TORNADO FORMATION --- OUR CURRENT UNDERSTANDING

Formation of mid-level mesocyclone

Supercell thunderstorms derive their rotation (about a vertical axis) from vorticity that is initially horizontal. This horizontal vorticity, also called *streamwise vorticity*, is caused by strong low-level wind shear. The formation of a rotating updraft, or a *mesocyclone* in the mid-levels, occurs when horizontal vorticity is tilted into the vertical by the storm updraft, followed by stretching of vertical vorticity in the updraft. This results in duel cyclonic and anticyclonic updrafts; however, dynamically speaking, only the cyclonically rotating updraft can persist.

It is now known that a mid-level cyclonic mesocyclone is insufficient to generate a tornado. In fact, the generation of a mid-level mesocyclone does not generate large enough vorticity values ($1\ s^{-1}$) for tornadoes. By the time the tilting and stretching would generate such large vorticity values, the parcel has lifted far away from the updraft. In fact, only 20-50% of all mid-level mesocyclones produce a tornado, so an additional mechanism is needed to create a low-level mesocyclone followed by tornadogenesis.

Requirement for tornadogenesis

Storm chasers have long observed that the formation of a rear-flank downdraft precedes the formation of supercell tornadoes. The rear downdraft is manifested visually by a clear slot on the right side (with respect to storm motion) of the mesocyclone. Most researchers also agree that a rear-flank downdraft is required to generate a low-level mesocyclone. There is disagreement on why this generates a strong low-level mesocyclone, but the large horizontal vorticity along the rear-flank gust front possibly gets tilted and stretched in the vertical, generating vorticity values which exceed the mid-level vorticity values. There may also be a positive feedback between the rear-flank downdraft and the low-level mesocyclone such that they mutually intensify each other. Other unknown factors include the necessary strength of the precipitation loading, and interactions with mid- and upper-air wind flow.

Another unknown actor is the exact relationship between the mid-and low-level mesocyclone. The low-level mesocyclone contains larger rotation, and therefore a larger pressure deficit. There is some agreement that when these two become vertically aligned, a downward pressure gradient results, creating a rotating descending tornado to the ground (known as an "occlusion downdraft").

There is still much we do not know. For example, many times conditions seem favorable for tornadoes, yet one does not form. Naturally forecasting where one will occur to make the necessary measurements is a challenge. Tornadoes occur on scales which are difficult to measure even during successful storm chases, as shown in Project VORTEX. There may still be an "extra ingredient" needed, such as a pre-existing cold pool to enhance convergence along the rear-flank downdraft.

Vortex breakdown

An interesting phenomenon happens in strong tornadoes in which the edge of the main vortex breaks down into separate vortices. These "suction vortices" form due to the intense horizontal shear, and are separate tornadolike vortices, each spinning about its own axis while circulating around the core of the main tornado.