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Session X. Airborne Doppler Radar / NASA

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Clutter Modeling of the Denver Airport and Surrounding Areas
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**CLUTTER MODELING
OF THE DENVER AIRPORT AND SURROUNDING AREAS**

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Abstract

To accurately simulate and evaluate an airborne Doppler radar as a wind shear detection and avoidance sensor, the ground clutter surrounding a typical airport must be quantified. To do this, an imaging airborne Synthetic Aperture Radar (SAR) was employed to investigate and map the Normalized Radar Cross Sections (NRCS) of the ground terrain surrounding the Denver Stapleton Airport during November of 1988. Images of the Stapleton ground clutter scene were obtained at a variety of aspect and elevation angles (extending to near-grazing) at both HH and VV polarizations.

This presentation will discuss the method of data collection, the specific observations obtained of the Denver area, a summary of the quantitative analyses performed on the SAR images to date, and the statistical modeling of several of the more interesting stationary targets in the SAR database. Additionally, the accompanying moving target database, containing NRCS and velocity information, will be described.

Denver Ground Clutter Observations and Data Collection **V. E. Delnore, Lockheed Engineering & Sciences Company**

Outline

Two years ago at the Williamsburg meeting, we described the ground clutter data we were hoping to obtain at Denver the following month. Well, the flight was a success, and now we want to describe the data and some of the analyses that we and the Environmental Research Institute of Michigan (ERIM) have done.

CLUTTER MODELING OF THE DENVER AIRPORT AND SURROUNDING AREAS

Outline

- Basis for Studying Ground Clutter
- Method of Measuring Ground Clutter
- Flight Lines and Observations
- Ground Clutter Statistical Modeling/Analysis
- Results of Statistical Analysis
- Moving Clutter Statistical Modeling/Analysis
- Summary

Basis for Studying Ground Clutter

The motivation here is that we're developing a Doppler radar to be carried on the airplane, looking down along the glide slope, to detect wind shear. But there's a backdrop of ground clutter we must deal with. To suppress the effects of ground clutter, we have to understand its distribution, statistics, and characteristics.

To do this, we flew a Synthetic Aperture Radar (SAR) at Denver -- not to detect wind shear, but to study ground clutter. What we learn about ground clutter from the SAR goes into a computer model of the airport environment as seen by the airborne Doppler radar. Les Britt will describe that to you in the next paper.

CLUTTER MODELING OF THE DENVER AIRPORT AND SURROUNDING AREAS

Basis for Studying Ground Clutter

- Lack of Historical Near-Grazing Clutter Data
- Simulate Weather Radar Operating in Presence of Ground Clutter
- Understand Airport Clutter Environments

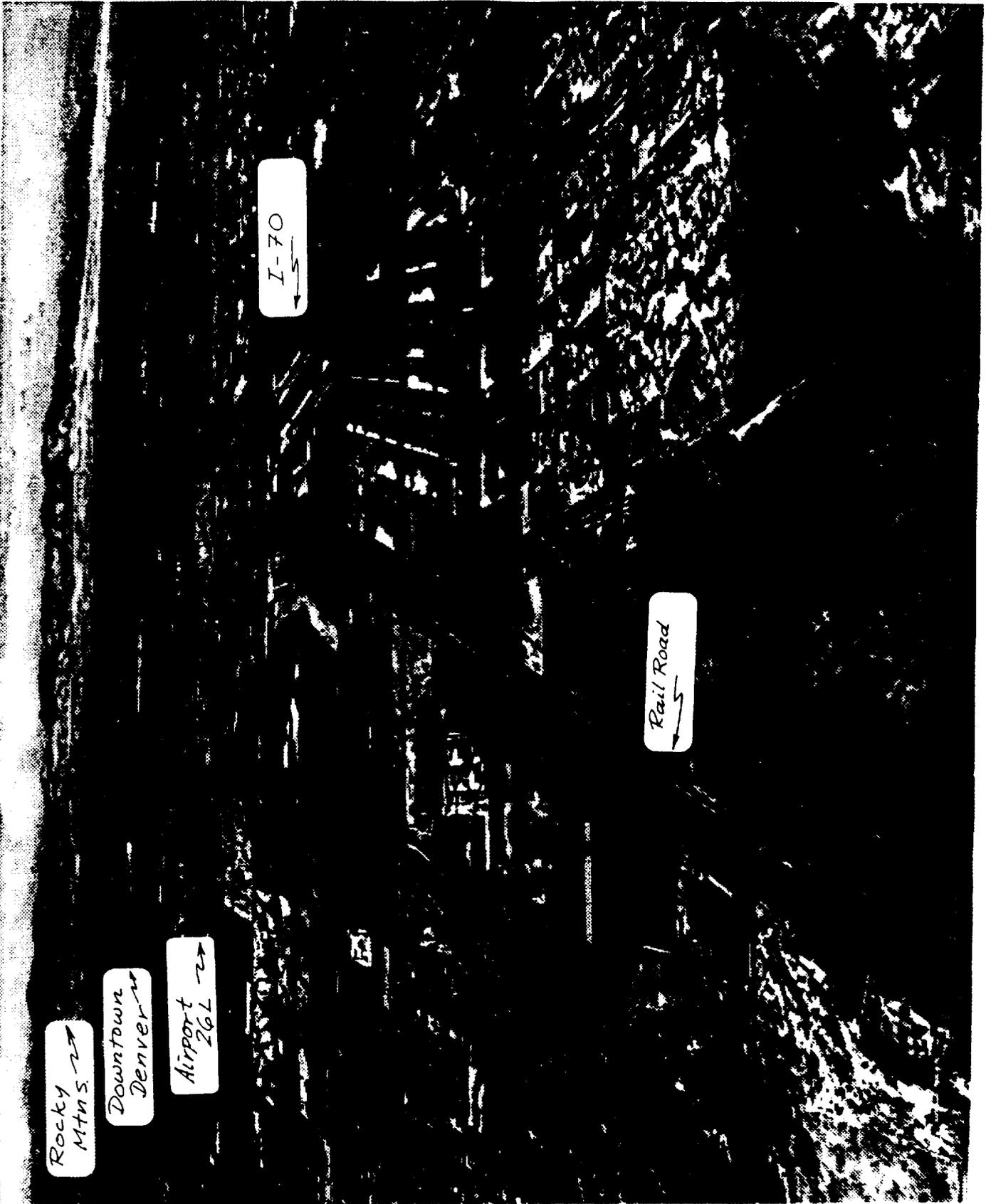
Radar's Eye View of Airport

Here's the approach to 26-Left at Denver.

You can see the runway, but look at all this other stuff around it: tall buildings, mountains, industrial parks, even moving stuff on these highways are railroads.

All reflecting your radar beam and sidelobe energy back up to you, cluttering up your radar screen and increasing the difficulty of any discrimination scheme in your signal processor.

This is what we're trying to sort out. We're not constructing a data base for a subtraction scheme, but instead trying to understand ground clutter so we can process it out in the general case.



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CLUTTER MODELING OF THE DENVER AIRPORT AND SURROUNDING AREAS

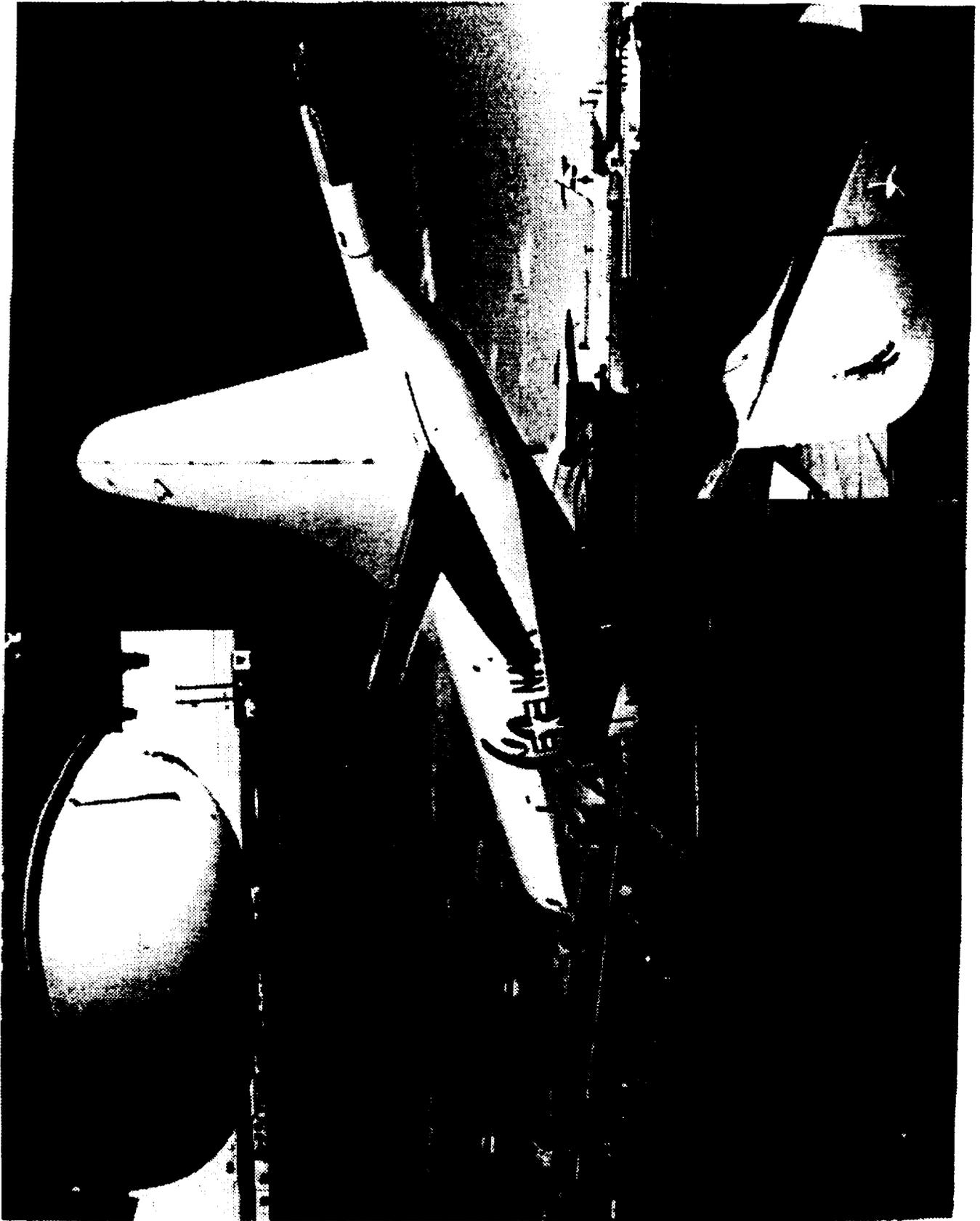
Method of Measuring Ground Clutter

- Synthetic Aperture Radar (SAR)
- Down/Cross Range Resolution
- Polarization

P-3 with SAR

Here is the P-3, at Buckley Air National Guard Base, a few miles southeast of Denver Stapleton, on the morning we flew.

We used an X-band SAR, with its antenna mounted on the belly of a P-3 operated by the Naval Air Development Center.



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CLUTTER MODELING OF THE DENVER AIRPORT AND SURROUNDING AREAS

Flight Lines and Observations

- Description of the Denver SAR Images
- Incidence Angles and Polarizations
- Ground Resolution

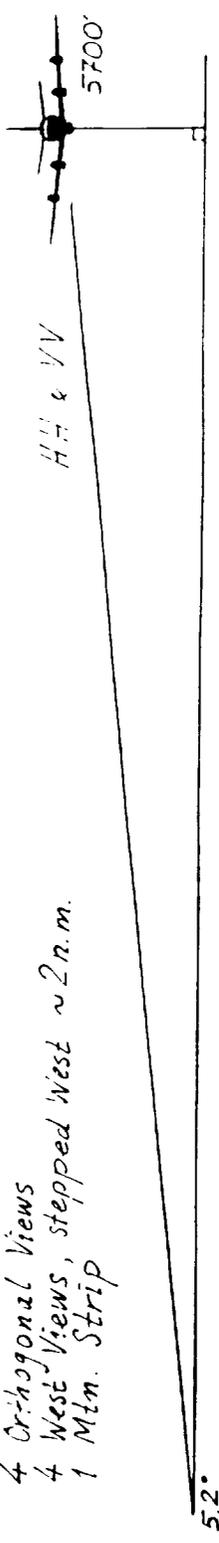
SAR Swath Geometry

This is the setup we used to map out the ground clutter. We flew several configurations, differing in depression angle and polarization.

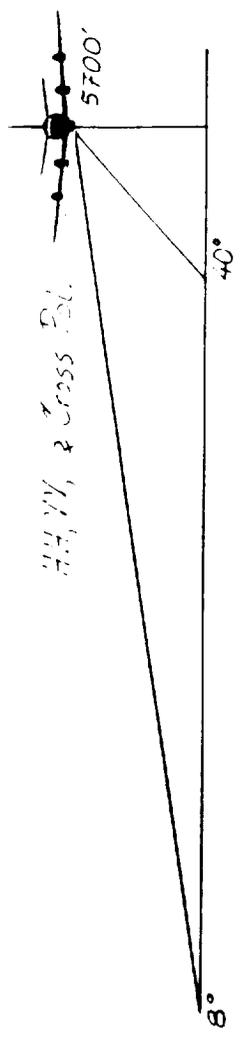
The P-3 is shown on the right, with the SAR looking out to its side, and mapping everything within this swath at a resolution of 3 m on the ground.

The usual scheme got us out to a depression angle of about 5 degrees, but for a couple of passes we flew at a lower altitude (all AGL, of course), and got out to 3 degrees. Reflectivity at these near-grazing angles is important, because that's what a real-aperture radar looking down a 3-degree glide slope will be seeing.

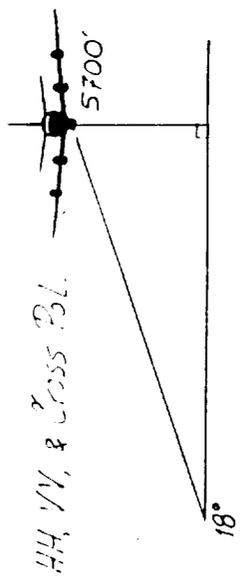
4 Orthogonal Views
 4 West Views, stepped West ~ 2 n.m.
 1 Mtn. Strip



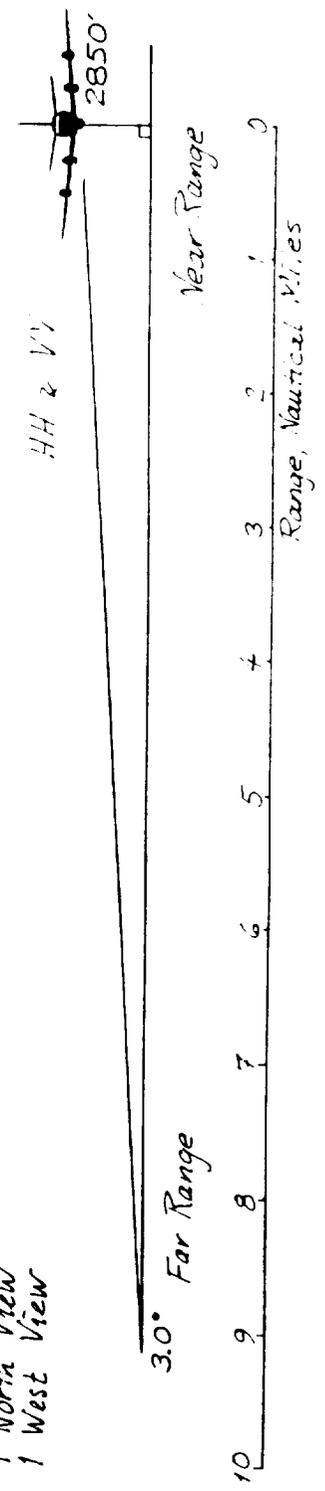
4 Orthogonal Views
 1 Mtn. Strip



1 North View
 1 West View



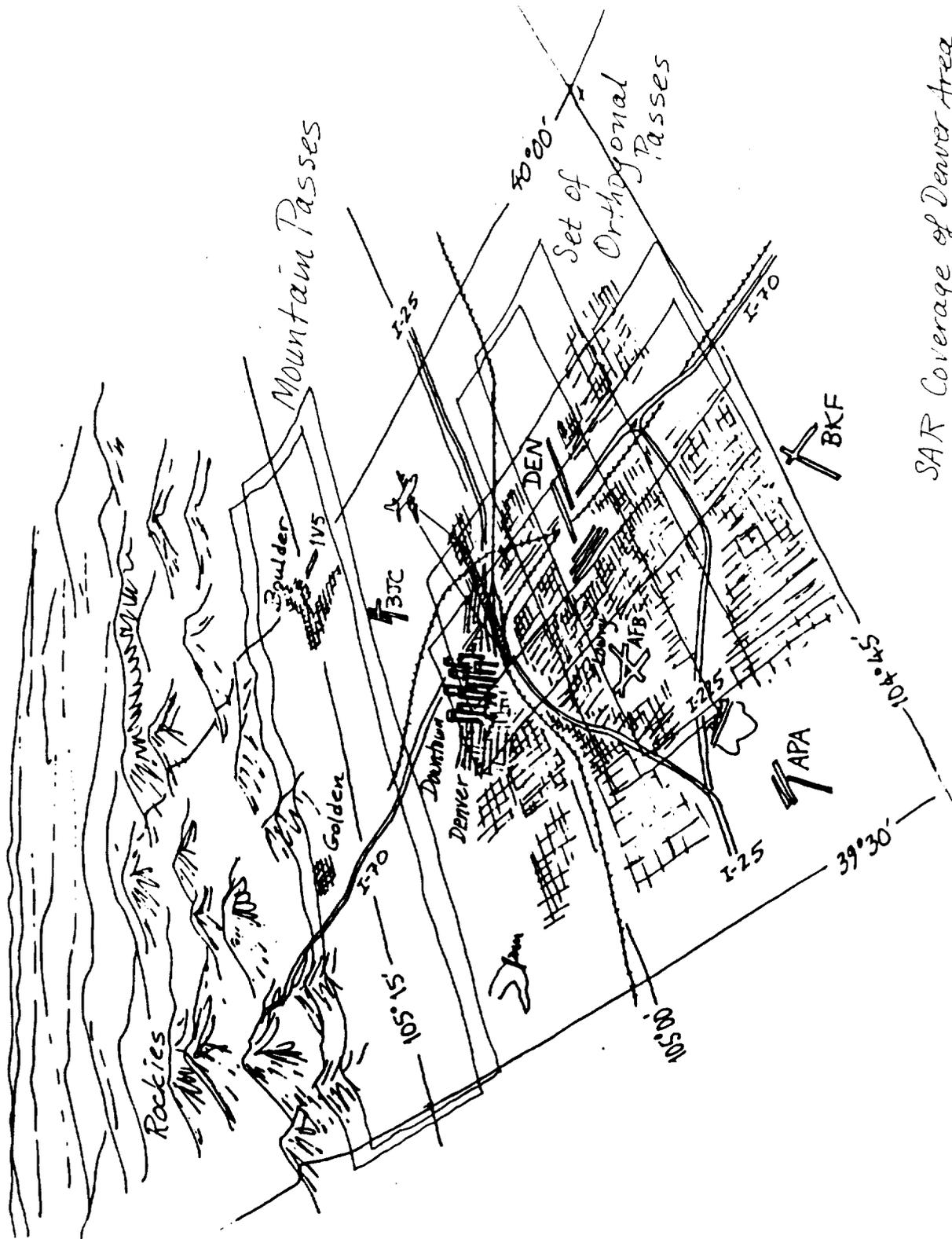
1 North View
 1 West View



SAR Swath Widths, Denver '88

SAR Coverage of Denver Area. Part 1

Here's a perspective sketch of the Denver area: The airport, downtown, the mountains, and Boulder; the marked areas on the ground show some of the areas we mapped. There are orthogonal looks at the same target area (the airport), and the mountain passes.

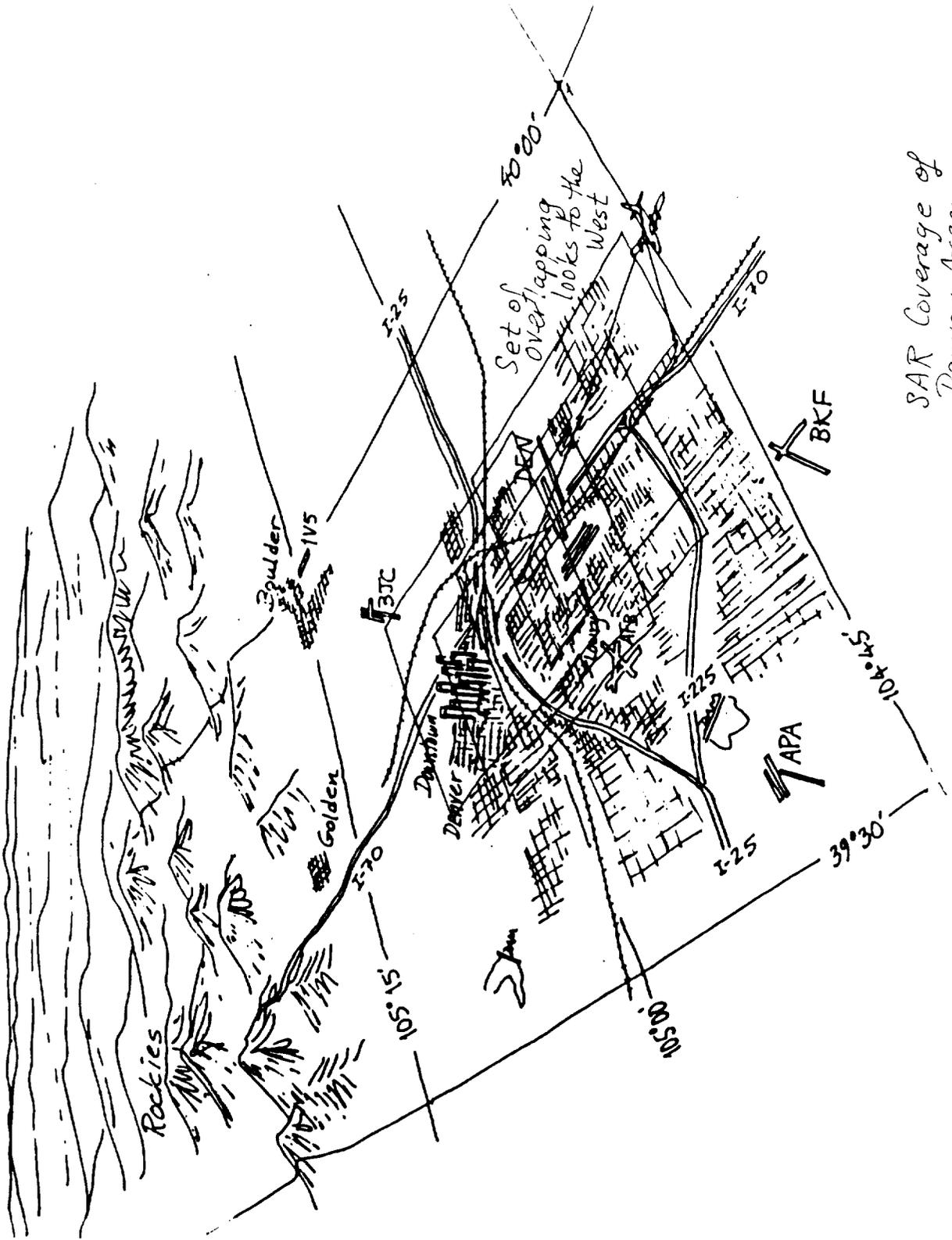


SAR Coverage of Denver Area,
Part 1

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SAR Coverage of Denver Area, Part 2

There are also 4 successive passes, each stepped about 2 1/2 miles over, and all looking in the same direction, so that we see each target at up to 4 different depression angles.



SAR Coverage of
Denver Area,
Part 2

SAR Image of Denver Area

Here's some of the processed data:

This is a false-color SAR image, rendered here in gray-scale, at 20 m ground resolution.

The image is corrected for range fall-off, but not normalized to any one depression angle, so what you're seeing is differences in reflectivity due to depression angle and to the target's characteristics.

The airport is the dark area in the center, with its runway areas and passenger terminal. you can see buildings, highways, and lots of clutter sources.

We've identified and cataloged the normalized radar cross section and depression angle of each type of target on several of these images, to model the stationary environment around Denver.

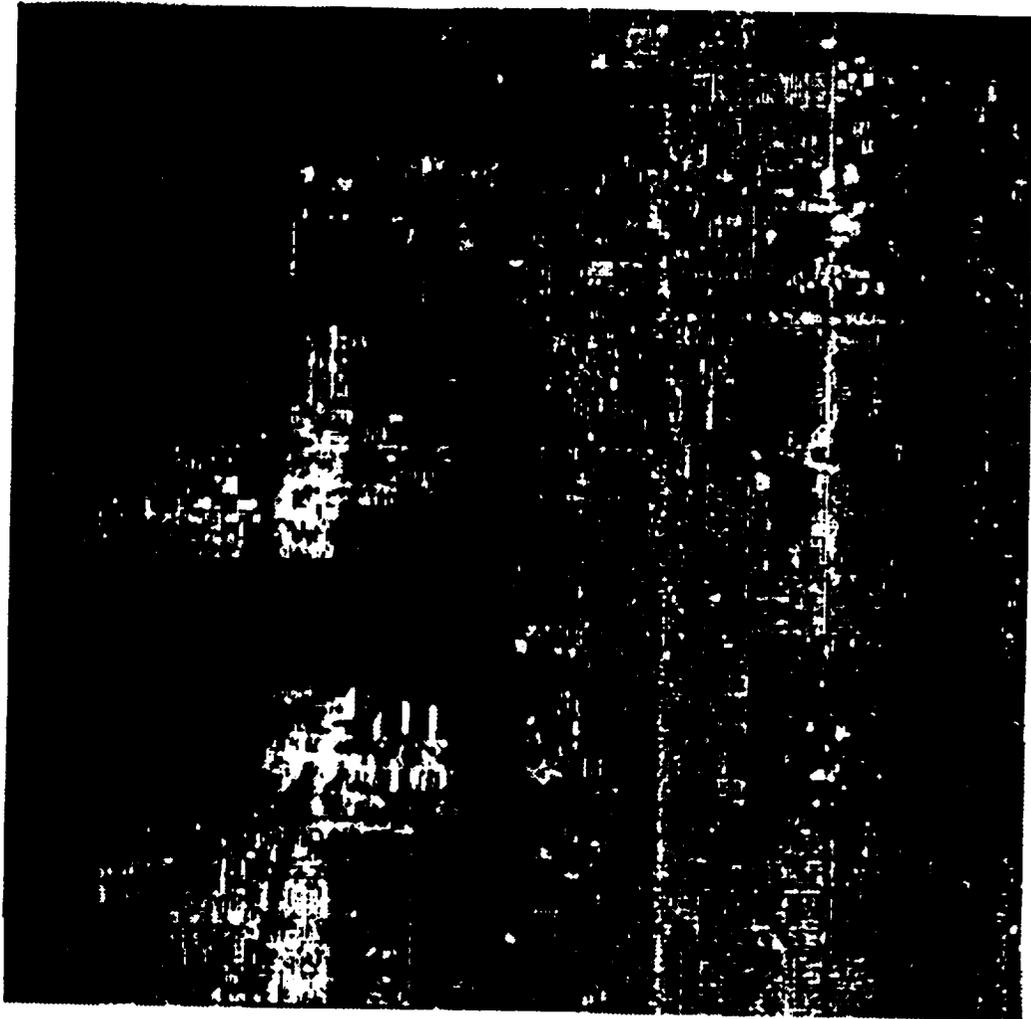
And, using aerial photographs and lots of students, we've estimated the distribution, density, and speeds of car, truck, and train traffic along some of these highways, streets, and railroads.

This gives us moving target information, which we feed into Les' model.

DENVER STAPLETON INTERNATIONAL

14.3 km HH POLARIZATION

82°



43°

11.4 km

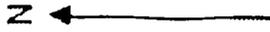
0

25



-45

dB



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Statistical Analyses and Ground Clutter Modeling
S. D. Harrah, NASA Langley Research Center

Preliminary Comments

In order to realistically simulate and evaluate the performance of any airborne Doppler radar as a forward looking wind shear sensor, it is imperative to generate an accurate representation of the backscattered ground clutter signal. Researchers at NASA LaRC have developed a robust airborne Doppler radar simulation program, which generates a realistic radar I/Q signal from a complex scattering scene. This scene may consist of weather, stationary ground clutter, and/or moving clutter. The simulation program incorporates a Normalized Radar Cross Section (NRCS) ground clutter database as its source for the ground clutter signal. A Synthetic Aperture imaging Radar (SAR) was employed to measure the backscattered NRCS levels of the terrain surround the Denver Stapleton airport. It should be noted that, all the angles in this section are referred to as incidence angles. The classical definition of incidence angle is the angle measured from the surface normal. Since it is impractical to measure the mean surface normal for each ground cell, the incidence angle referred to here is measured from vertical for each ground cell. It should further be noted that, some authors prefer to use the complement of the incidence angle often called the depression angle.

Ground Clutter Statistical Modeling/Analysis

In this portion of the presentation, I would like to show some of the results of a statistical analysis performed on the Denver Stapleton ground clutter database. The purpose of this analysis may be divided into three categories. First, to validate the backscatter levels observed in the SAR images. Second, to determine any pertinent statistical information which would help in the modeling of ground clutter at high incidence angles. Third, to determine if any statistical properties existed in the Denver ground clutter database which would help in the discrimination of the backscattered ground clutter and weather signals.

To achieve these goals, we analyzed the NRCS levels observed in the Denver ground clutter database to investigate incidence angle and polarization effects and to determine the utility of the spatial Normalized AutoCorrelation Function (NACF). In investigating incidence angle and polarization effects, we generated both full image and sub-image analyses. Some of the specific targets of interest, which we investigated were: the urban environment, isolated tall buildings, and scenes of the Rocky mountains. Some of the statistical parameters generated during the analysis of each image were: the dynamic range (minimum to maximum), the mean, and the variance, of the NRCS levels found in the Denver ground clutter database.

CLUTTER MODELING OF THE DENVER AIRPORT AND SURROUNDING AREAS

Ground Clutter Statistical Modeling/Analysis

- Investigate Incidence Angle and Polarization Effects
 - Full Image Analysis
 - Specific Targets
 - Urban Environment
 - Tall Buildings
 - Mountains
 - Distributions
 - Min. & Max.
 - Mean & Variance
- Spatial Normalized AutoCorrelation Function (NACF)

Denver Stapleton SAR Image (HH Polarization)

The next two SAR images are grey scale representations of the NRCS values obtained for the Denver Stapleton ground clutter scene. Each image has been calibrated, mapped from slant range to ground range, and corrected for range fall-off. The first image was obtained using HH polarization and the second used VV. The two images were recorded simultaneously using the ERIM SAR. Each image is comprised of thousands of cells, ~20 m X 20 m, in size. The approximate total dimensions of each image and the near and far range incidence angles are reported on each image.

DENVER STAPLETON INTERNATIONAL

HH POLARIZATION

14.3 km

82°



43°

11.4 km

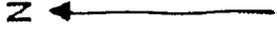
0

25



dB

-45



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Denver Stapleton SAR Image (VV Polarization)

Note that , the two images are on a common grey scale; thus, allowing a direct comparison of the intensity for common areas in each image. Because of the rather large quantity of data in each image, as well as, the large dynamic range of the NRCS values, I doubt that these reproduced images will be highly enlightening. Therefore, I would like to remind everyone that, a complete set of SAR images for Denver are available to anyone interested. This data can be obtained on a variety magnetic storage media and in almost any format.

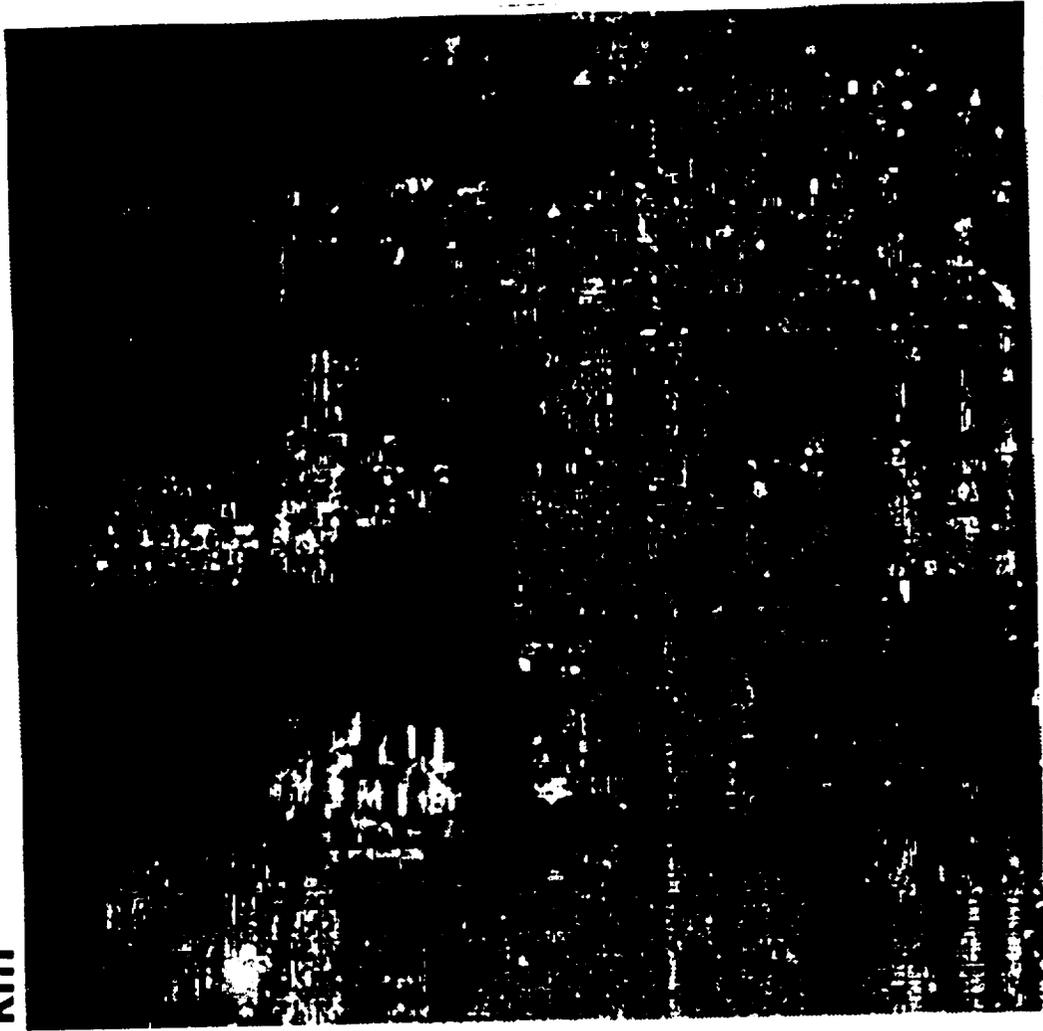
Although some differences can easily be seen in the two images, only through a statistical analysis can the differences be quantified.

DENVER STAPLETON INTERNATIONAL

VV POLARIZATION

14.3 km

82°



0

11.4 km

43°

25



-45

dB



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Histogram of the Denver Stapleton SAR Images

This histogram clearly shows the distribution of NRCS values in the two images. The mean and the standard deviation for each distribution are specified at the top of the plot. From this full image analysis it appears that VV polarization would produce a 10 to 15 dB lower ground clutter return than would HH polarization.

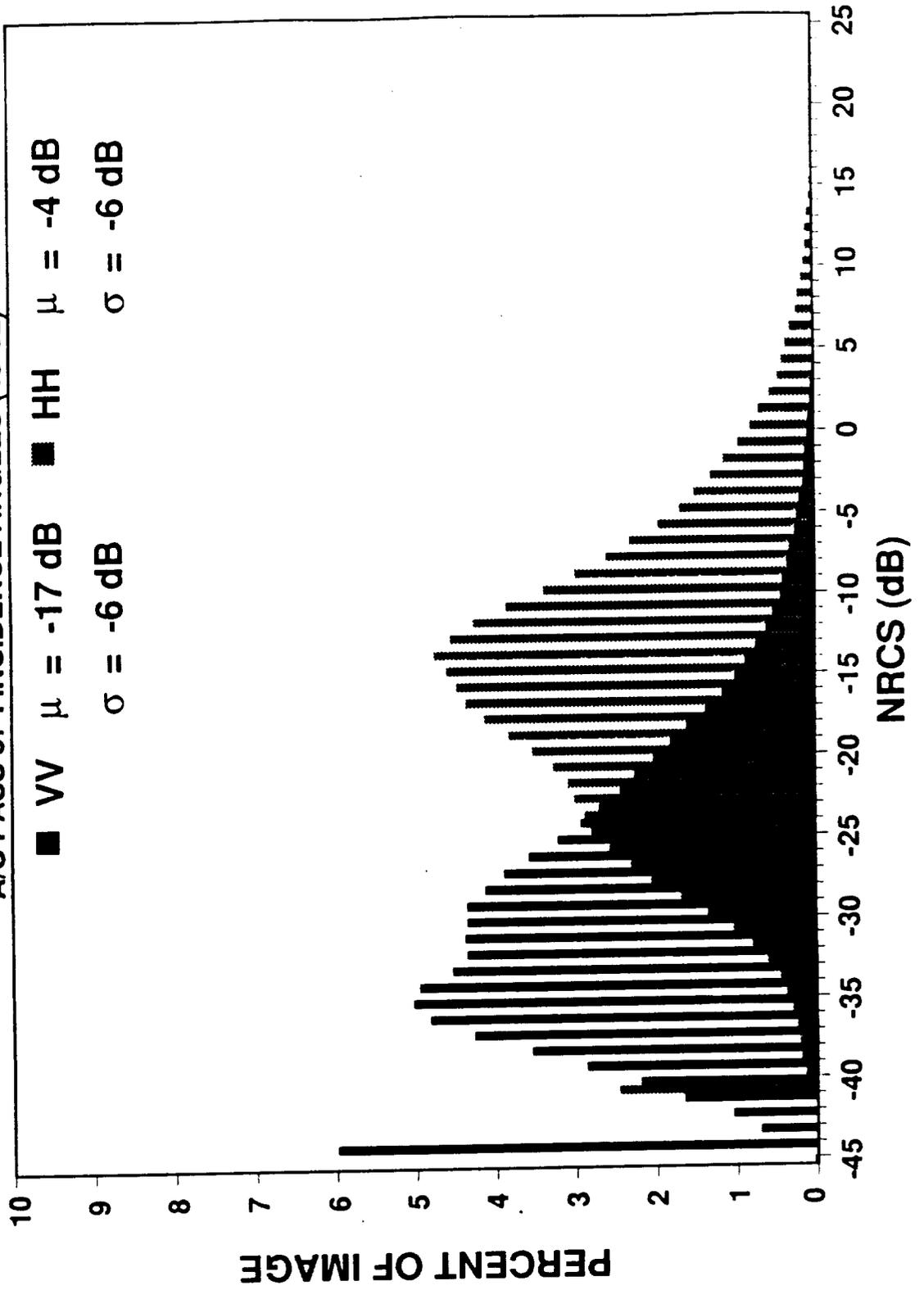
Often HH polarization is used in weather radars, since it gives a slightly larger rain return, typically a few dB. However, this occurs almost exclusively with large rain drop sizes, where the droplets flatten during their descent due to air resistance. But larger drop sizes also produces a larger signal, which in turn reduces the need for using the polarization sensitivity of rain. Since the 10 or 15 dB gained would out weight the 2 or 3 dB lost, the largest Signal-to-Clutter Ratio (SCR) for this clutter scene would be achieved using VV polarization.

Even though these statistics contradict the usual preference of HH polarization for a weather radar, we do not contend that all wind shear radars be built using VV polarization exclusively. Which polarization should be used for wind shear detection and under what circumstances, is still an open question and will be investigated during our flight program. It should be reemphasized that the statistics shown here are for large images consisting of many different scattering types, at very high incidence angles, and are only necessarily representative of this one image. Some images may produce larger VV returns. Image composition is the prime factor for determining which polarization will produce the larger returns.

Since image composition is the prime factor in determining polarization and more importantly in producing the larger SCR, full image analysis can only show the aggregate effect of all the scatterers over the entire image. In order to specify how each scattering type contributes, we divided each image into smaller near-homogeneous sub-images on which we performed the same types of statistical analyses. Because of time, I would like to show you, only a small fraction of the many sub-image results we have obtained, for specific targets of interest.

DENVER STAPLETON INTERNATIONAL AIRPORT

DENVER IMAGES 2 & 6 : (HH) & (VV) POLARIZATIONS
A/C PASS 37 : INCIDENCE ANGLES (43-82)



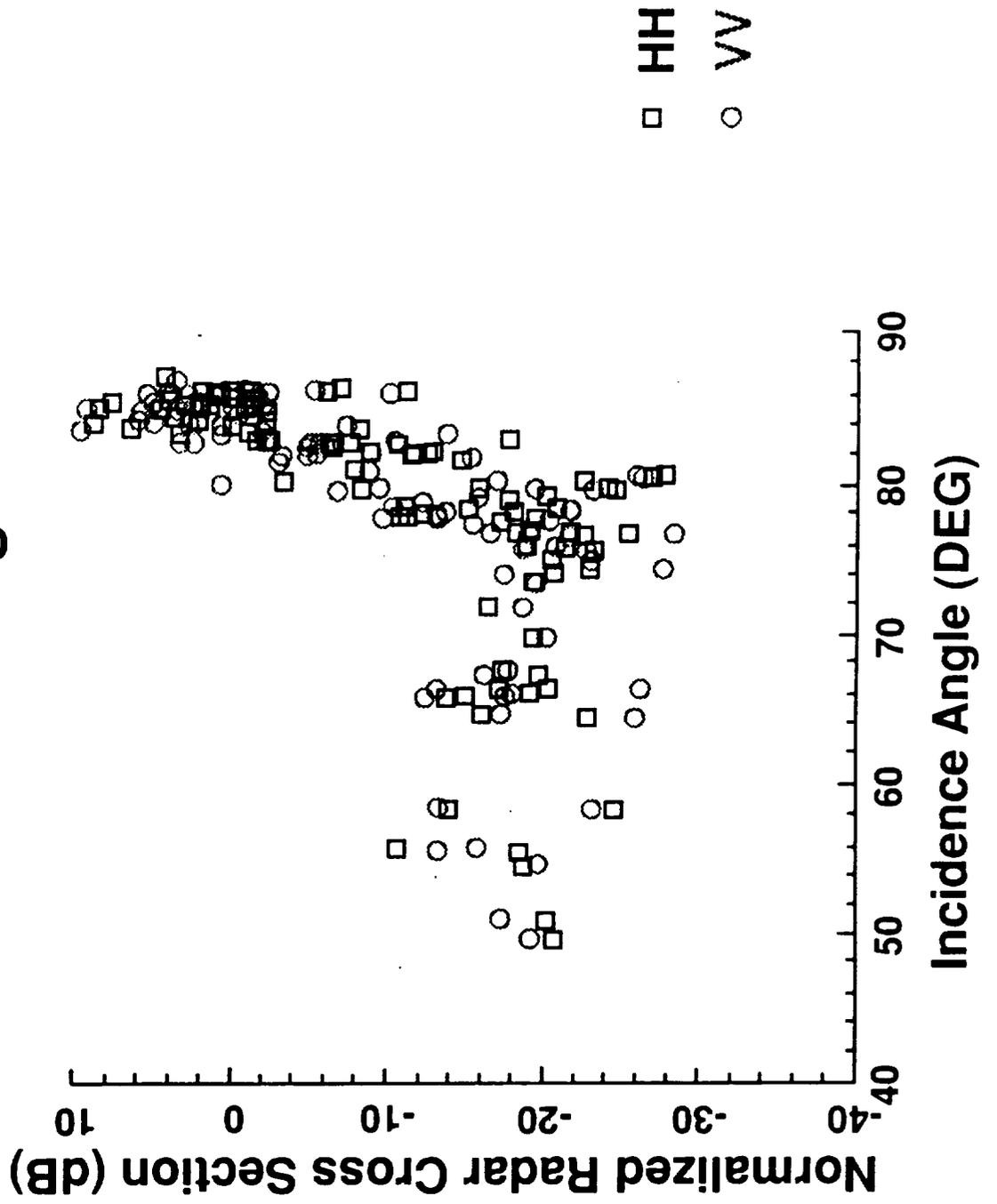
Scattergram of Tall Buildings in the Denver Stapleton SAR Images

Tall buildings, such as those in an urban environments, are primary sources of ground clutter, since they offer a large physical cross section and are constructed of metal and concrete. Also, at incidence angles near-grazing, which would be typical of a wind shear radar during landing, the flat sides of a building will produce a near specular return. Typical NRCS values are shown in the scattergram as a function of incidence angle. These NRCS values were calculated for numerous, isolated, tall buildings present in the SAR images.

This scattergram shows at least two important NRCS features of tall buildings. First, the influence of the incidence angle and the severity of tall building NRCS levels. Second, the insensitivity of the buildings in these images to polarization. In the case of the former, this plot shows that NRCS levels beyond the dihedral angle but 10° or more shy of grazing, produce little return. However, the NRCS can get quite large for near- dihedral or grazing incidence. The scattergram also shows that these buildings are polarization insensitive. So we might not gain any ground clutter suppression by choosing one polarization over another, for images (or environments) consisting of primarily tall buildings.

Although Denver has a number of tall buildings, it should be noted, that these areas do not comprise more than 10% of the total SAR image. Thus one might immediately guess that natural terrain causes the polarization sensitivity. Although natural terrain does account for some of the polarization sensitivity, it is the rural and lightly industrialized areas which seems to make the majority of the contribution.

Ground Clutter Tall Buildings



SAR Image of the Denver Central Business District (CBD)

The typical size and consistency of a sub-image is shown in this grey-scale representation of the Denver Central Business District (CBD). It should be recalled that, a sub-image consisted of primarily one type of scattering category. However as often was the case, even small areas contained different type of scatterers; note the several highways crossing this sub-image of the Denver urban scene.

The four westward-looking images of Denver, generated by four aircraft tracks each successively more westward, produced a unique situation. Since each image consisted of significant portions of the previously obtained image, it was possible to compare NRCS levels of the same sub-image at several different incidence angles (elevation) while maintaining roughly the same aspect angle.

CENTRAL BUSINESS DISTRICT

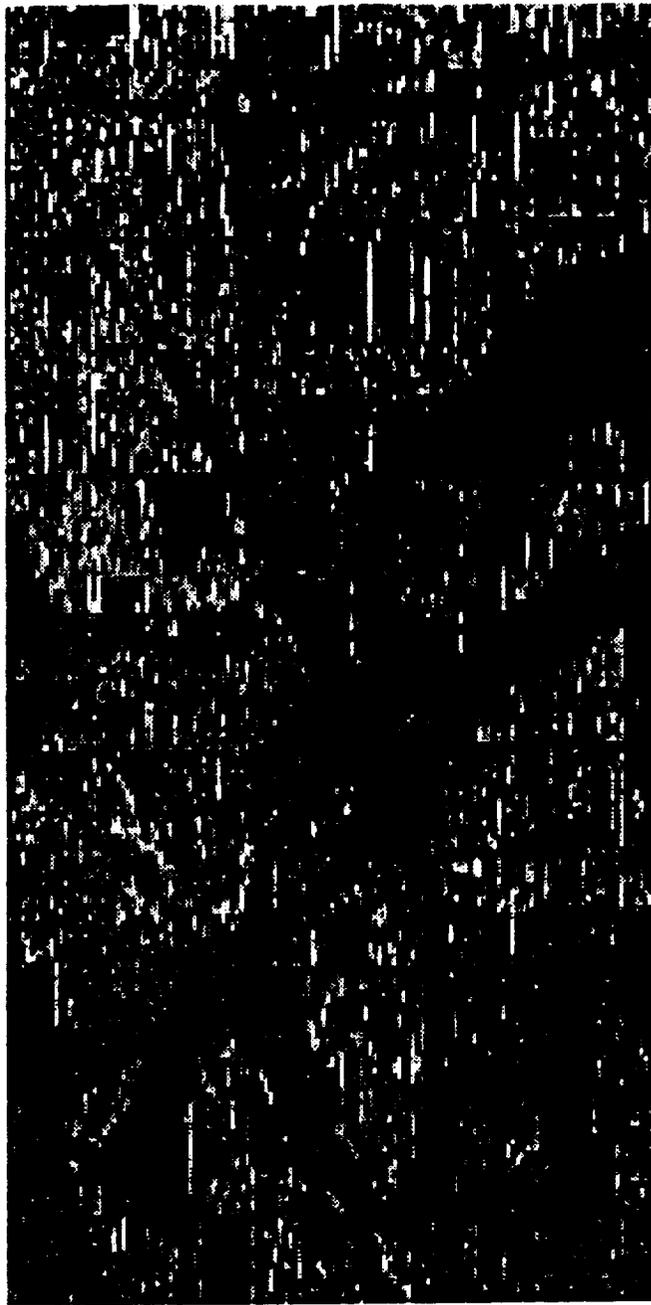
20



-40

dB

2.1 km



0

6.3 km

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Incidence Angle Statistics of the Denver CBD SAR Images

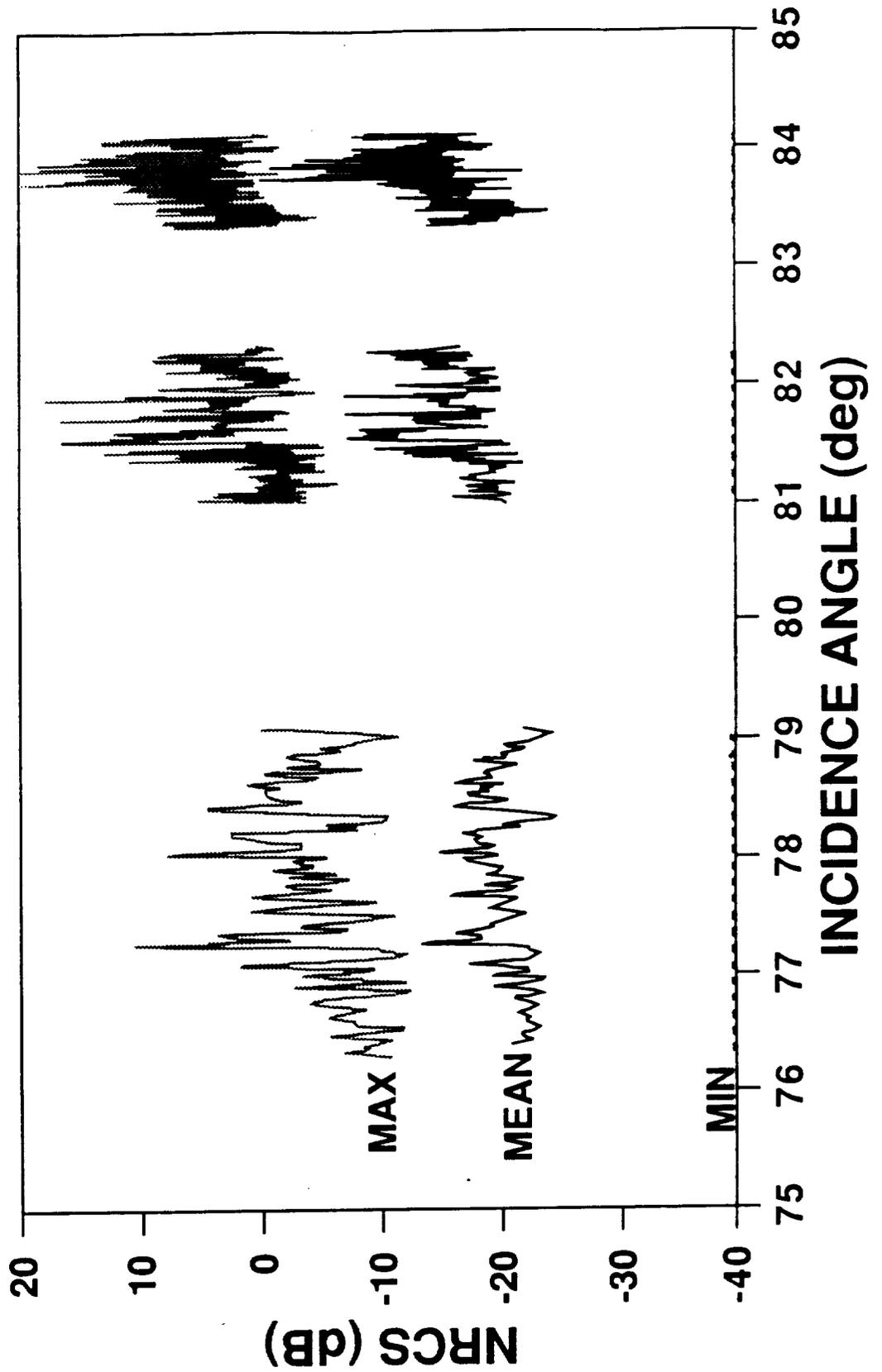
For Denver's CBD we were able to extract three sub-images, each recorded using HH polarization and each covering a different incidence angle range. Statistics were developed for each of the sub-images individually. Shown here are the minimum, mean, and maximum NRCS values for the specific incidence angles occurring in each sub-image.

The procedure used to develop these statistics is as follows. Each full image is analyzed and the location of the specific sub-image is determined. This portion of the image is electronically copied to a file along with its incidence angle information. Thus the statistics are representative of the the same ground area viewed at different elevation angles. Each sub-image is carefully examined to verify that it is comprised of the same location and number of cells as is in the other sub-images. Then the dynamic range and the mean NRCS for each row in each sub-image is determined. Naturally the mean and any other calculated statistics are generated from their linear scale values rather than their logarithmic representation. Since all the cells in a single row are at the same incidence angle, we may plot these statistics versus the incidence angle for each row, to obtain the figure shown here.

This type of graph shows the general trend in the specific clutter category (urban) as a function of incidence angle. The mean NRCS level is nearly constant across the entire range of incidence angles, increasing only ~5 dB around 84°. Note however that, the dynamic range increases some 20 to 30 dB over the range of incidence angles. This information is of great use, for statistically modeling urban ground clutter.

It might further be noted that, this complex, near-homogeneous urban clutter scene does not exactly agree with the previous scattergram plot of isolated, tall buildings (comparing the mean NRCS with those in the scattergram plot). Although agreement is good at the lower incidence angles (~76° - 79°), where the contributions by tall buildings, as suggested by the scattergram plot, is roughly comparable with the mean, the strong NRCS levels of tall buildings at the higher incidence angles does not seem to affect the mean NRCS level significantly. Since each range bin of our radar footprint is much larger than the cell size used in the tall building clutter, we would expect to see NRCS levels more indicative of the mean level rather than the maximum.

**DENVER STAPLETON INTERNATIONAL
CENTRAL BUSINESS DISTRICT**

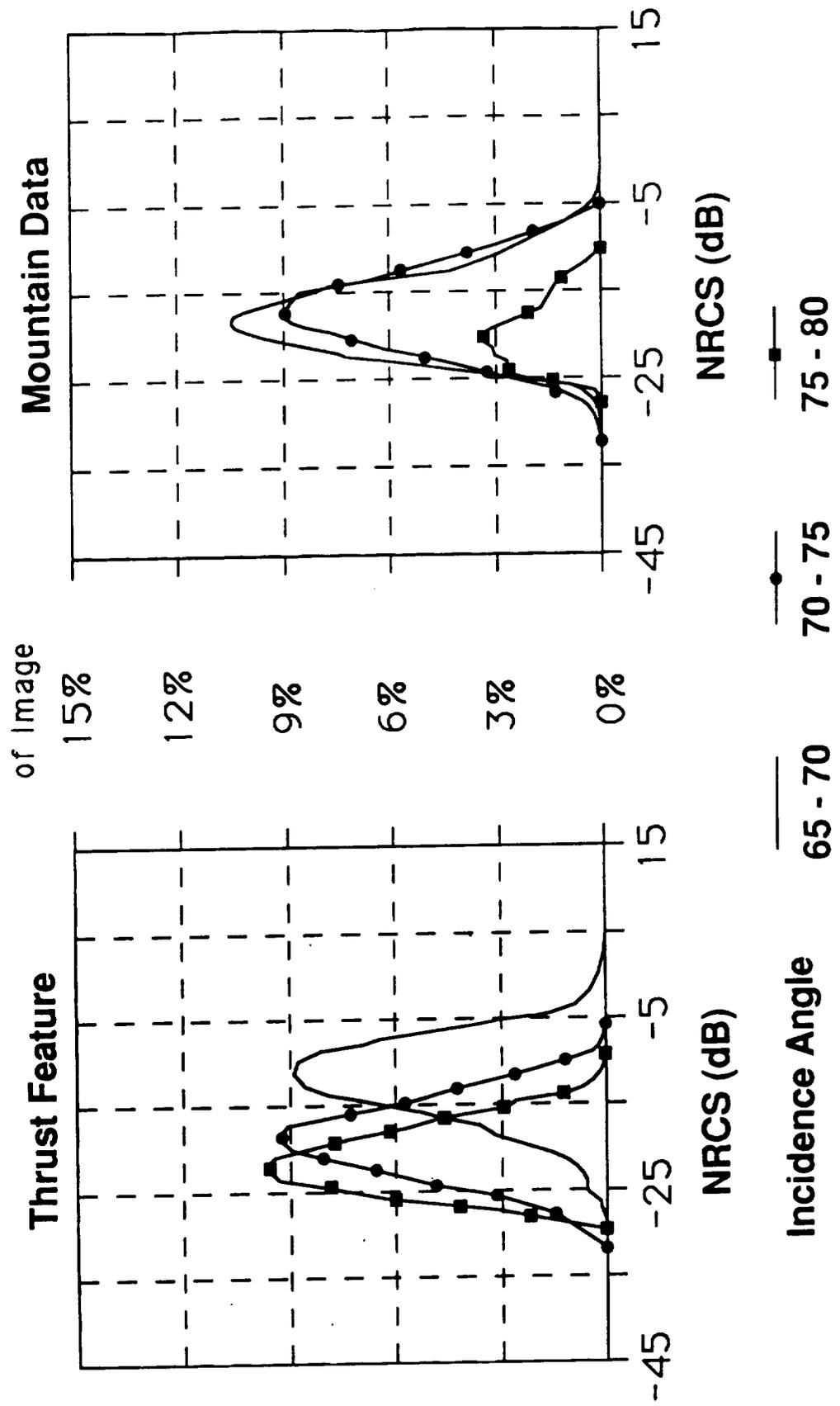


Statistics of the Rocky Mountain SAR Images

Another target of interest was the mountainous areas surrounding Denver. NRCS data was obtained of these areas in order to quantify the second-go-around returns from the mountains. This data was collected for both the "Thrust Feature" and the actual Rocky Mountains themselves. The plots show both typical NRCS levels and incidence angle effects for both types of scatterers. Specifically, the plots show that the only significant NRCS levels are contained in some of the "thrust feature" data; however, since these high levels only occur at low incidence angles, it is not likely that an aircraft's radar will encounter this "thrust feature". Furthermore, it should be noted that the "thrust feature" is a high, directionally dependent (aspect angle) scatterer and because of the aspect views obtained, the NRCS levels shown here should be representative of the largest levels that might be observed for these elevation angles.

Rocky Mountain NRCS Distribution

HH Polarization



Results of Statistical Analyses Performed on SAR Images

1. The mean NRCS levels, for each scattering category, contained in the Denver Stapleton ground clutter database are consistent with the few available sources of high incidence angle ground clutter data. This conclusion is based upon a literature survey and a comparison with previously obtained ERIM archived SAR images.
2. If a statistical model is incorporated into a computer simulation, rather than a direct measurement of actual NRCS levels, then the variance must be increased with increasing incidence angle. Although empirically derived formulae are often used in statistical models for NRCS ground clutter generation, these formulae typically only describe the variation of the mean NRCS level with incidence angle (i.e., they use a fixed variance). However, it is necessary to also incorporate fluctuations in the second moment statistic (the variance) as a function of incidence angle, if one is to produce a truly realistic, backscattered, ground clutter, radar I/Q sequence.
3. We have found little or no useful levels of the 2-dimensional, spatial, Normalized AutoCorrelation Function (NACF) in the Denver SAR images. Although we have not shown the results of the investigation of the applicability of using a 2D spatial NACF, it should be noted that such an investigation has been pursued. There have been numerous hypotheses suggested, by myself and other researchers, for the failure of such a technique applied to the Denver images. However, I do not feel that I can elaborate on each hypothesis without showing some of the substantiating plots, and since it has been determined that this information would not be appropriate for this level of a technical conference, I will only report this conclusion without the substantiating information.
4. A significant level of polarization sensitivity has been observed during full image analyses. However many of the sub-image analyses of the various targets of interest (primarily consisting of high NRCS ground clutter sources) have shown little or no polarization sensitivity. It appears that the primary factor determining a wind shear radar's polarization is the composition of the ground clutter scene. Different polarization configurations may be necessary in an operational wind shear radar with the choice of polarization based upon the constituent scatterers surround an airport. I believe this is a issue which will only be determined by experience, and at our next meeting I hope to be able to report our finding on this matter.
5. A detailed inspection of the Denver ground clutter database has shown that man-made targets are the only sources of large NRCS ground clutter at near-grazing incidence angles. Natural targets, in general, offer very low NRCS levels compared to man-made targets at the same high incidence angles. Full image and sub-image analyses have been performed in order to isolate and coregister large NRCS sources, thus producing this result.
6. The relative levels of backscattered signal returning as second-go-around from the mountainous terrain surrounding Denver should produce little effect on the performance of a wind shear radar. This too will be investigated during our experimental flights around Denver.

CLUTTER MODELING OF THE DENVER AIRPORT AND SURROUNDING AREAS

Results of Statistical Analyses Performed on SAR Images

- Mean NRCS Ground Clutter Levels Agree with Literature
- Variance Increases with Increasing Incidence Angle
- Little/No Useful Spatial Correlation Effects
- Some Polarization Sensitivity in Full Image Analyses
- Man-made Targets are the Only Large NRCS Clutter Sources
- Mountain Clutter will Produce Little Effect

Moving Clutter Statistical Modeling/Analysis

For an airborne wind shear radar, removal of a stationary ground clutter signal may be accomplished quite simply, provided that an accurate aircraft velocity can be established. This is because stationary clutter produces a narrow, localized-velocity, spectral signature; thus, filtering only requires a simple notch filter to be implemented in the frequency domain. Moving clutter however can be spread across the entire frequency domain, producing multiple velocity modes within a single range bin. Also, as described earlier, these man-made targets can be a primary source of large NRCS levels. Simply stated, moving clutter can, and should be expected to, exist in nearly every range bin and produce a continually changing, high amplitude, clutter signal across the entire frequency domain, which makes filtering it, the most difficult problem facing an airborne wind shear radar. Although the situation may sound bleak, much progress is being made in this area and will be discussed by Dr. Les Britt in the next presentation.

In order to investigate a variety of signal processing algorithms for moving clutter rejection, moving clutter databases, for the Denver and Philadelphia airports, were created. Also the additional functionality of incorporating moving clutter was added to the NASA airborne radar simulation program. To generate the moving clutter databases, it was necessary to measure certain pertinent parameters. First, all of the roads, highways, and railroad lines, which are to be incorporated, must be measured and coregistered with the SAR image database. Second, all of the various statistics which characterize moving clutter must be measured or analytically derived. These statistics must describe the spatial, RCS, and velocity distributions of the moving clutter image.

CLUTTER MODELING OF THE DENVER AIRPORT AND SURROUNDING AREAS

Moving Clutter Statistical Modeling/Analysis

- Pertinent Parameters
 - Coregistration
 - Spatial Distribution
 - RCS Distribution
 - Velocity Distribution

- Measurement/Determination of Their Values
 - Inspection of Aerial Photographs
 - NRCS Database and Literature Survey

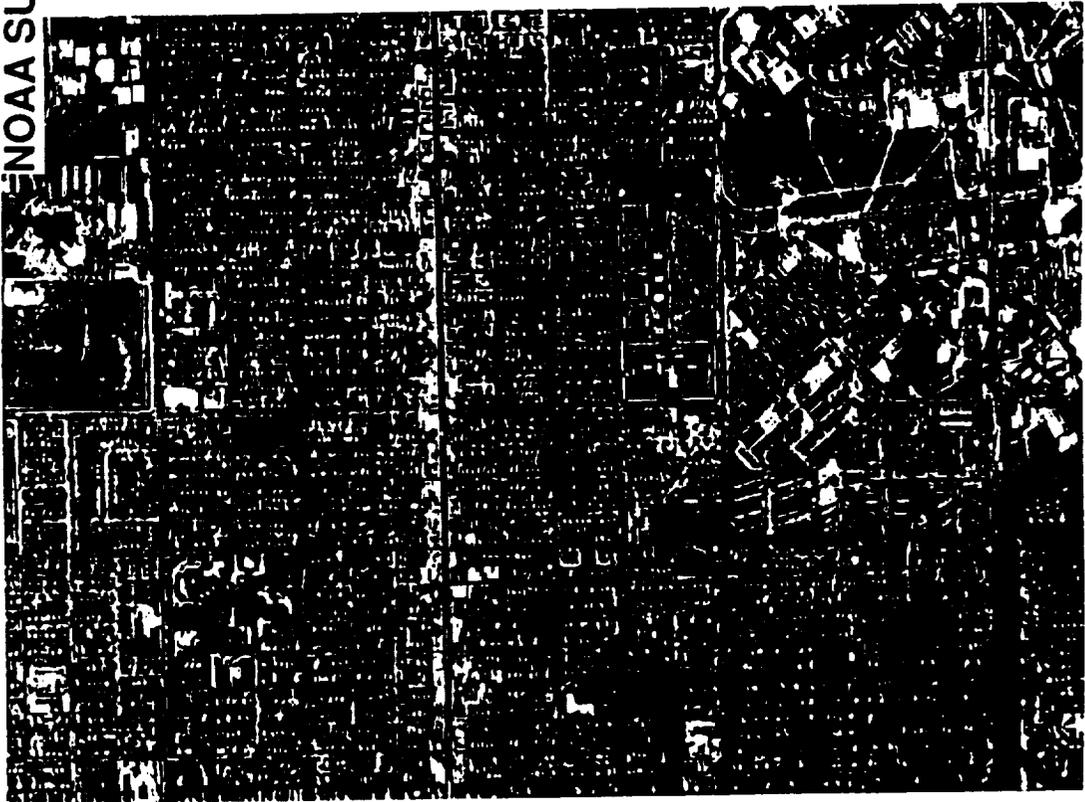
Aerial Photographs of the Denver Stapleton Area

Aerial photographs of the Denver and Philadelphia areas were examined to establish the locations of all the roads, highways, and railroad lines incorporated in the moving clutter database. This allowed coregistration of the moving and stationary clutter databases. In addition to "mapping out" each of the roads, several other parameters were estimated based upon the examination of these aerial photos. An estimate, of the number of cars, the number of trucks, and the mean speed for each vehicle type, was calculated for each road and highway included in the map.

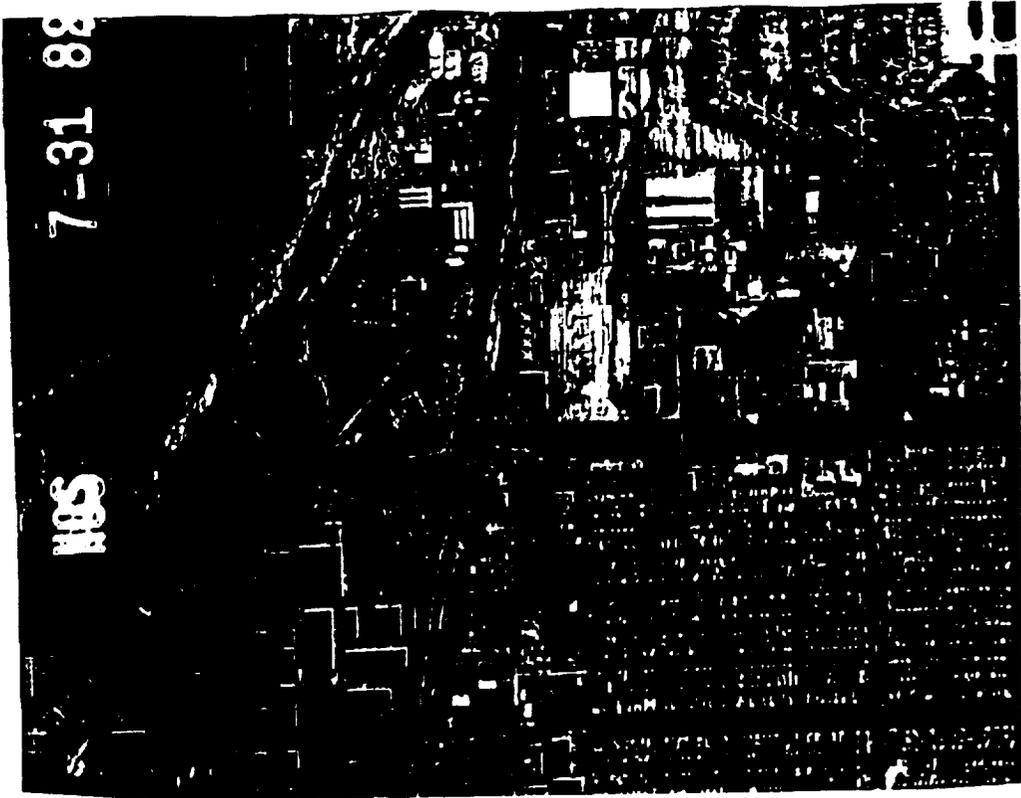
Based upon these measured parameters, a literature survey, and an intensive interrogation of the SAR images, a statistical model was developed for moving clutter in and around the Denver and Philadelphia airports. Using this model, a random sequence of 10,000 moving targets were generated and used in coordination with the NASA airborne radar simulation program.

DENVER STAPLETON AIRPORT

NOAA SURVEY MAPS



Residential



Interstate Highways
Moving Aircraft

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Denver Moving Clutter RCS Map

Shown here is a graphical view of only one of the parameters, RCS, describing the moving clutter database. It might be noted that this plot only shows a few of the major roads and highways in the Denver area. In generating a moving clutter database several parameters must be included, not just RCS. The entire parameter suite used in the simulation program includes: a spatial distribution, an RCS distribution, and a velocity distribution.

Spatial Distribution:

Using the aerial photos and extracted sequences from the SAR images, it was determined that most traffic is distributed uniformly over small stretches of highway. Using the estimated density of cars and trucks for a specific section of highway, a uniformly distributed random sequence of cars and trucks were generated along that road.

RCS Distribution:

Our moving clutter model uses log-normally distributed RCS. This is based primarily on measured observations in the ERIM SAR images of Denver, Philadelphia, and several other, archived, scenes. The RCS mean and standard deviation, respectively, used in our model for the Denver moving clutter was:

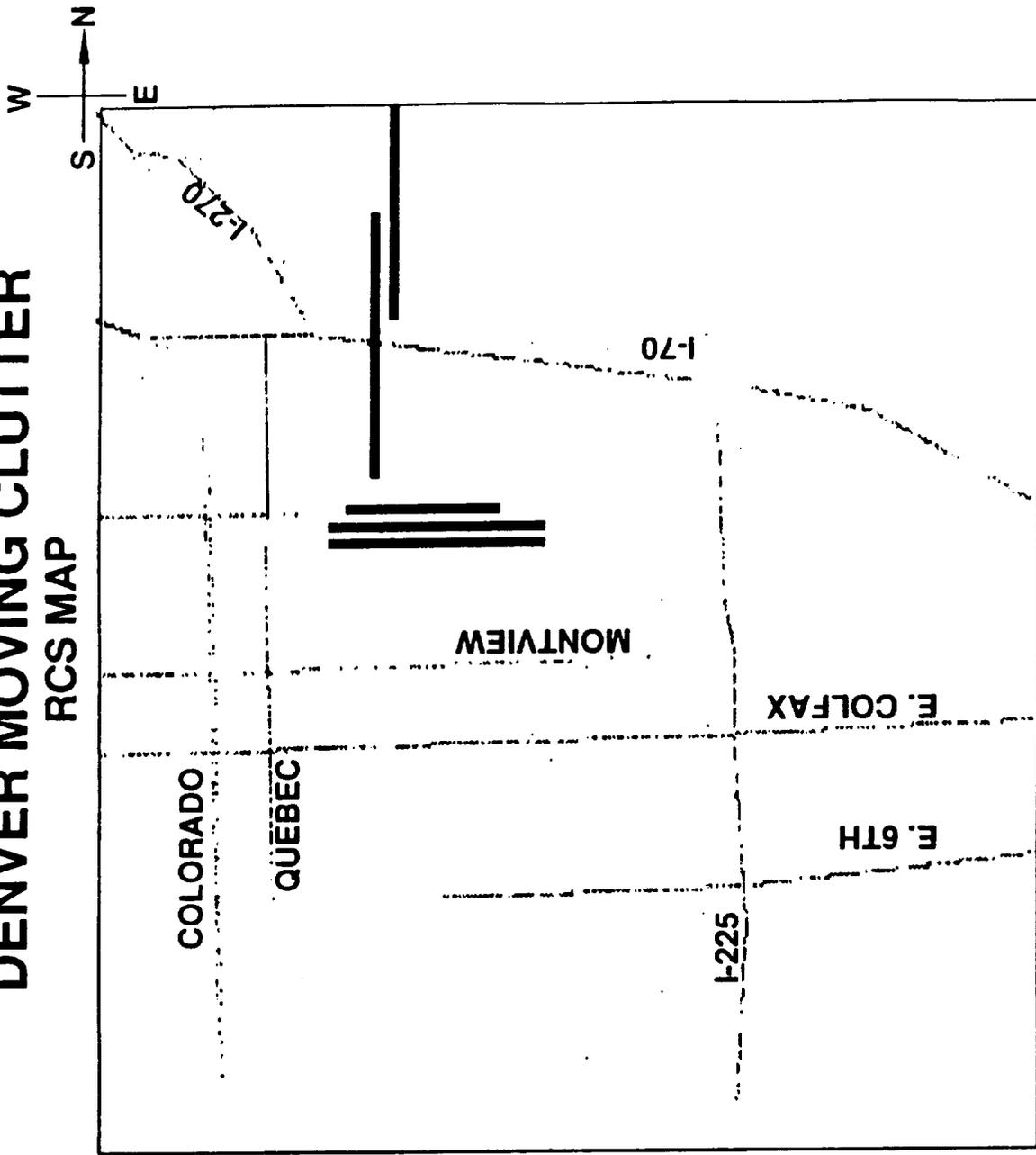
Automobiles	+4 & +2 dB
Train Cars	+10 & +2 dB

Velocity Distribution:

Based upon a literature survey, it was determined that traffic velocity primarily follows a normal distribution. An estimated speed limit, based upon the type of road, was used as the mean velocity and the standard deviation was approximately given by 10% of the mean. It should be noted that this parameter must retain a directional quality, if an accurate Doppler signature is to be generated. More simply stated, the moving clutter model must have inwardly and outwardly directed velocities with respect to the radar radial (i.e., positive and negative velocity components).

DENVER MOVING CLUTTER

RCS MAP



12



dB

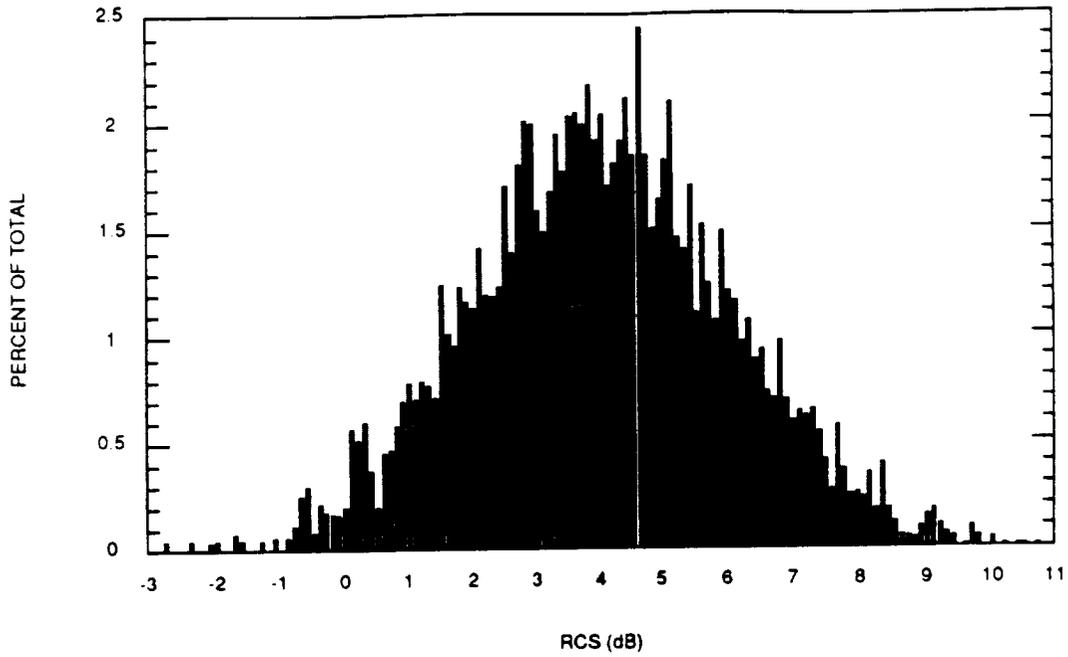
3-

Statistical Summary of Denver Moving Clutter Database

These two histograms show a statistical summary of the RCS and velocity distributions found in the Denver moving clutter database. Note the mean and standard deviation, for each distribution, is shown at the top of each plot. These histograms represent full image statistics and are generated from over 10,000 moving targets located in the database. Also, the velocity distribution contains moving targets from both interstate highways and residential streets; thus, it is not necessarily representative of the velocity profile on a single street or highway. Note also that, the velocity distribution is in fact only representative of the magnitude of the velocities within the database. As mentioned on the previous page, for an accurate radar simulation the Doppler signature, in a given range cell, will almost always contain both positive and negative velocities (frequencies).

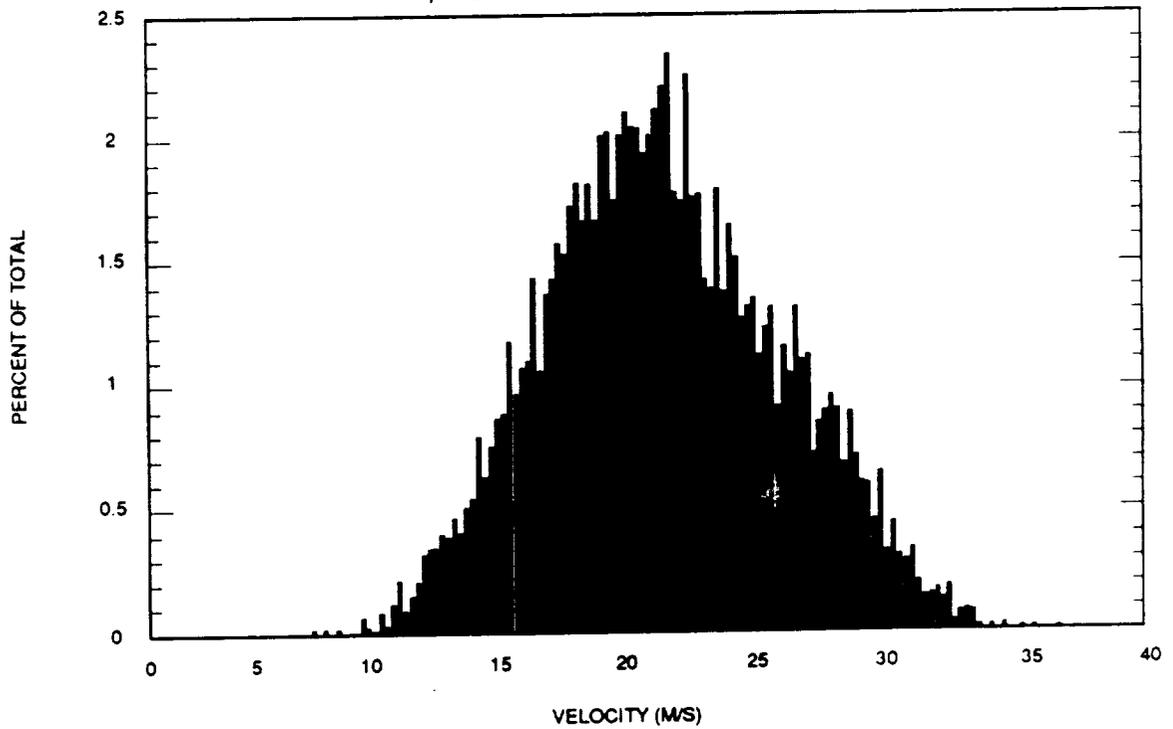
**DENVER MOVING CLUTTER DATABASE
RCS DISTRIBUTION**

$\mu = 4.0$ dB AND $\sigma = 2.0$ dB



**DENVER MOVING CLUTTER DATABASE
VELOCITY DISTRIBUTION**

$\mu = 29.6$ m/s AND $\sigma = 23.6$ m/s



Summary

In summary, the benefits of this research can be separated into two categories, general "scientific" knowledge and wind shear radar specific "engineering" information.

Scientific Benefits:

To my knowledge, this data represents the first, non-classified, consistent, very high incidence angle, NRCS ground clutter measurements. Additionally, since the measurements were obtained using a fully polarimetric, high resolution SAR, the NRCS levels in each ground clutter cell are representative of nearly homogeneous scatterers. This allows a measure of the true polarimetric properties of a single particular scatterer.

Engineering Benefits:

Information from these analyses have helped in producing design considerations for the NASA Wind Shear Radar. A few of these are: the need for HH and VV polarization capability to further study polarization and clutter suppression techniques, identification of man-made targets as the only major source of large radar cross section has help in lowering the fear of perpetual radar receiver saturation, and mountain clutter should not produce a significant second-go-around clutter signal thus reducing the necessity for special hardware and software processing algorithms.

Also the incorporation of realistic, high incidence angle, stationary and moving ground clutter data, into the simulation program has lessened the need for modelling. Which can only improve the accuracy and increase the realistic performance of the backbone of this program, the NASA airborne Doppler radar simulation program.

I would like to take this opportunity to remind everyone that, any of this data can be made available, on a wide variety of media and formats, by contacting:
E. M. Bracalente, V. E. Delnore, or S. D. Harrah
NASA Langley Research Center.

CLUTTER MODELING OF THE DENVER AIRPORT AND SURROUNDING AREAS

Summary

- **Scientific Benefits (Modeling Ground Clutter)**
 - Consistent High Incidence Angle NRCS Ground Clutter Measurements
 - High Resolution Allows for Isolation of Constituent Scatterers
 - Complete Polarimetric NRCS Measurements Recorded Simultaneously

- **Engineering Benefits (Wind Shear Radar Development)**
 - Hardware/System Design**
 - Some Polarization Sensitivity
 - Man-made Targets are the Only Sources of Large NRCS Clutter
 - Mountain Clutter will Produce Little Effect
 - Simulation Program**
 - Realistic High Incidence Angle Ground Clutter
 - Enabled the Addition of Moving Clutter

Clutter Modeling of the Denver Airport and Surrounding Areas Questions and Answers

Q: BRUCE MATTHEWS (Westinghouse) - NASA is and has been collecting an impressive amount and breadth of clutter data. Does this data conform to expectations as available from the literature?

A: STEVE HARRAH (NASA Langley) - I guess the answer is yes in that what we can compare it with we do get good agreement. However, there is a disparity in the models for very high incidence angle radar cross sections of different ground clutter types. With that in mind one has to be careful in just saying yes we agree with literature because literature states two or three different answers. We picked the right one.

Q: BRUCE MATTHEWS (Westinghouse) - Analytic models of various classes of scatterers, such as grass, forests, etc., as functions of grazing angle, wave length, etc. exist and can serve adequately in many, perhaps not all, purposes. Why has NASA chosen an empirical data bank approach rather than connected patches of analytic models?

A: STEVE HARRAH (NASA Langley) - First of all there is some disparity or disagreement among the different models. Secondly and possibly even more importantly, we're trying to account for all of the interactions between, say, cars, trees, grass and different things that one would actually see in the actual operation of a radar. If you simply associate a certain ground patch with grass and another with cars, you can get back the right cross section for each one of them, if they were individual and isolated, but not necessarily show the effect of trees on cars or cars on trees and so forth. So, you don't get all the multipath and all the complicated scattering that would go on if you simply use a analytic approach. From that standpoint the empirical does give us a very realistic look or interpretation of the data, what's actually on the ground. Secondly, the ground areas that we've been looking at are on the order of 10s of kilometers in both down range and cross range direction. It's very difficult to model that amount of data.

EMEDIO BRACALENTE (NASA Langley) - I want to add just some more to that question. Of course one of the things we were primarily concerned about was the urban type clutter around airports and the analytic models associated with buildings, urban environments, and the automobiles along the highways, at grazing angles or low depression or high incidence angles. This is not covered very much in the literature and very difficult to develop analytically. So we felt the only way to really be able to develop a high resolution small area set of individual scatterers representative of urban clutter was to actually take real data and form map, so that when you look at it with a full aperture antenna you sort of collect up a set of multiple scatterers within your beam that are representative of what the radar might see when it was looking at an actual urban clutter environment. That was probably one of the main reasons why we went out empirically rather than trying to do it analytically. In fact we had some effort under way looking at it analytically and it became pretty complicated and difficult to model every little patch in that way because of the lack of data.

Session X. Airborne Doppler Radar / NASA

Radar Simulation Program Up-grade & Algorithm Development
Charles Britt, RTI

