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A detailed study of advection sea fog formation to reduce the operational impacts along the Northern Gulf of Mexico

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THESIS

A DETAILED STUDY OF ADVECTION SEA FOG FORMATION TO REDUCE THE OPERATIONAL IMPACTS ALONG THE NORTHERN GULF OF MEXICO

by

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March 2007

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13. ABSTRACT (maximum 200 words)

This study creates rules of thumb for forecasting advection sea fog development and dissipation along the northern Gulf of Mexico for the months of December through March. Surface observations from Tyndall AFB, Destin-Fort Walton Beach Airport, Eglin AFB, Hurlburt Field and Keesler AFB were used in conjunction with the National Data Buoy Center's marine sensors to determine the low-level atmospheric state and the sea surface temperatures during advection sea fog events at the five locations listed above. Forecasting rules of thumb were created and then modified to maximize forecasting effectiveness. The criteria examined include: sea surface temperature, wind speed and direction, air temperature and dewpoint spread, dewpoint and sea surface temperature spread. Data from December 1999 to March 2004 and from December 2005 to March 2006 was used for the Keesler AFB analysis. Data from February 2005 to March 2006 was used for the Tyndall AFB, Eglin AFB, Hurlburt Field and Destin-Fort Walton Beach analysis. Missing sea surface temperatures limited the amount of winter time advection sea fog seasons that could be examined.

The averaged results from all of the locations indicate that fog with visibility less than or equal to three statute miles is present 86.8% of the time at the observing site within one hour of meeting the following criteria: sea surface temperature less than or equal to 18.7 degrees Celsius, onshore surface winds less than or equal to 12 knots or surface winds from any direction if the speed is less than or equal to three knots, surface air temperature minus surface dewpoint is less than or equal to one degrees Celsius and sea surface temperature minus surface dewpoint is less than or equal to 1.9 degrees Celsius. Results also indicate that fog is present 85.9% of the time at the observing site within two hours of meeting the following criteria: sea surface temperature less than or equal to 19.7 degrees Celsius, onshore surface winds less than or equal to 14 knots or surface winds from any direction if the speed is less than or equal to three knots, surface air temperature minus surface dewpoint is less than or equal to one degrees Celsius and sea surface temperature minus surface dewpoint is less than or equal to 3.0 degrees Celsius.

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A DETAILED STUDY OF ADVECTION SEA FOG FORMATION TO REDUCE THE OPERATIONAL IMPACTS ALONG THE NORTHERN GULF OF MEXICO

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Last, but not least, I would like to thank my wonderful wife Leah and our children, Shelby, Carson, and Spencer for your unconditional love and support.

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I. INTRODUCTION

A. BACKGROUND

Sea fog formation has affected coastal towns and mariners for many centuries. Although it occurs at many locations throughout the globe (Figure 1), it is still a phenomenon whose development is somewhat of a mystery to today's meteorologist. Understanding how the boundary layer is affected by the sea surface properties is key to truly understanding the formation of sea fog. Unfortunately, these events occur in vast, data sparse regions over open-ocean, which makes it difficult to obtain accurate data.

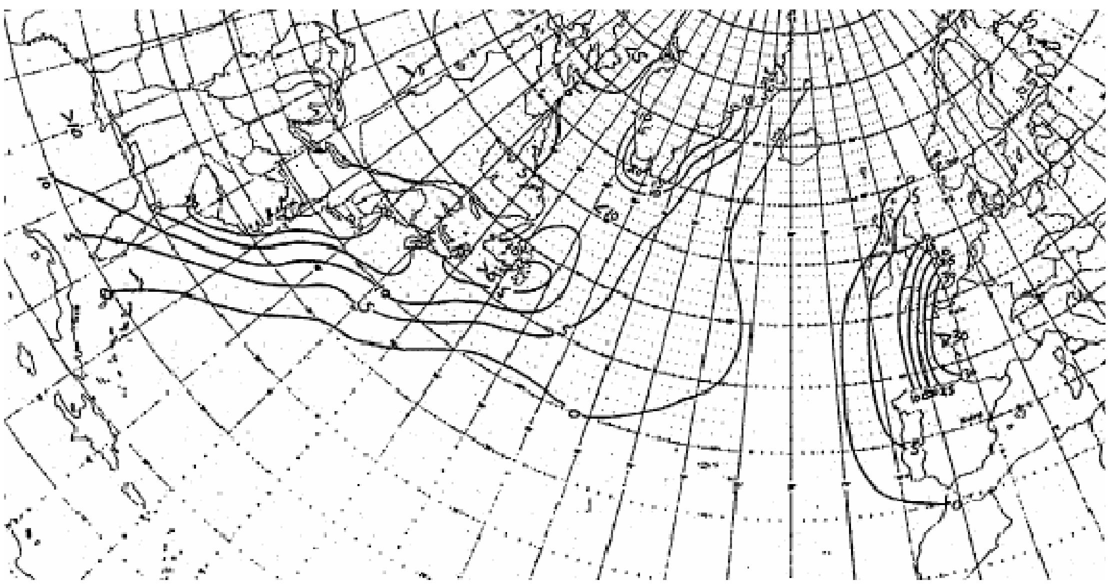

Figure 1. The frequency of fog over the North Atlantic and Gulf of Mexico for the cool season (October - March). The occurrence of fog was taken from a climatology produced for the U.S. Navy by the National Climatic Data Center at Asheville, N.C. (Guttman 1971). (From Burroughs 1987).

The formation of sea fog has great impacts for both the military and civilian communities. It affects military training operations, maritime freight transportation, commercial aviation, and many other events.

Many regions along the northern edges of the Gulf of Mexico are plagued with extensive areas of advection sea fog during the winter months. There are several Air Force Bases, as well as civilian airports that are greatly affected by this phenomenon (Figure 2). It generally occurs during the months of December through March, with January and February containing the most frequent occurrences. In a typical winter season this area will encounter approximately 12-19 days of surface visibilities equal to or less than two statute miles due to advection sea fog. Approximately 11 of those days occur during the months of January and February when the northern Gulf of Mexico is at its coolest sea surface temperatures (SST) of the year. During the spring, the shallow coastal waters warm up quite rapidly, causing the onshore flow to be much too unstable to form fog (George 1960).

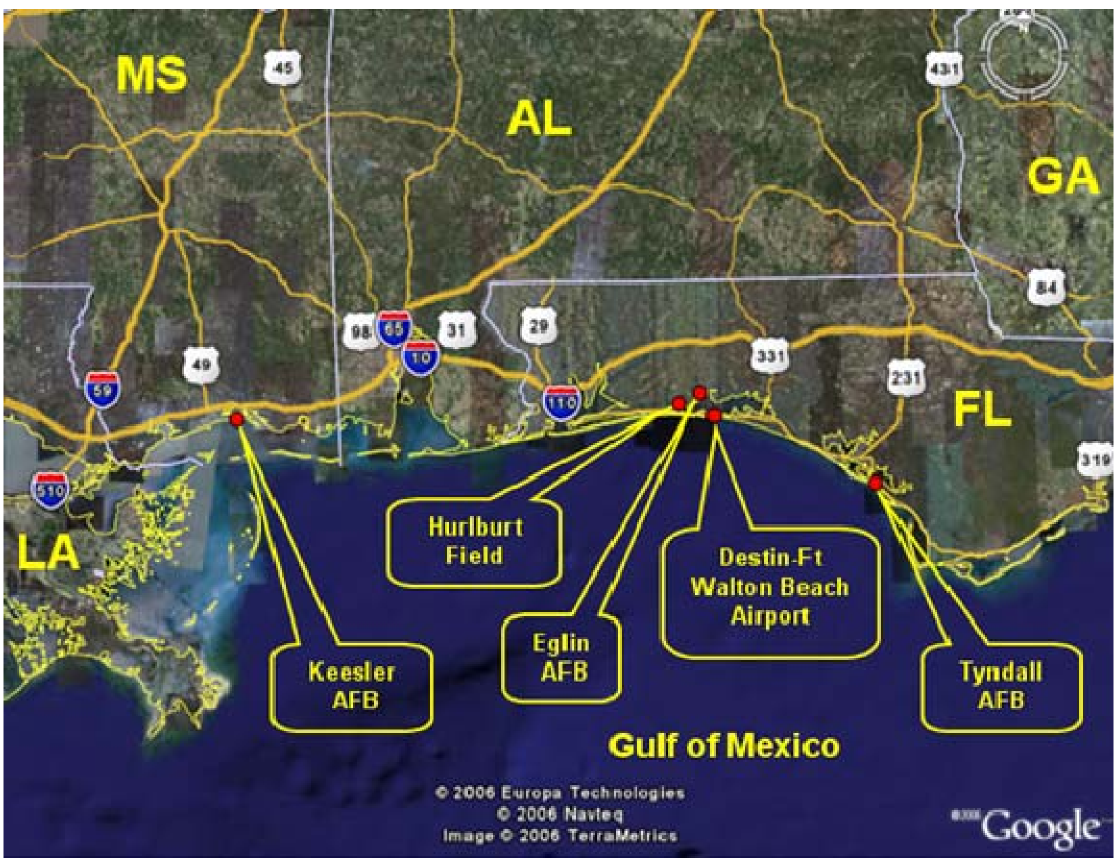

Figure 2. Keesler AFB, Eglin AFB, Hurlburt Field, Destin-Fort Walton Beach Airport, and Tyndall AFB are all located along the Northern Gulf of Mexico coast.

For many years now sea fog has received considerably less attention than fog over land (Koracin et al., 2000). One of the first major studies of fog at sea was accomplished by G. I. Taylor (1917) following the *Titanic* disaster. He conducted his research in the cold waters over the Banks of Newfoundland. In the 141 cases of fog he observed, 80% of the time the water was colder than the air (Taylor 1917; Batchelor 1996). Other early studies of sea fog were accomplished by Pettersen (1937) and Pilie et al., (1979). These studies proved that fog can form over warm water also (Koracin et al., 2000).

In 1971, a winter fog and stratus study at Eglin AFB, FL was published. It contained forecasting rules of thumb for visibility less than 7 statute miles due to fog and/or a stratus deck less than 1,500 feet. The study concentrated on onshore flow, stability, radiation and moisture content of the boundary layer over three consecutive winters. The percentage of correct forecasts over the period ranged from 68% to 77%. In the conclusion, it mentions for future investigation, if Gulf water temperatures become readily available, they should be studied for a possible connection with the fog/stratus onset and lifting times (Greenly 1971).

When sea fog is identified offshore during daylight hours, it can be expected to move over inland areas soon after sunset. After sunrise the fog will usually retreat and persist offshore throughout the day (Ricks 1981). Usually advection sea fog advects as a result of low level flow. In some cases, if the wind is light and conditions are favorable, the fog can form upstream.

B. MOTIVATION

According to the Air Transport Association, weather has a socio-economic impact to the aviation industry estimated at $6 billion annually, 40% is caused by fog and low status (Ellrod 2003). Aircraft are prohibited to takeoff or land when the horizontal surface visibility is less than the minimum weather criteria for the aircraft, pilot or the airfield. When this is the case, aircrews must cancel or postpone takeoffs and find suitable alternate airfields to land, which interrupts scheduling for the crews, customers, as well as the mission planners. These interruptions cause huge financial hardships for all parties involved.

Many of the military flying operations take place within the local Military Training Areas and Operating Areas (Figures 3 and 4). When considering Tyndall AFB, Eglin AFB, Keesler AFB and Hurlburt Field's large and varied missions, it's easy to understand that demand for the limited flying space is high. Tyndall alone schedules approximately 17,000 aircraft and airspace times per year (Vilpors 2006, personal communications). This is an extremely complex task further complicated by the onset of widespread advection sea fog common to the region during the winter months. Accurate forecasts of the timing and location of fog events enables planners to efficiently schedule valuable airspace and training missions which can cost $20K per hour.

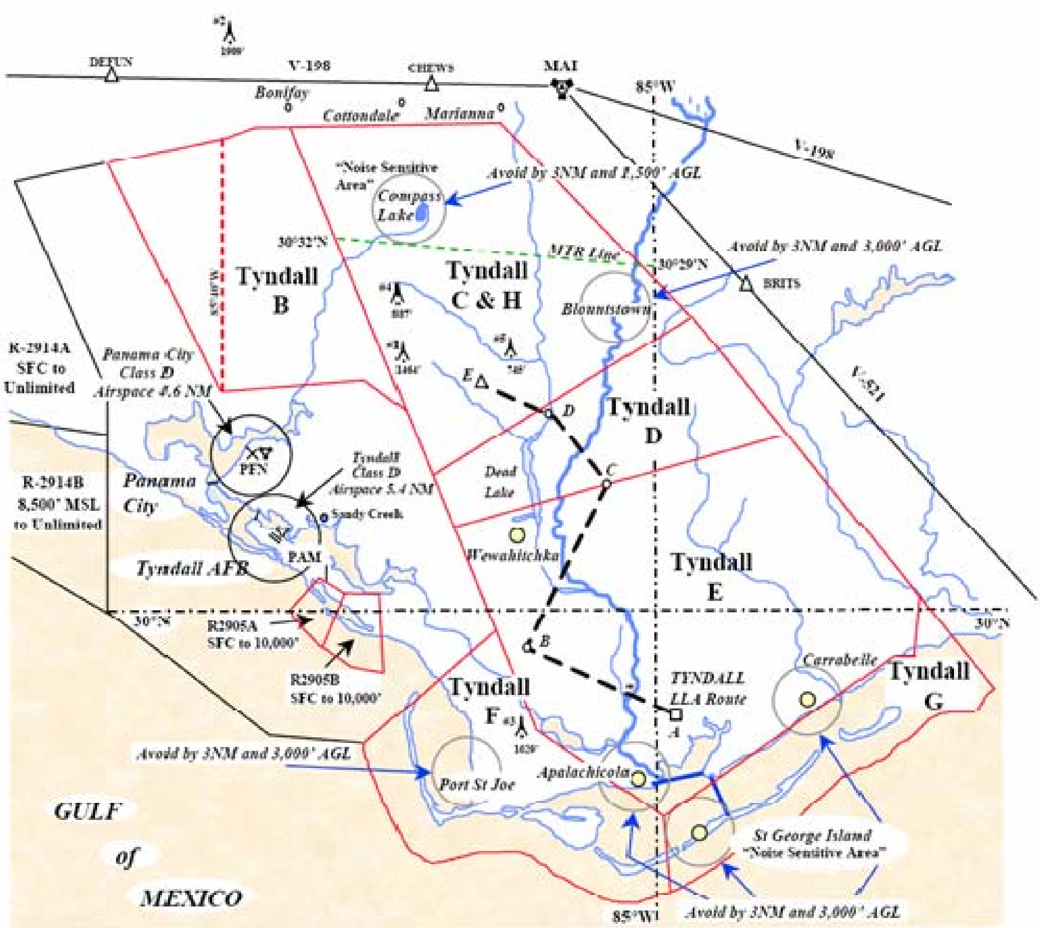

Figure 3. Illustrates Tyndall's Military Operating Areas (MOAs) and flying training areas. (From Mid-Air Collision Avoidance Pilot Education Program, Tyndall Air Force Base. http://www.tyndall.af.mil/MACA/moamap.pdf Accessed 10 September 2006).

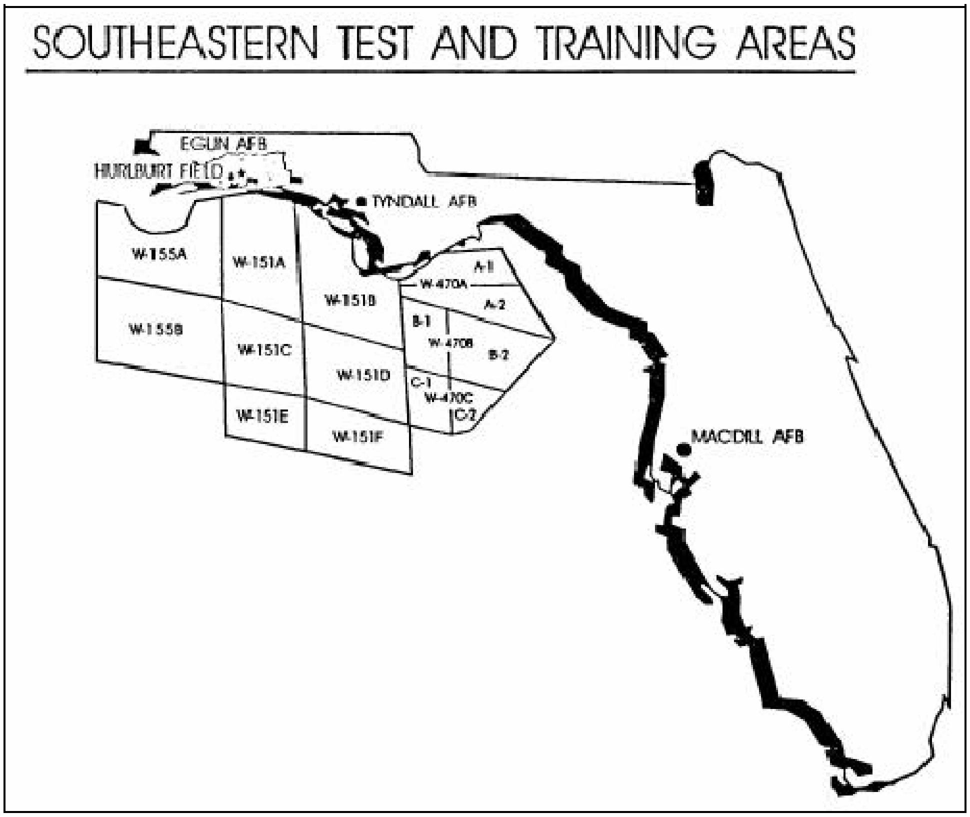

Figure 4. Illustrates some of the Military Test and Training Areas used by Keesler AFB, Eglin AFB, Tyndall AFB and Hurlburt Field off the coast of northwest Florida. (From Mid-Air Collision Avoidance Program Pamphlet, 15 December 2001. http://www.okaloosacountyairports.com/entirecolorpamphlet.pdf Accessed 10 September 2006).

1. Tyndall AFB

The host unit at Tyndall AFB is the 325th Fighter Wing, a subordinate unit of 19th Air Force and the Air Education and Training Command. Within the 325th Fighter Wing is the 1st, 2nd, 43rd and 95th Fighter Squadrons. They provide initial F-15C Eagle and F/A-22 Raptor qualification training for pilots, in addition to conversion and recurrence checkouts. Tyndall AFB is currently the only training location for the F/A-22. Another critical unit in the wing is the 325th Air Control Squadron. Their mission is to teach Battle Manager Doctrine, radar theory, surveillance operations, basic fighter control using contract-flown MU-2 aircraft and 325th Fighter Wing's F-15s. They also teach wartime E-3 operations and joint tactical operations.

Also found at Tyndall is the 53rd Weapons Evaluation Group. This group supports the Weapons Instructor Course air-to-air formal training syllabi. They operate approximately 50 full-scale QF-4 Phantom II aircraft and 85 BQM-34 and MQM-107 subscale targets to provide manned and unmanned aerial targets for local fighter aircraft. Group members also operate the Air Force's only two E-9A Widget airborne platform/telemetry relay aircraft that provide ocean surface surveillance and relay target telemetry of missiles fired over the horizon. They also conduct the Air Force Air-to-Air Weapon System Evaluation Program, known as Combat Archer. The 53rd Weapons Evaluation Group also evaluates the total air-to-air weapons system including aircraft, weapon delivery system, weapon, aircrew, support equipment, technical data and maintenance actions. They also host 38 air-to-air deployments annually at Tyndall. The annual firing of 300 missiles evaluates all Air Force air-to-air missile capabilities for the AIM-120 Advanced Medium Range Air-to-Air Missile, AIM-7 Sparrow missile, AIM-9 Sidewinder missile and aircraft guns, and also provides live missile training for combat Air Force crews. The group hosts active and guard deployments which launch 450 Precision Guided Munitions annually, which evaluate the Air Force's air-to-ground precision capabilities and also provides full-scale PGM employment training for combat Air Force crews, known as Combat Hammer. The weapons currently evaluated include the AGM-130, EGBU-15, GBU-10, GBU-12, GBU-24, GBU-27, GBU-28, GBU-31 JDAM, AGM-65 Maverick, AGM-86 CALCM, AGM-154 JSOW, AGM-88 High-Speed Antiradiation Missile, and the Wind Corrected Munitions Dispenser (United Publishers Tyndall 2006).

2. Hurlburt Field

The 16th Operations Group is assigned to the 16th Special Operations Wing at Hurlburt Field. The group plans, prepares and executes special operations, foreign internal defense, and worldwide security assistance. The 16th Operations Group also manages Air Force Special Operations Command's formal school for AC-130H/U Gunship and MC-130E/H Combat Talon I/II qualification and is the lead organization for distributive mission operations.

More than 1,400 people and 70 fixed- and rotary-wing aircraft are assigned to the group and provide day or night, all-weather access to hostile and/or denied airspace. There are six flying squadrons within the group which are located at Hurlburt Field. They operate the following aircraft: AC-130U Spooky Gunship, UH-1N Huey, C-47, MI-8, C130E, AN-26, MC-130H Combat Talon II, AC-130H Spectre Gunship, MH-53J/M Pave Low III/IV and U-28A.

Another flying unit at Hurlburt Field is the 14th Weapons Squadron. This squadron is an integral part of the US Air Force Weapons School. Their mission is to teach graduate-level instructor courses, which provide the world's most advanced training in weapons and tactics employment. They provide instruction for the F-15, F-16, A-10, AC-130, MC-130 and MH-53 airframes. (Hurlburt Field 2006)

3. Destin-Fort Walton Beach Airport

The Destin-Fort Walton Beach Airport is a general aviation, public use facility owned and operated by Okaloosa County. There are approximately 75 aircraft permanently based on the field. The airport has an average of 172 aircraft operations everyday, with 74% consisting of transient general aviation, 24% local general aviation, 1% air taxi and 1% military (AirNav.com 2006).

4. Eglin AFB

Eglin Air Force Base is the Air Force's largest base. It is also home to the Air Armament Center, the primary weapons research and development center for the United States Air Force. The Eglin Range consists of 724 square miles over land and 130,000 square miles over water with 51 specific test and training areas. The Eglin Range is the only weapons testing range that contains both water and land ranges in the Department of Defense (United Publishers Eglin 2006).

Eglin AFB also is host to many aviation units, including 33rd Fighter Wing, 53rd Wing, the Army's 6th Ranger Training Battalion and Unmanned Aerial Vehicle Battlelab. Eglin maintains a total of over 120 aircraft, including F-16, F-4, A-10, F-111, T-38, F-15, UH-1 and the C-130, AC-130, RF-4 and HC-130 aircraft, and generates more than 500 sorties per month. (Weaver 2006).

Eglin AFB is also the home of several weapons test and evaluation units, including AFOTEC Det 2, 53rd Wing, 308th Armament Systems Wing, 328th Armament Systems Wing and 46th Test Wing. The mission for these units is to ensure the Department of Defense is equipped with superior weapons systems.

5. Keesler AFB

Keesler is home to the headquarters of the 2nd Air Force and the 81st Training Wing. The 81st Training Wing oversees technical training for officers, airmen and civilians of the U.S. Air Force, Air National Guard and other Department of Defense agencies. The training covers numerous electronic, avionics, computer, personnel, and information management career fields. The only flying wing at Keesler is the 403rd Wing, which is an Air Force Reserve Wing that provides tactical airlift support during peace and war-time contingencies, and aerial weather reconnaissance in support of the Department of Commerce. The 403rd trains and performs its missions by utilizing eight C-130 Hercules transport aircraft, and 10 WC-130s, specially equipped with weather-gathering instrumentation (Keesler 2006).

C. CURRENT FORECASTING TECHNIQUES

The 9th Operational Weather Squadron (OWS) at Shaw AFB, South Carolina is responsible for providing operational forecasts and resource protection for Tyndall AFB, Eglin AFB and Hurlburt Field, while the 26th OWS at Barksdale, Louisiana is responsible for Keesler AFB. The Combat Weather Teams (CWTs) at Tyndall AFB, Eglin AFB, Keesler AFB and Hurlburt Field tailor the forecasts from the OWS to create mission execution forecasts which support their own unique air and ground operations.

The Keesler CWT devised a sea fog and advection graph that they use to forecast advection sea fog events (Figure 5). This graph is a means of comparing the temperature and dew point differences that exist at 1800L between the sensors at Keesler AFB and the mean Gulf of Mexico temperature. Verification of this graph yielded an 89% correct forecast for at and below 700 foot ceilings or at and below 3/4 mile visibility (Keesler AFB Combat Weather Team's Forecast Reference Notebook 2006). The Keesler CWT uses a forecasting rule of thumb which says to forecast conditions of 700 feet or less and visibilities 3/4 miles or less when the 1800L dew point is 60°F or higher during the months of December, January and February.

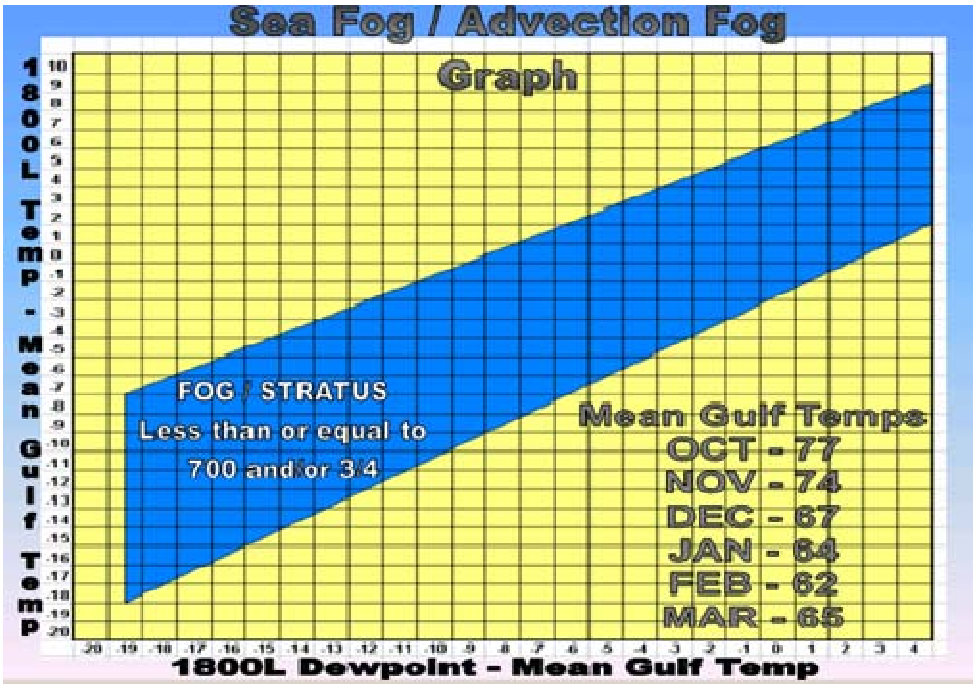

Figure 5. Advection sea fog forecasting tool used by Keesler CWT (From Keesler AFB Combat Weather Team's Forecast Reference Notebook).

The Eglin Forecast Reference Notebook guides the forecaster to forecast fog if the bay or Gulf surface temperatures are cooler than the surface dewpoints and southeast flow has been present for 24 hours.

The National Weather Service Forecast Office (NWSFO) in Tallahassee, Florida provides weather support for the civilian sector in this region, which includes forecasts for Destin-Fort Walton Beach Airport. This NWSFO currently does not have a forecasting technique for advection sea fog formation.

The advection sea fog characteristics in southern Louisiana have some similarities to the advection sea fog found off the Florida Panhandle Coast. The NWSFO in New Orleans/Baton Rouge, Louisiana, after much research, has constructed the following flowchart (Figure 6) to help their forecasters anticipate the onset of advection sea fog in their area of responsibility. This flowchart is very similar to the advection sea fog forecasting tool used by Keesler CWT. They both compare the sea surface temperature, atmospheric temperature and dewpoint to forecast for fog.

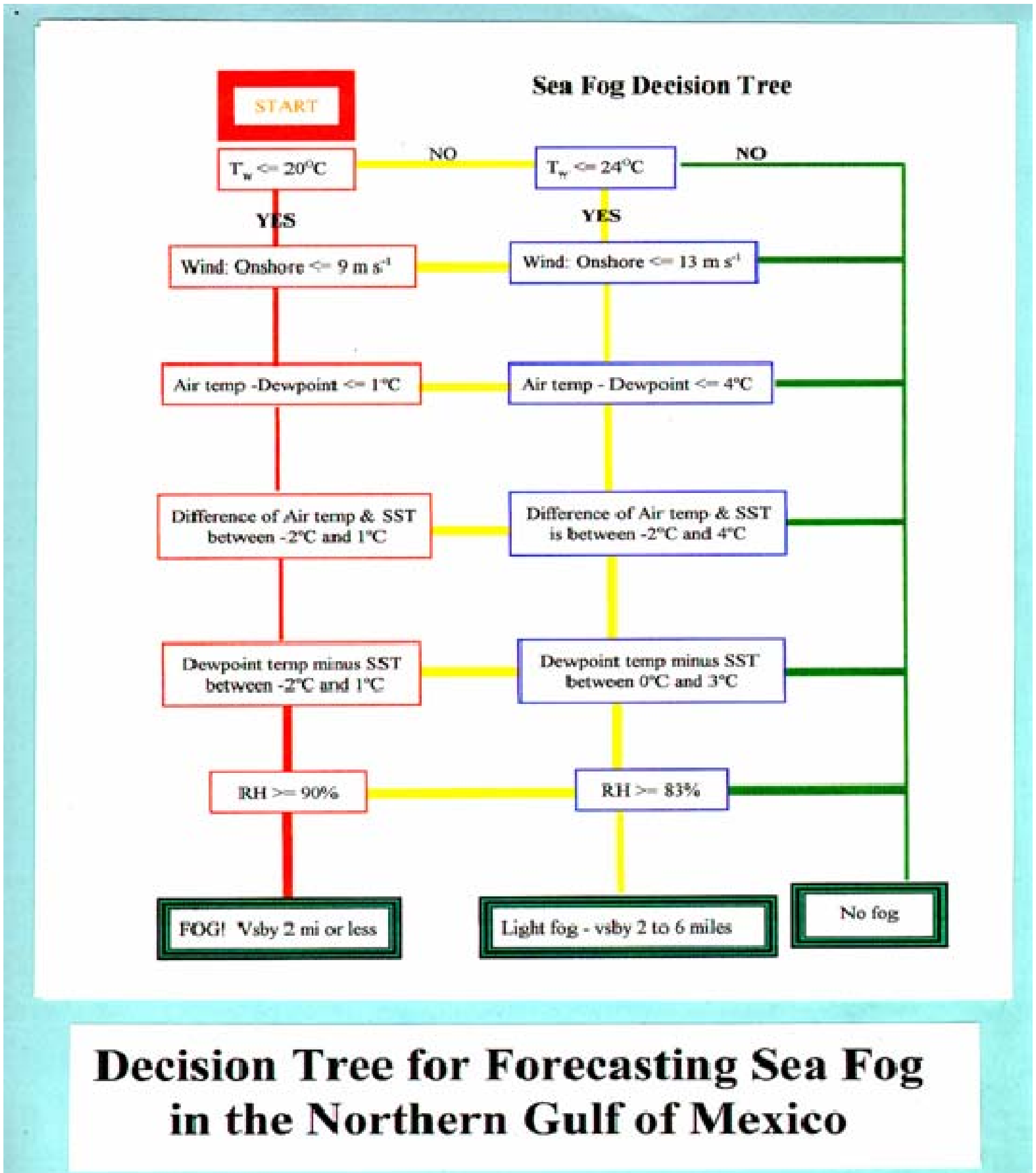

Figure 6. Shows the New Orleans/Baton Rouge NWSFO's Sea Fog Forecasting Decision Tree (From http://www.srh.noaa.gov/lix/html/seafog.htm Accessed 15 January 2007).

D. STATEMENT OF THE PROBLEM

During winter, a large problem facing forecasters along the Northern Gulf of Mexico region is the timing and location of advection sea fog. The timing and location are a function of the properties of the sea surface as well as the atmospheric boundary layer characteristics. Therefore, an accurate forecast of the sea surface temperature and the atmospheric boundary layer characteristics are critical steps in accurately forecasting advection sea fog timing and location.

The purpose of this study is to:

1. Examine the sea surface temperatures and the atmospheric boundary layer characteristics before, during and after advection sea fog events along the Northern Gulf of Mexico.
2. Determine accurate rules of thumb for forecasting advection sea fog formation and duration to be utilized by National Weather Service and military forecasters to increase the accuracy of advection sea fog forecasting.

This study will be restricted to the cold season, defined as December through March. The period of study is February 2005 to March 2006 for Tyndall AFB, Eglin AFB, Hurlburt Field and Destin-Fort Walton Beach Airport. The period of study for Keesler AFB is December 1999 to March 2004 and from December 2005 to March 2006. Surface weather observations were used to determine boundary layer characteristics and sea surface observations were used to determine sea surface temperatures in order to study the hourly evolution of the advection sea fog along the coast of the Northern Gulf of Mexico.

II. BACKGROUND

A. ADVECTION SEA FOG FORMATION

Advection sea fog, which is the most common type of sea fog, occurs when synoptic situations force warm, moist air over water that is cooler than the dewpoint. In this case, the sensible heat transfer from the air to the sea surface dominates (Binhua 1985). These conditions are favorable for fog formation due to the cooling of the warm, moist air. This usually occurs on the cold side of a strong sea surface temperature gradient. This type of fog event is the most persistent, expansive and frequently occurring in the world (COMET 2003).

B. MODIFYING EFFECTS

1. Sea Surface Temperature

Sea surface temperatures (SSTs) are one of the main factors in the development of advection sea fog. According to Binhua (1985) and illustrated in Figure 7, vast fog regions occur over sea areas where the SST is less than 20° C. Areas where the SST is between 20° C and 25° C have less fog development. When the SST is greater than 25° C, advection sea fog will not occur. Therefore, 25° C is considered the upper limit of SST for the formation of advection sea fog.

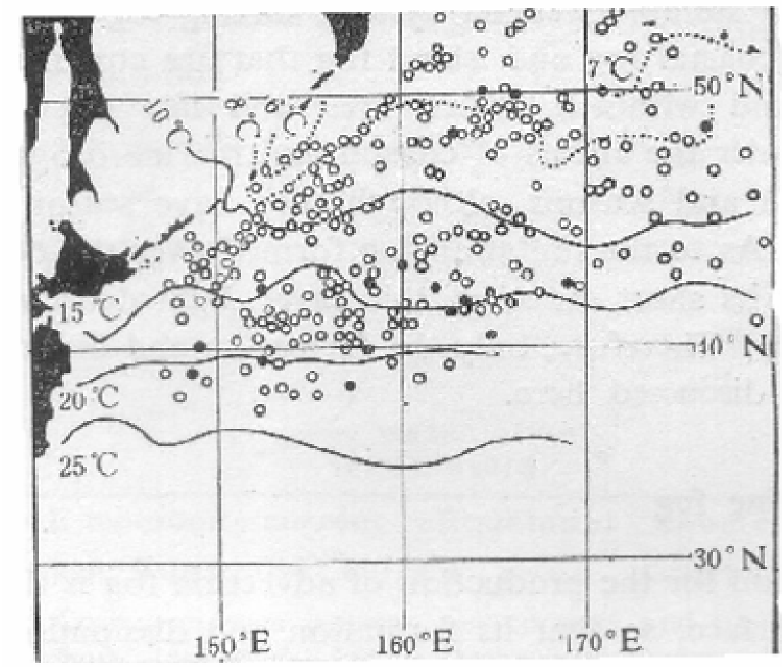

Figure 7. Illustrates the sea fog in relation to sea surface temperatures (11-20 July 1961). The white filled data points represent fog at the time of the observation. The black filled data points represent fog within 3 hours before the observation (From Binhua 1985).

The COMET module on advection fog (2003) explains that advection sea fog frequently develops over oceanic regions where ocean currents cause strong SST gradients. In these areas, warm poleward moving currents encounter cool equatorward moving currents and form a strong SST gradient. The fog generally develops over the cool water regions in these areas as seen in Figure 8.

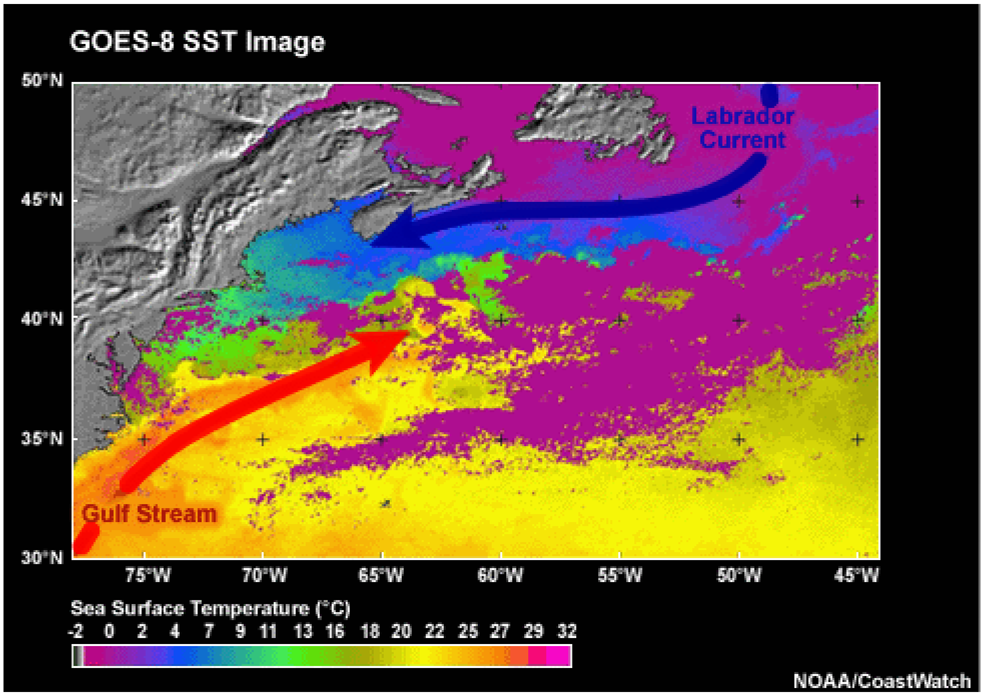

Figure 8. Fog tends to form on the cold side of a strong SST gradient (From COMET, http://www.meted.com/mesoprim/dynfog Accessed 10 September 2006).

2. Wind Speed and Direction

Wind speed and direction are very important in advection sea fog development. The synoptic situation must be such that the lower boundary layer flow must advect moist air from areas of warmer sea surface temperatures to areas of cooler sea surface temperatures at a rate at which the air can cool to its dewpoint and remain there. Usually, in order for the advection sea fog to move onshore, the direction of the wind must contain an onshore component. Generally, offshore boundary layer flow is relatively dry, which will lower dewpoint temperatures along the coast and inhibit advection sea fog development in these areas.

If the wind speed is too great, proper amounts of sensible heat transfer may not take place; therefore, the air will not be cooled to its dewpoint and condensation will not take place. Also, the high wind speeds can cause too much mixing in the lower portion of the boundary layer, resulting in no fog development. However, it is possible, if conditions are ideal, for fog to occur with surface winds up to 40 knots. A more stable boundary layer as well as the lack of terrain features are factors that contribute to the ability of fog formation in these high wind situations (COMET 2003).

3. Salt Content in the Lower Atmosphere

Binhua (1985) shows that fog formation can be related to the amount of salt in the lower atmosphere. This can be expressed by Raoult's Law, which states:

$$E_p = \frac{N(E_\infty)}{n + N}$$

where E_p and E_∞ are the saturation vapor pressures over a solution surface and a plane water surface respectively, n is the moles of the solute and N is the moles of the solvent (Binhua 1985). In the case of sodium chloride nuclei, E_p was found to be

$$E_p = 0.78(E_\infty).$$

Therefore, the saturation vapor pressure is much less over soluble NaCl nuclei than over pure water surface (Binhua 1985). In other words, the condensation begins on NaCl nuclei before the relative humidity of the air reaches 100%. So in the case of advection sea fog, which many of the nuclei contain NaCl, salt content in the air is very important for its formation and intensity.

4. Boundary Layer Characteristics

The inversion characteristics at the top of the boundary layer plays a part in the development of advection sea fog. Binhua (1985) states that fog tends to form when there is an inversion, and it tends to dissipate or transform into a low cloud with the breakdown of the inversion.

In the case of advection sea fog, the low level trajectory must initially be over areas with an upward heat flux and moisture flux. This process increases the moisture content and therefore raises the dewpoint. Due to the instability in the boundary layer at this time, the higher moisture content is well mixed through the layer. As the trajectory advects the recently moistened boundary layer over areas with a downward heat flux, the boundary layer begins to cool which strengthens the inversion. This cooling process continues until condensation occurs.

5. Droplet Size, Concentration and Liquid Water Content

Horizontal surface visibility in fog is extremely difficult to forecast. The visibility is determined by several factors, including size and concentration of the water droplets, as well as the liquid water content in the fog (Binhua 1985). To illustrate this, Kosehmieder (1920) proposed a mathematical formula for the horizontal visibility in fog,

$$V = \frac{\log \frac{1}{\varepsilon}}{\pi n r^2}$$

where V is the visibility in cm, ε is the ratio of the difference of brightness between the background and the object to the brightness of the background, n is the number of water droplets per cubic cm, and r is the diameter of the droplet. ε is usually in the range of 0.01-0.02, but can be as high as 0.06 for very dense fog (Binhua 1985). If ε is considered to be a constant, the following can be written:

$$V = \frac{C r_m}{\Delta a}$$

where r_m is the radius of the droplets in μm, Δa is the liquid water content in fog (g/m^3), C is a constant and is equal to 2.5 and V is the visibility in meters (Binhua 1985).

E. J. Mack et al., (1973) conducted two separate studies near the Farallon Islands off the coast of San Francisco, California in August 1972. On 19 August the 5m visibility decreased rapidly from 2200m to 200m and then increased to more than 1000m and remained. During this time, the liquid water content increased to a maximum of 90 mg/m^3, in addition the concentration of droplets increased to $45/cm^3$. This is one example that the liquid water content as well as the concentration of droplets are directly related to the visibility (Binhua 1985).

C. AREA GEOGRAPHY

1. Tyndall Air Force Base Geography

Tyndall Air Force Base is located on the Northwest Florida Gulf Coast at 30.04° N, 85.35° W. It is on a 15-mile long peninsula averaging 3 miles in width and lying amid East Bay, St. Andrews Bay and the Gulf of Mexico (Figure 9). Several small islands dot the coast, but they do not significantly affect the region's climate.

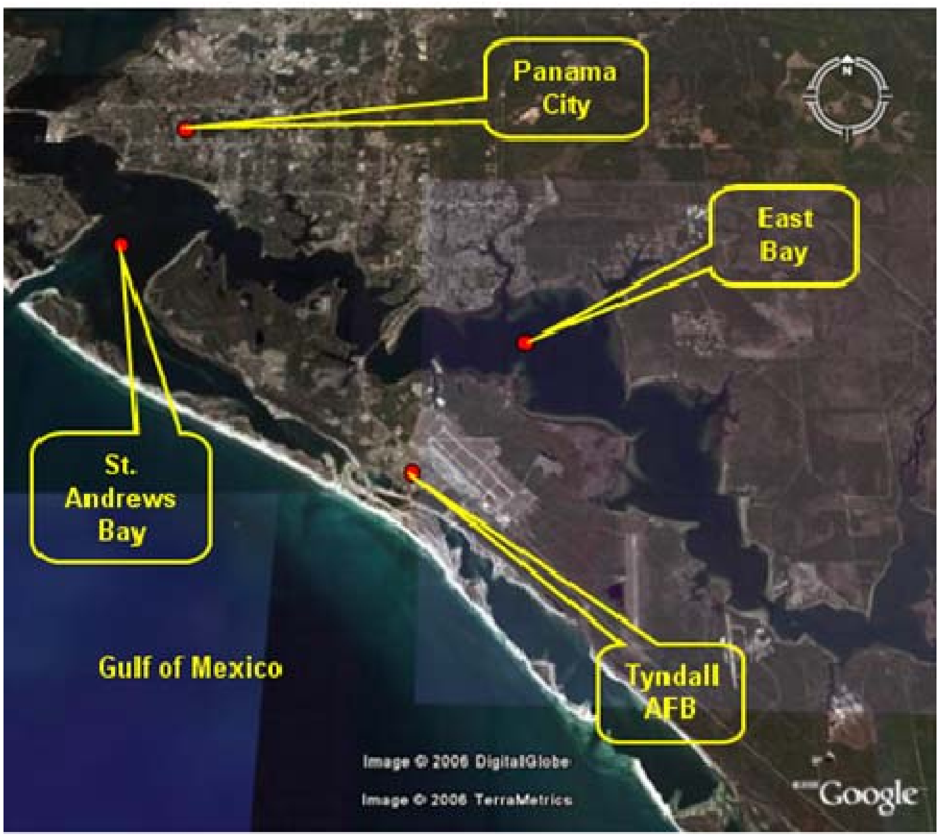

Figure 9. Location of Tyndall AFB and surrounding area.

Most of the area around Tyndall is marshland, but a heavily wooded region lies to the east. Panama City lies approximately eight miles to the northwest. Tyndall's field elevation is 18 feet, with no significant variations within the airfield complex. Within 100 miles of the base, gently rolling terrain dominates the countryside, with elevations 400 feet or less.

The coastal bays are large, shallow bodies of water, fed directly with fresh water inflow. Tyndall lies two miles from the East Bay and about 2.5 miles from St. Andrews Bay. The water depth of the bays rarely exceeds 40 feet. This allows for water temperature fluctuations much greater than those of the deeper Gulf of Mexico, both diurnally and seasonally.

Tyndall AFB is approximately 1.5 miles from the Gulf of Mexico. The Gulf's depth slowly drops to 100 feet, 11 miles offshore. Much further offshore, the water depth eventually drops to more than 12,000 feet. The temperature of the relatively shallow Gulf water fluctuates more rapidly than the temperature of the deeper water found further from shore.

Inspection of Figure 9 reveals that the coastline along this region is oriented 130° - 300°, which results in southeasterly, to southerly, to northwesterly flow being considered onshore flow. This onshore flow is important because it will advect the fog that forms over the cool Gulf waters inland (Tyndall AFB's Forecast Reference Notebook).

2. Hurlburt Field Geography

Hurlburt Field is located on the northwest Florida Gulf Coast at 30.42° N, 86.69° W. Large bodies of water and low hills dominate the topography (Figure 10). One half mile to the south is Santa Rosa Sound. This shallow sound is approximately .5 mile wide and is separated from the Gulf by Santa Rosa Island. Choctawatchee Bay lies six miles east, while East Bay and Pensacola Bay are approximately 15 and 25 miles to the west respectively. All of the surrounding bays rarely exceed 40 feet in depth. The Gulf of Mexico lies two miles to the south and gradually drops to a depth of 100 feet eight miles offshore. Inspection of Figure 10 reveals that the coastline along this region is oriented 110° - 260°, which results in almost any flow with a southerly component being considered onshore flow. Swamps and rivers dissect the low hills to the north. From the coast, the terrain rises slowly inland. Rolling hills reach 250-345 feet near the Alabama state line.

Figure 10. Location of Hurlburt Field, Destin-Fort Walton Beach Airport, Eglin AFB and surrounding area.

3. Destin-Fort Walton Beach Airport Geography

The Destin-Fort Walton Beach Airport is located at 30.40° N, 86.47° W. It is on a 23-mile long peninsula averaging two miles in width and lying between the Choctawhatchee Bay to the north and the Gulf of Mexico to the south (Figure 10).

Most of the area on the peninsula is populated. Destin lies approximately 1 mile to the west of the airport. The field elevation is 23 feet, with no significant variations within the airfield complex. The topography inclines northward from the Gulf of Mexico, and reaches Florida's highest elevation of 345 feet, approximately 40 miles to the north-northwest of the airport.

The Choctawhatchee Bay is a large, shallow body of water, which rarely exceeds 40 feet. Marshland and swamps line the northern edge of the bay. The airport complex lies approximately one mile from the Gulf of Mexico. About 8 miles offshore, the Gulf drops to a depth of 100 feet. Inspection of Figure 10 reveals that the Gulf coastline along this region is oriented 110° - 260°, which results in almost any flow with a southerly component would be considered onshore flow.

4. Eglin Air Force Base

Eglin Air Force Base is located on the northwest Florida Gulf Coast at 30.48° N, 86.53° W and has a field elevation of 87 feet. It lies on the northwest shore of the relatively shallow Choctawhatchee Bay, which is fed directly with fresh water inflow. The topography inclines gently to the north and is a minor weather factor. The majority of the terrain is either flat or made up of gentle rolling hills with many shallow creeks, numerous ponds and marshes.

Eglin is located approximately two miles from the Choctawhatchee Bay and 7 miles from the Gulf of Mexico. The town of Niceville is across a small branch of the Choctawhatchee Bay and is about three miles to the northeast. Inspection of Figure 10 reveals that the coastline along this region is complex due to the meandering shore of the bay. This results in a low level flow of roughly 90° - 210°, being considered onshore flow.

5. Keesler Air Force Base Geography

Keesler Air Force Base is located 30.41° N, 88.92° W, with a field elevation of 33 feet MSL. The base is located on the western side of the city of

Biloxi, MS. Keesler AFB is on the lower end of the east-west oriented Biloxi Peninsula that is approximately 10 miles long and one and one half miles wide (Figure 11). The flat sandy peninsula is separated from the mainland by the one half-mile wide Back Bay. The Biloxi Peninsula is protected from the deeper waters of the Gulf of Mexico by a chain of narrow islands 11 miles offshore. The shallow waters between the Biloxi Peninsula and the island chain constitute the Mississippi Sound, which has an average depth of 18 feet. To the south, the airfield complex lies approximately 1 mile from the sound. The northern end of the runway ends approximately 200 feet from the Back Bay. The terrain is very flat with small changes in elevation as you move north. Inspection of Figure 11 reveals that the coastline along this region is oriented 90° - 260°, which results in almost any flow with a southerly component being considered onshore flow.

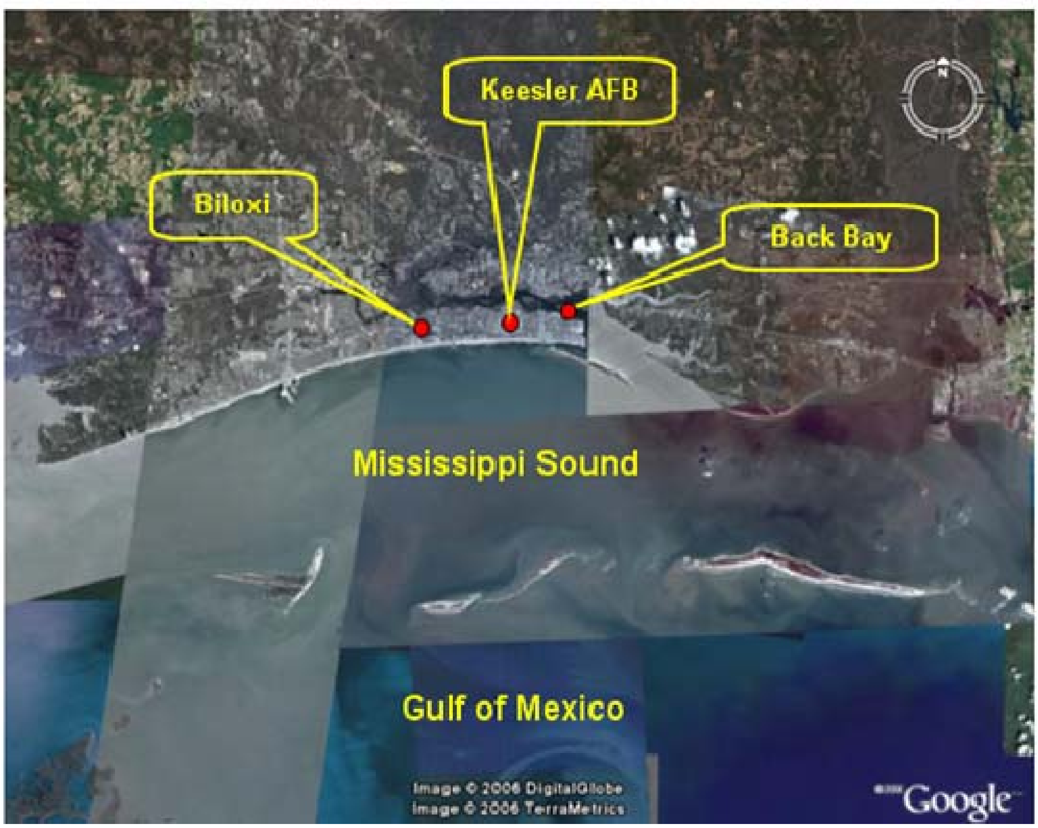

Figure 11. Location of the Keesler AFB and surrounding area.

D. WINTER CLIMATOLOGY

Several criteria have been given for advection sea fog development. One criterion is that the SSTs must contain a strong temperature gradient, with the cool sector being less than 25°C (Binhua 1985). The stronger the gradient, and the colder the cool sector, the greater the likelihood of fog formation. In the fall, the rivers empting into the Gulf of Mexico carry cooler water progressively into the coastal areas and a sharp temperature gradient is rapidly established (George, 1960). Figure 12 shows an example of this sharp gradient in the Gulf of Mexico during January 2006. The figure below is a combination of two images from two slightly different times on 25 January. This was done so the entire coastline could be shown in one image.

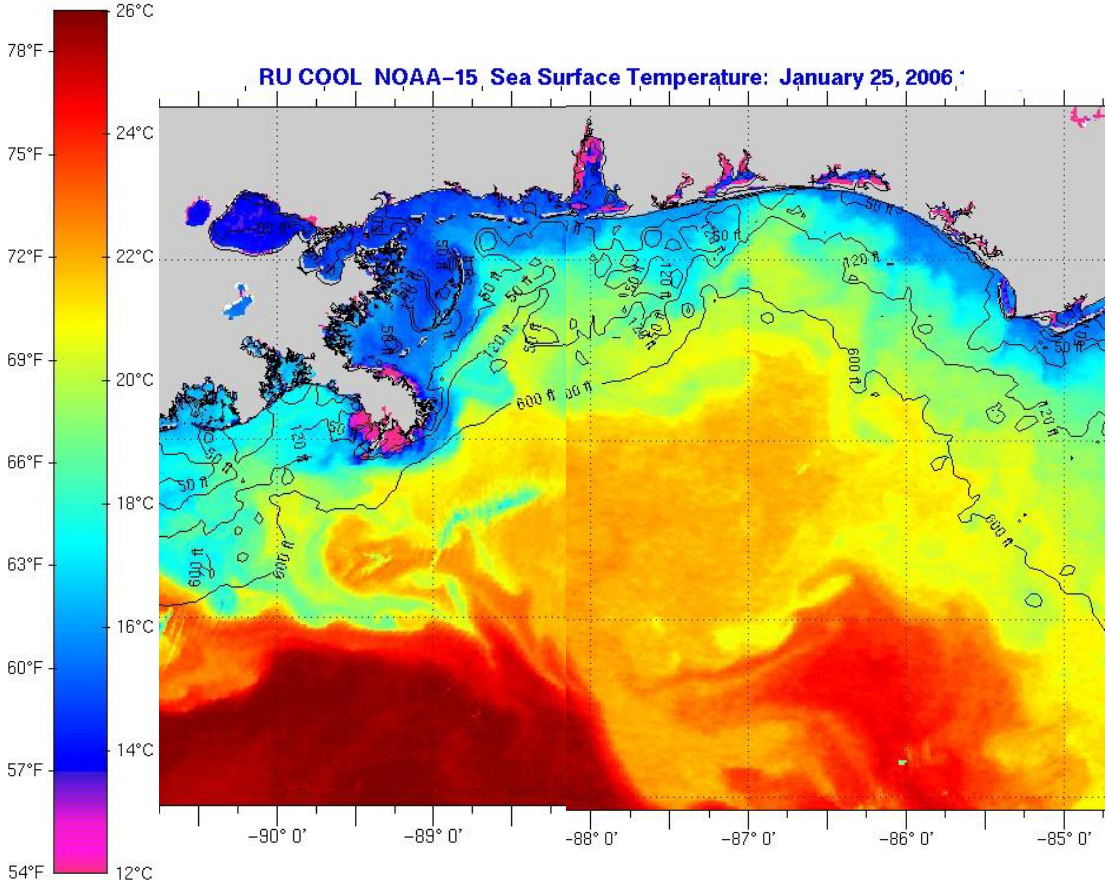

Figure 12. NOAA-15 satellite image from Rutgers University shows the strong SST gradient in place during January 2006 (After http://www.marine.rutgers.edu/mrs/sat_data/?product=sst&nothumbs=0 Accessed 5 December 2006).

Figure 13 shows the average monthly sea surface temperatures recorded for location 30.00° N, 86.00° W, which is located in the Gulf of Mexico approximately 25 miles WSW of Tyndall AFB. According to Binhua (1985), advection sea fog can form when SSTs are less than 25°C, and the colder the SSTs, the more fog events. With this in mind, we would expect a possibility of advection sea fog activity starting in late October, reaching maximum intensity in February, and then ending by May.

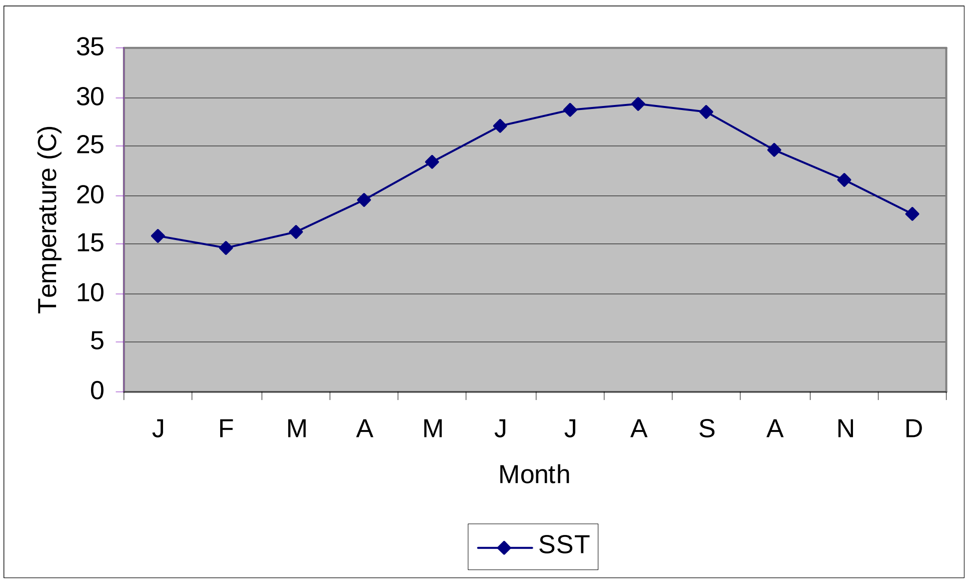

Figure 13. Shows the average monthly sea surface temperatures (°C) for location 30.00° N, 86.00° W (blue), which is located 25 miles WSW of Tyndall AFB. Data was obtained via US Navy Fleet Numerical Meteorology and Oceanography Center.

Another important criterion is that the surface dewpoint must be greater than the cool SSTs for advection sea fog to develop. To accomplish this, the low level flow must travel over the warm Gulf waters long enough to gain moisture, therefore raising the dewpoint. Then the warm, moist air must travel to the north over the cool SSTs at a rate that allows the water to cool the air to its dewpoint. We can use this information to determine when the advection sea fog may develop along the northern Gulf of Mexico.

Shown below in Figures 14 through 17, is the percentage of frequency of surface wind speed by direction at Tyndall AFB, Hurlburt Field, Eglin AFB and Keesler AFB for the month of February. Destin-Fort Walton Beach Airport is not represented because of lack of data. The percentage of frequency is listed along the y-axis with each wind rose containing a different scale.

Onshore flow at Hurlburt Field is from 110° through 260°. As seen in Figure 14 below, onshore flow for all wind speed ranges occurs roughly 23% to 49% of the time, depending on the time of day. This translates to advection sea fog having the possibility of occurring 23% to 49% of the time, as long as the other advection sea fog parameters are met. During daytime maximum atmospheric temperatures (18Z and 00Z) the frequency of onshore flow increases, similar to the other locations, which increases the likelihood of sea fog being advected over land. The wind speeds tend to increase around 18Z, which makes it more difficult for fog formation.

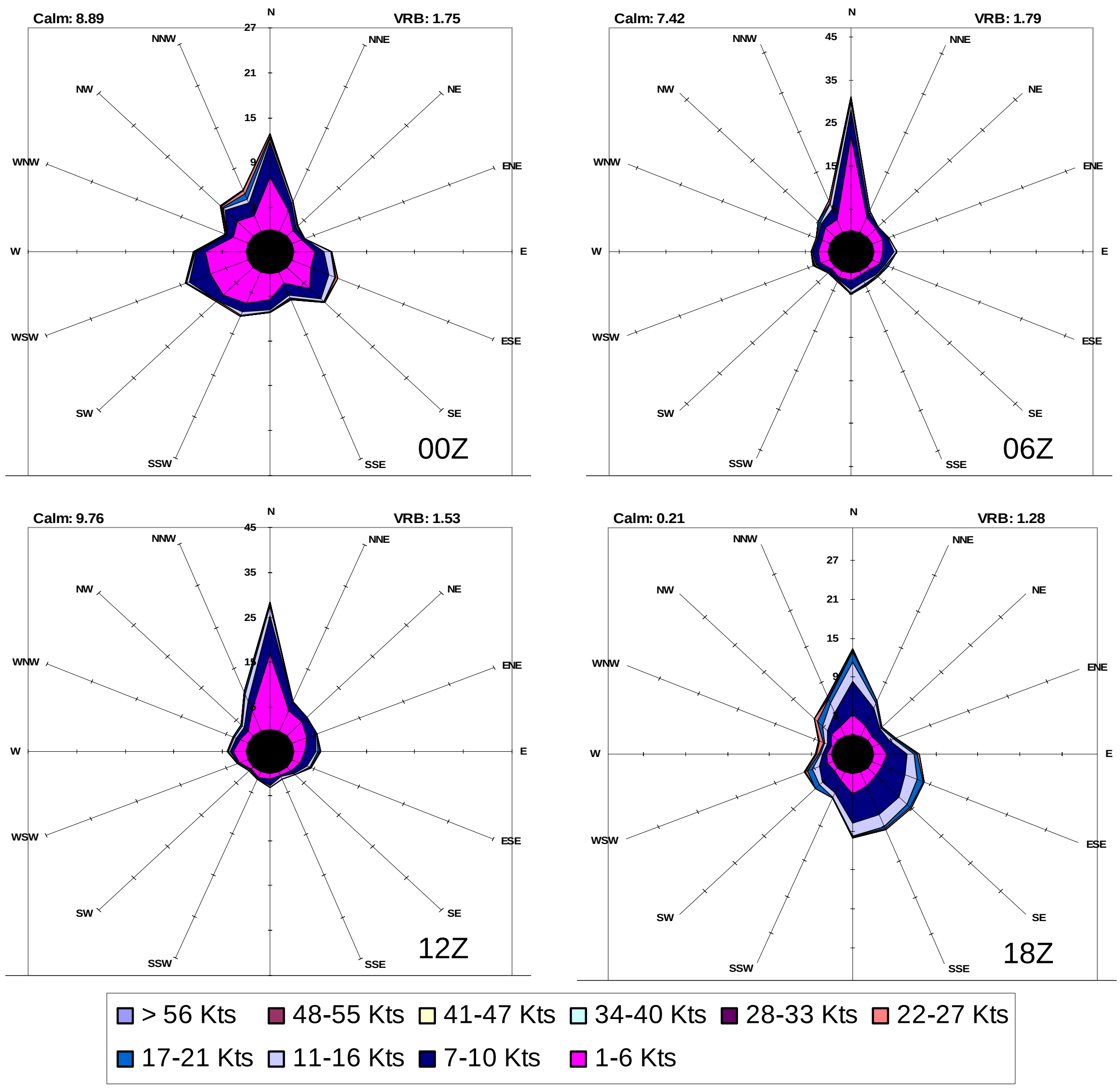

Figure 14. Percentage of frequency of surface wind speed by direction at Hurlburt Field during 00Z, 06Z, 12Z and 18Z for the month of February.

Flow at Tyndall AFB is considered onshore when the direction is from 130° through 300°. Figure 15 shows onshore flow at Tyndall AFB occurs 23% to 49% of the time for all speed ranges, depending on the time of day. This is the same percentage of frequency as Hurlburt Field. Advection sea fog has the possibility of occurring 23% to 49% of the time. Similar to the other locations the onshore speeds increase during warmer part of the day.

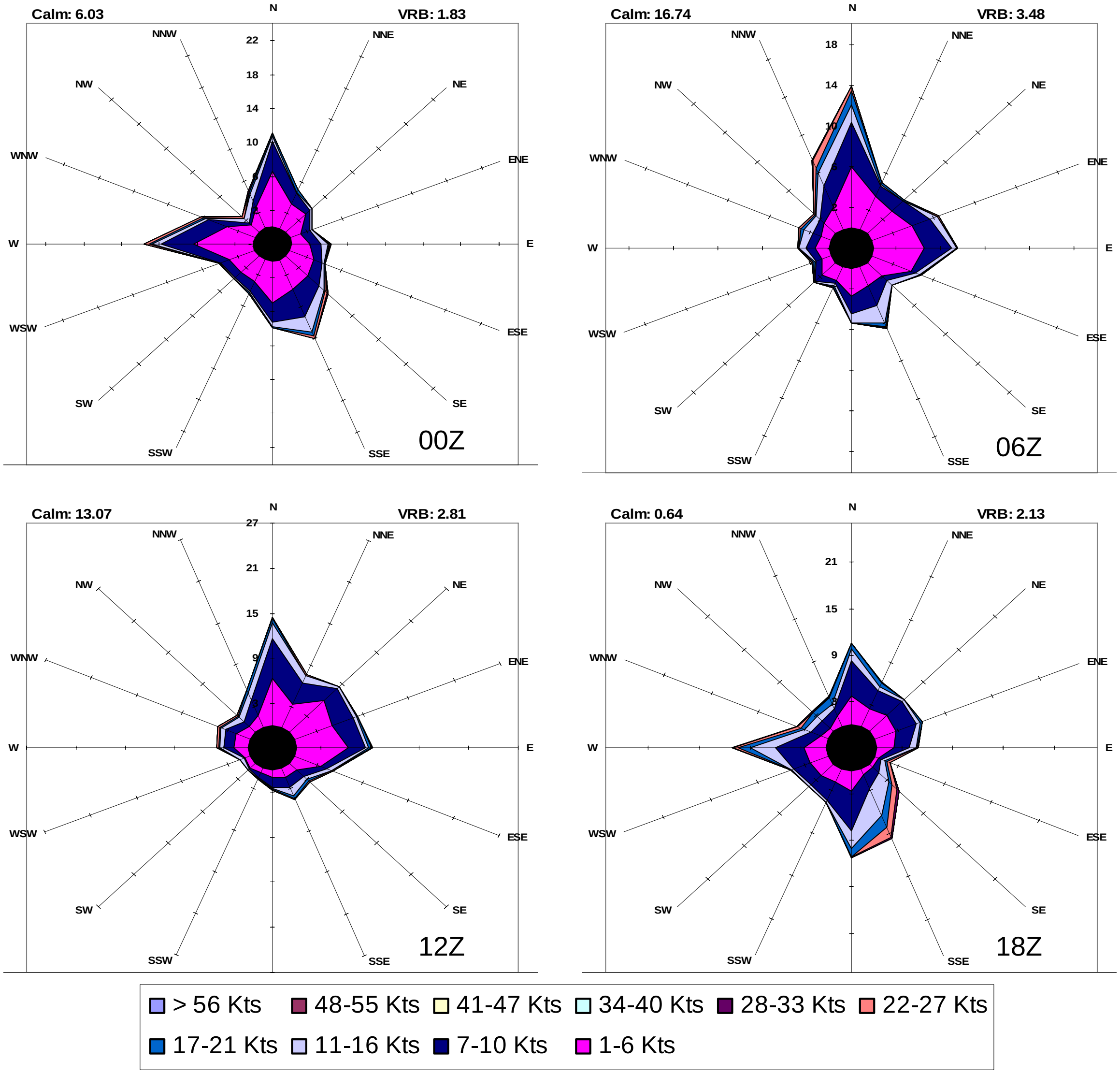

Figure 15. Percentage of frequency of surface wind speed by direction at Tyndall AFB during 00Z, 06Z, 12Z and 18Z for the month of February.

In this study, surface flow between 90° and 210° is considered onshore flow at Eglin AFB. This onshore component window is 30° to 50° narrower than the other locations; therefore we would expect a lower percentage of frequency. Figure 16 shows onshore flow occurs 10% to 39% of the time when all speeds are considered.

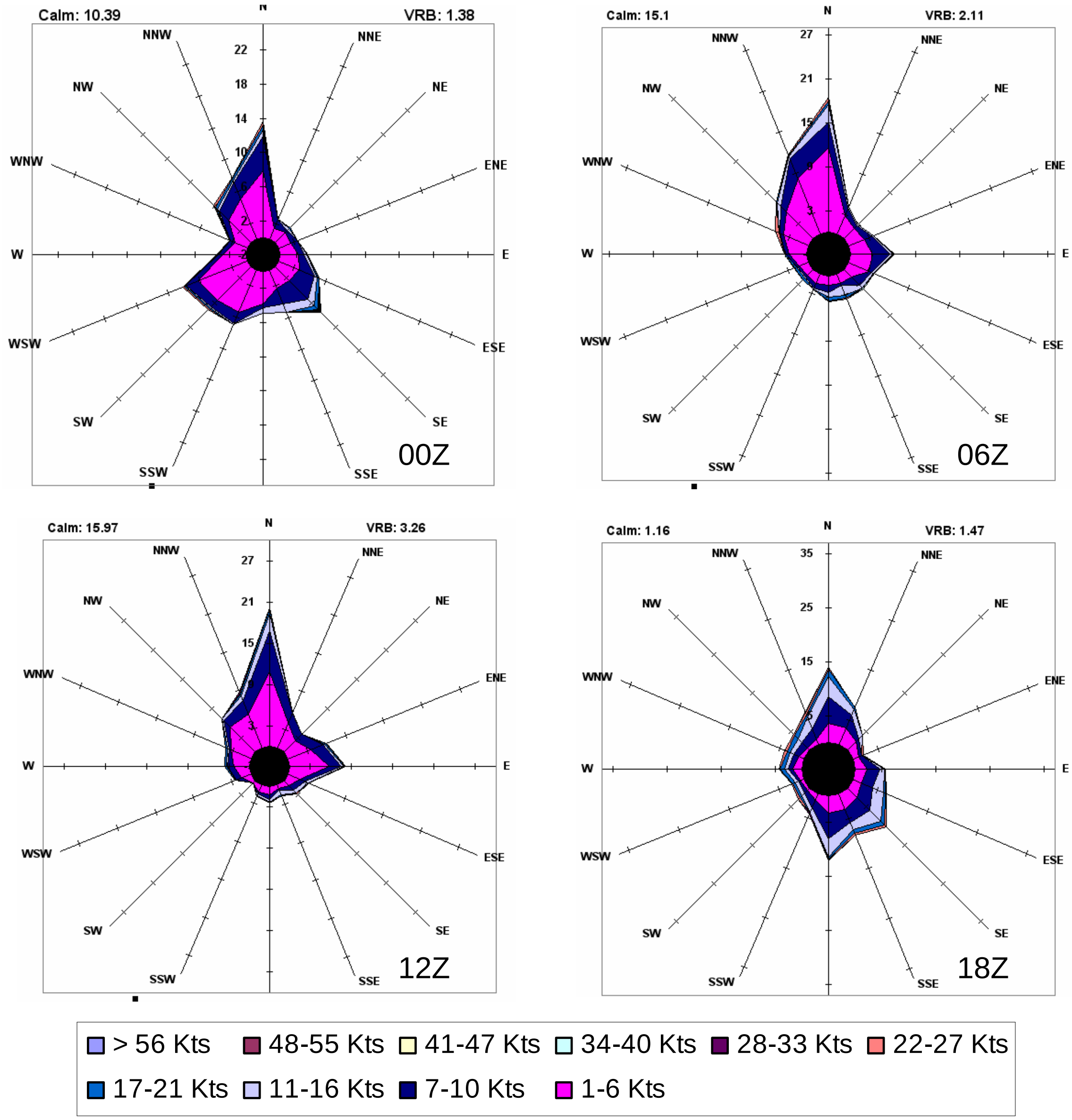

Figure 16. Percentage of frequency of surface wind speed by direction at Eglin AFB during 00Z, 06Z, 12Z and 18Z for the month of February.

Onshore flow at Keesler AFB is from 90° through 260°. Roughly 20% to 47% of the time there is onshore flow. Like the other locations Keesler AFB has maximum onshore flow during the time of maximum atmospheric temperatures.

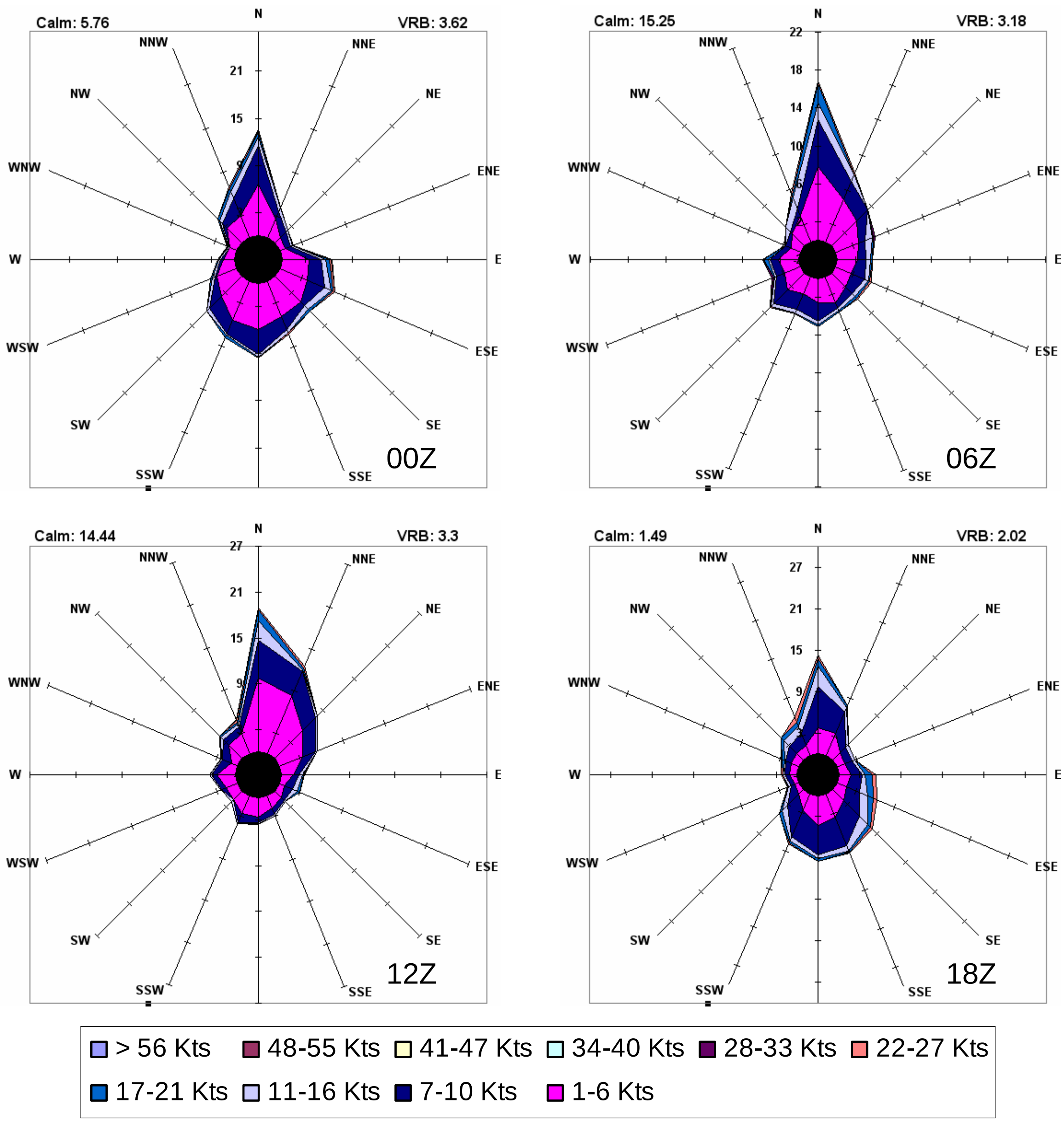

Figure 17. Percentage of frequency of surface wind speed by direction at Keesler AFB during 00Z, 06Z, 12Z and 18Z for the month of February.

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III. DATA AND METHODOLOGY

A. DATA

Sea surface temperature data was collected from two locations and surface observations were collected from five land-based observing locations. The data was collected by utilizing the Air Force Combat Climatology Center and the National Data Buoy Center's database.

1. Sea Surface Temperature Observations

The Gulf of Mexico sea surface temperature measurements from close to shore sensors in the Northwest Florida region didn't become available until February 2005. This limited the amount of wintertime advection sea fog events that could be accurately studied using these measurements in this region. For this study, sea surface temperature data was collected from February 2005 to March 2005 and from December 2005 to March 2006 from Station PCBF1 (Figures 18 and 19). This is the only sensor in Northwest Florida that gives an accurate measurement of the near-shore Gulf temperature. Several other sensors are in the area, but they either measure the bay water temperature, which can be drastically different from the Gulf water temperature or they are too far offshore to accurately depict the sea surface temperatures that directly affects the land-based observing locations along the shoreline.

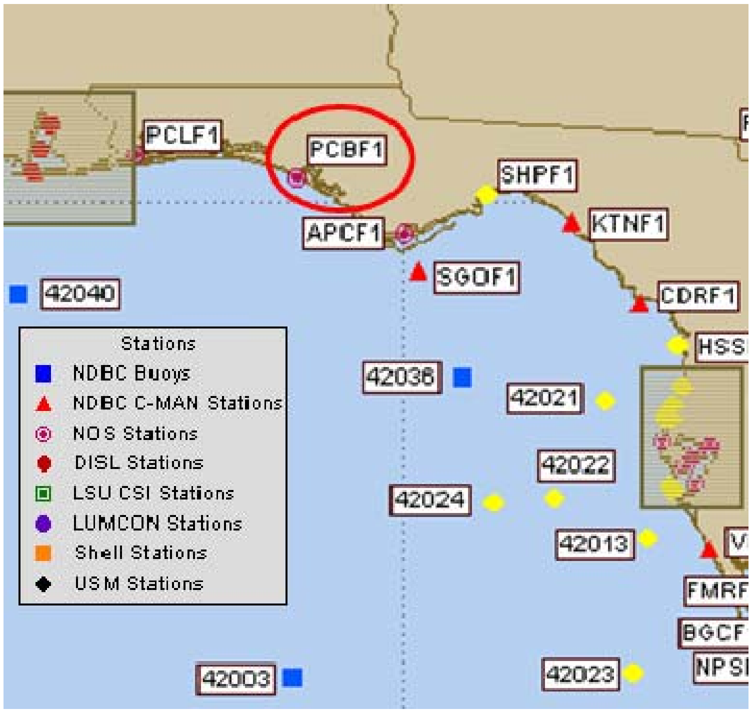

Figure 18. Location of Station PCBF1 in Northwest Florida (After http://www.ndbc.noaa.gov/maps/Florida.shtml Accessed 20 January 2007).

Station PCBF1 is positioned 140 meters from shore on the Panama City Beach City Pier (30.21 N 85.88 W), which is 21 statute miles to the northwest of Tyndall AFB. The Gulf depth at this location is approximately eight meters. In addition to sea surface temperature, it also measures wind direction and speed, including gust, atmospheric pressure and air temperature. Measurements are taken and transmitted at least hourly and sometimes as often as every six minutes.

The data from this sensor was used as an estimate of the sea surface temperature along the entire Florida shore from Tyndall AFB to Hurlburt Field, which includes Eglin AFB and Destin-Fort Walton Beach Airport. This stretch of water was assumed homogeneous since no major mechanisms were found that would greatly affect the Gulf water temperature along this shoreline.

Figure 19. Shows Station PCBF1 on the Panama City Beach City Pier (From http://www.ndbc.noaa.gov/images/stations/pcbf1.jpg Accessed 20 January 2007).

Measurements from Station 42007 (Figures 20 and 21) were used as an estimate of the close to shore sea surface temperatures near Keesler AFB. This site is located 23 statute miles south-southeast of Keesler AFB (30.09 N 88.77 W) at a water depth of 14 meters in the Gulf of Mexico. This buoy was chosen because it is the nearest station which gives an accurate temperature reading of the Gulf waters. This station also transmits wind direction and speed, to include gusts, wave height, dominate wave period, average period, mean wave direction, atmospheric pressure and tendency, air temperature and dewpoint data hourly.

The relatively wide Mississippi Sound lies between Station 42007 and Keesler AFB. Both the sound and the Gulf in this area have fairly flat and shallow sea bottom characteristics and many large inlets between the barrier islands. The tidal currents would be able to provide enough mixing so the sea surface temperatures in both the sound and the Gulf would be fairly homogeneous.

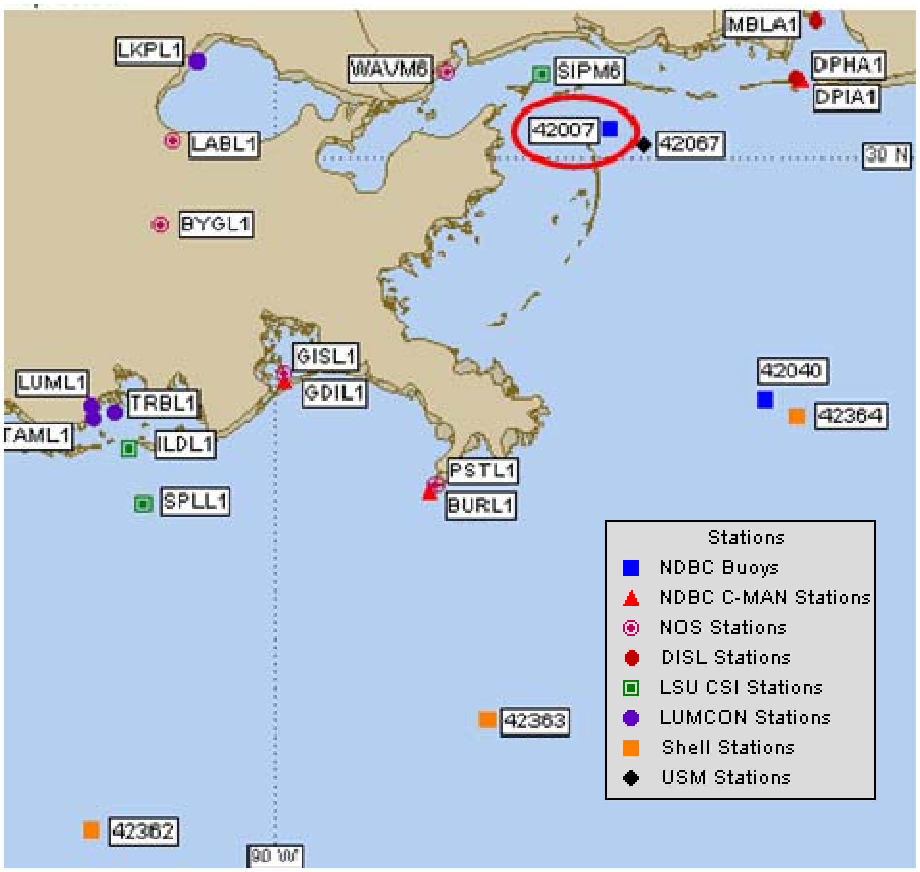

Figure 20. Location of Station 42007 south-southeast of Keesler AFB (After http://www.ndbc.noaa.gov/maps/WestGulf_inset.shtml Accessed 20 January 2007).

For this study, sea surface temperature data was collected during the months of December through March 1999 to 2004 and from December 2005 to March 2006. There is a gap in the study because data for the entire month of

December 2004 and 18 days of January 2005 is missing. Using the data from this season could result in possible biases due to the lack of data, so it was not used in this study.

Figure 21. Shows Station 42007 in the Gulf of Mexico (From http://www.ndbc.noaa.gov/images/stations/3m.jpg Accessed 20 January 2007).

2. Atmospheric Surface Observations

Surface observations were collected from February 2005 to March 2005 and from December 2005 to March 2006 for Tyndall AFB, Destin-Fort Walton Beach Airport, Eglin AFB and Hurlburt Field. Observations from Keesler AFB were collected during the months of December through March 1999 to 2004 and from December 2005 to March 2006. These months and years coincide with the sea surface temperature data that was collected from Stations 42007 and PCBF1. All types of observations were used in the study, to include METARs and SPECIs.

The process of recording and transmitting the observation differed between stations. Tyndall AFB's observations were taken by a certified human observer, during duty hours, which is typically 8 – 16 hours a day and no observations were recorded or transmitted on holidays. Hurlburt Field's observing process differs slightly. Up until 5 January 2006 they transmitted only observations that were augmented by a certified observer. This occurred at least every hour of every day except on holidays and from roughly 0500Z to 1200Z on Saturday and Sunday mornings. After 5 January 2006 during duty hours observations were augmented and transmitted by a certified observer and during non-duty hours non-augmented observations were automatically transmitted. The observations that came from the Destin-Fort Walton Beach Airport were non-augmented and were transmitted 24 hours a day, seven days a week. Eglin AFB sent augmented observations 24 hours a day. Finally, the observations that came from Keesler AFB were taken and transmitted by a certified observer generally between 1200Z to 0500Z, seven days a week, except holidays.

B. METHOD OF ANALYSIS

Numerical and observational studies have demonstrated that several factors largely determine the development, evolution and dissipation of advection sea fog. These factors are ample moisture in the atmosphere, stable atmospheric conditions, low level synoptic flow and sea surface temperatures. The analysis methodology was developed to ensure that each factor is well addressed.

1. Match Sea Surface Temperatures with Atmospheric Conditions

The next step in this study was to compile sets of atmospheric observations that were time matched, as close as possible, to the corresponding sea surface temperature measurement. This was accomplished so every atmospheric observation contained a sea surface temperature. This creates a more detailed air-sea interaction picture at any given time.

2. Removal of Disturbed Observations

Observations with restrictions to visibility, other than mist or fog, were deleted from the data sets. These restrictions to visibility include drizzle, rain, rain showers, thunderstorms, dust and smoke. Atmospheric phenomenon such as these can reduce the surface visibility making an accurate reduction of visibility due to fog nearly impossible to determine. Observations with missing surface air temperature, dewpoint, wind speed, wind direction or visibility were deleted from the data sets. Finally, observations that contained thunderstorms or rain showers in the vicinity were also deleted. These phenomena occur in unstable atmospheric conditions, which is not favorable for fog development. When all of the observations which are deemed disturbed are removed from the data set, it allows for a clearer picture of the atmospheric conditions before, during and after the fog events.

3. Establish and Optimize Advection Sea Fog Parameters

The next step in this study was to establish physical conditions that predominately occur during advection sea fog events. This leads us to believe when all of these physical conditions are met, one can assume a greater possibility of fog development. The New Orleans/Baton Rouge NWSFO's Sea Fog Forecasting Decision Tree (Figure 6) was used as a guideline to establish parameters for this study.

A FORTRAN program was developed (Nuss, 2006) that would identify every observation that satisfied the sea surface temperature, atmospheric temperature, dewpoint and wind speed and direction listed in Table 1. The program would then label each observation that satisfied the criteria with the word "fog". This highlighted times that the probability of fog was greatest. Then another FORTRAN program (Nuss 2006) examined each observation and identified the minimum surface visibility 60 and 120 minutes prior to the observation time and also 60 and 120 minutes after the observation time. It would then designate that minimum visibility value to the observation being examined. It would do this for every observation in the data set. This step allowed observations that satisfied the necessary atmospheric parameters but contained no fog at observation time but was subsequently advected in when fog occurred nearby, but not directly at the observation site. It allowed 60 and 120 minutes for the fog to advect or form at the observation site and then be recorded in an observation. After the two codes were executed, the output provided a list of observations with minimum visibility values, within the 120 and 240 minute window and also marked observations that met the fog formation parameters.

An air temperature and dewpoint spread of zero to three degrees Celsius is commonly used as a rule of thumb for forecasting cloud and fog development. According to the data from the different locations in this study, fog rarely existed with a spread of more than one degree Celsius.

Sea surface temperature less than or equal to 20° Celsius
Onshore surface winds less than 18 knots
Air temperature minus dewpoint temperature is less than or equal to 1° Celsius
Dewpoint temperature minus sea surface temperature is between -2° Celsius and 1° Celsius

Table 1. Original list of atmospheric parameters used to forecast advection sea fog

An observed visibility distance had to be determined to represent fog versa no fog in the observation. The value must be small enough to concentrate on the dense fog that inhibits operations, but large enough not to exclude a large portion of the fog events. Equal to or less than three statute miles was chosen to represent fog and greater than three statute miles represented no fog.

The next step was to separate the list of observations into four separate bins. This was accomplished by using Microsoft Office Excel to filter the observations that were labeled “fog” (satisfying the fog parameters) and the minimum visibility threshold used to identify fog versa no fog for each observation. One bin held all the observations that contained fog (a minimum visibility value less than or equal to three statute miles) and also were labeled “fog”. A second bin contained observations with fog that were not labeled “fog”. The third bin held observations with no fog that were labeled “fog” based on the parameters. The final bin was reserved for observations with no fog that were also not labeled “fog”. After the four bins were populated, the total number of observations in each bin was calculated and displayed in a 2X2 contingency table identical to the one in Table 2.

		FORECAST (did / did not meet fog parameters)	
		FOG	NO FOG
OBSERVED	FOG	A	B
	NO FOG	C	D

Table 2. Example of 2X2 contingency table used to display the number of observations in each bin, A through D.

In order to achieve the optimum fog parameters, the values in A and D must be maximized and the values in B and C must be minimized and equal to each other. Maximizing the values in A and D will increase the number of times accurate atmospheric conditions were chosen to identify the fog events. In other words, fog was forecasted and fog occurred, or fog was not forecasted and fog did not occur. The greater these values, the more accurate the fog parameters.

When A and D are maximized by modifying the fog parameters, this automatically minimizes the values in B and C, which will decrease the number of times inaccurate atmospheric conditions were chosen to identify the fog events. The values in B and C also need to be roughly equal. If they are not equal, the fog parameters are either too constrictive or too loose. For example, if the value in C is much larger than the value in B, the parameters must be constricted so less observations contain forecasted fog, therefore, more will reside in the forecasted no fog column, thus increasing the values in this column and decreasing the values in the forecasted fog column. The parameters must be modified using trial and error methods until the optimum fog parameters are found, which provides a list of conditions that best supports fog.

IV. RESULTS

This chapter presents the optimized fog parameters for Tyndall AFB, Eglin AFB, Destin-Fort Walton Beach Airport, Hurlburt Field and Keesler AFB after trial and error analysis was used to determine the best set of criteria. These optimized fog parameters can be used to better forecast advection sea fog events by forecasting for these parameters which generally coincided with fog events Each location had different factors that affected fog development such as, the shape of the coastline, proximity to bay or sound waters, distance from the Gulf and distance from the sea surface temperature sensor. Because of the differences, each location had a slightly different set of optimized fog parameters.

The modification of the fog parameters by trial and error was accomplished by slightly increasing and then decreasing the parameter values for the sea surface temperature, surface wind speed, air temperature-dewpoint spread and sea surface temperature minus dewpoint one at a time. The surface wind direction window size was increased and decreased and was also moved to the east and then to the west. Once each parameter was optimized the first time, the modification process of the parameters was accomplished two more times to maximize accuracy.

Due to lack of data, the data analyzed for Tyndall AFB, Hurlburt Field, Eglin AFB and Destin-Fort Walton Beach Airport was limited to February 2005 to March 2005 and from December 2005 to March 2006. All of the observations that contained missing data, rain showers or thunderstorms in the vicinity or a restriction to visibility, other than fog or mist, were deleted. The parameters were optimized using both the 120 minute window as well as the 240 minute window, and the number of occurrences was recorded into two 2X2 contingency tables for each location.

The data from Keesler AFB contained the months of December through March 1999 to 2004 and from December 2005 to March 2006. This large amount of data allowed for a more in-depth approach to find the optimized fog parameters. Each winter fog season (December through March) was analyzed and the optimized fog parameters were found for each season. This approach highlighted the variance between seasons at one location. The number of occurrences was then recorded into two 2X2 contingency tables for each season, one for each minimum visibility window.

Once the 2X2 contingency tables were created, accuracy in the form of statistics was calculated. This allowed for accuracy comparisons between locations, between minimum visibility windows or between different winter fog seasons.

Four different methods were used to determine the accuracy of the optimized parameters. The first method was the critical success index (CSI). This index is particularly useful when events with fog occur substantially less frequently than events with no fog, which is the case in this study. The following formula was used to determine the CSI for every 2X2 contingency table,

$$CSI = \frac{A}{A+B+C}.$$

A 100% accuracy has a CSI value of 1 and a 0% accuracy has a CSI value of 0. In this study, a CSI value of 33.3% represents the number of correct forecast (A) roughly equals the number of false alarms (B) and also roughly equals the number of missed forecasts (C), which shows little forecast skill.

Another statistical measure that was used was the false alarm rate (FAR). This calculates a percentage of the observations where fog was forecast but no fog occurred, as seen in the following formula,

$$FAR = \frac{C}{A+C}.$$

The lower the percentage, the fewer false alarms that occurred.

The third measure used in this study was the miss rate (MR). The miss rate calculates a percentage of the observations where fog was not forecast but fog did occur.

$$MR = \frac{B}{A+B}$$

As with the false alarm rate, the lower the percentage, the fewer missed forecasts that occurred.

Finally, a general correct rate was calculated to determine the percentage of accurate forecasts versus inaccurate forecasts. This value is slightly skewed because of the extremely large number in D, forecast events with no fog and events with no fog observed.

$$Corr = \frac{A+D}{A+B+C+D}$$

This value gives the percentage of forecasts that were correct, considering all bins.

The first table in sections A through D shows the optimized fog parameters for the two minimum visibility windows for each location. The next two tables present the number of observations in each bin using the optimized fog parameters for each visibility window and they also list the forecast statistics from each location.

Below in sections A through E the optimized fog parameters for the 240 minute minimum visibility window are less stringent than the 120 minute minimum visibility window. Events that barely satisfy the parameters tend to take longer to develop fog. The larger window allows more time for the borderline events to develop fog less than or equal to three statute miles, therefore the optimized parameters can be less stringent. The parameters that tend to be less stringent in the 240 minute window are the sea surface temperature, surface wind speed and the sea surface temperature minus the dewpoint.

This larger time window allows more time for the fog to develop during the borderline cases. With this in mind, the 240 minute minimum visibility window should have better statistical results. Of the 16 statistical measures calculated for this window, 15 showed an increase in the CSI when increasing the time window size from 120 minutes to 240 minutes. 12 of the 16 measures showed the MR decrease when increasing the time window size. In all 16 cases the FAR decreased as a result of using the 240 minute window instead of the 120 minute window. This shows it is more useful to use the larger window to forecast whether fog will develop; however, the exact time of fog development or dissipation is less accurate using the larger window because it is unknown exactly what time inside the window fog formation or dissipation occurs. The smaller window will have a smaller time uncertainty.

A. TYNDALL AFB

The bays around Tyndall AFB have less of an affect on fog development because of their shape and smaller size as compared to the other locations studied. Station PCBF1, where the sea surface temperature measurements were taken, is in close proximity to Tyndall AFB which results in a more accurate estimate of the sea surface temperature at Tyndall AFB as compared to the other locations. Because of these reasons the results from Tyndall AFB listed in this section will be used as a baseline for comparison with the other locations.

Listed below in Table 3 are the optimized fog parameters for Tyndall AFB. It shows that fog tends to be present during the 120 minute window when the sea surface temperature at Station PCBF1 is less than or equal to 19.0°C, the surface wind has an onshore component and is less than or equal to 12 knots, there is less than or equal to a 1°C surface air temperature-dewpoint spread and the sea surface temperature minus the dewpoint is less than or equal to 1.8°C. Fog tends to be present during the 240 minute window when the sea surface temperature is less than or equal to 20.0°C, the surface wind has an onshore component and is less than or equal to 14 knots, there is less than or equal to a 1°C surface air temperature-dewpoint spread and the sea surface temperature minus the dewpoint is less than or equal to 2.0°C.

	120 Minute	240 Minute
Sea Surface Temperature (SST)	$\leq$19.0°C	$\leq$20.0°C
Wind Speed	$\leq$12 kts	$\leq$14 kts
Wind Direction	80° to 290°	80° to 290°
Air Temperature minus Dewpoint Temperature	$\leq$1°C	$\leq$1°C
SST minus Dewpoint Temperature	$\leq$1.8°C	$\leq$2.0°C

Table 3. List of the optimized fog parameters for Tyndall AFB using the 120 and 240 minute minimum surface visibility windows.

Tables 4 and 5 list the accuracy measurements and the populated bins of the 2x2 contingency table for the 120 minute and the 240 minute minimum visibility windows. The general correct rate of 86% for both windows shows a relatively high success rate for determining the formation or dissipation of fog. The CSI value is low and the MR and FAR are high because of the difficulty in determining the formation of fog when the observations are very close to the optimized parameters. When the observations fall well within or outside of the parameter ranges the statistical measurements improve.

		FORECAST		
		FOG	NO FOG	MR = 44.3% FAR = 44.3% CSI = 38.6% Corr = 86.5%
OBSERVED	FOG	229	182	
	NO FOG	182	2093	

Table 4. Shows the number of observations in each bin and the advection sea fog forecast statistics for Tyndall AFB (120 minute window).

		FORECAST		
		FOG	NO FOG	MR = 36.3% FAR = 36.8% CSI = 46.4% Corr = 86.3%
OBSERVED	FOG	319	182	
	NO FOG	186	1999	

Table 5. Shows the number of observations in each bin and the advection sea fog forecast statistics for Tyndall AFB (240 minute window).

B. DESTIN-FORT WALTON BEACH AIRPORT

The optimized fog parameter concerning wind direction for Destin-Fort Walton Beach Airport differed from the other locations studied. Optimization of the parameters occurred only after the wind direction was ignored. This showed fog was not dependent on the wind direction at this location. The other locations studied had an onshore component, which would advect the saturated air from the cool Gulf waters onto the land. But in the case of Destin-Fort Walton Beach Airport, an offshore wind was capable of supporting a fog event. The sea surface temperature and sea surface temperature minus dewpoint parameters for both time windows listed in Table 6 also differed from other locations. This is the result of not knowing the exact temperature of the surrounding bay The major difference between this and other locations in this study is that this location is 90% surrounded by either bay water or Gulf water. This means that Choctawhatchee Bay is large enough to provide ample cooling, moisture or both to the boundary layer, resulting in fog development. The other two parameters are similar to all of the other locations.

	120 Minute	240 Minute
Sea Surface Temperature (SST)	≤20.0°C	≤20.0°C
Wind Speed	≤12 kts	≤15 kts
Wind Direction	Any Direction	Any Direction
Air Temperature minus Dewpoint Temperature	≤1°C	≤1°C
SST minus Dewpoint Temperature	≤2.4°C	≤7.0°C

Table 6. List of the optimized fog parameters for Destin-Fort Walton Beach Airport using the 120 and 240 minute minimum surface visibility windows.

Listed below are the statistics from Destin-Fort Walton Beach Airport for both minimum surface visibility windows (Tables 7 and 8). Even though the optimized fog parameters for this location were quite different from the other locations studied, the statistics were surprisingly similar. This is evidence that the forecast accuracy for Destin-Fort Walton Beach Airport is as good as the other locations, even though it is located in a much more complex boundary layer region.

		FORECAST		
		FOG	NO FOG	
OBSERVED	FOG	593	380	MR = 39.1% FAR = 39.4% CSI = 43.6% Corr = 84.5%
	NO FOG	386	3569	

Table 7. Shows the number of observations in each bin and the advection sea fog forecast statistics for Destin-Fort Walton Beach Airport (120 minute window).

		FORECAST		
		FOG	NO FOG	MR = 31.7% FAR = 31.8% CSI = 51.8% Corr = 84.4%
OBSERVED	FOG	825	383	
	NO FOG	385	3333	

Table 8. Shows the number of observations in each bin and the advection sea fog forecast statistics for Destin-Fort Walton Beach Airport (240 minute window).

C. EGLIN AFB

Table 9 shows the wind direction parameter from Eglin AFB was somewhat similar to Destin-Fort Walton Beach Airport, because Eglin is positioned so that surface winds from 100° to 120° are influenced by the bay waters. A wind from this direction is considered a possible fog producer. The sea surface temperature and sea surface temperature minus dewpoint parameter was also similar to Destin-Fort Walton Beach Airport. This is because Eglin AFB is located close enough to the Choctawhatchee Bay to be affected by the unknown bay water temperatures. The other two parameters are similar to all of the other locations.

	120 Minute	240 Minute
Sea Surface Temperature (SST)	$\leq$19.7°C	$\leq$20.0°C
Wind Speed	$\leq$11 kts	$\leq$14 kts
Wind Direction	100° to 210°	100° to 210°
Air Temperature minus Dewpoint Temperature	$\leq$1°C	$\leq$1°C
SST minus Dewpoint Temperature	$\leq$2.0°C	$\leq$3.2°C

Table 9. List of the optimized fog parameters for Eglin AFB using the 120 and 240 minute minimum surface visibility windows.

The statistical measurements below in Tables 10 and 11 are similar to the other locations.

		FORECAST		
		FOG	NO FOG	MR = 38.1% FAR = 38.4% CSI = 44.7% Corr = 85.3%
OBSERVED	FOG	596	367	
	NO FOG	371	3701	

Table 10. Shows the number of observations in each bin and the advection sea fog forecast statistics for Eglin AFB (120 minute window).

		FORECAST		
		FOG	NO FOG	
OBSERVED	FOG	768	358	MR = 31.8% FAR = 32.0% CSI = 51.6% Corr = 85.7%
	NO FOG	362	3547	

Table 11. Shows the number of observations in each bin and the advection sea fog forecast statistics for Eglin AFB (240 minute window).

D. HURLBURT FIELD

Hurlburt Field's optimized fog parameters listed in Table 12 is rather similar to Tyndall AFB's. The only major difference is the sea surface temperature parameter for the 120 minute window for Hurlburt Field is much less than this same parameter for Tyndall AFB. This could be the result of using Station PCBF1, which is relatively far away, to estimate the Gulf water temperature at Hurlburt Field. Hurlburt Field is located further from the Choctawhatchee Bay than Eglin and Destin-Fort Walton Beach Airport, so the bay has less of an effect on fog development at this location.

	120 Minute	240 Minute
Sea Surface Temperature (SST)	≤17.5°C	≤19.8°C
Wind Speed	≤11 kts	≤14 kts
Wind Direction	80° to 260°	80° to 260°
Air Temperature minus Dewpoint Temperature	≤1°C	≤1°C
SST minus Dewpoint Temperature	≤1.8°C	≤2.0°C

Table 12. List of the optimized fog parameters for Hurlburt Field using the 120 and 240 minute minimum surface visibility windows.

The statistical measurements for Hurlburt Field below in Tables 13 and 14 are similar to the other locations.

		FORECAST		
		FOG	NO FOG	
OBSERVED	FOG	411	325	MR = 44.2% FAR = 43.7% CSI = 38.9% Corr = 86.1%
	NO FOG	320	3592	

Table 13. Shows the number of observations in each bin and the advection sea fog forecast statistics for Hurlburt Field (120 minute window).

		FORECAST		
		FOG	NO FOG	
OBSERVED	FOG	601	333	MR = 35.7% FAR = 35.9% CSI = 47.3% Corr = 85.6%
	NO FOG	337	3385	

Table 14. Shows the number of observations in each bin and the advection sea fog forecast statistics for Hurlburt Field (240 minute window).

E. KEESLER AFB

1. Optimized Parameters and Results for Each Year of Data

Since ample observations were available for Keesler AFB, a slightly different technique was used to analyze the data. Instead of combining all the observations available and then optimizing the fog parameters based on the entire list of observations, the observations were separated into individual winter fog seasons (December through March), then optimized fog parameters were found (Table 15) and the two 2X2 contingency tables were populated for each season (Table 16). Finally, the accuracy rates were calculated for each contingency table (Table 17). By using this method, it was easier to see the variance between seasons. The variance was due to small changes in climatic conditions that slightly effected fog development and also a fair amount of uncertainty in the parameters and results.

The 2002-2003 optimized fog parameters differed from the other Keesler AFB seasons. The only noticeable difference in the data was the much lower occurrence in both observed and forecasted fog events, as compared to the other seasons. This smaller sample size skewed the results. This season was not used to calculate the averaged optimized fog parameters for Keesler AFB.

These results showed a slight effect from the Mississippi Sound on fog development, as shown in some of the elevated sea surface temperature minus dewpoint values. The difference in sea surface temperature parameter values from Tyndall AFB is a result of the sea surface temperature sensor being a great distance away from Keesler AFB and not being a truly accurate estimate of the water temperature close to shore. The other parameters are similar to those of Tyndall AFB.

In Tables 16 and 17 below, note the loss of accuracy during the 2002-2003 season due to the small amount of fog events during that year.

Season (Dec-Mar)	Minimum Visibility Window	SST	Wind Speed	Wind Direction	Air Temp minus Dewpoint	SST minus Dewpoint
1999-2000	120 min	≤17.1°C	≤12 kts	90° to 260°	≤1°C	≤1.9°C
	240 min	≤18.4°C	≤13 kts	90° to 260°	≤1°C	≤2.2°C
2000-2001	120 min	≤18.8°C	≤12 kts	90° to 260°	≤1°C	≤1.8°C
	240 min	≤19.1°C	≤14 kts	90° to 260°	≤1°C	≤4.4°C
2001-2002	120 min	≤19.6°C	≤13 kts	90° to 260°	≤1°C	≤1.7°C
	240 min	≤20.0°C	≤15 kts	90° to 260°	≤1°C	≤3.4°C
2002-2003	120 min	≤16.0°C	≤9 kts	90° to 260°	≤1°C	≤0.7°C
	240 min	≤17.0°C	≤11 kts	90° to 260°	≤1°C	≤1.3°C
2003-2004	120 min	≤18.7°C	≤13 kts	90° to 260°	≤1°C	≤2.4°C
	240 min	≤20.0°C	≤15 kts	90° to 260°	≤1°C	≤3.2°C
2005-2006	120 min	≤19.0°C	≤12 kts	90° to 260°	≤1°C	≤2.0°C
	240 min	≤20.0°C	≤14 kts	90° to 260°	≤1°C	≤3.5°C

Table 15. List of optimized fog parameters for Keesler AFB using the 120 minute and 240 minute minimum surface visibility windows.

Season (Dec-Mar)	Minimum Visibility Window	Forecast Fog / Observed Fog Forecast Fog / Observed No Fog	Forecast No Fog / Observed Fog Forecast No Fog / Observed No Fog
1999-2000	120 min	237	199
		203	2284
	240 min	296	251
		248	2125
2000-2001	120 min	359	192
		194	2082
	240 min	423	209
		213	1959
2001-2002	120 min	283	158
		162	1628
	240 min	364	170
		171	1521
2002-2003	120 min	86	88
		94	1615
	240 min	109	113
		110	1548
2003-2004	120 min	149	109
		107	1676
	240 min	211	113
		110	1607
2005-2006	120 min	156	129
		133	1761
	240 min	214	137
		139	1686

Table 16. Number of Keesler AFB observations in each bin per season using optimized parameters from each season.

Season (Dec-Mar)	Minimum Visibility Window	MR	FAR	CSI	Corr
1999-2000	120 min	45.6%	46.1%	37.1%	86.3%
	240 min	45.9%	45.6%	37.2%	82.9%
2000-2001	120 min	34.9%	35.1%	48.2%	86.4%
	240 min	33.1%	33.5%	50.1%	85.0%
2001-2002	120 min	35.8%	36.4%	46.9%	85.7%
	240 min	31.8%	32.0%	51.6%	84.7%
2002-2003	120 min	50.6%	52.2%	32.1%	90.3%
	240 min	50.9%	50.2%	32.8%	88.1%
2003-2004	120 min	42.3%	41.8%	40.8%	89.4%
	240 min	34.9%	34.3%	48.6%	89.1%
2005-2006	120 min	45.3%	46.0%	37.3%	88.0%
	240 min	39.0%	39.4%	43.7%	87.3%

Table 17. Shows annual advection sea fog forecast statistics for Keesler AFB.

2. Averaged Parameters and Results

The optimized parameters from all but one of the seasons were then averaged (Table 18). Parameters from December 2002 - March 2003 were excluded from this average due to the abnormalities in the results for that season. These averaged parameters were used to populate two new 2X2 contingency tables and create accuracy statistics for each season. This process showed the accuracy of using the averaged fog parameters for every season and presented an estimate of the reliability of using the averaged parameters to forecast Keesler AFB fog events in the future.

	120 Minute	240 Minute
Sea Surface Temperature (SST)	≤18.6°C	≤19.5°C
Wind Speed	≤12 kts	≤14 kts
Wind Direction	90° to 260°	90° to 260°
Air Temperature minus Dewpoint Temperature	≤1°C	≤1°C
SST minus Dewpoint Temperature	≤2.0°C	≤3.3°C

Table 18. List of averaged fog parameters for Keesler AFB using the 120 minute and 240 minute minimum surface visibility window

The results in Tables 19 and 20 show a high amount of accuracy, except for the 2002-2003 season, where the small amount of fog events skewed the results.

Season (Dec-Mar)	Minimum Visibility Window	Forecast Fog / Observed Fog Forecast Fog / Observed No Fog	Forecast No Fog / Observed Fog Forecast No Fog / Observed No Fog
1999-2000	120 min	273	163
		286	2201
	240 min	330	217
		340	2033
2000-2001	120 min	361	190
		195	2081
	240 min	404	228
		196	1976
2001-2002	120 min	227	214
		115	1675
	240 min	317	217
		129	1563
2002-2003	120 min	106	68
		197	1509
	240 min	141	81
		233	1425
2003-2004	120 min	135	123
		98	1685
	240 min	211	113
		106	1611
2005-2006	120 min	156	131
		130	1764
	240 min	215	136
		131	1694

Table 19. Number of Keesler AFB observations in each bin per season using the averaged optimized parameters.

Season (Dec-Mar)	Minimum Visibility Window	MR	FAR	CSI	Corr
1999-2000	120 min	37.4%	51.2%	37.8%	84.6%
	240 min	39.7%	50.8%	37.2%	80.9%
2000-2001	120 min	34.5%	35.1%	48.4%	86.4%
	240 min	36.1%	32.7%	48.8%	84.9%
2001-2002	120 min	48.5%	33.6%	40.8%	85.3%
	240 min	40.6%	28.9%	47.8%	84.5%
2002-2003	120 min	39.1%	65.0%	28.6%	85.9%
	240 min	36.5%	62.3%	31.0%	83.3%
2003-2004	120 min	47.7%	42.1%	37.9%	89.2%
	240 min	34.9%	33.4%	49.1%	89.3%
2005-2006	120 min	45.6%	45.5%	37.4%	88.0%
	240 min	38.8%	37.9%	44.6%	87.7%

Table 20. Annual forecast statistics using the averaged optimized parameters for Keesler AFB.

F. LIMITATIONS

There were many factors that limit accuracy in this study. Some were small and insignificant while others drastically affected the results. This section explains these limiting factors that degraded the statistical measurements and ways of minimizing or possibly eliminating them.

One problem that was encountered was that the sea surface temperature sensor was sometimes located a great distance away from the land-based observing site. Even though there exist relatively uniform water characteristics along the coast in this region, sea surface temperatures will differ due to different atmospheric fluxes and Gulf currents. This difference, in some cases, would be large enough to alter the results. This error can be minimized by using satellites to obtain sea surface temperature data from any suitable location. However, accurate measurements using this technique cannot be used during cloudy conditions due to signal absorption.

Another limiting factor was the effects of the bays and sound on fog development. Using the data available, there was no way to know exactly how much and how often these smaller bodies of water changed the results. There are no accurate sea surface temperature sensors in the bays or sound close to the land-based locations studied. Alternate data and methods could be used to include the temperature of the bays and sound in future studies.

Several factors within the atmospheric observations influence their accuracy. First, the certified human observer makes a judgment call when measuring the surface visibility. One observer might measure a visibility of 3.0 statute miles, while another measures 3.5 for the exact same location and time of day. The discrepancy would be the result of different experience levels between observers or the use of inaccurate techniques.

Automated visibility sensors can also give an inaccurate visibility measurement. These systems only measure the visibility at the sensor. It will not measure the fog found elsewhere over the airfield, like the human observer is able to. The automated visibility sensors are not as accurate as a human because they are not measuring a maximum distance that an object can be viewed, they only sample a small portion of the atmosphere and measure the amount of obstruction in that sample and then mathematically calculate a surface visibility value.

The greatest limiting factor is the process of rounding the temperature and dewpoint values to the whole degree Celsius by some observing systems. This severely limits the accuracy of these measurements. Since, fog formation is heavily dependant on the temperature and dewpoint having the exact same value, rounding these values can give false signals to the true nature of the atmosphere. Other observing sites report the values to the nearest tenth of a degree. Data from these sites can be used to generate new fog parameters, which would eliminate the errors that are associated with rounding the values to the nearest whole number.

G. TYNDALL AFB, 21-23 FEBRUARY 2006 CASE STUDY

All of the cases analyzed earlier in this study involved both fog and no fog events. This case study will calculate the results only during a fog event and show the accuracy of the optimized fog parameters.

Data from an advection sea fog event (21 - 23 February 2006) along the northern Gulf of Mexico was studied to see if the optimized fog parameters for Tyndall AFB were accurate. Wind data, temperature data and dewpoint data from the Tyndall AFB observations were used in conjunction with sea surface temperature data from Station PCBF1 to see if satisfying the optimized fog parameters coincided with observed fog visibility less than or equal to three statute miles.

1. Synoptic Situation

A surface stationary front was either over or to the north of Tyndall AFB throughout the period. The upper level pattern over Northwest Florida was zonal, with westerly winds above 850 mb. The atmosphere at 500 mb and above was dry with little thermal advection. At 700 mb and below, flow became more southwesterly, which allowed for greater moisture advection into the Tyndall AFB area. The analysis at 925 mb showed a tight thermal gradient north of the stationary boundary. In the lower levels a ridge axis associated with the Bermuda High stretched from South Florida to East Texas across the Gulf of Mexico. Onshore flow at Tyndall AFB occurred due to the surface stationary front to the north of the station, which would allow for possible fog development during this time of year. The satellite image in Figure 22 below shows the widespread fog and low stratus over the colder waters of the Northern Gulf of Mexico as well as inland locations.

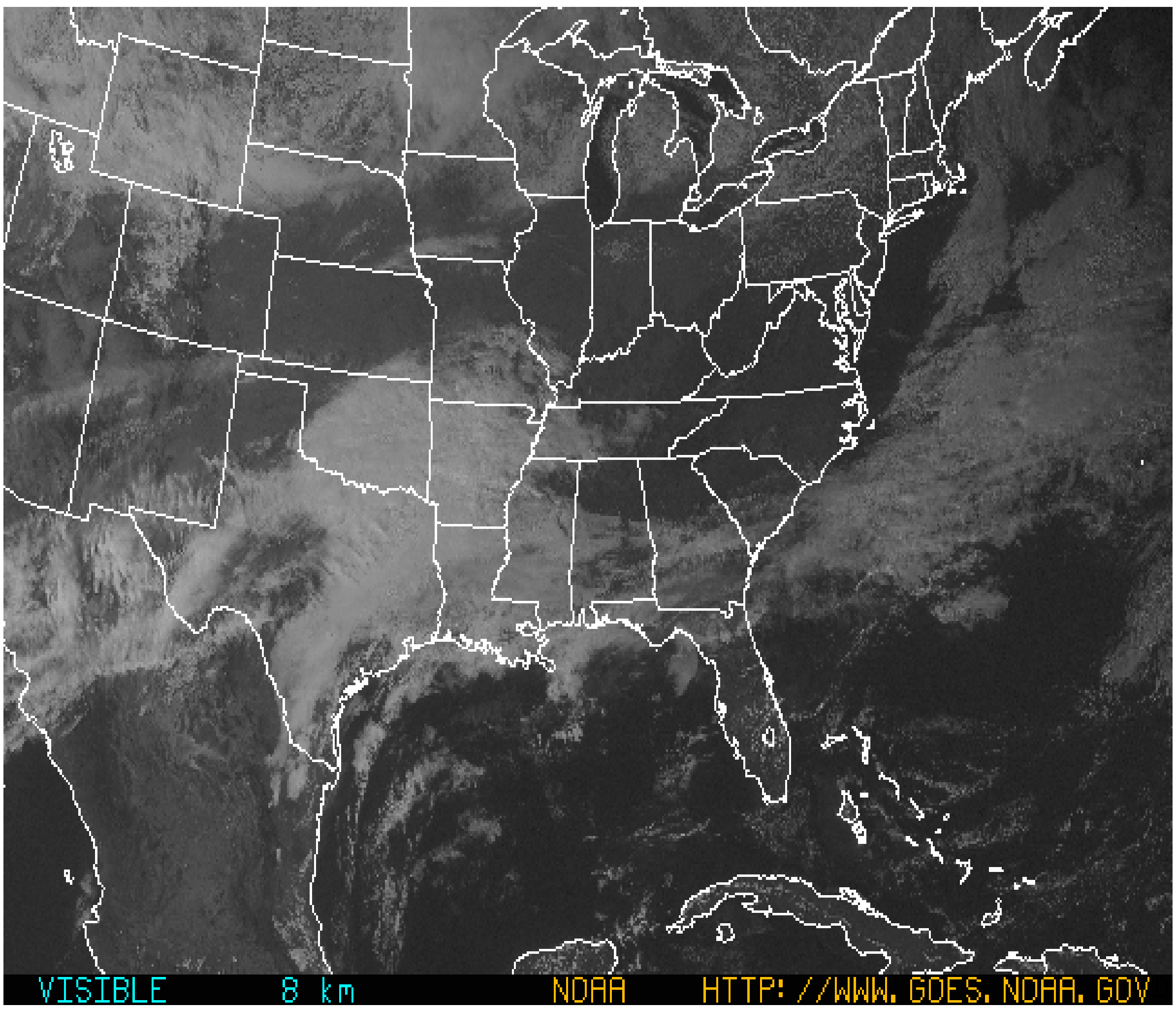

Figure 22. 2115Z, 21 February 2006 satellite imagery during Tyndall AFB advection sea fog event.

Figures 23 – 25 show surface conditions at three times during the fog event. Notice the generally southerly flow of 5 – 10 knots over the Gulf of Mexico south of the front. This is an ideal situation for the air to become nearly saturated over the warm waters of the Gulf, then cool to the dewpoint, becoming saturated when it slowly advects over the cooler waters close to shore.

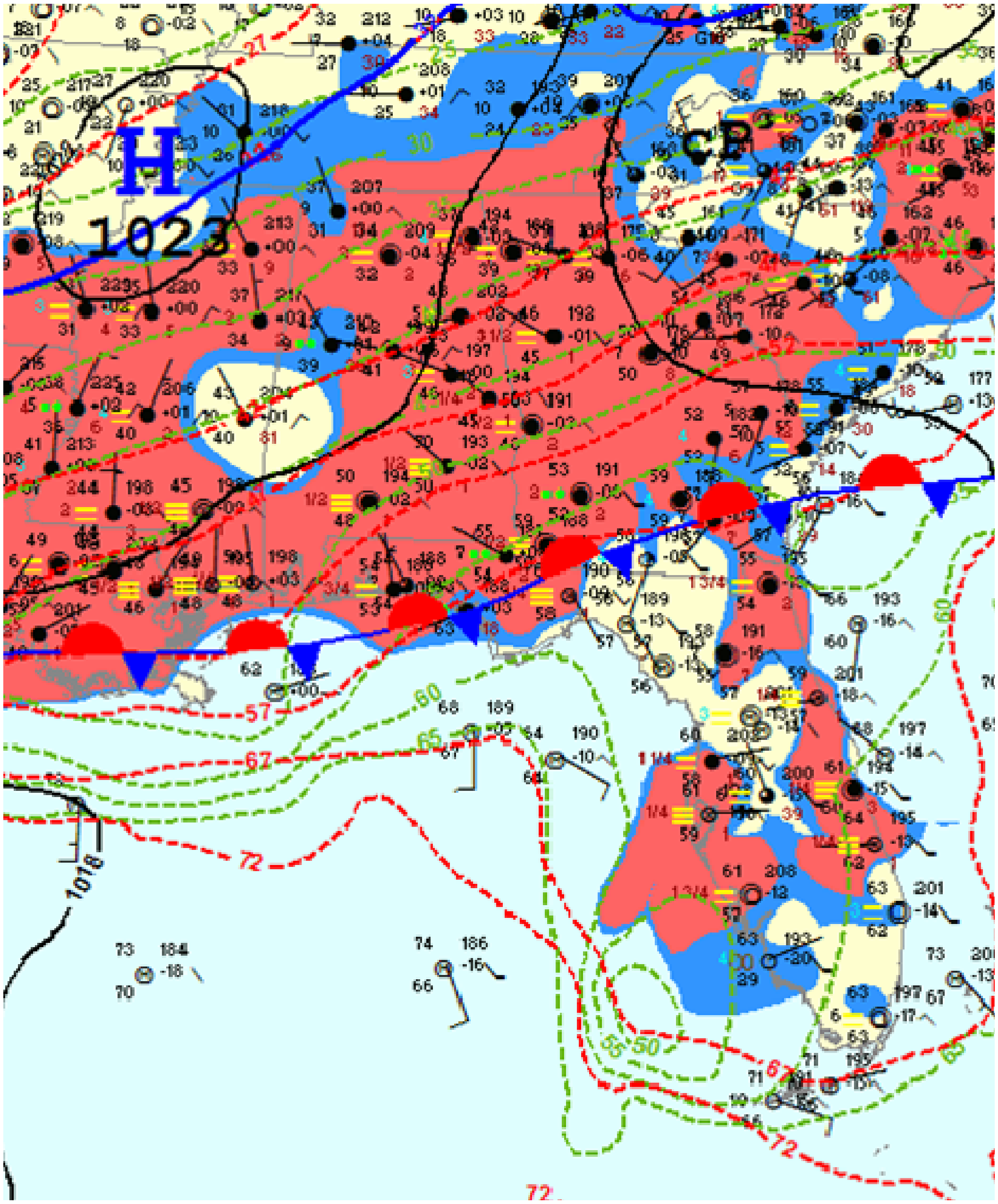

Figure 23. 0900Z surface analysis for 21 February 2006.

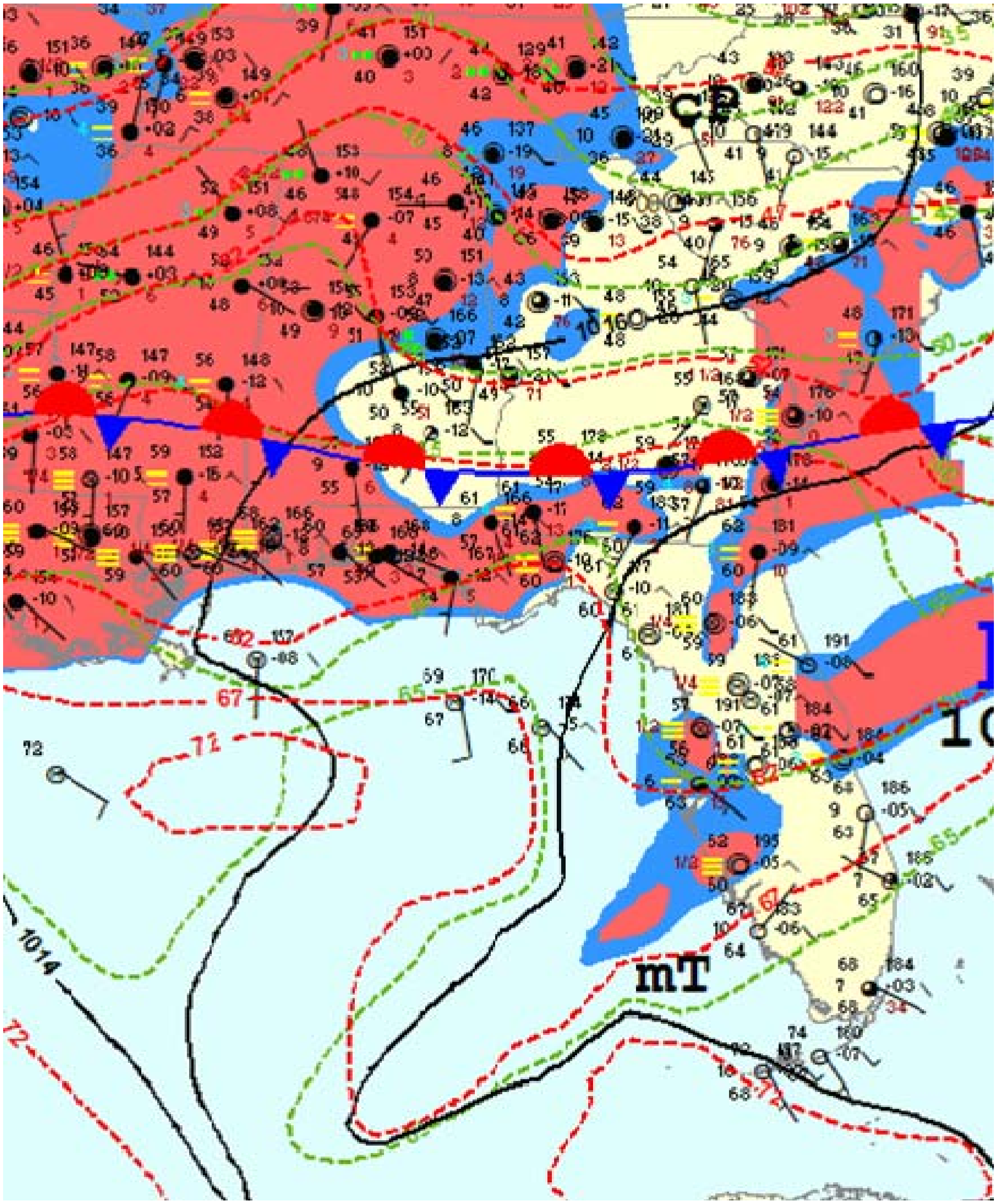

Figure 24. 0900Z surface analysis for 22 February 2006.

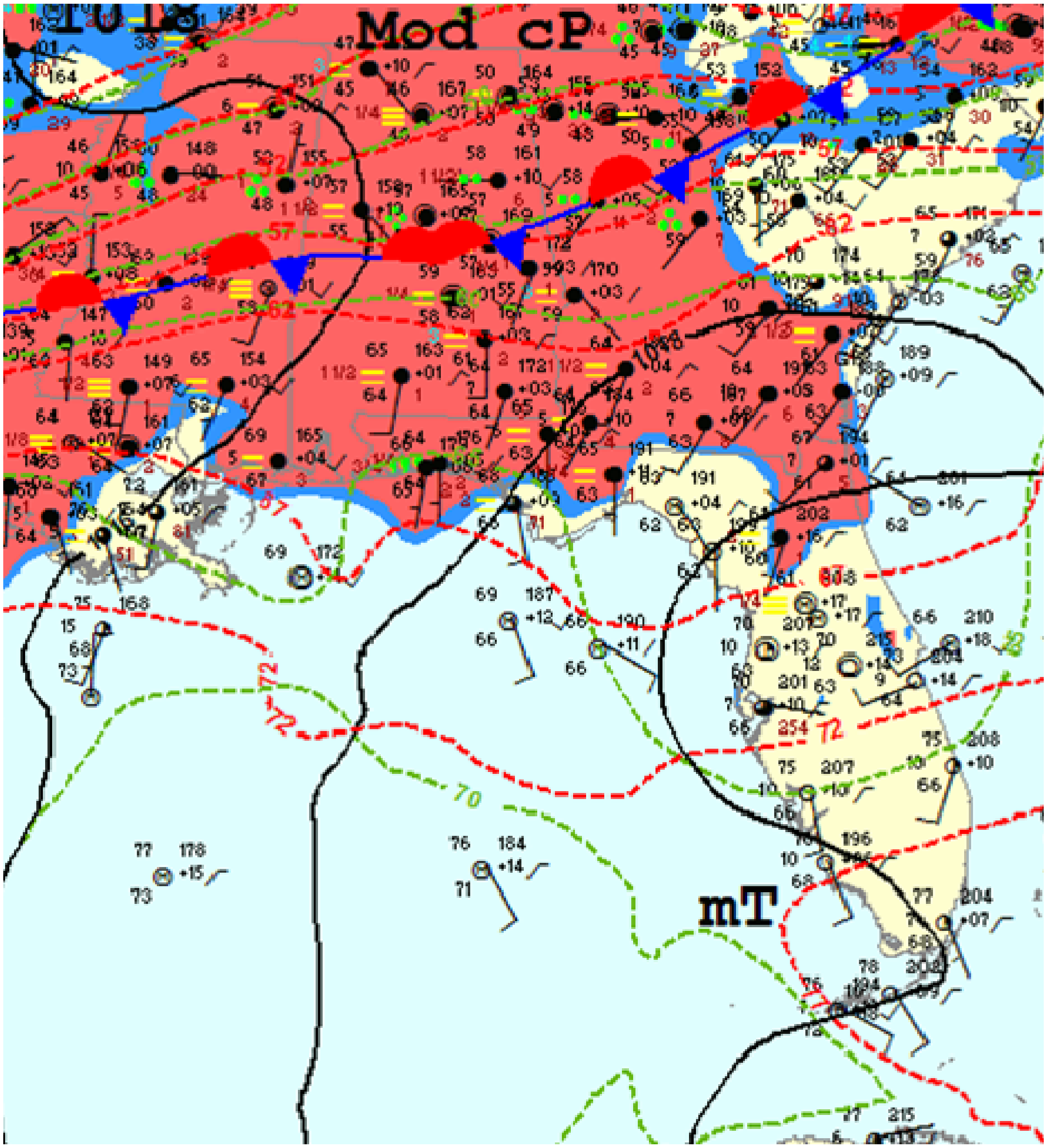

Figure 25. 1500Z surface analysis for 22 February 2006.

2. Optimized Fog Parameter Performance

Each Tyndall AFB wind, temperature and dewpoint measurement from 1155Z on 21 February 2006 to 0355Z 23 February 2006 and each Station PCBF1 sea surface temperature measurement from the same times was analyzed to see if they met the optimized fog parameters. Then they were compared to the minimum surface visibility within one hour of the observation to determine the accuracy of the parameters.

The populated 2x2 contingency table (Table 21) shows a very large number of observations in the "Forecast Fog and Observed Fog" bin for the 120 minute minimum visibility window.

		FORECAST (met fog parameters)	
		FOG	NO FOG
OBSERVED	FOG	42	3
	NO FOG	8	3

Table 21. Number of observations in each bin for (120 minute window).

The statistics found in Table 22 show extremely low MR and FAR values and an extremely high CSI value as compared to the entire data set examined earlier. This shows that during an advection sea fog event at Tyndall AFB these optimized sea fog parameters are very accurate. The main reason for the improved accuracy is most of the observations are well within the criteria, therefore greater forecast accuracy occurred.

120 Minute Minimum Surface Visibility Window
MR = 6.7%
FAR = 16.0%
CSI = 79.3%
Corr = 80.4%

Table 22. Shows the advection sea fog forecast statistics for period.

In this case, the parameters had an extremely high critical success index, moderate correct percentage and very low miss rate and false alarm rate. This illustrates that when the parameters are satisfied during a synoptic situation similar to this one, there is a high likelihood of fog occurrence at Tyndall AFB.

3. Model Performance

The 12-kilometer ETA model output was examined for this fog event. The 6-hour forecast values for wind speed and direction, surface temperature and dewpoint were very accurate when compared to the observations for the same times. In this case, this model output used in conjunction with the optimized parameters is accurate enough to forecast sea fog formation and dissipation six hours in advance.

V. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

The purpose of this study was to better forecast advection sea fog events along the northern Gulf of Mexico for the months of December through March. This can be accomplished by forecasting wind direction and speed, surface air temperature, dewpoint and sea surface temperature for every hour, then seeing if the forecasted conditions satisfy the set of optimized fog parameters, found in this study. If the variables are satisfied and there is no precipitation in the immediate area, the forecaster should forecast visibility to be less than or equal to three statute miles due to fog.

The predictability of advection sea fog using the optimized fog parameters as rules of thumb is accurate to about 86%, while the CSI value is accurate to about 40% for the 120 minute window (60 minutes prior and after observation) and about 45% for the 240 minute window (120 minutes prior and after observation). The accuracy of the 240 minute window improved over the 120 minute window due to the increased time given for formation or dissipation of the fog. The CSI values were much lower than the general correct rate values because of the many observations that were very close to the fog thresholds. Many observations satisfied all but one or two of the criteria. The criteria that were not satisfied sometimes were nearly satisfied, which gave fog a chance to develop. Also, when all of the variables are barely met, fog might not develop. This could be due to a factor not examined in this study. In these two cases Bins B and C will be more readily populated than Bins A and D, thus decreasing the CSI more than the general correct rate. When the observation is extremely far away from the fog thresholds, fog rarely forms. This will populate Bin D, which will cause the general correct rate values to increase while not affecting the CSI values.

The sea surface temperature measurements taken from Station PCBF1 were closer in proximity to Tyndall AFB than the other locations. This suggests that the estimate of Gulf sea surface temperature at Tyndall AFB was more accurate than any other location. The bays around Tyndall AFB are narrower than the bays and sounds near the other locations studied, thus affecting Tyndall AFB less than the other locations. Due to these two factors Tyndall AFB appeared to experience less interference which led to parameters that could be made more stringent, than the other locations. These more stringent parameters provide a more exact picture of when fog develops and dissipates.

The key to this process is the ability to accurately forecast wind direction and speed, surface air temperature, dewpoint and sea surface temperature when the conditions are near the fog thresholds. Forecasters generally are accurate when it comes to forecasting surface wind speed and direction. The problems lie with the ability to forecast the remaining criteria within roughly one degree accuracy. This can be a very daunting task. For example, if the forecaster forecast one degree too low for the dewpoint and one degree too high for the surface air temperature, instead of saturated conditions, the forecast had a two degree spread, which does not satisfy one of the fog parameters. Since one of the parameters was not met, the forecaster did not forecast fog to occur at that location and time. Looking back, if the forecaster would have forecast the surface air temperature and dewpoint accurately, all the variables would have been satisfied and they would have forecast fog during that time. This shows that all forecast values must be extremely accurate for this fog forecasting method to be effective.

Not all of the parameters have the same importance. For example, if all of the parameters were met except the wind was one knot above the criteria or the direction was 10° to far to the north, fog had tendency to form on occasion. However, if all of the parameters were met except there was a two degree air temperature and dewpoint spread, fog rarely developed. When conditions are approaching the fog thresholds, the forecaster needs to concentrate more on the air temperature and dewpoint forecasts as opposed to wind speed and direction which have less importance.

If all of the parameters in this study were correctly forecast all of the time, the accuracy of the forecaster's sea fog forecast, when using this method, would be roughly 86%. When you factor in the normal forecast errors of the forecaster, this percentage would decrease. There are several factors like accurate measurements of the dewpoint, sea surface temperature and air temperature that cannot be controlled and therefore reduce the overall accuracy of this method.

The statistical accuracy of the parameters is not as accurate during seasons with few fog events. The CSI, MR and FAR measurements decrease, however the general correct rate, which uses both fog and no fog events, maintains its accuracy. On the other hand, when the fog parameters are used only during a sea fog event, the CSI, MR and FAR measurements dramatically improve and the general correct rate decreases slightly.

B. RECOMMENDATIONS

1. Recommendations for the Forecaster

It was shown in the conclusion section how important it is to forecast the wind direction and speed, surface air temperature, dewpoint and sea surface temperature accurately as possible. When the fog parameters found in this study are satisfied, generally there are no major synoptic changes taking place in the area of interest. One of the best forecast methods to use in this circumstance is to follow persistence or a slightly modified version.

2. Recommendations for Future Research

Due to the lack of data from Station PCBF1, this study was not able to obtain optimized parameters during many seasons for Tyndall AFB, Hurlburt Field, Destin-Fort Walton Beach Airport and Eglin AFB. Another study similar to this one needs to be accomplished in five or six years. This study would include new data from Station PCBF1 during many additional seasons. By utilizing the additional seasons, the extreme below average as well as the extreme above average years will be averaged and more precise fog parameters can be obtained. This would improve the ability to accurately forecast fog for these locations.

Another interesting future research topic is to see how accurate an atmospheric model can forecast the fog parameters in this study. The answer to this would determine roughly how accurate a model could forecast advection sea fog events. As model accuracy continues to improve, this could lead to a model that is capable of indicating potential areas of advection sea fog.

If additional sensors could be deployed on Station PCBF1 and Station 42007, the same study could be accomplished using horizontal surface visibility, wind direction and speed, surface air temperature, dewpoint and sea surface temperature data from these offshore locations. This method would eliminate the effects of great distances between the sea surface temperature sensor and the atmospheric sensors and also the effects of radiation fog over land. This would be a more precise study of the formation and dissipation of advection sea fog.

APPENDIX A – FORTRAN CODE (METAR-DECODE)

Purpose – Extracts certain fields from raw METAR observations and creates an output file with fields needed to make fog prediction in separate columns.

```
  Program MetarDecode
c
c  program to read raw METAR reports and pull main fields out
c
      character report*200,t*3,td*3,ws*3,wd*3,day*2,hr*2,min*2
      character wx*40,vis*8,filein*100,fileout*100,mn*2,yr*2
c
      call getarg(1,filein)
      open(unit=10,file=filein,access='sequential',
     +  form='formatted',status='old')
      call getarg(2,fileout)
      open(unit=1,file=fileout,access='sequential',
     +  form='formatted',status='new')
      call getarg(3,mn)
      call getarg(4,yr)
c
  10  continue
      read(10,'(a200)',end=99)report
      print *,report(1:20)
      ll=nblank(report)
      it=0
      iwx=0
      iw=0
      do n=1,ll
c find altimeter setting for reference
       if(report(n:n+1).eq.'A2'.or.
     +  report(n:n+1).eq.'A3')then
c get temp/dewpt which is assumed to occur just before altimeter
        do k=n-2,n-10,-1
         if(report(k:k).eq.' ')then
          it=k+1
          go to 5
         endif
        enddo
  5     continue
        if(it.ne.0)then
        islash=0
        do k=it,n-2
         if(report(k:k).eq.'/')islash=k
        enddo
         if(islash.ne.0)then
            t=report(it:islash-1)
            td=report(islash+1:n-2)
         else
            t='MM'
```

```
             td='MM'
          endif
         else
             td='MM'
             td='MM'
         endif
        elseif((report(n-1:n).ne.'HZ'.and.report(n-1:n).ne.'DZ')
     +      .and.report(n:n).eq.'Z'.and.n.lt.24)then
c get the time and day
         day=report(n-6:n-5)
         hr=report(n-4:n-3)
         min=report(n-2:n-1)
        elseif(report(n:n+1).eq.'KT')then
c get the winds
         iwx=n+3
         do k=n,n-10,-1
          if(report(k:k).eq.' ')then
            iw=k+1
          go to 15
          endif
         enddo
  15     continue
         wd=report(iw:iw+2)
         if(report(iw+5:iw+5).eq.'K'.or.report(iw+5:iw+5).eq.'G')then
           ws=report(iw+3:iw+4)
         else
           ws=report(iw+3:iw+5)
         endif
        endif
       enddo
c pull out the vis, weather, and clouds
        if(it.eq.0.or.iwx.eq.0.or.iw.eq.0)go to 10
        ivz=0
        do k=iwx,it-1
          if(report(k:k+1).eq.'SM')ivz=k-1
        enddo
        if(ivz.ne.0)then
        iwx2=0
        do k=iwx,ivz
          if(report(k:k).eq.'V')iwx2=k+4
        enddo
        if(iwx2.eq.0)then
        vis=report(iwx:ivz)
        else
        vis=report(iwx2:ivz)
        endif
        wx=report(ivz+3:it-1)
        else
        wx=report(iwx-1:it-1)
        endif
c
        if(wd(1:3).ne.'VRB')then
        read(wd(1:3),'(i3)')iwd
        else
        iwd=0
        endif
        read(ws(1:3),'(i3)')iws
```

```
      if(t(1:2).ne.'MM')then
       if(t(1:1).eq.'M')then
       read(t(2:3),'(i2)')itc
       itc=-itc
       else
       read(t(1:3),'(i3)')itc
       endif
      else
       itc=99
      endif
      if(td(1:2).ne.'MM')then
       if(td(1:1).eq.'M')then
       read(td(2:3),'(i2)')itd
       itd=-itd
       else
       read(td(1:3),'(i3)')itd
       endif
      else
       itd=99
      endif
c
      if(ivz.ne.0)then
      is=0
      if(vis(1:1).eq.'M')then
       do k=2,8
        vis(k-1:k-1)=vis(k:k)
       enddo
      endif
      do k=2,8
       if(vis(k:k).eq.' '.and.vis(k-1:k-1).ne.' ')then
        isp=k
        go to 25
       endif
      enddo
  25  continue
      do k=1,8
       if(vis(k:k).eq.'/')then
         is=k
       endif
      enddo
      if(is.eq.0)then
        read(vis(1:isp-1),'(i3)')ivis
      xvis=float(ivis)
      else
      if(isp.gt.is)then
        ivis=0
        read(vis(1:is-1),'(i3)')inm
        read(vis(is+1:8),'(i6)')idm
      else
        read(vis(1:isp-1),'(i3)')ivis
        read(vis(isp:is-1),'(i3)')inm
        read(vis(is+1:8),'(i6)')idm
      endif
      xvis=float(ivis)+float(inm)/float(idm)
      endif
      else
       xvis=-99.0
```

```
      endif
      write(1,200)yr,mn,day,hr,min,iwd,iws,itc,itd,xvis,wx
     go to 10
 99  continue
     close(unit=10)
     close(unit=1)
200  format(3(a2,1x),2a2,1x,i3,1x,i3,1x,i3,1x,i3,1x,f8.4,1x,a40)
     stop
     end
```

APPENDIX B – FORTRAN CODE (NBLANK)

Purpose - Determines the length of a non-blank character string used by the program “fog_predict”.

```
integer function nblank (char)
c
       character*(*) char
       llen=len(char)
       i=1
c
       do while (char(i:llen).ne.' ')
         i=i+1
       enddo
c
       nblank=i-1
c
       return
       end
```

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APPENDIX C – FORTRAN CODE (FOG_PREDICT)

Purpose – Reads in output from “metar-decode” and sea surface temperatures from text files. The output file contains atmospheric fields, sea surface temperature for each observation and adds “fog” in a new column for each line of data that meets the fog parameters.

```
     program fog_predict
c  declare variables
      real wd,ws,gs,wh,dp,ap,mwd,slp,t,ts,td,vis,cslp
      integer ihr,imon,idy,mhr,mmon,mdy
      character line*80,filen*80,direct*60,file*20,wx*40,fg*3
       d2r=0.01745329
c
      direct='/h/ochome1/jking/Thesis/Data/all_years_output/'
c      print*,'Input Filename'
c      read(5,'(a15)')file
      file='42007_05_06.txt'
      l=nblank(direct)
      filen=direct(1:l)//file
c  open buoy data file
      open(unit=1,file=filen,
     +      access='sequential',form='formatted',status='old')
c  open station data file
      open(unit=2,
     + file='/h/ochome1/jking/Thesis/Data/all_years_output/'//
     +   'kbix_out_05_06.txt',
     +      access='sequential',form='formatted',status='old')
      open(unit=3,file='fog-prediction.txt',
     +      access='sequential',form='formatted',status='new')
c  read data file
      btime=0.0
 5    continue
      read(2,200,end=1000)iyr,imon,idy,ihr,imin,iwd,iws,itc,itd,xvis,wx
c get time since Jan 1
      stime=float(idy-1)*24.+float(ihr)+float(imin)/60.
      if(imon.eq.2)stime=stime+744.
      if(imon.eq.3)stime=stime+1416.
      if(imon.eq.4)stime=stime+2160.
      if(imon.eq.5)stime=stime+2880.
      if(imon.eq.6)stime=stime+3624.
      if(imon.eq.7)stime=stime+4344.
      if(imon.eq.8)stime=stime+5088.
      if(imon.eq.9)stime=stime+5832.
      if(imon.eq.10)stime=stime+6552.
      if(imon.eq.11)stime=stime+7296.
      if(imon.eq.12)stime=stime+8016.
      if(iyr.eq.6)stime=stime+8760.
c
      read(1,'(a80)')line
```

```
 10   continue
      read(1,'(a80)',end=1000)line
      read(line(1:80),*,err=900)iyear,
     + month,iday,ihour,min,wd,ws,gs,wh,dp,ap,mwd,
     +                  slp,t,ts,td,vis
      if(ts.eq.999.0)go to 10
      btime=float(ihour)+float(min)/60.0
      btime=float(iday-1)*24.+float(ihour)+float(min)/60.
      if(month.eq.2)btime=btime+744.
      if(month.eq.3)btime=btime+1416.
      if(month.eq.4)btime=btime+2160.
      if(month.eq.5)btime=btime+2880.
      if(month.eq.6)btime=btime+3624.
      if(month.eq.7)btime=btime+4344.
      if(month.eq.8)btime=btime+5088.
      if(month.eq.9)btime=btime+5832.
      if(month.eq.10)btime=btime+6552.
      if(month.eq.11)btime=btime+7296.
      if(month.eq.12)btime=btime+8016.
      if(iyear.eq.2006)btime=btime+8760.
      tdiff=btime-stime
      if(tdiff.ge.0.0)then
c
c apply fog prediction algorithm here
c
      fg='   '
      if(ts.le.19.5)then
c
       if(iws.le.14)then
       if((iwd.eq.0.or.(iwd.le.260.and.iwd.ge.70)).or.iws.le.3)then
c
        dt=float(itc-itd)
        acdt=ts-float(itd)
        if(dt.le.1.0.and.acdt.le.3.3)fg='fog'
       endif
       endif
      endif
c
      write(3,210)iyr,imon,idy,ihr,imin,iwd,iws,itc,itd,ts,xvis,fg,wx
      rewind(unit=1)
      go to 5
      endif
      go to 10
 900  continue
      print *,month,iday,ihour
 1000 continue
      close(unit=1)
      close(unit=2)
      close(unit=3)
 200  format(3(i2,1x),2i2,1x,i3,1x,i3,1x,i3,1x,i3,1x,f8.4,1x,a40)
 210  format(3(i2,1x),2i2,4(1x,i3),1x,f5.2,1x,f8.4,1x,a3,1x,a40)
c
      stop
      end
```

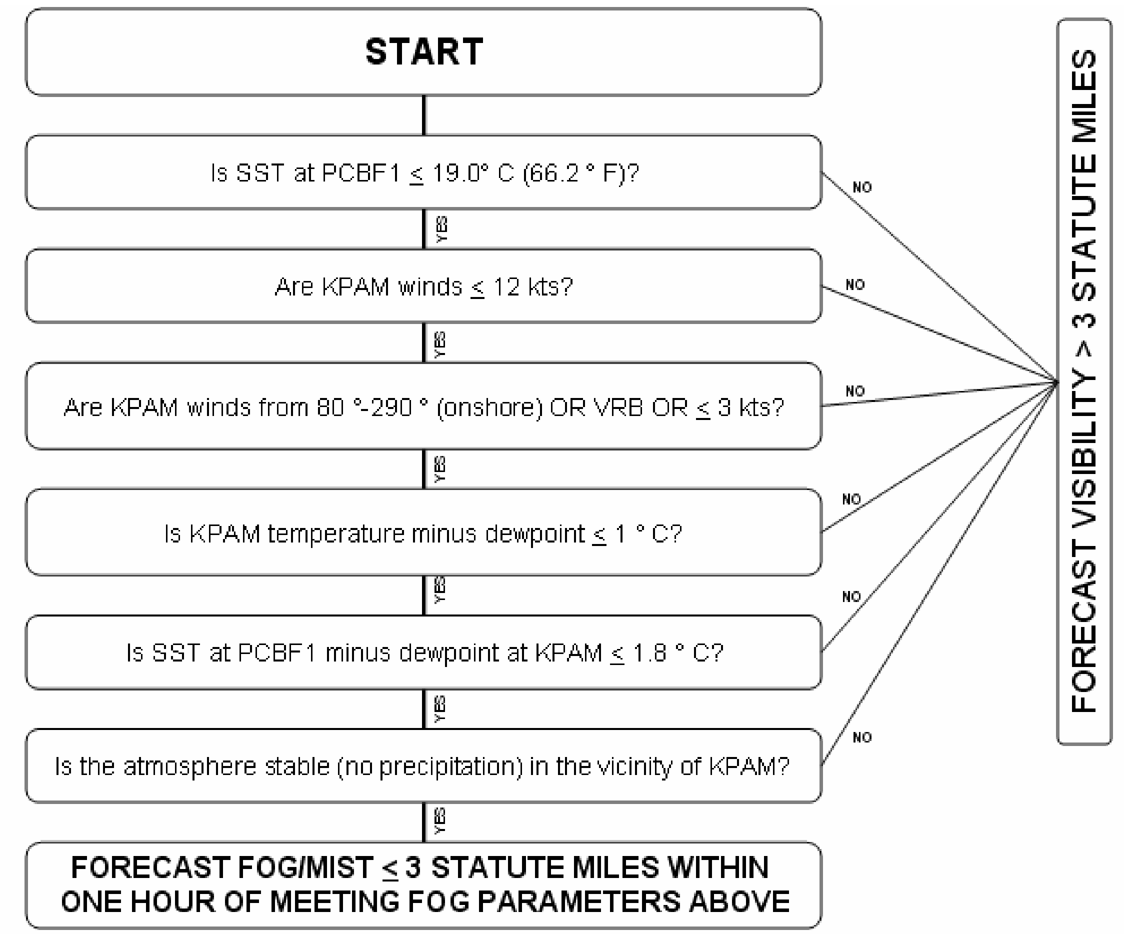
APPENDIX D – FORTRAN CODE (FOG-MULTIHOUR)

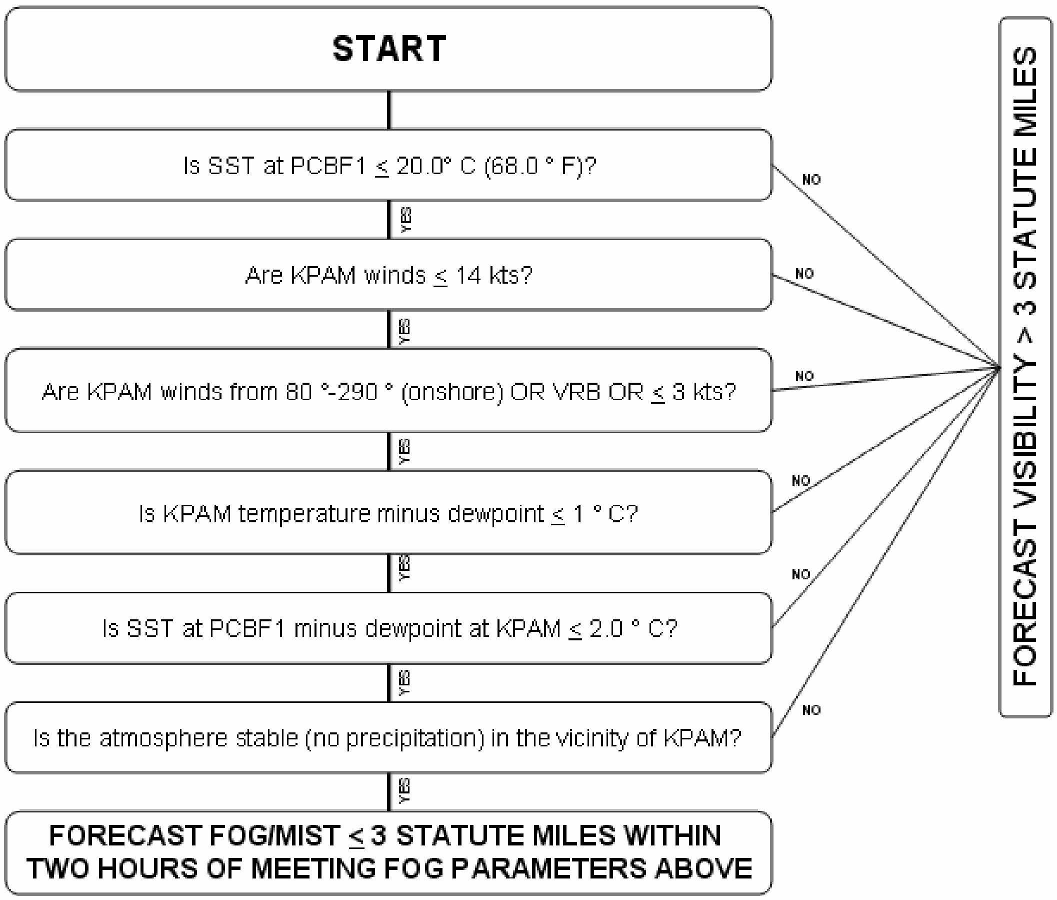
Purpose – Reads in output from “fog_predict” and creates a minimum visibility value contained within the 120 or 240 minute time window for each observation.

```
program fog_multihour
c
      real tsea(20000),vis(20000),time(20000)
      integer yr(20000),mon(20000),dy(20000),hr(20000),min(20000),
     +  wd(20000),ws(20000),tc(20000),td(20000)
      character fog(20000)*3,wth(20000)*40,fg*3,wx*40
c
      open(unit=1,file=
     + '/h/ochome1/jking/Thesis/Data/fog-prediction.txt',
     +    access='sequential',form='formatted',status='old')
      nobs=0
c
 10   continue
      read(1,210,end=100)iyr,imon,idy,ihr,imin,iwd,iws,itc,itd,ts,
     +   xvis,fg,wx
      nobs=nobs+1
      yr(nobs)=iyr
      mon(nobs)=imon
      dy(nobs)=idy
      hr(nobs)=ihr
      min(nobs)=imin
      time(nobs)=float(idy-1)*24.+float(ihr)+float(imin)/60.
      if(imon.eq.2)time(nobs)=time(nobs)+744.
      if(imon.eq.3)time(nobs)=time(nobs)+1416.
      if(imon.eq.4)time(nobs)=time(nobs)+2160.
      if(imon.eq.5)time(nobs)=time(nobs)+2880.
      if(imon.eq.6)time(nobs)=time(nobs)+3624.
      if(imon.eq.7)time(nobs)=time(nobs)+4344.
      if(imon.eq.8)time(nobs)=time(nobs)+5088.
      if(imon.eq.9)time(nobs)=time(nobs)+5832.
      if(imon.eq.10)time(nobs)=time(nobs)+6552.
      if(imon.eq.11)time(nobs)=time(nobs)+7296.
      if(imon.eq.12)time(nobs)=time(nobs)+8016.
      if(iyr.eq.06)time(nobs)=time(nobs)+8760.
      wd(nobs)=iwd
      ws(nobs)=iws
      tc(nobs)=itc
      td(nobs)=itd
      tsea(nobs)=ts
      vis(nobs)=xvis
      fog(nobs)=fg
      wth(nobs)=wx
c
      go to 10
 100  continue
```

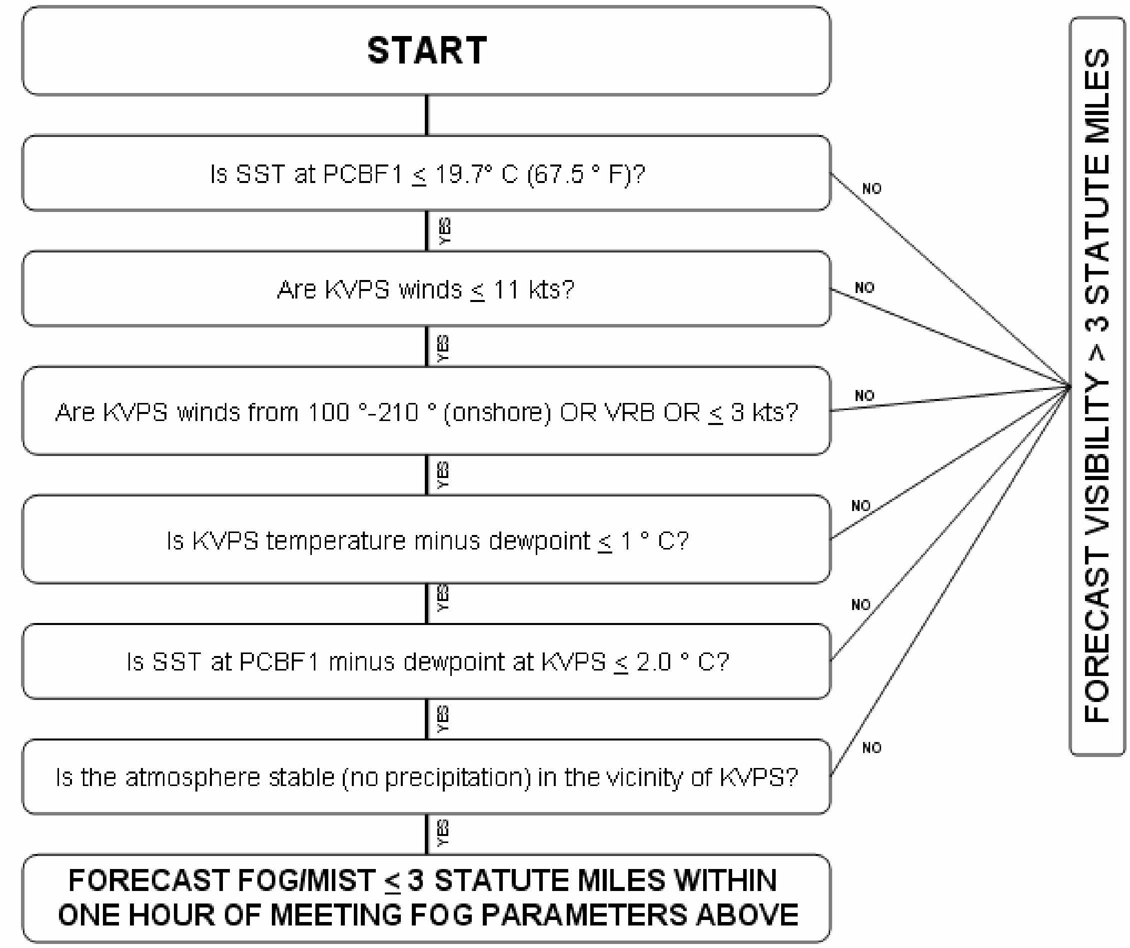
```
      close(unit=1)
      print *,nobs
c
c now check over specified number of hours to see if fog occurred
c
      open(unit=2,file='fog-pred.txt',
     +    access='sequential',form='formatted',status='new')
      do n=1,nobs
       ns=n-20
       if(ns.lt.0)ns=1
       ne=n+20
       if(ne.gt.nobs)ne=nobs
       vismin=100.0
       do k=ns,ne
       dt=abs(time(n)-time(k))
       if(dt.le.2.0)then
         if(vis(k).lt.vismin)vismin=vis(k)
       endif
       enddo
c now output new record that includes vismin
      write(2,220)yr(n),mon(n),dy(n),hr(n),min(n),wd(n),ws(n),tc(n),
     +   td(n),tsea(n),vis(n),vismin,fog(n),wth(n)
      enddo
      close(unit=2)
c
 210  format(3(i2,1x),2i2,4(1x,i3),1x,f5.2,1x,f8.4,1x,a3,1x,a40)
 220  format(3(i2,1x),2i2,4(1x,i3),1x,f5.2,2(1x,f8.4),1x,a3,1x,a40)

      stop
      end
```

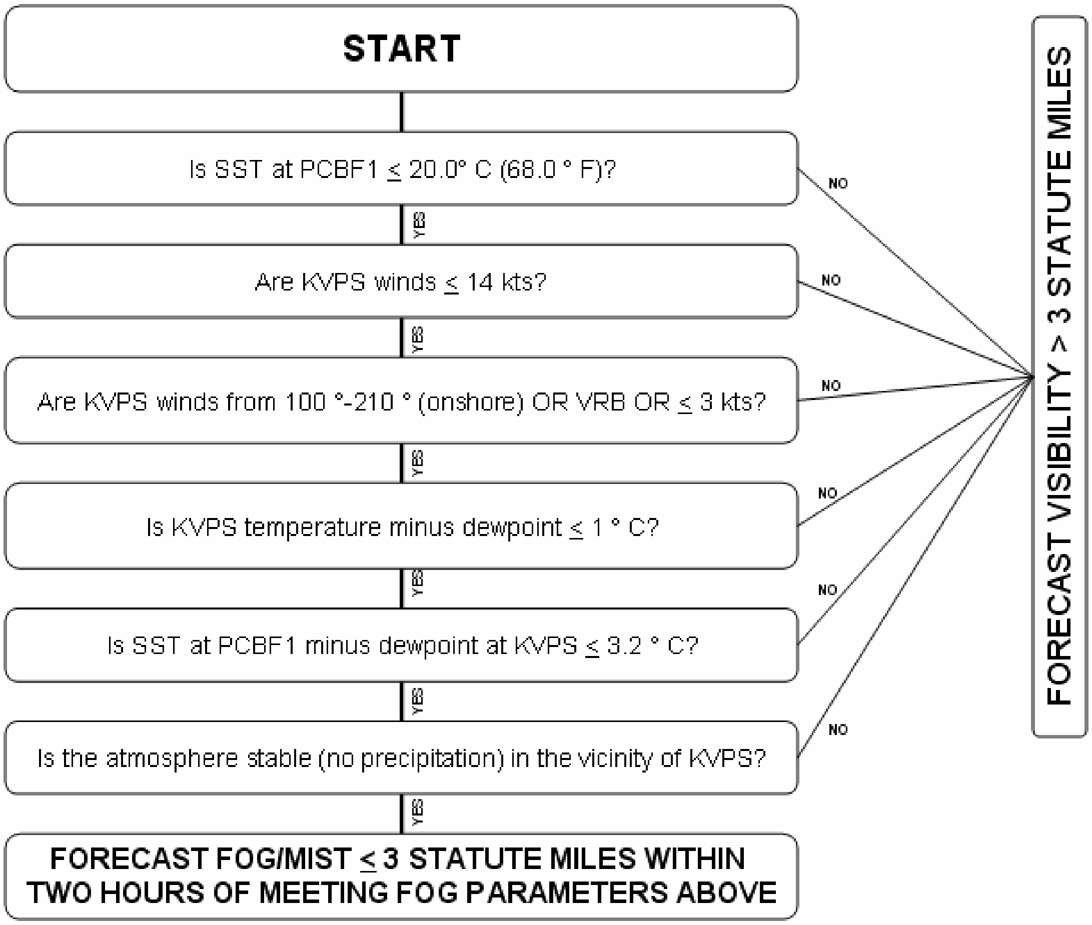
APPENDIX E – FORECAST DECISION TREES FOR TYNDALL AFB



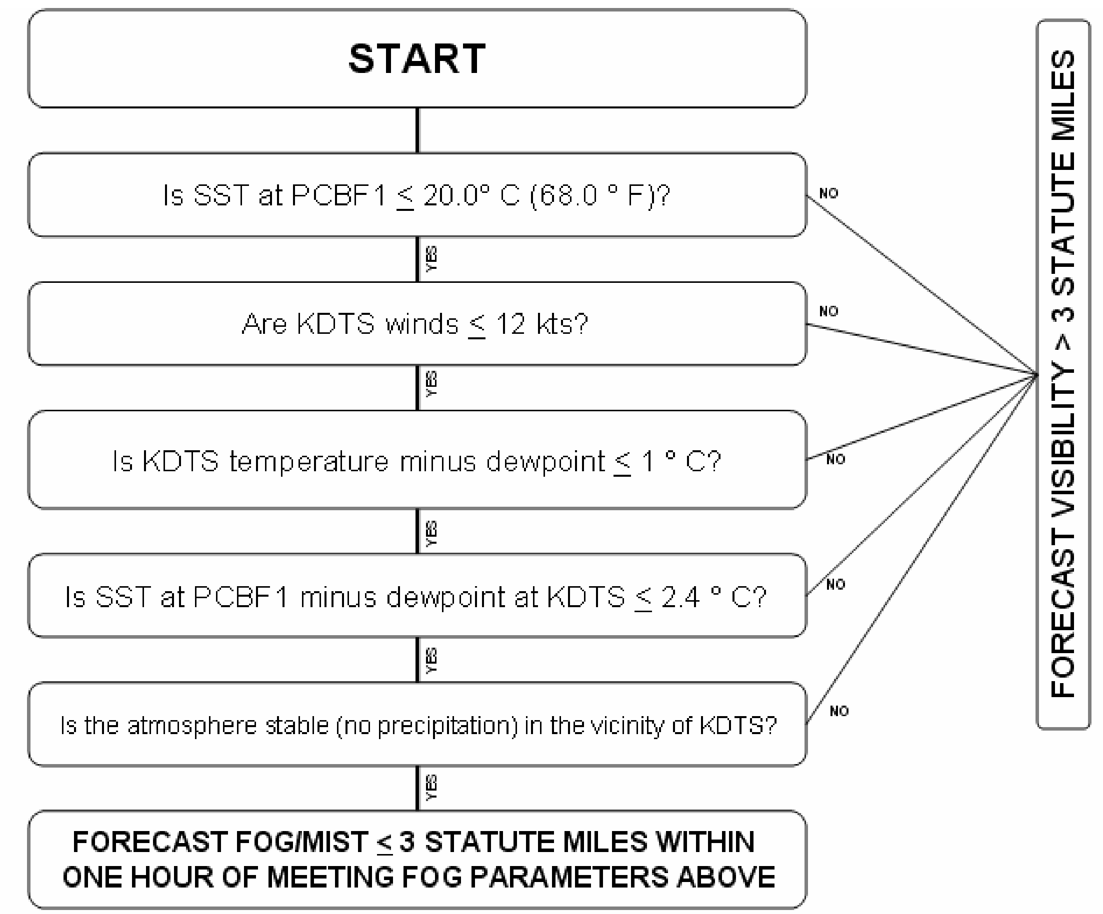

START
Is SST at PCBF1 ≤ 20.0° C (68.0 ° F)?
Are KPAM winds ≤ 14 kts?
Are KPAM winds from 80 °-290 ° (onshore) OR VRB OR ≤ 3 kts?
Is KPAM temperature minus dewpoint ≤ 1 ° C?
Is SST at PCBF1 minus dewpoint at KPAM ≤ 2.0 ° C?
Is the atmosphere stable (no precipitation) in the vicinity of KPAM?
FORECAST FOG/MIST ≤ 3 STATUTE MILES WITHIN TWO HOURS OF MEETING FOG PARAMETERS ABOVE
YES
NO
FORECAST VISIBILITY > 3 STATUTE MILES

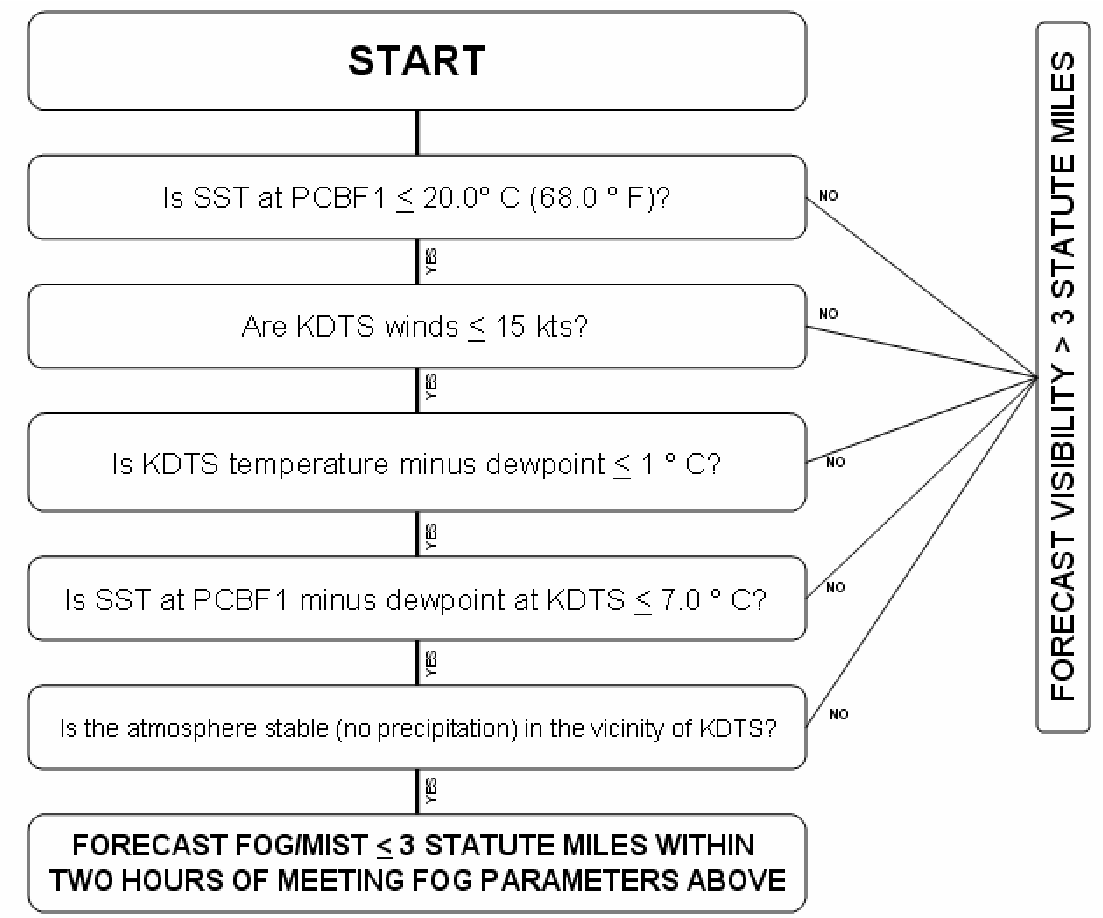
APPENDIX F – FORECAST DECISION TREES FOR EGLIN AFB



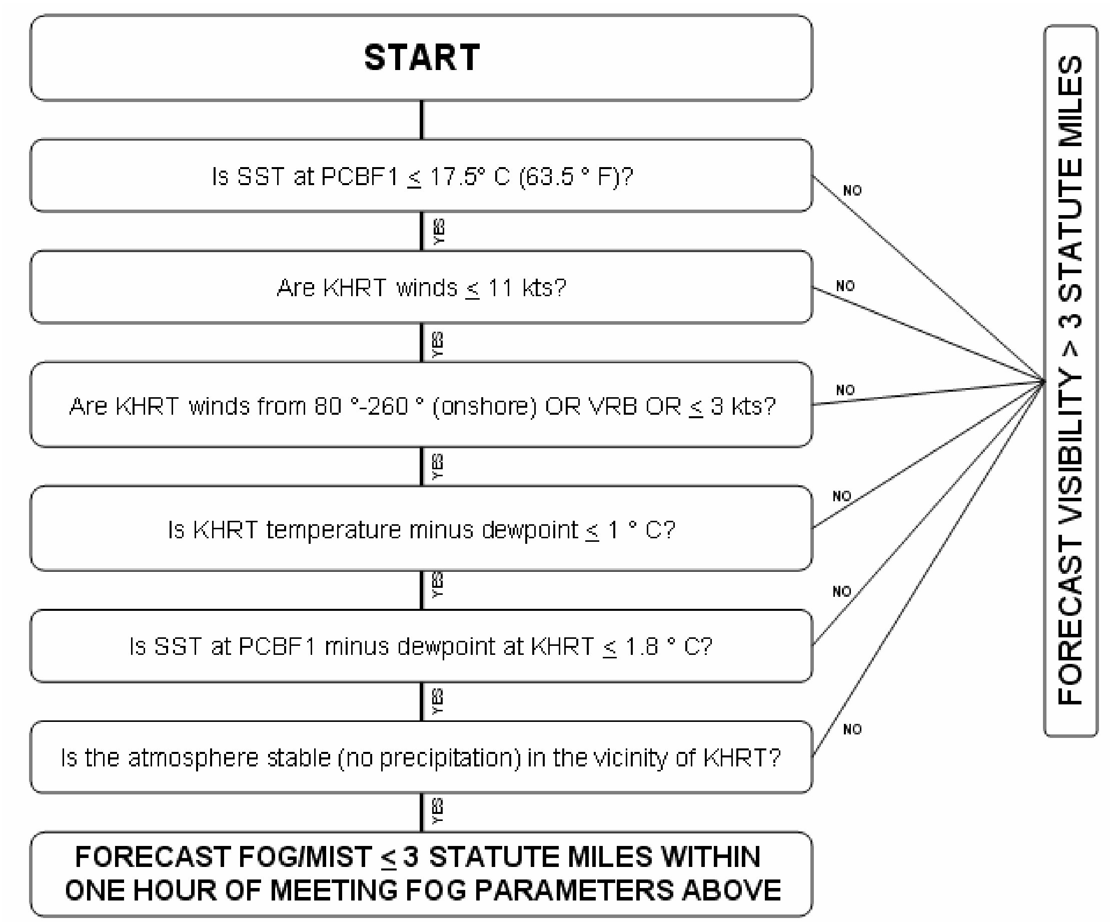

START
Is SST at PCBF1 ≤ 20.0° C (68.0 ° F)?
YES
Are KVPS winds ≤ 14 kts?
YES
Are KVPS winds from 100 °-210 ° (onshore) OR VRB OR ≤ 3 kts?
YES
Is KVPS temperature minus dewpoint ≤ 1 ° C?
YES
Is SST at PCBF1 minus dewpoint at KVPS ≤ 3.2 ° C?
YES
Is the atmosphere stable (no precipitation) in the vicinity of KVPS?
YES
FORECAST FOG/MIST ≤ 3 STATUTE MILES WITHIN TWO HOURS OF MEETING FOG PARAMETERS ABOVE
NO
FORECAST VISIBILITY > 3 STATUTE MILES

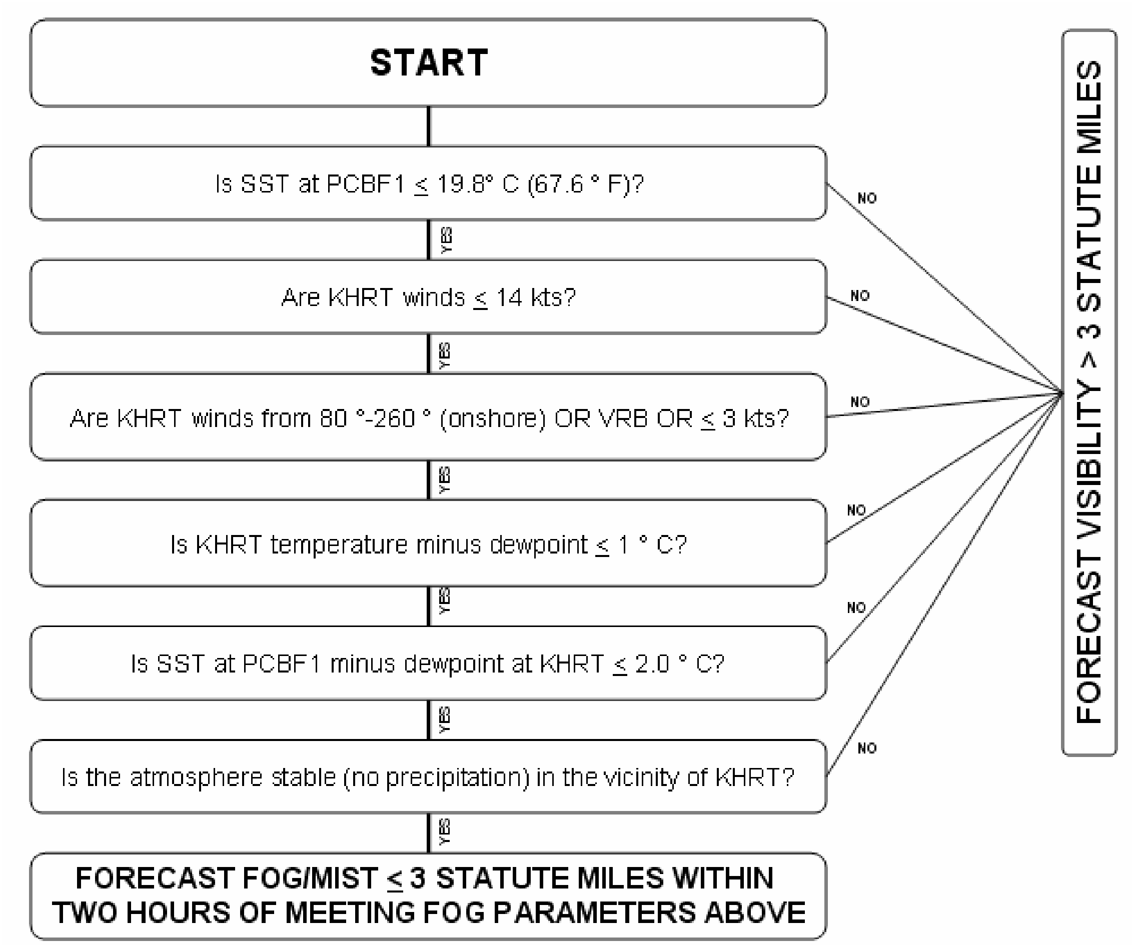
APPENDIX G – FORECAST DECISION TREES FOR DESTIN/FORT WALTON BEACH AIRPORT



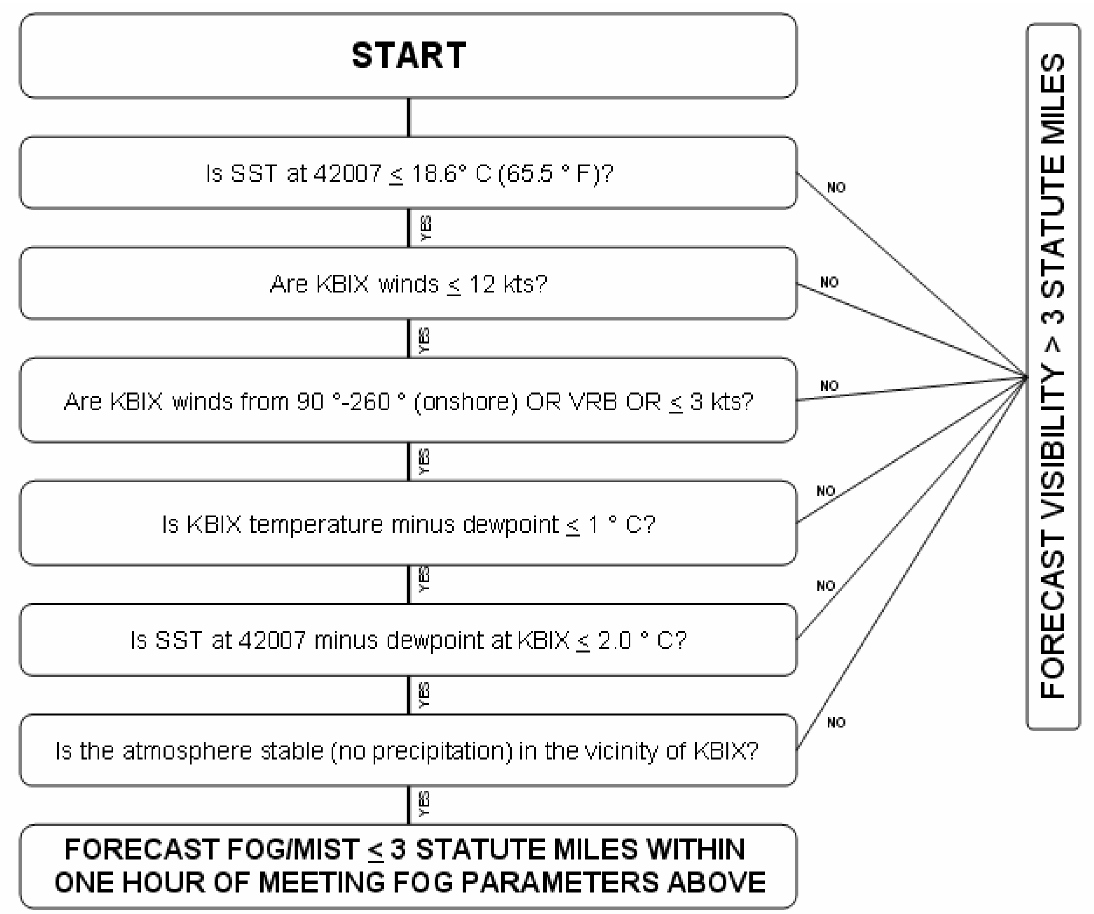

START
Is SST at PCBF1 ≤ 20.0° C (68.0 ° F)?
YES
NO
Are KDTS winds ≤ 15 kts?
YES
NO
Is KDTS temperature minus dewpoint ≤ 1 ° C?
YES
NO
Is SST at PCBF1 minus dewpoint at KDTS ≤ 7.0 ° C?
YES
NO
Is the atmosphere stable (no precipitation) in the vicinity of KDTS?
YES
NO
FORECAST FOG/MIST ≤ 3 STATUTE MILES WITHIN TWO HOURS OF MEETING FOG PARAMETERS ABOVE
FORECAST VISIBILITY > 3 STATUTE MILES

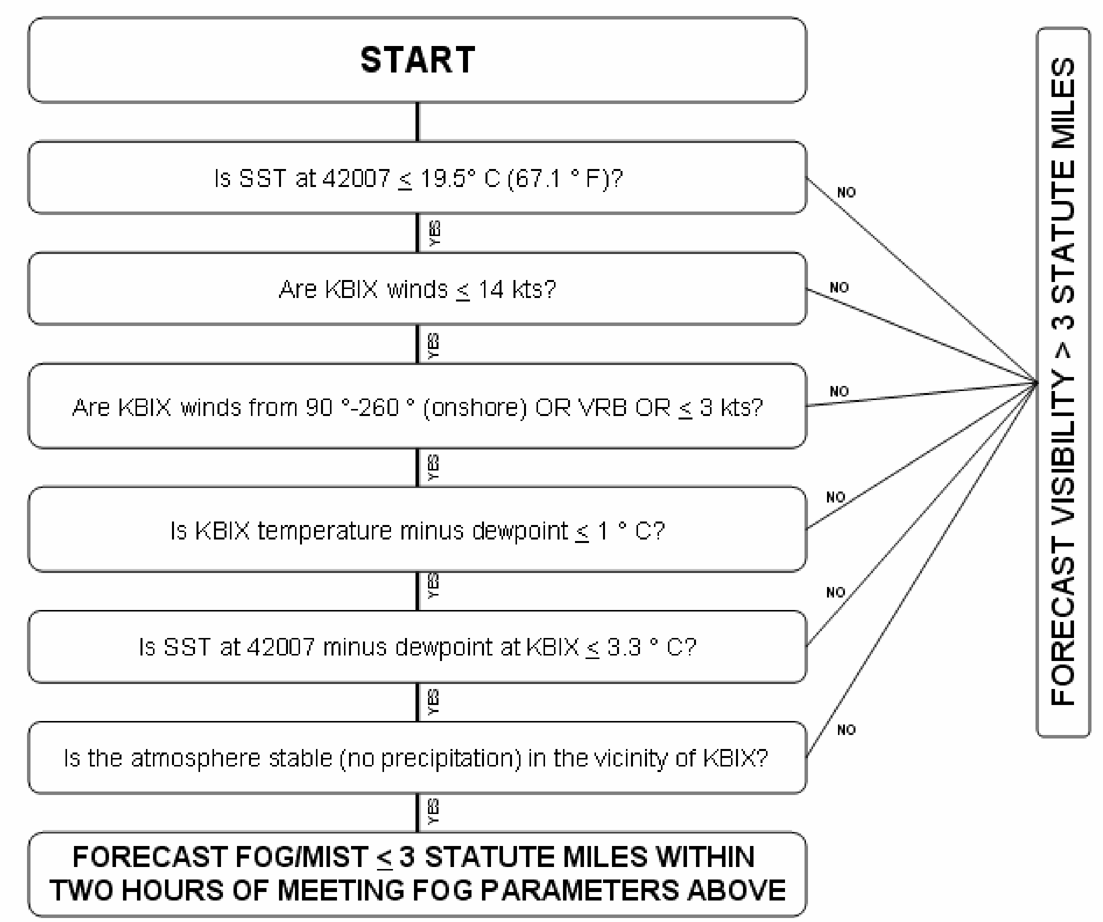
APPENDIX H – FORECAST DECISION TREES FOR HURLBURT FIELD




START
Is SST at PCBF1 ≤ 19.8° C (67.6 ° F)?
YES
Are KHRT winds ≤ 14 kts?
YES
Are KHRT winds from 80 °-260 ° (onshore) OR VRB OR ≤ 3 kts?
YES
Is KHRT temperature minus dewpoint ≤ 1 ° C?
YES
Is SST at PCBF1 minus dewpoint at KHRT ≤ 2.0 ° C?
YES
Is the atmosphere stable (no precipitation) in the vicinity of KHRT?
YES
FORECAST FOG/MIST ≤ 3 STATUTE MILES WITHIN TWO HOURS OF MEETING FOG PARAMETERS ABOVE
NO
NO
NO
NO
NO
NO
FORECAST VISIBILITY > 3 STATUTE MILES

APPENDIX I – FORECAST DECISION TREES FOR KEESLER AFB




START
Is SST at 42007 ≤ 19.5° C (67.1 ° F)?
Are KBIX winds ≤ 14 kts?
Are KBIX winds from 90 °-260 ° (onshore) OR VRB OR ≤ 3 kts?
Is KBIX temperature minus dewpoint ≤ 1 ° C?
Is SST at 42007 minus dewpoint at KBIX ≤ 3.3 ° C?
Is the atmosphere stable (no precipitation) in the vicinity of KBIX?
FORECAST FOG/MIST ≤ 3 STATUTE MILES WITHIN TWO HOURS OF MEETING FOG PARAMETERS ABOVE
YES
NO
FORECAST VISIBILITY > 3 STATUTE MILES

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   Monterey, California

3. Dr. Wendell A. Nuss
   Naval Postgraduate School
   Monterey, California

4. Dr. Carlyle H. Wash
   Naval Postgraduate School
   Monterey, California

5. Dr. Philip A. Durkee
   Naval Postgraduate School
   Monterey, California

6. Steven E. Vilpors, Maj, USAF
   Tyndall AFB, Florida

7. Michael D. Scott, Maj, USAF
   Eglin AFB, Florida

8. Mark A. Sheldon, 1Lt, USAF
   Keesler AFB, Mississippi

9. Steven Maile, Capt, USAF
   Hurlburt Field, Florida

10. Irv Watson
    National Weather Service Forecast Office
    Tallahassee, Florida

11. Michael Koziara
    National Weather Service Forecast Office
    Slidell, Louisiana

12. 9th Operational Weather Squadron
    Shaw AFB, South Carolina

13. 26th Operational Weather Squadron
Barksdale AFB, Louisiana

14. Air Force Weather Technical Library
Asheville, North Carolina