SECTORIZED HYBRID SCAN STRATEGY OF THE NEXRAD PRECIPITATION PROCESSING SYSTEM

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ABSTRACT

In preparation for the introduction of NEXRAD in the United States, a 'sectorized hybrid scan' has been developed for enhancing precipitation processing by radar. The sectorized hybrid uses data from the four low tilts of the radar volume scan to develop a composite, or hybrid, scan. The choice of the tilt to be used at a particular location depends upon range and altitude of the beam above the terrain. This processing has also provided for the production of regional radar coverage maps.

INTRODUCTION

The United States is on the verge of implementing a network of Doppler radars known as NEXRAD (Next Generation Weather Radar). A major component of the NEXRAD software is the Precipitation Processing System (PPS) developed by the National Weather Service (NWS) Office of Hydrology. PPS converts effective reflectivity factor data into hourly accumulations of rainfall over the radar field. Details of the PPS are described within a companion paper from this symposium (Hudlow et al, 1989).

A significant problem that has confronted radar hydrometeorologists over the years is compositing the effective reflectivity factor (hereafter in this paper simply referred to as reflectivity) from a radar volume scan into an areal gridded field of precipitation estimates. The lower tilts are known to be more likely contaminated by ground clutter at the near ranges and will be more affected by anomalous propagation (AP). The higher tilts are more likely to suffer from range problems particularly from incomplete beam filling and overshooting storm systems at further ranges. Joss and Waldvogel (1988) review a number of methods of using the vertical reflectivity profile to estimate precipitation. A reflectivity profile correction is proposed by Koistinen (1986).

This paper describes development of a 'sectorized hybrid scan' of reflectivity data that will be used within PPS. The sectorized hybrid scan is constructed to use the best data at each particular bin based on beam height, terrain effects, and beam blockage. Tests using the sectorized hybrid scan have shown the procedure to provide a great improvement over other techniques to composite data. This paper also describes an automated procedure that has been developed to determine the sectorized hybrid scan. Knowing which radar tilt will be used at any particular bin also allows one to develop radar coverage maps displaying the beam elevation at any particular point.

BACKGROUND AND DESCRIPTION

The concept of the sectorized hybrid scan is one that has evolved over the past 15 years. Initial attempts at developing a hybrid scan are described in some of the documents that resulted from GATE (GARP Atlantic Tropical

Experiment) in the mid-1970's (Richards and Hudlow, 1977; Hudlow et al, 1976). The GATE processing used three tilt angles to develop the hybrid scan. The third tilt (4.0°) was used for ranges less than 16 kilometers. The second tilt (2.0°) was used from 16 to 32-km. For the further ranges, several processing methods were examined. The most attractive method for the GATE data was termed 'bi-scan maximization'. This method uses the maximum reflectivity value from the low two tilts at a given range and azimuth. Bi-scan maximization was found to decrease the range degradation that often results from incomplete beam filling and attenuation losses.

When the PPS was being developed, it was decided to use a similar hybrid scan construction, using the four low tilts available from the NEXRAD volume coverage pattern (Ahnert et al,1983). For most locations, the nominal values of the center line axis of these tilt angles will be 0.5°, 1.45°, 2.40°, and 3.35°. These four low tilts, using the NEXRAD one degree beamwidth, will always be contiguous. The hybrid scan, however, was developed using GATE data collected over the ocean; NEXRAD would be frequently facing problems from blockage due to mountains and other terrain features. Modifications to account for terrain features led to development of the sectorized hybrid scan.

The tilt selection procedure for the hybrid scan was a function only of range (see figure 1); however, the procedure for the sectorized hybrid scan is a function of both range and azimuth. In areas where obstructions occur in the lower tilts, the sectorized hybrid scan uses a higher tilt. The sectorized hybrid array therefore will be an 230 by 360 array (to account for each 1° by 1 km bin) defining which tilt is to be used at that particular bin.

BENEFITS OF SECTORIZED HYBRID SCAN

The sectorized hybrid scan has a number of advantages relative to other compositing methods. The first is that the reflectivity data are collected over a more uniform altitude versus range as a result of using the increasingly higher tilts at the nearer ranges. At the far ranges (maximum range is 230 km for precipitation processing), the center line of the low tilt will be about 5 km above the radar site.

Another significant benefit is the reduction of clutter and other radar noise. A majority of the ground clutter in the radar volume scan occurs in the lowest tilts at near ranges. Since the sectorized hybrid scan does not use data from the lowest tilts close to the radar, a significant source of potential error is removed. The low tilt is also the most likely to be contaminated by AP. The preprocessing algorithm of PPS, which constructs the sectorized hybrid scan, has a tilt test to check for AP. If the percent area reduction between the two lowest tilts for ranges between 40 and 150 km is greater than a certain threshold (currently set at 50%), the low tilt is considered to be excessively contaminated and is not used in the construction of the sectorized hybrid scan. Other tests that are performed in the preprocessing algorithm include an outlier check which checks for excessively high reflectivity values and an isolated bin test. Corrections are also made for bins which may be partially obstructed by terrain or man-made obstacles.

The sectorized hybrid scan should also improve detection of orographic precipitation. Many precipitation processors simply have missing data beyond a certain range if the low tilt is blocked by terrain. By providing sufficient software intelligence, the location of these terrain features is known and the higher tilts can be used to detect precipitation occurring over the mountains. This capability will significantly increase the area of radar coverage.

Detection of bright band is another potential benefit of sectorized hybrid scan processing. Smith (1986) describes a method of detecting bright band using a similar multiple tilt processing scheme using reflectivity data alone. Although bright band detection is not currently a part of PPS, Smith's method is completely consistent with the capabilities of the PPS. The Office of Hydrology is in the process of determining the utility of this process and whether a change to PPS should be made in the future.

The sectorized hybrid scan and bi-scan maximization procedures are not without limitation. If a bright band is not detected and removed it could be potentially enhanced by choosing the maximum value as well as repeated in range due to the multiple tilt processing. Enhanced detection of virga resulting in overestimation of ground precipitation is also a possible result from bi-scan maximization. However, the potential benefits of using the sectorized hybrid outweigh these relatively minor limitations.

DEFINITION PROCEDURE

A procedure has been developed to determine the tilt angle to be used for each bin (one degree azimuth by one kilometer range) for the sectorized hybrid scan used in the NEXRAD PPS. Using this information, the radar beam elevation used in the NEXRAD era to estimate precipitation can be determined for any bin for any radar site.

The procedure uses the Defense Mapping Agency (DMA) Digital Terrain data base. This data base is a gridded (30" by 30") field with 10-m vertical resolution. In performing a comparison between the elevations in the DMA data base and those determined as part of the NEXRAD site surveys, the data base was found to have a mean accuracy of 15-m relative to the elevations reported in the site surveys. For the purpose of defining the hybrid scan and determining beam elevations, this accuracy should be adequate. Some minor modifications to the hybrid scan may result if higher resolution and more accurate terrain data are used.

The elevation of the beam, EBM, is defined as

$$EBM = ERAD + ETOWER + HCA + HBM - EG \tag{1}$$

where ERAD is the ground elevation of the radar site, ETOWER is the height of the radar tower, HCA is the height from the top of the tower to the center of the radar beam (5-m), HBM is the height of the radar beam at range R and elevation angle A, and EG is the ground elevation for the particular bin determined from the DMA data base. HBM is determined using the 4/3 effective earth radius model in the form:

$$HBM = \frac{R^2 \cos^2 A}{2(4/3)RE} + R \sin A \tag{2}$$

where RE is the radius of the earth.

The procedure that has been developed for defining the sectorized hybrid defines an 'optimal' elevation. The optimal elevation is a program variable currently set at 1200-m above ground. This procedure also checks for maximum elevations and blocked azimuths and then chooses the tilt with center beam elevation closest to the optimal elevation. The beam is also checked to assure that a minimum clearance of the bottom of the radar beam above ground (currently set at 150-m.) is maintained; however, the fourth tilt does not need to maintain the minimum clearance in order that data might be collected from the maximum area possible.

If a particular tilt angle is found to be blocked, it is determined whether the blockage is more or less than 50 percent. If the blockage is greater than 50 percent, the tilt angle is flagged as being not usable for the remainder of that azimuth. If the blockage is less than 50 percent, the tilt will not be used at the range where the blockage occurs but may be used at further ranges. PPS includes a scheme for correcting for partially blocked beams. Figure 2 is an example of how the sectorized hybrid might be constructed in a hypothetical area.

Two products, each in an alphanumeric and graphical form, are produced by this definition procedure. The first is a display showing for each range and azimuth bin, which of the four low tilts is to be used in constructing the sectorized hybrid scan. Areas of missing data resulting from excessively high radar beams or total blockage of the radar beam are also denoted. The second product is a display showing the elevation above ground for the sectorized hybrid. For display purposes, the radar beam elevation is defined from a point midway between the bottom and center line of the beam and is scaled into 750-m increments.

EXAMPLES

Testing of the hybrid scan procedures has been performed for a number of sites. The first NEXRAD will be installed near Oklahoma City, Oklahoma, in the Great Plains of the United States. Obviously, in the plains where no obstructions are occurring to block the beam and only minor terrain changes to affect beam elevation, the sectorized hybrid scan is fairly uniform over the entire 360° of the radar sweep (figure 3), and the sectorized hybrid scan is essentially identical to a non-sectorized hybrid scan.

A significantly different situation occurs for the Tucson, Arizona, NEXRAD site in the southwest United States. Tucson is located in mountainous region and as a result the sectorized hybrid scan is significantly affected as the lower tilts are blocked most of the way around the radar (figure 4).

Of course, since neither of these sites has a NEXRAD yet, testing of the effects of the sectorized hybrid scan processing is not possible. However, located just outside Boulder, Colorado,at the base of the Rocky Mountains, is the CP-2 radar which has many characteristics similar to NEXRAD. PPS has been operational in Denver using the CP-2 radar data since May 1988. PROFS (Program for Regional Observing and Forecasting Services) attempted implementing PPS initially with a non-sectorized hybrid scan; however, the precipitation products were found to be excessively contaminated by clutter. After a sectorized hybrid scan was developed, the precipitation estimates were found to be much more useful for the forecaster as most of the mountain clutter was removed. Procedures developed at PROFS to produce the sectorized hybrid were similar to those described in this paper. The precipitation accumulation products generated using the sectorized hybrid scan as the reflectivity input were found to be the most used NEXRAD type product on the workstation located in the forecast office in Denver (Rasmussen et al, 1989; PROFS, 1989).

The results of the sectorized hybrid definition can be used to determine the elevation of the radar beam using equation (2). This data can then be mosaicked together to show the radar coverage over a large region such as a state or river basin. Figure 5 shows the future coverage over the State of Oklahoma resulting from the NEXRAD coverage. Four NEXRADs will be located in Oklahoma. Coverage from NEXRAD sites in adjoining states will also provide essential radar coverage over Oklahoma.

CONCLUSION

The sectorized hybrid scan offers significant promise for improved precipitation processing by radar. The tests that have been performed thus far indicate that these preprocessing steps enhance the NEXRAD algorithms. The primary benefits that the sectorized hybrid and bi-scan maximization provide are in the reduction of ground clutter and AP, better altitude versus range definition, and potentially improved range performance and orographic precipitation estimates. The sectorized hybrid scan also offers the potential to be used by other NEXRAD algorithms as reflectivity input since the preprocessing that has been performed offers a much cleaner product than the base reflectivity data.

Two potential areas of limitation do exist. One is the enhanced detection of virga. However, since this phenomenon is generally relatively light precipitation, it should not seriously degrade the precipitation products. There is also some concern about azimuthal discontinuities in the mountainous regions. Figure 4 shows the sectorized hybrid using different tilts at neighboring azimuth bins. At the far ranges, this could result in a difference of a few kilometers in height which could lead to sharp discontinuities in rainfall rate estimates. However, if the alternative is no radar coverage, these potential discontinuities would seem to be an improvement.

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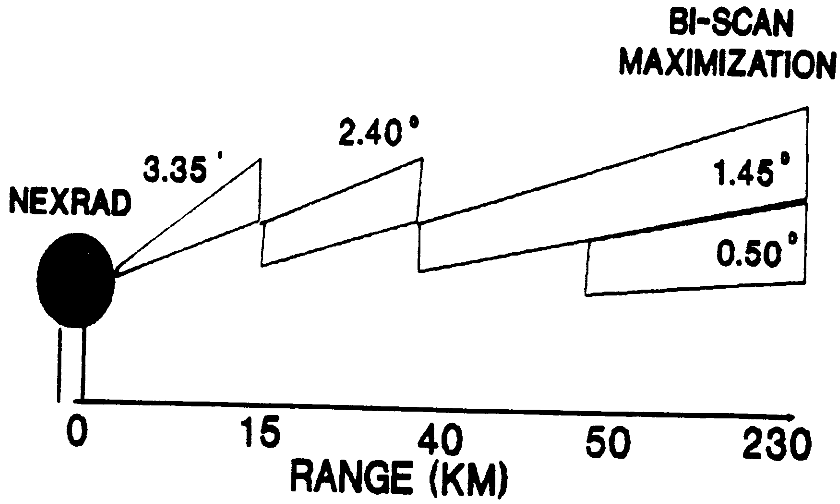

FIGURE 1 : Construction of hybrid scan with no blockage present. Ranges shown are approximate and will vary by site.

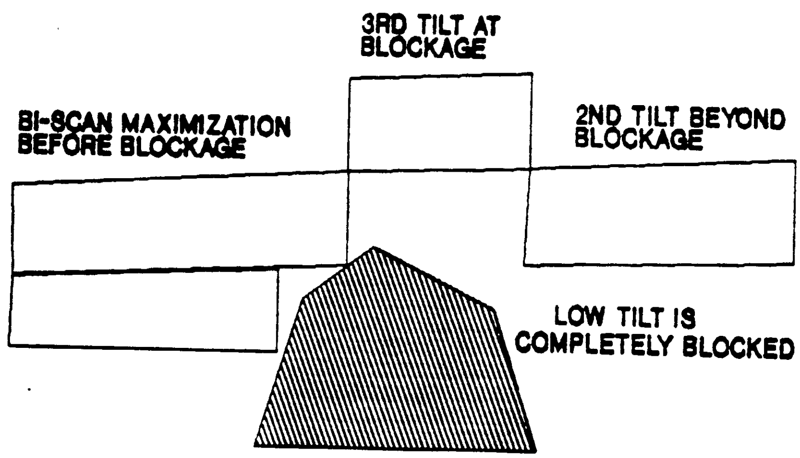

FIGURE 2 : Construction of sectorized hybrid scan in the presence of blockage.

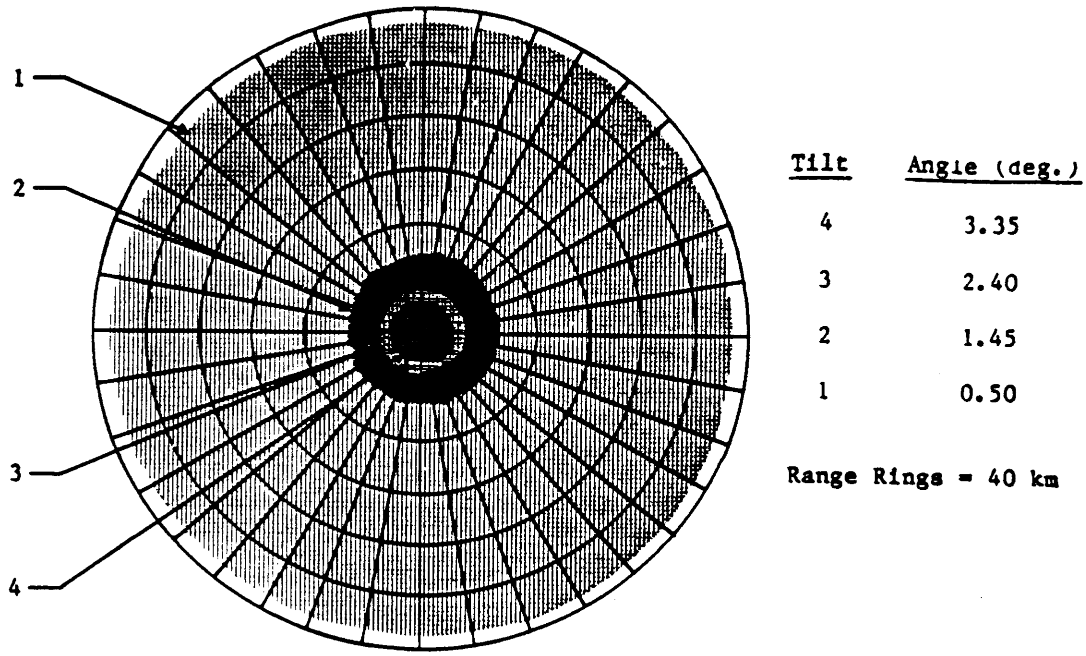

FIGURE 3 : Sectorized Hybrid Scan for Oklahoma City, NEXRAD.

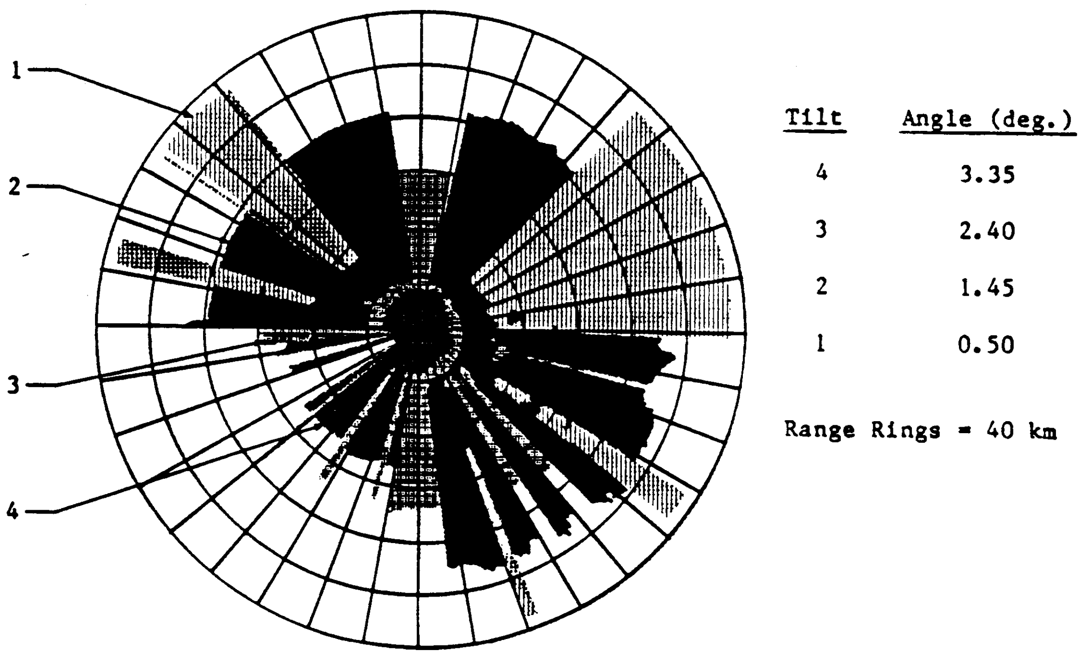

FIGURE 4 : Sectorized Hybrid Scan for Tucson, NEXRAD.

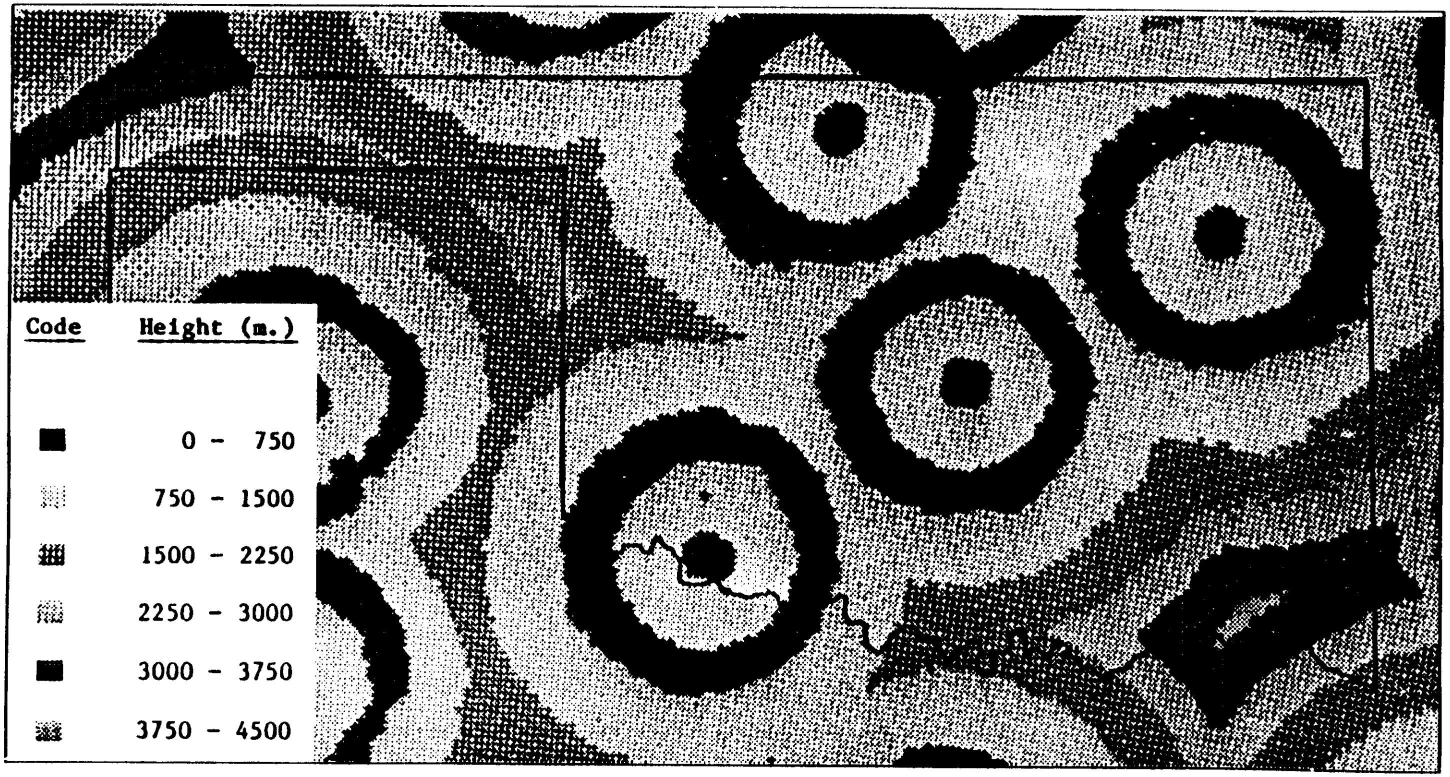

FIGURE 5 : Future NEXRAD coverage for State of Oklahoma showing height of point midway between bottom and centerline of beam.