FORECASTING FREEZING DRIZZLE: THE 3-4 FEBRUARY 2011 ICE STORM EVENT IN CORPUS CHRISTI, TEXAS

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I. Introduction

a. Event Summary

On 3-4 Feb 2011, a widespread freezing drizzle event occurred over the County Warning Area (CWA) of the National Weather Service Office in Corpus Christi, TX (WFO CRP) (Fig. 1). Prior to the onset of the freezing drizzle, an arctic cold front pushed through the CWA on 1 Feb associated with a large area of high pressure. Surface temperatures fell into the middle 20s to middle 30s with the arrival of the arctic cold front and remained at or below freezing through 4 Feb. As an upper level disturbance moved to the north of the area on 3-4 Feb, low-level isentropic lift produced drizzle in the low-level clouds over the CWA. Since the surface temperature was subfreezing, the drizzle instantly froze upon contact with trees, grassy surfaces, roads, and vehicles.

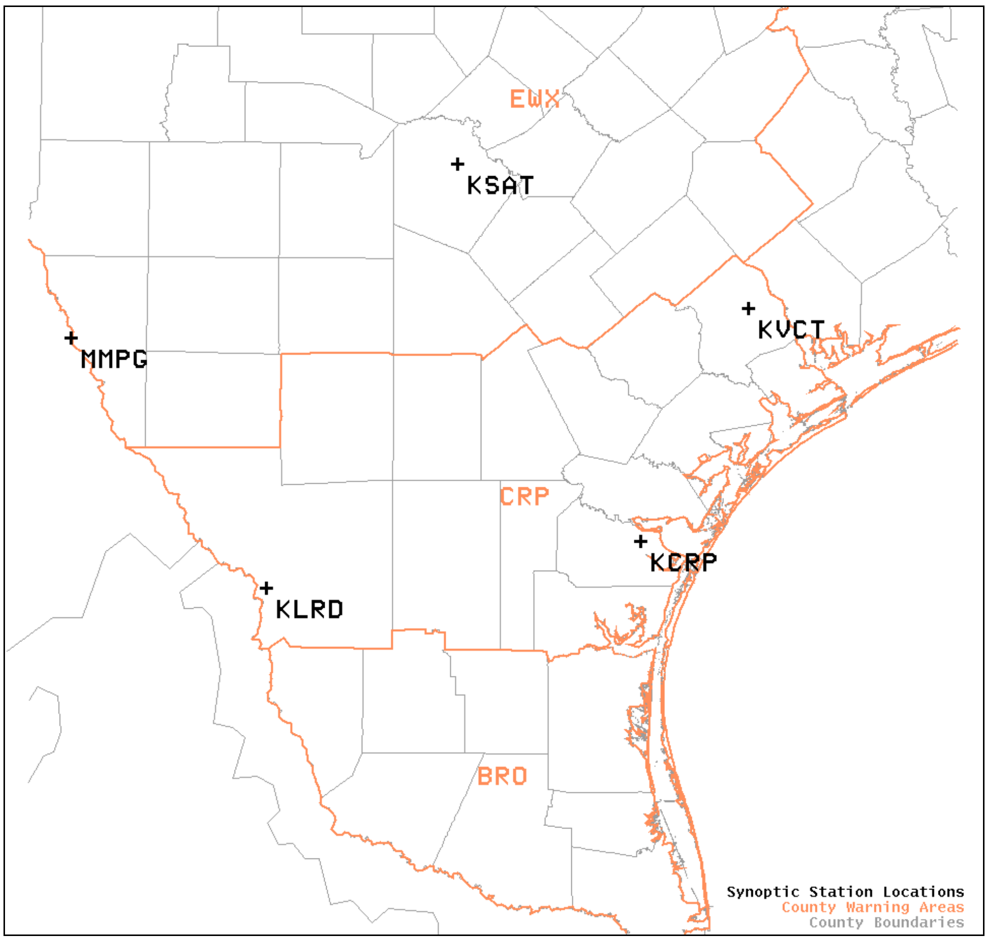

Fig. 1: A portion of South Texas, including the Corpus Christi CWA (CRP). Neighboring CWAs are also shown in orange. Observation sites referenced in the text are labeled in black.

The 12-hour freezing drizzle event, which occurred from 0000 to 1200 UTC 4 Feb, produced widespread ice accumulations of 1/10" to 3/8" (Fig. 2). The event was entirely dominated by freezing drizzle, except for extreme western and northern portions of the CWA, where a mix of light snow and sleet was observed. Snowfall was extremely light as Laredo, TX (KLRD) only reported a trace. Areas further north into the New Braunfels/San Antonio (EWX) CWA received snow accumulations of 1/4" to 1" as a band of snow moved across during the morning of 4 Feb (upper left in Fig. 3).

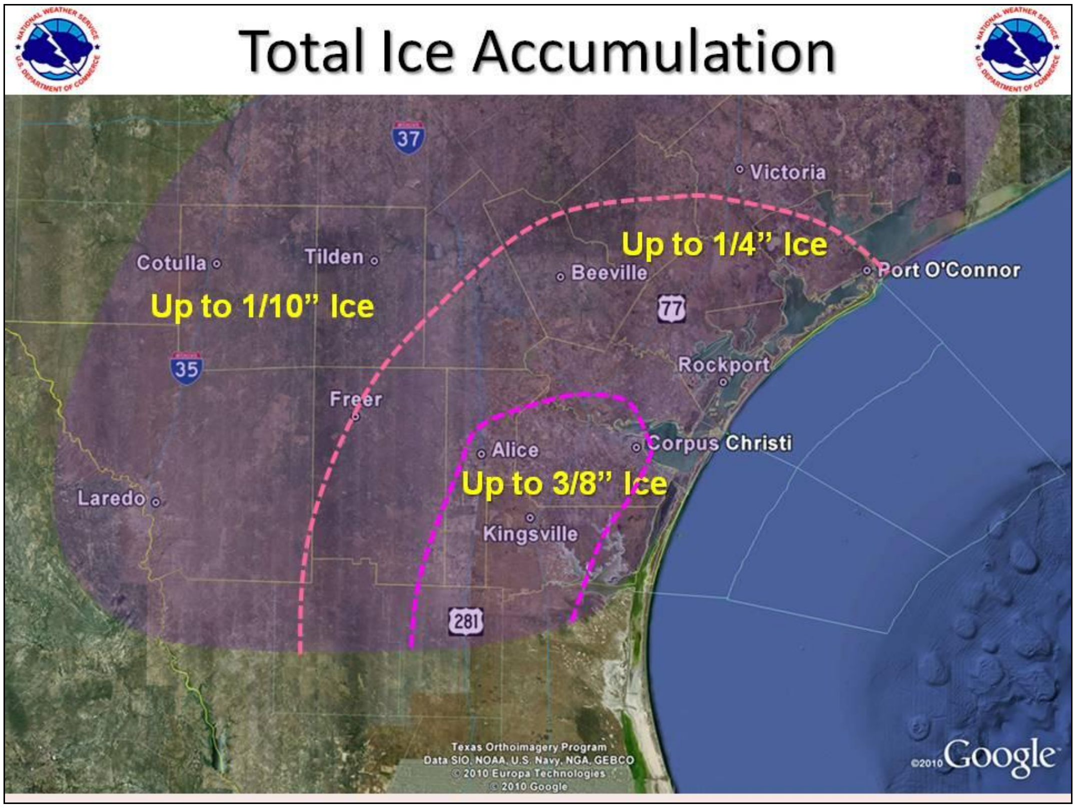

Fig. 2: Estimated total ice accumulation over the Corpus Christi CWA for the 3-4 Feb 2011 ice storm event. Significant ice accumulation also occurred over the Brownsville CWA, but is not shown here.

b. Motivation of study

The 3-4 February 2011 freezing drizzle episode was quite rare from a climatological perspective (Fig. 4), and thus a forecast challenge at WFO CRP. South Texas receives less than one winter precipitation event per year, with the last significant one being the 2004 Christmas snowstorm (Wilk et al. 2007). The motivation behind this study is to analyze various techniques that could be used to effectively predict the freezing drizzle event, thereby assisting WFO CRP forecasters in similar future events. In particular, the importance of considering ice microphysics foremost when forecasting winter precipitation is highlighted.

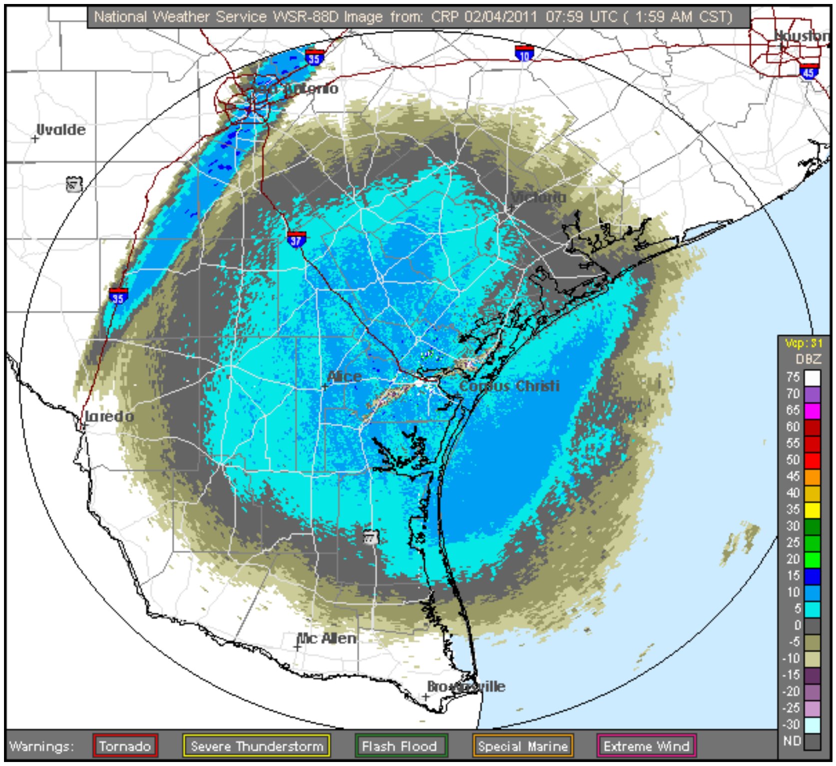

Fig. 3: KCRP 0.5 reflectivity (dBZ) at 0806 UTC 4 Feb.

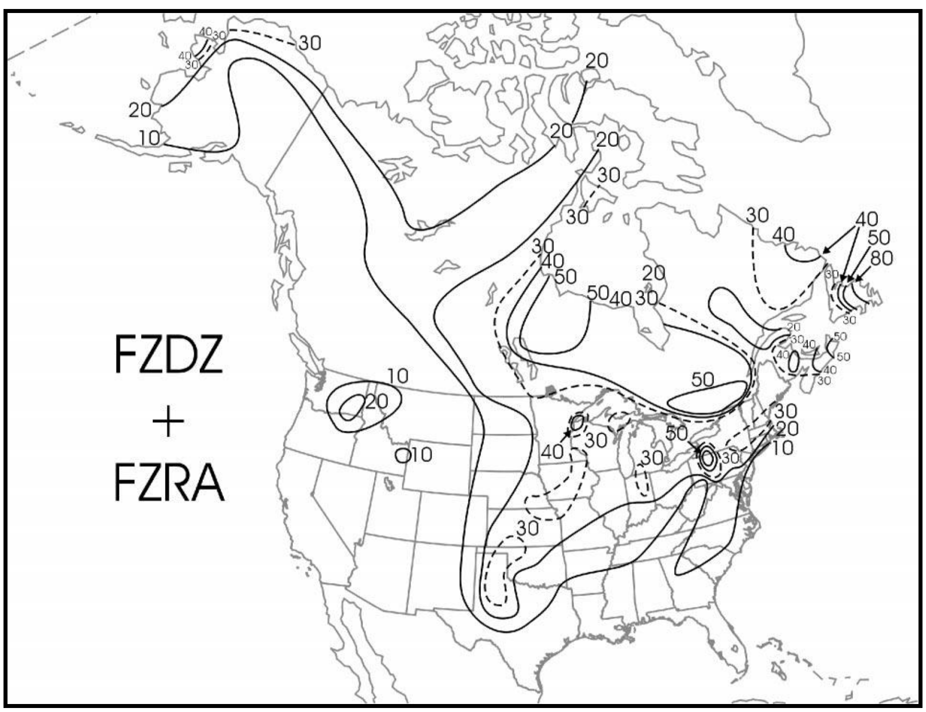

Fig. 4: Median annual hours of freezing rain and freezing drizzle combined from 1976 to 1990 (from Cortinas et al. 2004).

II. Synoptic Overview

The following section will provide an overview of the synoptic conditions leading up to the freezing drizzle event across South Texas. All of the plots in this section include GFS40 model data from the 1200 UTC 2 Feb initialization, around 36 hours before the start of the freezing drizzle event. One objective of the study is to use model data to identify techniques for *forecasting* freezing drizzle, so a model forecast is analyzed as opposed to a model analysis. It should be noted that the GFS40 forecast verified very well when compared with the model analysis over the time period of 3-4 Feb.

500 hPa heights and vorticity from 0000 UTC 3 Feb to 1200 UTC 4 Feb is shown in Fig. 5. The midlevel pattern across the CONUS at 0000 UTC 3 Feb is dominated by a large-scale trough across the southern Rockies and southwesterly flow across the southern U.S. (Fig. 5A).

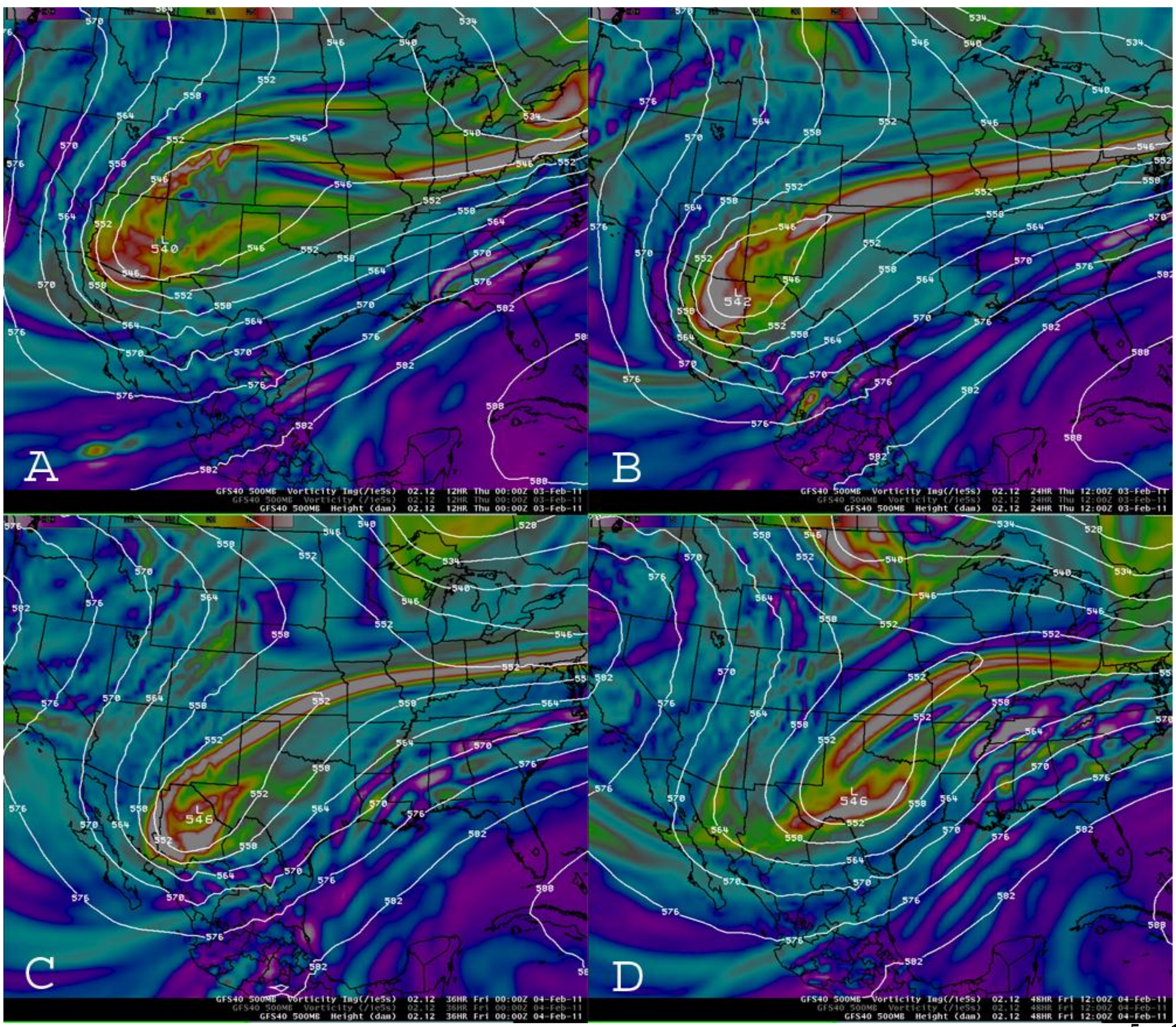

Fig. 5: GFS40 forecast of 500 hPa heights (dm, contours) and absolute vorticity (10^{-5} s^{-1}, shaded) valid at A) 0000 UTC 3 Feb, B) 1200 UTC 3 Feb, C) 0000 UTC 4 Feb, and D) 1200 UTC 4 Feb.

With a strong midlevel jet across the Four Corners region, the trough continues to dig southeastward and at 1200 UTC 3 Feb, a vorticity maximum is located over northern Mexico (Fig. 5B). By 0000 UTC 4 Feb, midlevel heights begin to rise within the closed trough center over northern Mexico and west Texas as the trough begins to lift northeast (Fig. 5C). As the trough continues to move northeastward through 1200 UTC 4 Feb, the strongest height falls are forecast across central and northern Texas (Fig. 5D).

Figure 6 shows a model forecast for 700-500 hPa temperature and quasi-geostrophic (QG) forcing valid at 0600 UTC 4 Feb. With the midlevel trough lifting northeastward into central Texas, the strongest Q-vector convergence (QG forcing for rising motion) is located to the north of the CWA, primarily across the EWX CWA. The midlevel QG forcing for ascent over the EWX CWA likely resulted in cooling and moistening in a layer that was cold enough to support ice nucleation (-10 to -14 ºC). The importance of ice nucleation during this winter weather event will be highlighted later in the article. This forcing mechanism was forecast to be largely absent across the CRP CWA, where the midlevel Q-vector convergence is weaker and 700-500 hPa temperatures are a few degrees warmer.

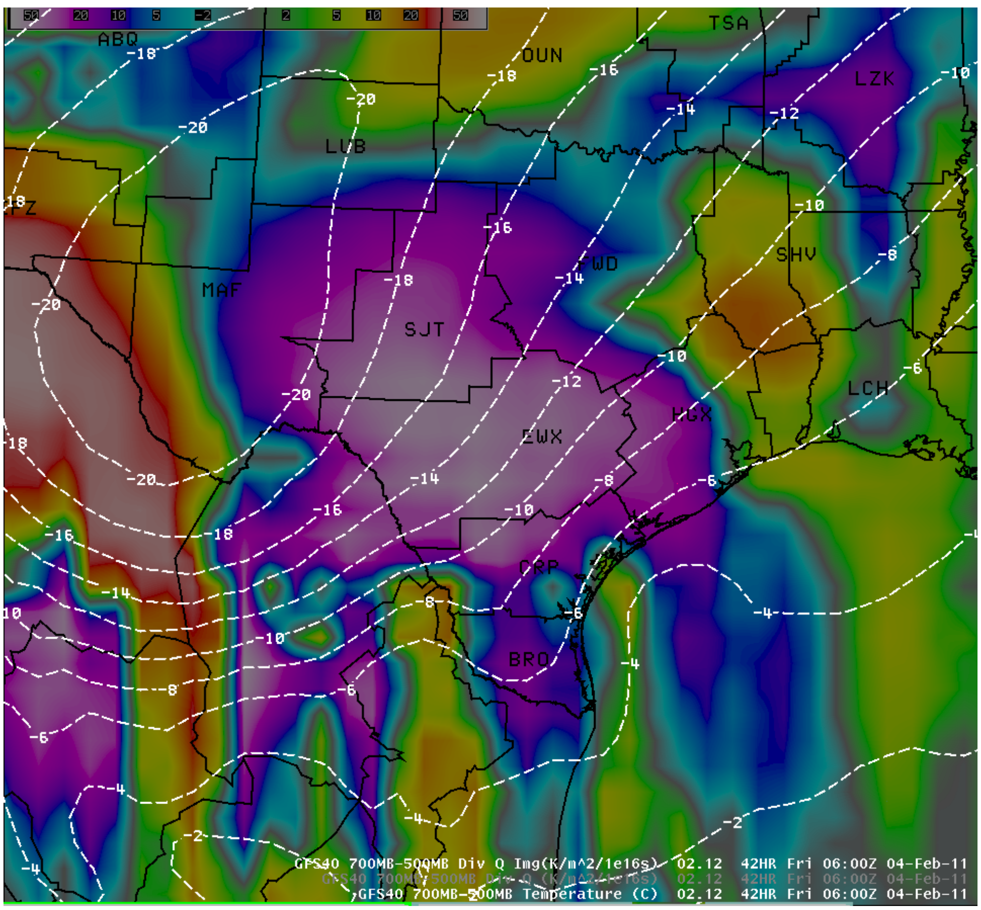

Fig. 6: GFS40 forecast of 700-500 hPa temperature (°C, dashed contours) and 700-500 hPa Q-vector divergence (K/m²x10⁶ s, shaded) valid at 0600 UTC 4 Feb. Cool colors represent convergence while warm colors represent divergence.

A large dome of cold arctic air plunged southward across South Texas on the morning of 1 Feb behind a strong cold front (not shown). Temperatures were in the upper 60s on the morning of 1 Feb and then plummeted to the lower 30s by that evening. Surface high pressure and northerly winds continued to remain entrenched across the southern Plains through 4 Feb (Fig. 7). As a result, most areas in the CWA had average daily temperatures in the lower to middle 30s over the 2-4 Feb period, which is over 25 degrees below normal. Specifically, the 3-day period ending on 4 Feb ranks as the 24^{th} coldest for Corpus Christi. The duration of freezing temperatures for this event was quite remarkable and cooled the ground temperatures significantly before the ensuing freezing drizzle event.

The forecasted surface conditions valid from 0000 UTC 3 Feb to 1200 UTC 4 Feb are shown in Fig. 7. A 1046 hPa surface high pressure center was forecasted to remain near the Texas panhandle from 0000 to 1200 UTC 3 Feb (Fig 7A, B). Northerly surface winds continue

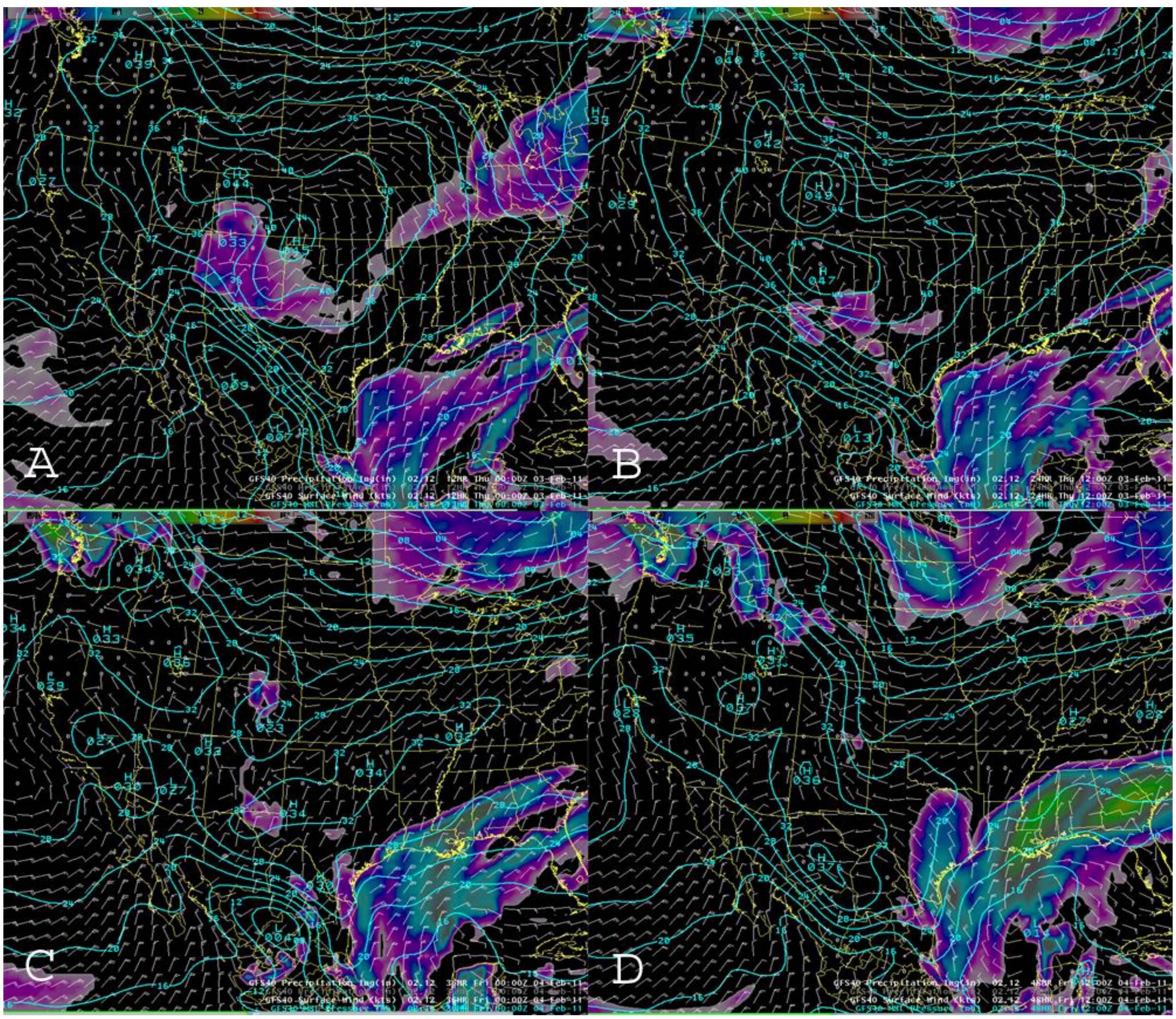

Fig. 7: GFS40 forecast of mean sea level pressure (hPa, contours), surface winds (kts, vectors), and 6-hour precipitation (inches, shaded) valid at A) 0000 UTC 3 Feb, B) 1200 UTC 3 Feb, C) 0000 UTC 4 Feb, and D) 1200 UTC 4 Feb.

to usher in unseasonably cold temperatures across South Texas. There is no precipitation forecasted over land, with less than a tenth of an inch across the adjacent Gulf waters. By 0000 UTC 4 Feb, the surface high pressure center weakens slightly (down to 1034 hPa) and shifts eastward (Fig. 7C). Very light precipitation is forecasted near Corpus Christi, but amounts are only a few hundredths of an inch. As the upper-level system begins to fill and lift northeastward from 0000 to 1200 UTC 4 Feb, there is a corresponding decrease in surface pressure across the southern Plains (Fig. 7D). The most noteworthy development at 1200 UTC 4 Feb is the forecasted increase in precipitation amounts across the CWA, especially across the coastal areas. A 6-hour precipitation total of 0.12 inches is forecasted for a point near KCRP, the location of the Corpus Christi International Airport.

The low-level isentropic lift can be examined by looking at Fig. 8. Southerly winds on the 290K isentropic surface will force air parcels to ascend in the atmosphere from a pressure of around 850 hPa in Brownsville to 800 hPa in Corpus Christi. This ascent combined with low condensation pressure deficits (around 5 hPa) will result in low-level saturation across South Texas. Although not shown, the isentropic lift was forecasted to increase on 4 Feb compared to one day earlier. After reviewing the forecast data on the synoptic scale, we arrive at the following conclusions. The strongest midlevel forcing is just to the north of the CWA from 0000 UTC to 12000 UTC 4 Feb associated with the lifting midlevel trough. While the midlevel forcing appears to be weak across the CWA, there is significant low-level lift and saturation in the unseasonably cold airmass.

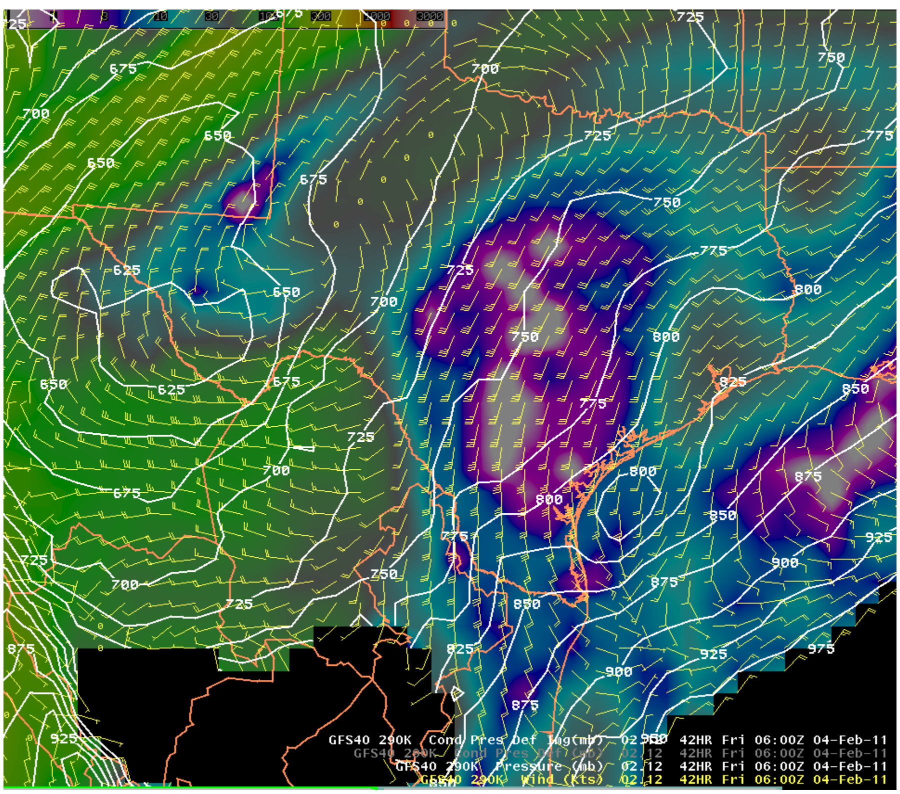

Fig. 8: GFS40 forecast of 290K pressure (hPa, contours), wind (kts, vectors), and condensational pressure deficit (hPa, shaded) valid at 0600 UTC 4 Feb.

III. Techniques for Forecasting Freezing Drizzle

a) *Ice Nucleation*

Forecasting freezing precipitation during the winter months is often a difficult problem for operational forecasters. The classical "melting ice process" for freezing precipitation assumes there are ice hydrometeors that fall and melt through a warm layer, and then supercool in a subfreezing surface layer (Huffman and Norman 1988). The warm layer is above 0 ºC and sufficiently deep to cause melting of the ice hydrometeors. However, studies by Bocchieri (1980) and Huffman and Norman (1988) found that 40% and 25%, respectively, of their freezing precipitation events did not have a warm layer aloft. In these events the entire sounding is subfreezing, and thus the freezing precipitation cannot be explained by the melting process.

Baumgardt (1999) thoroughly explains how supercooled liquid water droplets can persist at subfreezing temperatures. Assume that a cloud is entirely subfreezing, initially composed of only supercooled liquid drops and water vapor (no ice), and ice cannot fall into the cloud from neighboring clouds. The only way to introduce ice crystals into the cloud is through a process called heterogeneous nucleation. During heterogeneous ice nucleation, an ice nuclei is activated to form an ice crystal. Once ice nucleation occurs, the ice crystals will tend to accrete supercooled water droplets and fall through the cloud as snow. Thus, in order for a subfreezing cloud to have a high concentration of supercooled liquid drops, ice nucleation must be limited.

The major factor that determines ice nucleation is the temperature within the cloud (Baumgardt 1999). No ice nuclei can be activated at temperatures warmer than -4 ºC even if the cloud is supersaturated. A temperature of -10 ºC is often the threshold needed for ice nuclei activation within a cloud. So a subfreezing cloud having temperatures entirely between 0 and -10 ºC is not likely to form ice crystals and will contain only supercooled liquid. Operationally, it is important to diagnosis the vertical profile of temperature to determine whether or not ice nucleation will occur. The next few sections will explore this concept in further detail.

b) Sounding Analysis

Due to their vertical resolution, soundings are one of the most useful tools when determining winter precipitation type. Figure 9-1 shows a forecast sounding for a point near KCRP valid at 0000 UTC 4 Feb, at the onset of the freezing drizzle event. The observed KCRP sounding at the same time is also plotted. The forecast sounding predicted saturated conditions in the layer from 950 to 750 hPa, with dry air above. Temperatures within the saturated layer range from 0 to -5 ºC, which means that in-cloud temperatures are too warm to support ice nucleation. The dry air above 750 hPa ensures that there are no higher cloud layers immediately above the surface cloud layer. If there is a higher cloud layer, it can drop ice crystals into the lower layer. These crystals would act as freezing nuclei and produce snow instead of freezing drizzle. The forecast sounding verified reasonably well when compared with the observed RAOB. The observed sounding indicates a low-level saturated layer with very dry air above 750 hPa. While the observed temperature is slightly cooler in the cloud layer than forecasted, it is still too warm to introduce ice crystals into the cloud.

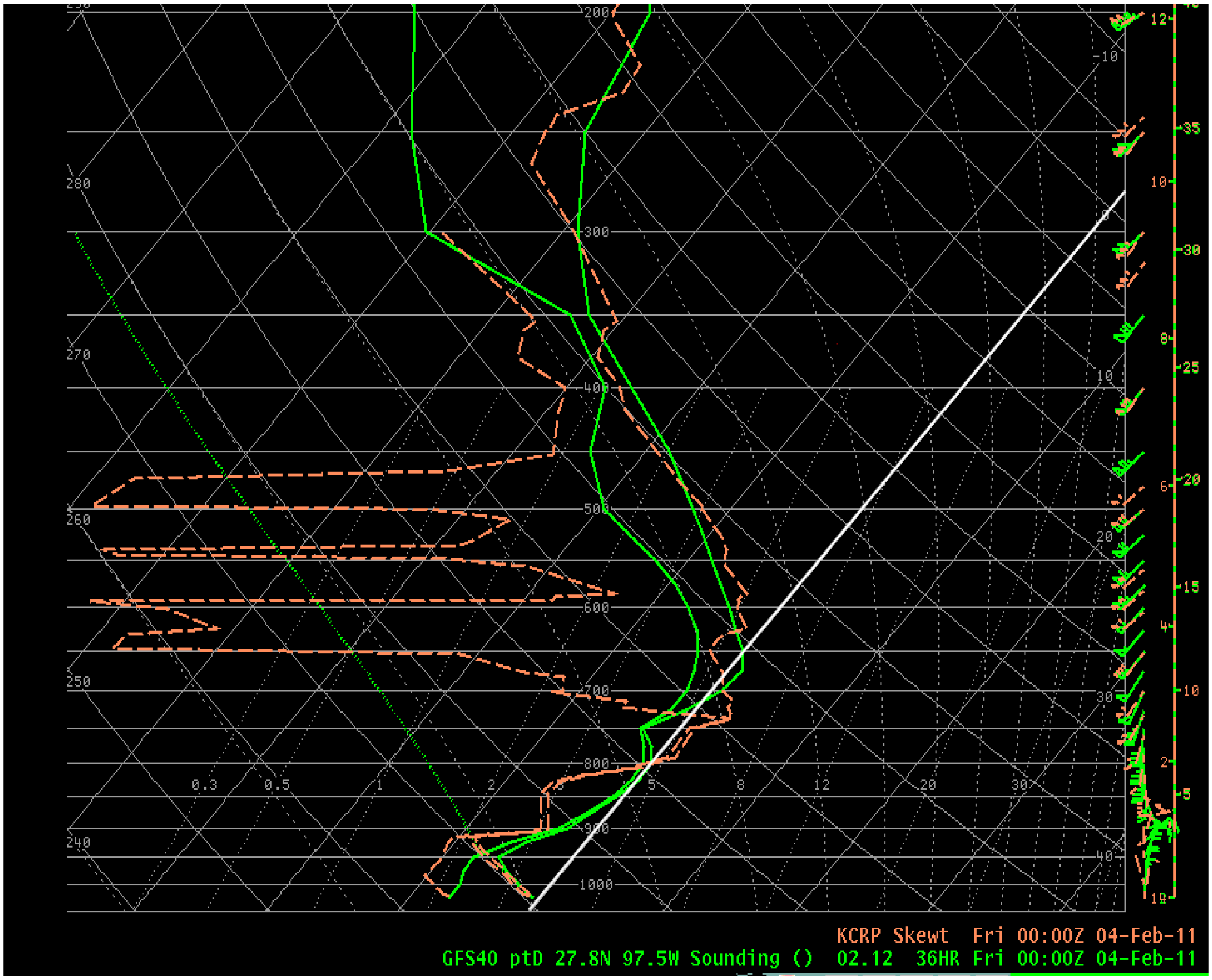

Fig. 9-1: GFS40 forecast sounding (green solid) for a point near KCRP valid at 0000 UTC 4 Feb and the observed KCRP sounding (orange dashed) at 0000 UTC 4 Feb. The solid white line represents the 0°C isotherm.

The forecasted and observed soundings for 1200 UTC 4 Feb, near the end of the freezing drizzle, are shown in Fig. 9-2. Both soundings are entirely subfreezing and continue to indicate a low-level saturated layer from approximately 925 to 675 hPa, with dry air above this cloud layer. At temperatures that support ice nucleation (cooler than -10 ºC) the atmosphere is very dry. The observed temperature at 925 hPa does get rather close to -10 ºC (around -9 ºC). In summary, the soundings in Figs. 9-1 and 9-2 exhibit the classic characteristics of freezing drizzle. There will likely be no ice crystal content because cloud temperatures are warmer than -10 ºC and dry air is above the low-level cloud layer. The clouds will be composed of liquid supercooled drizzle that will fall onto a subfreezing ground.

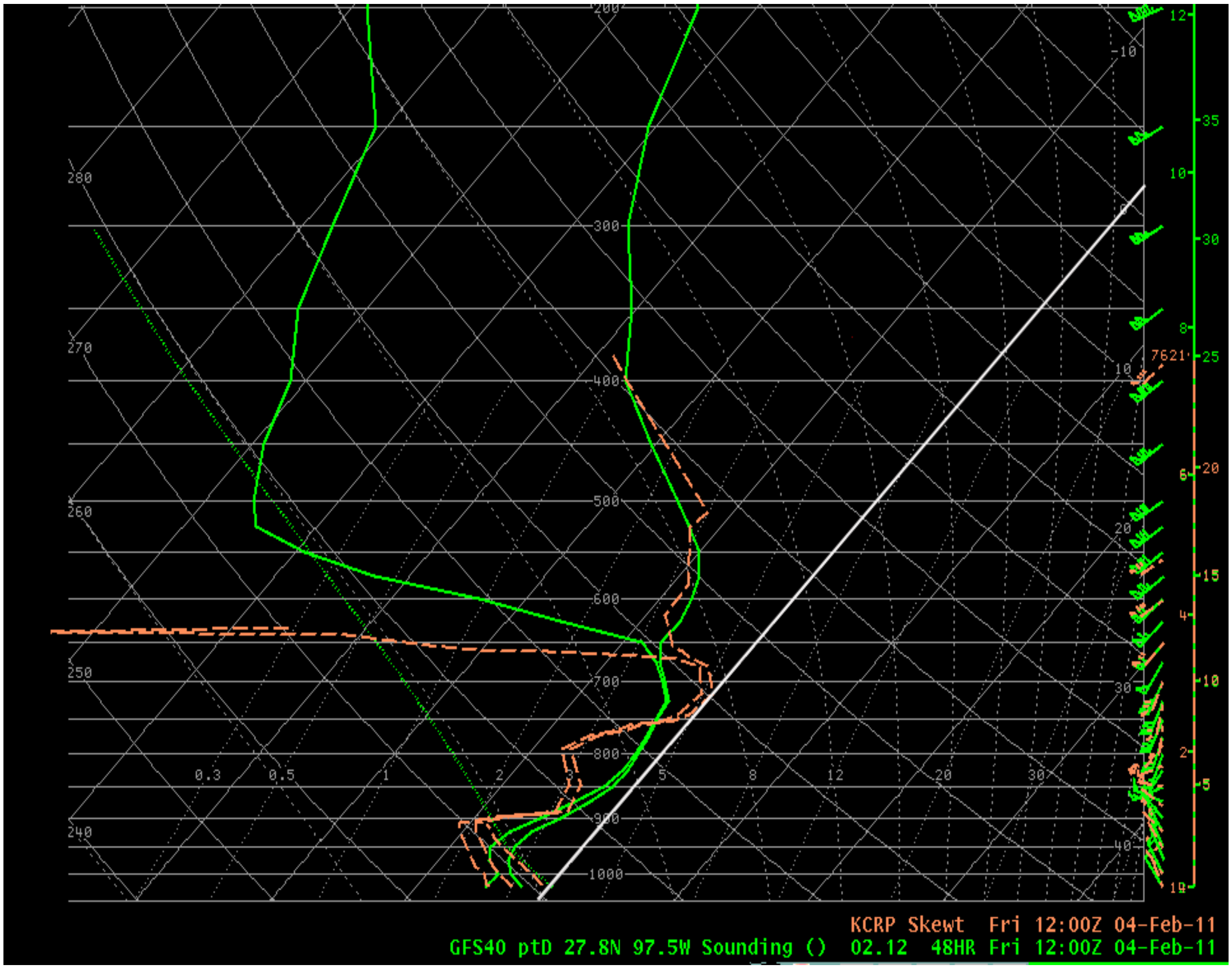

Fig. 9-2: Same as Fig. 9-1, except at 1200 UTC 4 Feb. There is a loss of observed sounding data above 400 mb as the radiosonde failed due to significant icing.

c) Time-Height Plots

Modeled vertical cross sections of temperature and relative humidity (RH) in a time series (Figs. 10-1 and 10-2) can be excellent tools to anticipate a freezing drizzle event. The advantage of using time-height plots is a forecaster can examine the evolution of temperature within the saturated layers. Figure 10-1 is such a plot for a point near KCRP over the period from 1200 UTC 2 Feb to 0600 UTC 5 Feb. There is a noticeable increase in low-level (925-725 hPa) RH starting at 1800 UTC 3 Feb associated with the developing low-level isentropic lift. The saturation depth is shown to increase slightly after 0600 UTC 4 Feb, during the heart of the freezing drizzle event. Temperatures within the saturated layer range from 0 to -6 ºC, revealing a temperature profile that is subfreezing but unable to support heterogeneous nucleation. Forecasted RH values are much lower (10-30%) above 600 hPa, where temperatures are colder than -10ºC. It is informative to compare this plot to one at a location further north in the EWX CWA.

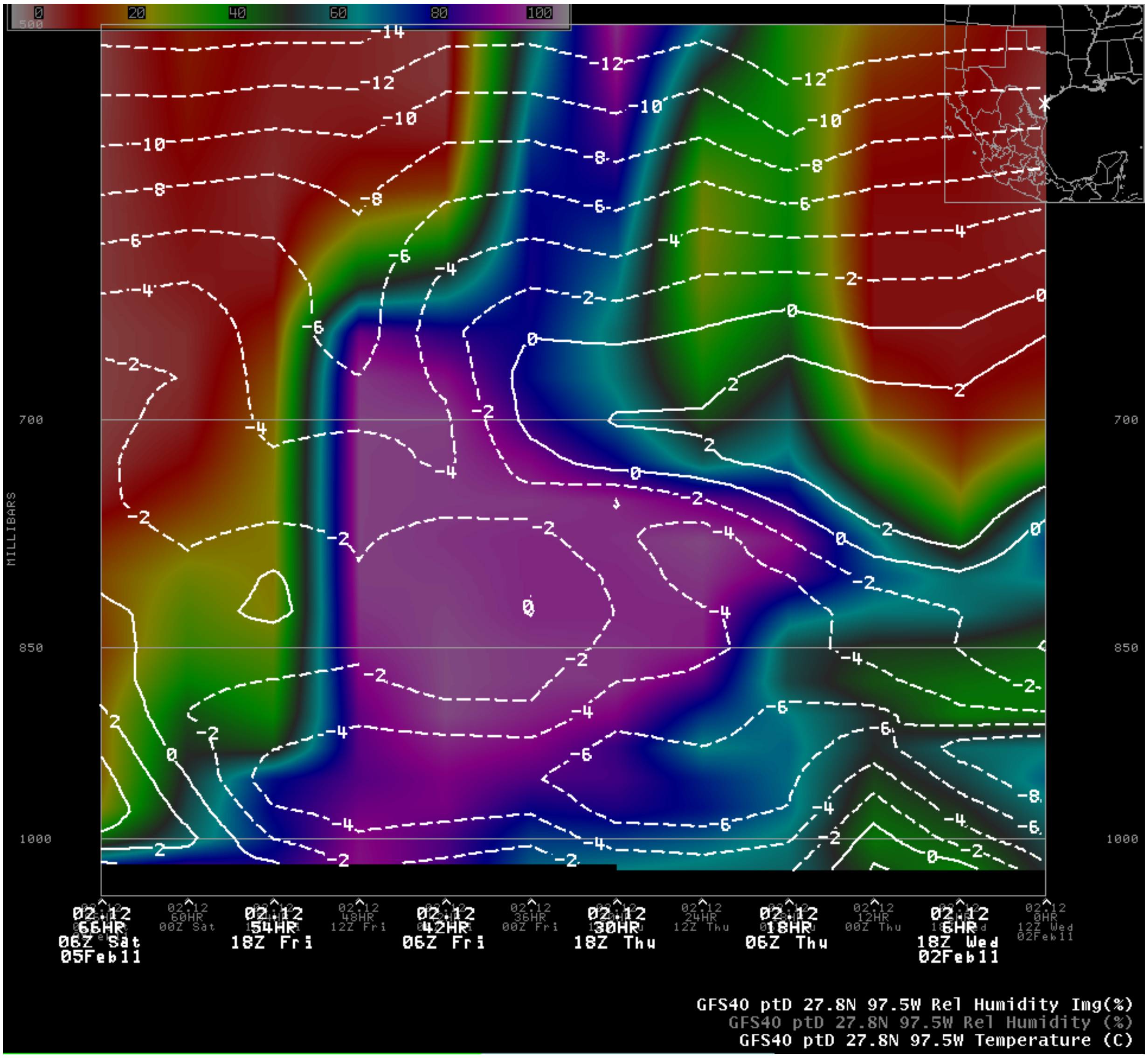

Fig. 10-1: GFS40 time-height cross section of forecast temperature (ºC, contour) and RH (%, shaded) at a point near KCRP and over the 1000-500 hPa layer. The time period runs from 1200 UTC 2 Feb to 0600 UTC 5 Feb.

Figure 10-2 displays the same forecast parameters as Fig. 10-1, except for a point near KSAT. Remember that the precipitation event around KSAT initially started out as freezing drizzle, and then transitioned over to a brief period of snow after 0600 UTC 4 Feb (Fig. 3). The temperatures over the 1000-500 hPa layer are forecast to be colder than at KCRP over the entire time period. At 0000 UTC 4 Feb, the saturated layer extends from 850 to 700 hPa with cloud temperatures of -4 to -8 ºC. This temperature profile is more indicative of freezing drizzle. However, between 0000 and 06000 UTC 4 Feb, higher RH values (90-100 %) extend upward into colder temperatures (-10 to -12 ºC). The saturation at these temperatures is in agreement with the increase in QG forcing for ascent in the 700-500 hPa layer (Fig. 6). Thus, the vertical profile of RH and temperature at KSAT at 0600 UTC 4 Feb is conducive to produce ice nucleation at cloud top temperatures around -10 ºC. With the subfreezing atmosphere below cloud top, these ice crystals will grow in-cloud and fall to the surface as snow.

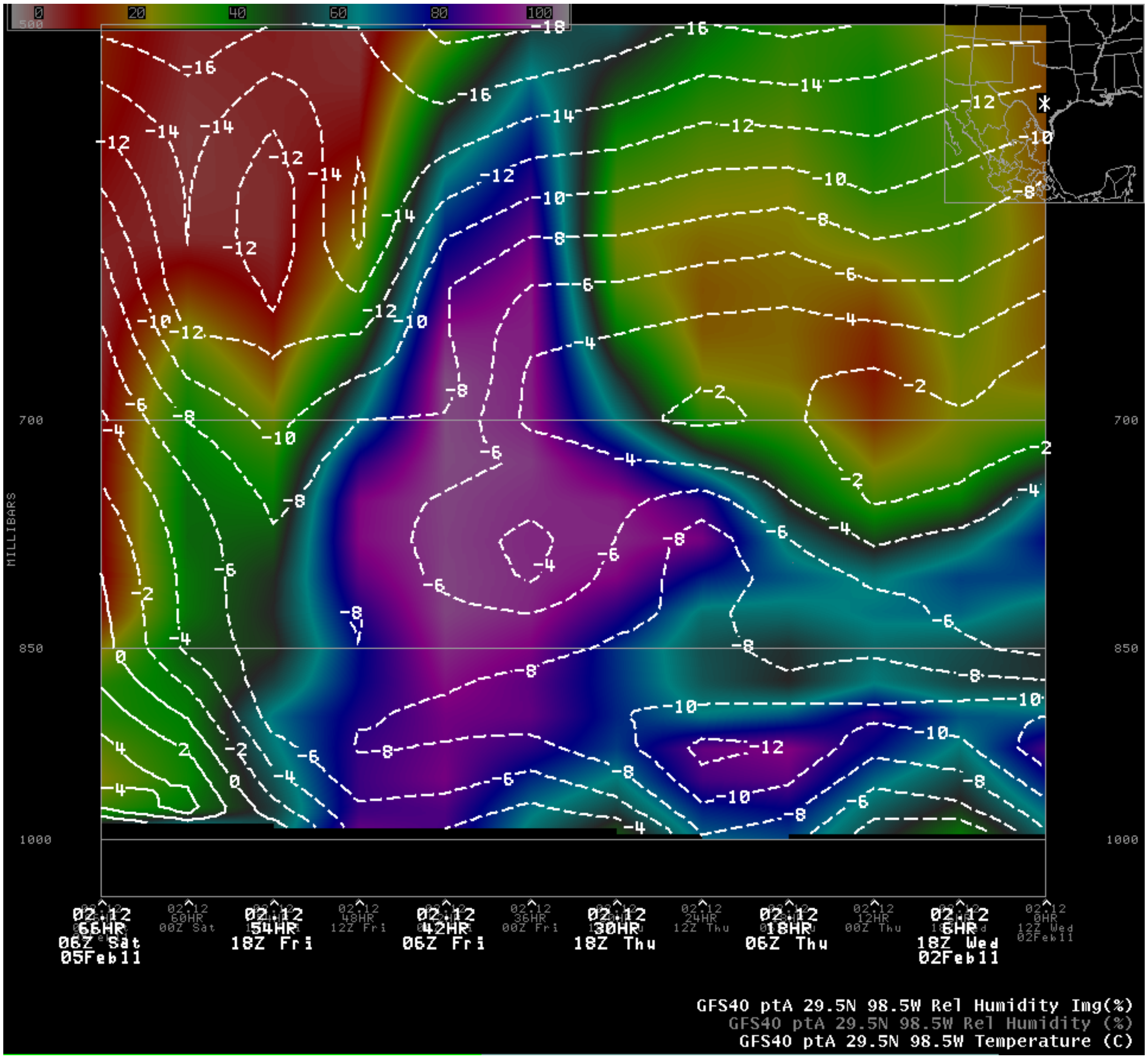

Fig. 10-2: Same as Fig. 10-1 except for a point near KSAT, the San Antonio International Airport.

d) Infrared Imagery

Infrared (IR) satellite imagery can be used in the short term to spatially diagnose cloud top temperatures and the potential for ice nucleation. A potential problem with using IR imagery for this purpose is that high clouds can mask the low-level clouds that the forecaster is trying to sample. Figure 11 shows a four-panel IR image over South Texas over the period from 0815 to 1245 UTC. The IR temperatures are effectively color-coded using the color table in Baumgardt (1999) to highlight the chances of ice at cloud top.

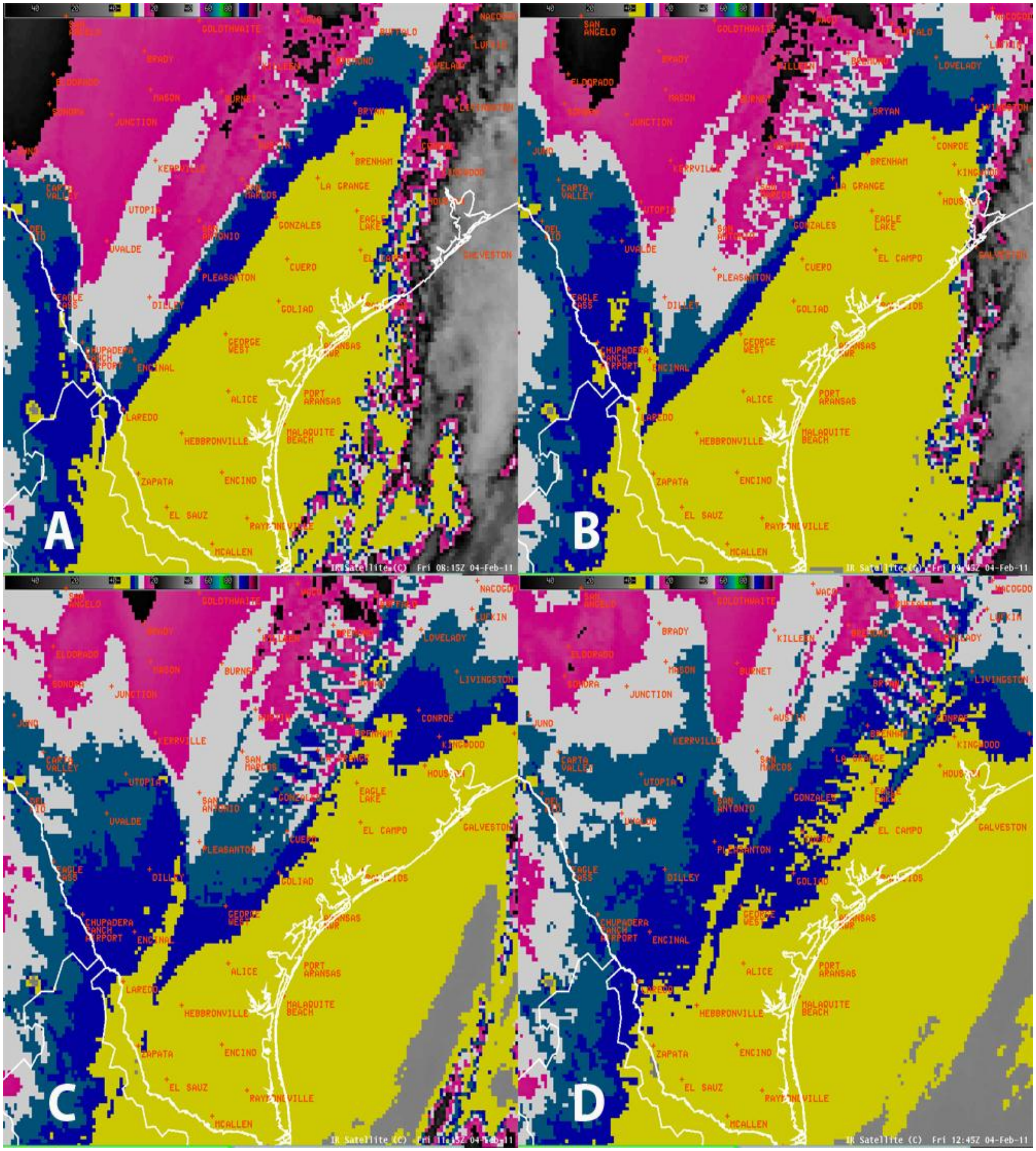

Fig. 11: GOES IR image on 4 Feb at A) 0815 UTC, B) 0945 UTC, C) 1115 UTC, and D) 1245 UTC. The colors and temperature ranges are defined as follows: yellow (0ºC to -8ºC, Liquid), blue (-8ºC to -10ºC, Likely Liquid), light blue (-10ºC to -12ºC, 60% Chance of Ice), white (-12ºC to -15ºC, 70% Chance of Ice), pink (-15ºC to -20ºC, 90% Chance of Ice), and black (-20ºC or less, 100% Chance of Ice).

At 0815 UTC, most of South Texas is covered by low-level clouds with temperatures between 0 and -8 ºC (yellow, Fig. 11A). These clouds likely only contain supercooled liquid drizzle and no ice crystals. A SW-NE oriented band of colder cloud tops (light blue to pink) is evident from Dilley to San Marcos, TX. This is the snow band that was beginning to move over EWX associated with the midlevel dynamics from the lifting trough. At 0945 and 1115 UTC, most of the coastal areas in the CWA are in low-level clouds that are too warm to support ice nucleation and freezing drizzle continues to be reported at the surface (Fig. 11B, C). The band of colder, ice-bearing clouds moves eastward across the EWX CWA, with the southern part of the band clipping northern sections of the CRP CWA. By 1245 UTC, this band lifts off to the northeast and weakens, with cloud top temperatures warming slightly within the band (Fig. 11D). The winter weather event is winding down and most of the CWA has only experienced freezing drizzle, which is confirmed by the IR imagery (yellow throughout the event).

e) TREND Technique

Operational forecasters routinely use winter precipitation type algorithms, like the TREND technique, to assist in the prediction of precipitation type. The TREND precipitation type forecast technique was developed by correlating observations of precipitation types with 1000-850 hPa and 850-700 hPa thicknesses (m) derived from sounding data at Greensboro, North Carolina (NWS Raleigh, 2008). It is important for forecasters to understand the inherent weaknesses of the TREND technique when viewing output from this method. The failure of this technique in forecasting the 3-4 Feb freezing drizzle event will be emphasized below.

A primary weakness of the TREND technique is that it does not account for cloud microphysics issues (NWS Raleigh, 2008). In other words, the technique does not check for saturation at temperatures that are cold enough to support heterogeneous nucleation of ice crystals. This weakness will clearly cause the TREND technique to fail in freezing drizzle events, when supercooled liquid is dominating over ice crystals. Forecasted 1000-850 and 850-700 hPa thicknesses valid at 0600 UTC 4 Feb are displayed in Fig. 12. The unseasonably cold temperatures in the low-levels result in low thickness values across South Texas. The 1000-850 and 850-700 hPa thicknesses for a point near KCRP are 1288 m and 1544 m, respectively.

The TREND nomogram (Fig. 13) shows the distribution of precipitation type as a function of partial thickness values. The TREND technique, when using the forecast thickness values valid at 0600 UTC 4 Feb, predicted *All snow or sleet and snow*. With the entire temperature profile below freezing (Figs. 9-2 and 10-1), snow would be the predominant precipitation type *if* ice crystals are present in the precipitating system. This is a great example of where the TREND method incorrectly leads to a forecast of snow/sleet when there is not likely to be ice in the cloud. For comparison, the thickness values during the 2004 Christmas snowstorm are also plotted on Fig. 13. Low-level thicknesses and temperatures during the 2004 snowstorm were comparable to the freezing drizzle episode. However, soundings from that event (Wilk et al. 2007) show saturation up to temperatures as cold as -25 ºC where ice nucleation could take place.

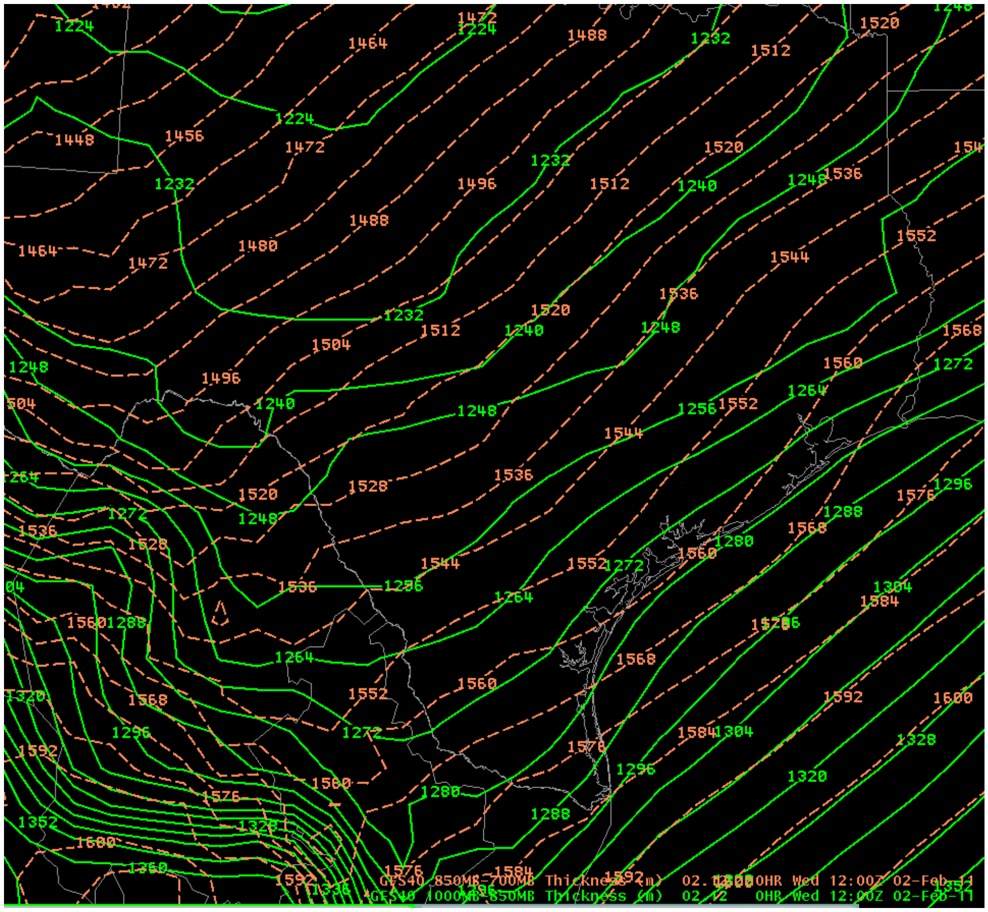

Fig. 12: GFS40 forecast of 1000-850 hPa thickness (m, orange dashed contours) and 850-700 hPa thickness (m, green solid contours) valid at 0600 UTC 4 Feb.

The failure of the TREND technique in the freezing drizzle event highlights the importance of using multiple methods (sounding analysis, time-height plots, etc.) to anticipate precipitation type. If the TREND algorithm is used in a vacuum, a forecaster would have gotten a forecast of snow in what turns out to be a freezing drizzle event. The Top-Down approach is the preferred method for forecasting winter precipitation type. This approach starts at the top of the environmental sounding and works toward the surface, tracing an actual hydrometeor trajectory through the environmental temperature and moisture profile (Baumgardt 2009). As we have seen through this study, the introduction of ice into the environment is a key forecasting issue. The method starts in the ice producing layer, at temperatures colder than -10 ºC, to examine whether or not ice is present in saturated layers. The remainder of the approach will not be detailed here, but it considers warm and cold layers below the ice producing layer and its effect on the falling hydrometeor. In this freezing drizzle event, forecast data indicated a profile at KCRP that was very dry at temperatures of -10 ºC and below. The Top-Down approach immediately alerted a forecaster that heterogeneous nucleation was not likely to occur.

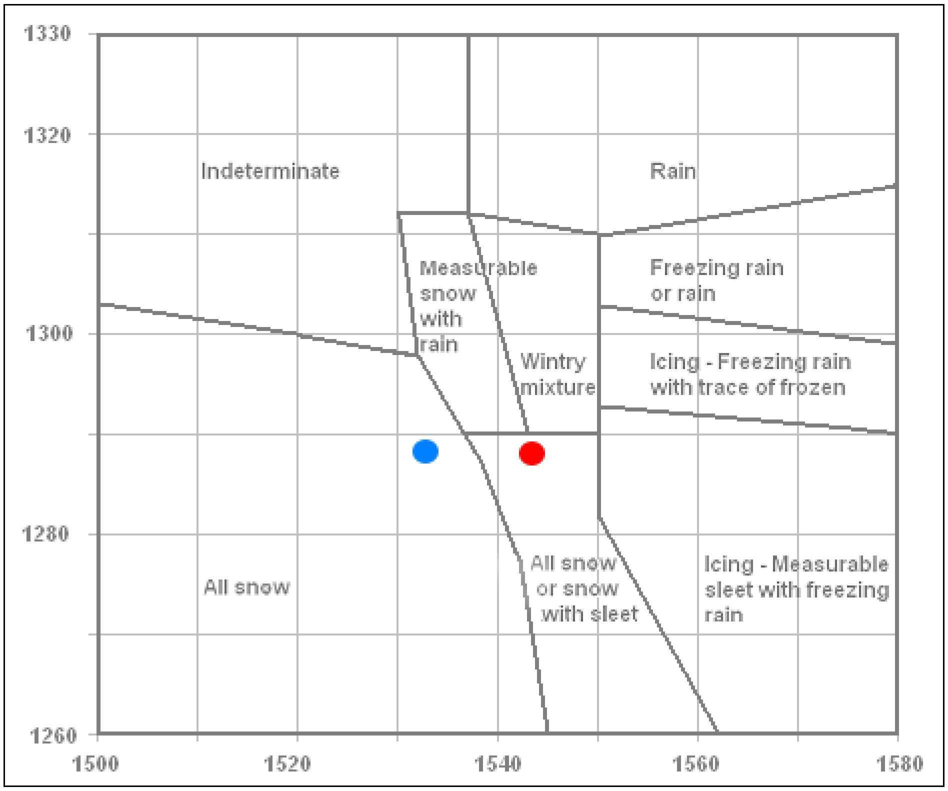

Fig. 13: TREND's predominant precipitation type nomogram. Values along the horizontal (vertical) axis represent 850-700 hPa (1000-850 hPa) thickness. The red dot is the GFS40 forecast valid at 0600 UTC 4 Feb near KCRP (Fig. 12). For comparison, the blue dot is from the observed KCRP sounding at 1200 UTC 25 Dec 2004 during the Christmas 2004 snowstorm.

IV. Summary and Conclusions

A widespread freezing drizzle event occurred over the WFO CRP's area of responsibility on February 3-4, 2011. The 12-hour event produced widespread ice accumulations of ¼" to ½", which resulted in very dangerous driving conditions and numerous traffic accidents. The freezing drizzle episode was quite rare and a forecast challenge at WFO CRP. This study has shown several methods that forecasters may use to anticipate a freezing drizzle event.

An analysis of the event revealed that low-level isentropic lift over an unseasonably cold air mass was the primary forcing mechanism for the freezing precipitation. Forecast and observed soundings at KCRP indicated a temperature profile that was entirely subfreezing. Temperatures in the shallow saturated cloud layer were between $0^{o}C$ and $-6^{o}C$, indicating that layer was too warm for ice crystal formation by heterogeneous nucleation. The operational numerical weather models accurately predicted the air in the layer where nucleation might occur ($\sim -10^{o}C$) would be very dry throughout the event. In the short term, cloud top temperatures estimated from IR imagery suggested that ice crystals were not likely in the clouds over Corpus

Christi. However, in the areas further north that received snow, the cloud top temperatures were less than -12^{o}C.

The TREND partial thickness technique incorrectly predicted snow and sleet would be occurring due to the subfreezing temperature profile. An inherent weakness of the TREND technique is that it assumes that ice crystals are present in the cloud. The Top-Down method for determining precipitation type was the better forecasting technique in this event, where the cloud layer was too shallow and not sufficiently cold to support ice nucleation.

V. Acknowledgements

I would like to thank Mike Buchanan, the SOO at WFO Corpus Christi for loading the meteorological data on our WES machine and for his review of this manuscript.

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