P1B.7 ANVIL EVOLUTION FROM NEXRAD DATA DURING CRYSTAL-FACE

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1. INTRODUCTION

Cirrus clouds, many generated from deep convective storms, make up an important component of the global heat balance particularly in the Tropics. The radiative properties of convectively-generated cirrus, and thus the role of cirrus clouds in regulating global climate, are poorly understood. The effect of cirrus clouds on the global energy balance represents one of the largest points of uncertainty in climate models.

One way to improve our understanding of cirrus clouds is to study the formation and evolution of the parent convective storm systems. This was one of the goals of last summer's Cirrus Regional Study of Tropical Anvils and Cirrus Layers – Florida Area Cirrus Experiment (CRYSTAL-FACE) in South Florida, which took place during the month of July 2002.

The goal of this observational study was to investigate the evolution of anvil - generating convection, from initial sea-breeze convective cells to the upscale growth and decay of mesoscale systems along the sea breeze front, and the resultant production of extensive anvil cloud. The approach was to use the network of NOAA/NWS WSR 88-D (NEXRAD) radars in South Florida, which provided continuous sampling of the three-dimensional structure of convective systems. These observations will be critical to place CRYSTAL-FACE aircraft microphysical measurements and ELDORA Doppler radar mass flux estimates in context of overall system lifecycle, and will further be important to guide cloud resolving model simulations of anvil evolution.

2. DATA

The main challenge for this work was access to the complete set of Level II data for the Florida NEXRAD sites of Key West, Miami, Tampa, and Melbourne (Figure 1 shows the coverage of these radars). Prior to the CRYSTAL-FACE campaign, South Florida NEXRAD radar data for three of these sites (Tampa, Miami, Key West) could be accessed only via an inefficient and incomplete exabyte tape archive. Our need for complete and reliable NEXRAD data access led to a partnership with an ongoing NOAA effort to upgrade the NEXRAD data archival system involving CAPS/Univ. of Oklahoma, UCAR, Univ. of Washington, NSSL, NWS and NCDC called Project CRAFT (Collaborative Radar Acquisition Field Test). The CRAFT project partners with field projects of opportunity to develop, for particular NEXRAD sites, data networks for transferring level II (raw) radar data directly to NCDC and then to user institutions. CRYSTAL-FACE provided hardware and data connections (DSL and cable modem to local ISPs) at low cost from the NEXRAD sites, allowing real-time access to the level II data by NCDC and then NASA GSFC. Thus, we were able to acquire a nearly complete level II dataset (95% latency), which would not have been possible with the previous exabyte archival system. This data network continues to provide real-time level II data from the South Florida NEXRADs to government and educational institutes via NCDC, which is currently benefiting many user communities.

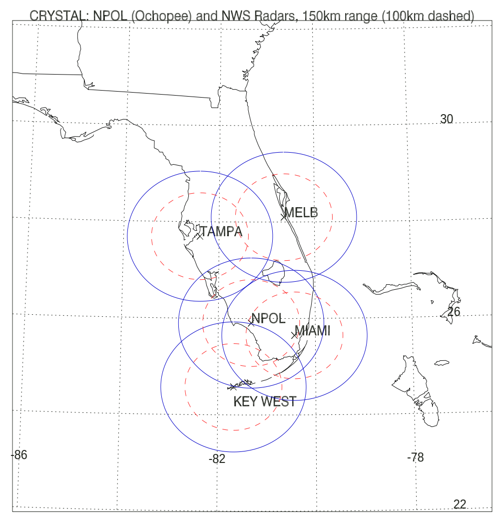

Figure 1. Coverage of the four 88-D NEXRAD radars in South Florida, and the NPOL polarimetric radar deployed for CRYSTAL-FACE. Solid and dashed circles are the 150 km and 100 km range rings, respectively.

The NASA NPOL polarimetric radar was deployed at Big Cypress State Reserve at Ochopee, FL for CRYSTAL-FACE. Although not part of this paper, NPOL polarimetric rain estimates will be used to tune Z-R relationships for each overlapping NEXRAD to construct rainfall maps covering all of South Florida for July 2002.

In this paper, three-dimensional volumes of level II radar reflectivity data from the 23 July 2002 event were interpolated to a 1 km x 1 km x 1 km grid for analysis, using the TRMM Radar Software Library (RSL) and NCAR Reorder.

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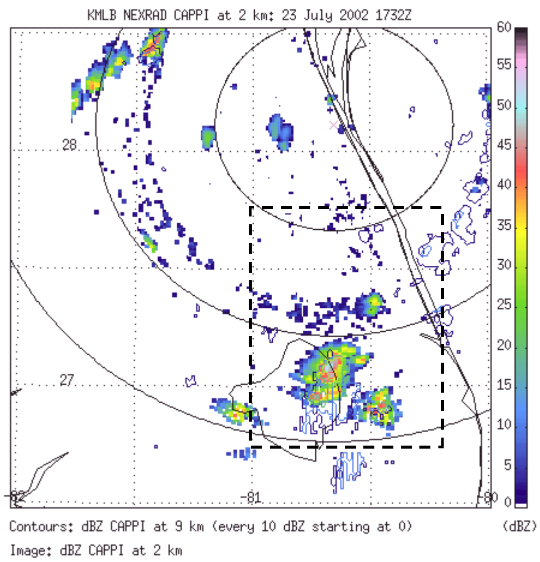
3. ANVIL GENERATION: 23 JULY 2002

In this section we describe the evolution of an afternoon convective system, which formed on 23 July 2002 between Lake Okeechobee and the eastern coast of Florida, within 100 km of the Melbourne NEXRAD site. The purpose was to study the formation and growth of a thick, mesoscale anvil of precipitation-sized particles generated by the convection.

We present a time sequence of two different views of the three-dimensional radar reflectivity field

A.



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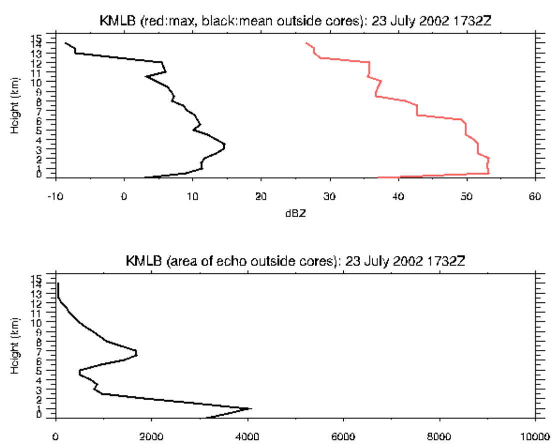

Figure 2. KMLB radar reflectivity analysis for 23 July 2002, 1732 Z (1332 LT). A) CAPPI image at 2 km AGL superimposed with contours of the CAPPI at 9 km AGL (10 dBZ contour interval starting at 0 dBZ). Range rings are every 50 km. B) Vertical profiles, within the 0.75^o x 1^o dashed area, of maximum dBZ value (upper panel, light rightmost trace), mean dBZ value outside of cores (upper panel, dark leftmost trace), and number of pixels (area) outside cores (lower panel).

associated with these systems. Shown in Figure 2a was a 2^o x 2^o CAPPI map (2 km AGL) of radar reflectivity from the Melbourne NEXRAD (10 cm wavelength, or S-band) at 1732 Z (1332 LT), showing a small group of strong convective cells developing near the eastern shore of Lake Okeechobee. Superimposed on this map were contours of radar reflectivity from a CAPPI at 9 km AGL (every 10 dBZ beginning at 0 dBZ). A new anvil of precipitation-sized particles can be seen from the 9 km CAPPI contours emanating from the location of the convective core on the eastern lake shore and extending to the southwest in the prevailing upper level winds. A line of patchy contours over the Atlantic Ocean, also extending to the southwest, represented anvil remnants from previous convection earlier that morning.

Vertical profiles of radar reflectivity and pixel count (areal coverage) are given in Figure 2b. The light (right) trace in the upper panel showed the maximum reflectivity value at each vertical level within the dashed box. This profile suggested that the cell group consisted of strong, deep convection, with a 50+ dBZ core up to nearly 6 km in height. The dark (left) trace in the upper panel showed the mean vertical profile of radar reflectivity outside of the convective cores (defined here by dBZ > 40). This profile represented the decaying portion of the convective cells, stratiform rain, and the developing anvil of precipitation-sized particles. At this time, this “anvil region” profile indicated a weak enhancement below the 0^{o}C level, likely associated with particle fallout in the vicinity of the convective cores. There is little signature of an anvil at this time in the mean dBZ profile, however the area of weak reflectivity values outside the core (Figure 2b, lower panel) suggested a small maximum near 7 km. This represented the height of the thickest portion of the developing anvil clouds.

By 1904Z (1504 LT), the small group of strong cells had moved northward on the eastern lake shore and had collapsed. Figure 3a showed a narrow long swath of anvil remnants extending to the southwest, which persisted after the decay of the parent convective cores. New developing convective cells may be seen 20 km northeast of the lake, beginning to form a line oriented northwest to southeast. Animation of the 2 km CAPPI images suggested that the outflow from the previous convection (Figure 2a) may have contributed to the formation this line parallel to the coast, presumably by the convergence of the outflow boundary and the sea breeze front.

The radar reflectivity profiles at 1904Z (Figure 3b) illustrated the new development of strong convection, while clearly showing the expanded anvil cloud from the previous convection. The maximum dBZ vertical profile again showed 50 dBZ to a height of 5 km, associated with the developing cells along the line. The strong dropoff of maximum dBZ values aloft indicated that these cells were newly forming and had not penetrated significantly to the upper troposphere. At the same time, the height of the maximum in the “anvil region” mean dBZ profile shifted upward to 5–6 km height compared to 1732Z, consistent with the growth of the anvil cloud. The

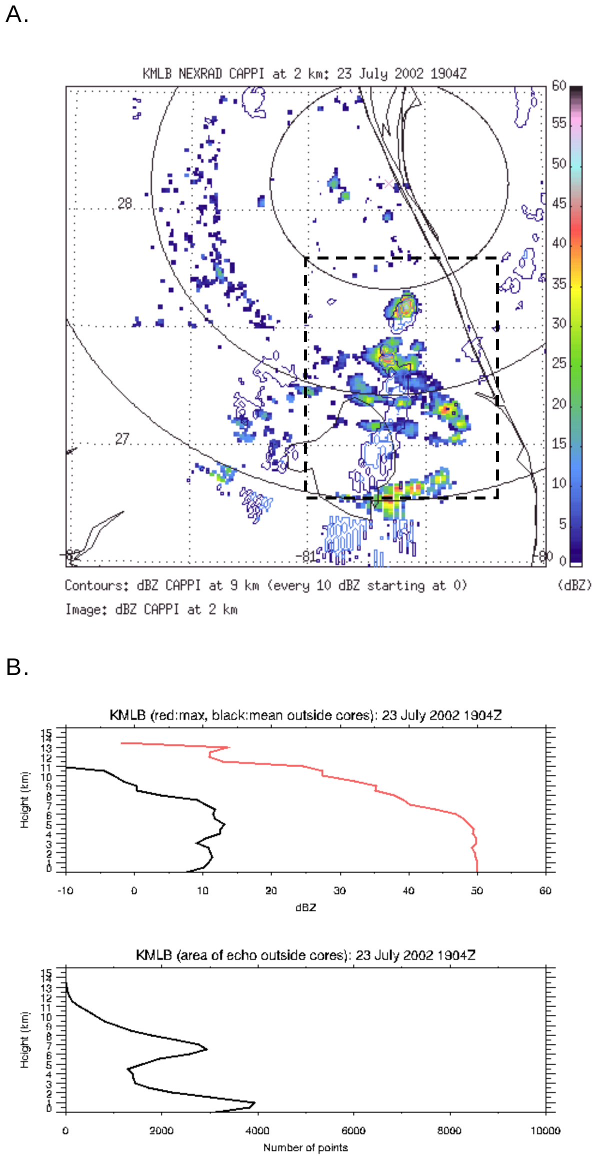

Figure 3. As in Figure 2, but for 1904 Z (1504 LT) 23 July 2002.

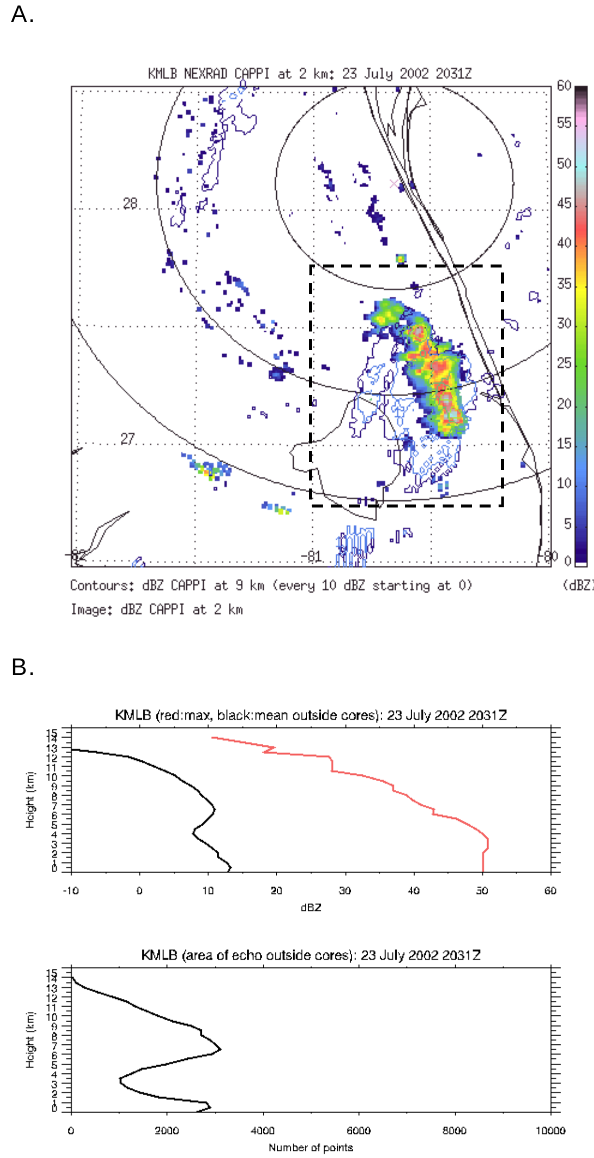

Figure 4. As in Figure 2, but for 2031 Z (1631 LT) 23 July 2002.

area of “anvil region” reflectivity nearly doubled since that time, consistent with the expansion of anvil cloudiness following the collapse of the previous convection.

After 1.5 hours (by 2031Z, or 1631 LT), the sea-breeze line of convection has matured to a solid line of strong cells, which remained stationary (Figure 4a). The heaviest raining cells were found on the southern end of the line, decreasing in intensity northward, consistent with the observation that the oldest cells were on the northern end of the line with the newest development to the south. Note that the longest anvil extension on the northern (older) end has begun to merge with the newer southern anvil to form a mesoscale anvil region. Interestingly, precipitation below this anvil cloud did not reach the surface.

The vertical profiles of radar reflectivity at this time (Figure 4b) revealed the continuing expansion, thickening, and intensification of the anvil. The vertical profile of maximum dBZ values still indicated the presence of strong convection. The anvil of precipitation-sized particles has expanded not only outward but also vertically. The height of the 0 dBZ value in the mean “anvil region” dBZ profile has increased from 9 km at 1904 Z to 12 km at 2031 Z, indicating more or larger precipitation-size particles extending upward. The anvil area profile (lower panel, Figure 4b) suggested that the anvil has also increased in horizontal area both upward and downward.

The final observation shown herein, at 2132 Z (1732 LT), indicated the complete collapse of the stationary line convection (Figure 5). In just one hour, the convective cores dissipated completely, leaving small patches of stratiform rainfall near the ground at the previous location of the line. At the same time, the 9 km

A.

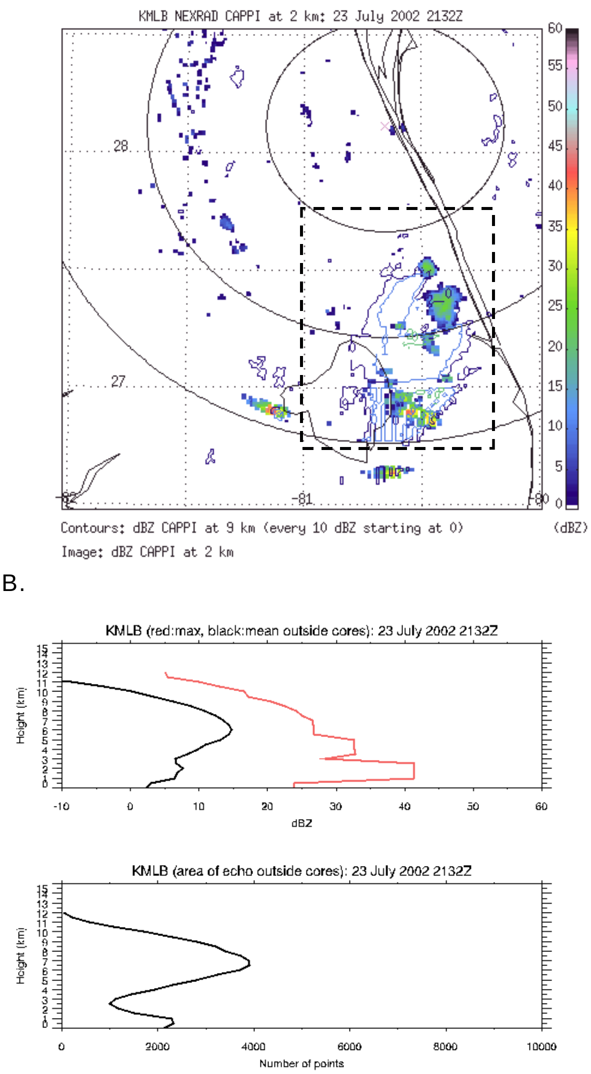

Figure 5. As in Figure 2, but for 2132 Z (1732 LT), 23 July 2002.

CAPPI contours suggested that the anvil region expanded to more than twice its area. Again, note the lack of stratiform precipitation under the anvil near the surface. The complete collapse of the convective cores was clear from the vertical profile of maximum dBZ, and the rapidity of this collapse was noteworthy. The mean dBZ profile and "anvil region" area profile demonstrated that the anvil not only maintained its thickness and areal extent, but actually increased in intensity. The maximum mean dBZ value was 15 dBZ at 7 km AGL compared to 10 dBZ an hour before. This anvil intensification following the decay of the convection was good evidence for a dynamical mechanism of particle growth within the anvil region independent of the convective cells, such as gravity wave forcing or mesoscale ascent. Subsequent to this time, the anvil region decreased in area and intensity over the next two to three hours before dissipating (not shown).

4. CONCLUSIONS

The evolution of anvil generation and growth was studied for the 23 July 2002 event from the perspective of Melbourne NEXRAD (S-band) radar reflectivity volumes during the CRYSTAL-FACE field campaign in South Florida. It was demonstrated that the NEXRAD observations provided a useful tool to examine the life cycle of the thickest portion of the anvil cloud (composed of precipitation-sized particles). The three-dimensional view of a large portion of the system given by the NEXRAD data represents an important compliment to the intensive aircraft, lidar, and airborne Doppler observations made during the campaign. NEXRAD observations were also quite useful in guiding the simulation of anvil generation with mesoscale models.

The most important finding for this case was that the extensive anvil region continued to grow upward, downward, and outward following the collapse of the generating line of convective cells, which likely formed at the convergence between outflow from previous convection and the sea-breeze front. This suggested that dynamics internal to the anvil region likely were important in growing precipitation-sized ice particles within the anvil cloud (Rutledge 1986). The anvil reached its greatest horizontal extent and intensity at 7 km AGL. The portion of the anvil made of precipitation-size particles (observable at S-band) reached at least 5 km in vertical extent following the collapse of the convective line. Precipitation in the anvil region generally evaporated completely before reaching the surface. The thickest portion of the anvil region was continually displaced away from the stationary convective source in the presence of upper level southeasterly flow, consistent with the behavior of convectively generated anvil cloud in an environment of vertical wind shear through the troposphere (Newton 1966, Rickenbach 1999).

5. REFERENCES

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