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TECHNICAL REPORT

DIGITAL AND PHOTOGRAPHIC PROCESSING STUDY FOR SHALLOW SEAS MAPPING FROM LANDSAT

UNITED STATES GEOLOGICAL SURVEY
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SYSTEMS DEVELOPMENT BRANCH

DIGITAL AND PHOTOGRAPHIC PROCESSING STUDY FOR SHALLOW SEAS MAPPING FROM LANDSAT

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ABSTRACT

The application of contrast stretch and haze removal techniques to Landsat/MSS imagery for shallow seas bathymetry is discussed. The application of these techniques is based upon procedures inherent in the EDIPS system processing. Application of both MSS band 4 and band 5 data are discussed in 1x and 3x gain mode. Both quantitative and qualitative (imagery) data are used to demonstrate the existence of bathymetric information after EDIPS processing.

INTRODUCTION

The Defense Mapping Agency (DMA) is in the process of studying techniques for incorporating Landsat data into their procedures for shallow seas mapping. Imagery of some 3,000 specific sites will be acquired by the Landsat satellite over a period of five years for DMA bathymetric evaluation. Present plans call for this imagery to be acquired in 3x gain mode for MSS bands 4 and 5 and 1x mode for MSS bands 6 and 7. The 3x gain mode for MSS bands 4 and 5 is chosen because studies in the past have indicated its superiority over the 1x gain mode for bathymetric information (Polcyn, 1976; Ross, 1976).

The Systems Development Branch (SDB) of the EROS Data Center (EDC) was tasked to determine the effect of standard and special EDIPS algorithms on Landsat data acquired for bathymetric purposes. The following areas were investigated:

1. The effects of standard contrast stretch procedures on the image information content.
2. The effects of haze and haze removal procedures.
3. The effects of different film recording radiometric transfer functions.
4. The use of digital processing techniques to simulate 3x gain data from 1x gain input data.
5. The operational data processing procedures necessary to satisfy DMA requirements in the most efficient manner for NASA/GSFC, EDC, and DMA.

TECHNICAL DISCUSSION

DMA Production System

The system as proposed by DMA (Puccinni, 1976) for their product production is shown in Figure 1. This system requires DMA to submit special orders for desired scenes after viewing initial pipeline imagery. An alternative system is also discussed in this report. This alternative system is a modified pipeline process which can be used to supply the enhanced 241 mm film image on the first data pass.

Existing EDIPS Pipeline Contrast Stretch Algorithm

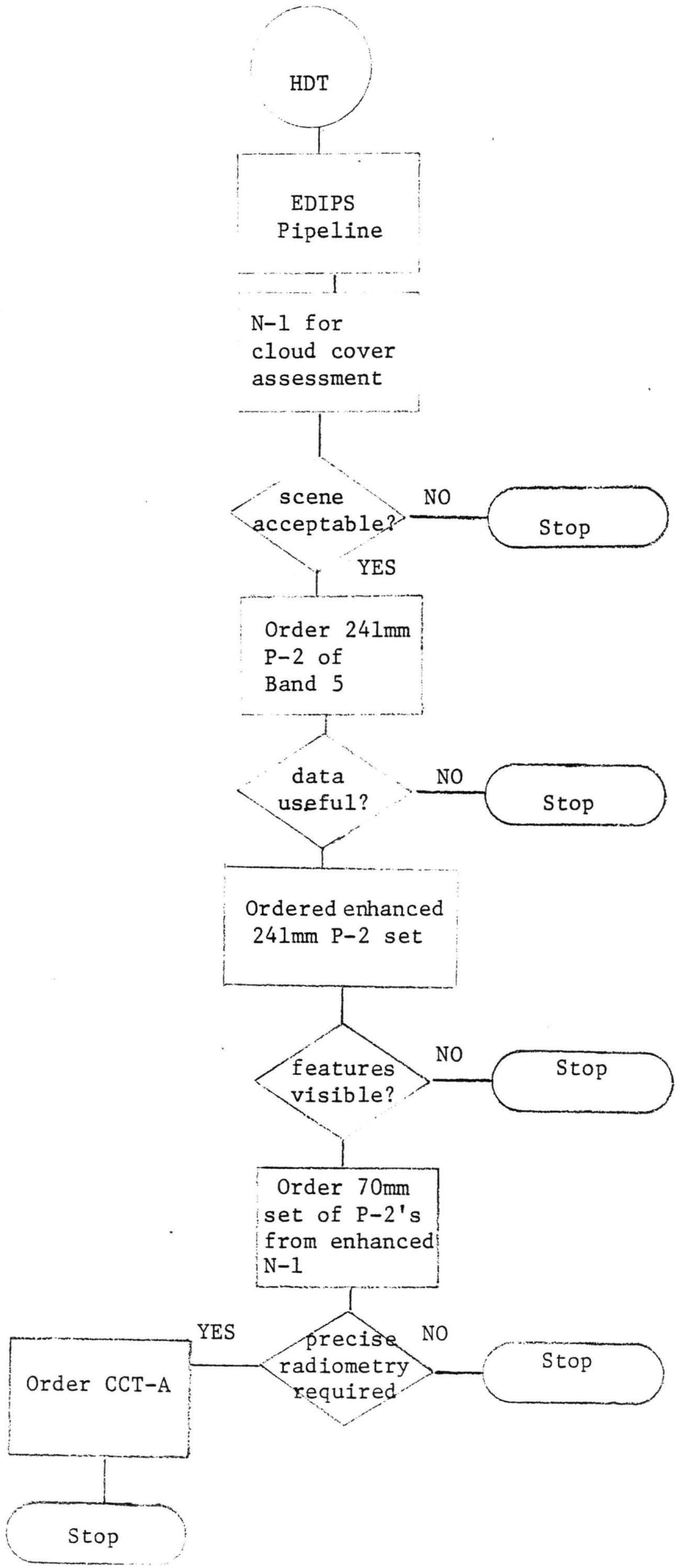
The EDIPS contrast stretch algorithm performs a linear stretch on the input data using a mapping defined by:

$$\text{OUTPUT} = (\text{INPUT} - \text{MIN}) \cdot \frac{127}{\text{MAX}-\text{MIN}}$$

where MIN = minimum input cutoff value

MAX = maximum input cutoff value

The MIN and MAX digital values are determined by a computer analysis of the histogram. The algorithm searches upward in the histogram for the first occurrence of n consecutive digital levels whose frequency of occurrence exceeds a specified level. Any such digital level is termed a spike. Both the number n of consecutive spikes and the frequency of occurrence threshold are programmable quantities which may be varied to suit different requirements. The low cutoff level is set at the lowest of the n consecutive spikes. At the high end of the histogram, the process is repeated in reverse with the highest of the n consecutive spikes being chosen as the cutoff value.


HDT
EDIPS Pipeline
N-1 for cloud cover assessment
scene acceptable?
NO
Stop
YES
Order 241mm P-2 of Band 5
data useful?
NO
Stop
Ordered enhanced 241mm P-2 set
features visible?
NO
Stop
Order 70mm set of P-2's from enhanced N-1
precise radiometry required
YES
NO
Order CCT-A
Stop
Stop

With the EDIPS contrast stretch algorithm, the threshold frequency can be chosen to be so low that no significant image data is truncated. Analysis of many histograms has shown that the low cutoff point can be chosen with great accuracy, since the frequency of occurrence rises very rapidly at the haze level. The haze level, or low cutoff point, is the lowest digital level in any scene with uniform atmospheric conditions. The high cutoff point cannot be chosen as accurately, however, and additional work is required to modify the present algorithm to distinguish clouds from bright ground features. At this time, the algorithm always selects the high cutoff point conservatively, thereby limiting the contrast stretch, rather than producing excessive truncation.

Effects of Haze

Path radiance, or haze, is the result of non image-forming light which reaches the sensor; that is, light which does not follow a direct path from subject to sensor. This can be sunlight which never reaches the ground, but is reflected or scattered back to the sensor, or it can be light from the subject or its surround which is scattered one or more times before reaching the sensor.

There are two principal effects of haze on an image. First, the overall brightness of the scene is increased by the radiance of the haze. The haze level can be thought of as the radiance of a 0% reflectance ground target as seen by the sensor. Thus, nothing in the scene can be darker than the haze level. The creation of haze and its effect on image contrast is shown in Figure 2.

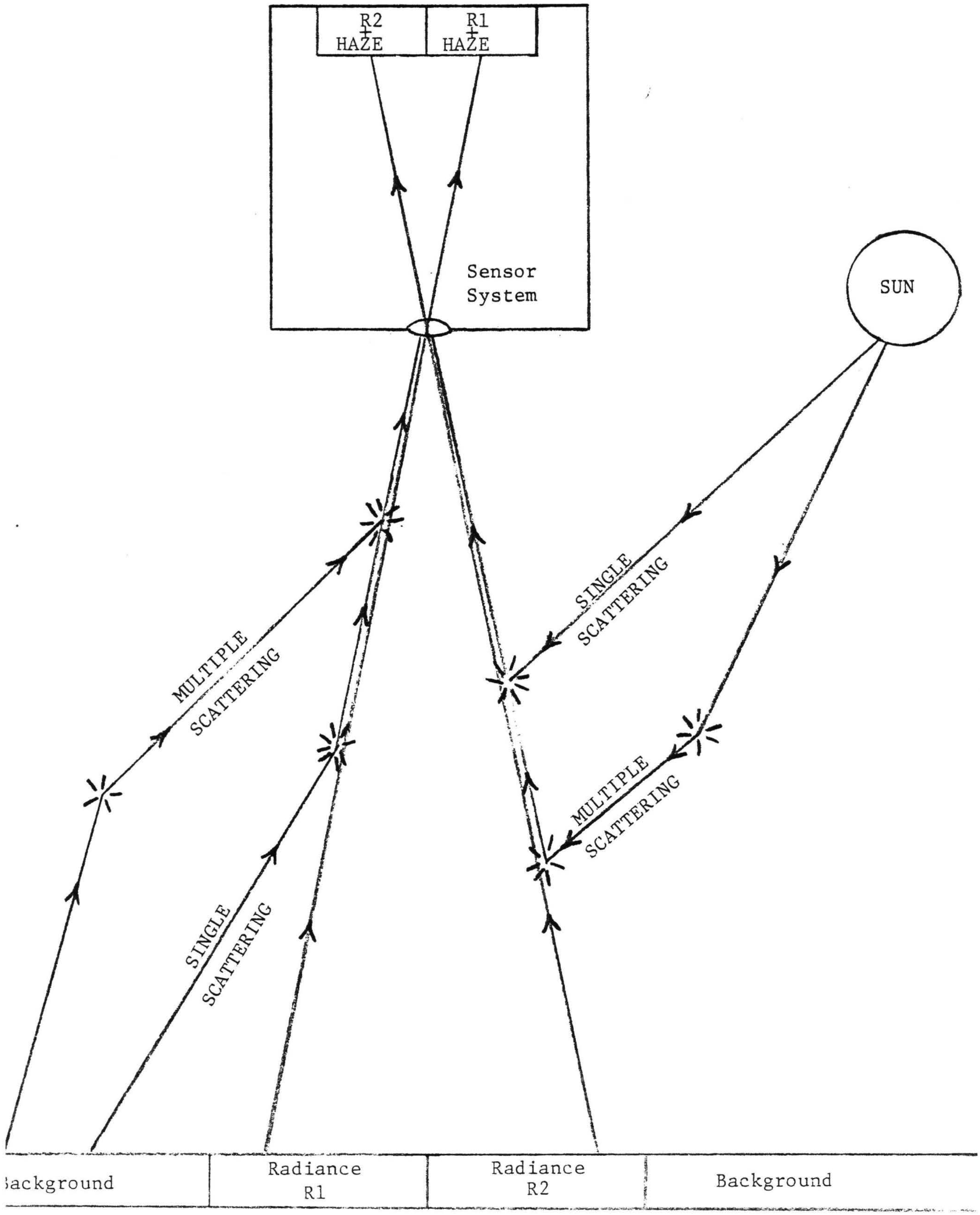


Figure 2. Effect of haze on image contrast

The second and more important effect is the reduction in contrast caused by haze. Since the same amount of haze is added to both low and high radiance subjects, its effect is proportionally greater at low radiance levels. This is illustrated in Table 1, which shows that haze reduces contrast most severely at the lower levels. Even in the very bright 120/30 target/background case, however, there is still a 25% loss of contrast.

Because of the greater scattering at short wavelengths, band 4 is most severely degraded by haze. The haze level in band 4 is also far more sensitive to atmospheric conditions than in the other bands.

3x Gain Mode

In addition to its 1x gain mode, the Landsat MSS sensor has a 3x gain mode which may be applied to bands 4 and 5 only. In the 3x gain mode, the sensor reaches saturation (a compressed digital level of 63) at one-third the saturation radiance level of the 1x gain mode (Figure 3).

As can be seen from the figure, 3x gain mode results in three times as large a digital count difference for a given brightness difference as does 1x gain mode. However, if Figure 3 is replotted to show log digital level vs. log radiance (Figure 4), 3x gain is shown to be only a lateral shift along the log radiance axis. The significance of Figure 3 is that it closely represents the way MSS data is recorded on film by GSFC. With this type of film recording, equal radiance ratios produce equal density differences.

Table 1. Effects of haze on observed image contrast in digital counts (0 to 127)

ound get el	Ground Background Level	Ground Contrast	Haze Level	Observed Contrast	Contrast Reduction Factor
.20	30	4	15	3.00	.25
80	20	4	15	2.71	.32
40	10	4	15	2.20	.45
20	5	4	15	1.75	.56
10	2.5	4	15	1.43	.64

Ground Contrast = target level/background level

Observed Contrast = (target + haze level)/(background + haze level)

Contrast Reduction Factor = 1- observed contrast/ground contrast

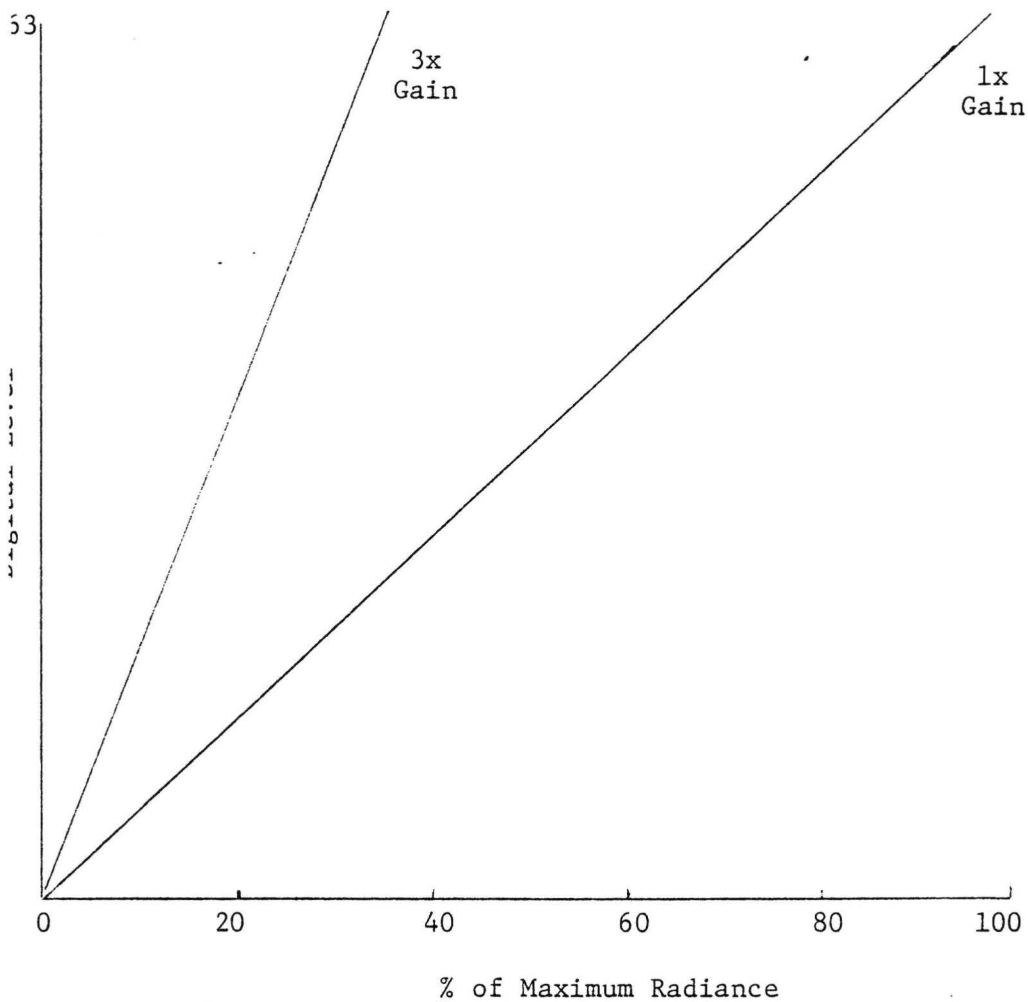


Figure 3a. Radiance response in 3x and 1x gain modes

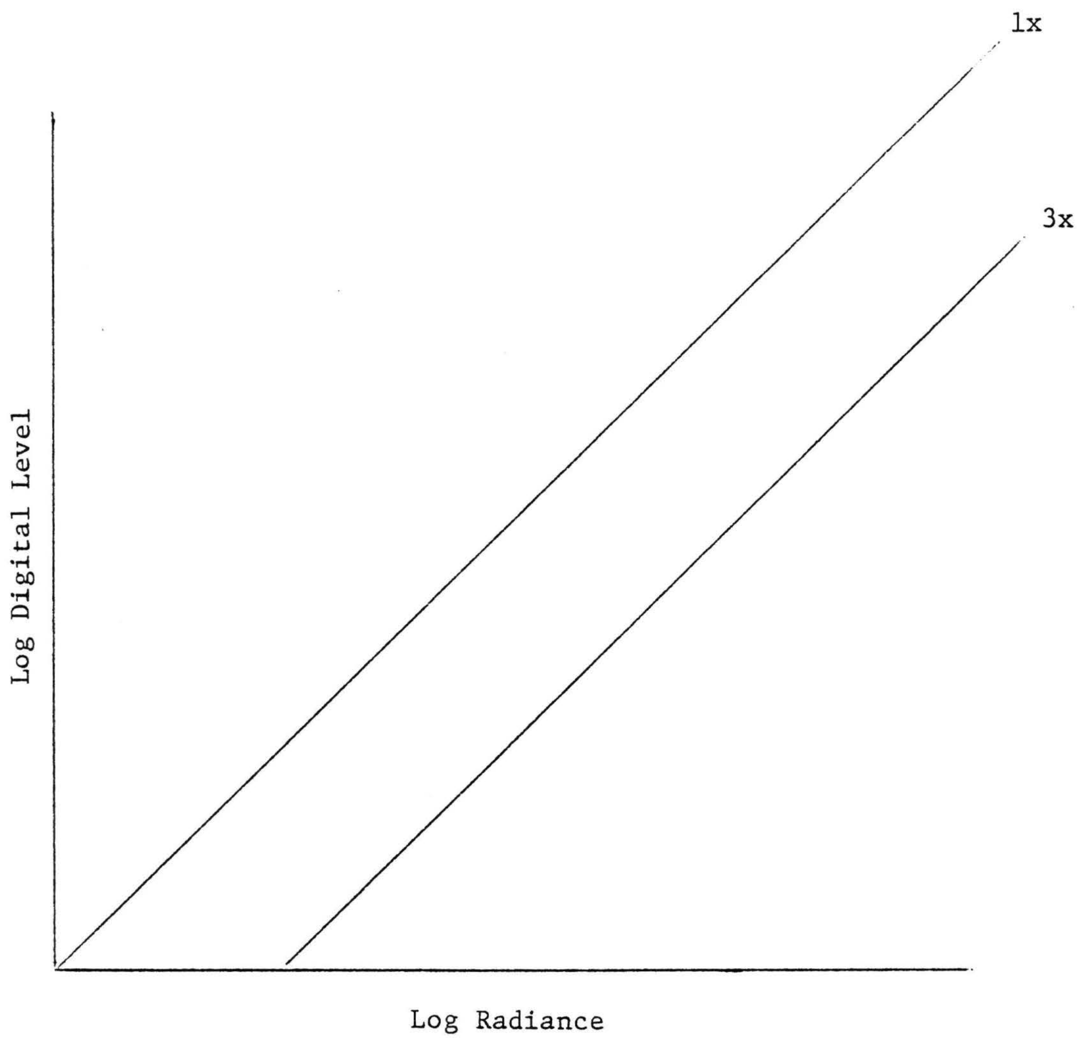


Figure 3b. Radiance response in 1x and 3x gain mode

Since a linear gain increase does not result in increased digital count ratios, one would not expect to see significantly greater detail in a 3x gain film image than in a 1x gain image, at least using the GSFC film recording technique. The 3x gain image will be lighter, which may improve viewing under dim illumination, but there will not be any greater density differences except in very low radiance areas with digital counts less than 4 (7-bit scale) in normal gain mode. Such areas are rarely encountered in band 4 and seldom in band 5 due to the path radiance (haze) which is always present.

Test Scene Histogram Analysis and Effect of EDIPS Contrast Stretch

Eight test CCT's were obtained for study, six of the Bimini area and two of the Palau Islands. Pertinent data on these scenes are listed in Table 2. The test scenes were all loaded into EDC's IDIMS digital analysis system and histograms generated for each. By using the capability of IDIMS to determine digital values of the scene areas displayed on the CRT, it was found that sensor saturation occurred in shallow water areas of all the 3x gain scenes. No saturation was observed in any of the normal gain scenes, with the exception of clouds.

If the standard EDIPS pipeline mode is used for processing 3x gain scenes, the result will be the same as if the high radiance cutoff points had been set to digital level 127, since the spike detector algorithm will interpret the saturated data as a spike. With non-saturated data, however, the upper cutoff point determined by the spike detector will vary with each scene, resulting in variable amounts of contrast stretch.

At the low radiance end of the histogram, all scenes showed a haze level considerably above zero (Table 2), especially in band 4. In the eight scenes analyzed, the haze level was very apparent from the histogram. There was typically no data at all below a certain level, with frequency of occurrence rising very sharply at the haze level. With this type of histogram, the spike detector algorithm can locate the haze level within one or two digital levels. It has been observed, however, that fully corrected digital data received by EDC from the GSFC Image Processing Facility has small amounts of data at all counts below the haze level. The existence of this extraneous data makes precise location of the actual haze level more difficult. Further investigation is required to determine the source of these extraneous counts and a method of dealing with them.

The use of the cumulative percentage criteria for determining histogram cutoff points (an alternate EDIPS procedure), is not an effective technique for shallow seas scenes, since much of the data lies within a few counts of the haze level. The use of a very small percentage runs the risk of selecting incorrect cutoff points due to extraneous data at or near digital level 0.

Evaluation of Transfer Functions

One objective of this project is to determine an optimum transfer function for the production of enhanced film images that are created after initial data screening. In order to speed this evaluation, use was made of the function mapping capabilities of the EDC IDIMS. The IDIMS system permits the use of eight different on-line lookup tables in order to modify the display's radiometric transfer function. By measuring the CRT's radiance as a function of digital input level, a calibration curve was obtained. This calibration curve was then used in conjunction with the lookup table program to generate function mappings to achieve various radiometric transfer functions. This technique allows one to view a close representation of the appearance of a film image without going through all the time-consuming film production steps. A large number of transfer functions can thus be evaluated very quickly.

The effectiveness of any transfer function was found to be very sensitive to the digital manipulation which preceded it. For example, it was found that a function which worked well for raw data was poor for haze removed data, and vice-versa. It was noted that, without haze removal, no single transfer function could be used with all scenes and still provide an effective display. When haze removal was applied, however, all scenes were more nearly uniform, allowing the application of a single, more effective transfer function.

Histograms of band 4 subareas of high gain scenes 2993-14385 and 2885-14444 were produced (Figures 4a and 4b) to determine the distribution of image radiance in areas where shallow water detail was visible. Both histograms show large amounts of data throughout the entire digital range with a peak

```
.64000E+02    .021643  I***********************
.68000E+02    .022504  I************************
.72000E+02    .025215  I***************************
.76000E+02    .094880  I*************************************************************************
.80000E+02    .061691  I******************************************************************
.84000E+02    .034290  I************************************
.88000E+02    .029490  I*******************************
.92000E+02    .016380  I*****************
.96000E+02    .013844  I***************
.10000E+03    .012775  I*************
.10400E+03    .019330  I********************
.10800E+03    .023557  I*************************
.11200E+03    .018038  I*******************
.11600E+03    .024354  I**************************
.12000E+03    .024864  I**************************
.12400E+03    .027432  I*****************************
.12800E+03    .033174  I***********************************
.13200E+03    .012663  I*************
.13600E+03    .030526  I********************************
.14000E+03    .030447  I********************************
.14400E+03    .011372  I************
.14800E+03    .029123  I*******************************
.15200E+03    .011212  I************
.15600E+03    .022791  I************************
.16000E+03    .018708  I********************
.16400E+03    .017687  I*******************
.16800E+03    .019282  I********************
.17200E+03    .018549  I********************
.17600E+03    .030319  I********************************
.18000E+03    .006427  I*******
.18400E+03    .019171  I********************
.18800E+03    .018852  I********************
.19200E+03    .022041  I***********************
.19600E+03    .011467  I************
.20000E+03    .008660  I*********
.20400E+03    .020447  I**********************
.20800E+03    .007799  I********
.21200E+03    .016810  I******************
.21600E+03    .000000  I
.22000E+03    .017624  I*******************
.22400E+03    .004657  I*****
.22800E+03    .007879  I********
.23200E+03    .011531  I************
.23600E+03    .003923  I****
.24000E+03    .006523  I*******
.24400E+03    .004944  I*****
.24800E+03    .004226  I****
.25200E+03    .047719  I***************************************************

  =        255.000       MIN=        62.0000
M =        139.600       STD DEV =        54.6644        FROM HISTOGRAM
```

Figure 4a.   Subarea histogram of scene 2193-14385

```
CTIONAL HISTOGRAM         HIGH4
AND NUMBER= 1   SL=   160   SS=   695   NL=   300   NS=   220

  LEAST VALUE   FRACTION   HISTOGRAM
   .96000E+02    .000015  I*
   .10000E+03    .000091  I*
   .10400E+03    .001788  I*
    10800E+03    .020530  I*********
    11200E+03    .013712  I******
   .11600E+03    .061364  I***********************
   .12000E+03    .061803  I************************
   .12400E+03    .032818  I*************
   .12800E+03    .080576  I******************************
   .13200E+03    .039091  I***************
   .13600E+03    .015606  I******
   .14000E+03    .035197  I**************
   .14400E+03    .023818  I**********
   .14800E+03    .022379  I*********
   .15200E+03    .020303  I********
   .15600E+03    .017030  I*******
   .16000E+03    .023500  I**********
   .16400E+03    .008167  I***
   .16800E+03    .017924  I*******
   .17200E+03    .009955  I****
   .17600E+03    .018076  I*******
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   .18400E+03    .017985  I*******
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   .19200E+03    .020606  I*********
   .19600E+03    .004455  I**
   .20000E+03    .008182  I***
   .20400E+03    .015530  I******
   .20800E+03    .003076  I*
   .21200E+03    .021227  I*********
   .21600E+03    .003242  I*
   .22000E+03    .024909  I**********
   .22400E+03    .007091  I***
   .22800E+03    .004606  I**
   .23200E+03    .034091  I*************
   .23600E+03    .002500  I*
   .24000E+03    .023409  I**********
   .24400E+03    .016561  I*******
   .24800E+03    .009985  I****
   .25200E+03    .241530  I*****************************************************************

X   =        254.000      MIN=          98.0000
AN  =        184.146      STD DEV =          53.8710        FROM HISTOGRAM
```

Figure 4b. Subarea histogram of scene 2885-14444 occurring at low radiance, representing the deep water included in the sub-image sample. These histograms show that the upper cutoff point must be set at the maximum digital level to avoid loss of shallow water detail. They also show that any intensity mapping to be used must have adequate contrast throughout the entire digital range, since the radiance distribution is relatively uniform.

In testing various intensity mappings on the CRT display, it was found that the EDC standard lookup table (Figure 4c) was very effective at preserving high gain image detail throughout the digital range as long as a haze removal procedure was performed. A linear density mapping (Figure 4d) was also used, but resulted in too great a loss of low radiance detail. A logarithmic mapping (Figure 4d) resulted in too great an emphasis on very low radiance data (after haze removal) and too much compression of high radiance data.

For the low gain bands, the EDC standard lookup table was modified to take account of the lower overall brightness (Figure 4e). Since no data was occurring above digital levels of about 55, the density range assigned to these levels was cut to a minimal 0.25. The entire density vs. digital level curve was also shifted toward the origin, in order to better match the data distribution.

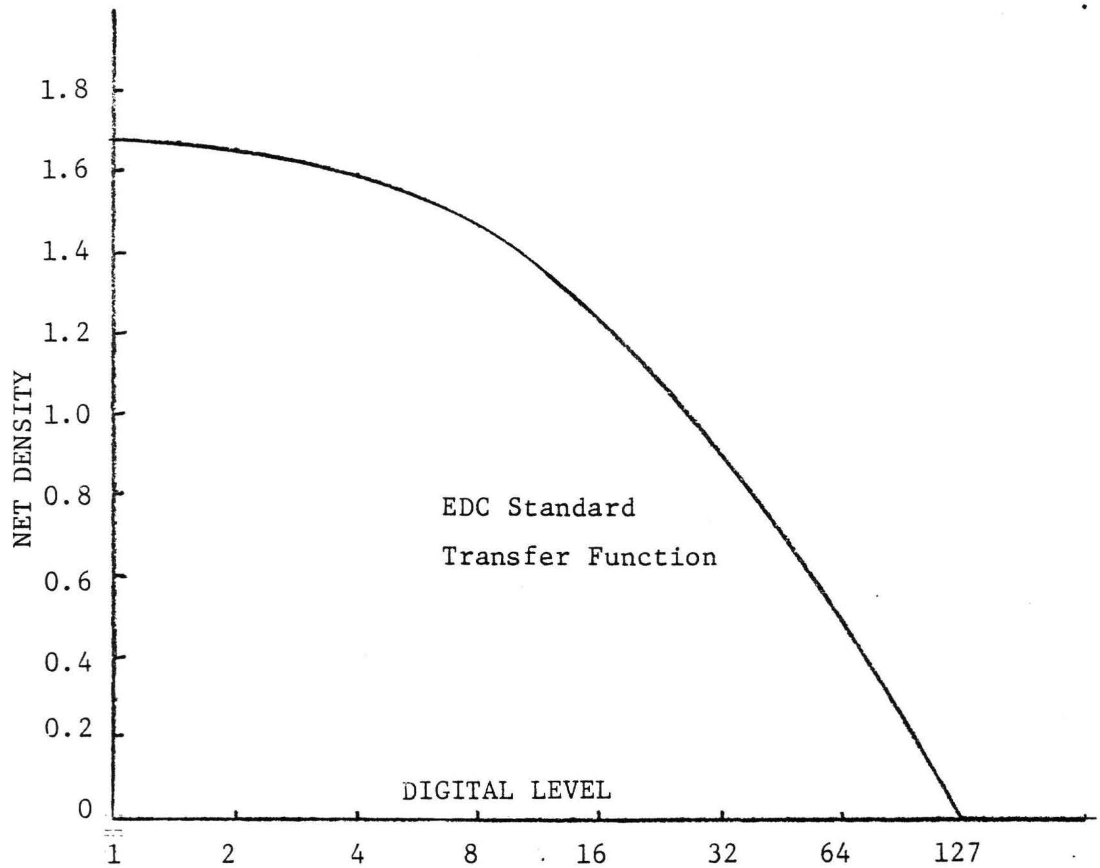
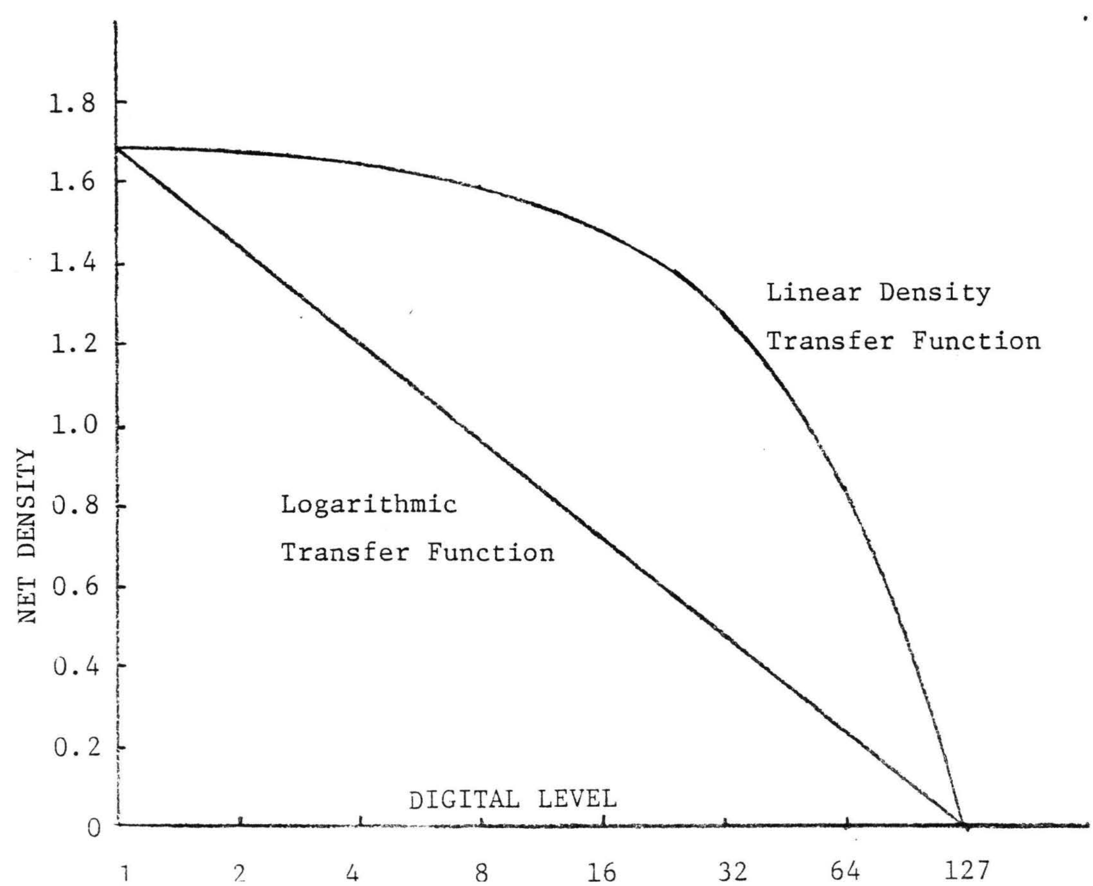


Figure 4c - High Gain Transfer Function



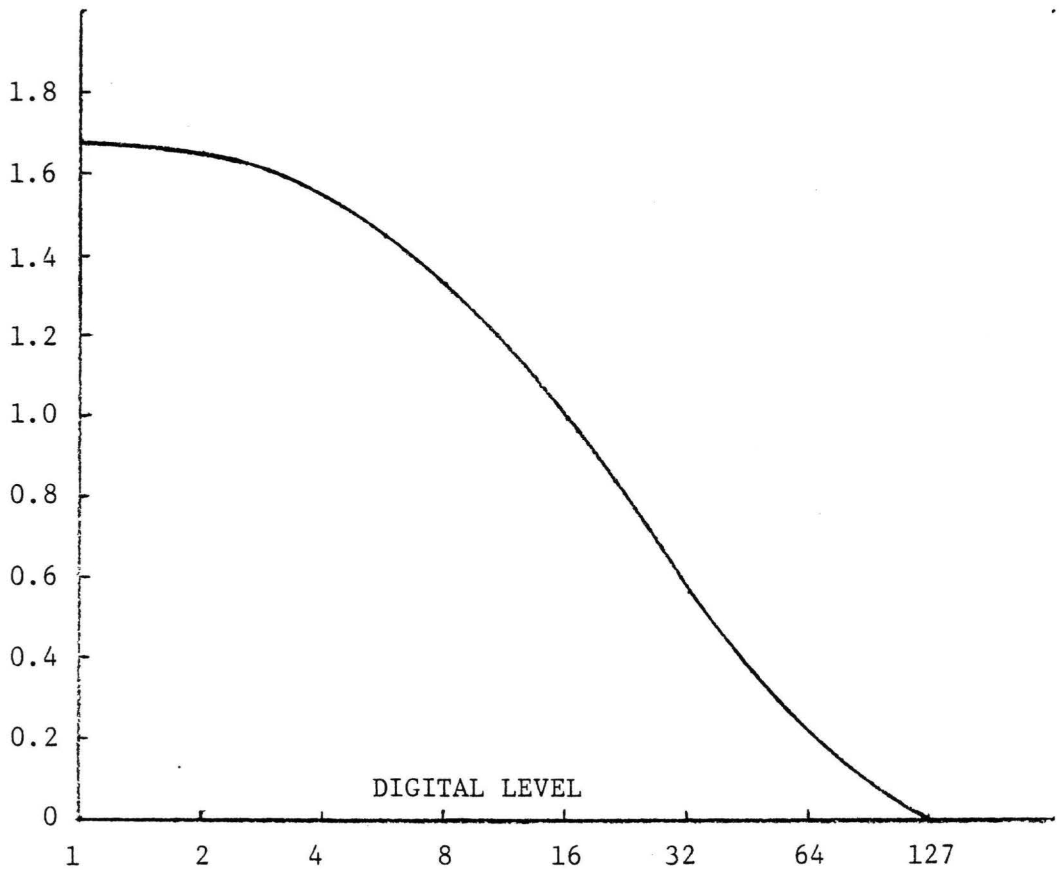


Figure 4e - Low Gain Transfer Function

Simulation of 3x Gain Using 1x Gain Data

The possibility of digitally manipulating 1x gain data to achieve the same effect as 3x gain data was investigated on four scenes, listed in Table 3. Full data on these scenes is given in Table 2.

Processing of all images proceeded as follows:

1. Image was read into IDIMS and scaled up to 8 bits.
2. If image was normal gain, a 3x contrast stretch was applied. Values from 0 to 85 were linearly stretched over a range of 0 to 255. 3x gain images were not contrast stretched.
3. Haze removal was performed on both 3x gain and stretched 1x gain images.
4. Film images were generated on the laser beam recorder.

Thus, for 1x gain, three separate images were produced--raw data, 3x stretch, and 3x stretch plus haze removal. For 3x gain, two images--raw and haze removal--were produced. For two of the scenes (#5678 and #2993) full size film images were produced for all stages. The other images were stored in the IDIMS system in such a manner that they could be compared simultaneously on the CRT display.

Table 2. Data inventory

cene ID	Acquisition Date	Sun Angle	Band 4,5 Gain	Band 4 Haze Level (7 Bit Scale)	IDIMS Name	Area
678-14102	02/25/77	30°	1x	13	Bimini, Low 2x	Bimini
889-15033	12/29/74	30°	1x	14	Bimini, 1889	Bimini
925-15015	02/03/75	34°	1x	13	Bimini, 1925	Bimini
993-14382	10/11/77	41°	3x	31	N2993	Bimini
993-14385	10/11/77	41°	3x	31	S2993	Bimini
885-14444	06/25/77	54°	3x	52	Bimini, High, 2x	Bimini
913-00162	07/23/77	46°	3x	26	Palau, 1083, 2x	Palau
913-00164	07/23/77	46°	3x	26	Palau, 1084, 2x	Palau

Table 3. Scenes for 1x gain/3x gain comparison

Scene ID	Gain
5678-14102	1x
1925-15015	1x
2993-14385	3x

The following factors were noted when visually comparing the high gain and stretched low gain images.

1. There was more saturation of high radiance data, such as urban areas, on the high gain images than on the low gain images. This suggests that the gain factor may be more than 3x for high gain. However, the situation was complicated by higher sun angles on the high gain scenes (see Table 2), which may have accounted for the higher degree of saturation.
2. In viewing both high gain and stretched low gain images together, there did not appear to be any clear advantage of high gain over low.
3. An intensity mapping optimized for one gain setting was not optimum for the other on raw data. However, when 1x gain data was stretched to 3x, a single intensity mapping could be used effectively.

STATISTICAL EVALUATION OF EFFECTS OF

HAZE REMOVAL AND CONTRAST STRETCH

ON 1x AND 3x GAIN MSS BAND 4 DATA

Data collected in Table 4 was evaluated over a series of three targets in the Bimini area. The data collected in Table 4 is a subset of the data in Table 2. Targets were selected to demonstrate the effect of EDIPS operations on land/sea interfaces. Various subsurface targets were selected to include variability in underwater features. The chart in Figure 5 shows the three targets used in the statistical evaluation. Target 1 shows the steepest descent from land to water (ΔLS). Target 2 has a less steep dropoff than target 1, and target 3 has little if any gradient. Deep water target areas were used for signal to noise evaluation. The target areas for SNR were to the west of target 1 and 2.

In Figure 6 the various percent transmission is given for various water types (Ross, 1976). The window for MSS band 4 is 500 to 600 nanometers and the transmission through the water types is from approximately 2.5% to 39.0%. Target 1 makes use of the difference between bay and ocean types. The Δ in % transmission for target 1 is on the order of 39%. Target 2 makes use of the coastal bay Δ and the Δ in % transmission is approximately 12.5%. Target 3's Δ runs from 1% to 2.5%.

Table 5 shows the Δ's that were computed from land/sea raw (ΔLS_R), contrast stretched (ΔLS_c) and haze removed (ΔLS_H) data. The percent improvement in ΔLS_R to ΔLS_c seen for raw versus contrast stretched data ranged from 32% to 84%. In all cases, it was seen that contrast stretch improved the land/sea ΔLS.

Table 4. Data used for statistical evaluation

(A subset of Table 2)

IDIMS Name	Gain
BIMINI.1927	1x
BIMINI.LOW.2x	1x
BIMINI.1925.RAW	1x
BIMINI.HIGH.2x	3x
S2993.RAW	3x

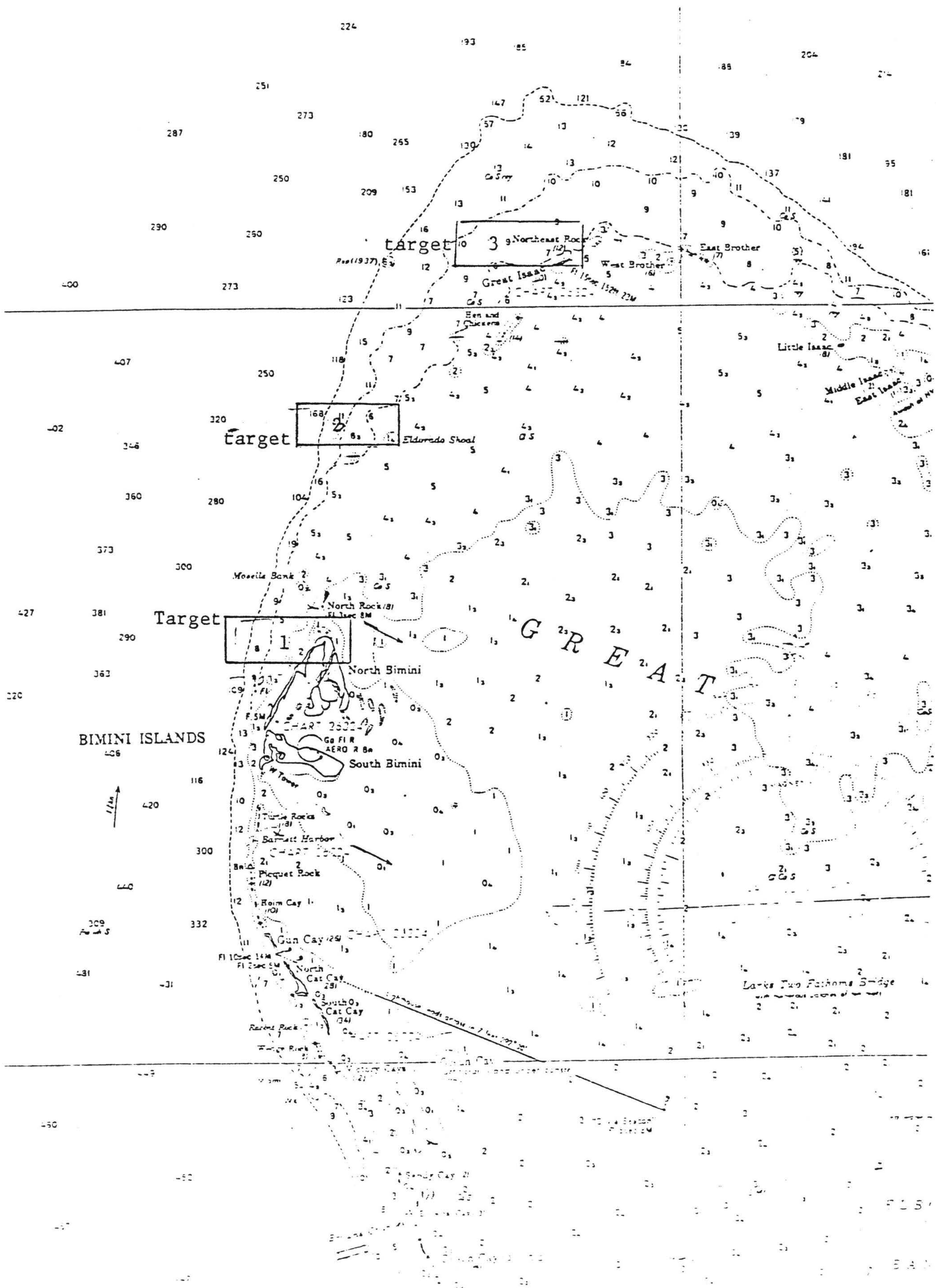


Figure 5. Chart of target areas

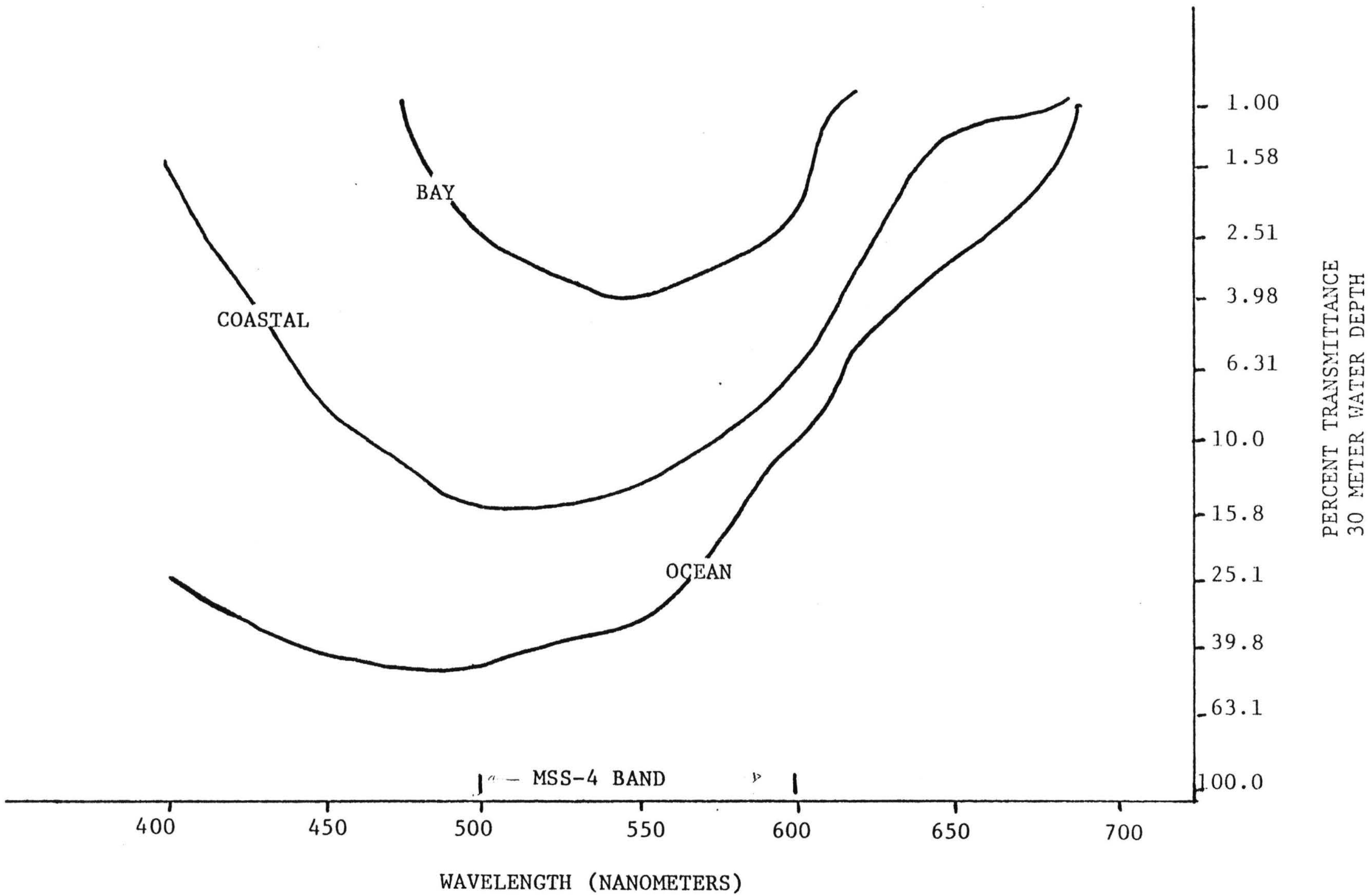


Figure 6. Spectral transmittance in 30 meter water depths

Table 5. Selected targets & their land/sea Δ's

Target	Gain	ΔLS_R	ΔLS_C	ΔLS_H	Measurement of Improvement
1	1x	43.02	77.03	43.02	.79
2	1x	10.84	19.26	10.84	.78
3	1x	4.50	8.30	4.50	.84
1	3x	91.4	-	91.4	-
2	3x	11.1	-	11.1	-
1	3x	80.63	107.0	-	.32
2	3x	43.60	58.5	-	.34
3	3x	12.18	16.5	-	.35

$$\frac{(\Delta LS_C - \Delta LS_R)}{\Delta LS_R} \times 100 = \text{measurement of improvement}$$

For haze removal no change in ΔLS was noted, demonstrating statistically that haze removal didn't affect the land/sea Δ's in the selected scenes. Note, this was done for 1x and 3x data. Marked improvement in Δ's was observed between raw and contrast stretched data as is shown in Table 5.

A series of histograms (see Figures 7a-e) are included to show the effects of the haze removal and contrast stretch operations on 1x and 3x gain data. Each of these histograms is taken over the complete quarter scene (215K samples). Most of the features seen in Figure 5 (the chart of the Bimini area) are included in the histograms. Figure 7a is a histogram of raw band 4 data. Note the positively skewed characteristic of the data. There is little if any data below the count level of 24. The data is rather tightly bunched between counts 28 and 76. Thus, 48 counts represents over 90% of the range of the data. With contrast stretching (Figure 7b) the data is spread over a wider range of 160 counts. The standard deviation increased from 24 to 46 counts, thus giving the observer a larger number of significant density levels to observe for detail. Finally, with the application of haze removal to simulated 3x gain data (Figure 7c), the low end haze was removed but all detail remained (σ = 46.4).

In Figure 7d, we observed 3x gain data. The data is more bimodal because of cloud contamination. In Figure 7e the haze is removed. The amount of data removed is approximately .0056% (or 1205 samples). The σ is preserved and discrimination of scene features is not degraded after haze removal.

```
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 .20000E+02    .000000 I
 .24000E+02    .000725 I*
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 .64000E+02    .024777 I******
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 .18000E+03    .000246 I*
 .18400E+03    .000209 I*
 .18800E+03    .000204 I*
 .19200E+03    .000242 I*
 .19600E+03    .000218 I*
 .20000E+03    .000195 I*
 .20400E+03    .000181 I*
 .20800E+03    .000195 I*
 .21200E+03    .000163 I*
 .21600E+03    .000242 I*
 .22000E+03    .000260 I*
 .22400E+03    .000158 I*
 .22800E+03    .000079 I*
 .23200E+03    .000158 I*
 .23600E+03    .000172 I*
 .24000E+03    .000111 I*
 .24400E+03    .000172 I*
 .24800E+03    .000107 I*
 .25200E+03    .004729 I*
MAX  =        255.000      MIN=        14.0000
MEAN =        43.1373      STD DEV =        24.9514      FROM HISTOGRAM
```

Figure 7a. Raw band 4 1x gain data

```
.44000E+02    .000000 I
.48000E+02    .000000 I
.52000E+02    .000000 I
.56000E+02    .000000 I
.60000E+02    .000000 I
.64000E+02    .000000 I
.68000E+02    .000000 I
.72000E+02    .000000 I
.76000E+02    .000725 I*
.80000E+02    .000000 I
.84000E+02    .022366 I******
.88000E+02    .395229 I***************************************************************************************************
.92000E+02    .000000 I
.96000E+02    .121739 I*******************************
.10000E+03    .058686 I***************
.10400E+03    .000000 I
.10800E+03    .029980 I********
.11200E+03    .028214 I*******
.11600E+03    .000000 I
.12000E+03    .017136 I****
.12400E+03    .027843 I*******
.12800E+03    .000000 I
.13200E+03    .029009 I*******
.13600E+03    .027583 I*******
.14000E+03    .000000 I
.14400E+03    .018994 I*****
.14800E+03    .010187 I***
.15200E+03    .000000 I
.15600E+03    .016955 I****
.16000E+03    .021823 I******
.16400E+03    .000000 I
.16800E+03    .012049 I***
.17200E+03    .014976 I****
.17600E+03    .000000 I
.18000E+03    .013680 I***
.18400E+03    .011868 I***
.18800E+03    .000000 I
.19200E+03    .014627 I****
.19600E+03    .010150 I***
.20000E+03    .000000 I
.20400E+03    .009899 I***
.20800E+03    .013926 I****
.21200E+03    .000000 I
.21600E+03    .007674 I**
.22000E+03    .006596 I**
.22400E+03    .000000 I
.22800E+03    .004520 I*
.23200E+03    .007460 I**
.23600E+03    .000000 I
.24000E+03    .002945 I*
.24400E+03    .005890 I*
.24800E+03    .000000 I
.25200E+03    .037263 I*********

MAX  =       255.000     MIN=        42.0000
MEAN =       122.501     STD DEV =        46.5362       FROM HISTOGRAM
```

Figure 7b. Contrast stretched band 4 1x gain data

```
.40000E+01    .022366 I******
.80000E+01    .000000 I
.12000E+02    .395229 I***************************************************************************************************
.16000E+02    .121739 I*******************************
.20000E+02    .000000 I
.24000E+02    .058686 I***************
.28000E+02    .029980 I********
.32000E+02    .000000 I
.36000E+02    .028214 I*******
.40000E+02    .017136 I****
.44000E+02    .000000 I
.48000E+02    .027843 I*******
.52000E+02    .029009 I*******
.56000E+02    .000000 I
.60000E+02    .027583 I*******
.64000E+02    .018994 I*****
.68000E+02    .000000 I
.72000E+02    .010187 I***
.76000E+02    .016955 I****
.80000E+02    .000000 I
.84000E+02    .021823 I******
.88000E+02    .012049 I***
.92000E+02    .000000 I
.96000E+02    .014976 I****
.10000E+03    .013680 I***
.10400E+03    .000000 I
.10800E+03    .011868 I***
.11200E+03    .014627 I****
.11600E+03    .000000 I
.12000E+03    .010150 I***
.12400E+03    .009899 I***
.12800E+03    .000000 I
.13200E+03    .013926 I****
.13600E+03    .007674 I**
.14000E+03    .000000 I
.14400E+03    .006596 I**
.14800E+03    .004520 I*
.15200E+03    .000000 I
.15600E+03    .007460 I**
.16000E+03    .002945 I*
.16400E+03    .000000 I
.16800E+03    .005890 I*
.17200E+03    .002346 I*
.17600E+03    .034917 I*********

AX  =      177.000     MIN=        .000000E+00
EAN =      45.2052     STD DEV =      46.3722      FROM HISTOGRAM
```

Figure 7c. Haze removed band 4 1x gain data

```
 .96000E+02    .000005 I*
 .10000E+03    .000046 I*
 .10400E+03    .001340 I*
 .10800E+03    .020958 I***************
 .11200E+03    .014980 I***********
 .11600E+03    .077637 I*********************************************************
 .12000E+03    .090048 I******************************************************************
 .12400E+03    .053244 I***************************************
 .12800E+03    .133487 I**************************************************************************************************
 .13200E+03    .071706 I*****************************************************
 .13600E+03    .033051 I************************
 .14000E+03    .055684 I*****************************************
 .14400E+03    .047773 I***********************************
 .14800E+03    .029109 I*********************
 .15200E+03    .031476 I***********************
 .15600E+03    .018775 I**************
 .16000E+03    .018402 I**************
 .16400E+03    .005010 I****
 .16800E+03    .013576 I**********
 .17200E+03    .005517 I****
 .17600E+03    .011835 I*********
 .18000E+03    .005775 I****
 .18400E+03    .011375 I********
 .18800E+03    .005043 I****
 .19200E+03    .012627 I*********
 .19600E+03    .002662 I**
 .20000E+03    .004941 I****
 .20400E+03    .009132 I*******
 .20800E+03    .002022 I*
 .21200E+03    .011904 I*********
 .21600E+03    .001943 I*
 .22000E+03    .013451 I**********
 .22400E+03    .003638 I***
 .22800E+03    .003546 I***
 .23200E+03    .015906 I************
 .23600E+03    .001437 I*
 .24000E+03    .011264 I********
 .24400E+03    .008331 I******
 .24800E+03    .005646 I****
 .25200E+03    .135698 I****************************************************************************************************

1AX  =        254.000     MIN=         92.0000
1EAN =        161.507     STD DEV =         48.0395       FROM HISTOGRAM
```

Figure 7d. Raw band 4 3x gain data

```
 .40000E+01    .020958  I***************
 .80000E+01    .014980  I***********
 .12000E+02    .077637  I*********************************************************
 .16000E+02    .090048  I******************************************************************
 .20000E+02    .053244  I***************************************
 .24000E+02    .133487  I**************************************************************************************************
 .28000E+02    .071706  I*****************************************************
 .32000E+02    .033051  I************************
 .36000E+02    .055684  I*****************************************
 .40000E+02    .047773  I***********************************
 .44000E+02    .029109  I*********************
 .48000E+02    .031476  I***********************
 .52000E+02    .018775  I**************
 .56000E+02    .018402  I**************
 .60000E+02    .005010  I****
 .64000E+02    .013576  I**********
 .68000E+02    .005517  I****
 .72000E+02    .011835  I*********
 .76000E+02    .005775  I****
 .80000E+02    .011375  I********
 .84000E+02    .005043  I****
 .88000E+02    .012627  I*********
 .92000E+02    .002662  I**
 .96000E+02    .004941  I****
 .10000E+03    .009132  I*******
 .10400E+03    .002022  I*
 .10800E+03    .011904  I*********
 .11200E+03    .001943  I*
 .11600E+03    .013451  I**********
 .12000E+03    .003638  I***
 .12400E+03    .003546  I***
 .12800E+03    .015906  I************
 .13200E+03    .001437  I*
 .13600E+03    .011264  I********
 .14000E+03    .008331  I******
 .14400E+03    .005646  I****
 .14800E+03    .135698  I****************************************************************************************************

MAX  =        150.000      MIN=          .000000E+00
MEAN =         57.5069     STD DEV =         48.0392       FROM HISTOGRAM

ONTROL-Y DISABLED
```

Figure 7e. Haze removed band 4 3x gain data

STATISTICAL COMPARISON OF SCENE QUANTIZATION FOR RAW AND CONTRAST STRETCHED DATA

Table 6 shows the improvement in scene quantization for raw and contrast stretched 1x and 3x data. The average SQ_C/SQ_R for 1x data was 1.85, whereas it was 1.80 for 3x data. The fact that the improvement factor SQ_C/SQ_R was always greater than 1.0 demonstrates the improved range of data after the contrast stretch operation.

SNR for 1x and 3x

In Table 7 are estimates of the SNR for 1x and 3x gain modes. Areas were chosen that appeared uniform in radiance (the $\overline{\sigma}_{1x} = 1.44$ and $\overline{\sigma}_{3x} = 5.15$) and with no visibly detectable clouds in the scene. Both scenes were of raw data and collected at different times. The $\overline{\sigma}_{3x}/\overline{\sigma}_{1x}$ was approximately a factor of three as was the average signal. This leads one to conclude that noise is amplified by 3x so that there is no gain in SNR in the 3x over the 1x mode.

Sources of Error

The sources of imagery errors are described in Figure 8.

The problem of haze is discussed on page 5 under the "Effects of Haze." In addition, it is noted that we are not in a position to determine the radiometric accuracy of the bathymetric information in the selected scenes post haze removal. Errors due to scene related problems are as follows:

Errors due to sea state would give false bottom information due to higher reflected light components. The errors due to turbidity would decrease the penetration of MSS band 4 (see Figure 6, Ref. 1).

Table 6. Scene quantization $\frac{(Mx-Mn)}{255}$

for 1x and 3x gain

1x			3x		
SQ_R	SQ_C	SQ_C/SQ_R	SQ_R	SQ_C	SQ_C/SQ_R
0.58	0.94	1.62	0.59	0.99	1.68
0.52	0.93	1.79	0.52	0.58	1.12
0.18	0.32	1.78	0.18	0.47	2.61
0.35	0.58	1.66			
0.02	0.07	3.50			

Table 7. Signal to noise estimates for band 4 MSS (raw) 1x and 3x gain scenes (flat water scene)

1X		3X	
μx	σx	$\mu 3x$	$\sigma 3x$
37.80	1.19	79.50	6.16
31.80	1.65	77.30	4.20
31.24	1.33	119.84	5.80
		118.62	4.44
$\bar{\mu}1x$	$\bar{\sigma}1x$	$\bar{\mu}3x$	$\bar{\sigma}3x$
33.61	1.44	97.6	5.15
	$\bar{\mu}3x/\bar{\mu}1x$	$\bar{\sigma}3x/\bar{\sigma}1x$	
	2.90	3.58	

Scene	Sensor	Processing
1. Atmosphere	1. Striping	1. Radiometric & geometric corrections
2. Sea state	2. Within band variability	2. EDIPS processing
3. Turbidity	3. Mirror edge effects	3. Incorrect truncation limits

Figure 8. Sources of imagery errors

One of the real problems in comparing the sensor information between band 4 and the 1x and 3x gain mode is that the data cannot be gathered simultaneously. Changes in sun angle and atmosphere are variables that are transients in any comparison. Therefore, future comparison of 1x and 3x gain should be done with the atmospheric and solar angle variations in mind. We did not collect enough samples to adequately compare the 1x and 3x gain data. Data should be collected over a year to make a good 1x and 3x comparison.

The major source of radiometric system error in the sensor system is the calibration between detectors. The detector variability produces the banding that one sees in an image. In Figures 9a and 9b are the digital printouts that demonstrate the banding problem that exists in 3x gain data. Unfortunately, any contrast stretch algorithm will probably accentuate the banding. Haze removal will have no digital effect, but may increase banding in film imagery.

A major source of error in the processing system is the radiometric correction. The important point to consider at this point is the reliability of the calibration algorithm applied to high gain data (Smith, 1978). According to GSFC, one of the problems with the 3x gain data is that it is calibrated with the same set of six reference voltage points that is used for 1x data. However, in the 3x data, four of these reference points are saturated. Another problem with the 3x calibration is the lack of performance evaluation sites which are used routinely for 1x calibration. The authors have not had enough experience with 3x gain data to document its radiometric accuracy. Experience has shown that 1x gain data is itself variable, making multitemporal scene-to-scene comparison after a lag of k days difficult. Our point is only to caution the reader about the potential 3x gain calibration error as it affects multitemporal comparisons.

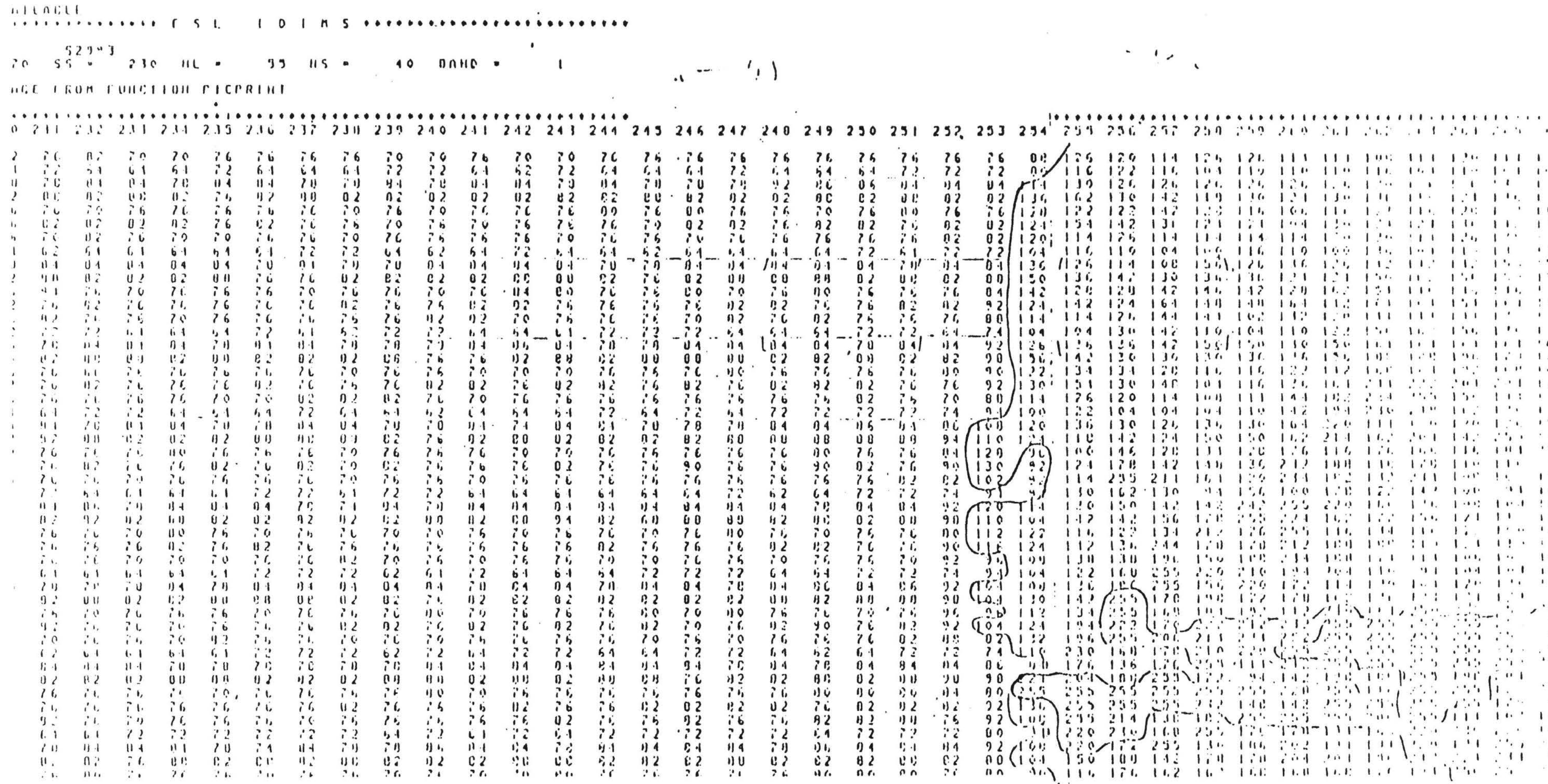

Figure 9a. High gain pre haze removed band 4

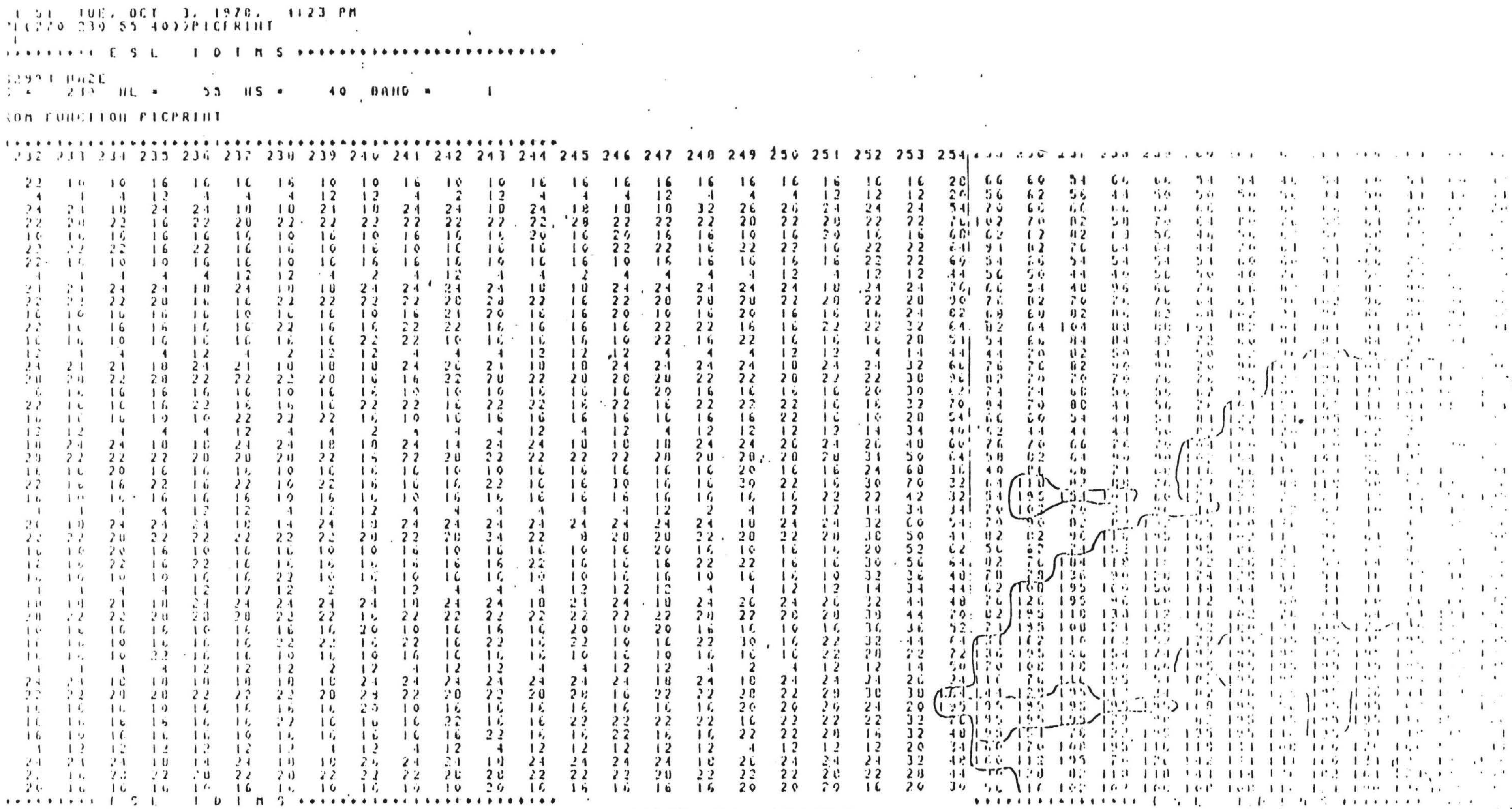

Figure 9b. High gain post haze removed band 4

CONCLUSIONS AND RECOMMENDATIONS

It is the authors' opinion that 3x gain data would create an operational processing problem for EDC if processed in the normal EDIPS pipeline mode because of the random distribution of images on HDT's. If all DMA scenes were on one HDT_p, however, EDC could set up a modified pipeline mode by creating special EDIPS data base parameters for DMA products.

Using an EDIPS modified procedure, the EDIPS data base would be set to process all DMA data with only haze removal applied (using the spike detector algorithm). Threshold spike frequencies will be set low enough so that no significant data is truncated.

Two special LBR lookup tables will be used--one for high gain (bands 4 and 5) and one for low gain data (bands 6 and 7).

The images produced in this manner will serve as both the initial screening film and the enhanced product. All 70 mm reductions will also be produced from these pipeline images.

It has been shown in this report that the haze removal process provides effective improvement by compensating for the contrast reducing effects of haze on low radiance water detail. The process can properly be interpreted as a corrective operation rather than an enhancement.

It is recommended that contrast stretch not be used for two reasons. First, the high gain data is already saturated on very shallow water and would thus receive little enhancement. Secondly, contrast stretch would introduce a variable amount of enhancement to all scenes, possibly limiting the ability to make multitemporal comparisons.

It is our conclusion that the 3x gain data in band 4 does not produce a significant increase in information content for imagery over 1x gain data. The increased quantization of 3x may lead to more precise bathymetry, but it is the authors' limited experience that evaluation of the 3x gain data contains a number of unknowns. As discussed under "Sources of Error", the banding is increased in 3x as well as the noise level of the data. Therefore, further work with 3x gain data is indicated at the engineering evaluation level. As demonstrated in Table 7, the signal and noise level do not indicate any gain in information.

In answer to DMA questions as outlined in the memo of 5 September 1978:

(1) Haze removal, as performed by EDIPS, does not remove any information or degrade bathymetry. On the contrary, it produces a significant improvement in the contrast of low radiance detail on film images.

(2) The present EDIPS contrast stretch algorithm will not degrade bathymetric information as long as the low cutoff threshold value is properly set. It is our belief that the current threshold of 0.02% can be reduced to 0.005 - 0.01%, thus preserving all significant low radiance detail. This change will have negligible effect on other data.

(3) One drawback of contrast stretch is the production of variable amounts of stretch depending on scene content and cloud cover. This may make multitemporal comparisons more difficult.

In conclusion, the options listed in Table 8 summarize the advantages and disadvantages of the various approaches of EDIPS to DMA processing.

Table 8. Options

(1) Standard Pipeline

Disadvantages: Variable contrast stretch

Single lookup table

Advantages: Quick turnaround

Cost savings

(2) Modified Pipeline - Haze removal only

Data output as one HDT by GSFC (streamed HDT)

Disadvantages: Additional load on IPF

Requires EDIPS software change to do HR via spike finder algorithm

Requires EDIPS software change to assign different lookup tables to different bands

Advantages: Cost savings

Not as fast as turnaround as pipeline, but faster than special order

(3) Special Order - Haze removal - different lookup table

Disadvantages: Random tape search - slow

Limited EDIPS special order capacity

Requires EDIPS software change to do HR via spike finder algorithm

One work order card per band required due to lookup table selection

Advantages: Maximum flexibility in algorithm selection

No impact on IPF

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