4.A.2 THUNDERSTORM GENERATED CIRRUS OBSERVED FROM X AND W-BAND AIRBORNE RADAR DURING CRYSTAL-FACE

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1. INTRODUCTION

The Cirrus Regional Study of Tropical Anvils and Cirrus Layers - Florida Area Cirrus Experiment (CRYSTAL-FACE) campaign based at Key West, Florida, focused on various aspects of cirrus cloud formation including anvils generated by deep convection. One of the goals for the field campaign was to determine the role of thunderstorm intensity (i.e., updraft strength) on the characteristics of the thunderstorm generated cirrus (altitude, location, longevity, etc). During CRYSTAL-FACE, up to 5 aircraft flying from low- to high-altitudes, were coordinated for the study of thunderstorm generated cirrus. The NASA high-altitude (20 km) ER-2 aircraft with remote sensing objectives flew above the convection, and other aircraft such as the WB-57 performing in situ measurements flew below the ER-2. The ER-2 remote sensing instruments included two nadir viewing airborne radars. The 9.6 GHz ER-2 Doppler Radar (EDOP) and the new 94 GHz Cloud Radar System (CRS) were both flown on the ER-2 during CRYSTAL-FACE. The instruments are complementary for studying convection and cirrus since CRS is more sensitive than EDOP for cirrus, and EDOP is considerably less attenuating in convective regions. In addition to EDOP and CRS, the Cloud Physics Lidar (CPL) and other optical and microwave radiometers flew on the ER-2 payload. This payload provided the first comprehensive measurements to simulate the "A-Train" which includes CloudSat.

The purpose of this paper is to document the upper-level wind and reflectivity structure of thunderstorm generated cirrus anvils for thunderstorms on 23 July 2002 using EDOP and CRS. Preliminary calculations of ice water content and particle sizes will be presented based on CRS, EDOP, and the CPL instruments. The relation between convective intensity (i.e., updrafts) and wind shear, on upper-level storm structure and cirrus generation will be discussed.

2. OBSERVATIONS

The flight pattern on 23 July 2002 included long southwest-northeast flight legs covering the convective (cirrus generating) region along the east shore of Lake Okeechobee, Florida and the extended cirrus anvil trailing off to the west-southwest of these cells (along the upper-level winds). In total, 8 transverses across this region were made over a 3 h period so that the generation and evolution of the cirrus and thunderstorms could be examined. Four of these passes are shown with

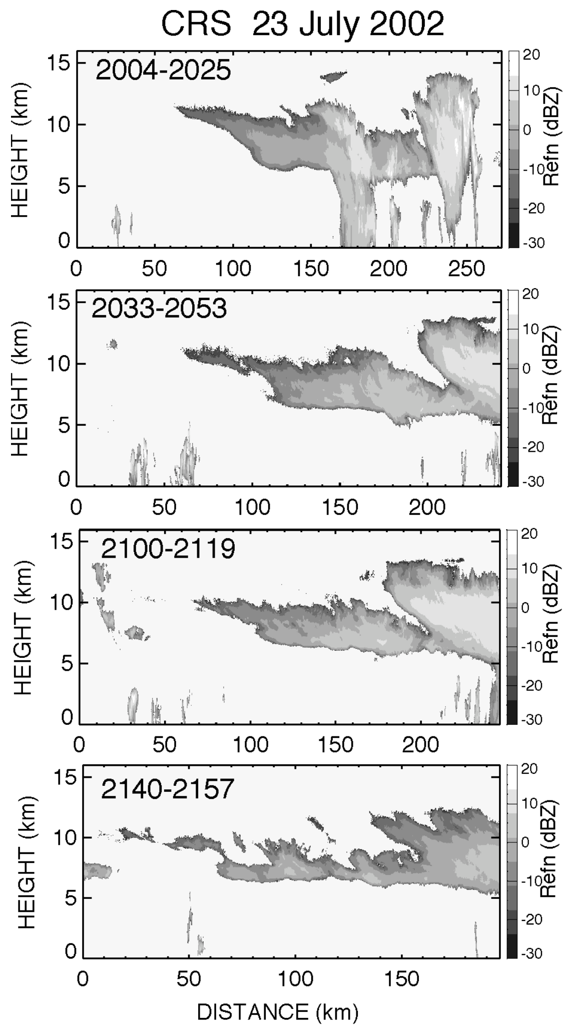

Figure 1. Sequence of southwest-northeast oriented CRS images covering convection and trailing cirrus on 23 July 2002.

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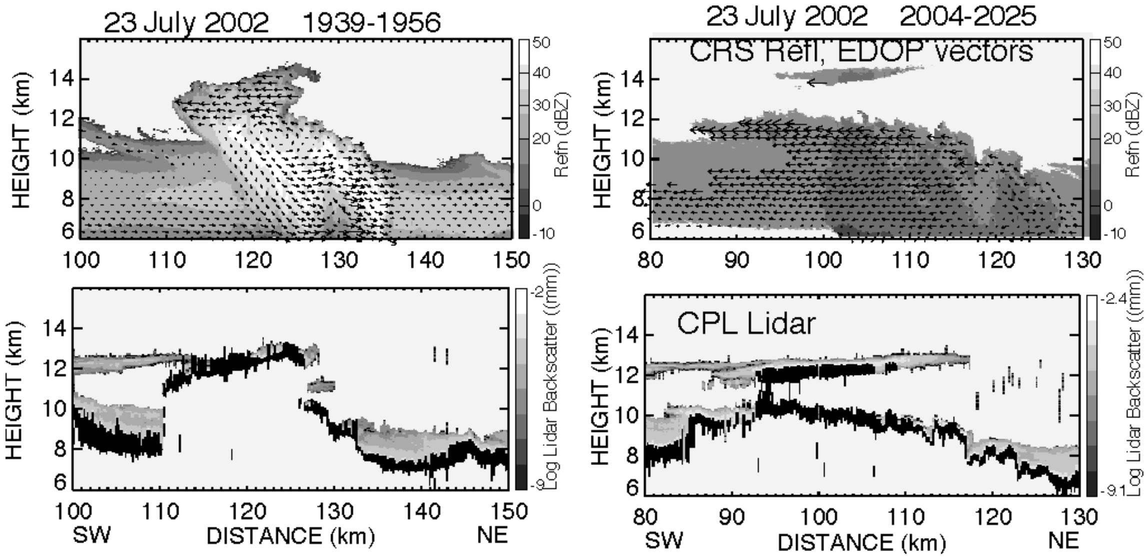

Figure 2. Convective cells during two consecutive passes. CRS reflectivity and EDOP-derived wind vectors (top panels), and CPL data mapped to EDOP and CRS image (bottom panels) are shown. Vector in upper right corner of top panels is 25 ms^{-1} reference.

CRS data in Fig. 1. The time evolution of the cirrus and thunderstorms from about 1939 to 2250 progressed from two strong convective early in the flight, to anvil generated cirrus later in the flight. The upper-level winds are easterly so the cirrus anvils are observed to trail off to the west of the convection. After about 2100, the convection weakened and the remaining cirrus advected downstream.

Figure 2 shows the dissipation of one of the convective cells with two flight lines spaced about 20 min apart. The convection observed during early flight lines had strong updrafts exceeding 10 ms^{-1} which lofted ice particles to the 10-15 km altitude level. The easterly winds in the upper-troposphere environment was effective at carrying these particles downwind (south-southwest). As the convection weakened, the top portions of the convection tilted downshear, and eventually the top of the cells sheared off. The larger ice particles sedimented rapidly and the residual cirrus consisting of small cirrus particles was barely detectable with the cloud radar but was clearly detected by the lidar.

The CRS, EDOP, and CPL data have been compared with respect to detectability of the cirrus. As is evident in Fig. 2, both radars detect the thunderstorm cores and anvil, but they do not detect the elevated thin cirrus layers above the radar anvil. The CRS signal becomes highly attenuated in convection as a result of mixed phase. In addition, large hydrometeors result in Mie scattering in the convective core and other regions resulting in significantly lower reflectivites at CRS's 94 GHz as compared with EDOP's 10 GHz measurements.

3. FUTURE WORK

The recent CRYSTAL-FACE measurements with the ER-2 have for the first time obtained comprehensive active and passive remote sensing measurements of cirrus and the convection that generates the cirrus. Current work is focused on examining the relation between the convection evolution and release of ice mass flux into the upper troposphere and the role of vertical wind shear in distributing the cirrus particles released from the convection. The above case is being examined by the author and co-authors with respect to estimation of particle size and ice water content.

Acknowledgements

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References

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