THE IMPORTANCE OF MID-LEVEL CONVERGENCE, EVAPORATION, MELTING, AND PRECIPITATION LOADING TO DAMAGING SURFACE WINDS

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Damaging surface winds are associated with bow echoes (mesovortices/rear inflow jets) and microbursts from multicell and isolated pulse storms. Differentiation of severe microburst-producing storms from ordinary cells can be difficult. Even with bow echoes, once a well-defined bow is observed, damaging surface winds are already occurring. The key is to anticipate the development of these downbursts and bowing segments before well-defined low-level structures are observed.

There are several precursors which are strongly correlated to the **development of damaging downburst surface winds**. These include **1) a high reflectivity core which begins at a higher altitude than other storms; 2) strong, deep convergence at mid-levels; 3) a rapidly descending reflectivity core;** and to a lesser degree **4) mid-altitude rotation; and 5) strong storm-top divergence.** Also, the following processes are important for **enhancing the speed of the downdraft: 1) precipitation loading/drag; 2) evaporative cooling; and 3) phase change from ice to liquid (melting).**

High reflectivity core which begins at a higher altitude than other storms: This indicates an intense updraft which has the ability to suspend more mass aloft for a longer period of time. These storms often are caused by boundary or cell mergers due to enhanced convergence. Thus, initial storms may be less of a severe threat than later cells initiated along the outflow of earlier, weakening storms. Use All Tilts and vertical cross-sections to assess this parameter.

Strong and deep MARC at mid-altitudes: Mid-altitude radial convergence (MARC; observed in SRM data) is a crucial factor for severe pulse storm and bow echo development. Convergence is evident from 10-25 kft (lower altitudes for shallower storms), i.e., 2-6 km AGL. Values of (**$V_{in} + V_{out}$**) (delta-V) of **50 kts or higher** along the same radial often are observed in storms which produce surface microburst winds. Storms displaying significant delta-V at multiple levels (greater vertical depth) are more likely to produce damage. However, accurate identification of the entire MARC field may not always be possible given only radial winds and the radar viewing angle, i.e., MARC may be occurring but is not fully detectable due to the orientation of the wind to the radar beam. This is most common for storms moving perpendicular to the beam.

Convergence occurs at the storm's **updraft/downdraft interface** either within the core of high reflectivity or along the leading edge of reflectivity. With RIJs, convergence may occur between elevated rear-to-front flow (originating from the back side of the storm) and front-to-rear updraft inflow (originating ahead of the storm). Convergence may be associated with a significant increase in Digital VIL (DVIL) as the deepening reflectivity core is suspended aloft. A subsequent rapid decrease in DVIL means the core is collapsing toward the ground and a microburst is imminent, occurring, or possibly already done as the storm weakens after core descent. Evidence of significant, deep MARC and increasing DVIL should prompt a warning.

MARC facilitates an increase in downdraft speed, especially if drier environmental air is entrained. MARC may or may not be observable for isolated storms, but usually is observable for multicell storms, including QLCSs. In fact, detection of strong MARC within part of a squall line may be an early indication that a downburst is imminent which could produce a bow echo (incipient bowing stage). In other words, MARC identification can result in issuance of a warning before any significant bowing is observed to produce lead time. Steep low-level lapse rates will facilitate downburst transfer to the surface.

Rapidly descending reflectivity core and precipitation loading/drag: These factors can play a central role in forcing an intense downward vertical acceleration. Sometimes, these phenomena are associated with warming/collapsing cloud tops on satellite imagery and a rapid DVIL decrease. The larger the reflectivity core and more coherent the descending mass, the greater the amount of air dragged downward. The drag effect can be substantial given a large water content in the cloud. If the mass falls through a sub-cloud layer with low RH and/or descends from a high cloud base, the core is more likely to cause a surface microburst due to evaporation and subsequent cooling in the sub-cloud layer (if steep low-level lapse rates are present). Thus, evaporation as well as melting and MARC may be required to produce intense microbursts.

Evaporative cooling: Negative buoyancy and downdraft strength are increased through evaporation of water into unsaturated air. Evaporation, which produces cooling due to the latent heat of vaporization, occurs when drier mid-level air is entrained into the storm or when precipitation falls into unsaturated air below cloud base. However, if dry air is entrained into the precipitation core at high levels, little evaporative cooling will occur since the air is too cold. As the core descends into warmer air, the effects of evaporative cooling become much more prominent. Thus, dry air at 700 mb is more important than at 500 mb. The presence of unsaturated environmental air and subsequent evaporative cooling after entrainment into the storm can have a substantial effect on downdraft strength. Note, however, that significant evaporation can take place without altering the general appearance of a radar echo since the smallest drops evaporate first and most efficiency. Small drops do not contribute significantly to overall reflectivity since it is proportional to the 6^{th} power of drop size.

Phase change from ice to liquid (melting): Negative buoyancy and downdraft strength also can be increased though a phase change from ice to liquid (melting) due to the latent heat of fusion. Therefore, a reflectivity core extending to a high altitude in the storm (well above the freezing level) suggests that there may be significant melting as the core descends toward the ground, thereby complementing the precipitation loading/drag effect. The cooling due to phase changes in water during descent (melting and evaporation) can play a significant role in accelerating the downdraft toward the ground.

Mid-altitude rotation: The presence of cyclonic rotation in a storm's updraft suggests the cell's ability to carry precipitation to high altitudes, and for separation of the updraft from the downdraft. A rotating storm must be monitored more closely for its ability to produce a downburst. However, rotation, while important, appears to be a lesser precursor of a damaging downburst than other factors. Mid-altitude rotation is not necessary for downburst production. Nevertheless, rotation can allow a hail core to fall separate from the main rain shaft, thereby reducing the melting of hail as it falls toward the ground.

Strong storm-top divergence: This factor can be important to surface downburst production, but to a lesser degree than other factors. Strong storm-top divergence in SRM data suggests an enhanced updraft with compensating strong storm-top ventilation. Thus, the strong updraft would have the potential to lift a significant reflectivity core to high levels, well above the 0 ^{o}C and -20 ^{o}C levels.

Radar products/signatures useful for identifying severe pulse storms: The use of "**All Tilts**" is the best strategy for assessing storm strength, depth, tilt, MARC, and rotation, as it allows a quick view of all reflectivity and SRM angles from the same volume scan. Other strategies include the use of 4-panels, and 0.5^{o} base reflectivity with composite reflectivity and the "mid" (24-33 kft) and "high" (33-60 kft) LRM products. Reflectivity >50 dBZ in the "high" layer with low values at 0.5^{o} suggests a developing intense cell which may be capable of a microburst given favorable environmental parameters. Do not wait until the core reaches 0.5^{o}! Also, reflectivity >65 dBZ anywhere in the storm and/or values >55 dBZ above 30 kft (highly dependent on storm top) may be associated with a downburst and/or large hail at the surface, assuming the freezing level and wet bulb zero heights are not too high. Assessing DVIL trends can be useful as well. Finally, **use CG lightning trends**; an increase in CG strikes indicates an intense storm whose core may be descending resulting in increased electric potential and thus a higher CG count (i.e., a storm about to produce a severe event).