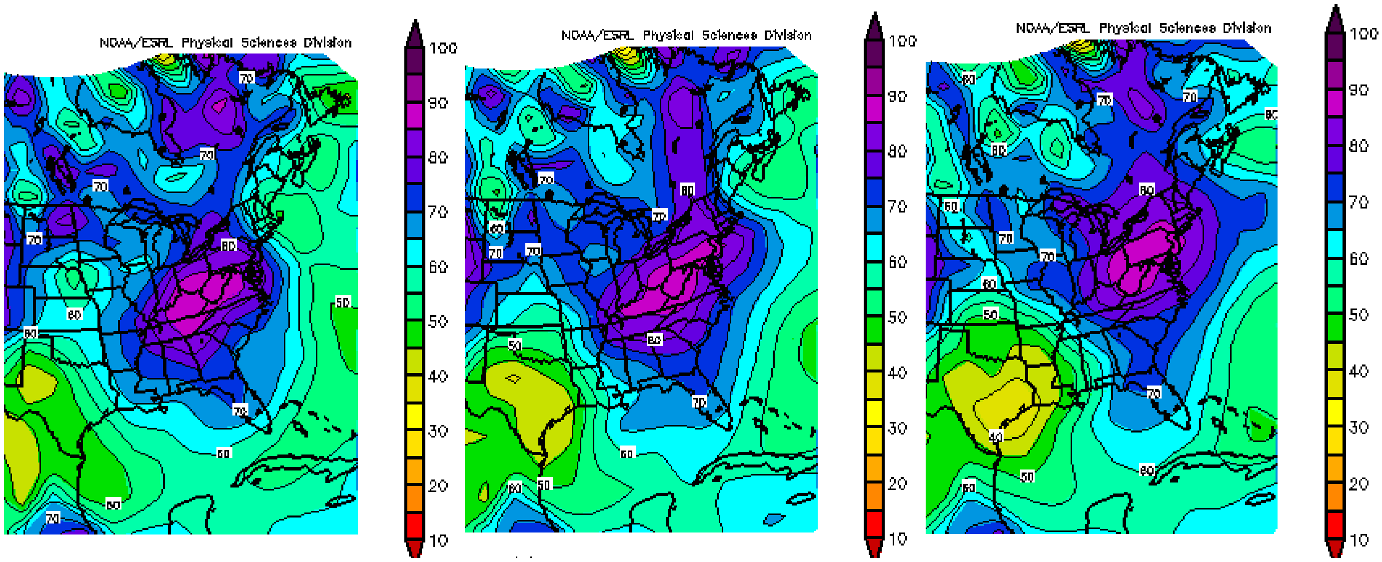

Figure 5c. Composite 850 mb relative humidity (%) overview of frontal/precipitation fog. From left to right: Start, middle and end of the event.

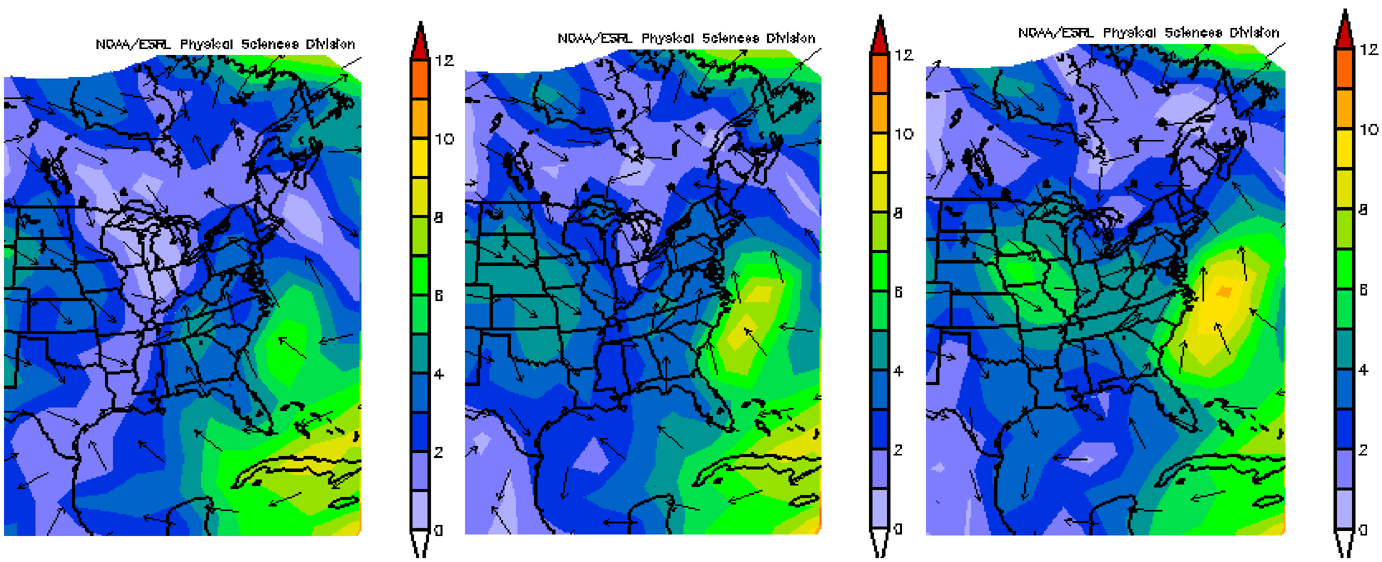

Figure 5d. Composite surface winds (ms^{-1}) overview of frontal/precipitation fog. From left to right: Start, middle and end of the event.

(a) GSO Sounding 00UTC 2 Dec 91 (b) GSO Sounding 12UTC 2 Dec 91

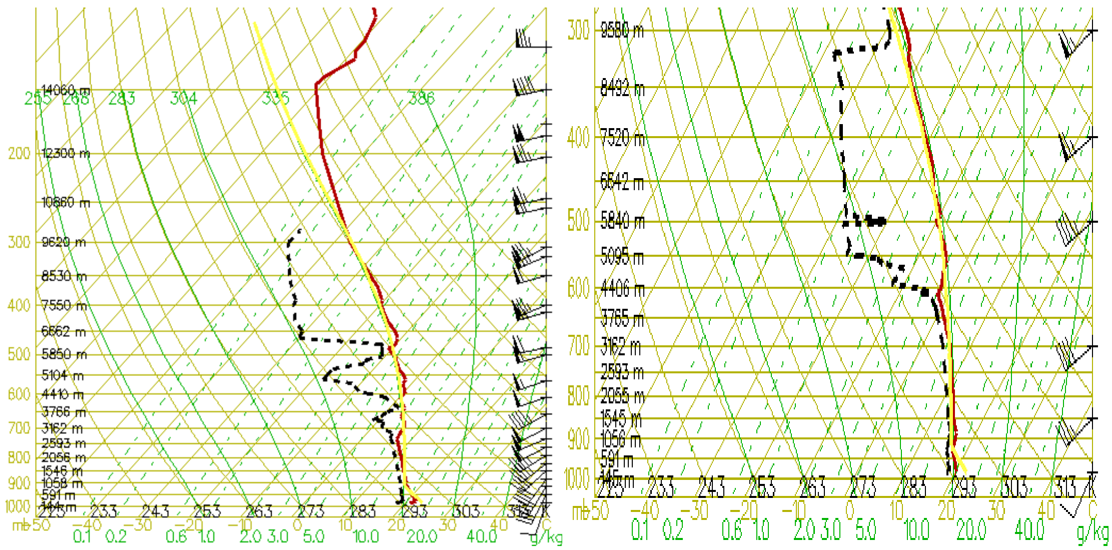

Figure 6. Frontal/precipitation Fog representative soundings at the (a) beginning, and (b) during the peak, of the event. Images courtesy of Plymouth State Weather: (http://vortex.plymouth.edu/)

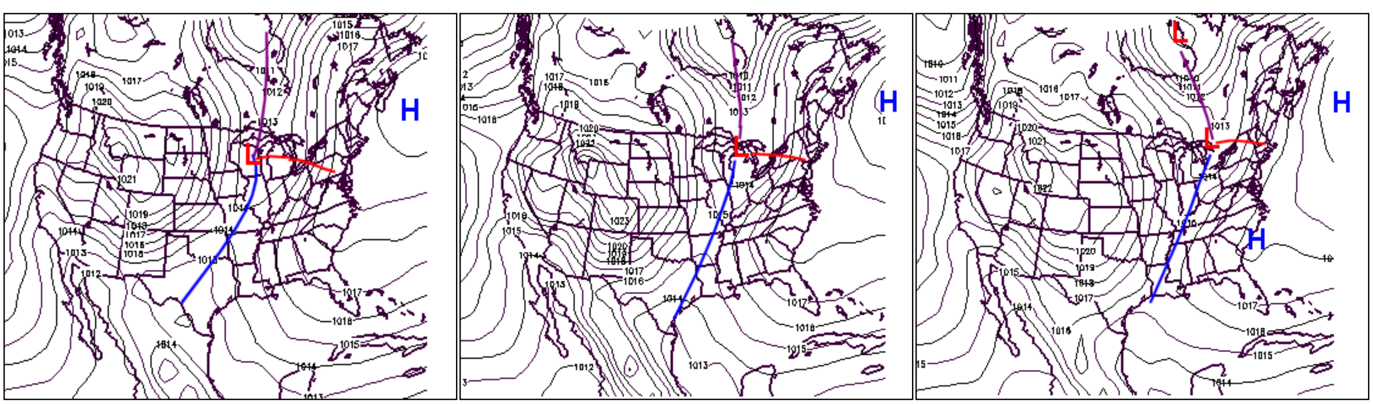

Figure 7a. Composite surface map of mean sea level pressure (mb) and overview of fog/no front cases. From left to right: Start, middle, and end of event.

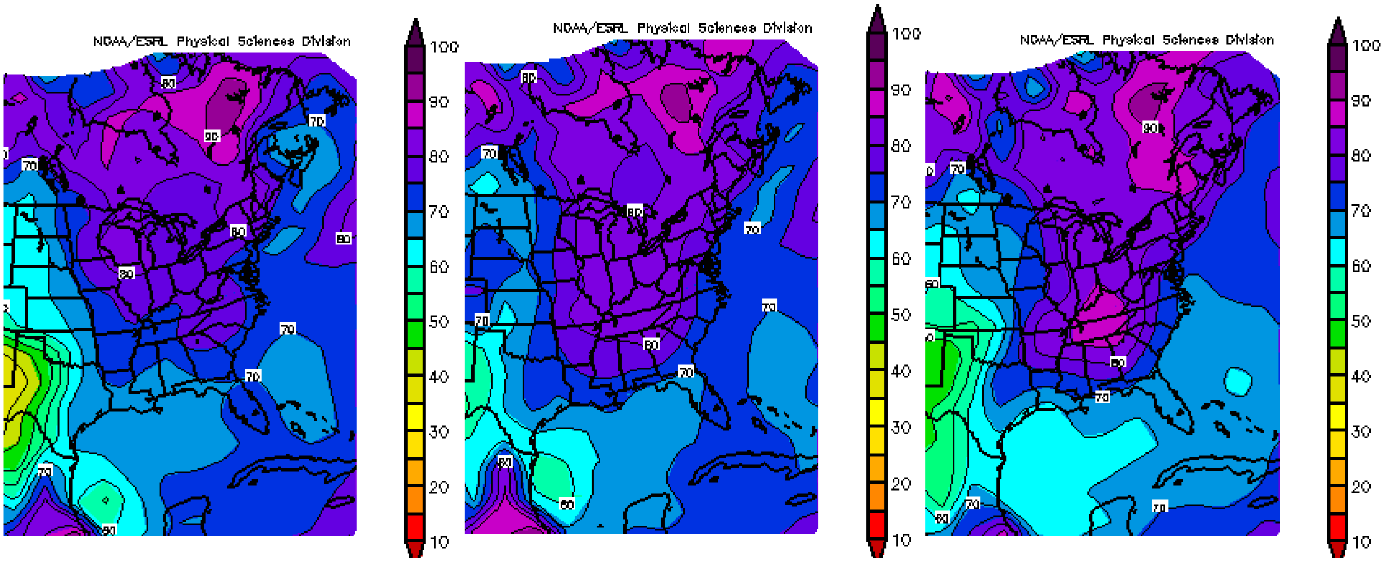

Figure 7b. Composite 925 mb relative humidity (%) overview of radiation fog/no front. From left to right: Start, middle and end of the event.

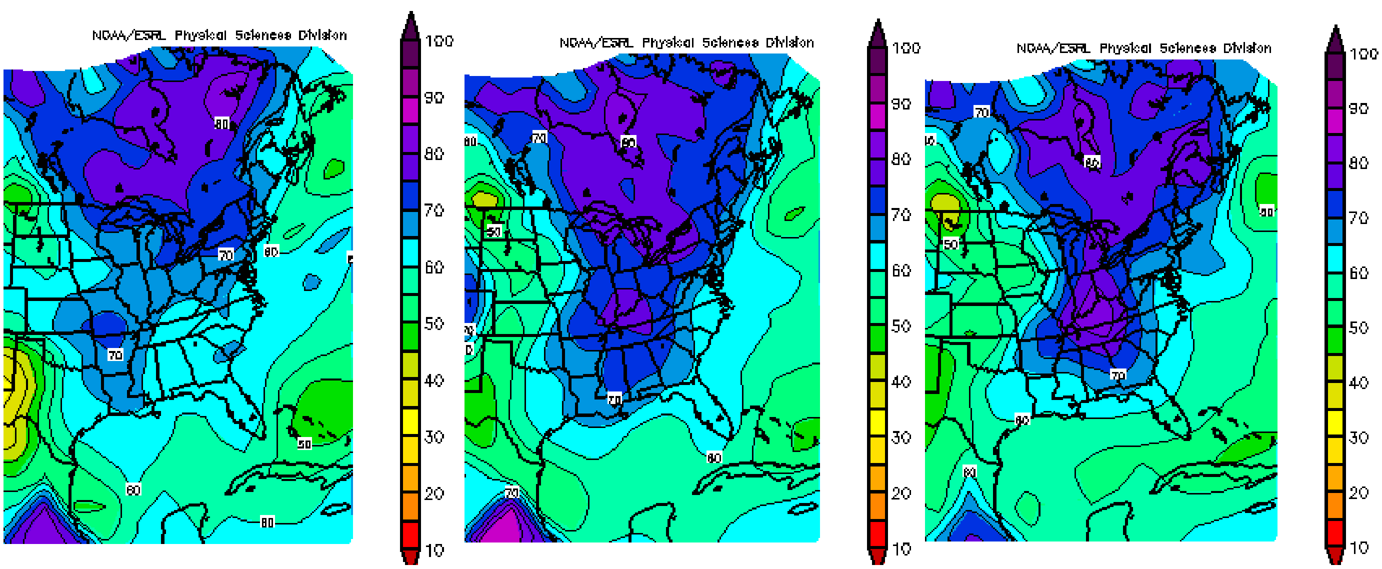

Figure 7c. Composite 850 mb relative humidity (%) overview of radiation fog/no front. From left to right: Start, middle and end of the event.

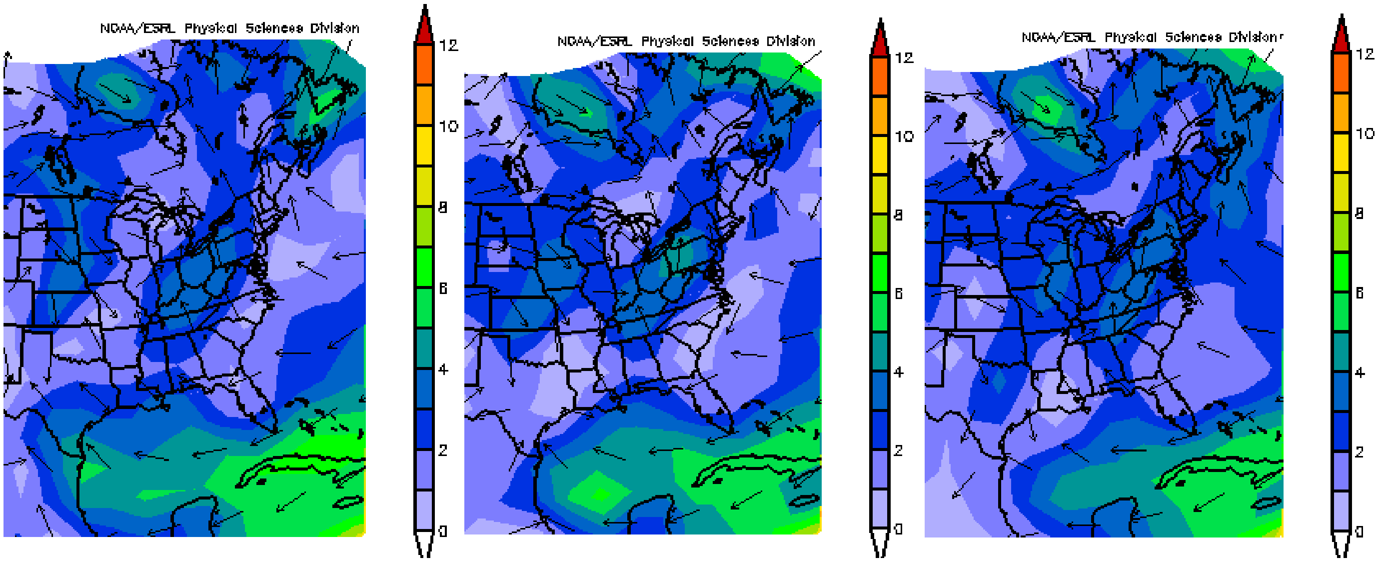

Figure 7d. Composite surface winds (ms^{-1}) overview of radiation fog/no front. From left to right: Start, middle and end of the event.

(a) GSO Sounding 00UTC 29 Dec 74 (b) GSO Sounding 12UTC 29 Dec 74

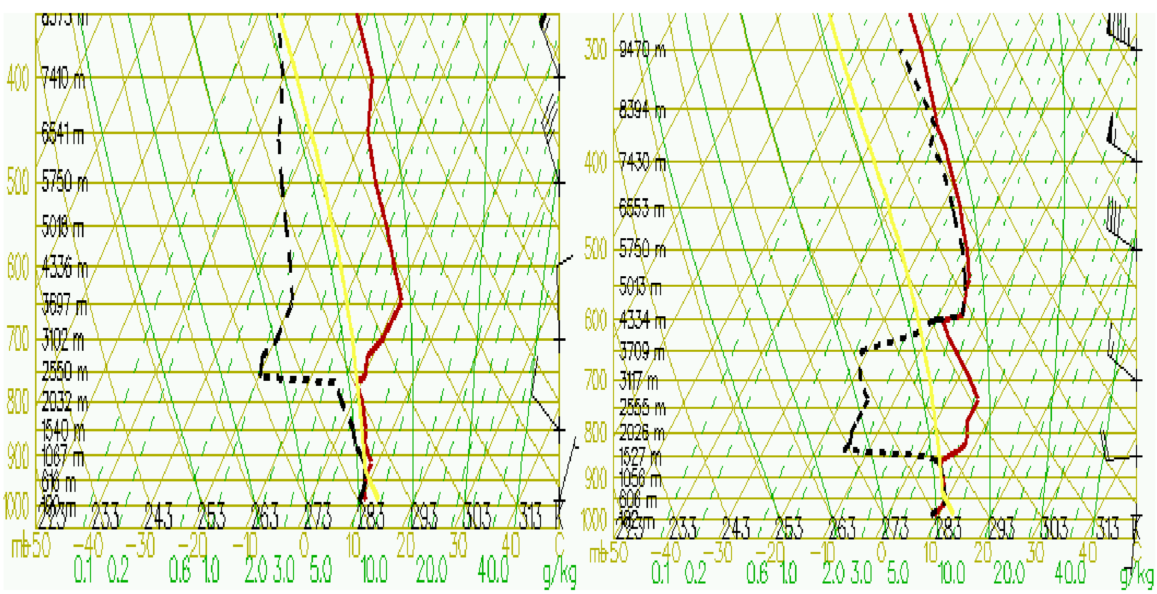

Figure 8. Radiation fog/no front representative soundings at the (a) beginning, and (b) during the peak, of the event. Images courtesy of Plymouth State Weather: (http://vortex.plymouth.edu/)

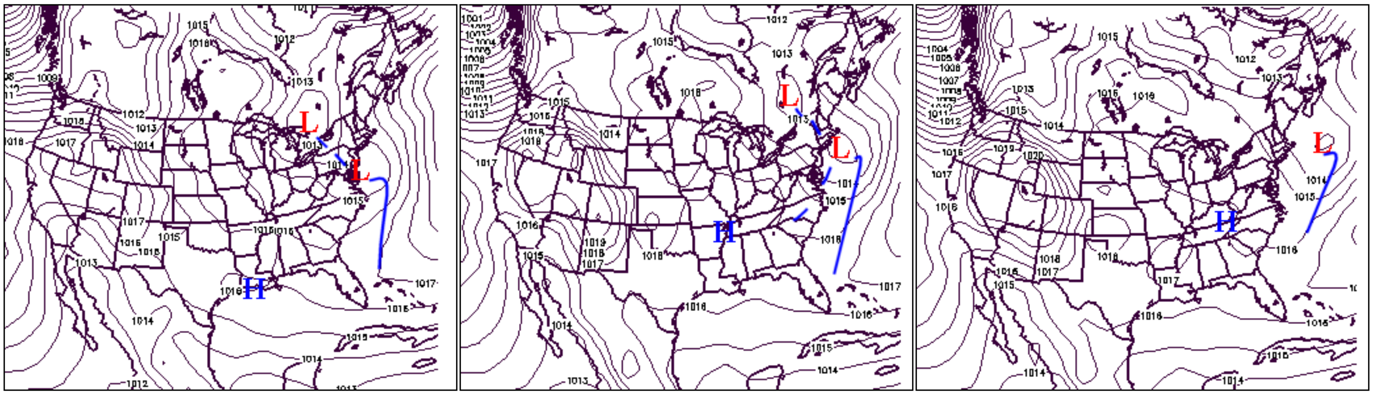

Figure 9a. Composite surface map of mean sea level pressure (mb) and overview of radiation fog/post cold front cases. From left to right: Start, middle, and end of event.

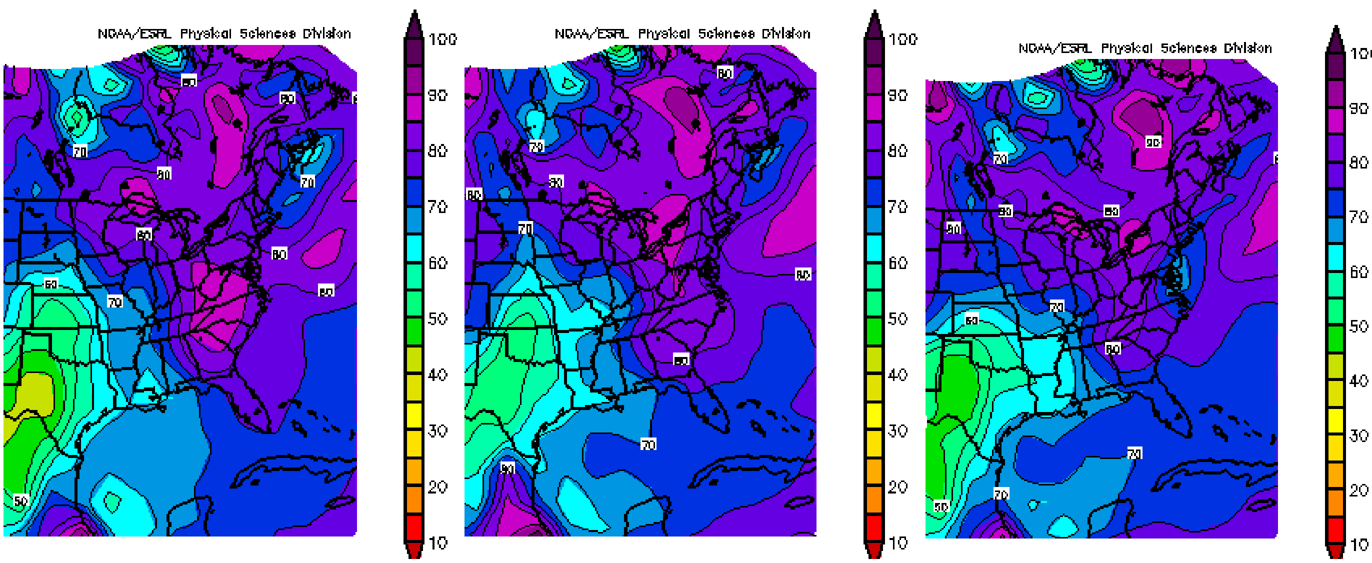

Figure 9b. Composite 925 mb relative humidity (%) overview of radiation fog/post cold front. From left to right: Start, middle and end of the event.

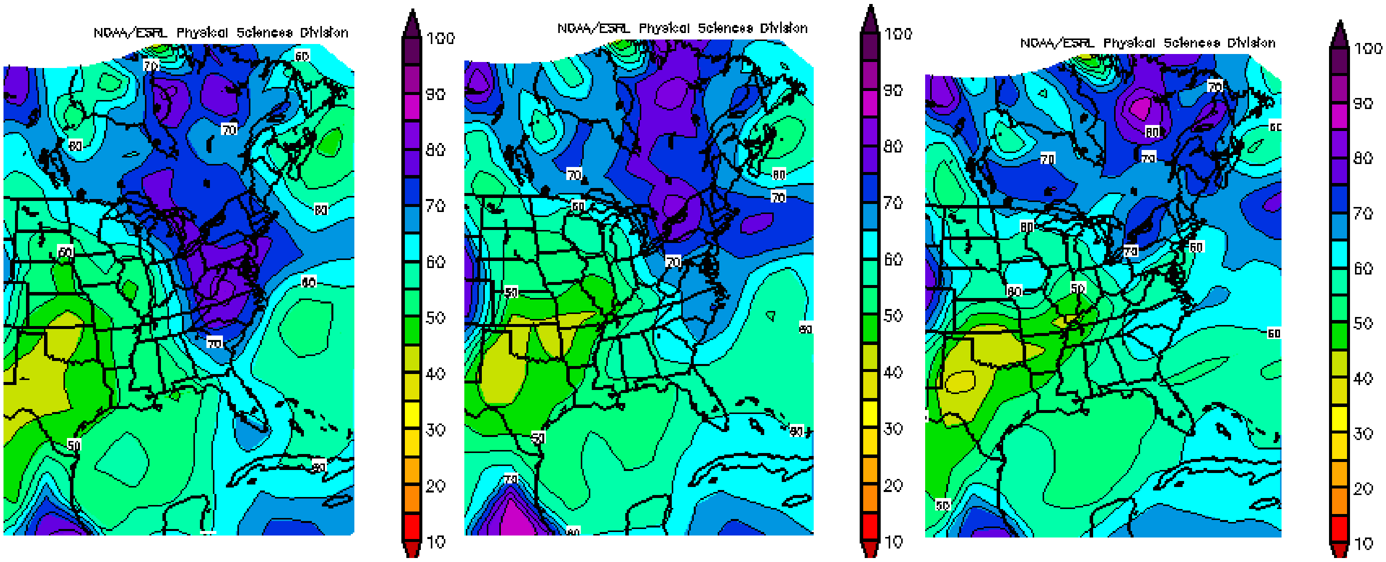

Figure 9c. Composite 850 mb relative humidity (%) overview of Radiation fog/post cold front. From left to right: Start, middle and end of the event.

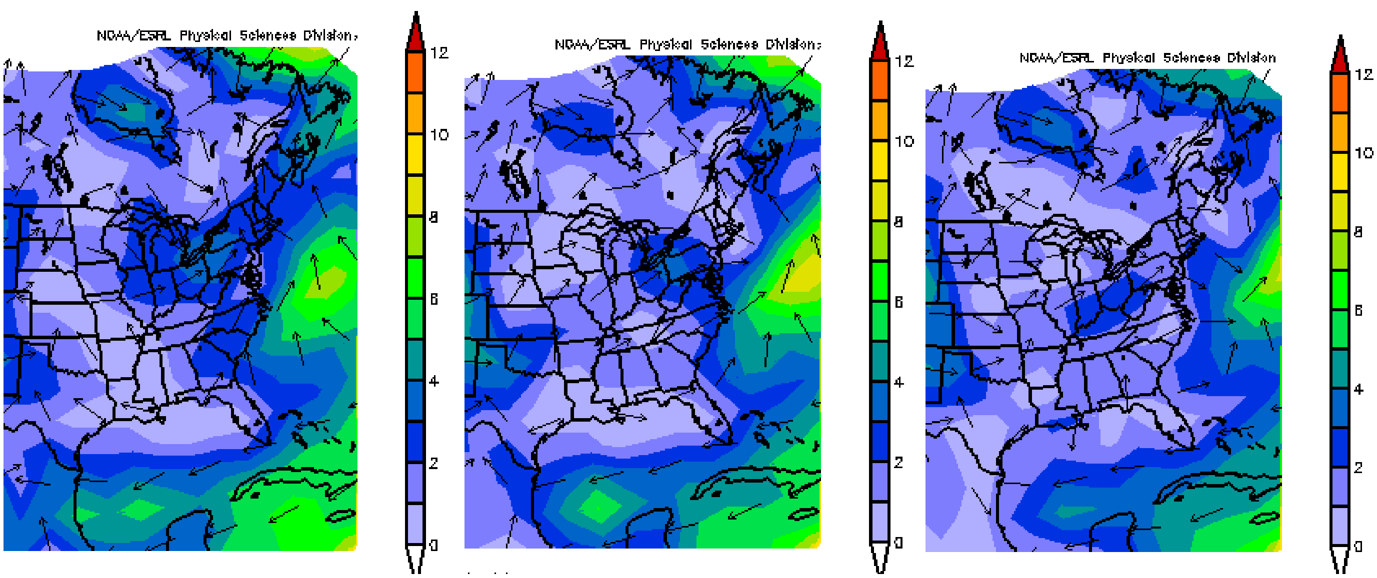

Figure 9d. Composite surface winds (ms^{-1}) overview of Radiation fog/post cold front. From left to right: Start, middle and end of the event.

(a) GSO Sounding 00UTC 7 Nov 89 (b) GSO Sounding 12UTC 7 Nov 89

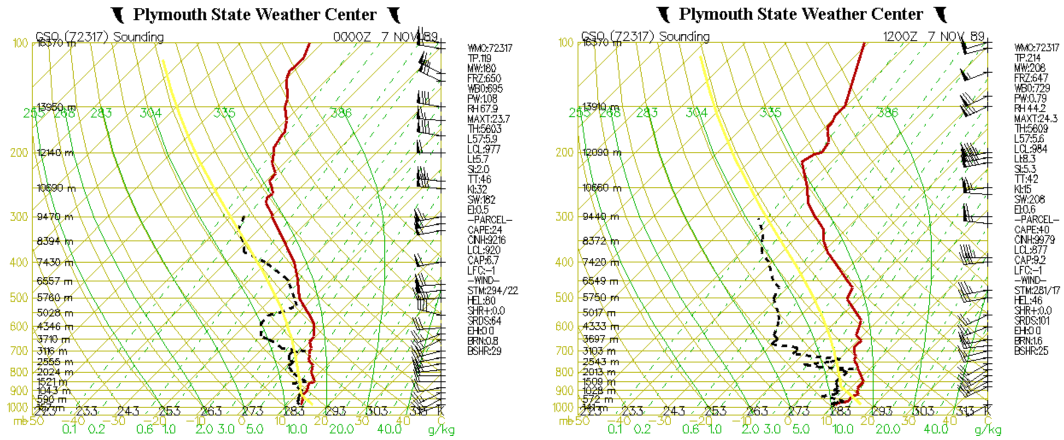

Figure 10. Radiation fog/post cold front representative soundings at the (a) beginning, and (b) during the peak of the event. Images courtesy of Plymouth State Weather: (http://vortex.plymouth.edu/)

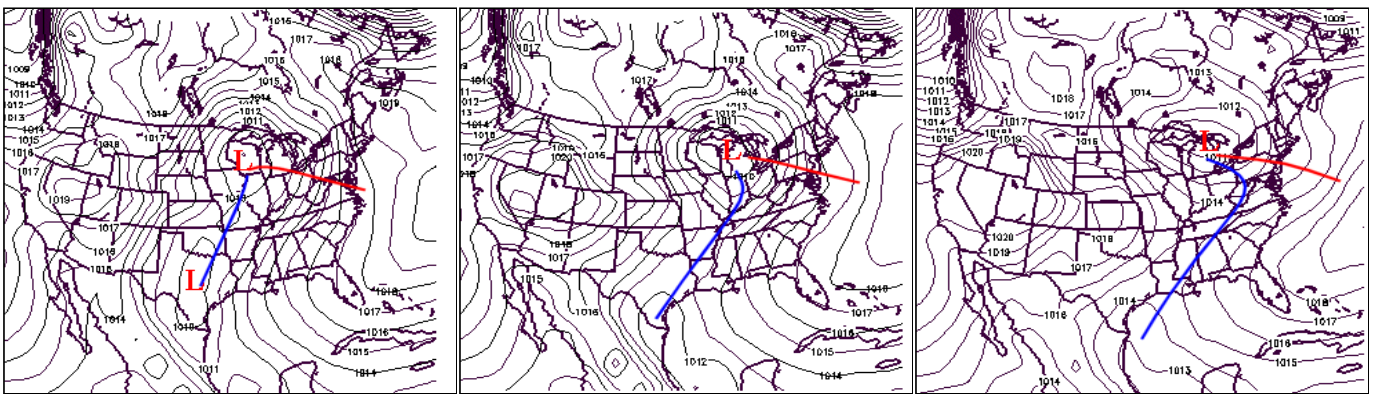

Figure 11a. Composite surface map of mean sea level pressure (mb) and overview of radiation fog/post warm front cases. From left to right: Start, middle, and end of event.

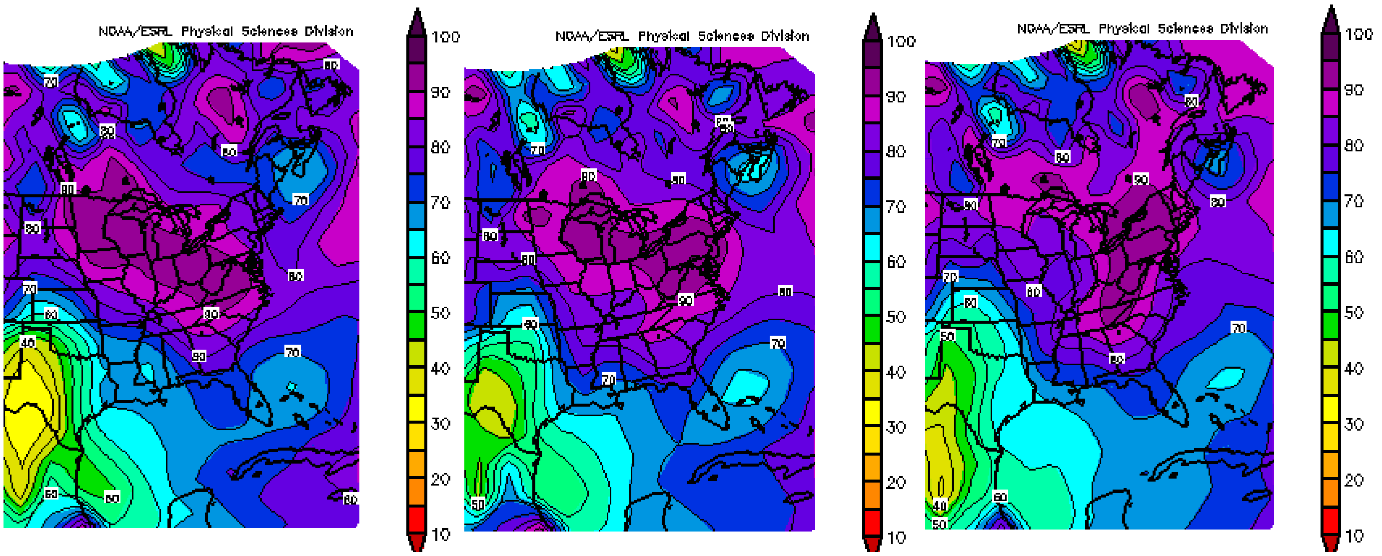

Figure 11b. Composite 925 mb relative humidity (%) overview of radiation fog/post warm front. From left to right: Start, middle and end of the event.

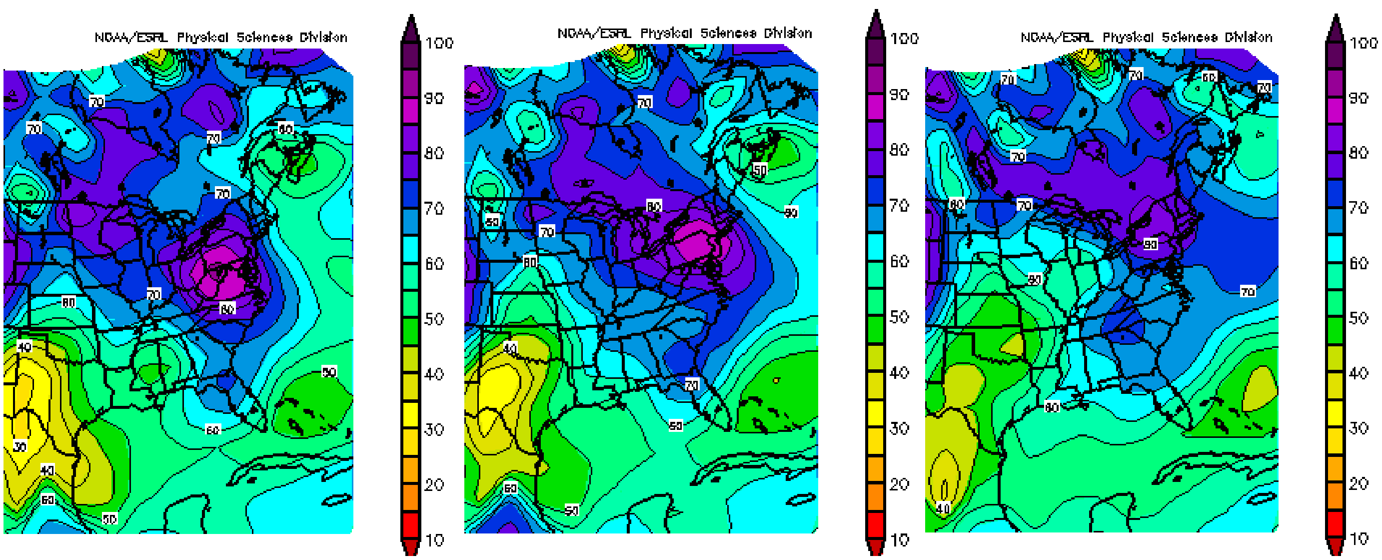

Figure 11c. Composite 850 mb relative humidity (%) overview of radiation fog/post warm front. From left to right: Start, middle and end of the event.

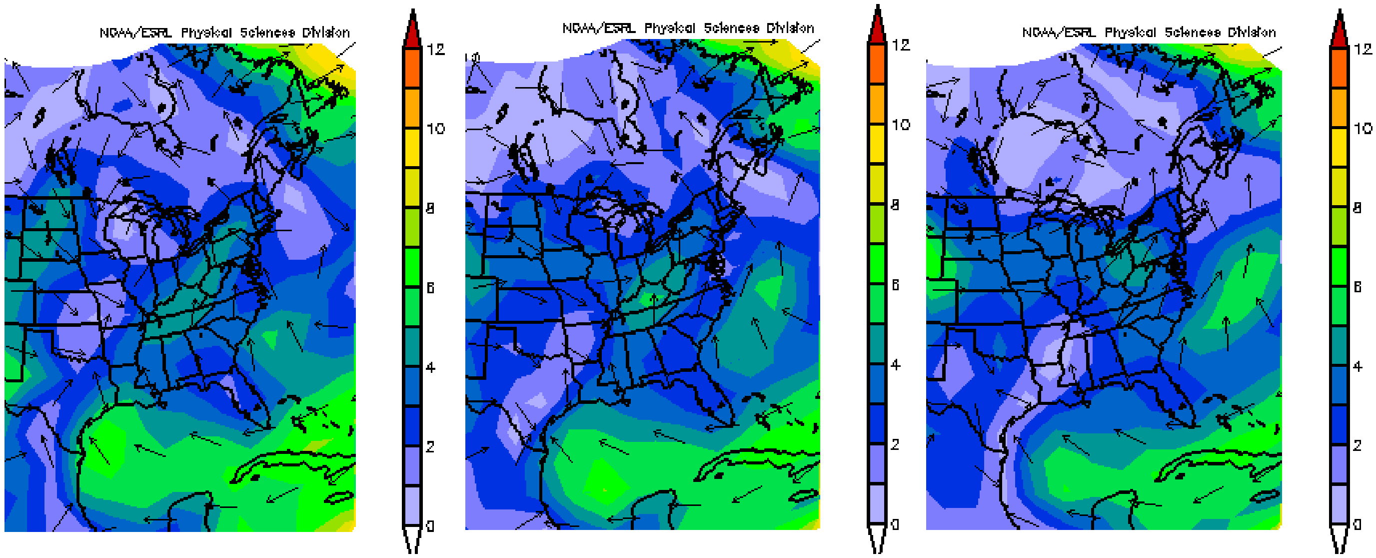

Figure 11d. Composite surface wind (ms^{-1}) map overview of radiation fog/post warm front. From left to right: Start, middle and end of the event.

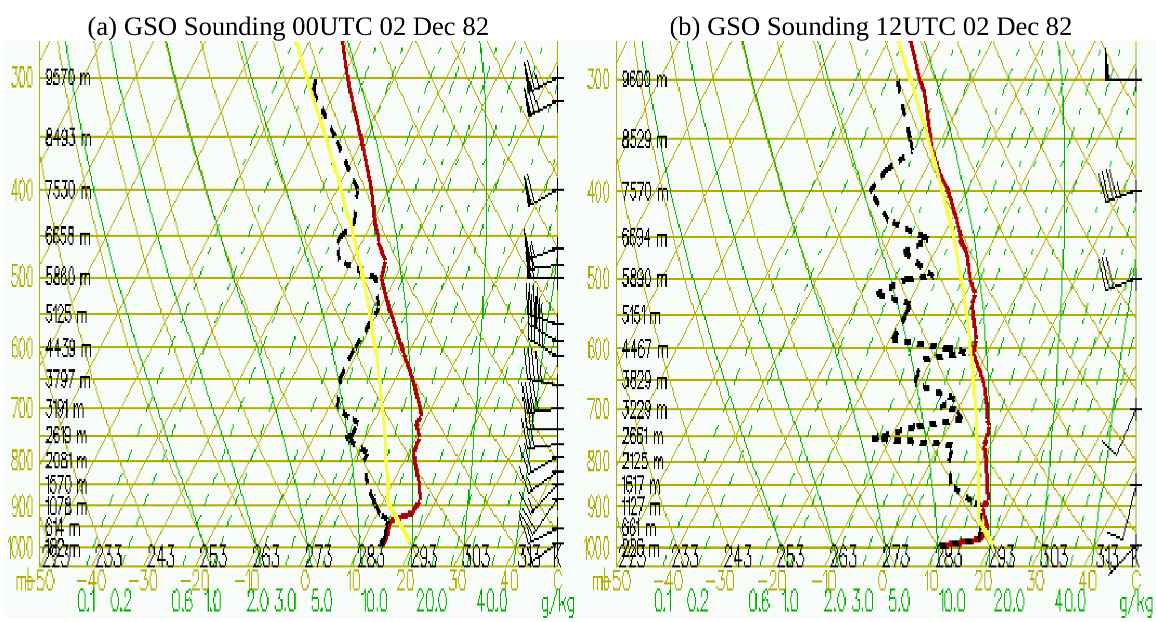

Figure 12. Radiation fog/post warm front representative soundings at the (a) beginning, and (b) during the peak, of the event. Images courtesy of Plymouth State Weather: (http://vortex.plymouth.edu/)

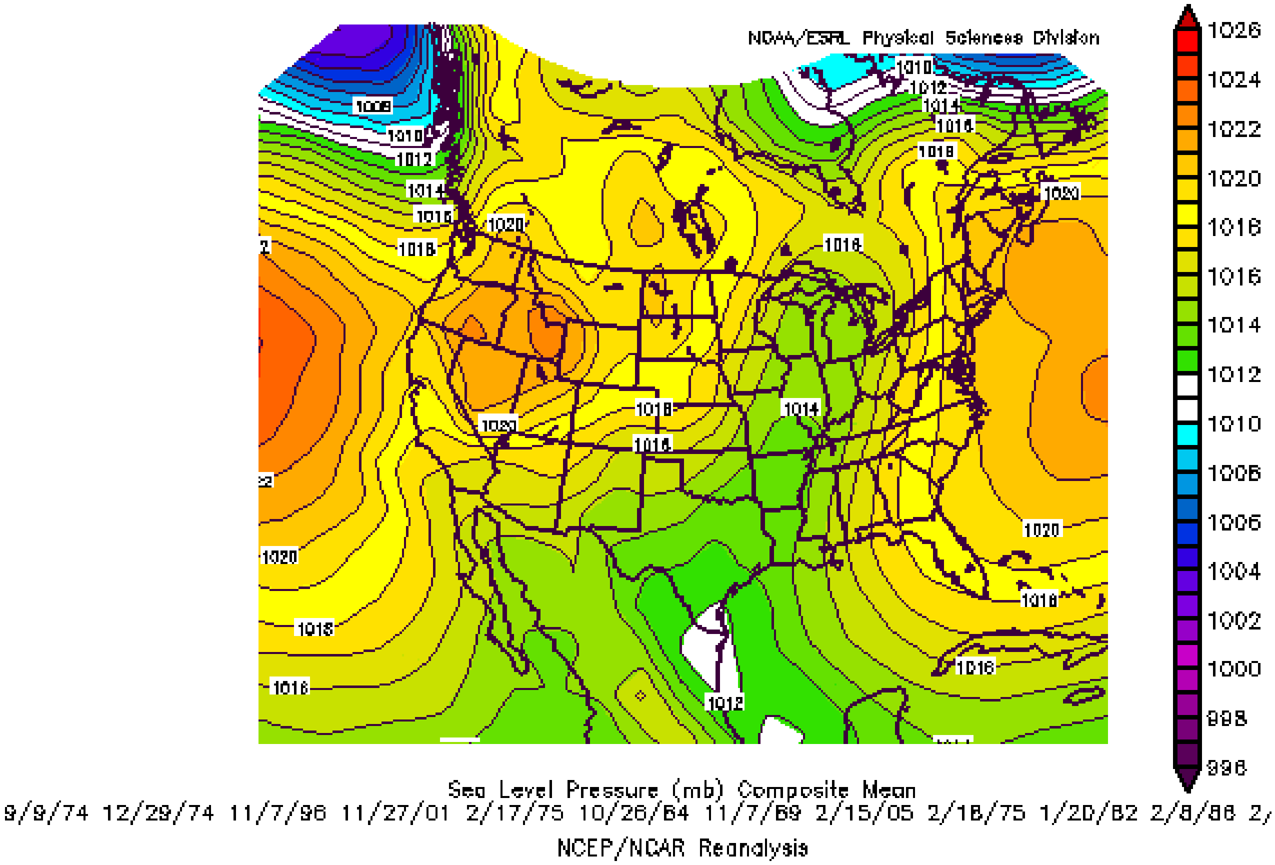

Figure 13. Mean sea level pressure (mb) composite for all categories.

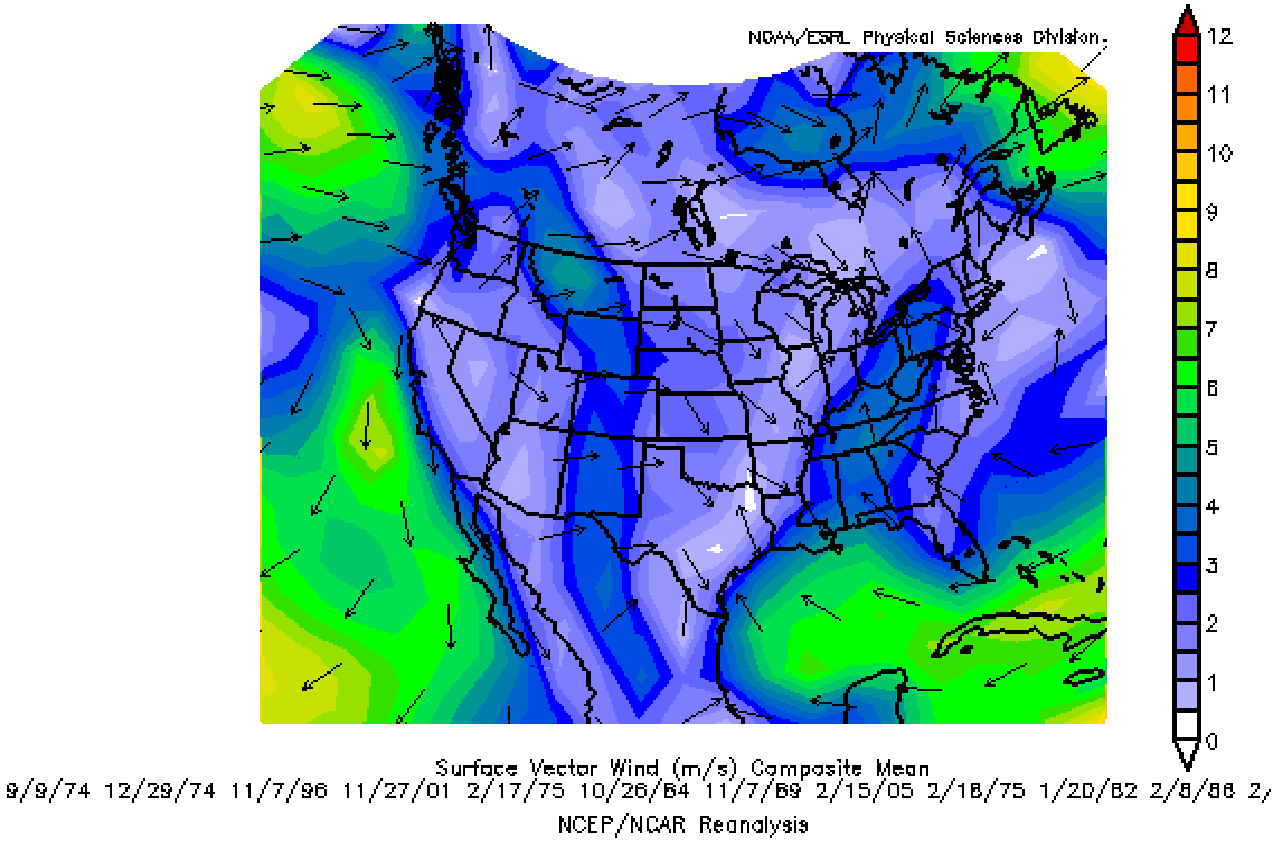

Figure 14. Surface wind speed (ms^{-1}) composite for all categories.

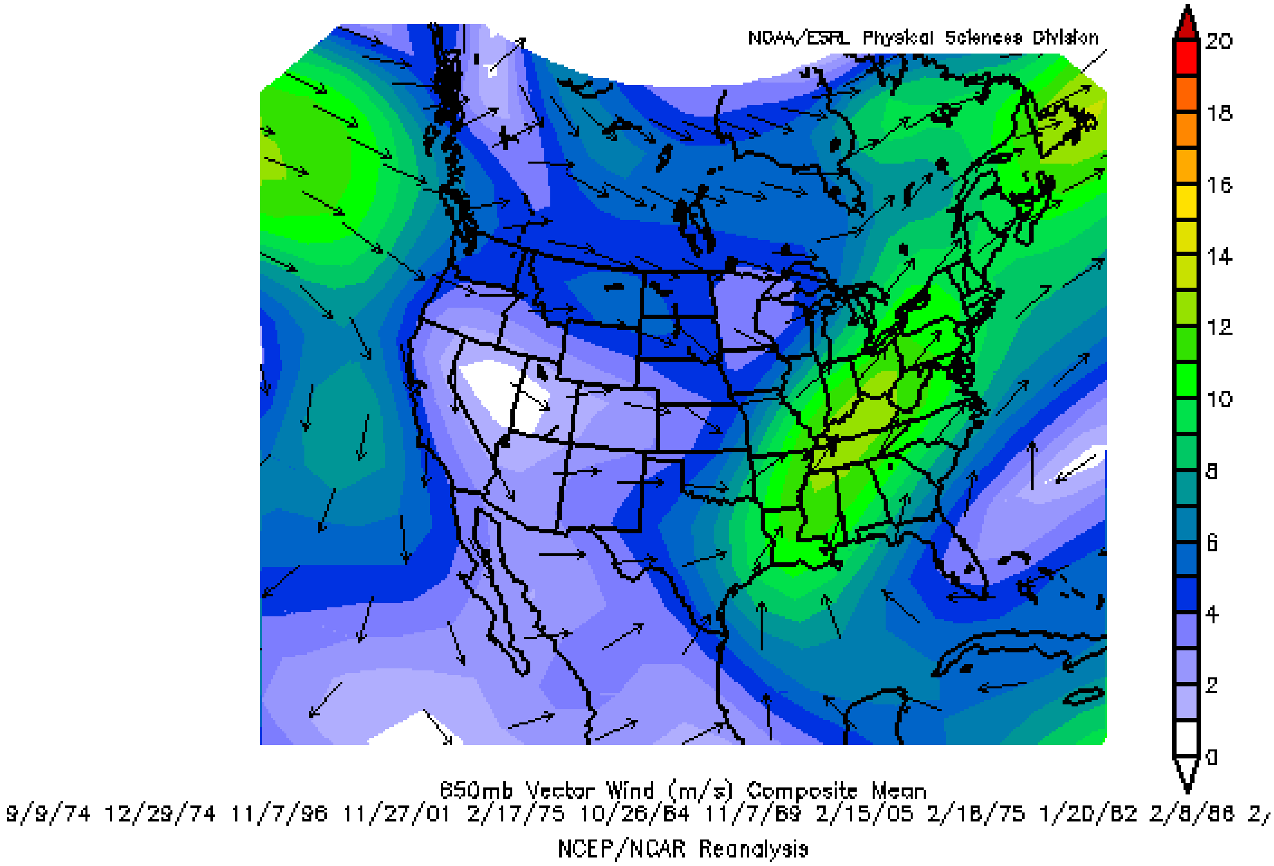

Figure 15. 850mb wind speed (ms^{-1}) composite for all categories.

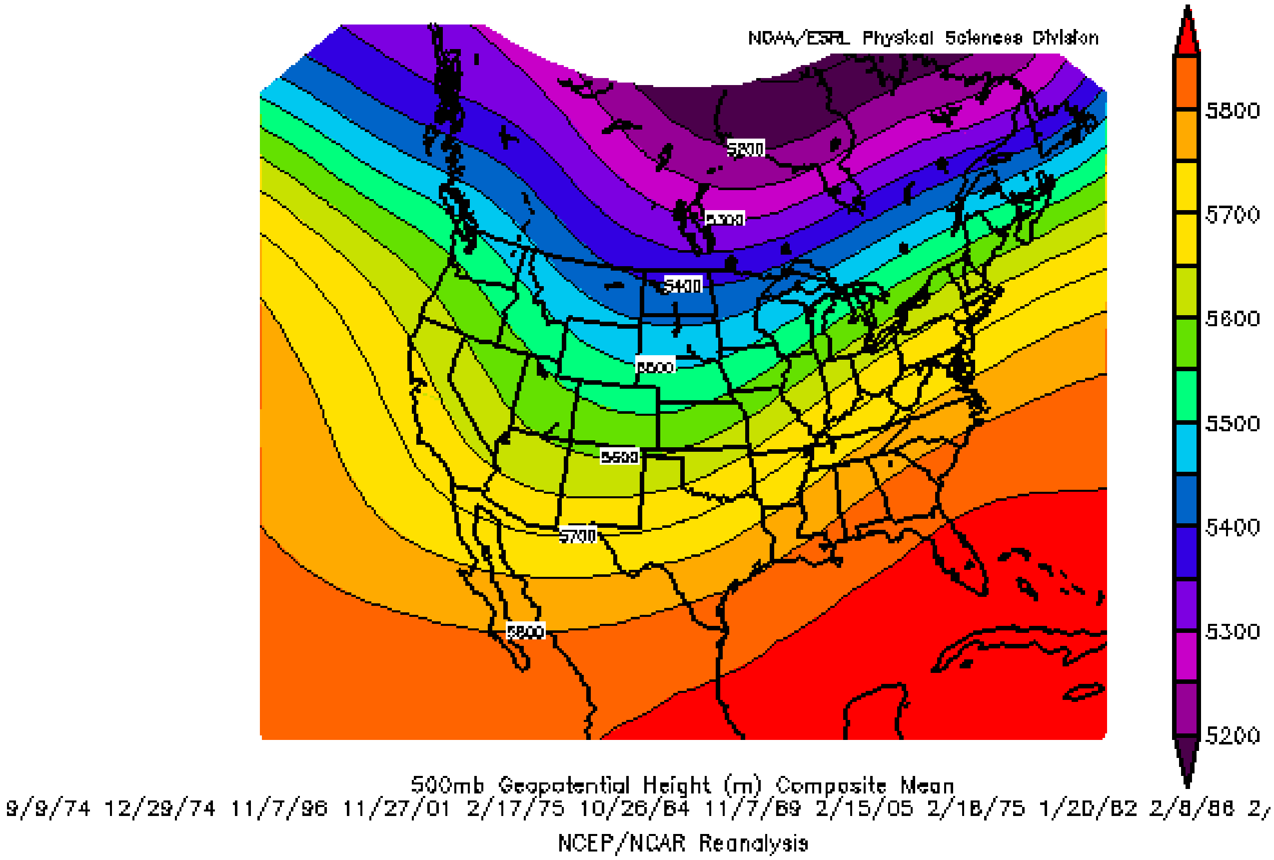

Figure 16. 500 mb height (m) composite for all categories.

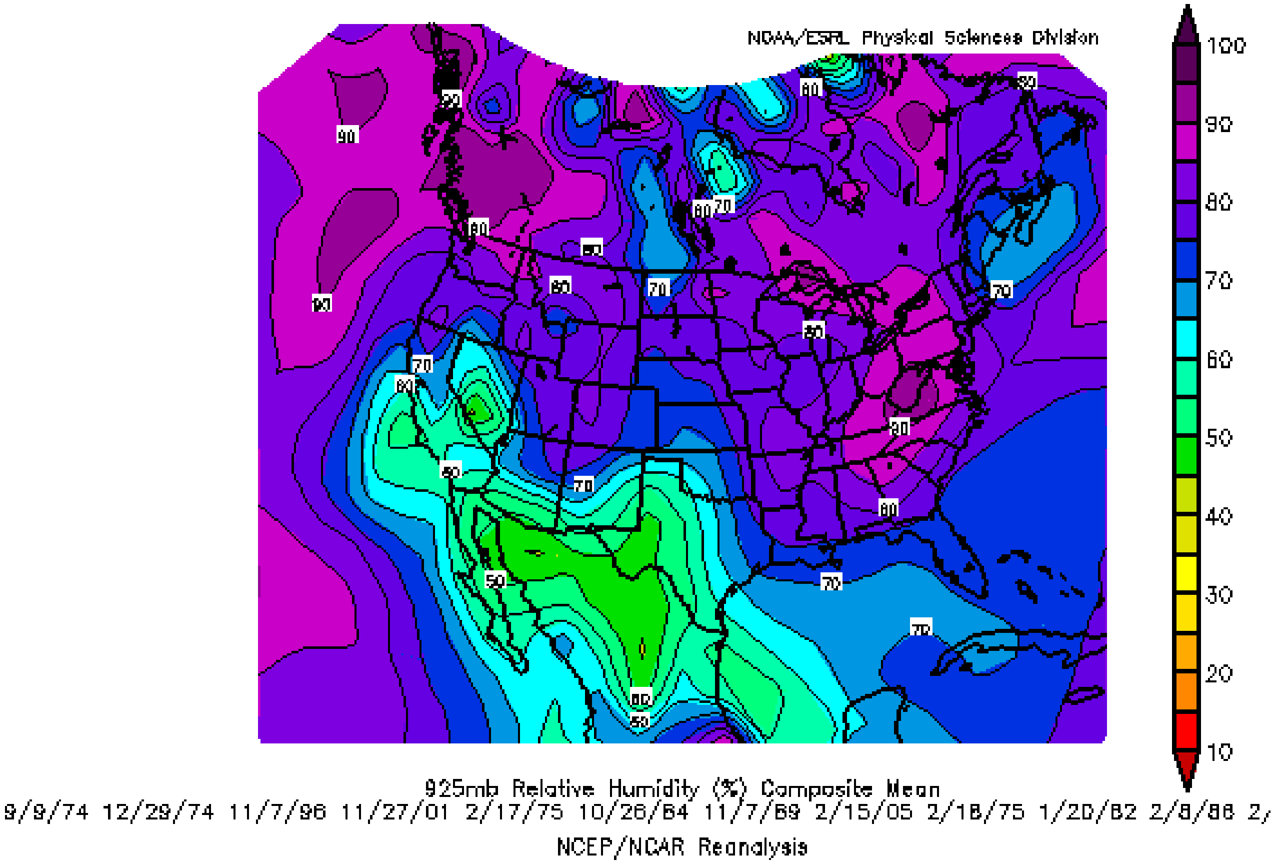

Figure 17. 925 mb relative humidity (%) composite for all categories.

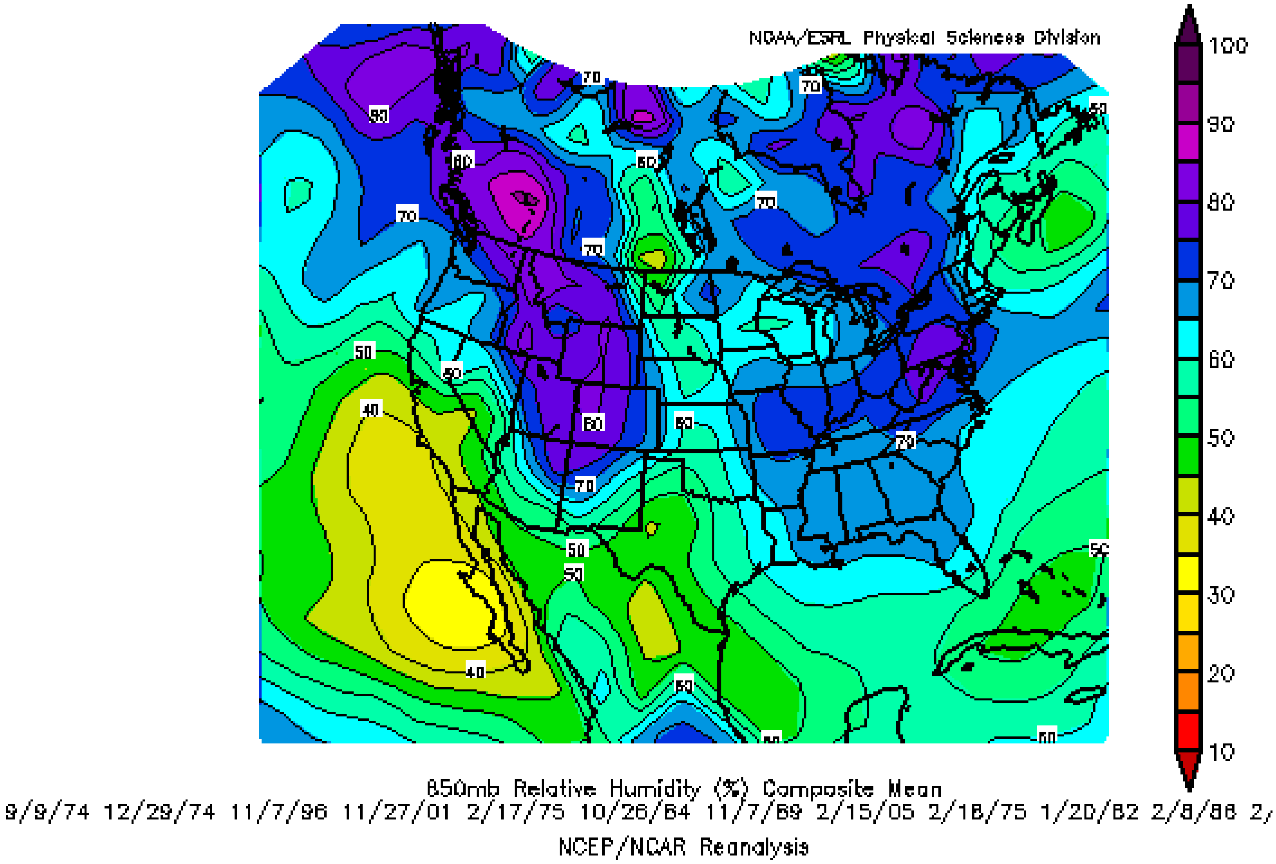

Figure 18. 850 mb relative humidity (%) composite for all categories.

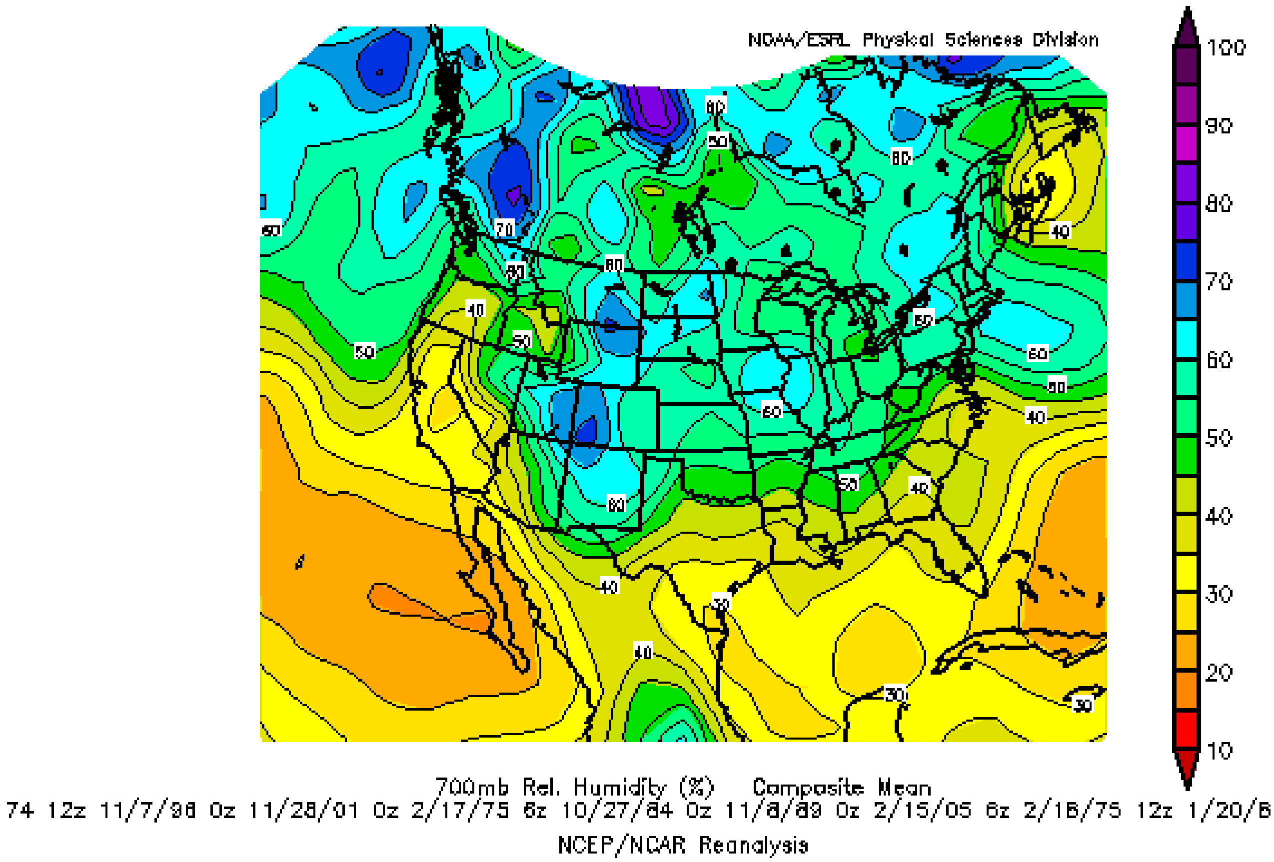

Figure 19. 700 mb relative humidity (%) composite.

APPENDIX

Dense Fog Events by Category
With Beginning and Ending Times UTC
And Precipitation Other Than Drizzle

I. Advection Fog (23 events)

Beginning	Ending	Locations with Fog	Precipitation
03/06/73 0700	03/06/73 1400	ROA and DAN	No
10/13/73 0900	10/13/73 1400	ROA and LYH	No
12/25/73 1100	12/25/73 1700	ROA and LYH	No
01/03/74 1700	01/04/74 0300	ROA and LYH	No
01/26/74 1800	01/27/74 0600	ROA and LYH	No
11/19/74 0100	11/19/74 1700	ROA, LYH and DAN	No
11/09/75 0900	11/09/75 1500	LYH and DAN	No
01/25/76 1800	01/26/76 2000	ROA, LYH and DAN	Yes
11/30/77 0000	11/30/77 1900	ROA, LYH and DAN	No
02/17/78 0400	02/17/78 1800	LYH and DAN	No
09/28/79 1200	09/29/79 1300	ROA, LYH and DAN	Yes
02/04/82 0200	02/04/82 1500	ROA, LYH and DAN	No
12/03/82 0400	12/03/82 1800	ROA, LYH and DAN	No
10/12/83 1000	10/12/83 1500	LYH and DAN	No
12/16/84 0900	12/16/84 1200	ROA, LYH and DAN	No
12/29/90 0600	12/30/90 1300	ROA, LYH and DAN	No
01/17/96 0700	01/18/96 1100	ROA, LYH and DAN	No
01/06/98 1200	01/07/98 0600	ROA and LYH	Yes
12/19/02 2300	12/20/02 08	LYH and DAN	Yes
03/01/03 0100	03/01/03 1600	ROA and LYH	No
11/18/03 1800	11/18/03 2300	ROA and LYH	Yes
11/28/05 1600	11/28/05 2300	ROA and DAN	No
12/18/08 0500	12/18/08 2300	ROA, LYH and DAN	No

II. Frontal/Precipitation Fog (41 events)

Beginning	Ending	Locations with Fog	Precipitation
12/14/03 0000	12/14/03 1000	LYH and DAN	Yes
12/20/73 2100	12/21/73 1000	LYH and DAN	Yes
01/01/74 0400	01/01/74 1100	ROA and LYH	Yes
01/07/76 2100	01/08/76 1300	ROA and LYH	Yes
12/12/76 0000	12/12/76 1500	ROA, LYH and DAN	Yes
09/17/77 0300	09/17/77 1300	ROA and LYH	Yes
01/08/78 1700	01/09/78 0000	LYH and DAN	Yes
01/25/78 2000	01/26/78 0300	LYH and DAN	Yes
04/19/78 1400	04/20/78 0200	LYH and DAN	Yes
11/15/78 2300	11/16/78 2000	ROA, LYH and DAN	Yes
11/17/78 1800	11/18/78 0200	LYH and DAN	Yes
01/07/79 0300	01/07/79 1900	ROA, LYH and DAN	Yes
01/13/79 1500	01/14/79 1400	ROA, LYH and DAN	Yes
01/21/79 0400	01/21/79 1500	LYH and DAN	Yes
02/23/79 2200	02/24/79 1800	ROA and LYH	Yes
01/11/80 0900	01/12/80 0300	ROA, LYH and DAN	Yes
02/20/81 0200	02/20/81 0800	ROA and LYH	Yes
12/27/81 0800	12/27/81 1500	LYH and DAN	Yes
01/03/82 1900	01/04/82 0300	ROA, LYH and DAN	Yes
01/23/82 2100	01/24/82 0100	ROA and LYH	Yes
03/17/82 0000	03/17/82 1100	ROA and LYH	Yes
03/20/82 2330	03/21/82 1600	ROA, LYH and DAN	Yes
12/15/82 2200	12/16/82 0500	ROA, LYH and DAN	Yes
01/23/83 1200	01/23/83 1900	LYH and DAN	Yes
02/06/83 0800	02/06/83 1500	ROA and DAN	Yes
02/04/84 0300	02/04/84 1200	ROA, LYH and DAN	Yes
02/04/86 0600	02/05/86 1100	ROA, LYH and DAN	Yes
12/02/91 0400	12/02/91 1100	ROA, LYH and DAN	Yes
01/13/93 1000	01/13/93 1500	ROA, LYH and DAN	Yes
02/22/93 0500	02/22/93 1300	ROA, LYH and DAN	Yes
02/12/94 2100	02/13/94 1300	ROA, LYH and DAN	Yes
11/28/94 0400	11/28/94 1600	LYH and DAN	Yes
11/02/95 0200	11/02/95 1300	ROA, LYH and DAN	Yes
09/17/96 0200	09/17/96 1000	ROA, LYH and DAN	Yes
12/17/96 0400	12/17/96 1200	ROA, LYH and DAN	Yes
12/04/97 0900	12/04/97 1400	ROA, LYH and DAN	Yes
12/13/99 2300	12/14/99 0600	ROA, LYH and DAN	Yes
01/10/00 0200	01/10/00 1100	ROA, LYH and DAN	Yes
02/04/06 1300	02/04/06 2100	ROA, LYH and DAN	Yes
02/11/06 1800	02/11/06 2200	ROA and LYH	Yes
01/05/07 1300	01/05/07 1800	ROA and LYH	Yes

III. Radiation No Front Fog (39 cases)

Beginning	Ending	Locations with Fog	Precipitation
03/04/73 0100	03/04/73 1430	ROA and DAN	No
09/11/73 0900	09/11/73 1330	ROA and LYH	No
01/10/74 0800	01/10/74 1500	ROA and DAN	No
08/16/74 0800	08/16/74 1330	LYH and DAN	No
08/27/74 0900	08/27/74 1300	ROA and LYH	No
09/09/74 0500	09/09/74 1400	ROA, LYH and DAN	No
12/29/74 0200	12/29/74 1930	ROA, LYH and DAN	No
10/01/75 1000	10/01/75 1500	ROA and DAN	No
07/29/76 0700	07/29/76 1200	ROA and LYH	No
11/09/77 1000	11/09/77 1600	LYH and DAN	No
11/14/78 1000	11/14/78 1500	LYH and DAN	No
08/26/79 0900	08/26/79 1300	ROA and LYH	No
08/28/79 0500	08/28/79 1300	ROA and LYH	No
09/04/79 0900	09/04/79 1400	LYH and DAN	No
10/02/79 0900	10/02/79 1400	ROA and LYH	No
10/02/80 0800	10/02/80 1330	LYH and DAN	No
06/03/82 0900	06/03/82 1530	LYH and DAN	No
09/15/82 1000	09/15/82 1300	LYH and DAN	No
10/06/82 1000	10/06/82 1500	LYH and DAN	No
11/02/82 1000	11/02/82 1530	LYH and DAN	No
11/03/82 0900	11/03/82 1830	ROA, LYH and DAN	No
11/23/82 0330	11/23/82 1600	ROA, LYH and DAN	No
04/08/83 1100	04/08/83 1500	ROA and LYH	No
06/30/83 0400	06/30/83 1300	ROA and LYH	No
07/01/83 0400	07/01/83 1300	ROA and LYH	No
11/02/83 1100	11/02/83 1500	ROA and DAN	No
11/03/95 0600	11/03/95 1300	ROA and LYH	No
11/07/96 0800	11/07/96 1200	LYH and DAN	No
11/27/01 0600	11/27/01 1600	ROA, LYH and DAN	No
09/03/02 0800	09/03/02 1330	LYH and DAN	No
10/23/02 0200	10/23/02 1600	LYH and DAN	No
11/21/02 2300	11/22/02 1400	LYH and DAN	No
08/21/03 1000	08/21/03 1300	ROA and LYH	No
05/18/04 0300	05/18/04 1230	LYH and DAN	No
09/12/04 1000	09/12/04 1400	LYH and DAN	No
06/30/05 0600	06/30/05 1100	LYH and DAN	No
01/13/06 0730	01/13/06 1930	LYH and DAN	No
07/26/06 1000	07/26/06 1400	LYH and DAN	No
11/14/08 0200	11/14/08 1230	ROA and LYH	No

IV. Radiation Post Cold Front Fog (34 cases)

Beginning	Ending	Locations with Fog	Precipitation
08/04/73 0800	08/04/73 1230	LYH and DAN	No
02/03/74 0800	02/03/74 1500	ROA, LYH and DAN	Yes
09/18/74 0100	09/18/74 1300	LYH and DAN	No
02/16/75 2200	02/17/75 1500	ROA, LYH and DAN	Yes
08/20/75 1000	08/20/75 1300	LYH and DAN	No
11/28/76 0800	11/28/76 2000	ROA, LYH and DAN	No
06/15/77 0700	06/15/77 1230	ROA and LYH	No
07/04/78 1000	07/04/78 1500	LYH and DAN	No
02/21/79 2300	02/22/79 1500	LYH and DAN	No
05/15/79 0800	05/15/79 1400	ROA, LYH and DAN	No
11/24/80 2300	11/25/80 0300	LYH and DAN	No
01/22/81 0000	01/22/81 1230	LYH and DAN	No
11/11/81 0700	11/11/81 1330	ROA and LYH	No
10/12/82 1030	10/12/82 1500	ROA and LYH	No
01/24/83 0000	01/24/83 0500	LYH and DAN	No
12/29/83 0000	12/29/83 0600	ROA and LYH	No
10/26/84 0300	10/26/84 1200	ROA, LYH and DAN	No
11/07/89 0200	11/07/89 1500	ROA, LYH and DAN	No
12/01/97 0100	12/01/97 1000	ROA, LYH and DAN	No
09/21/01 0400	09/21/01 0900	ROA and LYH	No
12/01/01 0700	12/01/01 0900	ROA, LYH and DAN	No
03/14/02 0230	03/14/02 1230	LYH and DAN	No
12/12/02 0200	12/12/02 1700	LYH and DAN	No
01/02/03 1200	01/02/03 2200	LYH and DAN	No
02/15/05 0100	02/15/05 1400	ROA, LYH and DAN	No
02/22/05 0600	02/22/05 1330	LYH and DAN	No
03/24/05 0330	03/24/05 0800	LYH and DAN	No
01/12/06 0000	01/12/06 1600	ROA, LYH and DAN	No
01/30/06 0700	01/30/06 1500	LYH and DAN	No
04/23/06 0200	04/23/06 1200	LYH and DAN	No
09/09/06 0630	09/09/06 1400	LYH and DAN	No
12/11/07 1130	12/11/07 1500	ROA and LYH	No
08/14/08 0300	08/14/08 1130	LYH and DAN	No
09/28/08 0500	09/28/08 1200	LYH and DAN	No

V. Radiation Post Warm Front Fog (39 cases)

Beginning	Ending	Locations with Fog	Measurable Precipitation
10/03/73 0900	10/03/73 1400	LYH and DAN	No
11/21/73 2330	11/22/73 1400	ROA, LYH and DAN	No
02/07/74 0500	02/07/74 1400	ROA and LYH	No
03/07/74 0700	03/07/74 1230	ROA and LYH	No
11/20/74 0830	11/20/74 1300	ROA and LYH	No
12/31/74 2330	01/01/75 0700	ROA and LYH	No
02/05/75 2300	02/06/75 1400	ROA and LYH	No
02/18/75 0230	02/18/75 1500	ROA, LYH and DAN	No
03/11/75 0000	03/11/75 1400	LYH and DAN	No
04/29/75 1000	04/29/75 1200	ROA, LYH and DAN	No
10/09/75 0500	10/09/75 1330	ROA and LYH	No
11/27/76 0800	11/27/76 1500	ROA and LYH	No
11/08/77 1100	11/08/77 1600	LYH and DAN	No
11/24/77 1100	11/24/77 1600	ROA, LYH and DAN	No
12/01/77 1100	12/01/77 1600	LYH and DAN	No
01/07/78 0000	01/07/78 1530	ROA and DAN	No
12/20/78 1600	12/21/78 0300	LYH and DAN	No
10/11/80 0530	10/11/80 1200	ROA and LYH	No
01/19/82 2200	01/20/82 1000	ROA, LYH and DAN	No
02/16/82 0530	02/16/82 1430	ROA and LYH	No
11/29/82 1000	11/29/82 1400	ROA and LYH	No
12/02/82 0000	12/02/82 1730	ROA, LYH and DAN	No
01/11/83 0030	01/11/83 0500	LYH and DAN	No
03/07/83 0130	03/07/83 1600	ROA, LYH and DAN	No
04/09/83 0900	04/09/83 1630	ROA and LYH	No
10/19/84 0900	10/19/84 1300	ROA, LYH and DAN	No
02/08/86 0400	02/08/86 1400	LYH and DAN	No
02/20/86 0200	02/20/86 1500	ROA, LYH and DAN	No
03/02/97 0000	03/02/97 0900	ROA, LYH and DAN	No
11/23/99 0300	11/23/99 1400	ROA and DAN	No
11/08/00 0600	11/08/00 1300	LYH and DAN	No
11/22/02 0030	11/22/02 1400	LYH and DAN	No
02/23/03 0000	02/23/03 0600	ROA and LYH	No
10/30/04 0400	10/30/04 1200	ROA and LYH	No
12/07/04 1100	12/07/04 1600	ROA, LYH and DAN	No
12/10/04 1400	12/10/04 1800	LYH and DAN	No
10/18/06 0630	10/18/06 1400	ROA, LYH and DAN	No
12/23/06 0600	12/23/06 1330	ROA and LYH	No
12/26/06 0500	12/26/06 1130	ROA and DAN	No

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