Observations of Snow Generating Cells
by Matthew Kumjian

For those of us living in Boulder, snow is a part of our lives. In fact, Boulder already received its first snow of the year this month (4 October). However, forecasting snowfall events and quantifying how much is falling is still a difficult endeavor, as anyone who pays attention to local forecasts knows!

Some of the most basic problems in understanding snowfall can be clumped into what we call “microphysics”, or the physical processes that govern the initiation of ice crystals, growth of snowflakes, and their interactions as they descend to the ground. For example, if we can quantify the efficiency at which snow crystals aggregate into those big, fluffy snowflakes, we will have a better idea of the rate at which snow is falling from the cloud (big aggregates fall faster than small, pristine ice crystals).

From January through April of 2013, I ran a small field campaign investigation called FROST (Front Range Orographic Storms). The main goals of FROST were to elucidate the fine-scale structure of winter precipitation over the Front Range, quantify the snow microphysical processes, and relate what we see in the radar data to what is happening at the ground. FROST involved two research polarimetric radars that provide information about the sizes, shapes, types, and concentration of snow crystals in precipitating clouds. In addition, with the help of students from Metropolitan State University, we launched radiosondes into the snowstorms from NCAR’s Marshall Field Site, located south of Boulder. The thermodynamic information available from the soundings is critical for interpretation of the radar data, as the type of ice crystals that grow in an environment depend on the temperature and humidity.

One fascinating feature that was observed in all 19 FROST cases is what are called snow “generating cells” located near the radar echo top (Fig. 1). These generating cells are kilometer-scale convective updrafts that are efficient at initiating and growing ice crystals owing to their ability to sustain larger water vapor supersaturations with respect to ice. In addition, the presence of rimed particles observed at the ground in several FROST cases strongly suggests that supercooled liquid water is present in the generating cells. Supercooled liquid water has important implications for radiation considerations.

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Snow Generating Cells (continued)

What causes these generating cells? Previous studies have suggested various mechanisms, but their convective appearance certainly suggests that they form when potential instability is released. We can look for regions of potential instability from our soundings. By definition, potential instability occurs in a layer where the equivalent potential temperature decreases with height. Soundings that we launched into snowstorms indeed revealed layers of potential instability (Fig. 2). In each case, the layer of potential instability coincided with the layer in which generating cells were observed.

In addition to the conventional surveillance and vertical cross-section scans, NCAR’s XPOL radar (one of the research radars, located at the Marshall Field Site) could point vertically in what we call “birdbath” mode. The birdbath scan from the time that the sounding was launched is shown in Figure 3. The positive (upward) velocities near the echo top are in the same layer as the potential instability. Maximum upward air motion is > 1 m s⁻¹, which is an order of magnitude larger than the shallow upslope flow that is a common mechanism for snow production along the Front Range.

The data collected during FROST presents a convincing case that generating cells are ubiquitous in winter storms in Northern Colorado and are driven by a release of potential instability. Recent field campaigns in other parts of the United States with high-resolution radars have also revealed a frequent occurrence of these generating cells with similar physical characteristics. Crucially, the small scale of these generating cells means that traditional operational observations (i.e., with the National Weather Service radars) are incapable of resolving them, as are many...
operational numerical weather prediction models. If generating cells are in fact ubiquitous in winter storms, then these efficient sources of snow production and possible supercooled liquid water are being missed. Understanding the microphysics and dynamics of these generating cells could therefore lead to improvements in how we treat the production and growth of snow in our models, ultimately leading to improved snowfall forecasts.

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Figure 2: Vertical profiles of the equivalent potential temperature (left panel) and its vertical derivative (right panel; the blue line is the smoothed profile). These profiles are computed from radiosonde data collected on 9 March 2013 at 1319 UTC. Note the layer of potential instability (where the blue curve becomes negative), between about 4.75 and 6.5 km.

Figure 3: Vertically pointing or “birdbath” data from the NCAR XPOL radar, collected at the Marshall Field Site on 9 March 2013 over a three-minute period starting at 1309 UTC. The left panel shows the radar reflectivity factor, the middle panel shows the Doppler velocity, and the right panel shows the average vertical profile of the Doppler velocity. Positive Doppler velocities (red colors) indicate upward motion in the 5.0 – 7.0 km layer, consistent with the sounding-inferred layer of potential instability.