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Collapsing precipitation cores in open-eyewall hurricanes at landfall: Are these cores actually downbursts associated with extreme surface wind gusts?

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1. Introduction

Hurricanes produce strong winds at landfall, particularly within their eyewalls. Over the last several years, GPS dropsonde data and coastal Doppler radars have observed low-level wind maxima, often extending down to elevations at or below 500 meters above ground level (AGL). In hurricanes, convective 3-s wind gusts may approach values twice that of the sustained wind (Powell et al., 2003). Fujita, Parrish et al., (1982) and Powell et al., (1991) suggest that many of these extreme convective winds in hurricanes are associated with thunderstorm downdrafts. Also, Powell and Houston (1996) indicate that strong horizontal shear along the lateral edge of the downdraft as it spreads along the ground may develop small vortices and extreme winds in hurricanes.

Collapsing cores of heavy precipitation appear to be prevalent in many tropical cyclones. Indeed, preliminary investigation of radar data indicate that "open-eyewall" storms repeatedly display large intense elevated cores of precipitation within their eyewalls which subsequently collapse toward the surface. Doswell (1985) (see Figure 1) shows that collapsing precipitation cores are often associated with downbursts (Fujita, 1985). Elmore and McCarthy (1992) show that the maximum outflow velocity in microbursts (i.e., small downbursts) occurs at approximately 250 feet AGL. These downburst winds, when superimposed on the already strong hurricane wind field, can produce localized regions of extreme winds and damage. Willoughby and Black (1996) indicate that heavy convective rain can generate precipitation-induced downdrafts which inject high-velocity air from the free atmosphere into the frictional boundary layer and that the surface wind accelerates even more as the "downburst" spreads along the ground. In Hurricane Andrew, they indicate that the most severe damage lay in streaks along the downwind of the convective cells' trajectories around the eye where the downbursts may have caused 20 m/s surges in wind speed on a >60 m/s basic flow (Wakimoto and Black, 1994).

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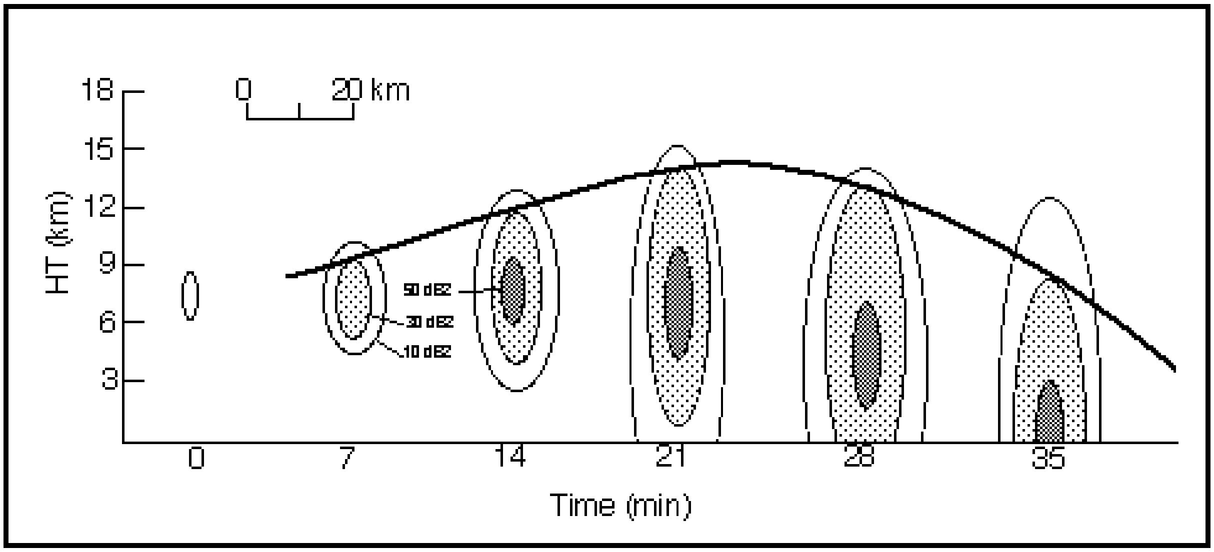


Figure 1. Time sequence of elevated precipitation reflectivity within a storm which then collapses toward the surface in the form of a downburst (from Doswell (1985)).

These collapsing cores are indicative of downbursts and should theoretically be associated with enhanced wind gusts in landfalling hurricane eyewalls.

2. Procedure

These downburst phenomena are only evident through careful and methodical use of high-resolution Doppler radar data, such as the WSR-88D Doppler radar Level II information, but radar can only detect the wind near the ground close to the radar due to earth curvature limitations; thus, radar data must be coupled with surface-based weather station observations during hurricane landfall events or with surface damage patterns to determine the effect of these downbursts on the surface wind field and to determine if, in fact, they are associated with extreme surface wind gusts.

Collapsing Core Identification Process: The traditional range-height indicator (RHI) display depicts a vertical cross section radially outward from the radar site. The procedure for identifying and tracking collapsing precipitation cores follows three general guidelines. These cores must:

1) Travel roughly towards or away from the radar site and display a path of motion aligned along the beam radial in order to be correctly analyzed.
2) Occur within approximately 100 km of coastal radar locations, and
3) Meet the “3-for-3” longevity requirement in which a reflectivity core must traverse at least 3 radar elevation tilts and must be evident for at least 3 consecutive volume scans while maintaining $\geq$ 40 dBZ reflectivity.

3. Results

Hurricane Ivan made landfall along the Alabama Coast early on 16 September 2004 (Figure 2). The storm displayed an open-eyewall structure at landfall (Figure 3). Elevated precipitation cores repeatedly collapsed toward the surface in Ivan's eastern eyewall as the storm made landfall (Figure 4a - e). This behavior is indicative of downbursts within the eastern eyewall of Ivan. Severe tree damage occurred well inland along the state line between Baldwin County Alabama and Escambia County Florida (Figures 5 and 6).

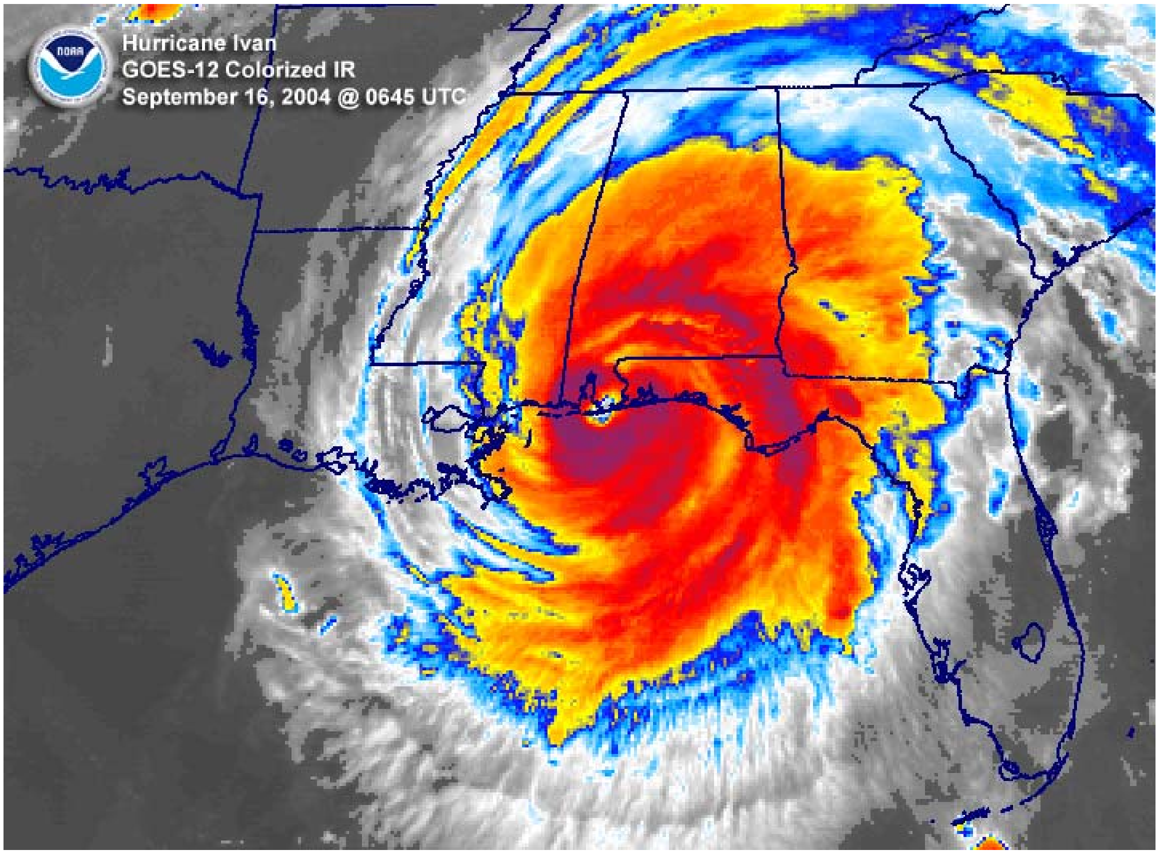
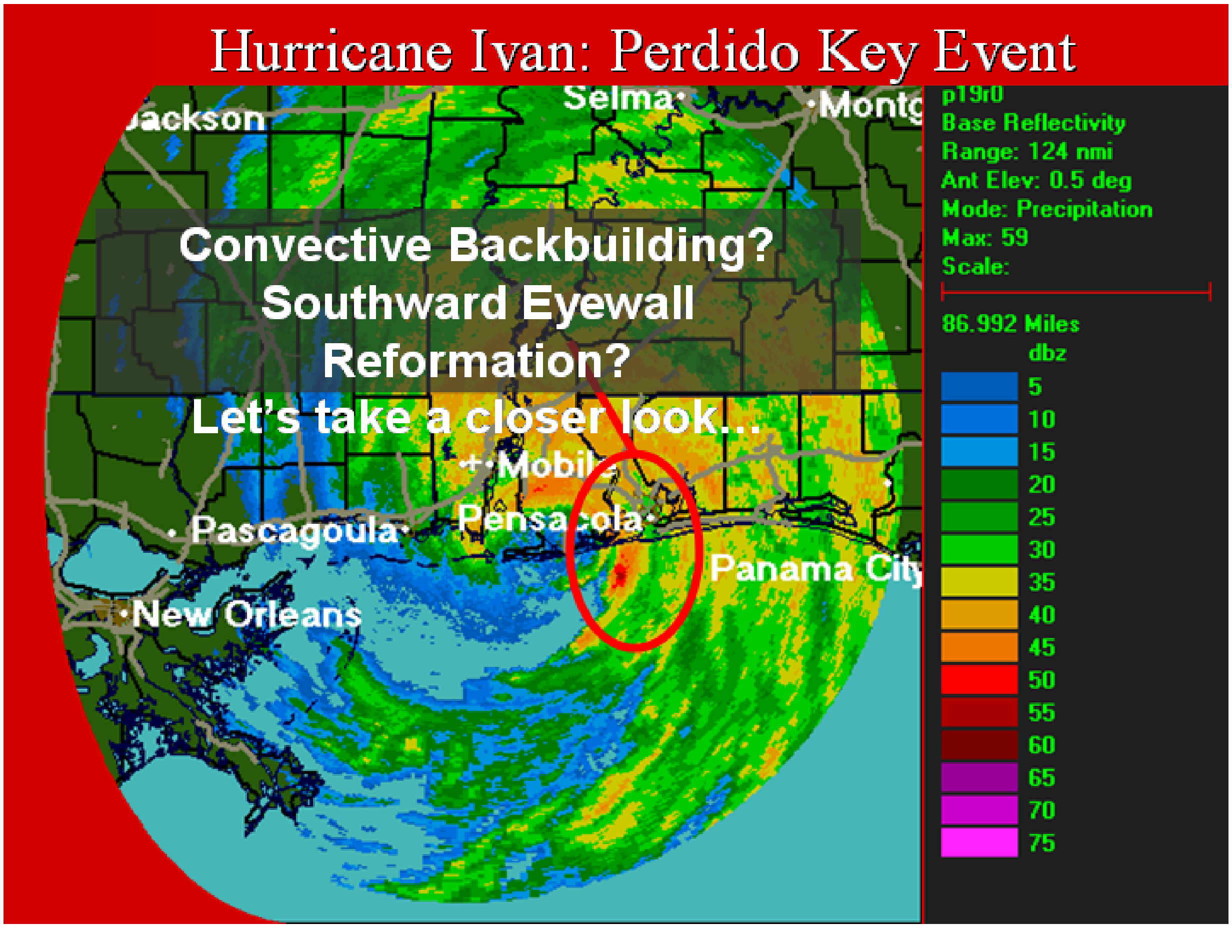


Figure 2. Enhanced infrared satellite image of Hurricane Ivan making landfall near Gulf Shores Alabama at 0654 UTC, 16 September 2004 (courtesy of NOAA).

a.



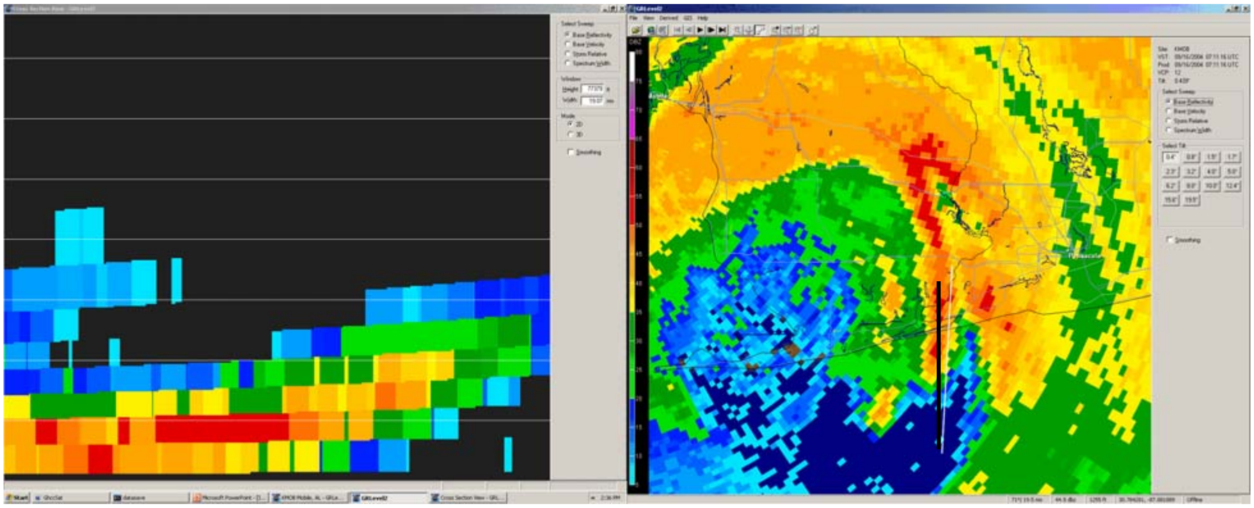
Hurricane Ivan: Perdido Key Event

Convective Backbuilding?
Southward Eyewall
Reformation?
Let's take a closer look…

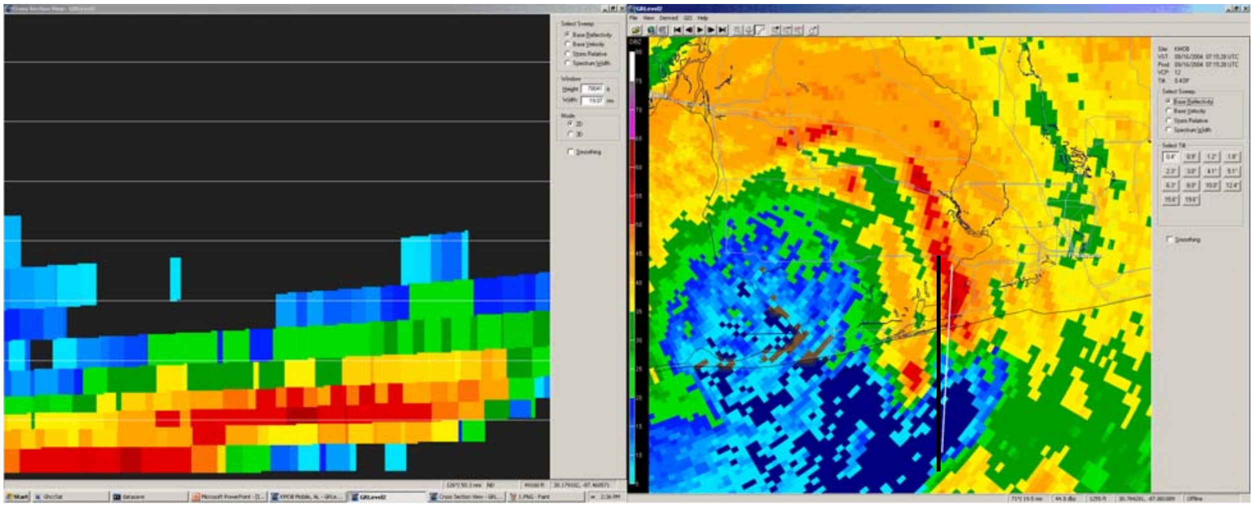
p19r0
Base Reflectivity
Range: 124 nmi
Ant Elev: 0.5 deg
Mode: Precipitation
Max: 59
Scale:
86.992 Miles

dbz
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75

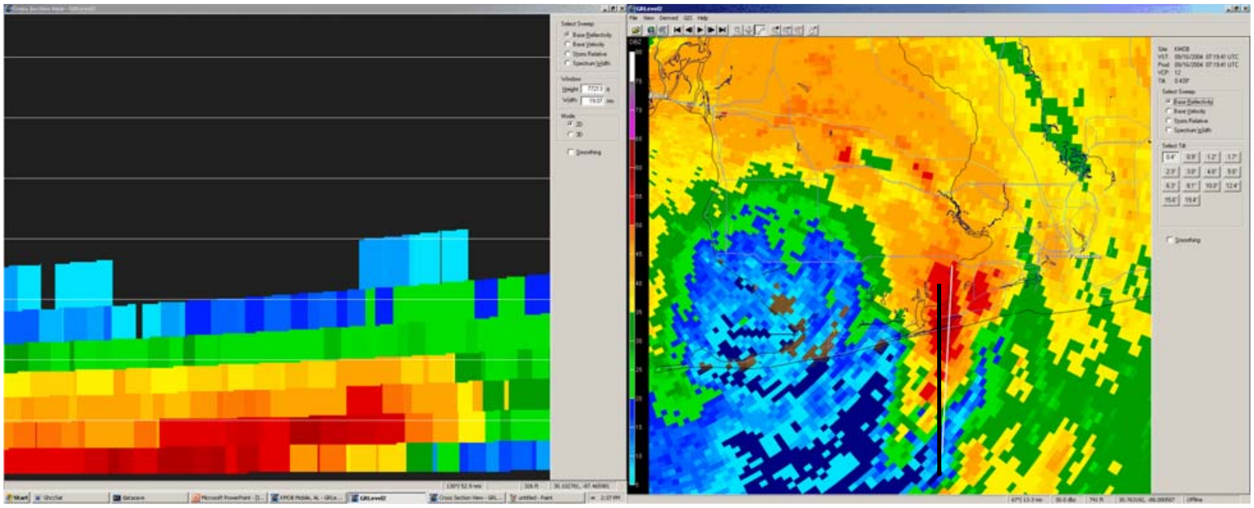
Figure 3. Radar image of Hurricane Ivan making landfall near Gulf Shores Alabama. Intense convection is found in the eastern eyewall near the Alabama/Florida state line. New convective cells are repeatedly developing along the upwind (southern) edge of the eastern eyewall.



a.



b.



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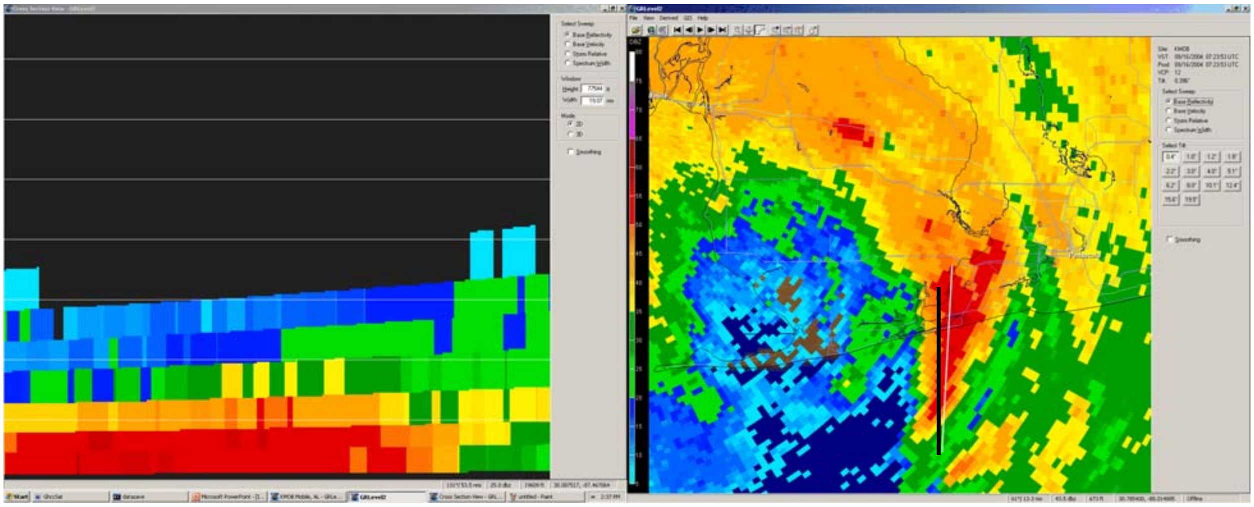

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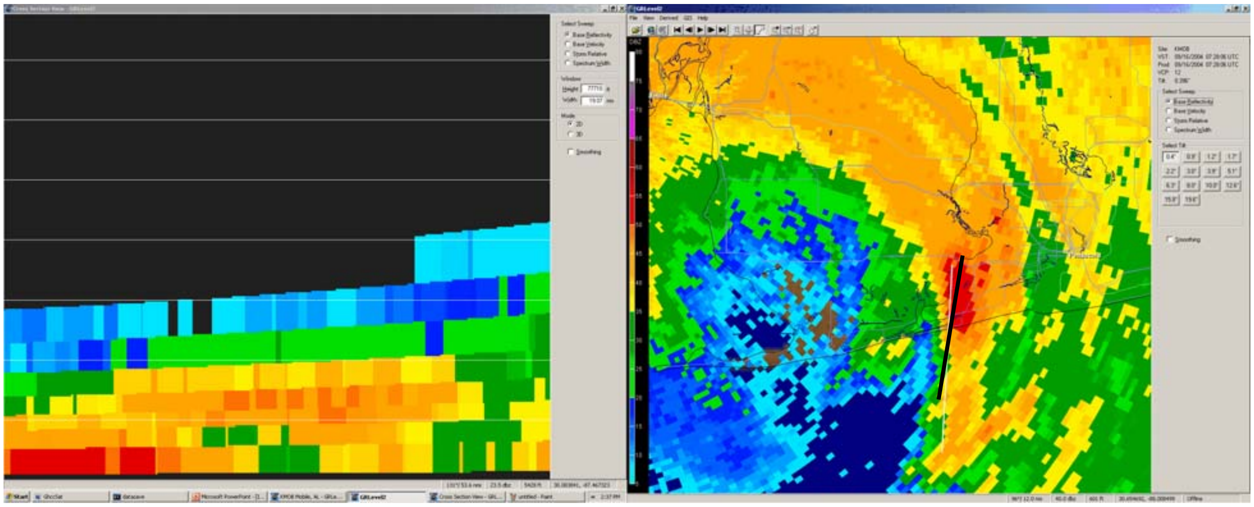

Site KMOB
VST 09/16/2004 07:28:06 UTC
Prod 09/16/2004 07:28:06 UTC
VCP 12

e.

Figure 4. A five-image sequence of collapsing precipitation cores in Hurricane Ivan's eastern eyewall along the Alabama/Florida state line early on 16 September 2004. In each set of frames, the left-most image displays a vertical cross section of reflectivity and the right-most image displays the horizontal base reflectivity. The black line in the right-most image marks the location of the cross section.

Figure 5. Severe tree damage occurred all along the path of these collapsing cores, indicating the presence of intense winds possibly associated with these downbursts.

Figure 6. More instances of severe tree damage along the path of Ivan’s eastern eyewall within the region impacted by collapsing precipitation cores and likely downbursts near the Alabama/Florida line.

4. Future Work

A numerical model, configured specifically for hurricane research, will be used to provide clues to the source of some of the surface gusts associated with these collapsing cores. For example, dry air intrusion into the hurricane several thousand feet above the surface needs to be investigated for its role in possible generation and enhancement of downbursts and extreme surface wind gusts in hurricanes. Evaporative cooling within dry air could significantly enhance the strength of thunderstorm downbursts, and therefore the resulting surface winds may be stronger than with just precipitation loading only. Numerical modeling will help evaluate the potential for dry air entrainment into some of these landfalling storms and the possible enhancement of downbursts.

Also, storms from the 2005 hurricane season are presently being studied for collapsing core events. Ground surveys are being accomplished in Hurricane Katrina's landfall region for additional evidence of collapsing cores in that storm. Collapsing core occurrences are also being spatially and temporally matched to available surface wind information.

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