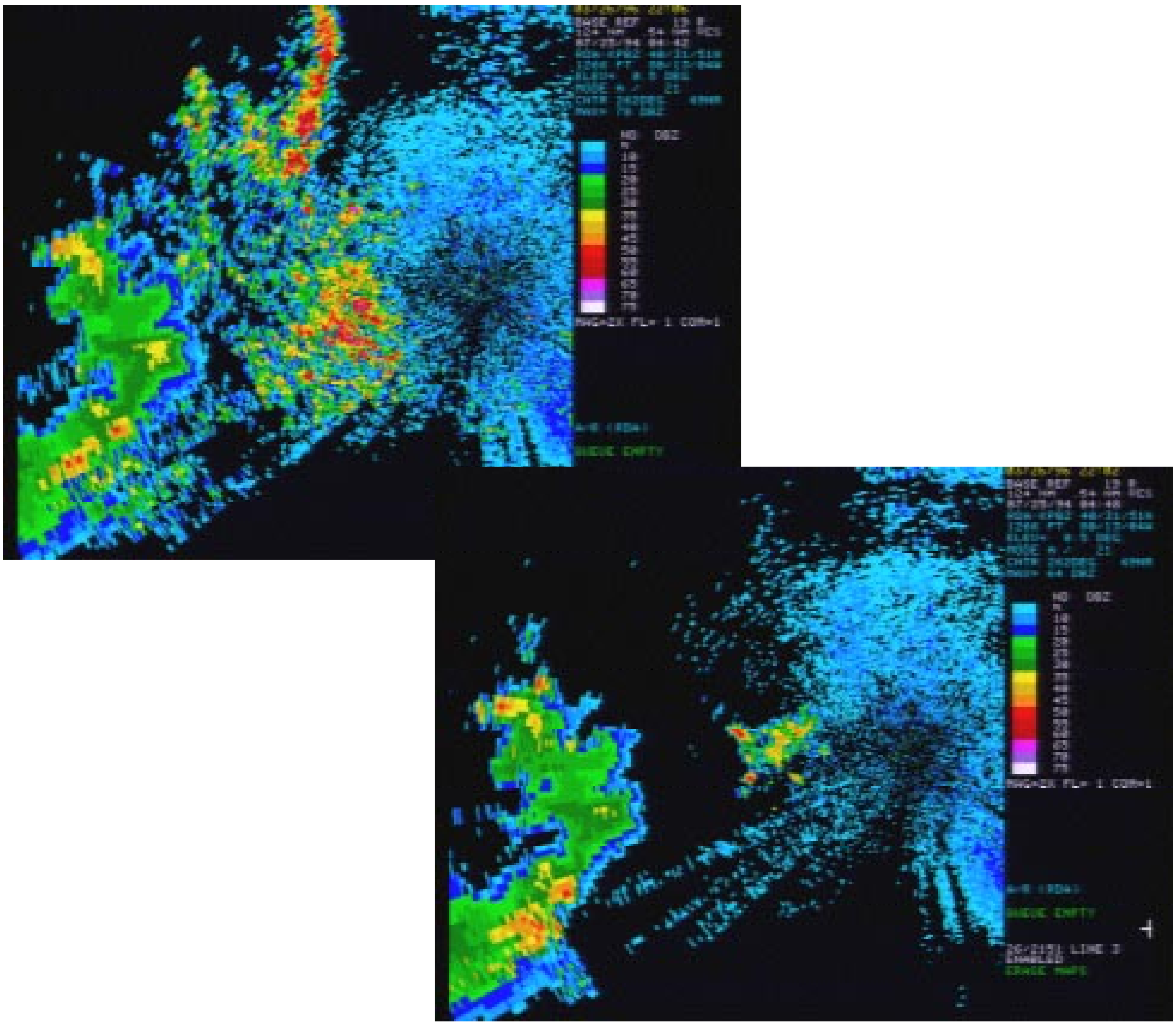
WSR-88D Clutter Suppression and Its Impact On Meteorological Data Interpretation



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January 1995

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1.0 Introduction

Ground clutter is generally defined as radar return from non-meteorological, ground-based targets. Ground clutter is usually limited to within 20 to 30 nm of the Radar Data Acquisition (RDA) site and to the lowest elevation slices. However, in rough terrain and under certain meteorological conditions, clutter contamination may be present to the furthest extent of the radar coverage area and may affect several elevation slices.

Ground clutter contamination has a significant effect on the accuracy of the base data estimates. Clutter-induced bias of base data not only brings into question the reliability of data presented on the base products, but also has a detrimental effect on all downstream algorithms.

Recovery of usable meteorological data from range bins contaminated by ground clutter return is the primary purpose of the clutter suppression technique employed by the Weather Surveillance Radar - 1988 Doppler (WSR-88D). The amount of data that can be recovered and the reliability of the reflectivity, velocity and spectrum width estimates from clutter contaminated range bins are functions of the active clutter suppression filter and the characteristics of the clutter itself. In this paper, we will explain the clutter suppression process as it pertains to the WSR-88D, discuss some data improvements attainable with proper implementation of clutter suppression, outline some pitfalls associated with improper clutter suppression application, and suggest operational methods to optimize the effectiveness of clutter suppression implementation from the Unit Control Position (UCP).

2.0 Base Data Estimate Bias Due to Ground Clutter Contamination

Ground clutter targets, by the very nature of their composition, are very efficient reflectors of electromagnetic energy. The innate ability of ground clutter targets to reflect more energy than nearby meteorological targets allows the clutter return to dominate the returned energy (power) for the affected range bin (See Figure 1).

A range bin is .13 nm (250 meters) in range by 1 degree in azimuth. Each range bin is made up of a number of range resolution cells. A range resolution cell is 1/2 pulse length (.13 nm) deep by one range sweep wide. A range sweep is defined as the azimuthal width of the area sampled by a single pulse which falls within the radial of interest. (The number of range sweeps per range bin varies based on the number of pulses per degree; therefore, the width of the range resolution cell also varies.) If the beam center line falls within the radial of interest, the data returned from that pulse is assigned to a range resolution cell location within a range bin for that radial. All range resolution cell values in a given range bin are used in calculating the base data estimate for that bin. See Figure 2.

Note: Figure 2 shows four and eight sweeps per radial for illustrative purposes only. In reality, the number of sweeps per radial ranges from approximately 40 to 200.

The base data estimate for each range bin is calculated using return from each range resolution cell contained within the confines of the range bin.

a. **Reflectivity (Z) Estimate.** Reflectivity is the measure of the efficiency of a target to reflect (absorb and re-radiate) radar energy. It is calculated by averaging the echo power from four successive range bins and then normalizing this average power for atmospheric attenuation and system noise. In general, clutter contamination will cause significantly higher reflectivity estimates because of the highly reflective nature of ground targets and the dependence of reflectivity (Z) on the magnitude of returned power.

b. **Mean Radial Velocity (V) Estimate.** Mean radial velocity is a power-weighted average of the motions from each radar range resolution cell contained within the range bin (Refer to Figure 2). Ground clutter return that dominates the echo power return for a given range resolution cell will produce a velocity estimate near zero knots for that range resolution cell. The velocity estimate for each range bin is calculated by measuring and averaging the rate of change between data points assigned to adjacent range resolution cells contained within the bin. Therefore, ground clutter return present in the **range bin** will bias the velocity estimate toward zero.

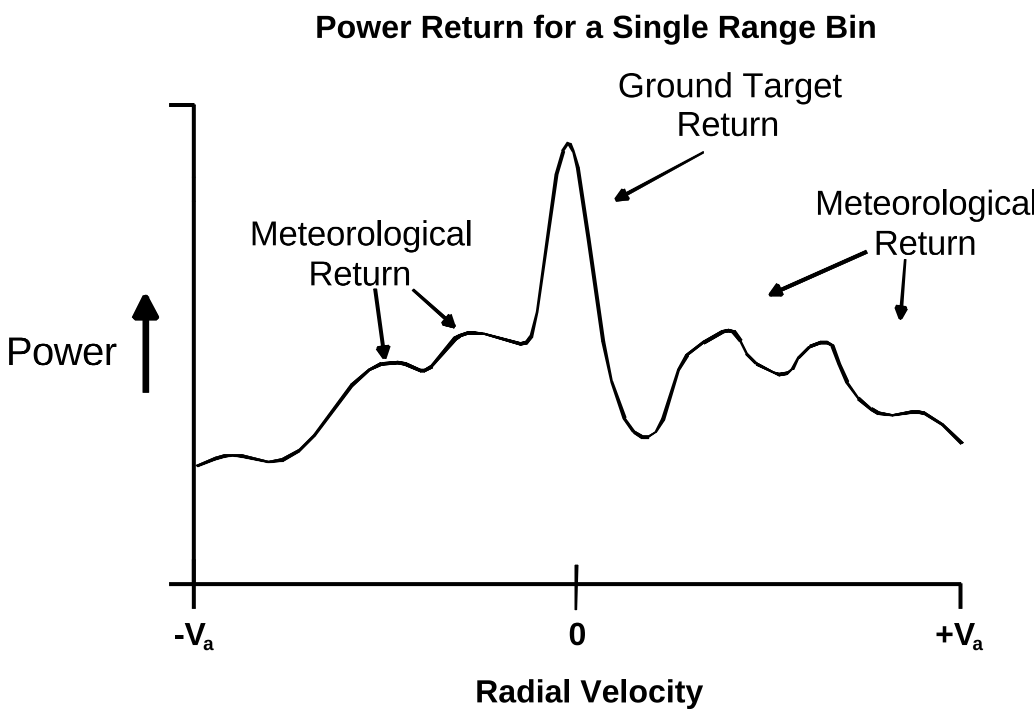

FIGURE 1. Example of power return for a single rain bin.

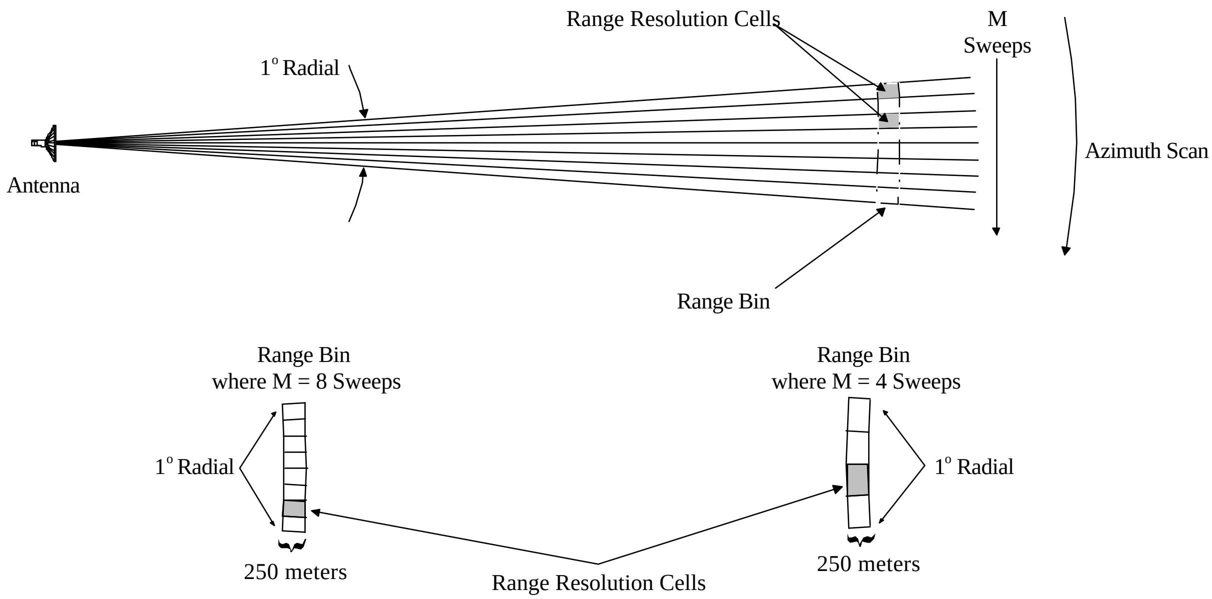

FIGURE 2. Beam Geometry.

c. Spectrum Width (W) Estimate. Spectrum width is a measure of the velocity difference between adjacent range resolution cells within a range bin. Any clutter contamination in the velocity estimate will also affect the spectrum width estimate.

The impact that the dominating clutter power return has on the base data estimates can be substantial. Additionally, the clutter-induced bias in the base data estimates affect the performance of ALL WSR-88D algorithms and products.

Clutter suppression for the WSR-88D is performed on each .13 nm by 1 degree range bin prior to the calculation of the base data estimates. Therefore, with appropriate clutter suppression invoked, the bias of the base data estimates due to clutter contamination within the range bin can be minimized.

3.0 Simplified Conceptual Model of Clutter Suppression Filter

As stated earlier, clutter is the radar return from non-meteorological, ground-based targets, either man-made or natural. Meteorological returns have a mean radial velocity which may fall anywhere within the Nyquist co-interval and produce a spectrum width of up to several meters per second. However, clutter returns consistently produce signals with near zero (<0.97 kts) radial velocities and narrow (<0.2 kts to ª0.6 kts) spectrum widths. These characteristics of clutter return allow the WSR-88D to employ filters to remove or reduce the power contribution from clutter, thereby decreasing its influence on base data estimates.

Clutter suppression filters are designed to reduce signal power whose mean radial velocity is at or near zero knots. To do this, clutter suppression filters reduce signal power within a “notch width” centered about the zero mean radial velocity value. This reduction in signal power effectively decreases the clutter's power contribution in the given range bin. To maintain meteorological return integrity, only the signal power whose radial motion falls within the notch width is reduced. (See Figure 3 on page 5.)

Remember, the goal of clutter suppression is to reduce only the power return contributed by clutter targets from the range bin prior to the calculation of the base data estimates. Therefore, for each range bin in areas where clutter suppression is in effect, the portion of the power return with near zero radial velocity will be reduced (filtered), as represented in Figure 3.

Any clutter return (power) not completely removed by the clutter filter is known as residual clutter. This residual clutter will be included in the calculation of the base data estimates for the range bin in which it resides. Note the residual clutter in Figure 3C.

4.0 A Brief Overview of WSR-88D Clutter Suppression

The WSR-88D provides for the suppression (reduction) of returned power whose radial velocity is near zero knots within predefined areas. The signal processor uses the Bypass Map, Default Notch Width Map, and operator-defined Clutter Suppression Regions to determine the areas in which to invoke suppression, and the amount of signal reduction to apply. The Bypass Map and Default Notch Width Map are used to identify and suppress areas of known ground clutter return. The operator may control the application of clutter suppression to known ground clutter areas and transient areas through the definition of clutter suppression regions. A brief definition of the clutter suppression options follows. Additionally, a flow chart illustrating the interaction of the clutter suppression options is provided in Figure 4.

4.1 Default Notch Width Map

The Default Notch Width Map consists of up to three concentric range definitions and includes a notch width value and an operator select code for each defined range. These definitions are OSF-controlled RDA adaptable parameters, not editable at the UCP. The current configuration specifies the Bypass Map in control and applies medium suppression to the Surveillance (reflectivity) channel and high suppression to the Doppler (velocity/spectrum width) channel out to 280 nm.

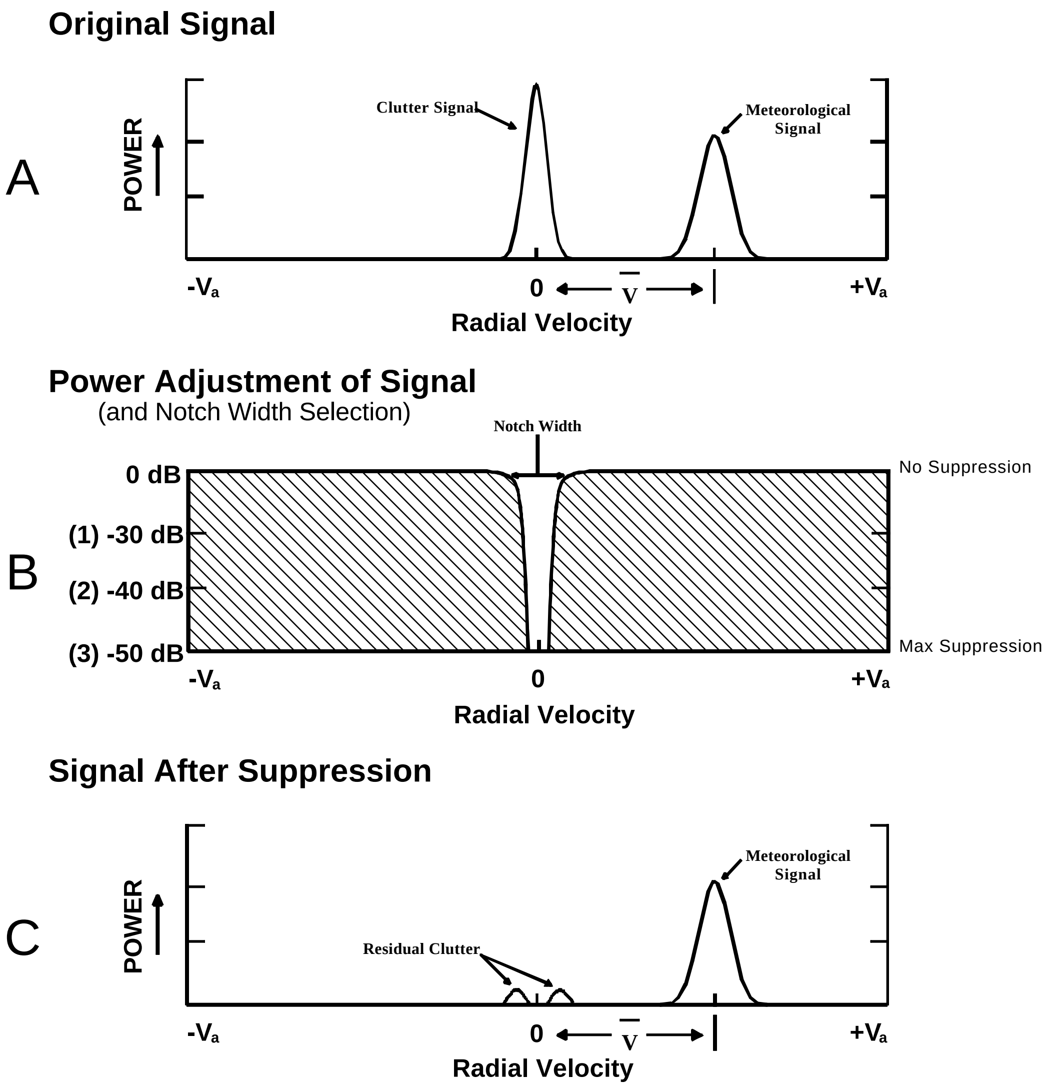

FIGURE 3.

A. A depiction of the input power for a given range bin. The clutter signal has a radial velocity centered around zero and the meteorological signal is offset from zero due to its radial velocity.

B. Represents the clutter filter with a notch width centered on zero radial velocity. The scale represents the ***amount of power reduction***, from 0 dB (no power reduction) to -50 dB (maximum power reduction), applied within the notch width.

C. A diagram of the resulting power after the algebraic addition of the signal from A and the power reduction factor from B (A+B=C).

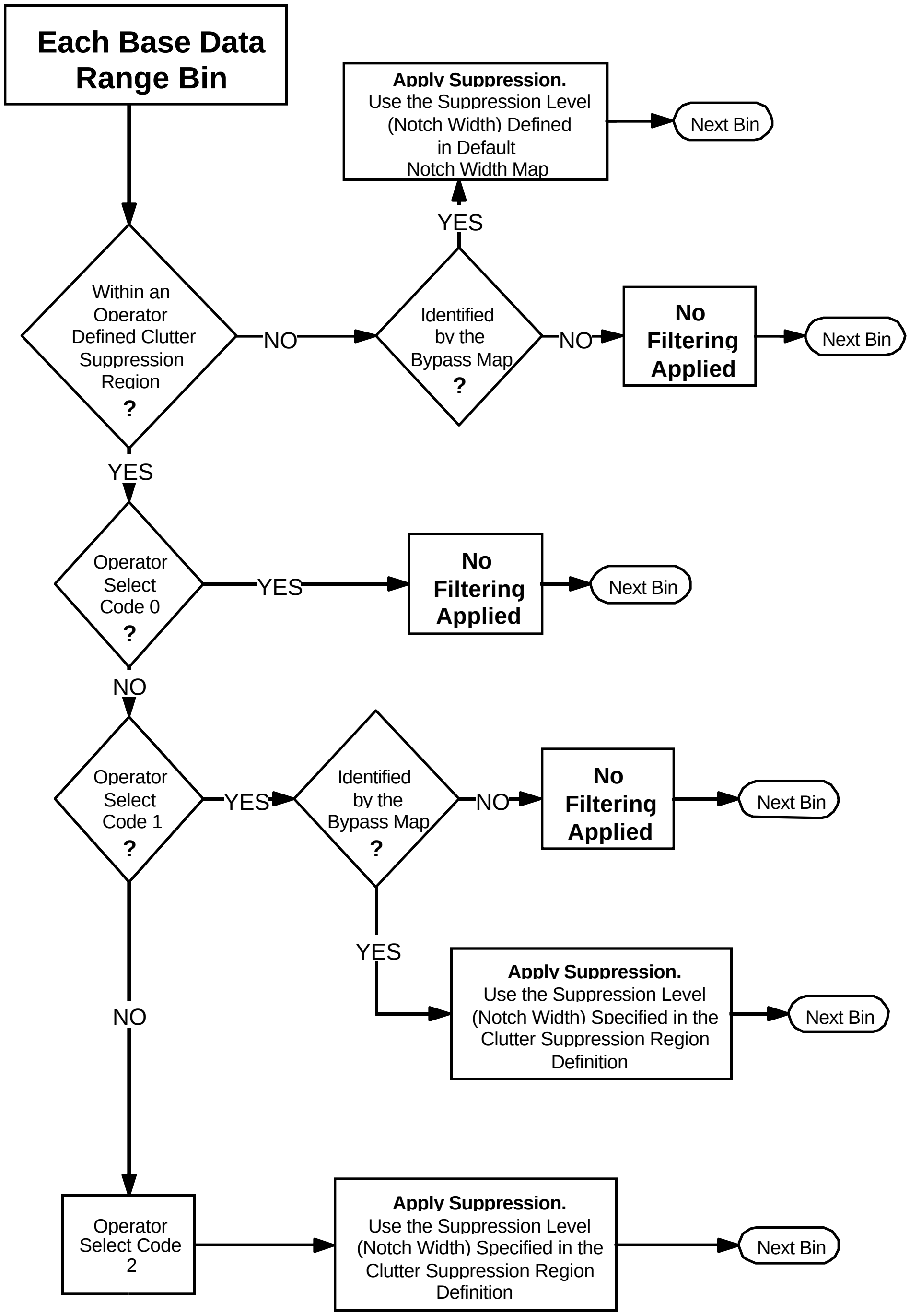

FIGURE 4. Interactions of clutter suppression options.

4.2 Bypass Map

The Bypass Map, generated by the Radar Data Acquisition System Operability Test (RDASOT) program, identifies areas measuring 1.4° by .54 nm which contain return from normal ground clutter targets. Only these 1.4° by .54 nm identified areas will have suppression applied when the Bypass Map is in control.

4.3 Operator-Defined Clutter Suppression Regions

The UCP operator may specify up to 15 individual regions per each of the four Clutter Suppression Region Files (11, 21, 31, 32). (Note: Clutter Suppression Region Files are not associated with any *specific* VCP.) Each region is delineated by start and stop ranges, start and stop azimuths, and an elevation segment number. The elevation segment number specifies which set of predefined elevation slices to include within the region definition. The elevations included in the different segments are defined in the RDA adaptation data.

The Clutter Suppression Regions are used to control the application of clutter suppression within the defined area by selecting from the options listed below.

4.3.1 Options for Clutter Suppression Within Operator-Defined Regions

Within each operator-defined region, the UCP operator has three choices to determine how filtering will be invoked.

a. **No Clutter Suppression: Operator Select Code 0.** This selection will turn off **ALL** filtering, including the Bypass Map identified areas, within the confines of the operator-defined region.

b. **Bypass Map in Control Using the Operator-Specified Notch Width: Operator Select Code 1.** This selection will invoke the selected suppression level (notch width) for each area identified by the Bypass Map within the confines of the operator-defined region.

c. **Forced Clutter Suppression Using the Operator-Specified Notch Width: Operator Select Code 2.** This option forces the specified suppression level (notch width) for **every** range bin within the confines of the operator-defined region.

4.3.2 Notch Width Selections

There are three notch width selections, or levels of suppression, available for inclusion in the Default Notch Width Map definitions and Clutter Suppression Region definitions (with Operator Select Codes 1 or 2). The notch width determines the target motions, around zero radial velocity, that will be subjected to signal power reduction (suppression). The Surveillance channel and Doppler channel are suppressed using different notch width values (See Table 1.) to reduce base data estimate bias in the different channels.

a. **Notch Width Selection 1.** Invokes a suppression level of approximately 30 dB (Low). See Table 1 for typical notch width values.

b. **Notch Width Selection 2.** Invokes a suppression level of approximately 40 dB (Medium). See Table 1 for typical notch width values.

c. **Notch Width Selection 3.** Invokes a suppression level of approximately 50 dB (High). See Table 1 for typical notch width values.

TABLE 1. Table 1: Notch Width Selections and Suppression Values

Channel	1		2		3	
	kts	dB	kts	dB	kts	dB
Surveillance	3.38	~30	4.85	~40	6.79	~50
Doppler	4.58	~30	6.05	~40	8.92	~50

Note: By design, the notch widths vary based upon antenna rotation rate. Therefore, the value listed in Table 1 is an approximation and varies with elevation angle and antenna rotation rate.

As depicted in Figure 5, the final filtering applied to each radial is a compilation of the Default Notch Width Map, the Bypass Map and the operator-defined Clutter Suppression Regions. The Bypass Map and Default Notch Width Map control the application of clutter suppression for each range bin ***not*** contained within an operator-defined Clutter Suppression Region. The operator-defined Clutter Suppression Regions have precedence for the application of clutter suppression. The hollow squares are areas previously defined for suppression by the Bypass Map, but are superseded by the operator-defined Clutter Suppression Regions.

In the absence of any operator-defined Clutter Suppression Regions, the WSR-88D will use the Bypass Map to determine where to apply clutter suppression and the Default Notch Width Map notch width definitions (stored RDA adaptation data) to determine the amount of suppression to be applied.

5.0 Negative Impacts of Inappropriate, Operator-Forced Clutter Suppression on WSR-88D Data

Forcing clutter suppression (Operator Select Code 2) for every range bin within an operator-defined region will effectively remove the power contribution of non-moving targets from the base data estimate. This strategy is appropriate to temporarily mitigate the effects of anomalous propagation. However, caution is warranted when such a strategy is employed as a long term solution for removal of clutter contamination from the base data estimates.

5.1 Zero Isodop Apparent in the Reflectivity Field

The clutter suppression technique employed by the WSR-88D applies power reduction factors to “clutter” returns to reduce their impact on valid meteorological data. The portion of the signal attributed to “clutter” is identified by its lack of motion. The WSR-88D applies a power reduction factor to the non-moving returned signal.

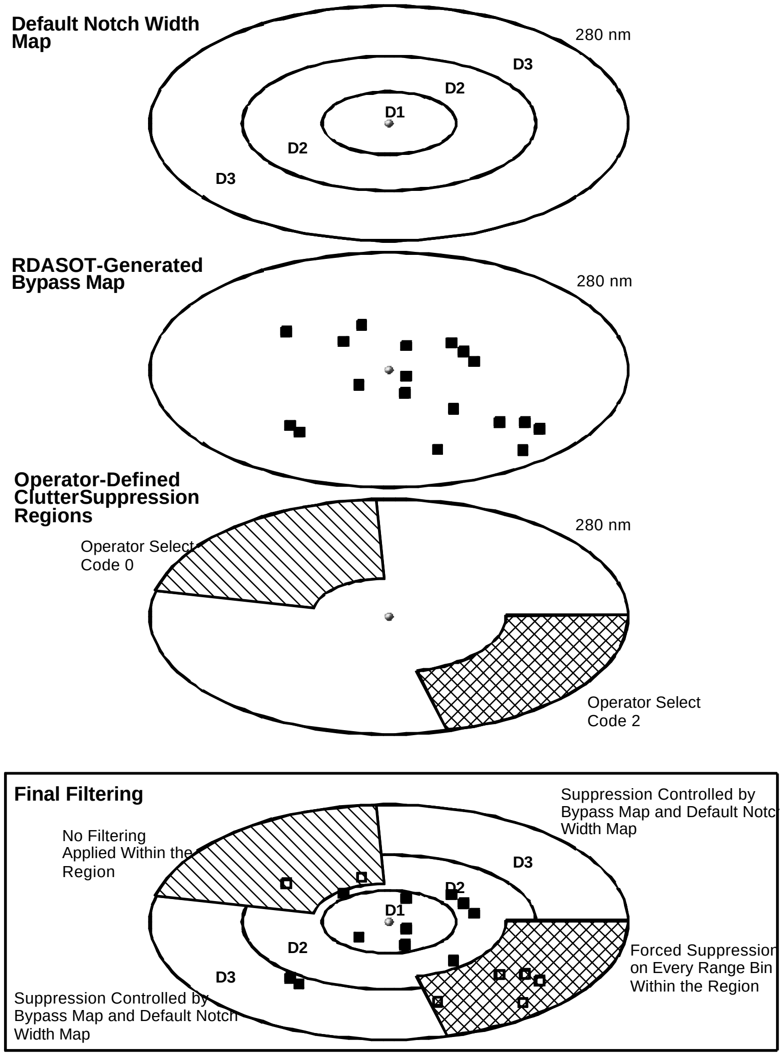

FIGURE 5. Final Clutter Filtering shown with its components.

The WSR-88D sees only the radial component of the actual target motion. Therefore, if the target is moving perpendicular to the radar beam it has a zero (or near zero) radial motion. If clutter suppression has been invoked for a given range bin whose radial target motion is zero (or near zero), the defined power reduction factor will be applied to that bin. This power reduction will result in a significantly reduced reflectivity estimate for the range bins whose mean radial velocity is at or near zero. See Figure 6.

5.2 Data Smearing

Data smearing is an artificial displacement of the returned power maxima into

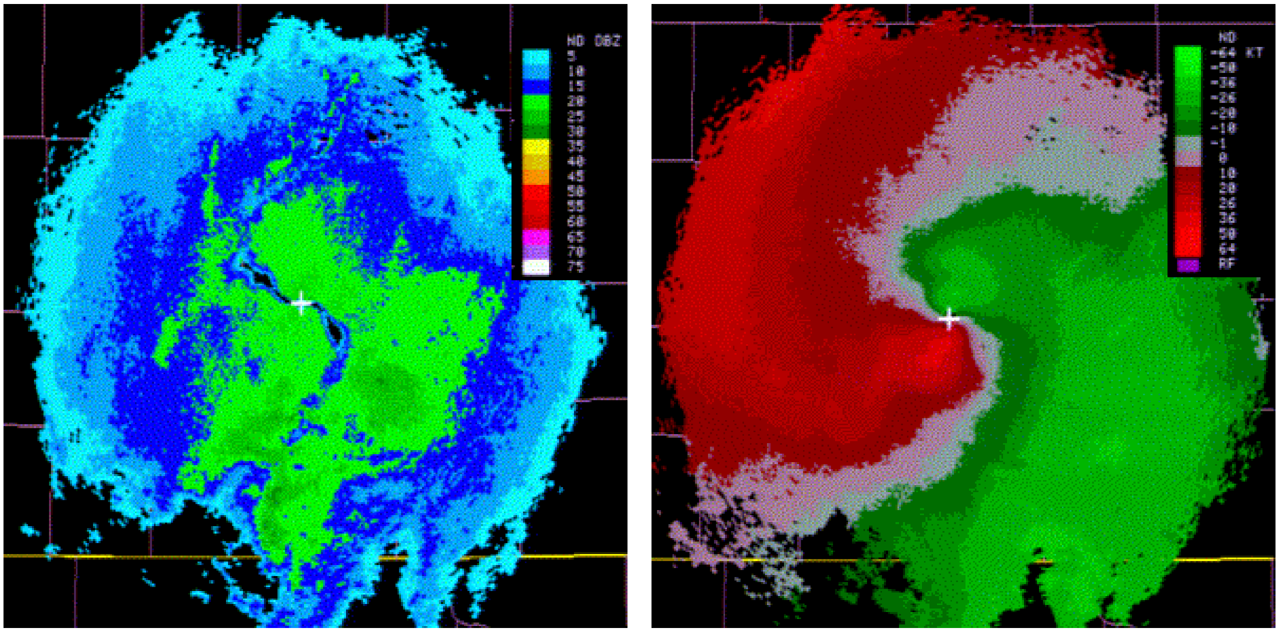

FIGURE 6. WSR-88D products showing improper use of clutter suppression.

clutter filter response times and occurs when high reflectivity gradients are present. The clutter filter decay rate is slower with narrower notch widths, therefore, data smearing is more likely to be seen when low suppression levels are used.

When data smearing occurs, weak reflectivity features on the trailing edge (azimuthally) of a high reflectivity gradient may be obscured. Additionally, the apparent areal extent of high reflectivity will be increased. The impacts of data smearing on the velocity and spectrum width estimates vary depending upon the relative power contributions from the range resolution cells for the affected range bin. For more information, refer to NWS EHB 6-521, Chapter 3.

Base data estimate bias introduced by clutter suppression filters can be mitigated by invoking clutter suppression regions only in areas where clutter is present.

6.0 Benefits Attained by Appropriate Clutter Suppression

The most obvious improvement as a result of proper clutter suppression is that ground clutter is removed from the graphical products displayed at the Principal User Processor (PUP) workstation. However, several more important data quality improvements can be realized by the intelligent application of clutter suppression.

6.1 Improved Base Data Accuracy

The most important benefit is the improved accuracy of the WSR-88D products. Since clutter suppression occurs prior to the calculation of the base data estimates, proper clutter filtering will result in the base data estimates being more representative of the actual meteorological situation (See Figure 7.) Consequently, the more accurate the base data estimates, the more reliable the output from downstream processing and algorithms and, as a result, the more accurate base and derived products.

6.2 Increased Availability of Second-Trip Velocity and Spectrum Width Data

By removing (reducing) the power contribution of ground targets from the base data estimate for first-trip range bins, the likelihood of assigning valid velocity and spectrum width data to second-trip range bins is increased.

Remember that the range unfolding of velocity (and spectrum width) data is a two-step process. First, the occurrence of overlying range bins (data from two or more range bins appearing at the same range due to multi-tripping of the high Doppler PRF) is determined by range folding the return at the surveillance PRF into the Doppler PRF intervals. If the difference in power of the two (or more) range bins being compared is less than or equal to the user-specified power difference (TOVER), both range bins are flagged as range folded (obscured). If the difference in power is greater than the specified power difference, the velocity data are assigned to the range bin having the greater power. The range bin with the weaker power is then flagged as range folded (obscured). In the situation of second (or third) trip meteorological return compared with strong clutter return from close to the radar (first trip), the return power of the clutter will usually exceed the meteorological power return by the specified power difference (TOVER). Therefore, if the clutter is not suppressed, the clutter contaminated bin will be assigned the velocity (and spectrum width) data while the bin with real meteorological targets will be flagged as range folded (obscured).

Note: When velocity and spectrum width range bins are flagged as range folded, those range bins are treated as “missing” by all downstream algorithms.

6.3 Decreased Velocity Dealiasing Failures in Clear Air Mode

A large number of velocity dealiasing failures that occur in VCP 31 can be attributed to ground clutter induced bias in the base velocity estimate. The removal of the ground clutter bias from the base velocity estimate will result in meteorologically plausible ambiguous velocity estimates. These ambiguous velocity estimates can then be readily dealiased by the dealiasing algorithm. However, residual ground clutter will continue to cause velocity dealiasing algorithm failures.

6.4 Improved Ability to Stay in Clear-Air Mode

The Clear-Air Mode Deselection logic employed by the WSR-88D compares the areal coverage of precipitation-like return to a specified value (nominal clutter area plus precipitation area threshold). If the areal coverage of precipitation-like

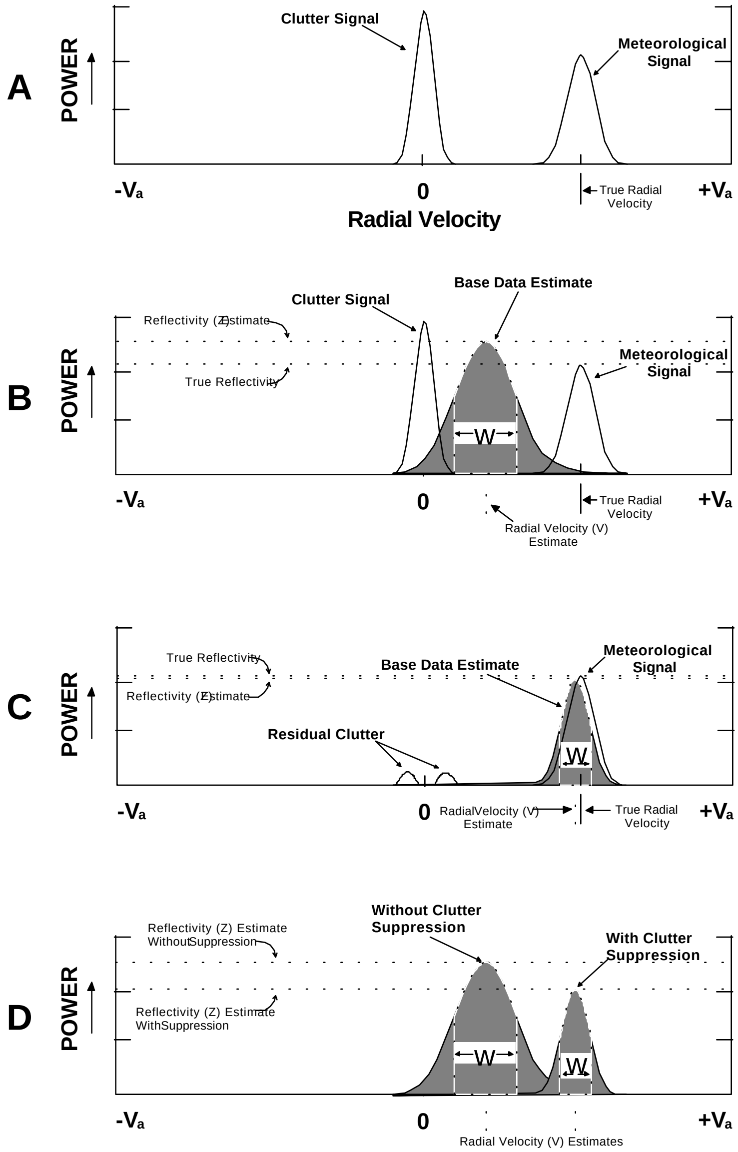

FIGURE 7.

A. A depiction of the input power distribution for a particular range bin. This smoothed depiction represents the power contributions from meteorological and ground targets.

B. The hatched, bell-shaped curve represents the average of the input power distribution with **no clutter filtering** performed. From this average, estimates for the base data (Doppler moments: Reflectivity (Z), Velocity (V), and Spectrum Width (W)) are derived.

C. The hatched, bell-shaped curve in this panel depicts the average of the input power distribution with **clutter filtering** applied, from which base data estimates are derived.

D. A comparison of the base data (Reflectivity, Velocity and Spectrum Width) estimates, using the same input power distribution, with and without clutter filtering applied.

return exceeds this value, the Radar Product Generation (RPG) computer commands the RDA computer to switch to Precipitation Mode.

The reduction of non-meteorological data from the areal coverage computation will result in a more accurate estimate of the actual precipitation present; thereby, reducing the likelihood of prematurely switching to precipitation mode due to ground clutter returns.

7.0 Suggested Clutter Suppression Management

Proper clutter filtering will enhance the accuracy and readability of the base products as well as the reliability of the derived products. To this end, the authors propose the following suggestions for clutter suppression management.

a. Generate a new Bypass Map as soon as practical after WSR-88D acceptance. This should be done when the meteorological conditions allow standard radar beam propagation. A new Bypass Map should also be regenerated whenever the “normal” ground clutter pattern changes (e.g., a high rise building is erected). In addition, it is recommended that a new Bypass Map be generated on a seasonal basis.

b. Generate a hard copy of the 0.5° reflectivity product with and without Bypass Map clutter suppression in effect. These hard copies will give the forecasters a sense of the effectiveness of the clutter filter in dealing with the normal ground clutter return.

c. Select a Clutter Suppression Region File to set aside as the baseline file. Using this file number, define two clutter suppression regions, one for each elevation segment number (as shown below). These regions should encompass the entire radar coverage area, specify the Bypass Map in control (Operator Select Code 1). For elevation segment 1, use a notch width selection of 2 (medium) for the Surveillance channel and a selection of 3 (high) for the Doppler channel. For elevation segment 2, use a notch width selection of 2 (medium) for both the Surveillance and Doppler channels. This Clutter Suppression Region File can be used to return to baseline clutter filtering after the requirement for forced clutter suppression (Operator Select Code 2) has abated.

d. At the beginning of each shift, download the baseline clutter suppression region file. This baseline clutter suppression region file will negate any forced clutter suppression, thereby revealing any ground clutter still present. This will serve to ensure that the forecasters know what clutter suppression file is in effect and will enable them to make an informed decision as to whether any forced clutter filtering is required.

e. Implement an office policy for documenting any changes to operator-defined clutter suppression regions and a procedure for recording the date, time and file number each time a Clutter Suppression Region File is downloaded to the RDA. This procedure will ensure that everyone responsible for data interpretation can determine the active clutter suppression region file.

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                       CLUTTER SUPPRESSION REGIONS                 PAGE  1 OF  2
COMMAND: AD,WXMAN1,CL,C,11,                                            RPG ALARM
FEEDBACK:COMMAND EXECUTED - AD,*****,CL,C,11,DO                      OPER A/L  21

             (M)odify, {LINE#}            (DE)lete, {LINE#}           (DO)wnload
                                           (E)nd                        (C)ancel
```

Region	Start Range	Stop Range	Start Azimuth	Stop Azimuth	Elev Seg Number	Operator Sel Code	Channel Width D	S
1	2	510	0	360	1	1	3	2
2	2	510	0	360	2	1	2	2
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0

8.0 Summary

A well trained staff utilizing a manageable documentation plan must be in place to ensure that the appropriate clutter filter definition is applied for each situation. The haphazard application of clutter suppression regions may be detrimental to the warning and forecast functions of an office. However, the intelligent application of clutter suppression regions can significantly improve the quality of WSR-88D products.

For additional information on the clutter filtering technique used in the WSR-88D refer to the NWS EHB 6-521 Chapter 3, Section 3-5. For step-by-step instructions for defining clutter suppression regions refer to the WSR-88D Operator Handbook Unit Control Position (UCP) Job Sheet 1-4.

9.0 Acknowledgments

The authors would like to thank Steven D. “Pal” Smith for his assistance in confirming research discoveries for this paper. Also, Cynthia A. Chrisman for her technical contributions and guidance in readability and grammaticality.