MAGIC

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A newsletter for non-scientists (and scientists) interested in MAGIC

The Doppler effect, explained in the last update, states that the frequency of a wave reflected by an object (a raindrop, for instance) that is moving toward the source (a vertically pointing radar, for instance) is greater than the frequency at which the wave was transmitted. Furthermore, the change in the frequency (the Doppler shift) determines the speed of the object (how fast the raindrop is falling toward the radar). Raindrops in the atmosphere fall with respect to the surrounding air at their so-called terminal velocities, and there is a unique relation between this velocity (or speed) and the raindrop size. In the simplest case, the Doppler signal measured by a vertically-pointing radar consists of frequency shifts, each shift corresponding to a given speed. By employing the relation between this speed and raindrop size, the Doppler signal can be related to the raindrop sizes.

How fast do water drops fall? For drops near the surface of the earth, the following approximate values will give an idea of the speeds involved. The terminal velocity of a cloud drop, with typical diameter 20 millionths of a meter (approximately one thousandth of an inch; as one meter is barely over three feet), is one centimeter (~1/2 inch) per second. For drops comprising drizzle, which are perhaps ten times as large, it is 3/4 of a meter (2 feet) per second. Small raindrops, with diameters one millimeter, fall at 4 meters (13 feet) per second, and large raindrops, with diameters 5 millimeters, fall at 9 meters (30 feet) per second (20 mph). Another way to look at this is to consider the times required to fall (in still air) a distance of ten meters, the height of a three-story building. Approximate values are fifteen minutes for cloud drops (this explains why fog, which is essentially a cloud, persists for so long), fifteen seconds for drizzle drops, two second for small raindrops, and one second for large raindrops.

Not only do we know the relation between raindrop size and terminal velocity, we also know how strongly raindrops of a given size reflect radio waves back to the radar. This information means that from the strength of the Doppler signal at a given frequency shift we can determine how many raindrops of the corresponding size are in the volume of air sampled by the radar. The sizes of the raindrops plus the number of drops of each size comprise an important quantity in meteorology known as the drop size distribution, or DSD. If the DSD is known, we can calculate the rainfall rate, as we know how much water is in each size of raindrop, how many raindrops of each size there are, and how fast drops of each size are falling.

Of course, things are never quite so simple, and there are, as always, several complications. Rain often occurs where there are downdrafts or updrafts. The speed measured by the radar (for an upward-pointing radar that isn't moving) is the speed of the raindrop relative to the ground, which is equal to the speed at which the raindrop would fall in still air (i.e., its terminal velocity) *plus* the speed of the downdraft (or *minus* the speed of the updraft). Also, raindrops with diameters greater than a few millimeters flatten as they fall, and their terminal velocities all approach the same value, making it difficult to determine their exact sizes from the measured speeds. Moreover, terminal velocities increase with altitude because the air becomes less dense. Some of these effects, like the last, are easily taken into account, but some, like the first, require more creative approaches.

How do we take into account downdrafts and updrafts? We know they occur, as cumulus clouds are formed by updrafts (as discussed in the 2012-01-20 MAGIC update). Updrafts also play an important role in hail formation (and where there are updrafts, there must be downdrafts). Hail is formed when small water drops are repeatedly carried high into the atmosphere where the water they have collected by intercepting other, smaller raindrops freezes until finally the hailstone is so large that the updraft can't prevent its fall (in other words, the terminal velocity of the hail is greater than the updraft velocity). These repeated excursions are why hailstones have rings.

In the next update I will describe two ways we can use radars to determine the speed of the downdraft (or updraft), and thus the DSD in actual situations.

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Please address any questions or comments to elewis@bnl.gov.
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