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Sun Angle Effect Preprocessing With Predicted Ramp Functions

by

David F. Strahorn

Paul E. Anuta

Among the many factors affecting the LARS multispectral scanner data is the geometric interaction of the sensor look angle and solar illumination angle. One of these interactions is quite well known to many LARS researchers as the "sun-angle" effect to some and solar ramping or just ramping to others. Ramping is the in mean scanner response as a function of scanner look angle for a given data set; or, the change in column mean from column to column for a given run.

Since the sun angles are functions of time of day, ramping can qualitatively be described in terms of generalities based on time of flight. Assuming that the aircraft is flying north to south, the mean response for column 1 for a morning flight is greater (higher average reflectance) than for column 222 (Figure 3). Just the opposite is true for afternoon flight (Figure 11) and fortunately, column 1 and 222 have about the same mean response for a noon flight (Figure 9).

This variation of mean response from side to side suggests that the spectral signature of a given ground cover will differ from side to side, a very undesirable situation for data which is to be automatically processed by computer since the variation in signature will introduce error into the classification. Actually, the extent to which the signature varies is proportional to the non-ideality of the reflectance characteristics of the ground scene, a perfectly diffuse reflector would not be affected.

The mean response is greatest when the scanner look angle is the same as the component of the solar zenith in the scanner look plane, which indicates that the maximum response is backscatter. Analysis of the small scale reflectance properties of most substances does not explain this observation; however, analysis of the large scale reflectance properties includes geometric orientation of the surface with respect to the observer (aircraft scanner) and the illumination source (sun). This explains the predominance of backscatter very simply. If the observer is looking parallel to the sun's rays, he will see only fully illuminated objects and no shadows, however, if he looks in a different direction, he will see some shadows. Clearly, the mean response is proportional to the illumination of the ground scene being sensed, and since this illumination is related to the angular interactions of the scanner and the sun and the geometric irregularities of the ground scene, the cause of the ramping is obvious.

Current Techniques

Currently, seriously ramped data, over about 20% ramping (see Appendix A for discussion of degree of ramping), is being handled in two ways, width-wise subclass selection and Mean Angular Response Correction preprocessing. The first is a technique used to analyze the actual ramped data by subdividing each important class into three subclasses: right side, center, and left side. Although this does decrease the adverse affect of ramping, it has some serious disadvantages: more training samples must be located, more ground information is necessary, there are more classes to work with thereby increasing the processing time; and most importantly, it requires more of the user's time for the analysis. Mean Angular Response Correction preprocessing (via the MARC program LARSYS 1060) produces a corrected data file for which the column means for a given channel have been normalized to the global mean. This correction is based on the assumption that over a complete flightline, the scanner should pass over about the same number of lines of any given ground cover in each column, therefore the mean response for each column should be constant. This assumption works well if there are over ten thousand lines of data collected. This approach creates problems for flights less than two thousand lines because the ground scenes differ from column to column, therefore the use of MARC normalizes out some effects due to the actual ground scene. This difference in average ground scene occurs in two ways: a difference from column to column, making the column mean plot erratic, and a difference from side to side of the flight, the right side may have more of a given class than the right side. The first of these problems was easily corrected by modifying MARC to use a smoothed column mean curve for its correction, this eliminated the column to column variation and the vertical "streaking" of the digital display pictures that was associated with this problem. The second of these problems, the bulk variation in average ground scene from side to side still has not been corrected.

Clearly, the techniques presently used to compensate for the ramping effect have some undesirable properties. It seems that these problems can be solved by developing a preprocessor which uses a predicted correction instead of a correction calculated from the data.

Ramping Effect Model

Examination of many column mean plots indicated that for any given data set, the ramping effect could be approximated by a third degree polynomial in scanner look angle (a function of column number). The polynomial coefficients should then be related to aircraft heading, solar azimuthal angle, and solar zenith angle for that flight. It was found that these three angles could be combined into two reduced solar angles (see Appendix): reduced azimuth (azimuthal angle minus aircraft heading), and reduced zenith, (component of solar zenith in scanner look plane). An empirical correlation was then developed.

Development of the Ramp Correlation

The ramp correlation is based on scanner data gathered during missions 40-46 of the Corn Blight Watch Experiment in the summer of 1971. This data was collected at an altitude of five thousand feet over primarily agricultural ground scenes, and therefore the correlation is limited to flights at this altitude over agricultural ground scenes.

The first step was to obtain the third degree coefficients for each data set. This was done by the program COLFIT which produced a matrix of coefficients which had been gain normalized (except the thermal I.R. band) to a C_0 of (zero) and C_1 of 100. Most of the data was collected at a calibrated lamp current of 5.5 amps, however some data was collected at 5.0 and 5.95 amps. The coefficients for the data sets collected at 5.0 and 5.95 amps were corrected using the following:

$$C_{ij}=C_{ij}^{*}e^{0.0133(5.5-I)}$$

where: C_{ij} - coefficient at current I

C_{ij}^{*} - coefficient at 5.5 amps

I - lamp current in amps

The data was then correlated by coefficient and channel so that there were thirty six correlations. The following functional form was used for the correlations because it can approximate any non-cyclic functional form efficiently:

$$C_{ij}=a_{ij0}+a_{ij1}\theta_A^3+a_{ij2}\theta_A^2\theta_Z+a_{ij3}\theta_A^2$$

$$+a_{ij4}\theta_A\theta_Z+a_{ij5}\theta_A+a_{ij6}\theta_Z$$

$$+a_{ij7}\theta_A\theta_Z^2+a_{ij8}\theta_Z^2+a_{ij9}\theta_Z^3$$

where:

C_{ij} - element of ramp matrix

a_{ijk} - element of correlation matrix

θ_A - reduced azimuthal angle

θ_Z - reduced zenith angle

The correlation was performed by a modified version of the IBM program, STEPR, for step-wise multiple regression. The resulting a_{ijk} matrix was then converted to a block data subroutine.

The correlation was then encoded into the RAMP preprocessor (LARSYS 1050). RAMP calculates the reduced solar angles for any LARS data set (from new Michigan scanner*), uses the correlation to predict the matrix of coefficients for the ramping model, and then using the model, produces a new data tape with which has been compensated for the ramping effect. The input deck is very simple and easy to use as described in the Program Abstract.

Testing the RAMP Preprocessor

The implementation of the ramping correction function has the inherent assumption that all ground scenes may be corrected with the same gain matrix. This is not a valid assumption since the amount of correction required will increase with the amount of geometric irregularity in the ground scene. Although some classes will be over corrected and some under corrected, it is hoped that the differences will not be so large as to over-ride the correction. This can only be determined by testing the analysis of RAMP preprocessed data as compared to unpreprocessed data. The preprocessed data offers a "cosmetic" improvement in digital display image quality which is an obvious aid in training and test sample location; however, the ultimate test of a preprocessor is its effect of LARSYSAA classification performance.

Six data sets from the Corn Blight Watch Experiment of 1971 were chosen, two each from the morning, noon, and afternoon.

* University of Michigan, Willow Run Labs M7 Scanner System which became operational in June 1971.

The LARS run numbers: 71029100 (20841M), 71040100 (207 42M), 71045700 (225 42M), 71078000 (209 46M), 71078400 (217 46M), and 71078600 (219 46M). Basic run information and sun angles for these data sets is tabulated in Tables 1a-f. These data sets are all internal to the correlation basis and the results may therefore be biased, an unavoidable situation since all available data was used to develop the correlation. So that gain changes do not affect the results of the test, the data was first calibrated with SMCAL (LARSYS 1039) to LARSYS calibration code 4. The four channels selected by the corn blight researchers as the four best for the original data were used; this places the burden of proof squarely on the preprocessed data since it may not be operating with its best set of channels. The training and test fields selected by the corn blight researchers were also used for the test. The data was calibrated and preprocessed, then both sets were classified and the ability to separate corn from other ground covers was compared for the RAMP-SMCAL data (preprocessed) with the SMCAL data (original).

Figures 1 through 12 contain graphs of the actual column mean and the ramp predicted column means and digital display photographs of original and preprocessed data for channels 3, 6, 9, and 12 of run 71045700 (morning) and channel 6 of runs 71029100 (noon) and 71078600 (afternoon).

Discussion of Test Results

Training and test classification performance for the six test runs is tabulated in Table 2. The degree of ramping for each run is tabulated against improvement in overall test performance in Table 3.

The results of the classification tests were much as expected. The two noon runs were affected very little because the predicted ramp functions were almost flat. The two morning runs which were extremely ramped showed improvement in corn and overall test performance and a decrease in other test performance. The two afternoon runs which were moderately ramped showed mixed results.

The correlation was developed for a "typical" ground cover, therefore it would be expected that the performance of corn classification would be improved since it is more irregular than the typical ground scene so that it is affected more than non-corn by changes in look angle. The test results confirm this analysis.

Recommendations

Preprocessing LARS MSS data with the RAMP correlation has both good and bad qualities, as does any preprocessor. On the good side, RAMP preprocessed data has cosmetic improvements over unpreprocessed data which aid in test and training sample location, improvements in classification of ground cover classes which have a large degree of geometric irregularity, and partial data normalization. However, the preprocessed data suffers in that the ability of classify ground cover classes which have little geometric irregularity is impaired.

The RAMP preprocessor may be used to aid in the classification of LARS MSS data for which ramping is severe and the ground cover types of interest geometrically irregular. The preprocessor should not be used when the cover types of interest are not irregular or not of the typical agricultural type. The researcher's discretion should be used for the majority of cases between these two extremes.

Two areas may warrant further study; 1 - use of the four best channels selected for the RAMP preprocessed data to test against unpreprocessed data classified with its own best four channels, and 2 - a test of the effect on classification accuracy of RAMP preprocessing on other ground cover types.

Degree of Ramping

A number of people have requested a "number" with which to describe the magnitude of the ramping effect in a given set of data. This magnitude may be described as the percent of the maximum deviation of the ramping effect from the global mean to the global mean. Although the true ramping effect is not known for any set of data, the ramping effect may be approximated by a plot of column means.

The degree of ramping (D.R.) may be calculated by first obtaining a column mean plot from MEANCAL, COLFIT, or RAMP and drawing a smooth (about third order) curve through the column means. Then pick the highest and lowest mean from the smooth curve ($\bar{X}max$ & $\bar{X}min$). The degree of ramping is then given by:

$$D.R. = [(\bar{X}max - \bar{X}min)/(\bar{X}max + \bar{X}min)]\ 100\%$$

Although this should be done for each channel since D.R. of any visible channel (6 is used in this paper) may be used to describe the entire run.

Reduced Solar Angles

The ramping effect is believed to be the result of geometric irregularities in the ground scene. If this is true, the angular relationship between the sun and aircraft would be important in describing the ramping effect. Using the ground as a reference frame, the angular relationship can be characterized by three angles: Solar azimuthal (θ_A), solar zenith (θ_Z), and aircraft heading (θ_H). The use of these three angles in developing a correlation function for the ramping effect presents two problems; an empirical function in three variables is difficult to correlate data with, and data has been collected at only two aircraft headings (180° & 225°) with the new scanner requiring any function terms including aircraft heading to be pseudo-linear in heading. However, if the aircraft is taken as the reference frame, the angular relationship may be described by two angles: The component of the zenith angle in the scanner look plane (Θ_{Zc}) and the relative solar azimuthal angle (Θ_{Ar}). These two reduced angles are calculated from the other angles as follows:

$$\Theta_{Ar} = \Theta_A - \Theta_H$$

$$\Theta_{Ec} = \mathrm{TAN}^{-1}(\mathrm{TAN}\ (90° - \Theta_Z)/\mathrm{COS}(90° \pm \Theta_H - \Theta_A))$$

$$\Theta_{Zc} = -90° - \Theta_{Ec} \quad \text{if} \quad \Theta_{Ec} \leq 0$$

$$\Theta_{Zc} = 90° - \Theta_{Ec} \quad \text{if} \quad \Theta_{Ec} > 0$$

These reduced solar angles were used to model the ramping effect since they represent the best description of the angular relationship.

APPENDIX

Table 1a-c Basic Run Information and Solar Angles for Test Data Sets

A. Solar azimuthal and elevation angles calculated for LARS run number 71029100

FLIGHT LINE.. CRN BLT LO FL208
DATE DATA TAKEN...... 7/12/71
TIME DATA TAKEN.... 1328 HOURS
AIRCRAFT ALTITUDE.. 5000 FEET
GROUND HEADING.... 180 DEGREES
SOLAR ELEVATION. 69.84 DEGREES
SOLAR AZIMUTH.. 204.89 DEGREES

B. Solar azimuthal and elevation angles calculated for LARS run number 71040100

FLIGHT LINE.. CRN BLT LO FL207
DATE DATA TAKEN...... 7/21/71
TIME DATA TAKEN.... 0933 HOURS
AIRCRAFT ALTITUDE.. 5000 FEET
GROUND HEADING.... 180 DEGREES
SOLAR ELEVATION. 43.11 DEGREES
SOLAR AZIMUTH.. 100.07 DEGREES

C. Solar azimuthal and elevation angles calculated for LARS run number 71045700

FLIGHT LINE.. CRN BLT LO FL225
DATE DATA TAKEN...... 7/27/71
TIME DATA TAKEN.... 1019 HOURS
AIRCRAFT ALTITUDE.. 5000 FEET
GROUND HEADING.... 180 DEGREES
SOLAR ELEVATION. 51.40 DEGREES
SOLAR AZIMUTH.. 108.50 DEGREES

Table 1d-f Basic Run Information and Solar Angles for Test Data Sets

D. Solar azimuthal and elevation angles calculated for LARS run number 71078000

FLIGHT LINE.. CRN BLT LO FL209
DATE DATA TAKEN...... 9/24/71
TIME DATA TAKEN.... 1241 HOURS
AIRCRAFT ALTITUDE.. 5000 FEET
GROUND HEADING.... 180 DEGREES
SOLAR ELEVATION. 49.10 DEGREES
SOLAR AZIMUTH.. 180.46 DEGREES

E. Solar azimuthal and elevation angles calculated for LARS run number 71078400

FLIGHT LINE.. CRN BLT LO FL217
DATE DATA TAKEN...... 9/24/71
TIME DATA TAKEN.... 1508 HOURS
AIRCRAFT ALTITUDE.. 5000 FEET
GROUND HEADING.... 180 DEGREES
SOLAR ELEVATION. 37.77 DEGREES
SOLAR AZIMUTH.. 229.66 DEGREES

F. Solar azimuthal and elevation angles calculated for LARS run number 71078600

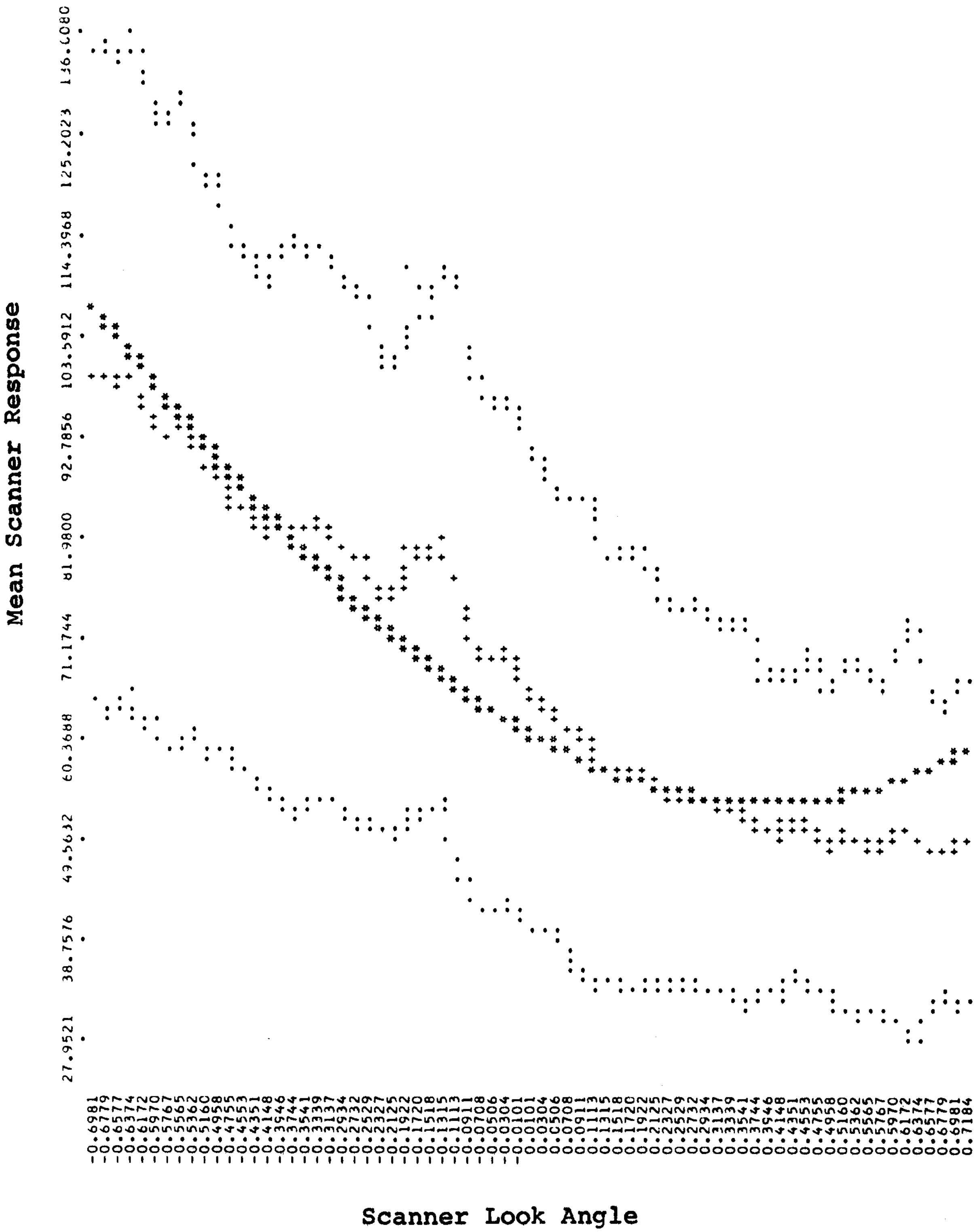
FLIGHT LINE.. CRN BLT LO FL219
DATE DATA TAKEN...... 9/24/71
TIME DATA TAKEN.... 1450 HOURS
AIRCRAFT ALTITUDE.. 5000 FEET
GROUND HEADING.... 180 DEGREES
SOLAR ELEVATION. 40.57 DEGREES
SOLAR AZIMUTH.. 224.90 DEGREES

Table 2 Classification Results in Percent Correct Classification

	TRAINING			TEST		
	CORN	OTHER	OVERALL	CORN	OTHER	OVERALL
71029100						
ORIGINAL	99.3	99.9	99.8	86.6	99.9	89.0
PREPROCESSED	99.0	99.8	99.7	85.7	99.8	88.3
71040100						
ORIGINAL	97.2	99.0	98.2	80.4	88.8	83.6
PREPROCESSED	97.8	96.3	96.9	83.0	85.9	84.1
71045700						
ORIGINAL	100	99.7	99.8	83.3	89.7	87.3
PREPROCESSED	100	99.7	99.7	94.5	83.2	88.2
71078000						
ORIGINAL	99.0	99.8	99.6	94.8	98.4	97.1
PREPROCESSED	99.0	99.7	99.6	94.9	98.4	97.1
71078400						
ORIGINAL	100	100	100	91.3	87.3	88.2
PREPROCESSED	99.9	99.9	99.9	86.0	88.8	88.1
71078600						
ORIGINAL	99.7	99.6	99.7	86.9	93.3	93.0
PREPROCESSED	99.6	99.7	99.7	86.0	93.9	93.6

Table 3 Comparison of Improvement in Classification vs. Degree of Ramping

Run Number	Degree of Ramping	Improvement in Overall Classification Accuracy
71029100	0	-0.7
71078000	0	0
71078600	14.3	0.6
71078400	27.2	-0.1
71040100	31.0	0.5
71045700	36.0	0.9



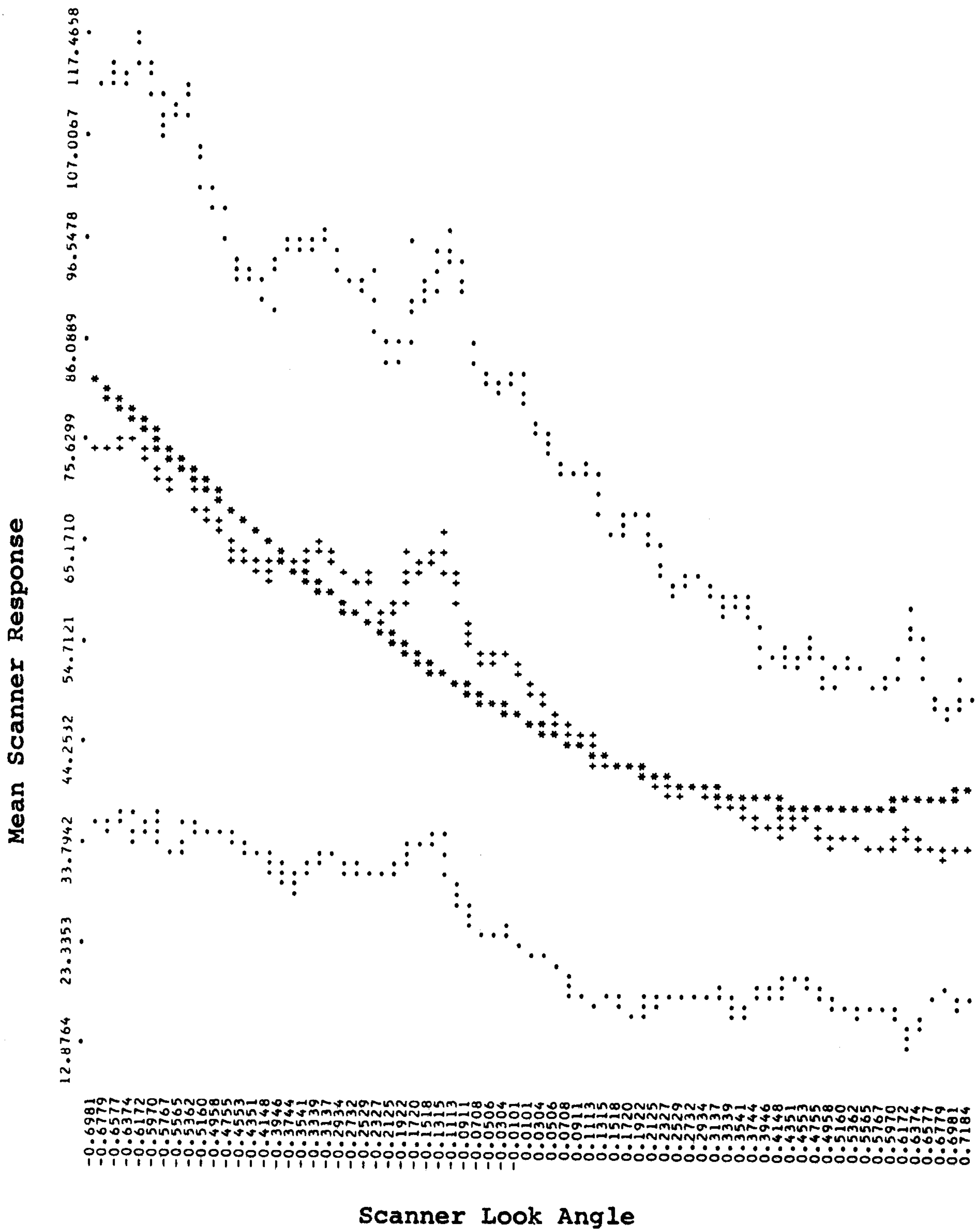
+ - Actual Column Mean
* - Ramp Predicted Column Mean
• - Actual Column Mean ± One Standard Deviation

Figure 1 Column Mean Plot for Channel 3 of Run 71045700 (morning)

2A Original

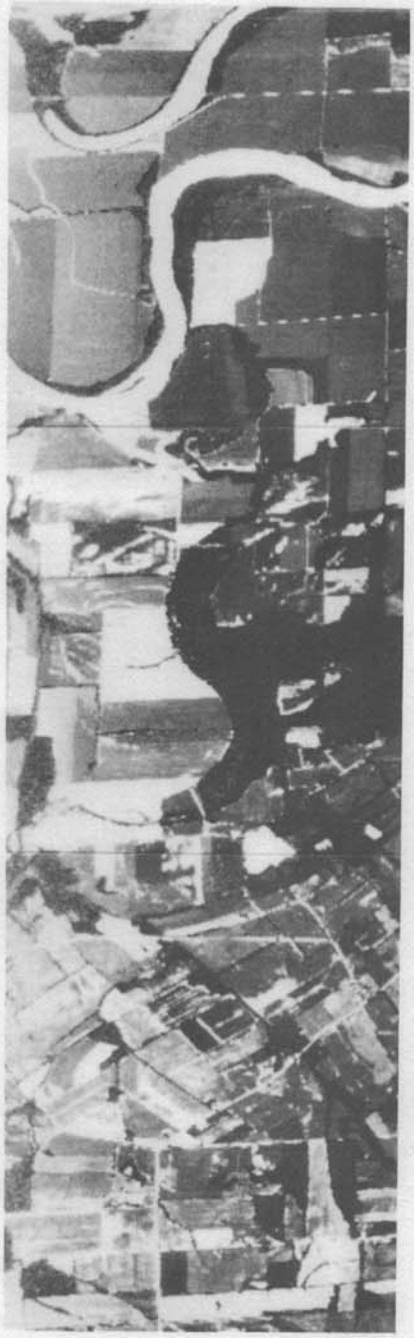
2B Preprocessed

Figure 2 Digital Display Photographs for Original and Preprocessed Data from Channel 3 of Run 71045700 (morning)



+ - Actual Column Mean
* - Ramp Predicted Column Mean
• - Actual Column Mean ± One Standard Deviation

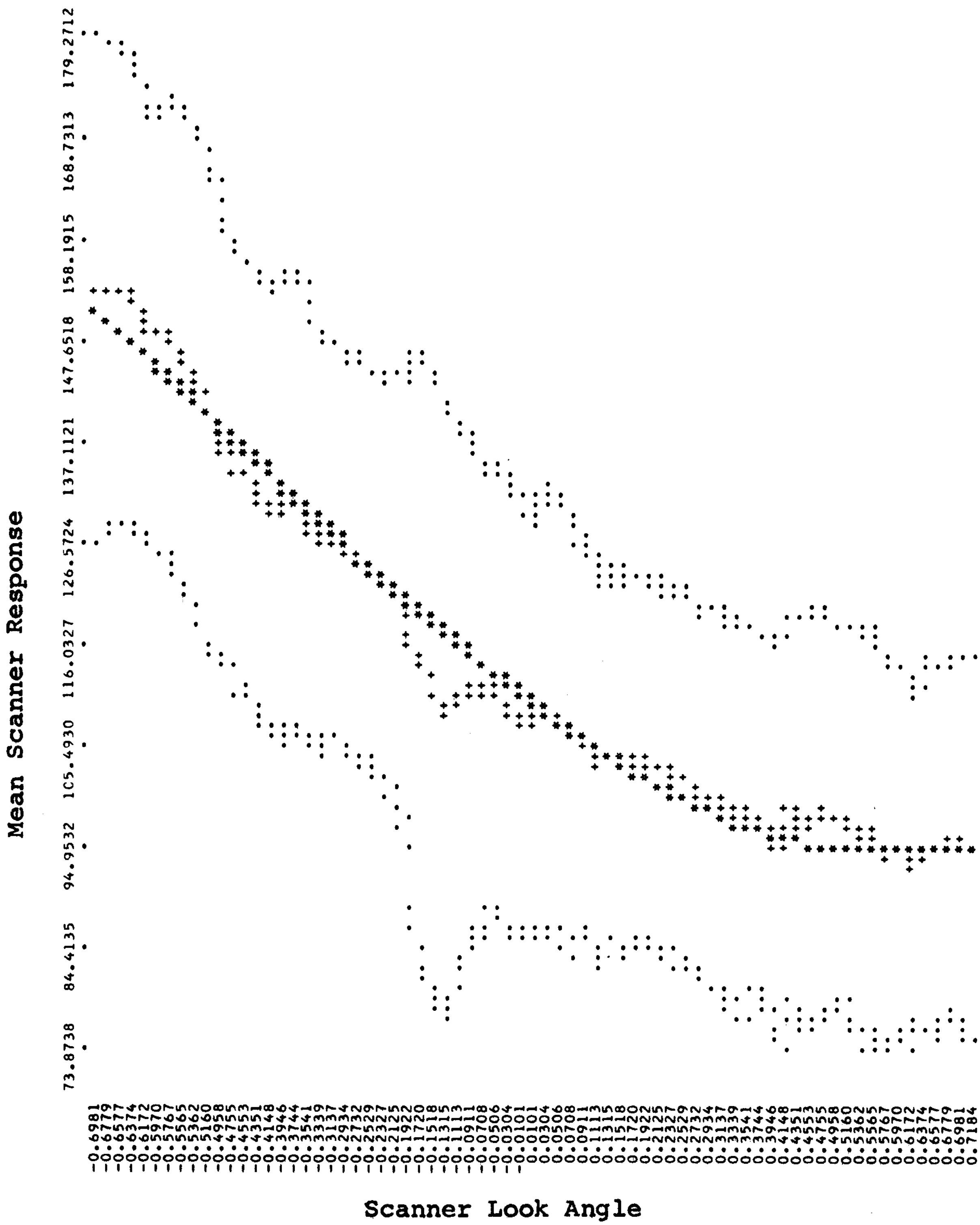
Figure 3 Column Mean Plot for Channel 6 of Run 71045700 (morning)



4A Original

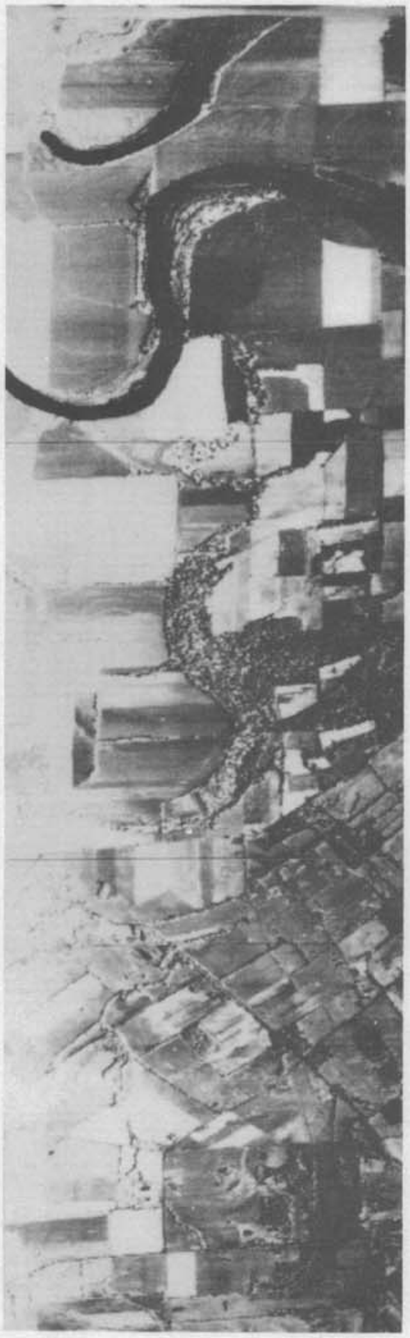
4B Preprocessed

Figure 4 Digital Display Photographs for Original and Preprocessed Data from Channel 6 of Run 71045700 (morning)



+ - Actual Column Mean
* - Ramp Predicted Column Mean
• - Actual Column Mean ± One Standard Deviation

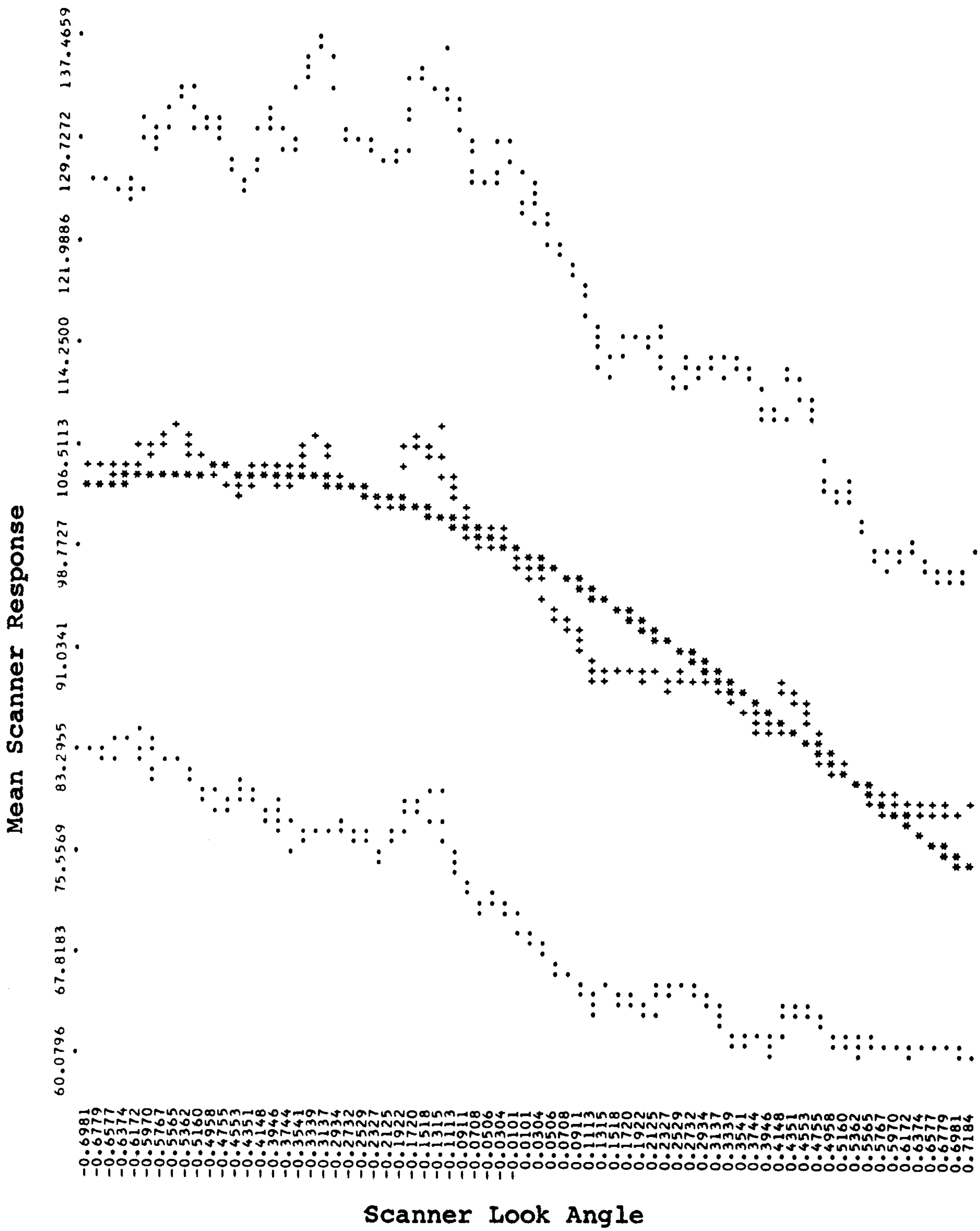
Figure 5 Column Mean Plot for Channel 9 of Run 71045700 (morning)



6A Original

6B Preprocessed

Figure 6 Digital Display Photographs for Original and Preprocessed Data from Channel 9 of Run 71045700 (morning)



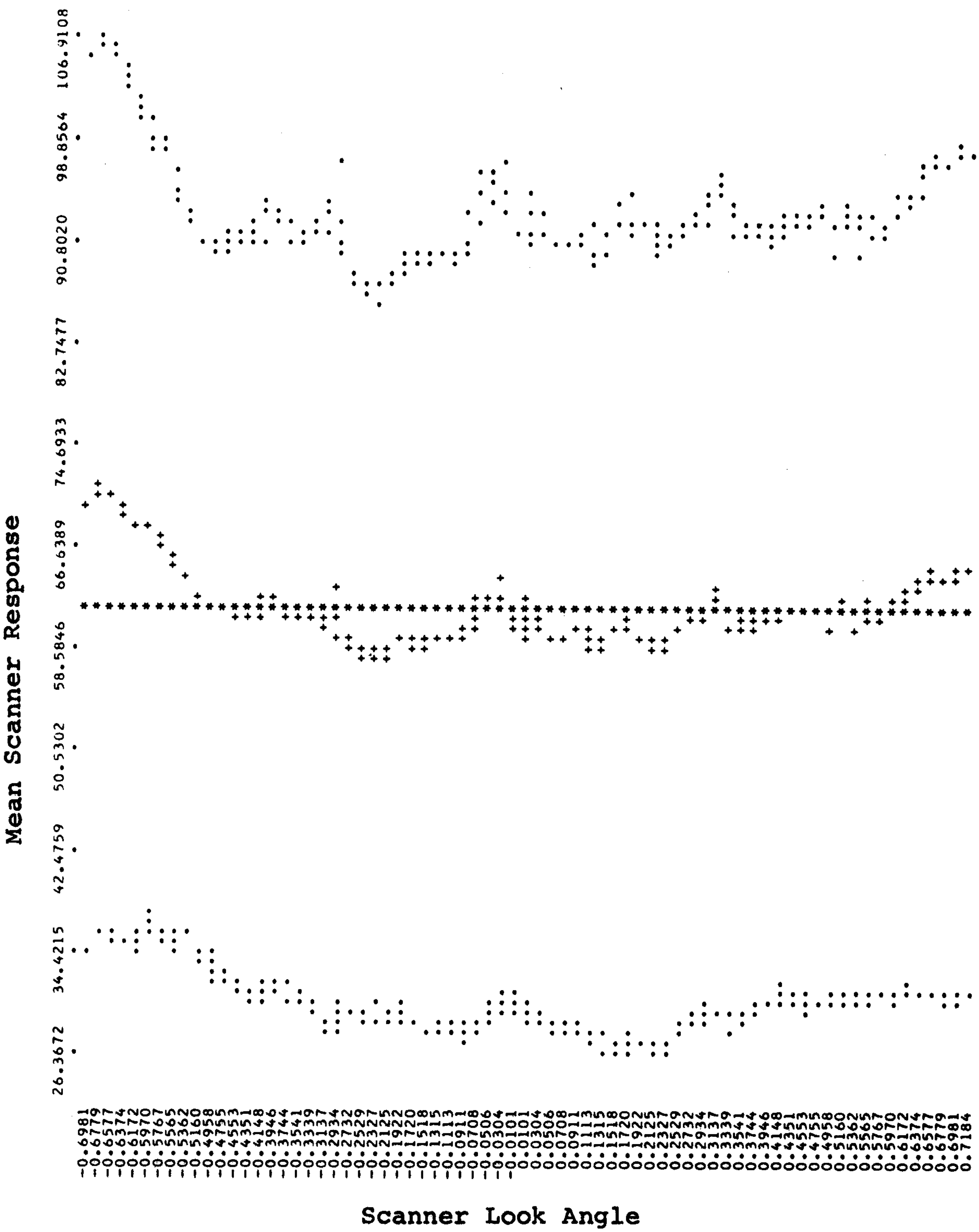
\+ - Actual Column Mean
* - Ramp Predicted Column Mean
• - Actual Column Mean ± One Standard Deviation

Figure 7 Column Mean Plot for Channel 12 of Run 71045700 (morning)

8A Original

8B Preprocessed

Figure 8 Digital Display Photographs for Original and Preprocessed Data from Channel 12 of Run 71045700 (morning)



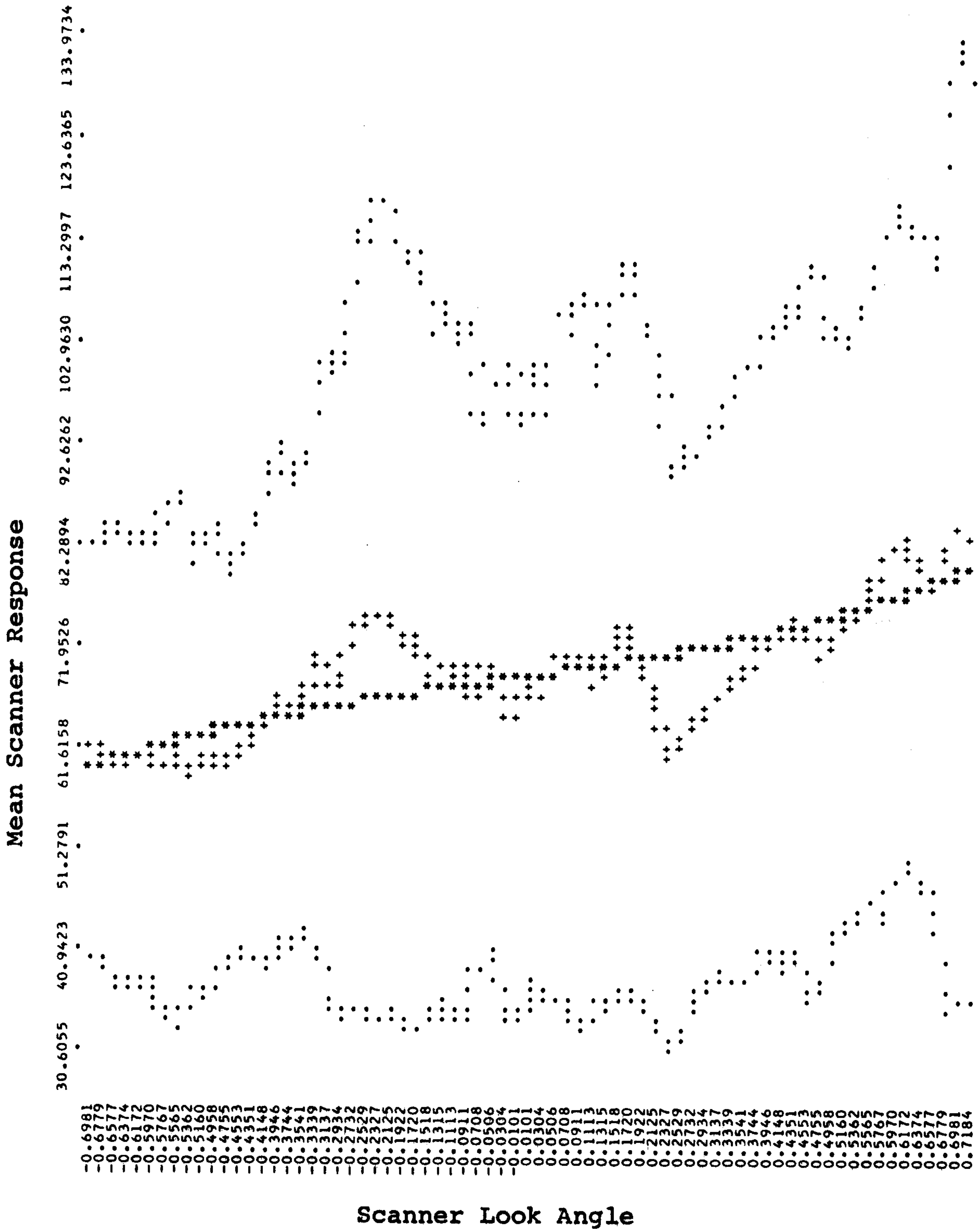
+ - Actual Column Mean
* - Ramp Predicted Column Mean
• - Actual Column Mean ± One Standard Deviation

Figure 9 Column Mean Plot for Channel 6 of Run 71029100 (noon)

10A Original

10B Preprocessed

Figure 10 Digital Display Photographs for Original and Preprocessed Data from Channel 6 of Run 71029100 (noon)



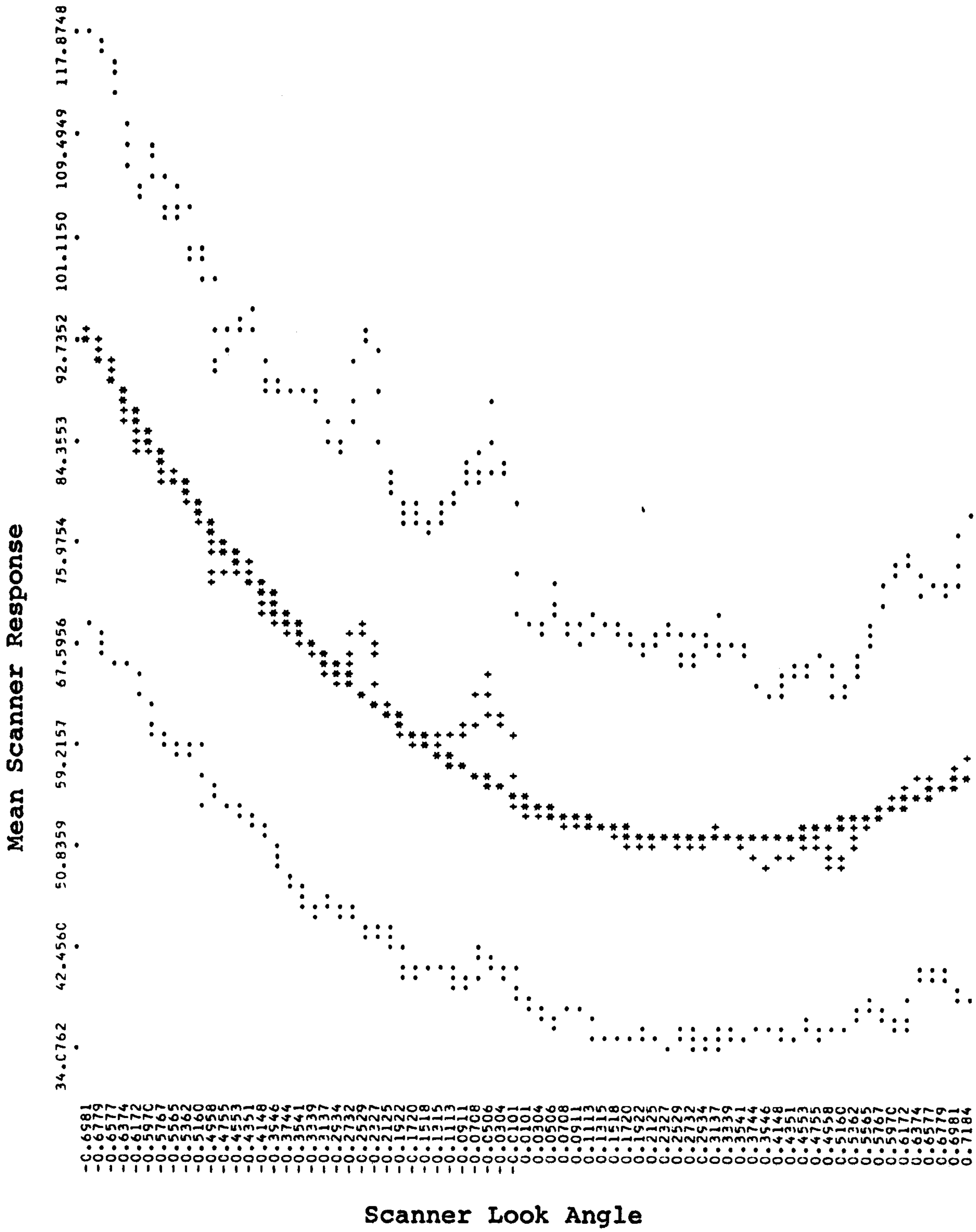
+ - Actual Column Mean
* - Ramp Predicted Column Mean
• - Actual Column Mean ± One Standard Deviation

Figure 11 Column Mean Plot for Channel 6 of Run 71078600 (afternoon)

12A Original

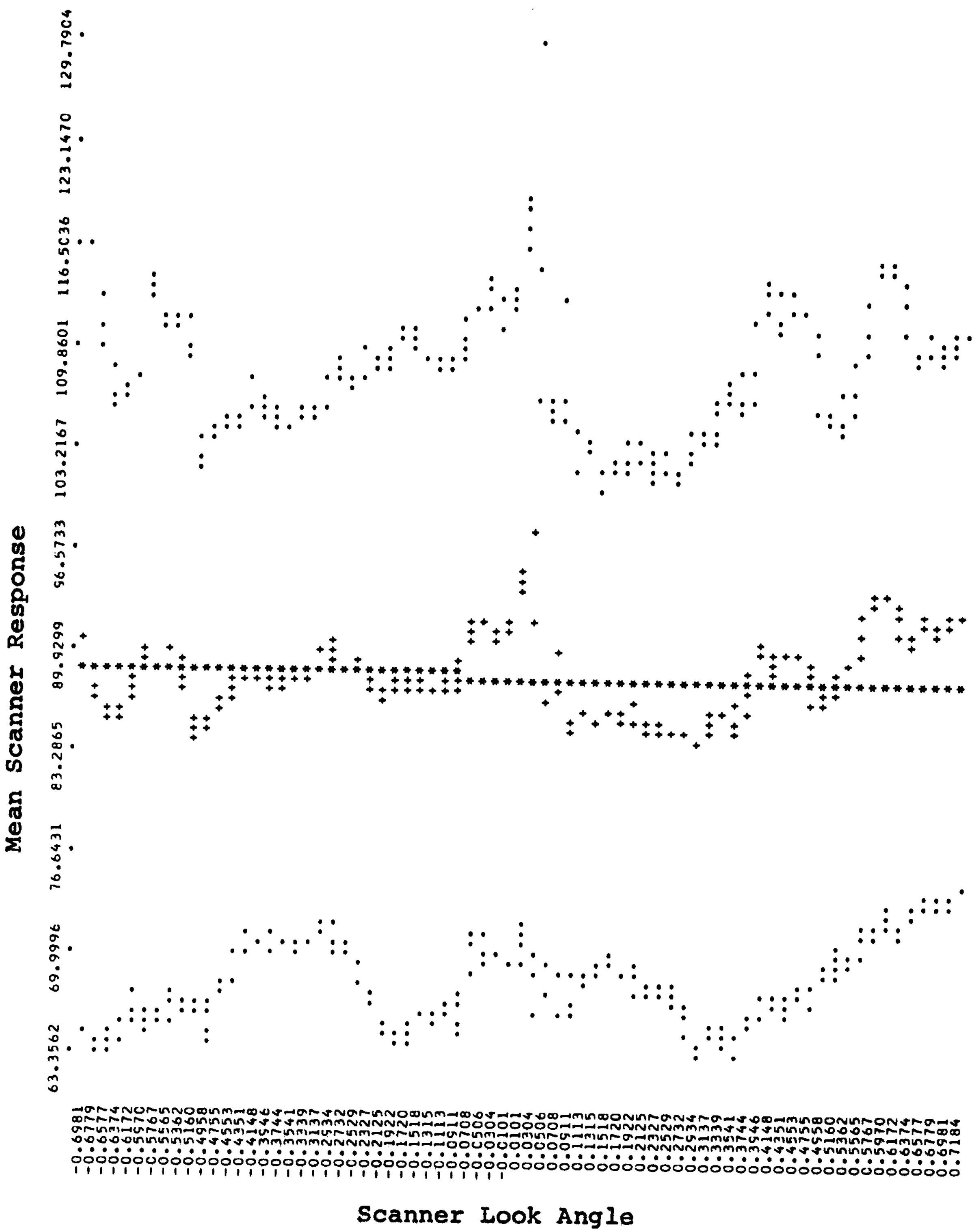
12B Preprocessed

Figure 12 Digital Display Photographs for Original and Preprocessed Data from Channel 6 of Run 71078600 (afternoon)



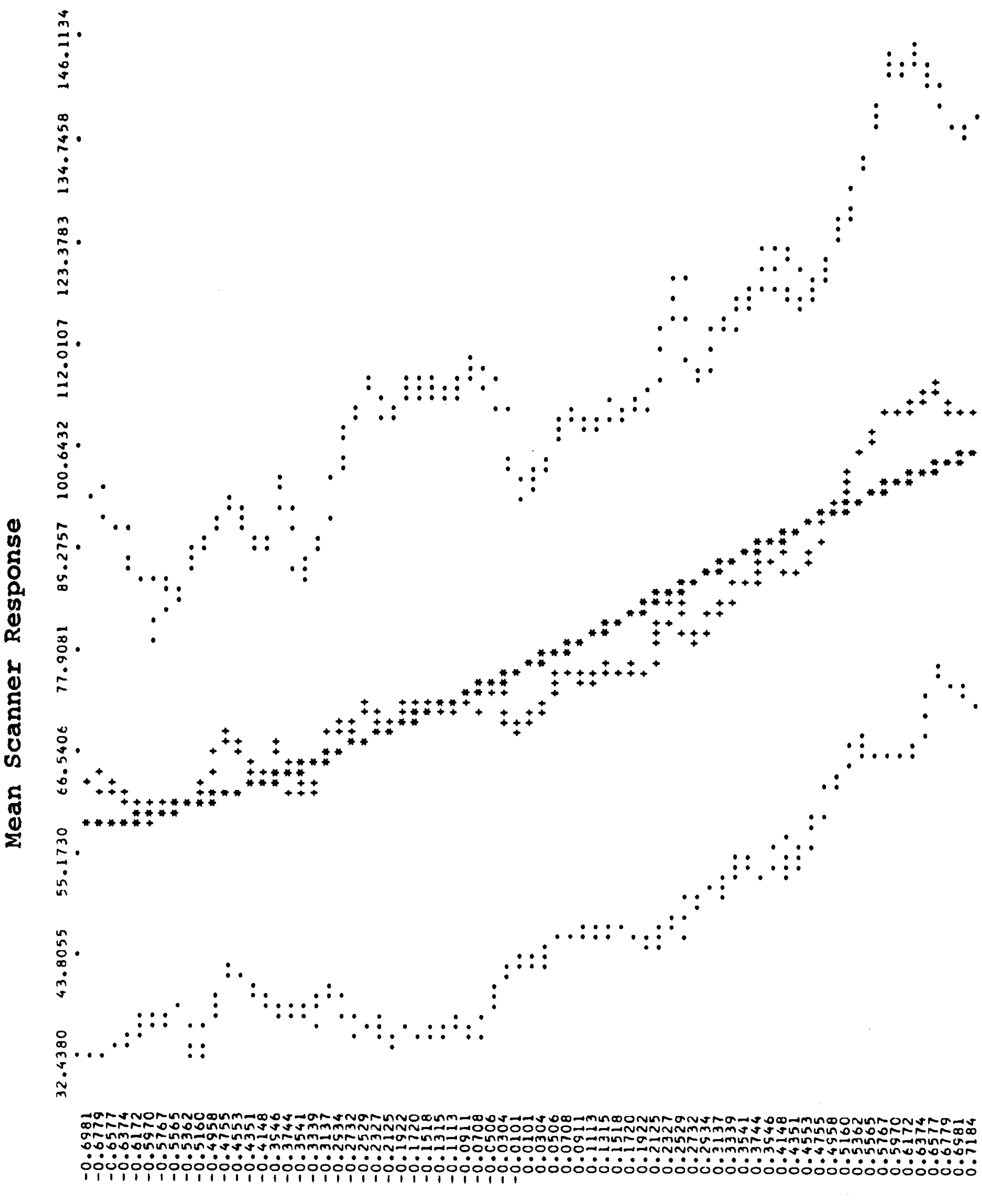
\+ - Actual Column Mean
* - Ramp Predicted Column Mean
• - Actual Column Mean $\pm$ One Standard Deviation

Figure 13 Column Mean Plot for Channel 6 of Run 71040100 (morning)



+ - Actual Column Mean
* - Ramp Predicted Column Mean
• - Actual Column Mean $\pm$ One Standard Deviation

Figure 14 Column Mean Plot for Channel 6 of Run 71078000 (noon)



\+ - Actual Column Mean
* - Ramp Predicted Column Mean
• - Actual Column Mean ± One Standard Deviation

Figure 15 Column Mean Plot for Channel 6 of Run 71078400 (afternoon)