Satellite Imaging Techniques for the Analysis of High-Impact Historical Severe Thunderstorm Events

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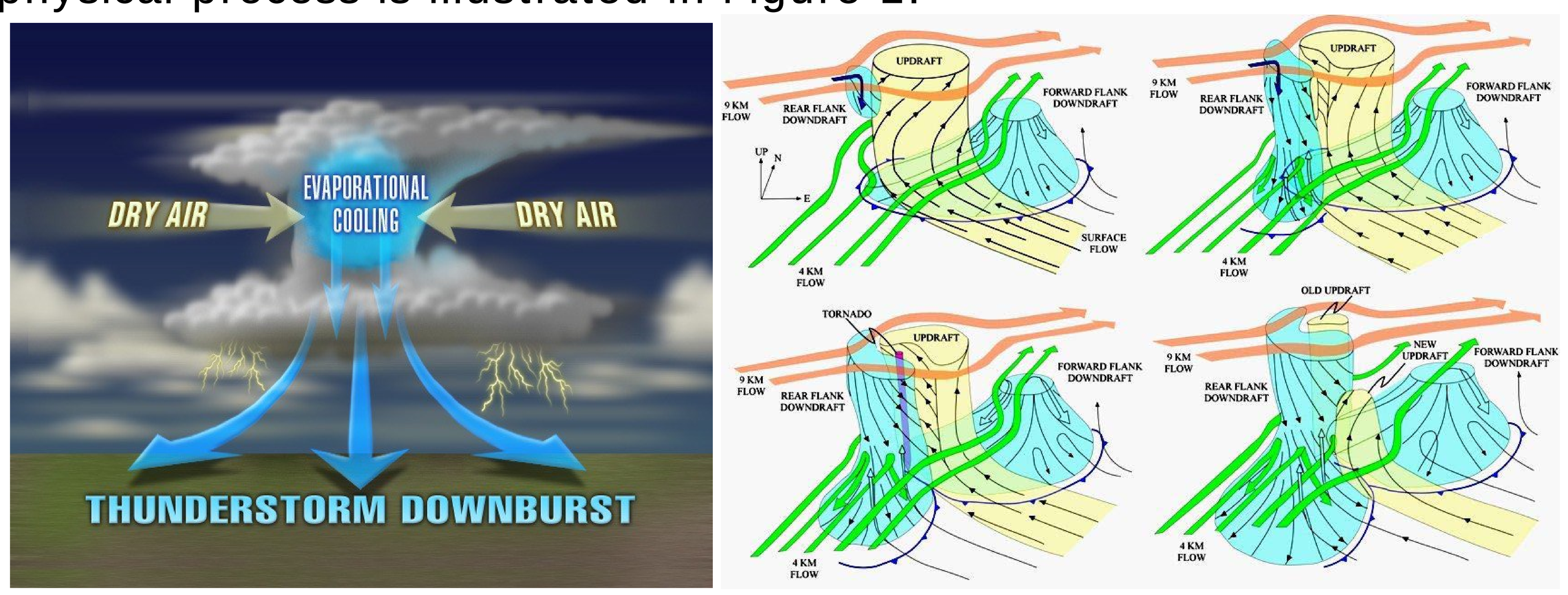
1. INTRODUCTION AND BACKGROUND

Convective storms that generate hail, lightning, and damaging winds have been identified as a formidable hazard to life and property. Even more impactful are stronger storms that generate and loft liquid-phase hydrometeors to high altitudes where freezing occurs and collisions between drops, graupel, and ice crystals lead to electrification. Condensate loading, sometimes combined with the lateral entrainment of subsaturated air in the storm middle level, initiates the convective downdraft. The subsequent melting of frozen hydrometeors and subcloud evaporation of liquid precipitation, in conjunction with precipitation loading, result in the cooling and negative buoyancy that accelerate the downdraft in the unsaturated layer. A **downburst**, in general, is defined as a **strong downdraft** that induces an outburst of damaging winds at or near the ground, and a **microburst** as a very small downburst with an outflow diameter of less than 4 km and a lifetime of less than 5 minutes. This physical process is illustrated in Figure 1.



Courtesy Buechler et al. (1988), Goodman et al. (1988)

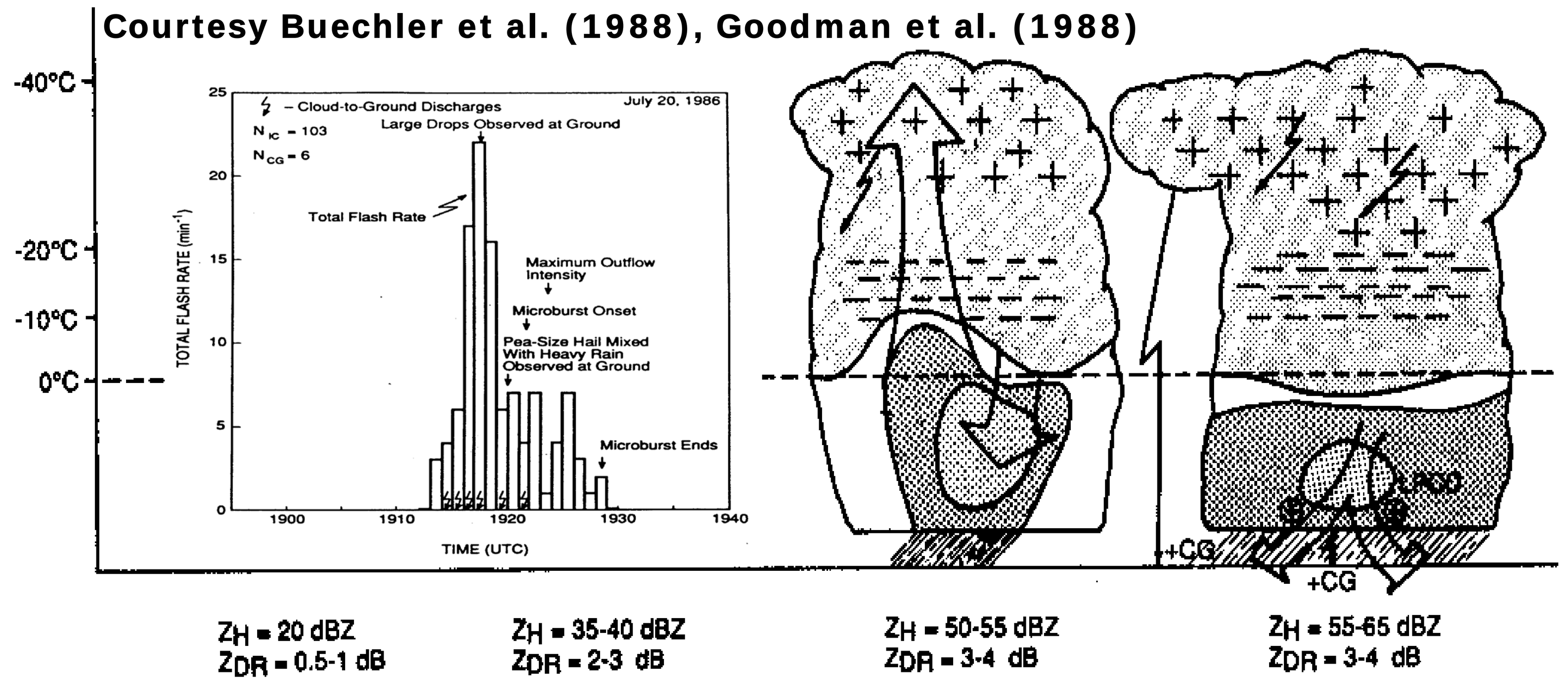


Figure 1. Conceptual model of downburst generation within ordinary and supercell thunderstorms.

2. METHODOLOGY

Selected thunderstorm events that demonstrate the physical process of downburst and tornado generation as observed simultaneously by the legacy Geostationary Operational Environmental Satellite (GOES)-8 imager, the GOES-16 Advanced Baseline Imager (ABI), Doppler radar (NEXRAD), and boundary layer profilers (BLP) are analyzed. Vertical wind profile data, up to 5 km AGL, from the Cooperative Agency Profilers (CAP) system has been applied to further study the favorable environment for severe convective storm winds and the vertical structure of storm outflow. On 24 September 2001 and 2 November 2018, severe downburst-producing and tornadic thunderstorms occurred in the United States Mid-Atlantic region that resulted in structural and tree damage, downed power lines, and traffic disruptions. These studies serve to demonstrate the physical relationship between downburst and tornado generation by showing the close proximity of tornado and straight-line wind damage, especially apparent in Doppler weather radar imagery.

3. CASE STUDIES

24 September 2001 College Park Tornado

A remarkable EF-3 intensity (Enhanced Fujita Scale) tornado tracked from College Park to Columbia, Maryland on 24 September 2001, developing 3-4 km southwest of College Park from a supercell storm at approximately 2116 UTC. The tornado then tracked 30 km where it dissipated over eastern Howard County, Maryland, by 2150 UTC. This tornado was the only significant tornado event to directly impact the Washington, DC metropolitan area since 2000, and caused 2 deaths, 55 injuries, and over $100 million in property damage.

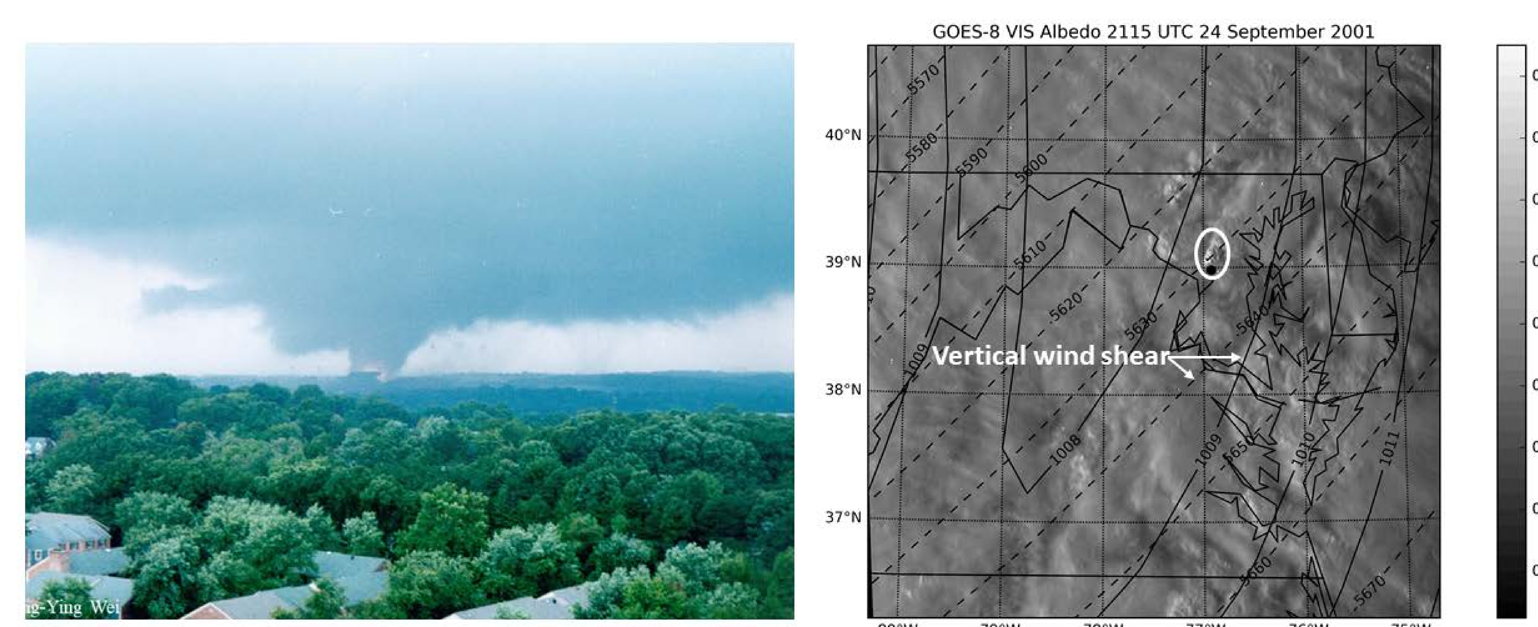


Figure 2. The College Park tornado at 2121 UTC 24 September 2001 (left) viewed about 3 km from the northeast (courtesy of Dr. Ming-Ying Wei of NASA), and a corresponding GOES-8 visible albedo image at 2115 UTC 24 September with overlying sea level pressure (hPa, solid lines) and 500 hPa geopotential height (m, dashed lines) derived from the ECMWF reanalysis.

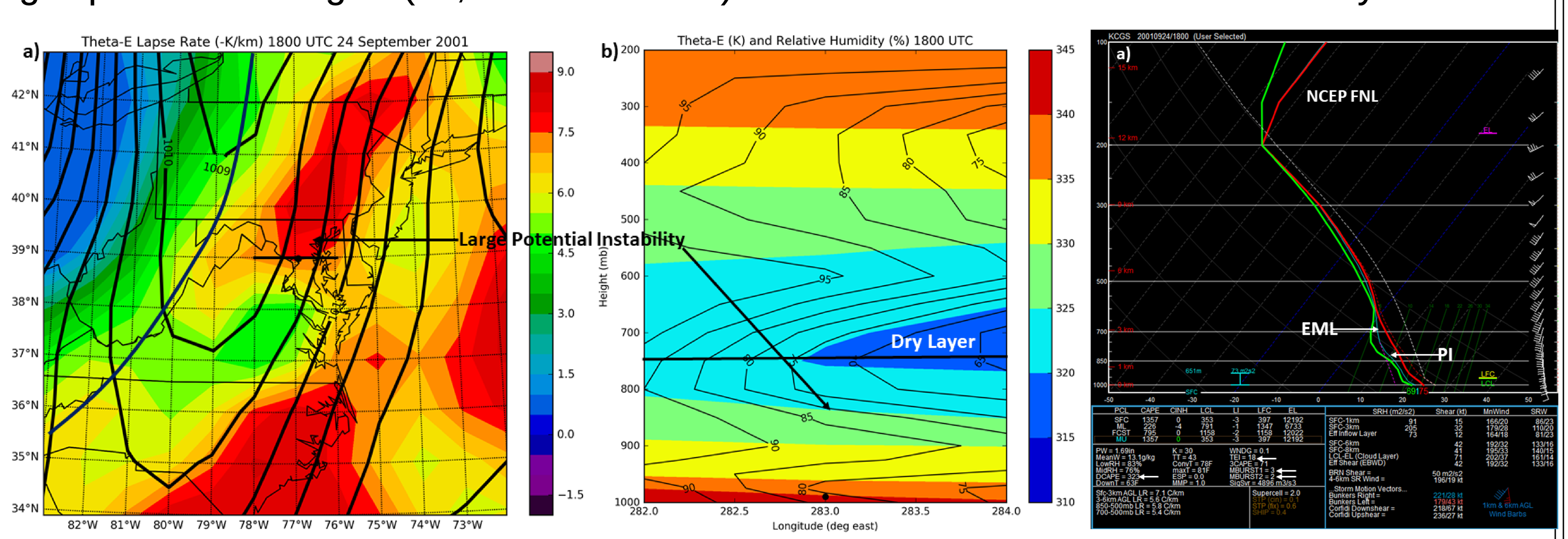
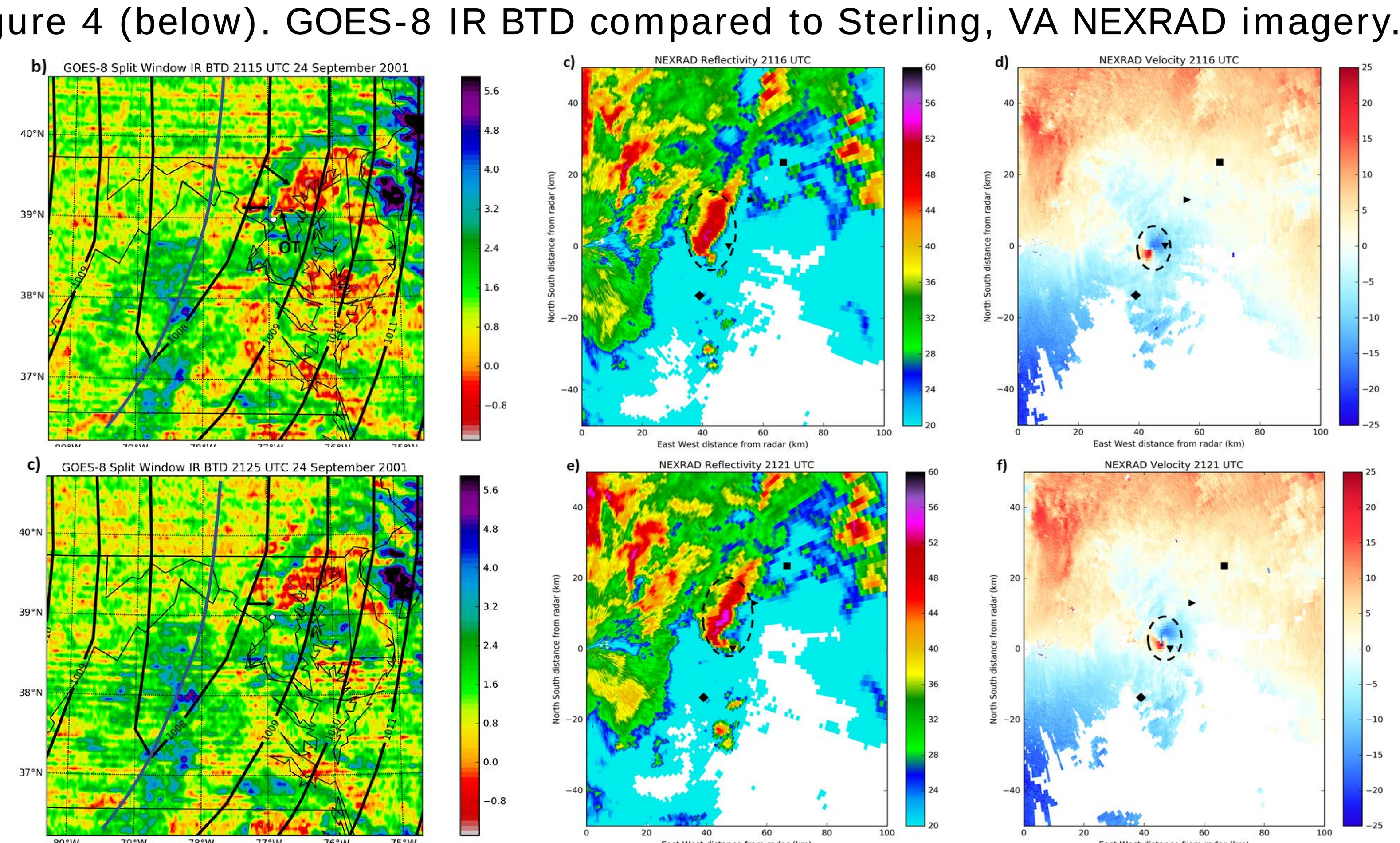


Figure 3. Theta-e lapse rate (left) and vertical theta-e cross section at 39°N latitude over the Washington, DC area (middle) at 1800 UTC 24 September 2001 derived from an NCEP Final (FNL) reanalysis dataset. Corresponding thermodynamic profile over College Park at 1800 UTC is shown on the right.

Figure 4 (below). GOES-8 IR BTD compared to Sterling, VA NEXRAD imagery.



2 November 2018 Central Maryland Tornado and Downbursts

During the evening of 2 November 2018, a line of intense convective storms developed along a cold front tracking over the Blue Ridge Mountains of Maryland and Virginia. A series of distinctive bow echoes evolved as the linear convective system propagated through central Maryland and was associated with an outbreak severe wind (downburst) events and EF-1 intensity tornado occurrence over Carroll County.

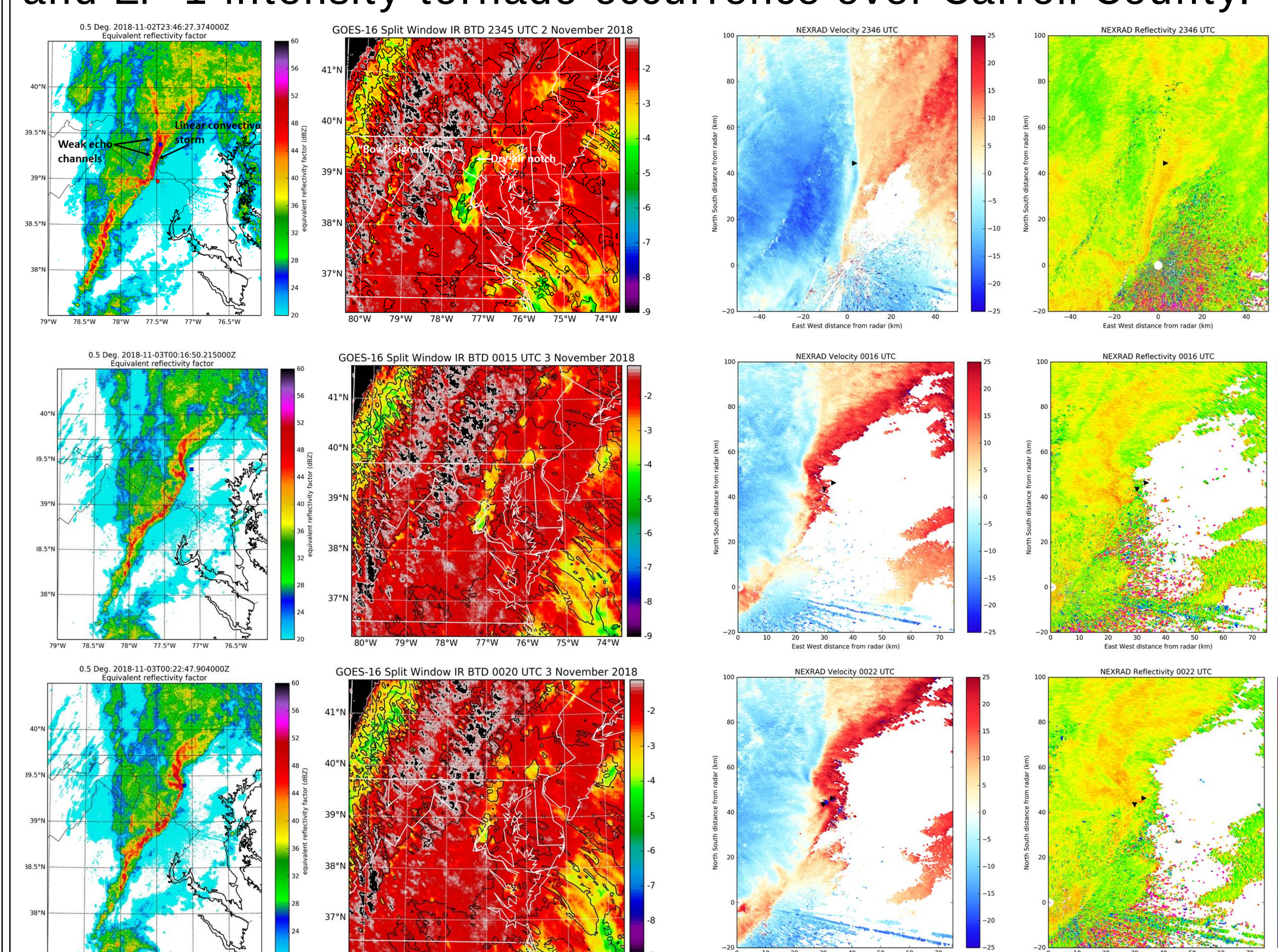


Figure 5. Sterling, VA NEXRAD reflectivity and velocity compared to GOES-16 split window IR BTD imagery on 2-3 November 2018.

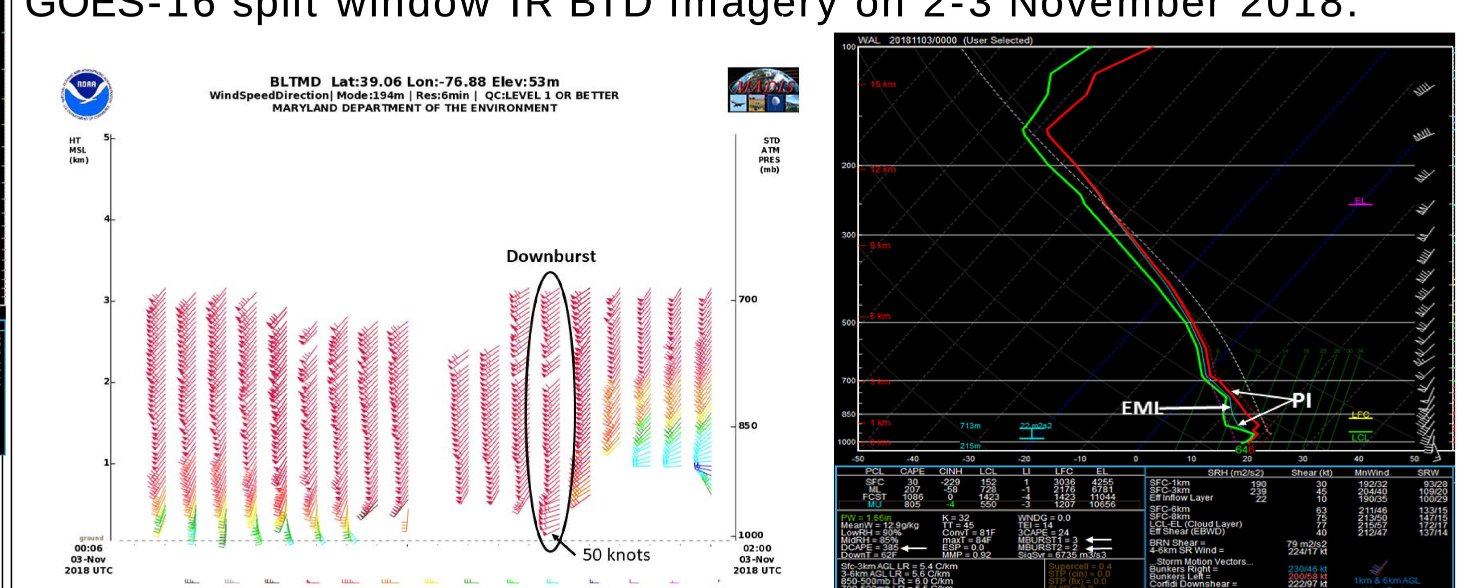


Figure 6. Vertical profile of wind speed and direction from the Beltsville, Maryland Boundary Layer Profiler (BLP) compared to the RAOB thermodynamic profile from Wallops Island, VA.

4. DISCUSSION AND CONCLUSIONS

4-km resolution GOES-8 and 2-km resolution GOES-16 ABI split-window channel BTD imagery, compared to NEXRAD imagery, displayed a high level of detail in storm structure and was effective in identifying storm-scale features, including dry-air intrusions, and hook and bow echoes. NEXRAD velocity and differential reflectivity imagery revealed that intense thunderstorm-generated outflow wind (i.e. downburst) is an important initiator for tornadogenesis.

References are available by request.

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