Dual Doppler Radar Coordination Using Nomograms

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ABSTRACT

A simple nomogram technique to facilitate dual Doppler radar data collection is presented. Equations and nomograms are developed for relating the position of a given target relative to two radars. The results are general, but application is made to the National Severe Storms Laboratory radars at Norman and the Cimarron site 40 km northwest of Norman.

1. Introduction

When using two Doppler radars at different locations to measure the two-dimensional velocity field of a meteorological phenomenon, it is necessary to scan over the same region with both radars. There are several ways of doing this, e.g., 1) using a computer to slave both radars as in COPLAN scanning (Lhermitte and Miller, 1970), or 2) using a map with concentric circles around each radar as a reference. At the National Severe Storms Laboratory (NSSL) data on severe storms are most commonly collated by radars at low elevation angles ($<15°$) and ranges <60 km. The following describes a method by which nomograms may be used in the coordination of two radars. The nomograms given are for the NSSL radars located at Norman and at the Cimarron site, separated by a distance of 41.39 km, but the analytical results are applicable to any set of radars.

2. Nomograms

Relations are derived to obtain the azimuth, elevation and range (β_2, α_2, R_2) of a given target for a second radar when its position coordinates relative to a first radar (β_1, α_1, R_1) are known. Fig. 1 illustrates a dual radar network with both radars having zero elevation angles (i.e., $\alpha_1=\alpha_2=0$), viewing a point (x, y) in the horizontal plane. It is assumed for simplicity that the effect of curvature of the earth is negligible for the horizontal ranges at which data are to be collected. The ranges and azimuths of point (x, y) from radar 1 located at (x_1, y_1) and from radar 2 at (x_2, y_2) are R_1, β_1 and R_2, β_2 respectively. The expressions for x and y are then given by

$$x=x_1+R_1 \sin\beta_1=x_2+R_2 \sin\beta_2, \tag{1}$$

$$y=y_1+R_1 \cos\beta_1=y_2+R_2 \cos\beta_2. \tag{2}$$

If the x-y distances between the two radars are given by

$$\left.\begin{aligned}\Delta X&=x_2-x_1\\ \Delta Y&=y_2-y_1\end{aligned}\right\}.$$

(1) and (2) then become

$$R_2 \sin\beta_2-R_1 \sin\beta_1=-\Delta X, \tag{3}$$

$$R_2 \cos\beta_2-R_1 \cos\beta_1=-\Delta Y. \tag{4}$$

Solving for R_2, we have

$$R_2=\frac{R_1 \sin\beta_1-\Delta X}{\sin\beta_2}=\frac{R_1 \cos\beta_1-\Delta Y}{\cos\beta_2}. \tag{5}$$

The final solution relating the azimuth of a target relative to radar 2 to R_1, β_1 is

$$\beta_2=\tan^{-1}\left(\frac{R_1 \sin\beta_1-\Delta X}{R_1 \cos\beta_1-\Delta Y}\right). \tag{6}$$

Squaring and adding (3) and (4) after solving for $R_2 \sin\beta_2$ and $R_2 \cos\beta_2$ give the range of the given target from the second radar in terms of the first radar position coordinates:

$$R_2=[R_1^2+\Delta X^2+\Delta Y^2-2R_1 \times(\Delta X \sin\beta_1+\Delta Y \cos\beta_1)]^{\frac{1}{2}}. \tag{7}$$

It is noted that the ranges used in the calculation are horizontal ranges, which may result in an error less than a few hundred meters when slant ranges in the quasi-horizontal collection mode are used. In the calculations, the Norman and Cimarron radars are separated by a distance of 41.39 km and oriented in a direction 309.9° to 129.9°, resulting in

$$\left.\begin{aligned}\Delta X&=(-41.39\text{ km}) \cos 39.9°\\ \Delta Y&=(+41.39\text{ km}) \sin 39.9°\end{aligned}\right\}.$$

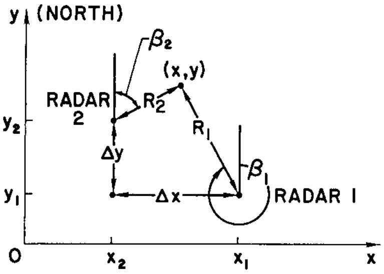

FIG. 1. Geometry of radars. The radars are located at (x_1, y_1) and (x_2, y_2), where the x axis is E–W, and the y axis is N–S. The point (x, y) is at horizontal distances R_1 and R_2 from radar 1 and radar 2, respectively.

Using (6) and (7), curves are generated for the NSSL radars so that the range and azimuth of a given point in space, relative to the Cimarron radar, can be determined when the Norman position coordinates are known. These are shown in Fig. 2.

The ratio of horizontal ranges from the two radars may be used to compute the elevation angle of a target from one radar when its elevation angle from the second radar is known. Fig. 3 gives contours of ratio of Norman range to Cimarron range as measured directly from Fig. 2, and is to be used as an overlay to Fig. 2. The elevation angles for radars observing a point (x, y) at height z are then related by

$$\left.\begin{aligned} z &= R_2 \tan\alpha_2 = R_1 \tan\alpha_1 \\ \alpha_2 &= \tan^{-1}\left[\frac{R_1}{R_2}\tan\alpha_1\right] \end{aligned}\right\}. \tag{8}$$

Fig. 4 gives elevation angles for each radar as determined from the ratio of ranges given in Fig. 3.

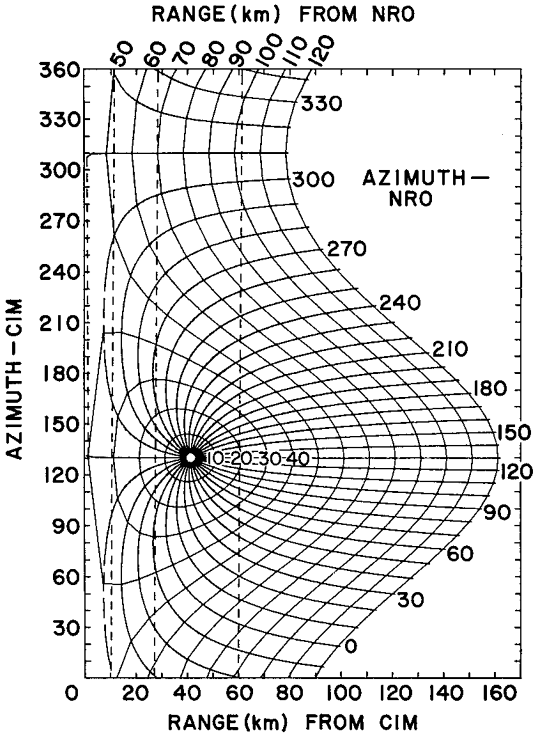

FIG. 2. Nomogram to determine Cimarron (CIM) radar coordinates from Norman (NRO). Range is in kilometers and azimuth in degrees. The solid lines are nomogram curves. The dashed lines indicate continuations between the nomogram curves.

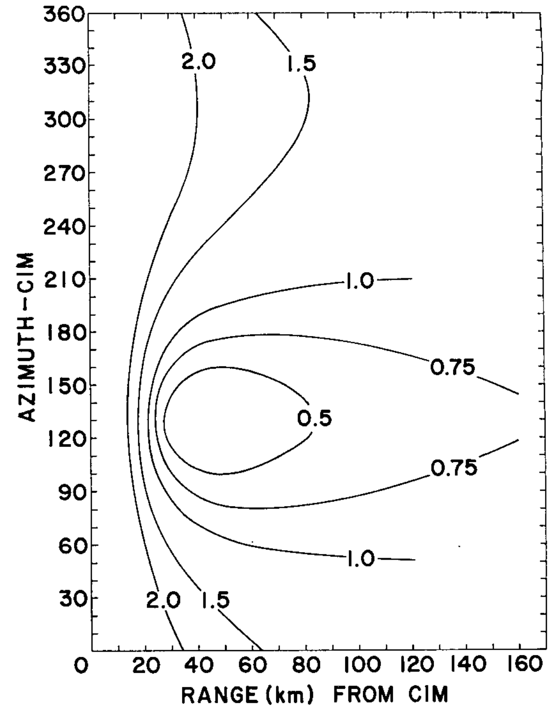

FIG. 3. Ratio of Norman range to Cimarron range (overlay to Fig. 2).

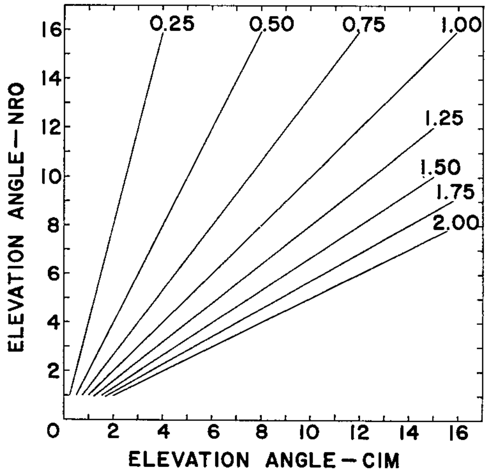

FIG. 4. Elevation angles of a given target from two radars for various values of the ratio of horizontal ranges (i.e., Norman range ÷ Cimarron range).

3. Conclusions

From the set of curves in Figs. 2 and 4, two radars can be designed to look over approximately the same region. It should be noted that the accuracy of the nomograms decreases at large distances since the curvature of the earth has been ignored. By ignoring curvature, the radar observations from a single radar are taken with respect to a plane tangent to the earth's surface at the radar location. At 0° elevation angle, and a range of 60 km, a radar has an approximate altitude error of 200 m and a considerably smaller range error. The error when using (7) and (8) is the difference between the errors of each radar, and thus is not as large as for a single radar.

The above nomograms were used during the 1974 Spring Program at NSSL. Precise synchronization of radars was not critical since an objective analysis yielding horizontal winds is used to assimilate radar data.

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