Anomalous Propagation and Other Doppler Radar Curiosities – OR – What is that junk?!

By Joe Nield, Meteorologist

Above: The WSR-88D at Indianapolis, Indiana.

Aside from the general increase in computing power, Doppler Radar, specifically the Weather Surveillance Radar – 1988 Doppler (WSR-88D), is arguably the single most vital tool in our arsenal to keep the public safe, and has been the biggest driver behind the historical improvement in our ability to detect and warn for severe and tornadic thunderstorms and other weather phenomena. What surprises many people, however, is that weather radar doesn't only detect weather. To understand this, first let us take a brief glance at the history of weather radar and how it works.

HISTORY - The utility of radar for meteorological purposes was first established during World War II, when radar operators noticed echoes from various forms of precipitation on their scopes. The details of these discoveries are difficult to trace even now, due to the secrecy of radar operations during the war. After the war, military scientists continued developing their understanding of these echoes, and by the late 1940s, the U.S. Weather Bureau was beginning to use radar in daily operations. These early radars were extremely crude by modern standards, but they allowed meteorologists to detect precipitation at distances away from observation sites, and to begin to unravel the mysteries of storm structure and evolution.

Above: A circa World War II radar operator works on a radar system.

Below: A radar display showing precipitation in 1965

By the 1960s, research and testing into Doppler Radar had already begun, and was mentioned as a potential future capability in the Weather Bureau assessment report of the April 11, 1965 Palm Sunday tornado outbreak. It would take until the late 80s and early 90s for Doppler Radar to begin to replace conventional reflectivity-only radars in operational use nationwide. Since the deployment of the WSR-88D network, operational updates have focused largely on improved

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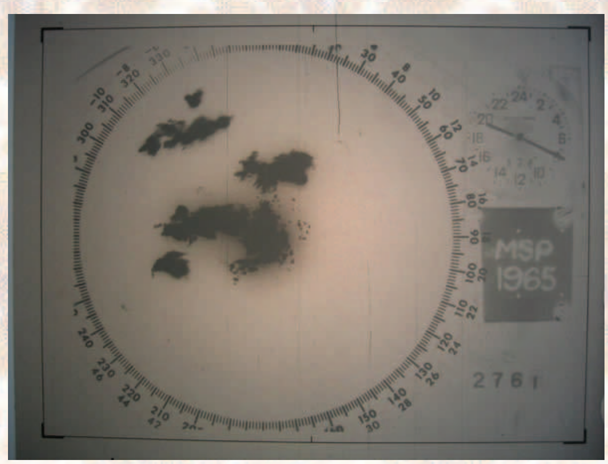

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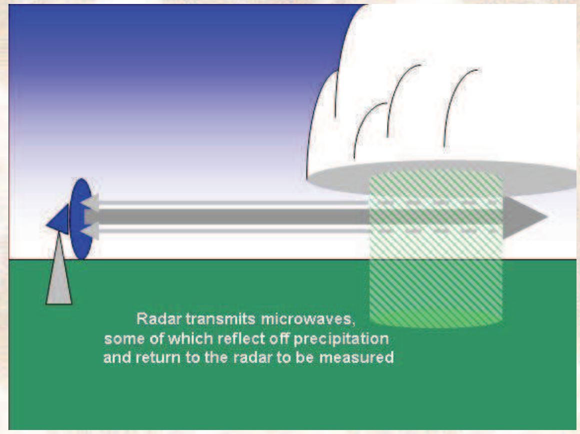
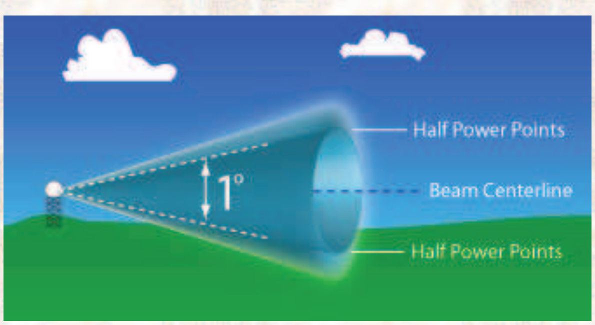
bandwidth for super-resolution products, and improvements in data processing, clutter suppression, and precipitation estimation.



Above: A example of a radar transmitting mircowave radiation to detect precipitation.

FUNCTION - Weather radar works by sending extremely short, directed bursts of microwave radiation, and then "listening" for returned radiation reflected off of scatterers in the atmosphere or occasionally on the ground. These pulses last only 0.0000016 seconds, with a listening period about 1,000 times longer. The net result of this is that the radar is only actually transmitting about 7 seconds out of every hour, and listening for returned pulses the rest of that time. Scatterers of these pulses can include raindrops, hailstones, snowflakes, birds, bugs, dust, airplanes, and even cars on the highway. The direction and distance to the target scatterer is known by tracking the direction of the antenna and the time between pulse emission and return of the reflected radiation to the radar. The amount of energy that is reflected is dependent on the dropsize distribution, that is, the number and diameter of raindrops or other scatterers in a given volume. This dependence introduces some difficulty into the use of radar data for precipitation estimation, because a large number of small drops will return the same power as a small number of large drops, with obvious implications for the resultant rate and amount of rainfall. Doppler radars measure not only the returned radiation reflected back to the radar, but also the phase shift of that radiation, which allows the radar to determine the motion of the scatterers in question.

BEAM BEHAVIOR - As was mentioned earlier, weather radars don't just detect weather. They can also detect birds, bugs, dust, airplanes, cars, and even the ground itself. To understand how this happens, we must understand how the radar beam behaves. The radar beam is best pictured as a spreading cone, widening as it moves away from the radar site. The highest energy is concentrated at the center of the beam, with energy levels fading as one moves away from the centerline. Due to this beam spreading, the radar's ability to resolve small scale features decreases with increasing distance. In fact, the beam width increases by nearly 1,000 feet for every 10 miles of travel. As such, small scale features that may be easily resolved within a county or two may become masked several counties away.



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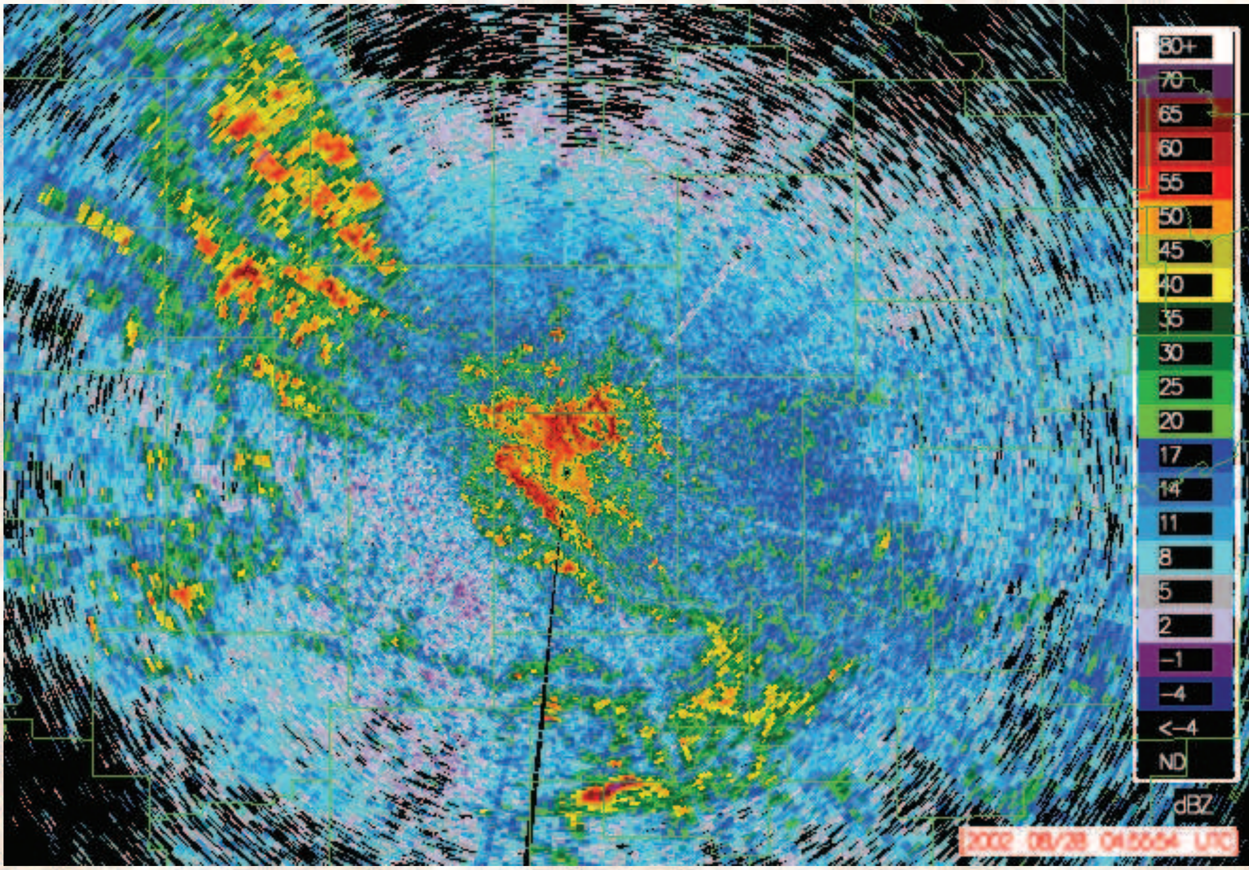
The beam also does not travel in a straight line as it moves away from the radar. It is refracted in different ways depending on density differences in the atmosphere. These differences are caused by variations in temperature, moisture, and pressure, and affect the speed and direction of the beam. This introduces uncertainty into the process of interpreting radar data, as we cannot be sure of exactly where the beam is, we can only infer where it will most likely be in a standard atmosphere, and take into account conditions which may affect beam travel when determining the accuracy of these inferences. If the atmospheric density is less than normal, the beam will bend very little and will easily overshoot features at long distances. This is called subrefraction. Superrefraction is the opposite – density is greater than normal, and the beam is bent excessively, sometimes directed into the ground itself (this would be referred to as ducting). Ducting often occurs when strong low-level temperature inversions (increases in temperature with height) are present – many times late at night/early in the morning due to radiative cooling, or behind cold fronts. Ducting can also occur in areas where thunderstorms have cooled the low levels of the atmosphere, forming a small scale inversion. This can often lead to problems even during a significant weather event.



One of the ways ducting can impact radar images is through anomalous propagation (AP). AP occurs when the radar beam is refracted onto the ground itself, returning a great deal of energy in a fashion typically easily distinguishable from weather echoes. An example of AP is seen in the picture above.

The noisy and blocky areas to the northwest and southeast of the radar site (center) are areas of AP. As you can see, this could mask important features if storms were in those areas, and also lead to confusion for unfamiliar users of the data. The area around the center of the image is ground clutter, an often unavoidable impact of the beam detecting buildings, trees, and other stationary targets near the radar site,

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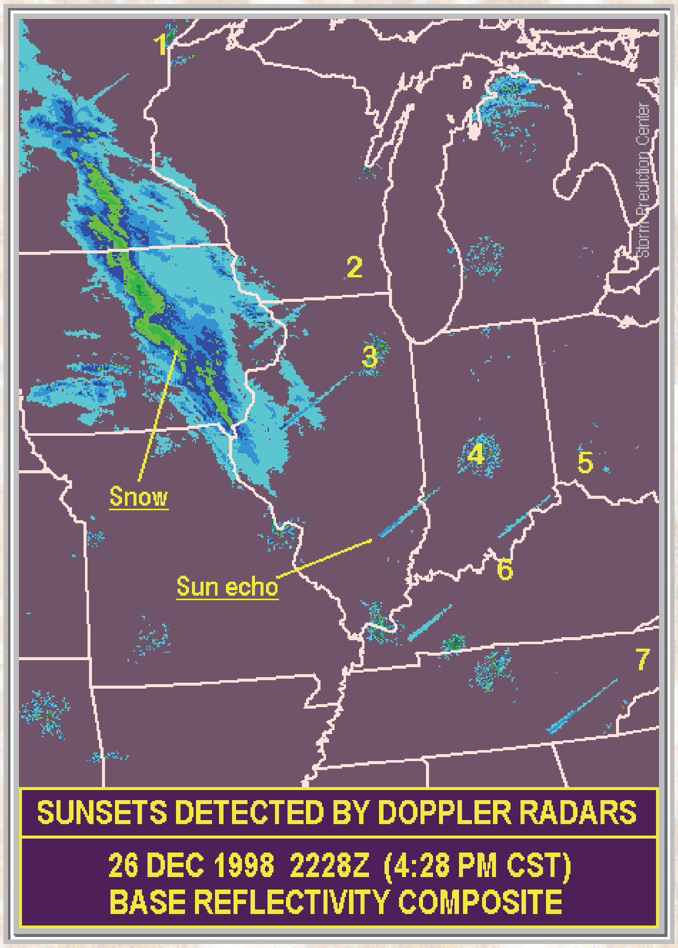

Above: Sunset is detected by Doppler radar systems across the Ohio Valley and Midwest.

before the beam has a chance to climb high enough to overshoot them.

The radar beam can also detect cars on the highway on occasion for similar reasons. The image on page 6 of this issue of Skywatch shows a velocity image and high speeds are being detected from cars along interstates 465 and 70 near Indianapolis.

Because the sun emits radiation on all wavelengths, including those emitted and detected by the radar, sunrises and sunsets are detectable as well, when the sun is low enough in the sky for the radiation to be detected by the dish. This is visualized by a thin line in the direction of the sun. An example of this follows:

Weather radar detects these and other interesting features, and it is the job of the radar meteorologist to learn the characteristics of the radar, its peculiarities, and interpretation of the various images it provides. It is one of the most interesting, dynamic, and rewarding aspects of the career of a meteorologist. For more information on weather radar and other meteorological topics, visit the NWS JetStream Weather School online at http://www.srh.noaa.gov/jetstream/index.htm