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INTRODUCTION TO THEMATIC MAPPER INVESTIGATIONS

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INTRODUCTION TO THEMATIC MAPPER INVESTIGATIONS

SECTION I: RADIOMETRY

This section of the Introduction to Thematic Mapper (TM) Investigations is an overview of papers which deal with radiometric characterization of the TM sensor. Spectral characteristics are summarized in the paper by Markham and Barker. Papers dealing primarily with geometric characteristics of TM are overviewed in Section 2 of this introduction by Brian Markham.

References in this introduction will be in one of four forms:

- P:Author (Example: P:Bernstein)
  "P" refers to a paper in one of the two TM volumes in these February, 1983 Proceedings, and the name of the author is the first author. If there is more than one paper by the same first author, the name of the second author will also be included.

- S:Author, p (Example: S:Barker, Ball et al., Vol. I, 130-139)
  "S" refers to a summary in one of the two volumes of abstracts in NASA Conference Publication 2326 (1984) entitled "Landsat-4 Science Investigations Summary including December 1983 Workshop Results." The page location in the publication is given by "p". In almost all cases there will be a reference to either the summary or to the papers in the proceedings, but not to both.

- I:Author (Example: I:Malila)
  "I" refers to one of the papers in the May, 1984 issue of IEEE Transactions on Geoscience and Remote Sensing entitled "Special Issue on Landsat-4." The table of contents of this issue is given at the end of this report.

- Author, Year (Example: Engel, 1980)
  References to other papers are given by first author and year of publication, with the complete citation being at the end of this report. There is no intention to provide more than a few such references to other papers since this is a report on the radiometric and geometric activities of the Landsat Image Data Quality Assessment (LIDQA) investigators (Table 1).

For most users, the primary scientific requirement is to convert digital numbers (DN) on computer compatible tapes (CCT) to radiance or spectral radiance units. Minimum and maximum spectral radiances for the six reflective bands are given for radiometrically calibrated tapes for two periods of time:

Scrounge-Era prior to August 1983 (S:Barker and Ball, Vol. I, 130-139, Table 3)

TIPS-Era after 15 January 1984 (S:Barker, Vol. I, ~~pp.~~ 140-180, Table 1; and P:Barker, Appendix 9.1).

For both the reflective bands and the emissive thermal band, TM6, the actual dynamic range used in calibrating the digital imagery is contained in one of the fields of the CCT. For perfectly calibrated noise-free data, these post-calibration dynamic ranges are all the radiometric information needed.

Investigations reported here, and still in progress, are characterizing and monitoring the radiometric performance of the TM sensor on both Landsat-4 (TM/PF) and on Landsat-5 (TM/F). These efforts include pre-launch calibration and in-orbit calibration of sensors. There has not yet been an opportunity to characterize the performance or optimize the parameters used in the radiometric ground processing of TM imagery. This section is divided into three topics: characterizing pre-launch sensor performance, characterizing in-orbit sensor performance, and characterizing calibrated digital image data quality.

Pre-Launch Sensor Performance

Summary charts on the TM sensor description and characteristics are given here (S:Engel, Vol. 1, 41-61) and in a previous paper (Engel and Weinstein, 1983). Details of the absolute radiometric calibration using an integrating sphere are given for Landsat-4 TM/PF (P:Barker and Ball) along with summary results on gains and offsets for Landsat-5 TM/PF (P:Barker, Appendices 9.3 and 9.4). Many special tests were performed before launch, especially on Landsat-5 TM/F, and tapes from these tests provide an option for future re-calibration based on a knowledge of how to reduce certain systematic sources of variability that were not characterized until after launch. Re-calibration of the integrating sphere may also result in a further updating of the post-calibration dynamic range in the parameter file of the TM Image Processing System (TIPS). Independent measurement of absolute radiometric calibration is being attempted by comparing in-orbit imagery with simultaneous

TABLE 1. LANDSAT SCIENTIFIC CHARACTERIZATION - LIDQA INVESTIGATORS

University (U.S.)	Private Industry	Government Agencies	Outside U.S.
Anuta (Purdue/LARS)	Bernstein (IBM)	Anderson (NASA/ERL)	Begni (France)
Colwell (California/Berkley)	Everett (EARTHSAT)	Bender (USGS/Reston)	Fusco (ESA)
Dozier (California/Santa Barbara)	Gurney (SASC)	Erickson (NASA/JSC)	Jackson (England)
Duggin (State U. New York)	Malila (ERIM)	Hill (NASA/ERL)	Parada (Brazil)
Ford (California/Davis)	Wukelic (Battelle)	Hovis (NOAA/NESS)	Rasool (France)
Khorram (N. Carolina)		Kahle (NASA/JPL)	Strome (Canada)
Klemas (Delaware)		Kieffer (USGS/Flagstaff)	
Schott (Rochester inst. Tech.)		Lauer (USGS/EDC)	
Slater (Arizona)		MacDonald (NASA/JSC)	
Welch (Georgia)		Price (USDA/ARS)	
		Thormodsgard (USGS/EDC)	
		Wrigley (NASA/Ames)	
		Zobrist (NASA/JPL)	

observations from the ground (S:Castle, Vol. II, 15-19; S:Hovis, Vol. I, 181-185). Absolute calibration had a specified accuracy requirement of 10% of full scale in each band.

In-Orbit Sensor Performance

As part of the investigations program, several scientific teams have had access to raw uncalibrated TM digital imagery on engineering tapes, including foreign ground stations with direct access to TM transmission from Landsat. Several radiometric studies have used uncalibrated digital imagery, either CCT-BT tapes produced during the Scrounge-era or "unity" CCT-AT tapes from TIPS, in conjunction with the background shutter and internal calibration data provided either on CCT-ADDS tapes in the Scrounge-era or on CCT-CALDUMP tapes in the TIPS-era. These studies characterize the in-orbit sensor performance, prior to ground processing. Scrounge-era digital products are described (P:Barker and Gunther).

Background on radiometric procedures used in the Scrounge-era processing of the reflective bands is provided (P:Barker, Abrams; (procedure paper)). Processing of Landsat-4 data during Scrounge-era was done one scene at a time. Results for approximately fifty Landsat-4 scenes are summarized in terms of within-scene types of systematic variability and between-scene apparent changes in gain or sensitivity (S:Barker, Vol. I, 140-180, and P:Barker). Emphasis in these studies is placed on characterizing precision, or relative radiometry, rather than on absolute accuracy. The most significant types of within-scene systematic variabliy on the order of 1-2 DN, are:

- Bin-Radiance Dependence
- Scan-Corrleated Shifts
- Coherent Noise
- Bright-Target Saturation.

There may also be some variability, less than 0.5 DN, from:

- Within-Line Droop
- Forward/Reverse Scan Differences.

The following papers deal with the radiometric characterization of in-orbit TM sensor performance from raw data:

- P:Barker and Abrams, Characterization Paper
  - Stability of Internal Calibration System
  - Pre-Launch Sensor Performance (Vacuum Shift)
  - Post-Launch Sensor Performance
  - Stability with Time
  - Noise (Coherent)
  - Location of Calibration Collect Window
  - Non-Uniformity in the A/D Converter (Bin-Radiance Dependence)
  - Recommendations for Operating and Processing

- P:Lansing
  - Thermal Band Characterization

- P:Murphy
  - Raw Data from the Canada Centre fo Remote Sensing (CCRS)
  - Gains and Offsets
  - Histograms (Bin-Radiance Dependence)
  - Striping

- I:Murphy
  - Background in Shutter Region (Scan-Correlated Shift)
  - Internal Calibration Region

- P:Justice
  - Band-to-Band Correlations

- P:Metzler and I:Malila
  - Scan Angle Effects (Within-Line Droop)
  - Quantization-Level Histograms (Bin-Radiance Dependence)
  - Down-Track Trace of Scan-Line Mean Signal (Scan-Correlated Shift)
  - Correlation of Scan-Line Means

- P:Kieffer
  - Variation of Response with Scan Direction (Forward/Reverse Scan Differences)
  - Level Shift (Scan-Correlated Shift)
  - Overshoot
  - Gain Sag
  - High Frequency Noise (Coherent Noise)

- P:Barker ("R and R Paper")
  - Table of Contents, as listed in Table 2.

The characterization of possible within-line droop and foward-reverse-scan differences is currently limited by an inadequate quantification of the effects of bright target saturation (P:Barker).

It is assumed that between-scene variability of detector sensitivity or electronics will be calibrated out by adjustment in gain and offset to the raw data. One method to check the reasonableness of this assumption is to monitor the apparent change in gain, and offset, with time and if it is changing significantly, to see if that change can be accounted for by expected changes in a channel within a band, rather than a change in characteristics of the internal calibration system. Results for Landsat-4 TM/PF apparent gain changes with time are presented and analyzed in the "R and R" paper (P:Barker).

Image Data Quality

If the sensor and calibration were perfect and unaffected by geometric resampling, then a user of TM digital imagery need only acquire a calibrated and geometrically corrected CCT-PT tape and apply it directly to their information extraction requirements. That is the ideal objective for the product of ground processing. This section identifies the radiometric

TABLE 2.

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investigations of the final CCT-PT, and more generally, its immediate pre-cursor, the radiometrically unresampled CCT-AT. Both of these tapes are available to the public. To the extent that these investigations of image data quality find the radiometry within required tolerances, there is no need to proceed backwards to determine whether or not the observed radiometric variability, or uncertainty, can be reduced by alternative ground processing procedures, or calibration, or whether it is an uncorrectable, innate characteristic of the sensor. Within the specifications of the system, it was the design objective of TIPS to produce a CCT-PT that would require no further calibration by the user. Specifications call for a post-calibration radiometric precision of $\pm$ 1 DN. In the absence of both a line-by-line calibration and an as yet undemonstrated capability for within-line removal of effects of bright-target saturation, it will not be possible to obtain the objective in all scenes. Suggestions have been made for possible correction of known sources of systematic errors.

The following papers report on the radiometric characteristics of radiometrically calibrated TM digital image products:

- P:Irons
  - TM Data Processing (During Scrounge-Era)
- P:Lyons
  - Scrounge-Era Processing
- I:Fischel
  - TM Radiometric Correction Algorithms (During Scrounge-Era)
- P:Barker and Abrams, Procedure Paper
  - Ground Processing (During Scrounge-Era)
- P:Barker and Gunther
  - TM Image Products (Format and Characteristics of Tapes)
- P:Murphy and I:Murphy
  - Radiometric Processing at CCRS
- P:Bernstein and I:Bernstein
  - Sensor Data Entropy
  - Histograms
  - A/D Converter Non-Linearity (Bin-Radiance Dependence)
  - Failed Detectors (Landsat-) and Compensation
  - Sensor Noise (32 KHz) and Reduction
  - Radiometric Correction Processing
  - Striping Removal
  - Probabilistic Calibration
- P:Bartolucci
  - Classification
  - Clustering
  - Principal Components
  - Covariance
  - Correlation Matrices
  - Water Temperature Mapping

- I:Anuta
  - Coherent Noise (3.12 and 17 pixel/cycle)
  - Scan Angle Response
  - Principal Components
  - Temperature Mapping

- P:Metzler
  - Qauntization Level Histograms (Bin-Radiance Dependence)
  - Down-Track Means (Scan-Correlated Shifts)

- P:Kieffer
  - Detector-to-Detector Variations (Striping)
  - Scan-to-Scan Variations (Banding)
  - Forward/Reverse Scan Differences
  - Level Shifts (Scan-Correlated Shifts)
  - Dynamic Response
  - Gain Sag
  - Coherent Noise
  - Between-Band Correlation

- P:Podwysocki
  - Striping.

SECTION II: GEOMETRY

The TM geometric analyses/discussions can be divided into four categories: (1) pre-launch characterization of the sensor geometry, (2) discussions of the geometrical processing algorithms, (3) post-launch characterization of the geometrical behavior of the TM instrument and (4) post-launch geometrical characterization of fully corrected (P-type) TM data. Under the first category, the geometry and geometrical measures of the TM sensor are discussed. The TM geometric correction operations and the differences between the interim TM processing system (Scrounge) and the final system (TIPS) are presented in the second section. Under the third category, the emphasis is on characterizing the magnitude of satellite vibrations (jitter) and the modulation transfer functions. In the fourth category, analyses have concentrated on evaluating band-to-band registration accuracy and the internal geometric consistency of the TM data. The referencing convention followed by Barker in the first section of this introduction will also be followed here.

Stringent specifications on the radiometric and geometric performance of the TM instrument necessitated greater complexity in the instrument than in previous MSS instruments. Key new TM geometric features include (S:Engel, Vol. I, 41-61): (1) two focal planes, one containing the silicon detectors of bands 1-4 and the second containing the cooled detectors (InSb and HgCdTe) of bands 5-7, (2) nominally 30 meter IFOV's in bands 1-5, 7 with 16 detectors per bands, (3) bi-directional cross-tracking scanning with a scan line corrector to maintain a perpendicular scan, and (4) an angular displacement sensor to record vibrations at the sensor. A summary of the pre-launch geometrical data collected on the TM instrument is presented (S:Engel, Vol I, 65-89): (1) measured instantaneous fields of view (line spread function half widths), without electronics effects, (2) focal plane step response characteristics (rise-time, overshoot, settling times), (3) square wave responses, (4) band-to-band registration, and (5) mirror scan profiles. These pre-launch measurements have been used (Schueler, 1983: Markham, 1984) to provide estimates of the line spread functions and transfer functions for the Thematic Mapper. Along-scan estimates of the line spread function half-widths were approximately 36 meters for bands 1-5, 7 and 137 meters for band 6.

The TM geometric ground processing was initially performed by the Scrounge system (P:Lyon) and transferred to the operational Thematic Mapper Image Processing System (TIPS) (P:Beyer) in the Fall of 1983. Both of these systems use spacecraft attitude, ephemeris, and mirror scan correction data transmitted from the satellite, combined with pre-launch sensor data (e.g., band-to-band spacing and detector electronic delays) to generate systematic correction data (SCD). In addition in TIPS, control point processing is being used to remove bias and drift errors in the SCD, generating Geodetic Correction Data (GCD). Then, using the GCD or SCD the data are geometrically corrected, registered to a map projection and resampled by a cubic interpolation algorithm to 28.5 by 28.5 meter pixels. The standard cubic convolution weights were used in the Scrounge resampling process until 1 April 1983. New weights, as recommended by Park, 1983 which result in a smaller overshoot near edges in images were then implemented (I:Fischel). The TIPS system will also use the revised weights.

Due to the pre-launch concern with high frequency vibrations of the spacecraft, especially due to the scan mirrors, the post-launch TM instrument geometrical analyses were concentrated on jitter. Most of the observed jitter was at 7KHz in the along-scan direction and can be easily corrected. The along-track effect of this jitter is to produce underlap or overlap between adjacent scans. Analyses conducted (S:Kogut, Vol II., 54; P:Kogut) indicated that the range of underlap and overlap was in the neighborhood of 0.7 pixels.

Several investigators are examining the spatial resolution characteristics of the TM P-data (P:Schowengerdt, P:McGillem). Although this does not correspond to the spatial resolution of the TM instrument due to resampling and atmospheric degradations, it provides an overall system measure. These analyses are concentrating on estimating the sensor Line Spread Functions (LSF), or modulation transfer functions (MTF) based on the rendition of step-like or line-like features on the Earth's surface that intersect the scan pattern at oblique angles. Early results pointed to a system resolution (LSF half-power points) of 39 meters in a Webster Co., Iowa scene (P:McGillem) which is consistent with sensor characteristics and a moderate degradation due to atmospheric and resampling effects. Later estimates indicated LSF half-widths of 39-45 meters (I:Anuta). The forward and reverse scan MTF's have also been compared as well as the MTF of the interpolation/ resampling processing (I:Wrigley). Results indicated little, if any, difference in the system MTF from forward to reverse and a resampling MTF that was as expected.

Band-to-band registration accuracy was the most intensively studied geometric characteristic of TM P-data (P:Card, P:Fusco, P:Gurney, P:Podwysocki, P:Yao, I:Bernstein, I:Walker). Registration between the four primary focal plane bands (1-4) was reported to be well within specifications ($<$ .2 pixels) as was the registration between bands 5 and 7. Between the prime focal plane and the secondary focal plane, a misregistration of 0.5 to 0.8 pixels along scan and 0.2 to 0.3 pixels across-scan was reported. In addition, band 6 data was found to be misregistered by approximately 3 resampled pixels. Shifts in the locations of the focal planes due to launch stress and vibration testing (bands 1-4 versus 5 and 7) and software errors (band 6) were deemed responsible for the misregistrations. Software changes were incorporated to account for the shifts and errors in early 1983 (I:Fischel).

The lack of geodetically corrected data has limited the ability of investigators to characterize the geodetic accuracy of processed TM P-data. Early results found that the discrepancy between systematically corrected data and the ground is largely translational (S:Thormodsgard, Vol. II, 62-63) indicating that the internal geometry is quite good and that the images can be corrected with only a low-order mapping to a projection. Later results I:Walker; (I:Welch) have confirmed the high internal accuracy of TM data.

Additional geometrically related analyses of TM data included (1) an analysis of the geometric accuracy of the GSFC filmwriter used for TM images, which showed that TM low frequency distortions are likely to be less than the distortions introduced by the filmwriter (P:Batson) and (2) a linear feature detection analysis which confirmed the resampled pixel size as 28.5 meters and showed linear feature detection capabilities to as small as 6 meters (P:Gurney).

Overall, the TM instrument and ground processing techniques appear to be functioning properly and to within specification to the extent tested. Pre-launch concerns of excessive jitter did not materialize. Post-launch estimates of the system's spatial resolution are consistent with pre-launch estimates. In the initial Scrounge tapes there were band-to-band misregistrations. The source of these errors has been located and apparently corrected. The Scrounge system did not geodetically correct the data, however, systematically corrected data is internally consistent and the discrepancy with ground projections appears to be primarily translational and/or rotational. The TIPS processing system currently in use is under evaluation for its geometric properties: band-to-band registration and geodetic accuracy in particular.

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