VAISALA / APPLICATION NOTE

Heikki Pohjola, Application Manager 2011

The Vaisala Weather Radar WRM200 – Catching Storms and Insects at Long Ranges

With dual polarization techniques shifting from the lab into operational weather radar systems such as the Vaisala Weather Radar WRM200, many weather services that traditionally used S-Band systems are now considering dual polarization C-Band systems. The primary motivation is cost – the cost of a turnkey C-Band system can be a half to one third that of an S-Band system with comparable antenna gain and transmitter power. And at roughly half the size of an S-Band system, C-Band radars are easier to site in environmentally or socially sensitive areas; they also have significantly lower total life cycle costs.

The fundamental difference between the two bands can be explained by Rayleigh scattering theory. The backscattered power depends on 1/Wavelength^4. This means that, all other things being equal, C-Band radar receives 16 times more power (12 dB) than a comparable S-Band radar. Thus, to have the same sensitivity as a 250 KW C-Band system, a comparable S-Band system would need a 4 MW transmitter! This gives C-Band radar quite an advantage in terms of detecting echoes at long ranges, such as a typhoon or thunderstorm at a distance of 500 km, for example.

However, the greater scattering at C-Band also contributes to attenuation, such that when the beam passes through a large region of heavy rain, attenuation occurs to a much greater extent at C-Band than at S-Band. The loss of power leads to errors in the calculated reflectivity and, thus, rainfall rate. In the worst case, when there is a long path of intense precipitation, the signal could be attenuated below the radar's minimum detectable level, in which case all information is lost – total attenuation. This is, however, a rare occurrence. In the case of attenuation, dual-polarization radar can correct for signal attenuation quite accurately. The differential phase, or so-called PHIDP, is essential in any dual-polarization correction algorithm, and is usually measured by simultaneous transmission and reception of horizontal and vertical polarization – the STAR approach.

In STAR mode, transmission power is split and transmitted peak power is 125 kW per channel with a standard 250 kW transmitter. This means that single-polarization measurements have the advantage of being 3 dB stronger because the transmission power is not split. In practice the overall situation is different, because modern weather radars have many other technological advantages that mean they exceed this 3 dB advantage. One of them is the improvement in receiver technology. Ten years ago most radar receivers were specified for 3 dB noise figures. Today it is very common for receivers to have noise figures approaching 1 dB, as is the case with the Vaisala Weather Radar WRM200's receiver. This gain in sensitivity of almost 2 dB is equivalent to a 58 percent increase in transmission power.

In this document we demonstrate how a WRM200 radar with a 250 kW transmitter is capable of detecting not only very weak signals from insects at long distances, but also a storm at long distances – in the case of latter, at the more than 450 km range. The main factor that limits detectability is, however, the curvature of the Earth and not the technology used.

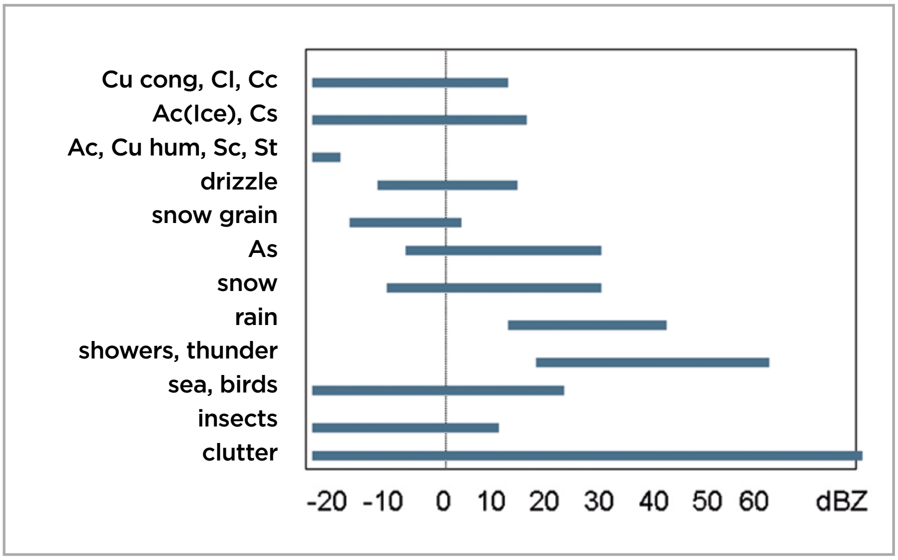

Fig. 1 *Typical dBZ values of various phenomena (Koistinen J., FMI).*

Limiting Factors to Radar Detectability

Weather radar detectability is basically limited by two factors: minimum detectable signal (MDS) and height of the measurement beam. MDS is related to the technical features of the radar, whereas the height of the radar beam is fundamentally related to the curvature of the Earth: as the distance from the radar increases, the height of the radar beam from the ground also increases (see **Figure 2**). Typically, the targets that give the lowest reflectivities detectable by the radar are insects (see **Figure 1**). Traditionally weather radar has primarily been used for measuring precipitation, but measuring insects has been important for wind measurement (VVP profiles) and detecting meteorological phenomena such as sea breezes or gust fronts, which are revealed by the insects in the clear sky. With dual polarization now being the operational standard, both the detection and classification of insects has become more and more important (Leskinen et al 2010).

As shown in **Figure 1**, the weakest reflectivities from insects can be around -20 dBZ. If we calculate the maximum range where the signal is above the MDS level, we end up with the results concerning different transmitter power shown in the first column of **Table 1** (below). It can be seen that for the low reflectivities like -20 dBZ, even with the highest transmitter power it is not possible to detect -20 dBZ reflectivity at ranges greater than 55 km. The difference in detection range between the 500 kW transmitter and the WRM200 (single polarization mode) is only marginal: 39 km at 250 kW and 55 km at 500 kW respectively. The performance of the radar's other components plays a more important role in this respect. Typically, most insect signals are around -5 dBZ and more. As **Table 1** shows, for reflectivities of -5 dBZ and 0 dBZ the maximum detection range is already more than 150 km for the 125 kW transmitter and more than 200 km for the 250 kW transmitter. However, insects are typically in a relatively shallow layer, even in a warm air mass. This means that the limiting factor in most of the measurement cases is actually the increasing radar beam height at greater distances from the radar and not the radar sensitivity. Because of this, insects remain below the height of the lowest measurement beam at ranges of 150 km or greater from the radar. As shown in **Figure 2**, at a range of 150 km from the radar the beam is already at a height of 2.5 km, with the typical lowest elevation angle being 0.5 °. The four-thirds earth radius model (Doviak and Zrnic 1993) is used for the calculation of the propagation path of the electromagnetic waves. Because most of the insects are in the layer below this altitude, i.e. below the lowest measurement beam, they are impossible to detect, regardless of the transmitter peak power. So the limiting factor in terms of detecting insects in a shallow layer is the curvature of the Earth and not the transmitter power.

Also, increasing the transmitter power in order to increase the sensitivity – i.e. increasing the maximum detection range – is very expensive and, as demonstrated in the example above, does not solve the problem. The 3 dB gain in sensitivity is equivalent to the result that would be achieved by doubling the transmitter power. With the WRM200 (250 kW transmitter) insects can also be detected in dual-polarization mode (125 kW) at ranges of up to 150 km.

Long-range Measurement Over the Baltic

Typically, weather radars in operational weather radar networks have measurement ranges of 250 km. This is the particularly the case in cold climates, where precipitation occurs in a relatively shallow layer and the detection range in many cases is limited (Koistinen et al 2005). In the wintertime snow can be very shallow, less than two kilometers high, and the detection range can be limited to less than 100 km from the radar due to the curvature of the Earth. In these kinds of cases the only solution is a dense radar network. Operational weather radar networks are designed to fulfill the requirement of the measurement range in summer conditions, but in the wintertime many of them are not dense enough to fulfill this requirement (Saltikoff et al 2010).

However, in the tropics, where the height of the tropopause can be more than 15 km and deep convection (thunderstorms) can reach extreme altitudes, weather radar range can be much greater than 250 km. In these kinds of conditions, the top of a thunderstorm or typhoon can be detected at ranges as great as 500 km.

Peak power (KW)	-20 dBZ (km)	-10 dBZ (km)	-5 dBZ (km)	0 dBZ (km)
125	28	85	152	270
250	39	120	215	385
500	55	170	305	540

Table 1 *Maximum detectable ranges of the Vaisala Weather Radar WRM200 for different reflectivities with transmitter powers of 125 kW and 250 kW. As a comparison, the performance of similar equipment with a transmitter power of 500 kW is shown. Minimum detectable signal (MDS) at 1 km for the WRM200 is -49 dBZ (-115 dBm) (125 kW peak power, 2 μs pulse length).*

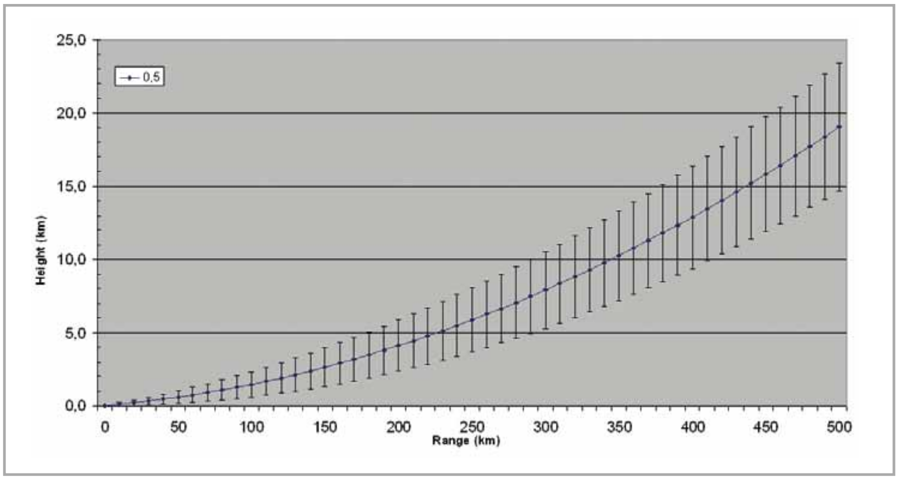

Fig. 2 *Height of the elevation beams at different ranges from the radar. Center line of 0.5 ° elevation beam with error bars illustrating the broadening of the beam at the various distances shown.*

In summer 2010 we experienced an unusual warm air mass over the Baltic region. Severe thunderstorms developed in this air mass and top of the convection reached exceptionally high altitudes. This situation allowed us to verify the WRM200's detection capability at long ranges, i.e. up to 450 km. As shown in **Figure 3**, the WRM200 detects the thunderstorm at a range of 450 km. Detecting precipitation at ranges of 450 km in a cold climate like Finland's is extremely rare. The long-range measurements shown in **Figure 3** are related to last summer's exceptionally warm air mass in Finland, which brought some heavy thunderstorms with high tops and also broke the over-100-year-old temperature record, which now stands at 37.2 °C. Lightning strikes measured by the Vaisala Global Lightning Dataset GLD360 verify that radar measurement is a real weather case and not a spurious echo. Minimum detected reflectivity at that range was 9.5 dBZ, which is 2.5 dB above the MDS of the WRM200 located in Kerava, southern Finland at a range of 450 km. This indicates that it would have been possible to detect the approaching storm from further away than 450 km, but in this case the WRM200 range was limited to 450 km due to the scanning strategy.

At extreme measurement ranges such as these, the radar measurement volume is huge and completely over 10 km above the ground. As shown in **Figure 3**, the center of the one-degree measurement beam is at 16 km. Also, due to the broadening of the beam, the bottom and top are at 20 km and 12 km high respectively, i.e. the measurement beam is around 8 km wide. Because of this it is hard to estimate the actual height of the thunderstorm top that the radar is measuring; however, for qualitative estimation of the approaching storm it is highly valuable information, giving more lead time compared to the typical operational measurement range of 250 km.

GLD360 Gives Even More Lead Time in Storm Detection

Figure 4 shows the storm situation three hours before the radar first detects the storm. At first the cluster of GLD360-detected strokes is not accompanied by radar returns outside the 450-km range, but then the storm moves within radar range over Latvia and Lithuania, as shown in **Figure 3**. Image boundaries represent the coverage of the GLD360 dataset cropped from the global data. As a result, the GLD360 data provides lead time – in this case three hours – for thunderstorms of interest within the radar's range. Also, additional strokes in other storms were apparent in these 15-minute time segments. Since actual lightning activity does not always directly correspond with radar reflectivity, the thunderstorm life cycle and threat information from the combined dataset is more accurate than when either dataset is shown separately. The GLD360 as a global data set can be applied in this way anywhere in the world.

References

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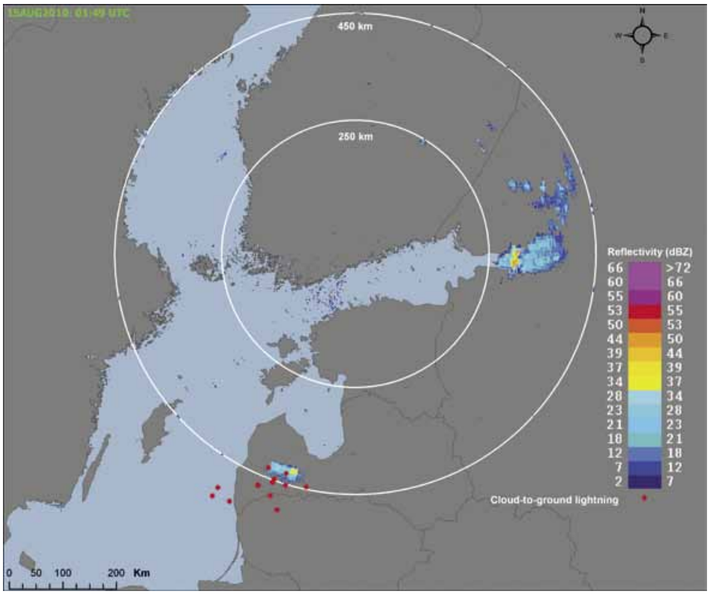

Fig. 3 *Reflectivity measured by the Vaisala Weather Radar WRM200 combined with lightning strikes of 15 minutes accumulation measured by the Vaisala Global Lightning Dataset GLD360.*

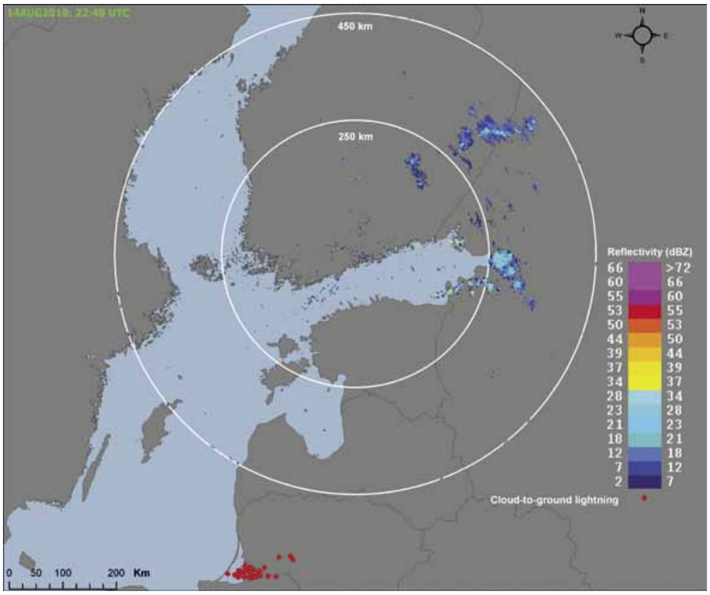

Fig. 4 *Reflectivity measured by the Vaisala Weather Radar WRM200 combined with lightning strikes of 15 minutes accumulation measured by the Vaisala Global Lightning Dataset GLD360. The first detection of the storm approaching Scandinavia, shown at the bottom of the image, was provided by the GLD360.*

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us at sales@vaisala.com