A Modified Fog Detection Algorithm Developed at the Miami Weather Forecast Office

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ABSTRACT

Limited visibility due to fog poses a significant danger to travelers. Accurate fog forecasts provide travelers with ample time to make preparations for low visibility conditions. Previous to this study, the Miami's NWS Weather Forecast Office used a combination of factors to forecast fog, mainly moisture and wind speeds derived from forecast and observed soundings. However, a quantitative approach based on research results has not been used yet in South Florida. Due to its subtropical climate that combines marine, Everglades, and urban conditions, traditional fog forecasting techniques are not directly applicable to South Florida.

Here we perform a retrospective analysis of the past three fog seasons in South Florida (from November 1 to April 30) using METAR data, radiosonde profiles, and in some cases satellite imagery. The reanalysis applies the United Parcel Service (UPS) Airlines technique based on crossover temperature and modified Richardson number, to all cases. The results demonstrate that a combination technique that uses the crossover temperature in conjunction with a 15-knot maximum threshold of 925 mb winds for fog formation yields the most accurate fog formation predictor at the study location. The crossover temperature is defined as the minimum dew point observed during the warmest daytime heating hours. Fog is forecast when the shelter temperature is expected to cool to a few degrees below the crossover temperature, rather than a few degrees below the dew point. This combination technique successfully predicted 65% of all fog events compared to 38% when the crossover temperature was used in conjunction with the modified Richardson number. Possibly the subtropical location limits the frequency of turbulent mixing due to synoptic features, which may explain why the 925 mb winds outperform the modified Richardson number used in the UPS airlines technique.

1. Motivation of Work

Reduced of visibility due to fog can pose a significant hazard to travelers. In fact, a 1995-2000 study by the National Transportation Safety Board found that 63% of all weather-related fatal aircraft accidents were due to Low Instrument Flight Rules (LIFR)/fog situations (Pearson 2002). Fog is also notorious for multi-vehicle accidents for land travelers, with the capability to injure or kill dozens of people (Croft 2002). While the American Meteorological Society Glossary defines fog as reducing visibility below 1km, for the purpose of this paper fog will be defined as a reduction in visibility below 2 miles (3.7 km) due to a surface - layer condensation.

The site chosen for this study is Tamiami Airport, located in the suburbs of Southwestern Miami-Dade County. Due to the nature of the site, the primary fog analyzed is radiation fog. While the conditions favorable for fog formation, such as clear skies, high humidity in the boundary layer, low turbulence, and a surface temperature inversion, are well known, formation is very sensitive and an inaccurate forecast for any one of them. Even a slight change in weather conditions, can produce a faulty fog forecast. Here we analyze similarities among fog events over the past 3 years and assess the accuracy of two fog forecasting techniques: the Crossover Technique (Baker et al. 2002) and the Modified Richardson Number (Baker et al.

2002). The purpose of this paper is to fine-tune these techniques and to modify them to improve the prediction of fog in South Florida, taking into account the subtropical climate. No study like this one has been done before at the Miami Weather Forecast Office.

2. Background

Radiation fog occurs when radiational cooling of the surface boundary layer lowers the air temperature to, or below, the dew point temperature (AMS Glossary). While this general idea is simple, the details of the process of the formation of radiation fog can be complex. The Environment Canada Handbook on Fog and Fog Forecasting does an excellent job of describing the thermodynamics of this process (Toth et al. 2010).

The usual techniques for forecasting fog require surface saturation and light surface winds. Surface saturation is usually forecast when the temperature is expected to cool to or a few degrees below the dew point (Baker et al. 2002). While this technique can be successful, a more effective technique is one that incorporates a vertical profile of humidity.

One such technique is the Crossover Technique (Baker et al. 2002). In this approach, the minimum dew point temperature during afternoon peak heating hours is recorded. This temperature is called the Crossover Temperature. If the surface temperature is expected to drop to or below this value, then fog should be forecast according to the crossover technique. This is because under normal atmospheric conditions, specific humidity decreases upward (Baker et al. 2002). Mixing of boundary layer air during peak heating hours, causes strong upward transport of water vapor, and the surface dew point lowers. The rate at which the dew point drops provides critical information about the hydrolapse. If the dew point decreases during the peak afternoon heating hours, a decrease in moisture with height can be assumed and thus there is an decreased fog risk for the following night. Conversely, if the dew point remains constant or even increases during the time the boundary layer is well-mixed, the fog risk increases.

The crossover technique should be applied only when there is not a significant source of moisture advection as well as when moisture is not being added through precipitation (Baker et al. 2002). The UPS paper, suggests that when moisture advection is present, forecasters should replace the crossover temperature with a “suitable replacement that better reflects the expected humidity profile of the nocturnal stable layer” (Baker et al. 2002).

In addition to the crossover technique, UPS Airlines also developed a technique to calculate turbulence within the boundary layer, the Modified Richardson Number, hereafter referred to as MRi (Baker et al. 2002). In this technique, the strength of the surface inversion, in degrees Celsius, is divided by the square of the maximum wind speed within the surface boundary layer. The results can be grouped into three categories of either “mixy, marginal, or decoupled.” Conditions that support a decoupled boundary layer favor fog formation.

Furthermore, ground temperature can have a significant effect on the formation of fog. One of the most important factors is soil heat flux (Cox 2007). At night, a nocturnal boundary layer forms very close to the ground in response to radiative surface cooling (Wallace and Hobbs 2006). The rate at which the nocturnal boundary layer cools can be heavily influenced by the temperature of the underlying soil (Baker et al. 2002). A cooler ground temperature will promote cooling of the nocturnal boundary layer by conduction (Cox 2007).

Forecasts for both the crossover technique and the MRi can be easily calculated and viewed using BUFKIT, which is a “forecast profile visualization and analysis toolkit” (NWS Forecast Office at Buffalo 2013). BUFKIT was developed by the staff at the National Weather Service office in Buffalo, New York, and the Warning Decision Training Branch in Norman, Oklahoma (NWS Forecast Office at Buffalo 2013).

The chosen site for this reanalysis was Tamiami Airport, hereafter referred to KTMB (Fig. 1). This location was selected because of its unique “hybrid” location between inland rural, swampy areas to the west, and the coastal, metro areas to the east (Fig. 2). In effect, this location provides a general, smoothed out representation of fog events in South Florida. It does not record as much fog as inland locations, while it does record more fog than the metropolitan airports, such as Miami International. Locations for fog reanalysis in South Florida were limited, and KTMB seems to be the best fit to meet the previously described “hybrid” criteria.

Figure 1. Google Earth snapshot of KTMB, depicted by the pin with the letter ‘A’. North is at the top of the figure. This photograph demonstrates the urban landscape to the east of KTMB, however, the areas directly to the west are far less developed as seen by the larger agricultural plots of land.

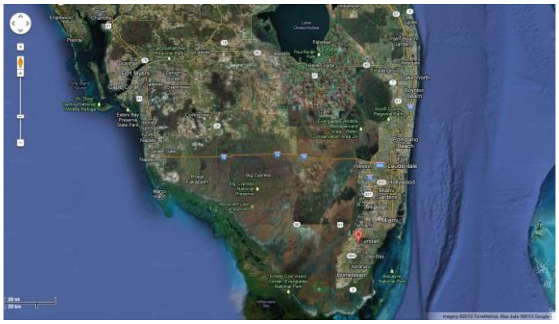

Figure 2. Google Earth snapshot of South Florida. KTMB is depicted by the pin with the letter ‘A’. Notice how KTMB is located on the western edge of the Miami metropolitan area and is adjacent to the Everglades, to its west.

3. Method

Since there has been no previous approach to quantitative fog forecasting for South Florida from the Miami National Weather Service, this study analyzed the aforementioned techniques as well as explored possible alternatives.

We focus on South Florida’s nominal fog season from November 1 through April 30. Every day during the 2010-2011, 2011-2012, and 2012-2013 fog seasons was reanalyzed for fog formation.

This was done by using archived METAR data. We designed this reanalysis to replicate what forecasters would do in real-time fog forecasting situations. We applied the crossover and MRi technique to every day in the past three fog seasons that had usable data to determine if fog would have been forecast for that day. It is important to note that this procedure assumes a perfect minimum temperature forecast since the actual minimum temperatures are used in the crossover technique reanalysis. The reason for using the actual temperatures rather than a forecast temperature is to improve the accuracy of the reanalysis. The purpose of this reanalysis is to decide which technique works best under idealized conditions. For those days in which precipitation was recorded or a frontal passage occurred, the crossover technique and MRi were not applied, since these days did not meet the previously mentioned criteria.

For the purposes of this study, fog events occurred if visibilities dropped to or below 2 miles due to the presence of a surface cloud layer rather than because of precipitation. All fog events were recorded during the 3 studied fog seasons. If the crossover technique correctly predicted fog, the event was deemed a "success." If fog was not predicted by the crossover technique, but fog occurred at KTMB, the fog event was deemed a "missed event." Finally, if fog was predicted using the crossover technique, but fog was not recorded at KTMB, the event was deemed a "false alarm."

On all days that met the success, miss, or false alarm criteria, MRi was calculated to analyze how much it aided or hindered fog forecasts originally made using the crossover technique. In order to calculate the MRi, the strength of the surface inversion, as well as the maximum wind speed within this inversion, was derived from the 12Z MFL sounding. The sounding takes place on site of the Miami National Weather Service, which is about 9 miles from KTMB, but a similar distance from the coastline. Even though weather conditions may be slightly different, the sounding data was still viewed as an acceptable substitution for what would be a model forecast if this was forecast in real time.

4. Results

This approach yielded, 534 days of usable data. Of these, 88 were fog events. While year-to-year fluctuations of accuracy did occur, the crossover technique successfully forecast 64 (72.7%) of fog events and missed 24 (27.3%) . In total, the crossover technique registered 51 false alarms.

Although the Baker et al. (2002) study did not design the MRi to be used as a standalone technique to predict fog formation, we tested it in this mode here. When used as a standalone fog forecast technique, the MRi successfully forecast 47 out of the 88 fog events (53.4%), and missed 41 events (46.6%). This is a relatively low success rate compared to the crossover technique. Furthermore, it is advised that the MRi should not be used as a standalone fog forecast technique since the dominant factors in fog formation in South Florida are moisture content and moisture fluxes.

The next step was to consider the MRi's ability to predict fog events when combined with the crossover technique (Baker et al. 2002). This process was implemented by using the MRi as a second "filter" in fog forecasts at KTMB (Fig. 3). Thus, if fog was forecast using the crossover technique it was further tested to see if fog would still be predicted by using the MRi. If neither the crossover technique nor the MRi forecast fog, then a fog event was not forecast. By combining these techniques, false alarms were reduced from 51 to 20. However, the apparent success of employing this strategy is initially misleading. While false alarms were reduced, the number of successful forecasts of fog events was also significantly reduced from 64 using only the crossover technique to 33 using the combination of crossover and MRi. This procedure yields a success rate of only 37.5%.

Therefore, it was determined that the standalone crossover technique was a more accurate predictor of fog in South Florida than when it was used in tandem with the MRi. A possible explanation for this could be that changes in the moisture content of the boundary layer have a greater impact than turbulence, since South Florida nights are not very turbulent, meteorologically speaking.

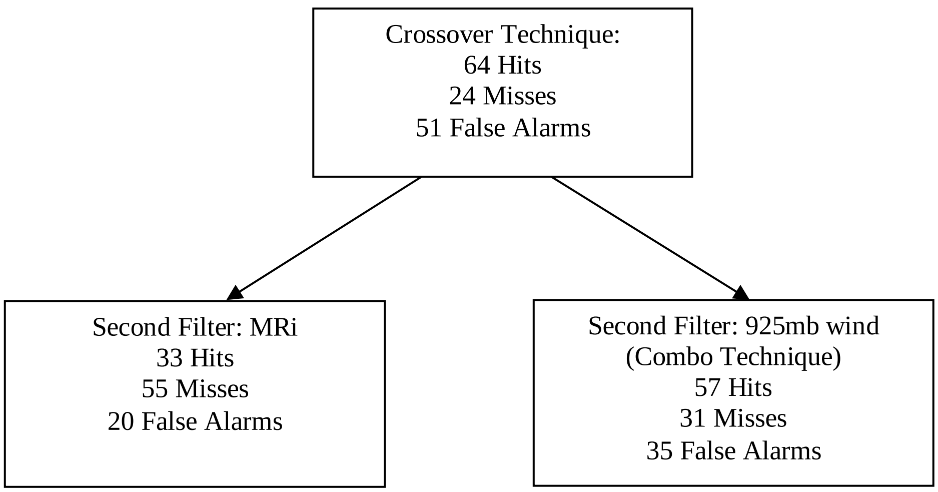

Figure 3. A flowchart of results using only the crossover technique, the crossover technique in conjunction with the MRi, and the combo technique.

Nonetheless, the large number of false alarms (51) yielded by the crossover technique still leaves much to be desired. After a careful analysis of the causes of the false alarms produced by the crossover technique, many of the false alarms were attributed to too-strong winds above the surface, occasionally produced by a weak low level jet. South Florida does not often experience strong low level jets such as occurs in, for example, the Great Plains. Nonetheless, when winds in the upper half of the boundary layer increase, they mix momentum down to the surface and impede the formation of fog. In order to detect these occurrences, many different alternative techniques were tested to supplement to the crossover technique. Among these predictors, the speed of the 925mb winds emerged as the best alternative.

In this technique, hereafter referred to as the "combo technique," the crossover technique is first applied. If fog is predicted using the crossover technique, then the 925mb winds are analyzed. If 925mb winds at the studied location are expected to be $\leq$15 knots, then fog should be forecast. If 925mb winds were > 15 knots the combo technique implies the event would have most likely been a false alarm and fog should not be forecast. A flowchart of this process is given in Fig. 4.

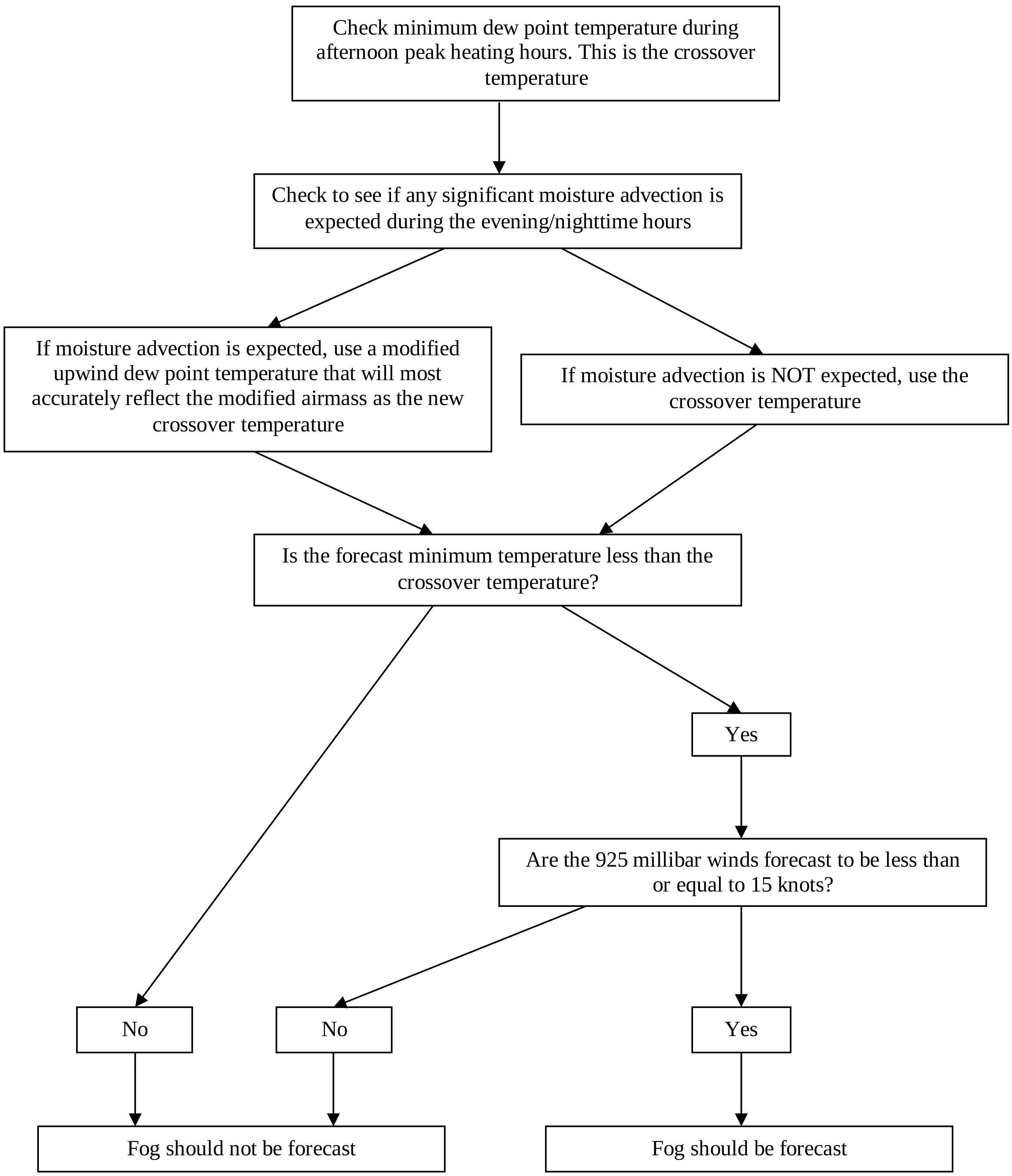

Figure 4. This flowchart outlines the necessary steps for forecasting fog using the combo technique.

By employing the combo technique for the last three fog seasons, a success rate of 64.8% was recorded, which is much greater than the success rate of the crossover technique in tandem with the MRi, but slightly less than the crossover technique as a standalone predictor. The combo technique also reduced the number of predicted false alarms from the total of 51 using only the crossover technique to 35. This is a 31% reduction in false alarms at the expense of only a 7% lower amount of successfully predicted fog events. A complete set of results can be seen in Table 1.

Table 1 shows the results for each of the techniques used in the reanalysis for the past 3 fog seasons. S represents successes, M represents misses, and FA represents false alarms. The MRi and 925 mb columns display the results that would be obtained if a perfect Crossover Technique forecast is made. While this may be unrealistic, the purpose of placing these columns in the table is to demonstrate how few cases the 925 mb technique misses compared to the larger amount the MRi misses.

Fog Season	# of Days Analyzed	# of Events	Crossover Technique	MRi	925 mb	Crossover Technique & MRi	Crossover Technique & 925 mb
2010-2011	177	36	26 S 10 M 24 FA	19 S 17 M	29 S 7 M	15 S 21 M 11 FA	23 S 13 M 20 FA
2011-2012	180	28	18 S 10 M 15 FA	14 S 14 M	25 S 3 M	8 S 19 M 3 FA	16 S 12 M 10 FA
2012-2013	181	24	20 S 4 M 12 FA	14 S 10 M	21 S 3 M	10 S 14 M 6 FA	18 S 6 M 6 FA
Total	538	88	64 S 24 M 51 FA	47 S 41 M	75 S 13 M	33 S 55 M 20 FA	57 S 31 M 35 FA
Success %	-	-	73	53	85	38	65
FA Reduction %	-	-	0	-	-	61	31

To further illustrate the use of this technique we present a few case studies. The first is the morning of 3 February 2012. The first step was to check for the crossover temperature from the previous morning. The minimum dew point temperature observed on the afternoon of 2 February was 64^{o}F. It was significant that the dew point was relatively constant during peak heating hours, indicating that humidity increased with height within the boundary layer (Baker et al. 2002). This condition was favorable for fog formation. Thus, when the minimum temperature dipped to 64°F on the morning of the 3rd, it was reasonable to believe that fog would form. However, the synoptic set up created a very difficult forecast. While fog had indeed formed on the morning of the 2nd, a stationary cold front was draped across the central portion of the state and a tight pressure gradient was expected to allow a light breeze to develop overnight. Would the breeze be strong enough to prevent the formation of fog? This was where the combination of the crossover technique with 925mb winds became useful. The 12Z sounding on the morning of February 3rd revealed that although there was a surface inversion, which was also favorable for fog formation, winds increased quickly above the surface. At 925mb winds were 20 knots, and as a result the combo technique would not have forecast fog. Fog did not, in fact, form on the morning of 3 February, even though the relative humidity was reported at 100% at 2:53 AM and 3:53 AM LST. A false alarm that would have been forecast using solely the crossover technique was averted with the combo technique.

In addition to the prevention of false alarms, the combo technique was frequently successful in prediction of fog. The crossover technique predicted fog for the morning of 9 February 2013. The dew point during the afternoon of 8 February reached a minimum of 67°F, while the minimum temperature on the morning of the 9th was 60°, a whole 7° below the crossover. This cooling was probably aided by the passage of a very weak cold front (Fig. 5). The 12Z sounding on the morning of 9 February also supported a fog forecast with 925mb winds of 7 knots. Although very light surface winds were reported throughout the night, the lack of strong mixing allowed the relative humidity to reach 100% by 5:09 AM LST. By 7:15 AM, visibilities had fallen to 0.2 miles, as foretold by another successful fog prediction from the combo technique. Satellite imagery of this fog event appears in Fig. 6.

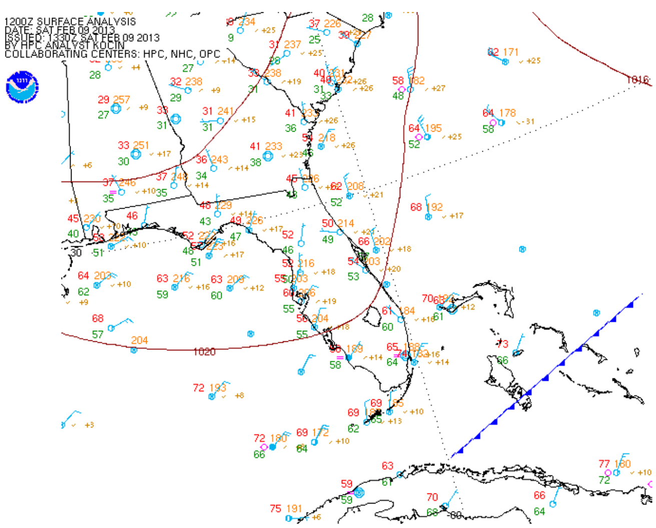

Figure 5. Surface analysis map for 12Z 9 February 2013 created by the Hydrometeorological Prediction Center (HPC). A cold front had already moved through the area leaving light northerly winds in its wake.

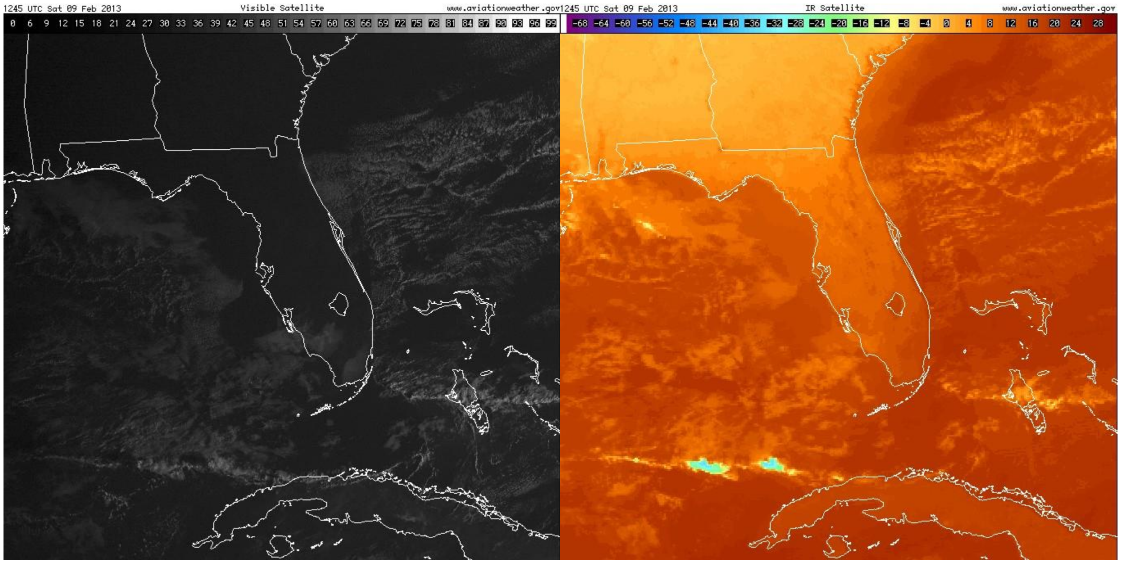

Figure 6. On the left side of this figure is a visible satellite image taken on 12:45Z 9 February 2013. Fog can be seen in its dissipating phase over the inland areas of extreme Southeastern Florida, including over KTMB. On the right side is an enhanced infrared satellite image taken at the same time. With the lack of cirrus obstructing the surface, the edge of the fog bank is visible in the darker orange colors over extreme Southeast Florida.

Unfortunately, there were times when missed fog events and false alarms still did occur. An example of such a false alarm was 11 December 2012. The crossover technique yielded a morning low 2^o degrees cooler than the minimum dew point from the previous afternoon. South Florida was under southerly winds ahead of an approaching cold front. This front had also passed through Miami on the morning of 10 December 2012, when it did produce a fog event that was successfully predicted by the combo technique. With the combo technique again predicting fog and 925mb winds of 13 knots, there was little reason to believe another fog event wouldn't occur on 11 December. However, the surface winds did not drop off to calm as they did on the morning of December 11. Instead winds up to 5-10 knots were reported at the surface overnight and rather than fog forming, skies became mostly cloudy shortly after midnight and eventually overcast a few hours later. The mixing created by these winds allowed the dew point to drop off overnight as moisture was transported upward in the boundary layer and clouds formed. This case demonstrates one of the flaws of the combo technique: it does not always accurately predict when the boundary layer will decouple. Nonetheless, the combo technique is still a more consistently accurate predictor of fog in South Florida than the crossover technique in tandem with the MRi. Even in this instance, the MRi also yielded a false alarm.

Other cases demonstrate this same flaw in the combo technique, but with the opposite result. Sometimes the boundary layer decouples when it is not expected to and fog forms when it is not predicted. These missed events can be very hazardous to unwarned travelers. On 8 February, fog formed when the combo technique did not predict it, although the crossover technique did. The crossover technique produced a minimum temperature two degrees lower than the minimum dew point found during the afternoon of 7 February, however the 925mb wind on February 8, was 16 knots. In fact, the entire boundary layer from 1000mb to 925mb recorded winds of at least 15 knots in the 12Z sounding. Nonetheless, surface winds were calm for much of the early morning hours on 8 February. The boundary layer decoupled ahead of an approaching cold front, which is shown in Fig. 7. The very moist boundary layer produced fog (Fig. 8).

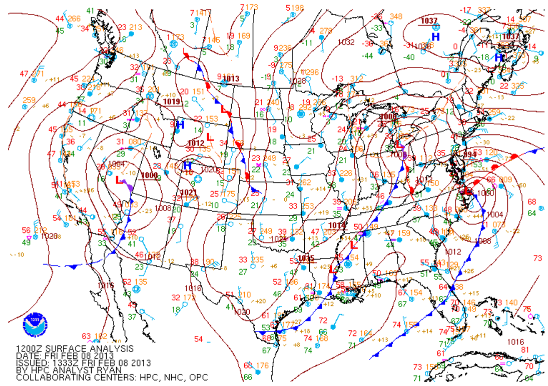

Figure 7. Displays the 12Z surface analysis created by the Hydrometeorological Prediction Center (HPC) on 8 February 2013. This surface analysis generally correlates to Fig. 4. A cold front was observed over the central portion of the state, which resulted in a southwesterly surface wind flow over South Florida. This synoptic pattern is very common in fog events over South Florida.

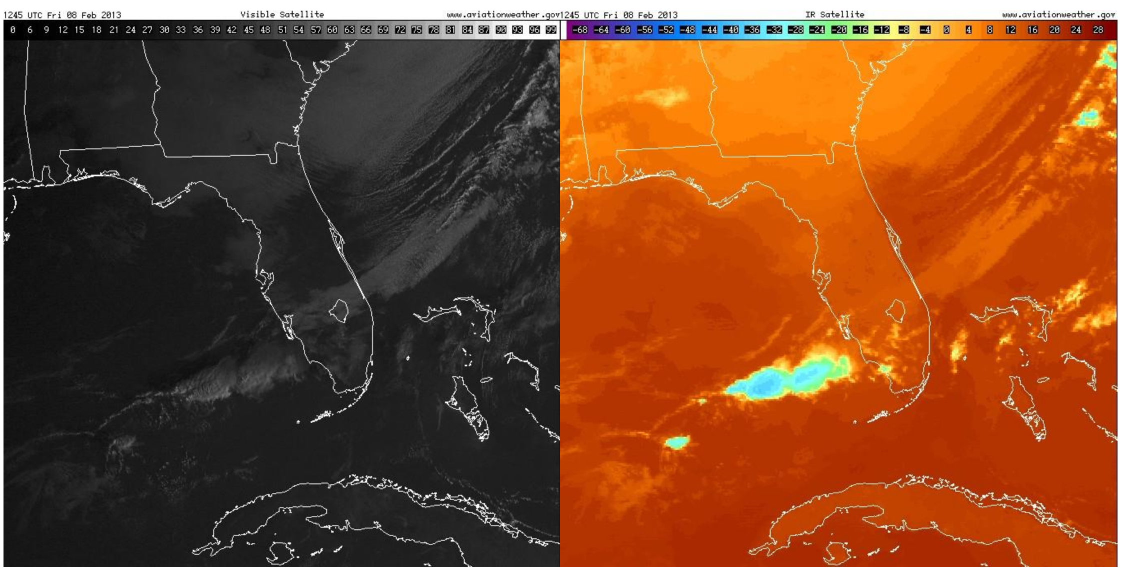

Figure 8. On the left side of this figure is a visible satellite image taken on 12:45Z February 8, 2013. On the right side of the figure is an enhanced infrared satellite image taken at the same as the visible image. In addition to convection over the Gulf of Mexico, fog can be seen in its dissipating phase over the inland areas of extreme South Florida. It easier to detect the fog using the visible image rather than the infrared satellite image.

5. Conclusions

Prior to this paper, no analysis of quantitative fog forecasting techniques for the South Florida area served by the Miami National Weather Service Forecast Office existed. In order to develop an effective quantitative fog forecast, a select location, KTMB, was chosen and it was reanalyzed over the past three fog seasons. The first approaches tested were the crossover and the Modified Richardson Number techniques.

Both were considered as potential standalone techniques, as well as in combination. In the absence of compelling success, additional experimental forecasting techniques were also applied to the same three fog seasons. This paper demonstrates that the combo technique which combines the crossover technique with a maximum 15 knots threshold of 925mb winds for fog formation yields a more accurate predictor of fog formation at KTMB.

It is important to recognize that this paper provides a retrospective analysis of fog forecasting. When used in real-time forecasting situations, forecasters will not have the luxury of knowing the exact measurements required by the combo technique. These include, the minimum temperature for the crossover technique and the 925mb winds at the location in question. Instead, forecasters will have to depend upon subjective or computer projections in order to forecast fog with the combo technique. Thus, the technique is only as good as the forecast upon which it is based. Fortunately, BUFKIT already computes the crossover technique from model forecast soundings and there are multiple model forecasts of 925mb winds for South Florida.

Also, there will be times when the combo technique cannot be applied directly, most notably during strong moisture advection. In these circumstances, forecasters will have to rely on an accurate forecast of a modified dew point in the combo technique. It remains to be seen how the technique will fare in real-time forecasting situations at other subtropical sites.

Possible future work can include applying the combo technique to locations other than KTMB to verify its accuracy. During the upcoming fog season, the combo technique will be employed by the Miami National Weather Service to evaluate its accuracy using a Grid Forecast Editor Procedure (GFE). Conditional probabilities of fog based upon forecast difference between crossover and forecast minimum temperature and 925mb winds can be constructed. Furthermore, selection of the computer models that most accurately forecast the crossover technique and 925mb winds for the combo technique should be studied.

Acknowledgments. We would like to thank the National Weather Service (Dr. Pablo Santos) and Florida International University (Dr. Hugh Willoughby) for creating the opportunity for this collaboration between the university and the NWS. We also thank the forecasters at the Miami National Weather Service Forecast Office who provided insightful information about fog formation and advection in South Florida, particularly at KTMB, as well as summarizing current techniques for remotely detecting fog.

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