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A MULTI-PLATFORM ANALYSIS OF THE CENTRAL TEXAS FLOODS OF MAY 13, 2004

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1. INTRODUCTION & SYNOPTIC SITUATION

Deep, moist convective storms developed during the early morning hours of May 13, 2004 over portions of central Texas southeast of Waco in an area of strong onshore flow of tropical air from the nearby Gulf of Mexico. In less than twelve hours, some areas of Milam and Robertson counties received 11 to 17 inches of rainfall. Widespread disastrous flooding resulted.

Preliminary estimates of property damage totaled $2.7 million in each county and an additional $2 million in crop losses were estimated for Robertson County, where 107 farm dwellings and service buildings were destroyed, and a number of small dams failed.

Following the passage of a strong cold front more than 10 days prior to the event, return flow from the Gulf commenced on the 4th and continued without interruption through the morning of the 13th. Moisture return was gradual, but by the evening of May 12th dew points were ~22° C across the area and had reached ~ 25° C along the immediate coast, ~95 miles to the south. Surface analyses from NCEP did not depict, nor did objective and manual analysis of surface observations reveal any surface boundaries near the area.

Objective analysis of 00 UTC upper air data revealed a mid and upper level synoptic scale trough west of the area over the Rockies. A weak mid-level trough was advancing eastward ahead of the primary trough. Streamline and isotach analysis revealed a jet stream maximum exceeding 70 knots over the Great Plains and a subtropical jet maximum exceeding 70 knots over northern Mexico. Between the two jets, a broadly diffluent southwesterly flow covered much of Texas.

The area that would become the center of the excessive rainfall event on the 13th lies in the southeastern corner of the County Warning Area (CWA) of the NWS office located in Fort Worth. The afternoon zone forecast package (ZFP) on the 12th placed the probability of measurable precipitation at 60% for the daylight hours on the 13th.

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The area forecast discussion (AFD) mentioned that warm advection would develop over most of the CWA by midday Thursday and heavy rainfall would be possible with the approach of a cold front, mainly from late Thursday into early Friday (the 14th). The evening AFD update, issued around 01 UTC on the 13th, opined that no precipitation was expected "overnight" .

Indeed, the operational numerical models were not at all alarming with respect to QPF output, at least through noon on the 13th, as neither the ETA nor the GFS produced precipitation that exceeded flash flood guidance across the area. The GFS model (from the 00 UTC run) did produce a large area of very intense precipitation after 18 UTC on the 13th, but over far eastern Texas.

In this study we will utilize a variety of platforms, some in situ and some remote, to document the development and evolution of this event. These will include automated surface observations, products from the WSR-88D radars, wind profiles from profilers operated by NOAA and by the Texas Commission on Environmental Quality, rawinsonde observations, and satellite imagery from the eastern GOES unit. We will also make use of the 0-hour (analysis) output from the Rapid Update Cycle (RUC) model as a source of pseudo-real-time gridded data above the surface. Figure 1 shows the area of the study, including county lines, radar and profiler sites, and selected surface observation sites.

2. SITUATION AT 06 UTC

Examination of reflectivity data from WSR-88D sites around the area (not shown) and IR imagery from the eastern GOES satellite (Figure 4a) indicated scattered deep convection developing around 06 UTC in a small area between Austin and Houston. Cells initially moved toward the north-northeast, gradually forming a broken line that was oriented west-northwest to east-southeast. As the broken line moved across the area, additional cells developed in a broad triangular area between San Antonio, Waco and Houston, with a gradual increase in intensity and coverage.

The RUC 0-hour (analysis) output (not shown) revealed a deep southeasterly flow across the Texas coastal plains toward Waco and the Dallas-Fort Worth area. Of potential significance,

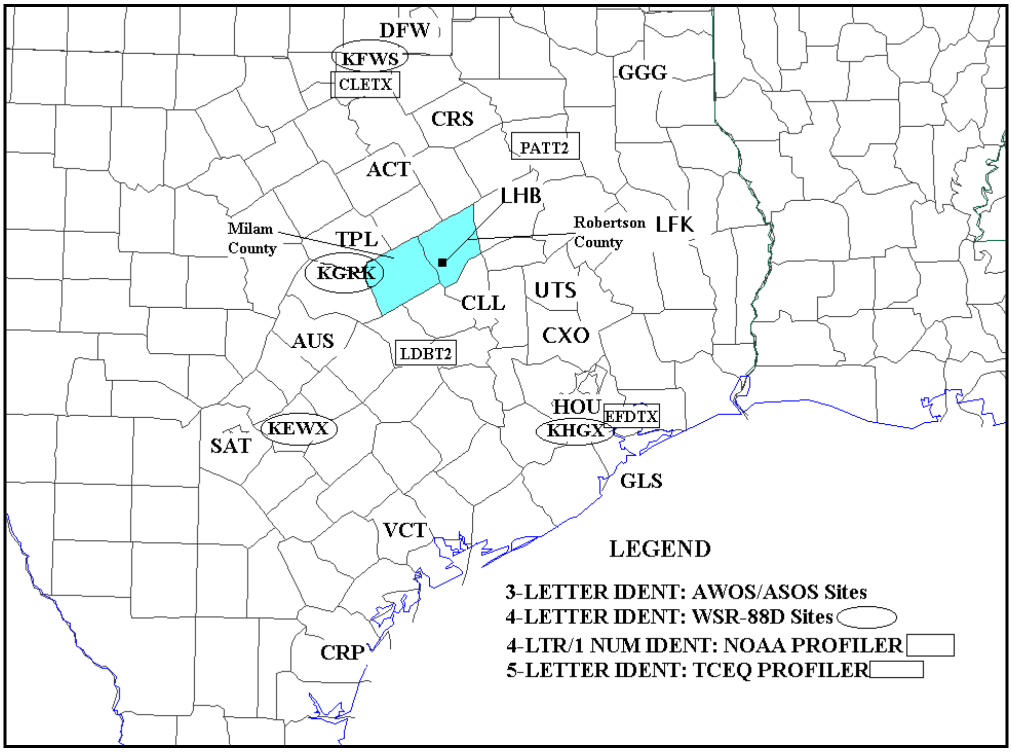

Fig. 1. Map depicting area of interest on May 13, 2004. Shaded counties are Milam and Robertson.

the 250 mb analysis revealed an area of weak divergence over the area where the first storms had developed, with a stronger area of divergence upstream over northern Mexico, southwest of Laredo.

3. SITUATION AT 09 UTC

Areal coverage of deep convective cells was continuing to expand at 09 UTC. Figure 2a shows a composite of 0.5 degree base reflectivity at the WSR-88D site at Granger (KGRK) for 0858 UTC and 09 UTC surface observations plotted in the usual manner.

Infrared imagery from the eastern GOES satellite (Figure 4b) depicted the initial convective area moving away to the northeast over Huntsvile (UTS) and Conroe (CXO) while a new (and stronger) area of storms was developing from east of Temple to east of Austin.

The RUC 0-hour (analysis) output for 09 UTC revealed a continuation of the deep southeasterly flow of warm, moist air into the area. Perhaps of greater significance, divergence at 250 mb had increased and the isotach analysis at that level depicted a zone of stagnating flow over the area between Austin and Houston. Fig. 3 shows a zone of less than 30 knot flow oriented southeast to northwest from approximately Galveston to Waco. The most intense and rapidly expanding deep convection was within this stagnation zone.

Just before 10 UTC, the Hydrometeorological Prediction Center (HPC) updated the Excessive Rainfall Discussion (QPFERD) to outline an area over southeastern Texas into Louisiana where isolated excessive rainfall would be possible. The southwestern corner of the area was Hearne (LHB), in Robertson County. The issuance mentioned that latest model guidance pointed to a 12 to 16 hour period of isolated heavy rainfall across the region, and noted that the latest satellite and radar observations were “very supportive”, with increasing convection through south central Texas that was directly related to subtropical shortwave energy lifting northeastward.

4. SITUATION AT 12 UTC

By 12 UTC, it was obvious that a serious situation was unwinding across the area bounded roughly by Austin, Waco and Bryan-College Station. About 1120 UTC, the NWS office at League City (HGX) issued a tornado warning for Brazos County, including the Bryan-College Station area as an intense storm cell moved across that area. Storm cells were developing and repeating over areas of Milam and Robertson counties, which prompted the NWS office at Fort Worth to issue a Significant Weather Update shortly after 1115 UTC, that cited strong thunderstorms with very heavy rain in Milam, Robertson and Falls counties.

The 3-hour accumulated precipitation product from the WSR-88D at KGRK at 1215 UTC (not shown) indicated a large area of rainfall exceeding 2 to 3 inches northeast of the radar site, with a small area near and west of Hearne showing more than 4 inches. Very heavy rainfall was continuing across the area, as seen in Figure 2b, a composite of 0.5° base reflectivity from KGRK at 1203 UTC with the 12 UTC surface observations plotted in the usual manner.

Base velocity products (0.5 degree) from KGRK between 11 UTC and 13 UTC (not shown) indicated the development of very strong east to west outflow from the area of intense rainfall over eastern Milam and western Robertson counties toward the KGRK radar site. Around 12 UTC a significant area of >50 knot inbound velocity was shown from near Cameron to near the KGRK site. In loops of the velocity product, this strong outflow can be seen passing across the GRK site, with the flow only gradually subsiding. Then, by 13 UTC, strong convergence developed very near the KGRK site associated with yet another (but more limited) burst of deep convection.

The RUC 0-hour (analysis) output for 12 UTC revealed a continuation of the deep southeasterly flow of warm, moist air into the area, with expansion of the area of divergence at 250 mb (Fig. 4). The isotach analysis at that level depicted a zone directly over the area of deep convection where flow was less than 20 knots.

Infrared imagery from the eastern GOES satellite depicted the signature of a developing mesoscale convective complex in the same area, with an expanding area of very cold cloud tops over Milam, Robertson and southern Falls counties, as seen in Fig. 7(c), from 1215 UTC.

5. SITUATION AT 15 UTC

By 15 UTC, disastrous flooding was occurring over eastern Milam and western Robertson counties, particularly in areas around Milano and Hearne. The KGRK 0.5 degree base reflectivity scan (Figure 2c) did indicate some significant changes in the structure of the activity from the radar site east and northeast across Milano and Hearne into Leon County. The echo pattern had become more linear, with one area of very intense activity located very close to the radar site, and another over Leon County.

Of interest from a severe weather perspective was a feature about 20 miles south of the KGRK site, where there appeared to be an intersection of two outflow boundaries, or a wave pattern in a single boundary. Looping of the product over time indicated that the cells were forming into a line and beginning to move toward the southeast. Immediately ahead of the line, cool outflow was noted at College Station while warm, moist inflow continued at Giddings.

Both the one-hour and the three-hour accumulated precipitation products from KGRK are missing or unusable (from the NCDC archive) for the period from approximately 13 UTC to almost 16 UTC. However, review of reflectivity data from KGRK and other WSR-88D sites leaves no doubt that very heavy rainfall persisted during that entire period.

The RUC 0-hour (analysis) output for 15 UTC (Fig. 5) revealed a continued expansion of the area of divergence at 250 mb. The isotach analysis depicted a zone directly over the area of deep convection where flow was less than 20 knots, and depicted the area of maximum divergence to be centered west of Lufkin.

Infrared imagery from the eastern GOES satellite at 1515 UTC (Figure 4d) depicted a mature MCC, with a very large area (>110,000 km^2) in which cloud tops were at or below –52° deg C. An interesting feature seen in animation of the IR imagery between 11 UTC and 17 UTC was a cyclonic looping of the coldest cloud tops over and west of the zone of most intense rainfall.

6. SITUATION AT 18 UTC

By 18 UTC, the developing linear system had raced southeastward, particularly on the western end, with the heaviest convective activity from Bryan-College Station southward, but new development was occurring from Temple eastward across southern Falls and northern Robertson counties. Figure 2d is the KGRK 0.5° base reflectivity for 1758 UTC

The RUC 0-hour (analysis) output for 18 UTC (Fig. 6) relocated the most intense divergence at 250 mb westward from the 15 UTC position to near Centerville (in Leon County) and showed further intensification of the divergence. The isotach analysis indicated that the area of stagnation (where flow was less than 20 knots) was shifting southeastward away from central Texas toward the Texas coast near Houston.

Infrared imagery from the eastern GOES satellite at 1745 UTC (not shown) depicted some weakening of the MCC, with significant shrinking of the area of coldest cloud tops, and a reorganization of the coldest tops into a more linear formation east and southeast of Bryan-College Station into a more north to south orientation.

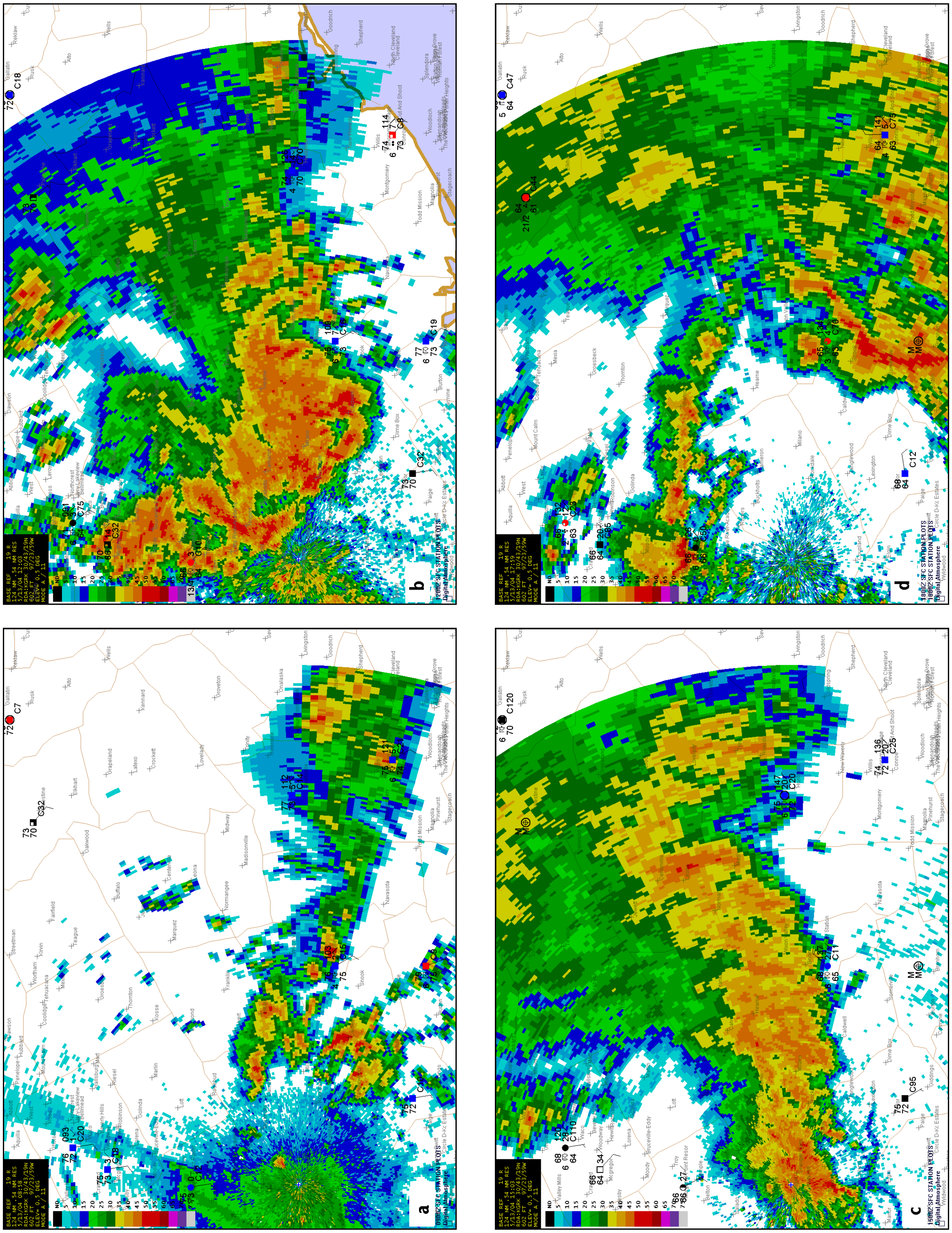

Fig.2 (a-d). 0.5° base reflectivity from Central Texas WSR-88D (KGRK) near Granger, TX. Times of images are as follows: (a) 0858; (b) 1203; (c) 1503; (d) 1758.

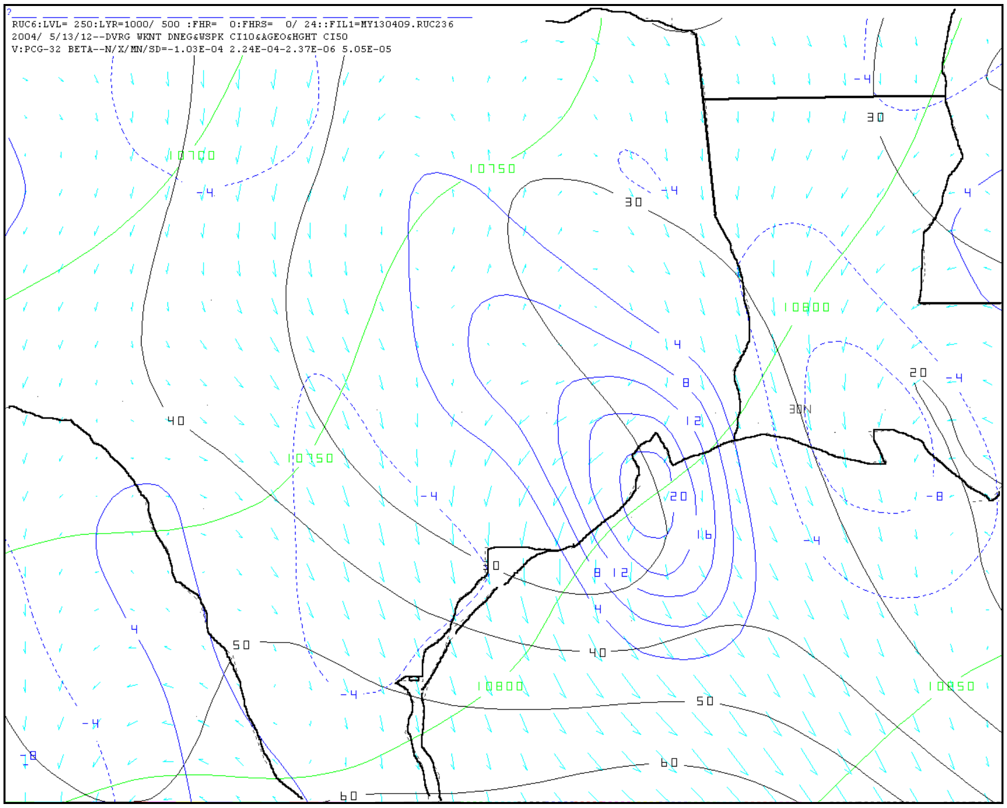

Fig. 3. 0-hour Rapid Update Cycle (RUC) analysis at 250 mb for 09 UTC. Divergence (solid blue, dashed = negative; isotachs in knots (solid black); heights (green); ageostrophic wind barbs in knots (turquoise).

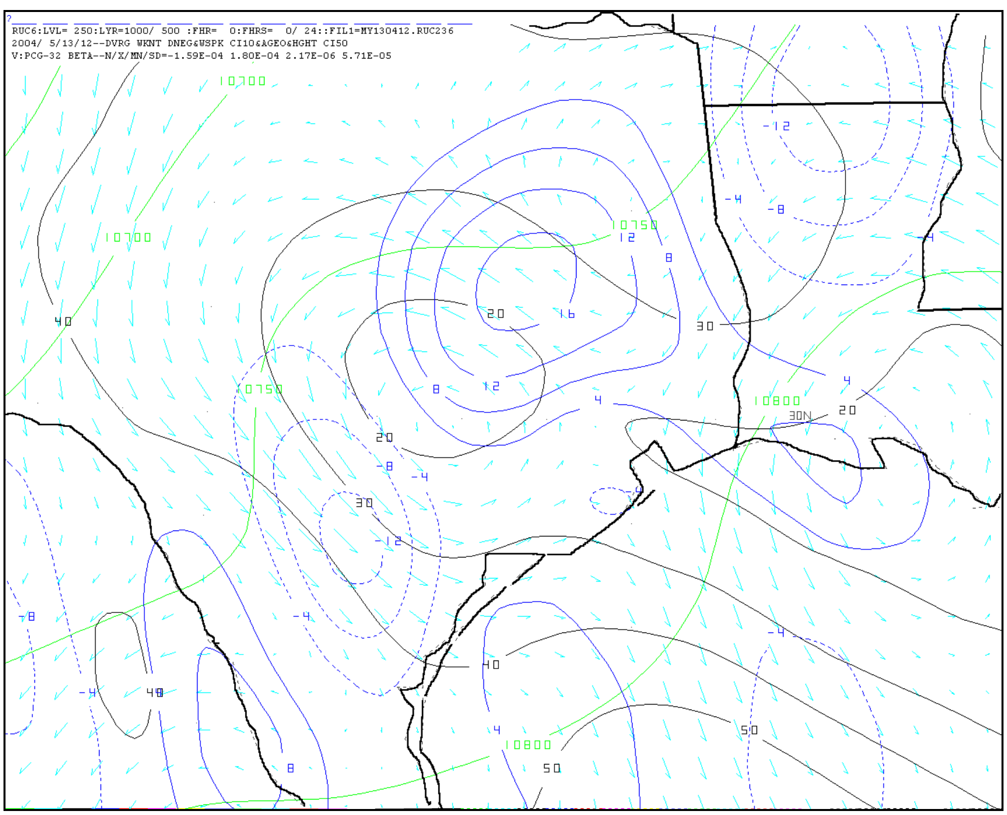

Fig. 4. As in Fig. 3 but for 12 UTC.

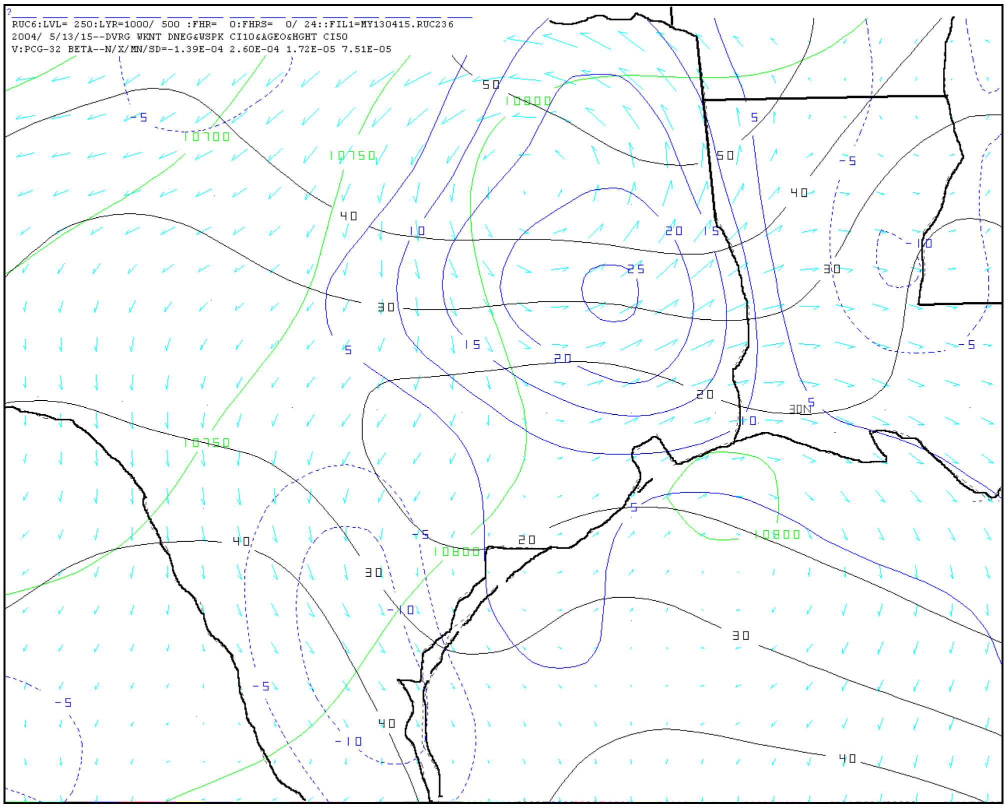

Fig. 5. As in Fig. 3 but for 15 UTC.

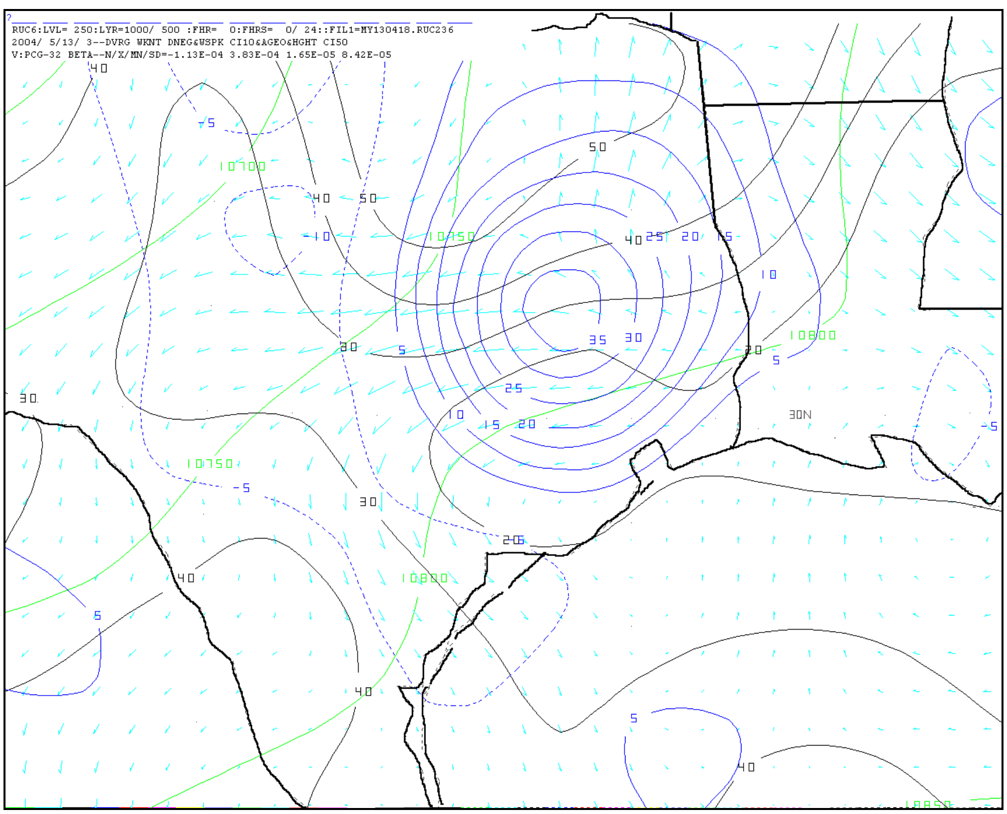

Fig. 6. As in Fig. 3 but for 18 UTC.

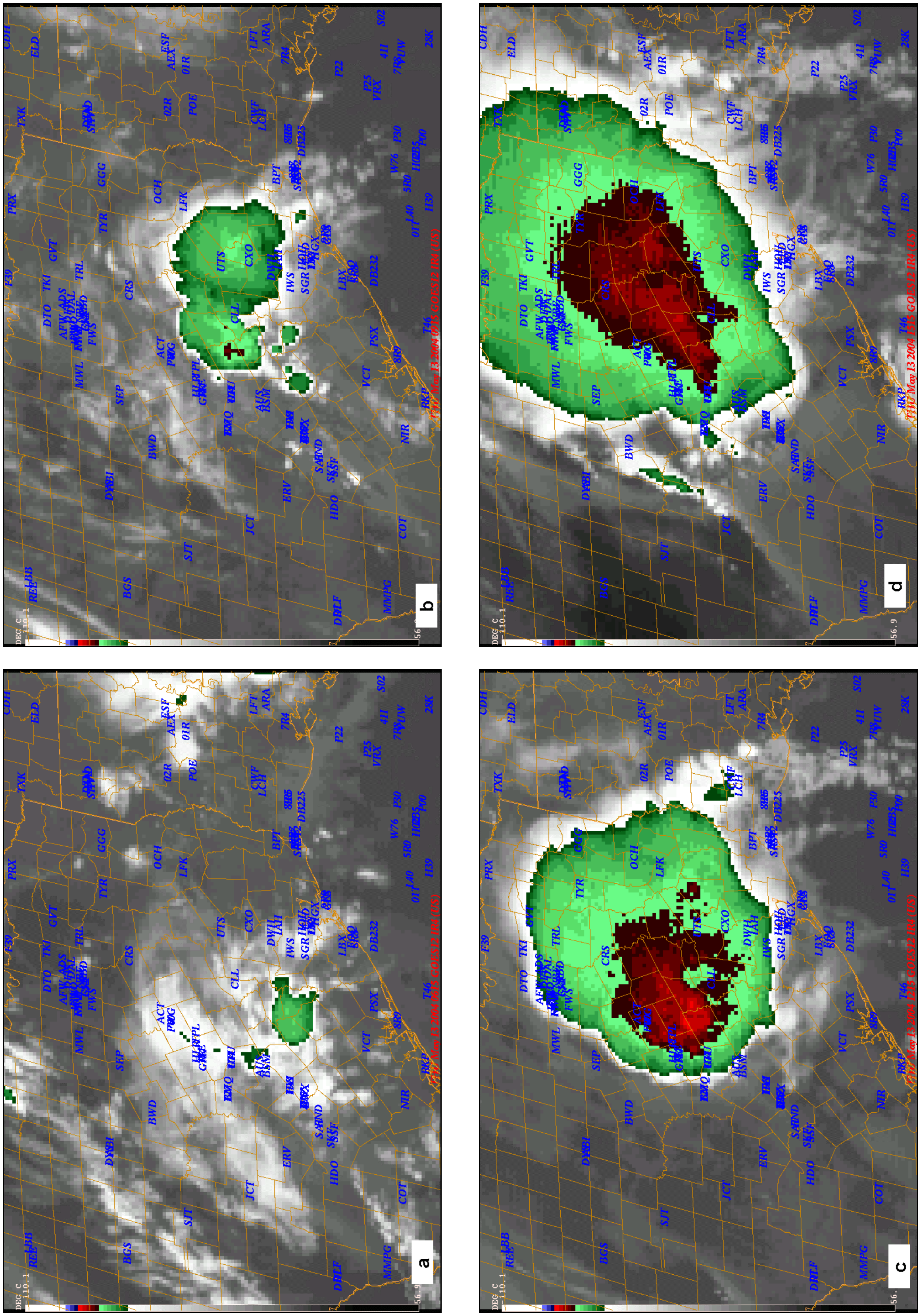

Fig. 7 (a-d). GOES-12 infrared imagery from the following times (UTC): (a) 0615; (b) 0915; (c) 1215; and (d) 1515

7. TOTAL RAINFALL AMOUNTS

Figure 8 shows the storm-total precipitation product from the KGRK WSR-88D at 2007 UTC. A large area of >10 inches precipitation was indicated over eastern Milam and western Robertson counties, southward into northern Burleson County. Imbedded within the ten-inch area was an area from near Hearne southwest to near Milano where the product indicated >12 inches. This is effectively a 12-hour total as this product was not showing any significant accumulations at 08 UTC.

A variety of surface data was examined in an attempt to generate ground-truth measurements of accumulated rainfall. Probably the most reliable reading was obtained from the Hearne Airport (KLHB) AWOS. Inspection of the archived on-line observations transmitted by this station revealed a number of data outages during several periods between 12 UTC and 16 UTC. Fortunately, the unit, does maintain a 30-day archive on-site.

The unit includes a tipping bucket precipitation measuring system which resets to zero after each 20-minute automated report. With the assistance of the manufacturer (Vaisala), the complete data record for May 13th was recovered, and it revealed a 12-hour rainfall at Hearne of 12.21 inches (for the period ending at 2005 UTC). Table 1 displays the 20-minute, 1-hour, 3-hour, and total precipitation accumulation for the period 0805 UTC through 2005 UTC.

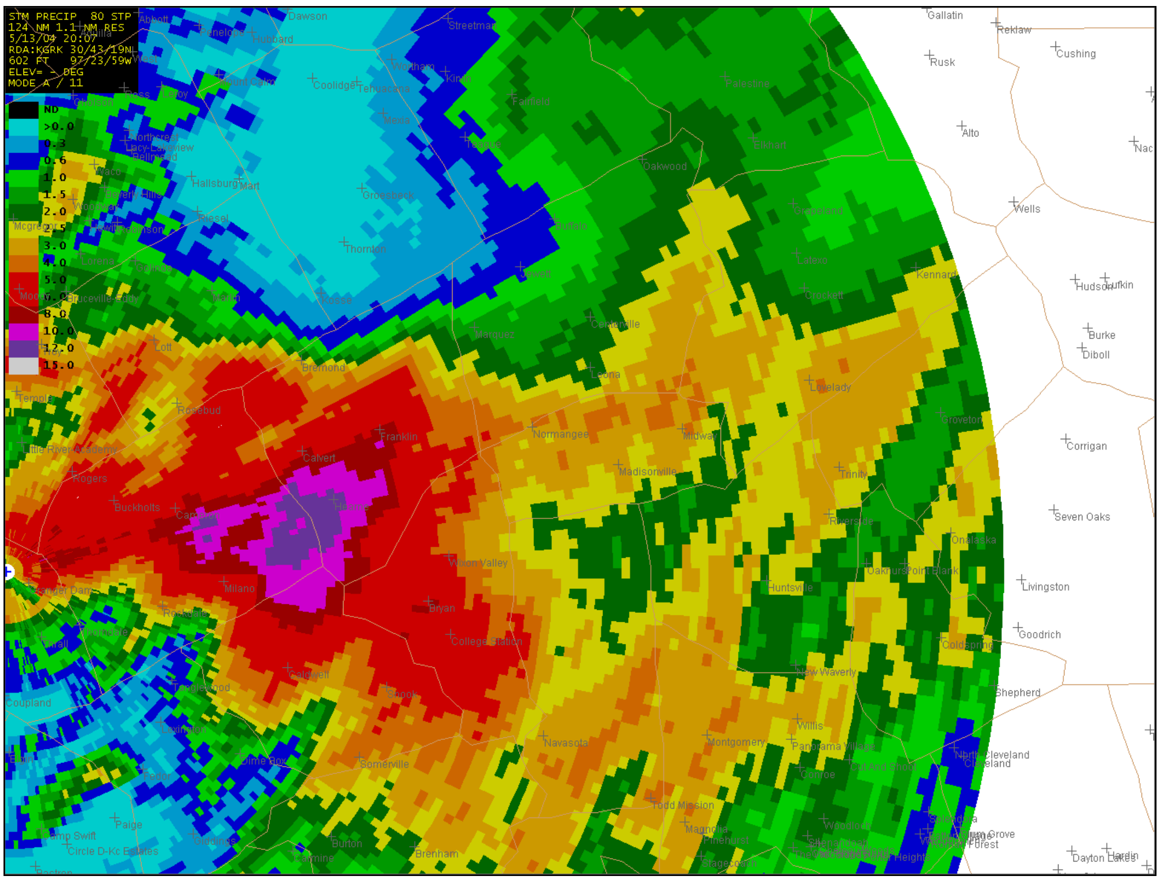

Fig. 8. Storm-total precipitation product from KGRK at 2007 UTC on May 13, 2005.

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In an attempt to further define the extent and intensity of precipitation during this event, various sources of precipitation records were obtained. These included daily records from ASOS and AWOS stations, USGS stream gauging stations (which report 15-minute precipitation accumulations), a number of AWS schoolwatch weather stations, and NWS cooperative observer weather records. Figure 9 displays the results of this effort. There are several quality control items worthy of mention: (a) the AWS stations in the affected area may have experienced power outages during the event, which would result in data loss for some period of time, resulting in an incomplete record; (b) the NWS cooperative observers generally take only one record precipitation observation daily, and usually at 8am CDT, in the very middle of this event. To account for the latter issue, the authors have combined and adjusted two days of records at those stations.

TIME	20MIN	1HR	3HR	TOTAL
0805	0	0	0	0
0825	0	0	0	0
0845	0	0	0	0
0905	0.06	0.06	0.06	0.06
0925	0.06	0.12	0.12	0.12
0945	0.27	0.39	0.39	0.39
1005	0.27	0.66	0.66	0.66
1025	0.58	1.12	1.24	1.24
1045	0.57	1.42	1.81	1.81
1105	0.25	1.40	2.06	2.06
1125	0.21	1.03	2.27	2.27
1145	0.53	0.99	2.80	2.80
1205	0.26	1.00	3.00	3.06
1225	0.61	1.40	3.55	3.67
1245	0.74	1.61	4.02	4.41
1305	0.93	2.28	4.68	5.34
1325	1.34	3.01	5.44	6.68
1345	**1.57**	**3.84**	6.44	8.25
1405	0.69	3.60	6.88	8.94
1425	0.48	2.74	7.15	9.42
1445	0.61	1.78	7.23	10.03
1505	0.43	1.52	7.40	10.46
1525	0.62	1.66	**7.41**	11.08
1545	0.20	1.25	6.87	11.28
1605	0.34	1.16	6.28	11.62
1625	0.05	0.59	4.99	11.67
1645	0.25	0.64	3.67	11.92
1705	0.20	0.50	3.18	12.12
1725	0.04	0.49	2.74	12.16
1745	0	0.24	2.13	12.16
1805	0	0.04	1.70	12.16
1825	0	0	1.08	12.16
1845	0	0	0.88	12.16
1905	0	0	0.54	12.16
1925	0	0	0.49	12.16
1945	0.02	0.02	0.26	12.18
2005	0.03	0.05	0.09	12.21

Table 1. 12-hour precipitation at Hearne, TX AWOS (KLHB) on May 13, 2004, showing accumulation in 20-minute increments, running one-hour and three-hour accumulations, and total accumulated precipitation. Red (bold) numerals indicate maximum period accumulations for 20-minute, 1-hour and 3-hour periods.

8. WIND PROFILER DATA

About two years prior to the May 13th event, the NOAA profiler at Plattville, CO was relocated to a site near Ledbetter, TX in a joint effort by NOAA, the Lower Colorado River Authority (LCRA), and Texas A&M University. The primary goal was to fill a perceived gap in upper air data as the closest rawinsonde sites are located at Corpus Christi, Lake Charles and Fort Worth.

Fortuitously, the Ledbetter (LDBT2) site was located only ~45 miles south of the heaviest rainfall in this event, and thus in a position to provide important information regarding the evolution of the event on the inflow side. Figure 7 shows the 60-minute resolution wind data from LDBT2 covering a 14-hour period from 07 UTC to 21 UTC on May 13th. The 11 UTC data is missing from the graphic. The profiler archive for the period was dumped to a text file which permitted recovery of the 11 UTC data. The 0-3 km data is summarized in Table 2.

Perhaps the most striking feature of both Figure 10 and Table 2 is the significant acceleration in southerly flow that developed around 11 UTC. Between 10 UTC and 11 UTC, the lowest gate (621 m) shows the wind backing (from 175 to 157 while the velocity increases from 34 to 43 knots. By 12 UTC, the first gate is measuring 48 knots, with >40 knots indicated at all gates through 3 km. This intense southerly flow continues until gradually abating around 15 UTC.

A working hypothesis is that the acceleration was related to the development of a mid-level vorticity center related to the mesoscale convective complex located north of the LDBT2 site within the area of intense precipitation. In an attempt to test this hypothesis, data from other profilers and from the VAD wind profile products at nearby WSR-88D sites was inspected.

The closest of those sites was the KGRK WSR-88D site located at Granger Lake in northeast Williamson County. VWP data from ~10 UTC shows a southerly flow of 20 to 35 knots at the lower gates gradually turning to the south-southwest and then the southwest through 3 km. The maximum velocity is ~35 knots between 1.5 km and 3km. At ~11 UTC, the flow is southerly in the lowest two gates at 20 to 30 knots, turning gradually to the south-southwest and then the southwest through 3km. Maximum velocity is ~40 knots in the layer between 1.5 km and 2.5 km. This flow is quite strong and not entirely inconsistent with the LDBT2 profiler data, although not as deep and not as persistently southerly.

By ~12 UTC, the flow at KGRK is significantly different from that seen at LDBT2, with a southeasterly flow of 20 knots at the lowest gate, turning at the next gate to south-southwest at 30 knots and gradually veering to southwesterly through 3 km. The highest velocity is ~30 knots. By ~13 UTC, the lowest gate at KGRK shows the arrival of the strong (~25 knots) east-northeasterly flow associated with the westward-migrating rain-cooled outflow mentioned previously in Sec. 4. The flow turned to the southwest at the remaining gates through 3 km, at a velocity no greater than 35 knots. Thereafter, a gradual decrease in the 0-3 km flow was indicated.

The KEWX WSR-88D VAD wind profile data was inspected and it reflected that the strongest low-level flow occurred shortly after 12 UTC but was <35 knots. Around 2 km, the flow was briefly ~40 knots. However, the data did not reflect the intense, deep southerly flow seen at LDBT2. Data from CLETX depicted a more south-southwesterly flow that did not reach 40 knots at any time. Data from the NOAA profiler at Palestine (PATT2) was missing for the period 08 –15 UTC.

9. ANALYSIS, DISCUSSION AND CONCLUSION

The definition of an MCC is based on satellite imagery and requires that the convective system's cold cloud shield should exhibit certain characteristics. (Fritsch and Forbes 2001, Maddox 1980) The requisites of a mesoscale convective complex (MCC) include: a cloud shield with continuously low IR temperatures ($\leq$33° C) over an area of at least 10^5 km^2 with an interior cold cloud region with temperatures $\leq$-52° C over an area $\geq$$0.5^5$ km^2, and having a duration of at least 6 hours. Maddox (1980) also specified that at maximum extent, eccentricity (minor axis/major axis) should be $\geq$0.7.

IR satellite imagery for this convective system was analyzed according to the foregoing specifications. Maximum extent of the cold cloud tops (satisfying both of the requisite specifications) was observed at 1645 UTC, when cloud top temperatures of $\leq$-33°C covered an area of approximately 3.25 X 10^5 km^2 within which was found a region where cloud top temperatures were $\leq$-52°C covering an area of 2.12 X 10^5 km^2. This system was, therefore, slightly more eccentric than the Maddox specification.

Fritsch and Forbes (2001) also define the life cycle phases of MCCs, relying in part upon earlier work by Maddox (1980) and Zipser (1982). The stages, in sequence, are as follows: initiation, development, mature, and dissipation. The initiation stage covers the time from formation of the first storm(s) until the IR cold cloud tops first satisfy the minimum required for an MCC; the development phase begins at that point and continues until the maximum extent of IR cold cloud tops (as specified previously) is reached; the mature phase begins at that point and continues until the extent of IR cold cloud tops no longer satisfies the minimum required for MCC definition; the dissipation phase begins at that point and continues until convection ends.

In this case, initiation occurred ~0730 UTC just east of Austin (AUS) as storms fired just behind the southwest flank of a precursor MCS that was centered between College Station (CLL) and Houston (HOU). The development stage began at ~1115 UTC when IR satellite imagery indicated that the minimum requisites for an MCC (temperatures and extent) had been met. The mature stage began at ~1645 UTC, as noted above.

Fritsch and Forbes (2001) identified certain thermodynamic patterns and dynamical features that are usually present when MCCs develop. These include pronounced low-level convergence in the terminus region of developing low-level jets, where vertical motion associated with the low-level convergence contributes significantly to destabilization of the local environment prior to the onset of deep convection. Lifting and destabilization are especially strong when a low-

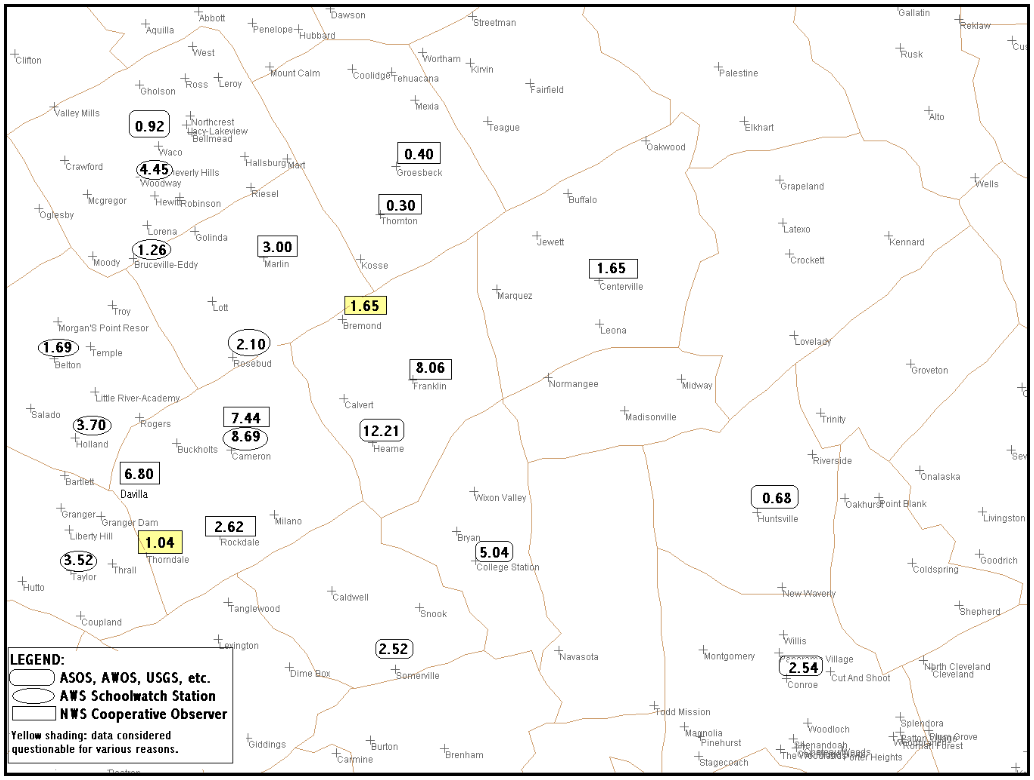

Fig. 9. 24-hour rainfall accumulation from various sources.

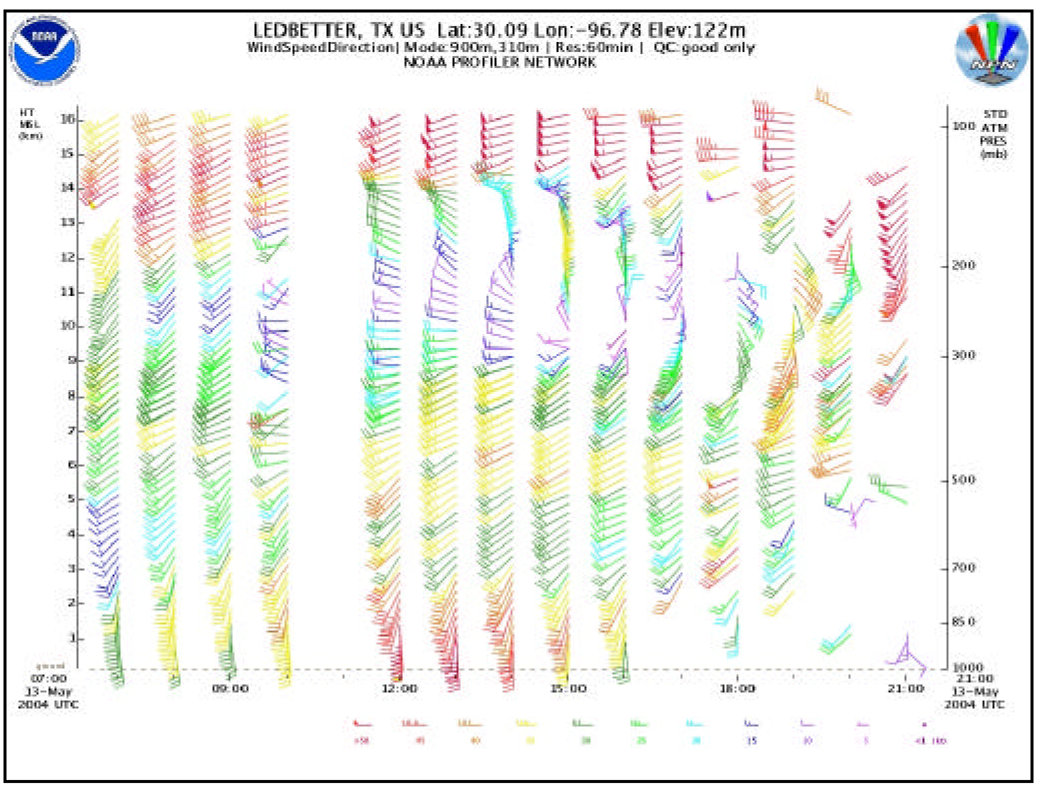

Fig. 10. Wind profile (speed in knots) from 07 to 21 UTC at NOAA Profiler at Ledbetter, TX (LDBT2).

LDBT2	.621	1.121	1.621	2.121	2.621	3.121
0600	167/29	174/27	192/36	192/43	207/16	207/15
0700	170/30	180/31	186/31	186/33	199/20	203/18
0800	170/31	183/33	191/34	189/36	197/27	199/32
0900	M	180/31	188/32	M	195/35	M
1000	175/34	178/36	189/36	194/37	206/36	210/37
1100	157/43	179/41	196/36	204/40	209/34	215/32
1200	175/48	175/44	194/43	196/43	214/40	210/35
1300	176/46	186/46	196/45	204/41	204/37	220/32
1400	179/43	186/42	193/40	208/42	204/39	217/33
1500	182/35	187/38	195/42	203/35	213/33	223/28

Table 2. 60-minute average wind data from Ledbetter, TX (LDBT2) NOAA profiler.
(time in UTC; height in kilometers above MSL; wind speed in knots).

level jet intersects the thermally-direct circulation associated with frontogenetic forcing. In addition, a weak mid-level short wave may be approaching the genesis region and such a system further enhances low-level convergence associated with the low-level jet. Finally, warm advection usually dominates the lower troposphere while diffluent flow is found in the mid and upper troposphere.

Examining this event in light of the foregoing, we find that while there was a modest low-level jet in place, the event did not occur near its terminus. As noted earlier, analyses through 06 UTC revealed no sign of a low-level baroclinic boundary in the region where the MCC developed. Similar analyses at 09 UTC were also negative for such a boundary. It is possible that the first MCS, which moved across the area from Austin to Houston just prior to the initiation of convection that became the MCC, may have created a diffuse boundary that drifted northward within the broad south-southeasterly flow, helping to precondition the lower troposphere for additional deep convection. There was a weak mid-level short wave advancing toward the genesis region ahead of the synoptic scale trough which was still well to the west. And as noted earlier, warm advection did dominate the lower troposphere with a mildly diffluent flow aloft.

Fritsch and Forbes (2001) note the apparent importance of the low-level jet, normally a nocturnal feature, in the development of MCCs. Citing a number of sources, they posit that "… nocturnal low-level jets develop as a result of adjustments that take place as 1) the mixed layer decouples from the surface as the surface cools and 2) horizontal temperature differences develop as a result of sloping terrain (e.g. the Great Plains) and an east-west gradient in the Bowen ratio (the ratio of surface sensible to latent heat flux)." They note that these processes are independent of the dynamics of migratory disturbances, so the low-level wind accelerations produced by the nocturnal low-level jet provide a significant enhancement to the low-level warm advection and convergence that would normally be present as a result of an approaching short wave and/or synoptic scale circulation.

This event did not occur on the Great Plains, and although it initiated during a nocturnal period, it persisted well into the middle of the following day. With respect to the importance of sloping terrain and its involvement in the generation of nocturnal low-level jet features, the topographic realm of central and southern Texas is significant. The higher terrain of the Rocky Mountains retreats westward across western Texas, but then reappears west and southwest of Del Rio in the form of the Sierra del Burro Mountains, and continues southeastward through Coahuila and the western portions of Nuevo Leon. These terrain features (part of the Sierra Madre Oriental), although not rising as high above sea level as the mountains of Colorado and northern New Mexico, generate a significant gradient eastward toward the coastal plains of central and southern Texas, as well as eastern Nuevo Leon and Tamaulipas.

Fritsch and Forbes (2001) suggest that MCC events can be classified into one of two types. The type-1 events involve slantwise ascent above a surface-based front or baroclinic zone. Type-2 events occur in warm sector environments without the presence of synoptic scale frontal forcing, relying instead upon downdraft-generated cold pools originating from deep convective storms typically rooted in a well-mixed boundary layer. As downdraft-generated cold pools expand, they supply layer lifting and a source for slantwise ascent. Convective overturning in type-2 events can be downshear, upshear or remain upright, depending upon the relative strengths of low-level vertical wind shear and the downdraft-generated cold pool. Unlike the type-1 events, in type-2 events the slantwise front-to-rear ascent does not begin until after a cold pool develops.

Our analysis of this event points to a type-2 classification, primarily due to the absence of a low-level baroclinic boundary. In addition, the evolution of the event suggests that downdraft-generated cold pools were critical to the evolution of the MCC.

Fritsch and Forbes (2001), citing Maddox et al. (1986), Houze et al. (1990), and Tollerud and Collander (1993), note that if severe weather occurs in association with an MCC, it usually occurs during the initiation stage. There were several warnings for severe weather during the event (both for possible tornadoes and for damaging straight line winds), and most of the documented severe weather events occurred during the transition from the initiation stage to the development stage. They also cite McAnelly and Cotton (1989) and Collander (1993) for the proposition that the heaviest rainfall typically occurs in the development stage, which was certainly the case in this event. They further note that the heaviest rainfall is usually concentrated on the equatorial flank of the coldest cloud shield, which is often the southwestern flank. Examination of the WSR-88D products and the IR satellite imagery in this event is consistent with that pattern.

A number of authors (see Fritsch and Forbes, 2001) have proposed that long-lived mid-level mesovortices (also called mesoscale convective vortices, or MCVs) with warm cores are thought to be an inherent process characteristic of MCCs. The dynamical structure and circulation of these MCVs are said to resemble those of tropical disturbances. A close examination of animations of both the GOES-12 IR imagery and of the 0.5° base reflectivity products from KGRK reveals the evolution of features associated with at least one MCV with this system.

The KGRK 1203 UTC product (Fig. 2(b)) is suggestive of a spiraling series of banded convective elements arranged around a central point. There is, however, an area of little or no activity in the vicinity of College Station. About the same time, the GOES-12 IR product (Fig. 7 (c)) shows an interesting arrangement of cloud-top temperatures, with an area of warmer cloud tops near College Station (CLL). These two features are seen both before and after this time, but were more prominent prior to this point in time. The authors propose the possibility that this feature represents an "inflow notch" for the MCV, where very strong inflow and ascent were displacing convective elements northward (in a fashion reminiscent of inflow notches sometimes seen with supercell thunderstorms).

Another interesting feature, seen in both products but more apparent in the animation of the radar product, is the appearance that the most intense convection (coldest cloud tops in IR) make a cyclonic loop over several hours time between ~11 UTC and ~15 UTC. The authors have no current explanation for this apparent evolution, but it is hypothesized that more than one MCV may have developed with this MCC, with the possible interaction of two MCVs to produce the looping of the most intense convection as seen by radar and of the coldest cloud tops.

We intend to follow up on the latter hypotheses in subsequent research, perhaps making use of the 0-hour RUC analyses in an attempt to locate and track the mid-level vortices.

Finally, Fritsch and Forbes (2001) discuss the ability of MCCs to modify the local, regional and (occasionally) the synoptic environment. Recall that this event took place in advance of a major synoptic-scale trough that was advancing eastward into the southern plains. Significant severe weather events were expected on May 13th as the dynamics of the advancing trough interacted with the warm, moist and unstable low-level environment over Texas, Oklahoma, Missouri and Kansas. The MCC appears to have directly interfered with the expected evolution of severe weather on the 13th.

Severe weather events were actually focused (Fig. 11) in an arc extending from Wichita Falls to Abilene to Junction to San Antonio, which generally represents the westward limits of the cold outflow generated by the morning MCC over central Texas. The Texas events primarily involved marginally severe hail, while the northeastern Oklahoma events were predominantly strong straight-line wind events. Very few severe events were reported in Kansas and Missouri. We propose that the intense MCC that occurred exhausted the low-level instability over a large area of Texas via a variety of processes, including convective overturning, intense cold pool development and spreading outflow, and disruption and obstruction of the warm, moist and unstable southerly flow from of the Gulf of Mexico. As a result, the extent of the severe weather associated with the primary upper trough was greatly diminished.

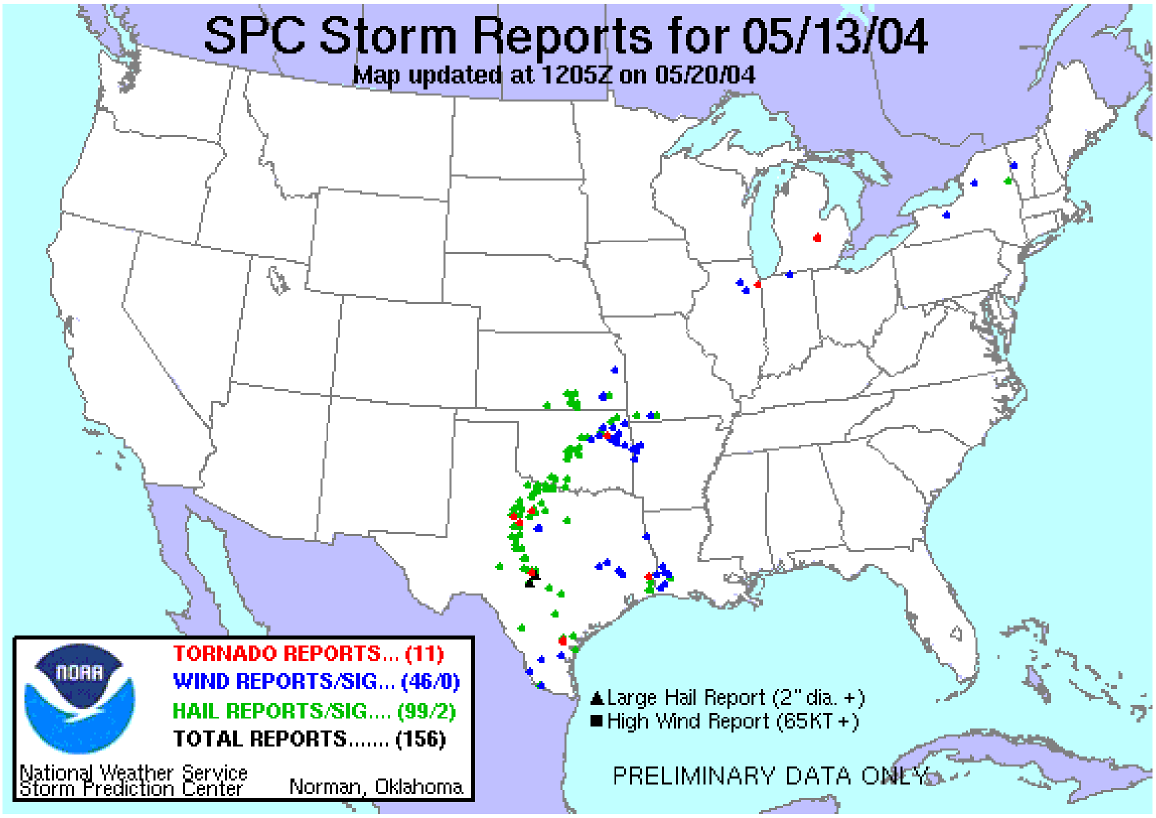

Figure 11. SPC Storm Reports for May 13, 2004.

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