VAISALA / APPLICATION NOTE

Attenuation Correction of C-Band Weather Radars

For decades, Doppler weather radar has been the tool for meteorologists to obtain high resolution observations of precipitation. Quantitative estimates of precipitation (QPE) allow meteorologists to gather the cumulative rainfall measurements that aid authorities in everything from aviation safety to hydropower optimization. However, there remain challenges in obtaining sufficient accuracy – one of them being attenuation of radar signals in heavy precipitation. Attenuation is the gradual loss of power as the radar energy travels through rainfall. This causes errors when converting the amount of received energy to rainfall rates. Historically, different measures have been attempted to correct this.

Vaisala Dual Polarization C-Band Weather Radar Surpasses S-Band

Classical gate-to-gate algorithms for attenuation correction were tried on conventional radars with fairly poor results. An overestimation on the closer range gates resulted in an even worse estimation on gates further down the range. Given that X-band and C-band wavelengths both experience attenuation, regions of the world with heavy precipitation were previously left with only the limited option of deploying the larger, more energy-intensive, and more expensive S-band weather radar. With the advent of dual polarization technology, Vaisala has been able to successfully correct for the attenuation in the C-band radar echoes, resulting in quantitative precipitation estimates that rival S-band in accuracy in actual field testing.

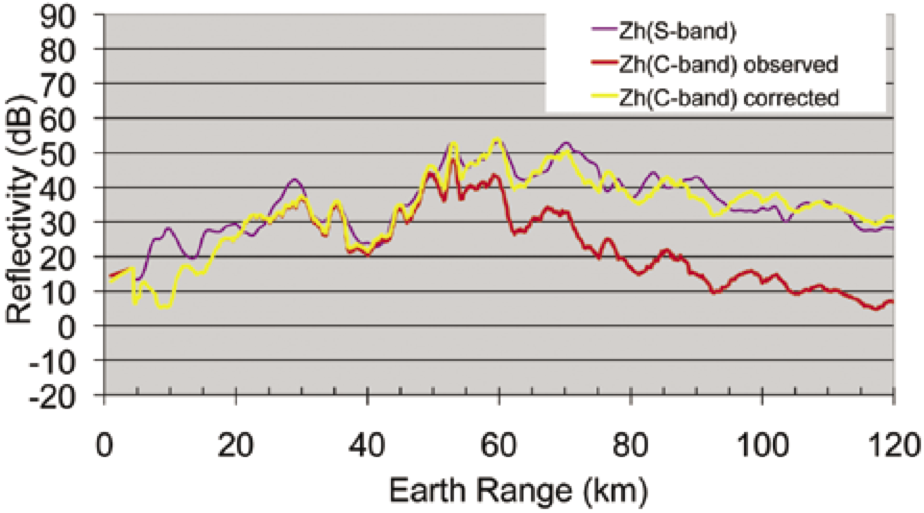

Figure 1.A single ray comparison of C-band reflectivities (observed and corrected for attenuation) versus S-band reflectivity, towards the intense rain at 40 degrees azimuth.

Weather radar is designed to observe hydrometeors and other atmospheric scatterers by emitting and receiving radio frequency (RF) signals. These signals are first transmitted from the antenna as collimated pulses, propagated through the atmosphere, and scattered back from the hydrometeors to the radar receiver. Technically, the choice of radar frequency (the wavelength) is a compromise between optimizing the sensitivity of the radar for identifying the atmospheric targets and limiting the degree of attenuation (the loss of sensitivity) along the signal path.

Radars utilizing shorter wavelengths have a clear advantage in terms of signal sensitivity. Conversely, these same wavelengths experience significant attenuation effects generated by the hydrometeors along their signal trajectory. The level of attenuation increases sharply as the wavelength shortens. For a given intensity of rainfall, signals at the X-band (3.2 cm) attenuate 30 times more than signals at the largely unattenuated S-band (10 cm). The phenomenon remains relatively moderate at the C-band (5.4 cm) with an attenuation factor of less than four compared to S-band (Doviak and Zrnic 1993). For a given wavelength, the strength of attenuation grows proportionally to the rainfall intensity.

In practice, intense rain often leads to a complete loss of the X-band signal, severely limiting the range of radar usability, while the moderately attenuated C-band radar signals can still penetrate through even the most intense rain. However, the measurement of C-band echo power is strongly biased. Clearly, attenuation has been one of the major mechanisms responsible for deteriorating quantitative estimates of rainfall intensity (R) in heavy rain whenever the conventional measure of radar reflectivity factor (echo power, Z_h) is applied. In the past, there was only one practical solution to mitigate this specific issue – invest in longer-wavelength, more expensive S-band weather radar systems.

Today however, advances in polarimetric weather radar technology can provide meteorologists with greater sensitivity at significantly lower cost using C-band weather radar with attenuation correction. By calculating the differential phase shift between the vertical and horizontal orthogonal signal planes, we can precisely estimate the attenuation of the returning C-band echoes.

An Operational Solution Put to the Test

The polarimetric method is based on the differential phase (Φ_{dp}) which is the power weighted average phase difference between the received signals in horizontal and vertical channels. The measured Φ_{dp} contains a component which evolves smoothly in range. The evolution of Φ_{dp} is a reference measure of attenuation. In this approach, the quantitative rainfall information delivered by the smooth phase measurements are combined with the reflectivity data. As a result, the observations are corrected for attenuation bias while their highest spatial resolution is conserved.

A significant precipitation event at mid-latitudes (34° 38.8’N, 86° 46.3’W) was analyzed using the observations from the ARMOR polarimetric C-band radar in Huntsville, Alabama, USA (PETERSEN et al., 2007). The independent observations made at the proximate NEXRAD S-band radar (NEXRAD 2007) were used for comparison as an unattenuated reference. The weather event was a prefrontal squall line approaching Huntsville from the northwest. The extended line structure was clearly visible in the S-band data, while the maximum reflectivities exceeded 58 dBZ. The fields of differential phase were observed at the polarimetric radar and evolved significantly along the rays passing through the intense regions of precipitation. The effects of attenuation in the C-band were evident in the reflectivity fields beyond the intense precipitation to the northeast and west when compared with the corresponding S-band observations.

The impact of the attenuation correction on the reflectivity fields of the case study is quantified in Figure 1. Attenuation effects up to 20 dB are resolved in the C-band reflectivity data, rendering them comparable to S-band observations. In the sweep display, the quality and high spatial resolution of the reflectivity fields are found to be preserved within all the radar ranges, including significant regions of non-meteorological echoes from the southwest to southeast.

The Vaisala Weather Radar Advantage

As a market leader with over 70 years experience in meteorology, Vaisala was eager to take up the challenge of providing high quality weather data at a more competitive price. Vaisala has successfully accomplished this by developing an advanced dual polarization C-band Weather Radar that corrects the attenuation with dual polarimetric algorithms. This shorter wavelength weather radar performs on par with S-band in the same condition testing at a fraction of the CAPEX (Capital Expenditure) and with significant savings on annual OPEX (Operational Expenditure).

Launched in 2007 with the market-leading Sigmet signal processing software, the Vaisala C-band Weather Radar has been an instant success, securing over half the market share in new C-band weather radar deployments. The first commercial installation was in Estonia in 2008, with over 30 installations now in place all around the world.

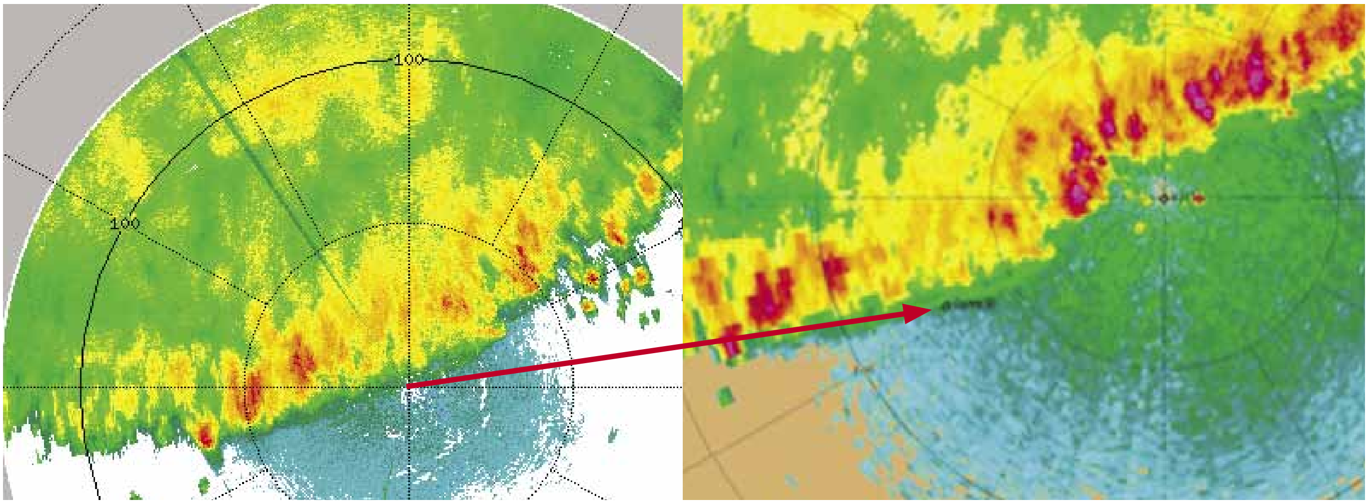

Figure 2. Left panel, corrected reflectivity fields at C-band, and right panel, S-band measurement at the same time. The arrow is pointing to the C-band radar location versus S-band radar location.

C-Band Outperforms in Cost and Reliability

Vaisala C-band Weather Radar operates on a shorter wavelength, 5.5–5.7 GHz, which means it has several intrinsic advantages over S-band. The radar uses a 250 kW magnetron transmitter, which is significantly smaller in size, weight, and energy usage. The difference in antenna weight can be as much as half that of S-band. In real financial terms, the CAPEX investment for C-band is 33–50% less compared to the standard S-band weather radar.

Similarly, there are considerable OPEX savings to be achieved with several key design features. Self-calibration, remote real-time monitoring, and detailed fault reporting will result in fewer service visits over the lifetime of operation. The magnetron tube also has a longer lifecycle in the C-band due to its lower energy usage. Since many radar stations are located in remote areas for coverage optimization, service and maintenance visits incur sizeable costs – hence, greater reliability results in significant savings in the total lifetime cost.

Reference

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For more information, visit
www.vaisala.com or contact
us at sales@vaisala.com

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