On the Minimum Useful Elevation Angle for Weather Surveillance Radar Scans

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ABSTRACT

The antenna beam pattern for low elevation angles is examined in relation to the radar horizon to assess the impact of base-scan elevation angle on sensitivity to near-horizon weather features, as well as its effect on reflectivity measurements and ground clutter. The results from a simple model neglecting details of surface characteristics and multipath propagation suggest that a base elevation angle of about 0.3 beamwidth above the horizon would yield near-optimum sensitivity with acceptable degradation in reflectivity observations and ground clutter.

1. Introduction

The standard NEXRAD (WSR-88D) volume coverage patterns (VCPs) include a ‘‘base scan’’ at an elevation angle of 0.5°, that is, one-half the antenna beamwidth. Concerns have been expressed that some weather features extending only slightly above the radar horizon might be missed by such scan patterns. It has even been suggested that the minimum elevation for a VCP base scan be reduced to zero degrees. Doing so would increase the intensity of ground-clutter echoes, making them more difficult to deal with, and interfere with quantitative measurements on the base-level scan. Therefore, it is worth examining the extent to which echoes from the low-lying weather features of concern could be enhanced by this procedure. That is the subject of this paper.

2. Models describing the situation

Figure 1a illustrates the (idealized) current situation, in which the antenna beam (represented by the circle indicating the usual 3-dB beamwidth) is elevated for the base scan so that the lower 3-dB point just grazes the horizon. (In fact, the horizon is almost always irregular, so this situation can obtain only for certain azimuth directions.) The lowest beam elevation used is thus just one-half of the beamwidth, or 0.5° for the WSR-88D. Figure 1b illustrates one proposed alternative, in which the lowest scan elevation is zero degrees; the beam axis then grazes the horizon, and half the ‘‘beam volume’’ intersects the surface.

a. The low-lying weather feature

The problem can be analyzed in terms of a thin layer of reflectivity (assumed uniform) extending just above the horizon. Such a layer is depicted in both panels of Fig. 1. Ignoring any multipath effects, the advantage of the arrangement in Fig. 1b over that in Fig. 1a, in terms of the strength of the echo received from the reflectivity layer, would be greater than that for any higher layer (up to half the beamwidth above the horizon). A thicker layer can be treated as the superposition of a series of these thin layers. And for any narrow feature, say a reflectivity column extending up into the beam, the advantage would be just the same as that for a wide feature of equal depth (at least under the beam model described below).

b. The beam pattern

As in previous analyses, the antenna beam pattern will be approximated by a two-dimensional Gaussian function. This type of model is commonly used to describe the main lobes of antenna beam patterns (Bogush 1989), at least within the 3-dB beamwidth. Probert-Jones (1962) used such a model in his classic development of a weather radar equation. The gain of typical antennas falls off more rapidly than the Gaussian function outside the 3-dB points, but for present purposes it should provide reasonable approximations for the relative sensitivities to near-horizon echo features.

Characteristics of such a two-dimensional Gaussian function can be found in statistics texts, where it is described as a ‘‘bivariate normal distribution.’’ The pat-

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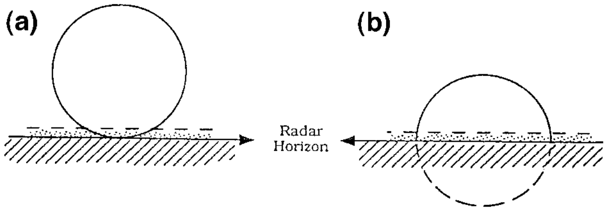

FIG. 1. Schematic illustration of two possible base-level scan configurations. (a) Elevation of beam axis at half the antenna beamwidth and (b) elevation of axis at zero degrees. The layer along the horizon represents a low-lying reflectivity feature.

tern for a circular beam can be described by the gain function

$$\mathrm{G}(\alpha, \beta) = \exp\{-(\alpha^2 + \beta^2)/\gamma^2\}, \qquad (1)$$

where α and β are azimuth and elevation angle deviations, respectively, measured from the beam axis. The relationship to the usual half-power beamwidth Θ is given by

$$\Theta = 2\gamma\sqrt{\ln 2}. \qquad (2)$$

The important characteristic of this pattern, for present purposes, is that for any specified elevation deviation β, the azimuth pattern is a Gaussian with the same constant value of γ (or Θ).

3. Analysis of sensitivity variation

With the foregoing models, the analysis of the effect of antenna elevation angle on sensitivity to near-horizon echo features is straightforward. For example, at the half-beamwidth elevation angle illustrated in Fig. 1a, the azimuth pattern along the horizon is a Gaussian similar to that through the beam axis but with just half the maximum gain. The radar echo strength would be proportional to the integral of $G^2(\alpha, -\Theta/2)$ across the horizon feature. Its value would be 6 dB (i.e., 3 dB each for transmit and receive) less than that which could be obtained by aligning the beam axis along the horizon as in Fig. 1b.

Similar analysis for other antenna elevation angles leads to the results listed in the second column of Table 1. The maximum sensitivity to low-lying echo features would be obtained using zero elevation angle (as in Fig. 1b). However, the increase over the sensitivity obtained using the half-beamwidth elevation angle (Fig. 1a) is only about 6 dB. Moreover, most of the increase could be obtained by using an elevation only slightly less than the half-beamwidth value: an elevation of one-third of the beamwidth would provide more than 3 dB of the total 6-dB enhancement possible at zero elevation angle.

In view of the poorer approximation of the beam pattern outside the 3-dB beamwidth, this Gaussian-based analysis probably somewhat understates the benefit that might be achieved by reducing the base elevation angle. On the other hand, layers of infinitesimal thickness at the horizon are unlikely to be detectable; for thicker layers the advantage would be reduced from that calculated for an infinitesimal layer. The greater lens-effect loss (Shrader and Weil 1987) at the lower elevation angle would detract a bit from the calculated increase. The Lloyd's mirror effect (Blake 1980) also tends to produce a minimum in the antenna gain along paths just grazing the horizon. On balance, the results in Table 1 are probably a reasonable guide to the sensitivity increase that might be obtained by operating at a lower base elevation angle.

4. Effect on reflectivity measurements and ground clutter

As the minimum elevation angle is lowered, more of the lower part of the beam's main lobe impinges upon the surface. This has two deleterious effects: (a) it degrades the reflectivity data from the radar, when viewing beam-filling targets, and (b) it tends to increase the strength of the ground-clutter echoes.

Again, using the Gaussian model for the beam pattern, it is possible to calculate the portion of the weighted ''echoing volume'' of the beam that does not intersect the ground for various elevation angles. In mathematical terms, this is just the ratio

$$\frac{\displaystyle\int_{\beta_h}^{\infty}\int_{-\infty}^{\infty} G^2(\alpha, \beta)\, d\alpha\, d\beta}{\displaystyle\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} G^2(\alpha, \beta)\, d\alpha\, d\beta}, \qquad (3)$$

where β_h is the value of β corresponding to the horizon

TABLE 1. Relative sensitivity and beam occultation vs elevation angle.

Elevation angle (fraction of beamwidth)	Relative sensitivity, two way (dB)	''Echoing volume'' above horizon (%)	Reflectivity loss (dB)
0.7	−11.8	99.0	0.0
0.6	−8.7	97.7	−0.1
0.5	−6.0	95.2	−0.2
0.4	−3.8	90.8	−0.4
0.3	−2.2	84.1	−0.8
0.2	−1.0	74.7	−1.3
0.1	−0.2	63.2	−2.0
0.0	0.0	50.0	−3.0

ray. Values of this ratio, expressed as a percentage and not corrected for refraction effects, appear in the third column of Table 1. The values in the fourth column indicate the effect on the radar's reflectivity estimates for uniform beam-filling targets in terms of the loss due to the occultation of the lower part of the beam (since that part of the beam volume could not contain precipitation particles).

The indications of this analysis parallel those of the sensitivity analysis. At the nominal half-beamwidth elevation, only about 5% of the weighted beam volume intersects the surface. The associated loss of 0.2 dB of potential precipitation echo would have negligible effect on the reflectivity estimates for beam-filling targets. Lowering the elevation to about one-quarter of the beamwidth would increase these values to about 20% and 1.0 dB, respectively. The suggestion is that operation at a base elevation of about one-third the beamwidth would degrade the reflectivity measurements minimally.

The increase in ground clutter is more difficult to assess. The straightforward effect of increased antenna gain along the horizon ray can be deduced from the second column of Table 1; for example, lowering the base elevation angle from 0.5 to 0.3 beamwidth would increase the strength of the echo from a target on the horizon ray by 3.8 dB. However, many clutter targets lie below the horizon ray, and the effect on echoes from them may be greater.

5. Summary

An analysis considering simple models of low-lying reflectivity features and the antenna beam pattern shows that the radar sensitivity to such features could be increased, at most, by about 6 dB by lowering the base-scan elevation from one-half the beamwidth above the horizon (as currently used with the WSR-88D) to zero. Consequently, it is unlikely that many weather features visible to the radar are being missed by the current VCPs.[1] Moreover, using a zero-degree elevation angle would disrupt any quantitative reflectivity measurement capability (and also interfere with the Doppler velocity measurements) on the lowest traverse because the ground would intercept half the beam. That would also enhance the ground-clutter echoes as well as cause greater multipath interference in the elevated part of the beam.

The analysis further shows that most of the potential increase in sensitivity to low-lying echo features could be obtained by lowering the base-scan elevation to around one-quarter to one-third of the antenna beamwidth (0.25°–0.35° for the WSR-88D). The problems cited above would still arise but to a lesser extent. Thus, a case might be made for implementing a NEXRAD VCP with minimum elevation of 0.3° above the horizon; any further reduction would do more harm than good. Where the horizon is irregular, detailed analysis may be needed to arrive at the best compromise for the base elevation angle. The information provided herein should be useful in that process.

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[1] A possible exception to this may occur with an elevated radar site where part of the horizon dips appreciably below the horizontal.