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An Investigation of Several Aspects of Landsat-5 Data Quality

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Several Landsat-5 TM scenes were received during the reporting period: Parmer County, TX (31/36) of 6/8/84 as a P-tape; Shelby, MT (39/26) of 7/18/84 as a GCP-corrected P-tape; San Francisco, CA (44/34) of 5/2/84 as a GCP-corrected P-tape; White Sands, NM (33/37) of 10/28/84 as an unity RLUT A-tape and Great Salt Lake, UT (39/31) of 7/2/84 as a standard A-tape.

Band-to-Band Registration

Quadrant 4 of the Parmer County, TX scene was tested for band-to-band registration by the block correlation method. The results are shown in Table 1. The results are very similar to our earlier analyses of Landsat-5 TM data for the Corpus Christi and Huntsville scenes. Within focal planes, all bands were very well registered to one another including the thermal band. Between the primary and secondary focal planes, there was a mean misregistration of 0.71±0.03 pixels in the across-scan direction and 0.19±0.03 pixels in the along-scan direction. The Huntsville results were 0.66±0.02 and 0.13±0.02 pixels, respectively. Although the 95% confidence intervals do not quite overlap between the two scenes, the results are close enough to be considered identical. An effort will be made to determine when the software corrections were implemented to bring the two focal planes into registration. When that date has been determined, we will test one or two scenes processed after that date to determine the effectiveness of the corrections. The dates of the implementation should be generally available to the user community, particularly the TM AO investigators, so the users can avoid the early data from both Landsat-4 and Landsat-5 if they wish to do so.

Table 2 is a summary of all the band-to-band registration results we have accumulated to date. Only the mean misregistrations are listed for each scene. Within a given satellite, the stability of these results for a given band pair is of the order of a few hundredths of a pixel for most band pairs. Table 2 shows the initial misregistration between focal planes and the results of two apparently different attempts to correct it (the Sacramento data of 8/12/83 and the remake of the NE Arkansas scene of 8/22/82). Table 2 also shows the initial problems with the thermal band and that they have long since been corrected.

Geodetic Registration

The original concept for testing geodetic registration envisaged testing P-tapes that had been fully corrected using ground control points (GCPs). In that case, the geodetic location of a pixel was

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supposed to be accurate within 0.5 pixels 90% of the time. Unfortunately, GCP-corrected P-tapes have been rare and we have yet to receive our requested GCP-corrected P-tape of the Sacramento scene of 2/1/83. In light of these facts, we decided to test the Scrounge format tape of the same Sacramento scene which we had on hand. The analysis would demonstrate the geodetic accuracy prior to the GCP-correction and it could be compared to the GCP-corrected data when we received it. Note that the Scrounge data was never intended to meet the 0.5 pixel accuracy specification.

The test for geodetic accuracy was conducted by locating control points in the image and on 7.5' quadrangle maps (1:24,000 scale), estimating the image coordinates to the nearest half-pixel (14 meters), digitizing the map coordinate to the nearest 0.00001 degree (1.1 meters), using the digitized map coordinate in a program provide by EROS Data Center to predict the image coordinate of the point, and comparing the observed image coordinate with the predicted coordinate. June Thormodsgard of EROS provided the program to predict the coordinates from the information in the HAAT file of a Scrounge tape (i.e. the WRS center, WRS offset, the projection and the rotation angle). The control points were selected after consultation with the Geometronics Branch of the Geological Survey in order to select points with the best possible location accuracy on 7.5' quadrangles.

The results for the comparison for fourteen control points taken throughout the scene are shown in Table 3. The line/sample coordinates for the control points as interpreted from the image using an interactive display system are listed under Image Location. The coordinates derived by the EROS geolocation program from the digitized map points are listed under Predicted Location and the differences between the two are listed under Error. In general, the correspondence is far better than expected for system-corrected data. The mean errors and standard deviations for these fourteen points are 0.0 ± 1.2 lines and -9.7 ± 1.7 samples. (Our workshop report that the line direction error was 4.0 ± 1.2 was incorrect because the image file header record had been treated as four image lines and those lines should have been subtracted from the image line coordinates.) Note that the standard deviations are of the order of 1.5 pixels or three times the allowable error for geodetic registration. Although the population is small (14 points) these standard deviations are probably a good estimate of those for a much larger population. If so, these standard deviations indicate that the present technique will not be adequate to test geodetic accuracy to 0.5 pixels. We are pursuing improvements with the Geometronics Branch at the Geological Survey as mentioned in the previous report.

Interdetector Noise

The goal of the interdetector noise task is to characterize the differences in response between detectors in a TM band. This includes Fourier analysis to determine the periodic noise in individual detectors on A tape data. Previously, we examined nearly uniform areas over water bodies in two Landsat-4 scenes: Washington D.C on 11/2/82 and San Franscisco on 12/31/82. Periodic noise was present in TM1-4 in both scenes. A noise component at a spatial frequency of

0.31 cycles per pixel (32 KHz in the time domain) was particularly prominent. We also explored the relationship between varying amounts of noise in individual detectors and low level striping due to the histogram normalization used in A-tape production. Similar analysis of Landsat 5 data is being performed.

Two 256x256 pixel windows over the Great Salt Lake in quadrant 4 of the 7/2/84 scene were examined recently. One window was in a dark water area and the other in water with medium grey levels. The forescans and backscans were copied into separate files before analysis because other Landsat Data Quality investigators had shown that some artifacts of TM imagery were dependent on scan direction. Means, standard deviations and power spectra for each detector in each direction were computed.

Periodic noise was detected in all bands of Landsat-5 except TM6, where the low sampling rate of the sensors would obscure the noise at the frequencies observed in the other bands. Noise at .087 and .174 (a harmonic of .087) cycles per sample was detected in TM1-TM5 and TM7. (In Landsat-4, TM bands 5 and 7 were free of periodic noise.) Noise was particulary strong in TM5, with root sum square (RSS) peak-to-peak values in the frequencies .0859, .0898, .1718, and .1757 cycles per sample (cps) ranging from 0.54 in detector 1 to 3.26 in detector 7. Table 4 shows the results for these frequencies for the dark water area. Noise at .05 cps, .21 cps, and .42 cps (a harmonic of .21 cps) was observed in TM1-4, but not in TM5 or TM7.

Analysis of of the Salt Lake scene windows will be completed to quantify the noise content in all detectors and determine its consistancy within the scene. Spectral analysis of some small areas on the B-tape of an October 1984 White Sands scene will be performed to detemine the consistency of periodic noise in Landsat-5 scenes.

The grey level means of each of the two water areas in the Great Salt Lake were calculated in order to determine any dependence on scan direction or on individual detectors. Separate means were calculated for each detector in each band for both scan directions. The results are shown for the dark water area in Tables 5 and 6. To examine any scan direction effect, the differences between the forescan and backscan means were calculated for each detector. The mean difference for each band is shown in Table 6 together with the standard deviation of the sixteen differences (four for TM6). Table 6 shows that the forescan means were approximately one and one half grey levels higher than the backscan means in TM1-4 in the dark water area. The differences between forescan and backscan means in TM5,7 were less than 0.1 grey level. The differences were approximately one grey level in the medium water area for TM1-4 and again less than 0.1 for TM5,7. In the January workshop, we had reported differences between TM5 forescan and backscan means of about three grey levels. These apparent differences were due to an error in calculation on a forescan data set. Tables 5 and 6 show the corrected TM5 means. Since the Great Salt Lake is east of the Great Salt Desert, the differences beween scan directions were probably due to the bright target saturation effect noted by other Landsat Data Quality investigators. Detectors in the primary focal plane have been observed to have elevated responses after saturation or near saturation (grey levels above 200). The dark water area, in particular, was east of such an area but the medium water area was affected only minimally. The magnitude of the saturation effect on the Salt Lake data may have been exaggerated for two reasons: round-off in quantizing the sensor data to 255 levels, and an uncorrected offset of about 50 pixels between the location of the forescans and backscans.

Tables 5 and 6 could also be used to examine effects due to individual detectors within a scan (i.e. residual striping). Different patterns were present in different bands. TM1 and TM3 exhibited an odd detector/even detector oscillation about their means with an amplitude of 0.3-0.5 grey levels. TM4, TM5 and TM7 had more complex, but still regular patterns. The maximum difference between detector means was found in TM3 and was 1.7 grey levels. These differences, although small, may be statistically significant, but the effects due to auto-correlation will have to be considered before any statement on significance can be made.

Modulation Transfer Function

The MTF analysis of the Thematic Mapper on Landsat-4 was completed by Schowengerdt during this period. Results of the San Mateo Bridge MTF analysis of two dates (12/31/82 and 8/12/83) were previously reported and showed the effective IFOVs (EIFOVs) were 40.8 and 48.6 meters, respectively. For the August 12, 1983 scene a near-simultaneous underflight occurred with a multispectral aircraft scanner covering TM bands 1-4 at 7 meter resolution. Selected areas of TM and aircraft scanner data near San Jose and Stockton, California were registered, matched for radiometry, and Fourier transformed. The ratio of the Fourier transforms yielded the complex transfer function whose modulus was the MTF. After correction for the magnification of the TM image and several smoothing steps (spectrally, 3x3 filtering in the Fourier domain, azimuthally in the Fourier domain by 30 degree sectors, and least squares polynomial fitting), the MTFs were obtained for both areas.

The MTFs from the two-image analysis were quite consistent for the two study areas and with the MTF derived from the bridge analysis in the same scene although the latter was somewhat lower. EIFOVs derived from the two-image analysis were 40.4 meters along-scan and 42.4 meters across-scan for the San Jose area and 38.7 meters along-scan and 46.0 meters across-scan for the Stockton area. Schowengerdt suggested that all these values for the EIFOV are higher than those developed by Brian Markham of Goddard from a system model because that model did not account for sampling the original signal into 30 meter pixels. Schowengerdt's Progress Report covering the period and showing the MTF plots is attached to and made part of this report.

The White Sands resolution target of sixteen 15 meter, black, oiled squares was laid down successfully in late September 1984. By the time of the first TM acquisition on October 28, parts of the target had been covered by sand due to unusual winds and rainfall. A 35 mm photograph taken from a helicopter at 5000' on the same day should be useful in correcting for these problems when processing the TM data for MTF. An A-tape with unity RLUTs has been received for the scene.

TABLE 1

Summary statistics for band-to-band registration of Thematic Mapper band combinations for Quadrant 4 of the Parmer Co., TX scene of June 8, 1984 in TIPS format. All correlation blocks with the correlation coefficient <0.6 were discarded (<0.3 for bands 6 vs 7). The unit of misregistration (shift) is pixels.

TM Bands	Shift Direction	Number of Blocks	Mean Shift	Std. Dev.	95% Confidence Interval for Mean Shift
3 vs 1	Across-scan	182	-.03	.07	-.04 to -.02
	Along-scan	182	.00	.07	-.01 to .01
3 vs 2	Across-scan	196	-.04	.05	-.04 to -.03
	Along-scan	196	-.01	.04	-.01 to .01
3 vs 4	Across-scan	150	-.01	.11	-.02 to .00
	Along-scan	150	-.01	.13	-.04 to .01
3 vs 5	Across-scan	188	-.71	.16	-.73 to -.69
	Along-scan	188	.21	.14	.19 to .23
3 vs 7	Across-scan	174	-.72	.15	-.74 to -.69
	Along-scan	174	.17	.12	.16 to .19
5 vs 7	Across-scan	193	-.01	.06	-.01 to .00
	Along-scan	193	-.03	.08	-.05 to -.02
6 vs 7	Across-scan	126	-.05	1.25	-.27 to .17
	Along-scan	126	-.42	1.18	-.63 to -.21

TABLE 2

Summary of band-to-band registration results for Thematic Mapper band combinations for several Landsat-4 and Landsat-5 scenes. The unit of misregistration (shift) is pixels.

TM Bands	Shift Direction	NE Ark Scrounge	NE Ark-4 TIPS*	Sac'to 2/1/83	Sac'to-1 8/12/83*	Sac'to-4 8/12/83*	Corpus-1 3/6/84	Hunts-1 3/15/84	Parmer-4 6/8/84
3 vs 1	Across-scan	-.04	-.04	-.05	-.04	-.05	-.03	-.03	-.03
	Along-scan	-.03	-.04	-.04	-.05	-.04	.01	.00	.00
3 vs 2	Across-scan	--	.02	--	.01	.02	-.03	-.04	-.04
	Along-scan	--	-.02	--	-.03	-.02	.00	.00	-.01
3 vs 4	Across-scan	.01	.00	.02	.01	-.01	-.02	-.02	-.01
	Along-scan	.01	.07	.01	.02	-.01	-.03	-.03	-.01
3 vs 5	Across-scan	.25	.10	.33	.17	.16	--	-.65	-.71
	Along-scan	.49	-.10	.57	.14	.12	--	.13	.21
3 vs 7	Across-scan	.16	.04	.20	.11	.10	--	-.66	-.72
	Along-scan	.49	-.10	.58	.14	.11	--	.12	.17
5 vs 7	Across-scan	-.06	-.06	--	-.06	-.05	--	-.01	-.01
	Along-scan	.01	.00	--	-.01	.00	--	-.03	-.03
6 vs 7	Across-scan	-3.2	.39	.3	.29	.16	--	.03	-.05
	Along-scan	-3.0	-.12	-2.8	-.03	.02	--	.10	-.42

Landsat-4 | Landsat-5

* Corrected for post-launch misregistration of secondary focal plane.

TABLE 3

GEODETIC REGISTRATION TEST

Sacramento, CA (44/33), February 1, 1983
System Corrected Scrounge Format

Control Point	Image Location(L/S)	Predicted Location(L/S)	Error(L/S)
1. Clarksville	3624.0/5531.0	3623.4/5540.6	0.6/ -9.6
2. Rocklin-A	2926.0/5229.0	2923.7/5238.5	2.3/ -9.5
3. Rocklin-B	3165.0/5042.0	3168.1/5056.6	-3.1/-14.6
4. Elk Creek	792.0/ 633.0	791.8/ 642.6	0.2/ -9.6
5. Shippee	247.0/3170.5	246.3/3181.1	0.7/-10.6
6. Valley Ford	5755.5/ 193.0	5757.9/ 200.8	-2.4/ -7.8
7. Linden	5836.0/6272.5	5835.2/6281.9	0.8/ -9.4
8. Galt	4830.0/5037.0	4831.3/5047.4	-1.3/-10.4
9. Kenwood	5198.0/1235.0	5199.2/1244.5	-1.2/ -9.5
10. Detert	4089.5/1242.0	4089.2/1256.6	0.3/-14.6
11. Sutter Buttes	2095.0/3029.0	2095.7/3038.6	-0.7/ -9.6
12. Maxwell	1524.0/1800.0	1523.3/1808.7	0.7/ -8.7
13. Princeton	1154.0/2087.0	1154.4/2095.3	-0.4/ -8.3
14. Lake Combie	2189.0/5431.0	2188.0/5439.8	1.0/ -8.8

Mean Error(L/S): $0.0 \pm 1.2 / -9.7 \pm 1.7$

TABLE 4

Periodic Noise Components in Thematic Mapper Band 5

Peak-to-Peak Values at Discrete Spatial Frequencies for
Dark Water Area Forescans in Great Salt Lake on July 2, 1984

	Spatial Frequency, cycles/sample				
Detector #	.0859	.0898	.1718	.1757	RSS
16	.45	.29	.21	.24	.62
15	.61	.40	.38	.66	1.06
14	.45	.26	.16	.26	.60
13	.85	.42	.35	.56	1.15
12	.71	.45	.27	.38	.97
11	.58	.33	.21	.29	.76
10	.41	.29	.20	.40	.67
9	.84	.53	.15	.42	1.09
8	.55	.33	.20	.32	.75
7	2.65	1.52	.44	1.06	3.26
6	.52	.34	.23	.35	.75
5	.85	.55	.31	.57	1.20
4	.61	.40	.27	.51	.93
3	1.04	.57	.32	.34	1.27
2	.56	.33	.22	.28	.75
1	.38	.25	.16	.24	.54

TABLE 5

Grey Level Means by Detector for
Salt Lake Dark Water Forescans

Detector	TM1	TM2	TM3	TM4	TM5	TM6	TM7
16	70.8	26.8	16.9	11.5	4.5	137.4	5.0
15	69.6	26.8	16.3	11.3	4.7	"	5.1
14	70.3	27.0	16.8	11.6	4.5	"	4.6
13	69.5	27.0	16.6	11.3	4.7	"	4.6
12	70.5	26.5	16.8	11.4	5.2	137.4	4.7
11	69.6	26.2	16.1	11.3	4.3	"	4.3
10	70.5	27.1	16.6	11.2	4.4	"	4.5
9	69.9	26.9	15.9	11.3	4.3	"	4.6
8	70.5	26.4	16.6	11.6	4.6	137.4	4.5
7	69.4	26.9	16.2	11.0	4.6	"	4.2
6	70.6	26.4	16.7	11.3	5.3	"	4.5
5	69.7	26.9	15.7	11.0	5.1	"	4.3
4	70.4	27.2	16.8	11.2	4.8	137.2	4.4
3	69.9	26.8	15.9	11.3	4.8	"	4.4
2	70.7	27.1	17.0	11.3	4.5	"	4.9
1	70.0	26.7	16.3	11.0	4.6	"	4.9
Band Mean	70.1	26.8	16.4	11.3	4.7	137.4	4.6

TABLE 6

Grey Level Means by Detector for
Salt Lake Dark Water Backscans

Detector	TM1	TM2	TM3	TM4	TM5	TM6	TM7
16	69.7	25.4	15.7	9.8	4.6	137.8	5.0
15	68.4	24.9	14.4	9.6	4.7	"	5.2
14	69.2	25.7	15.6	9.7	4.6	"	4.6
13	68.3	25.0	14.6	9.6	4.7	"	4.7
12	69.5	25.0	15.5	9.7	5.2	137.8	4.8
11	68.4	25.0	14.3	9.9	4.4	"	4.4
10	69.5	25.5	15.5	9.9	4.5	"	4.5
9	69.0	25.2	14.4	9.7	4.4	"	4.7
8	69.3	25.2	15.9	9.8	4.7	138.0	4.6
7	68.3	25.5	14.2	8.9	4.7	"	4.3
6	69.3	25.1	15.4	9.9	5.3	"	4.6
5	68.6	25.5	14.4	9.7	5.2	"	4.3
4	69.3	25.6	15.5	9.7	4.9	137.8	4.5
3	68.7	25.0	14.6	9.9	4.9	"	4.5
2	69.2	24.9	15.7	9.9	4.5	"	4.9
1	68.2	25.3	15.0	9.3	4.7	"	4.9
Band Mean	68.9	25.3	15.0	9.7	4.8	137.8	4.6
Mean Difference	1.2	1.5	1.4	1.6	-0.06	-0.5	-0.05
Standard Deviation	0.2	0.3	0.4	0.2	0.04	0.2	0.03

LANDSAT-4 AND -5 THEMATIC MAPPER
MODULATION TRANSFER FUNCTION (MTF) EVALUATION

Progress Report

September 15, 1984 - December 15, 1984

submitted to:

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Introduction and Summary

During this contract period, we have completed the MTF analysis for the Landsat-4 TM. This analysis involved the San Mateo Bridge as a special target in two scenes, 12/31/82 and 8/12/83, of the San Francisco region. We also performed a two-image comparison of TM and high resolution aerial Daedalus scanner imagery taken on the morning of the 8/12/83 scene. The results from these analyses are consistent and appear to be repeatable, leading to a high degree of confidence in the MTFs obtained.

Also during this contract period, we successfully constructed an oil-on-sand target on the White Sands Missile Range in New Mexico for MTF studies of the Landsat-5 TM. Within six weeks of the target's construction, however, it had been degraded by continuing rainfall and wind at the site. A Landsat-5 image of the target was obtained on October 28, 1984, and a 35mm photograph of the target from a helicopter at 5,000 feet altitude on the same day will be used to calibrate the changes in the target since initial construction. Re-oiling of the target is planned for the first quarter of 1985.

San Mateo Bridge Analysis

The results of the San Mateo Bridge MTF analysis was reported in the progress report of August 14, 1984. For convenience the final EIFOVs obtained are repeated here in Table 1.

TABLE 1

SAN MATEO BRIDGE MTF ANALYSIS

TM EIFOV(m)

TM band	date 12/31/82	8/12/83
1	-	49.8
2	-	50.9
3	33.6	48.1
4	40.8	45.4
5	41.9	46.9
6	-	-
7	40.0	44.5

Bands 1 and 2 from the 12/31/82 date were of such low contrast that reliable MTF data could not be obtained. This problem of low contrast, and consequently low signal-to-noise, for the shorter wavelength bands is also probably influencing the EIFOV for band 3. The inconsistently low value in band 3 is therefore ignored in further comparisons with the two-image analysis results. Likewise, the image of the bridge in TM band 6 (thermal) has negligible contrast because of the 120m IFOV in that band.

Two-image Analysis

The final procedures for comparison of TM and high resolution aerial scanner imagery were described in earlier progress reports. The steps in the analysis are summarized in Figure 1:

FIGURE 1

TWO-IMAGE ANALYSIS PROCEDURE

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1. Register TM and high resolution imagery

   This is accomplished by visual location of control points in the two images, followed by a least-squares power series polynomial fit to the control points to obtain the warping function. In this case, 50 control points were obtained, and a quartic polynomial was used. This high order was required to match high frequency line "wiggles" in the aerial scanner imagery.

2. Match TM and high resolution imagery radiometry

   This was accomplished by calculating the two-dimensional scattergram between the registered images. A linear least-squares fit to the scattergram was then done, yielding the linear gray level transformation to be applied to the high resolution imagery to make its mean and variance equal to those of the TM imagery. This step is important in minimizing FFT border effects in later steps.

3. Mask common area and fill border

   The same ground area was masked in both sets of imagery and the surrounding border region filled with the image mean value within the masked region. This step is important in minimizing FFT border effects, in conjunction with Step 2.

4. Ratio FFT of two 512 X 512 images

The geometrically and radiometrically registered pair of images may be considered an object-image pair, with the TM image being the result of spatial filtering, by the TM MTF, of the high resolution (object) image. By linear filtering theory, therefore, the ratio of their Fourier transforms yield the complex transfer function, whose modulus is the MTF.

5. Correct for 4X magnification of TM image

In the registration process, the TM image was first magnified by a factor of four with bilinear resampling to permit convenient visual control point selection and comparison with the high resolution imagery. This resampling acts as a filter on the the TM image that must be corrected for. Empirical calibration of the filter was done by comparing Fourier transforms of the the TM image before and after magnification.

6. Smooth the MTF

The result of the ratio in Step 4 is quite noisy from frequency-to-frequency and smoothing is necessary in order to obtain reliable results. Several smoothing steps were used:

Average the complex transfer function of the bands 1-4 in the primary focal plane
3 X 3 median filtering of the complex transfer function
Azimuthal averaging of the complex transfer function in 30 degree sections
Least-squares polynomial fitting of the azimuthally-averaged MTF

A comparison of the final MTFs obtained from two different areas in the 8/12/83 scene is shown in Figure 2. This profile is along the same frequency direction as measured by the the bridge analysis. Figure 2 indicates that the two-image technique is quite repeatable between these two image areas.

In Figure 3, the MTF derived from the two-image analysis is compared to that resulting from the bridge analysis for the same scene. It is clear that the two independent techniques are yielding comparable results.

Finally, in Figure 4, a comparison is made between these image-derived MTFs and system model MTFs obtained by Markham (NASA Technical Memorandum 86130). The image-derived MTFs are considerably lower than the system model MTFs because the system model did not attempt to include the effects of sampling, resampling (the TM data analyzed are P-data corrected for systematic geometric distortions), and atmospheric scattering. All of these are factors in the final image-derived MTF, however. A summary comparison of EIFOVs derived using various techniques is given in Table 2:

TABLE 2

EIFOV SUMMARY

TM4 BANDS 1-4 AVERAGE EIFOV(m)

technique	date	EIFOV (m)
San Mateo Bridge	12/31/82	40.8 (TM4 only)
	8/12/83	48.6
San Jose Two-image	8/12/83	40.4/42.4 (scan/track)
Stockton Two-image	8/12/83	38.7/46.0
System Model (Markham)		35.9/32.1

White Sands Target

In late September, 1984, surveying and construction of the target shown in Figure 5 were performed at White Sands. The target is created by spraying road oil on the sand in the prescribed pattern. The target is designed to sample the TM pixel grid (and consequently its point spread function) by a subpixel increment of 0.25 and thereby avoid aliasing in the measurement.

By the time of the first successful TM acquistion, 10/28/84, the target had been degraded and partially covered by sand because of unusually heavy rainfall and winds at the test site. However, the condition of the target was recorded in a 35mm photograph taken from a helicopter at 5000 feet altitude on the day of the satellite overpass. We have received the TM image in raw, unprocessed form and plan to digitize the 35mm target image for use in analysis of the TM image.

FIGURE 2.

COMPARISON OF TWO-IMAGE ANALYSIS FOR TWO AREAS

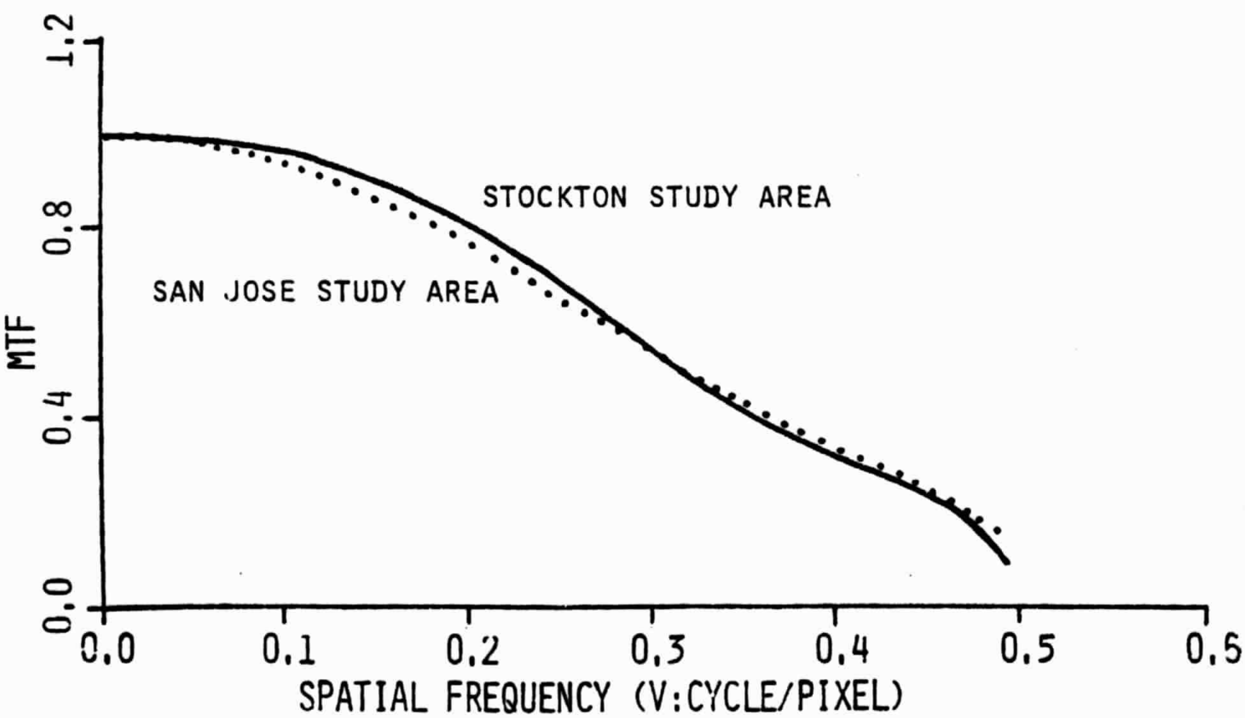

FIGURE 3.

COMPARISON OF BRIDGE AND TWO-IMAGE ANALYSES

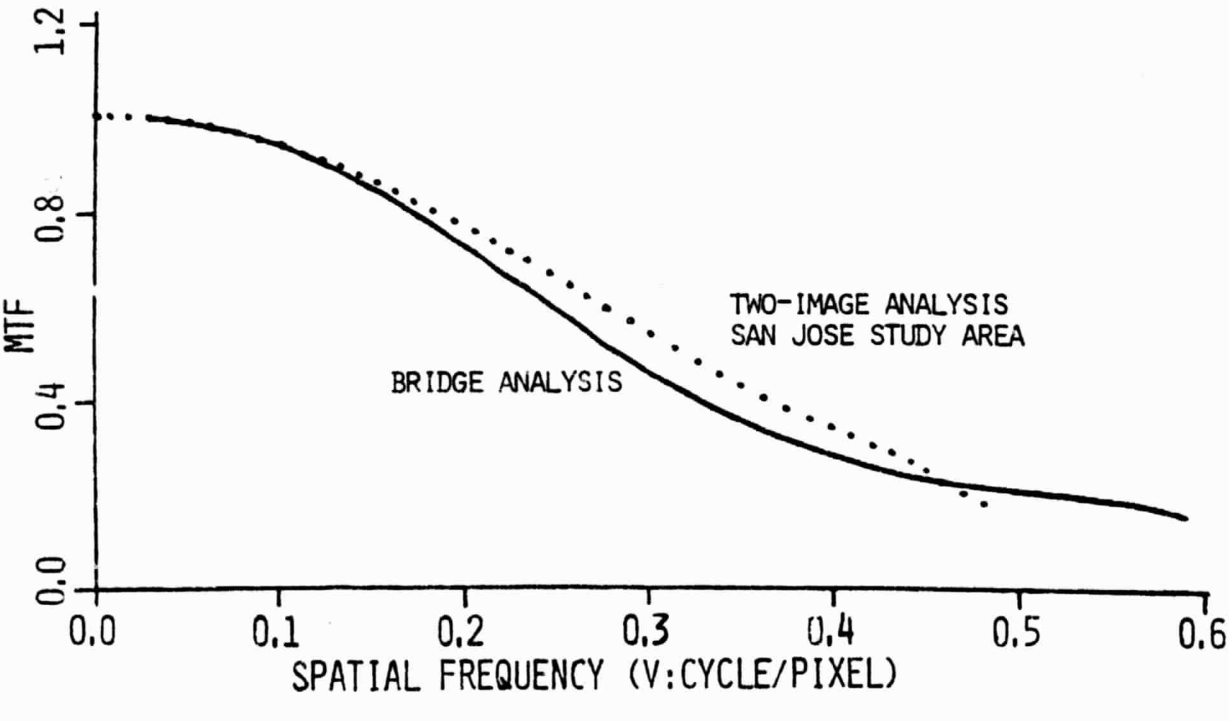

FIGURE 4.

COMPARISON BETWEEN IMAGE-DERIVED AND SYSTEM MODEL MTFs

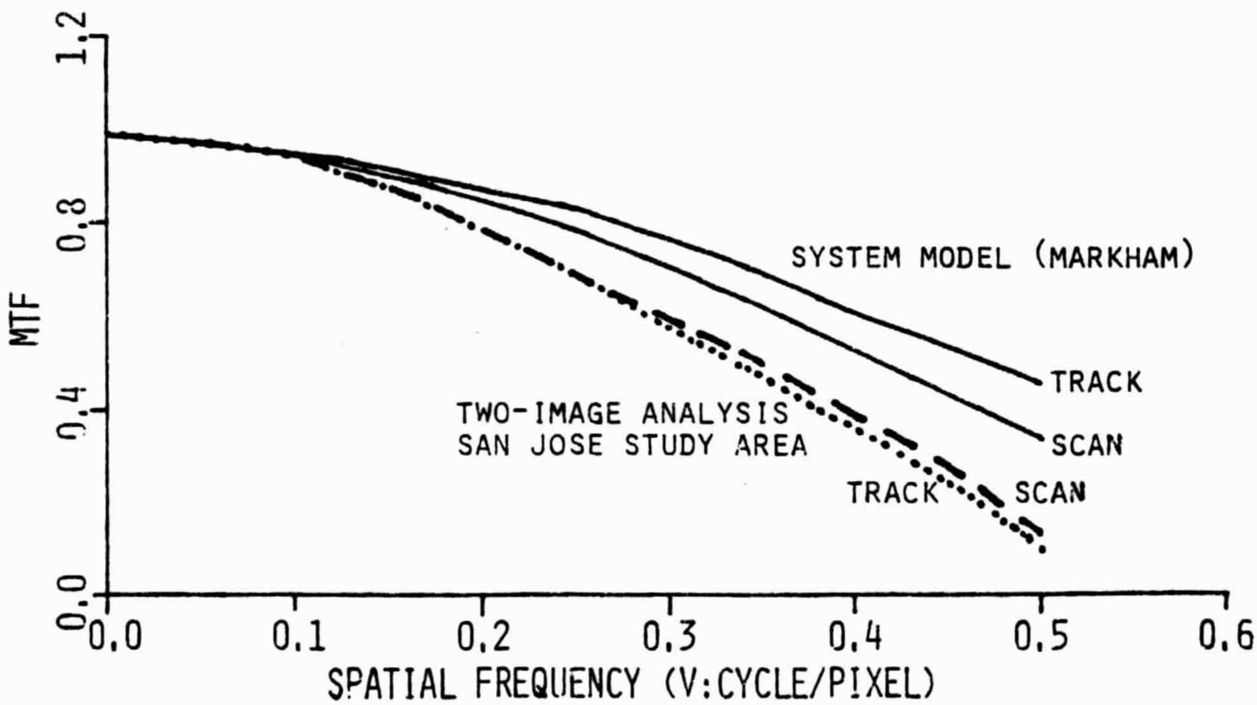

FIGURE 5.

TM WHITE SANDS TARGET - 10/84

- EACH BLACK SQUARE IS 15 X 15M
- CENTER-TO-CENTER DISTANCE IS 157.5M (5.25 PIXELS)