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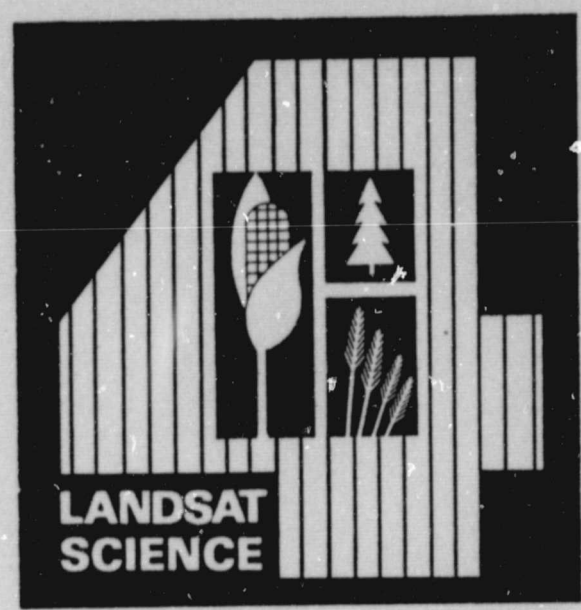
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Landsat-4 Scientific Characterization Early Results Symposium *TM-85389*

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22-24 February 1983
NASA
Goddard Space Flight Center
Greenbelt, Maryland 20771

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Landsat-4 Scientific Characterization Early Results Symposium

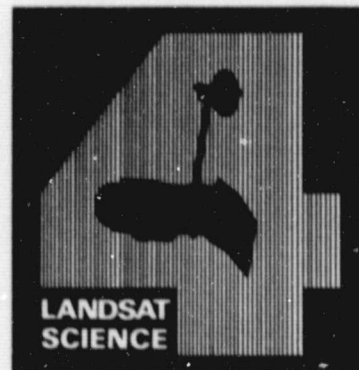
22-24 February 1983

**Goddard Space Flight Center
Greenbelt, Maryland 20771**

Organized by:

The Landsat-4 Science Office

- Vince Salomonson, Project Scientist**
- John Barker, Associate Project Scientist**
- Darrel Williams, Assistant Project Scientist**



Landsat-4 Scientific Characterization Early Results Symposium

Tuesday, 22 February

Bldg. 8, Auditorium

7:30 a.m.	Registration
9:30 a.m.	First General Session Introduction, Description and Highlights
12:00 noon	Lunch
1:30 p.m.	Second General Session Representative Early Results
5:30 p.m.	Adjourn

Landsat-4 Scientific Characterization Early Results Symposium

Wednesday, 23 February

Bldg. 8, Auditorium

- 7:30 a.m.** **Registration**
- 8:00 a.m.** **Third General Session
Scientific Characterization**
- 9:30 a.m.** **Adjourn**
- 10:00 a.m.** **TM Introductory Session**
- 12:30 p.m.** **Lunch**
- 1:30 p.m.** **TM Radiometry and Geometry Session**
- 5:20 p.m.** **Adjourn**

Bldg. 3, Auditorium

- 10:00 a.m.** **MSS Session
MSS Investigations Results**
- 12:30 p.m.** **Lunch**
- 1:30 p.m.** **MSS Investigations Results, Continued**
- 2:30 p.m.** **MSS Methods and Results**
- 5:30 p.m.** **Adjourn**
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Landsat-4 Scientific Characterization Early Results Symposium

**Thursday, 24 February
Bldg. 8, Auditorium**

8:00 a.m. Registration

8:45 a.m. TM Radiometry and Geometry Session, Continued

12:00 Noon Lunch

1:10 p.m. TM Radiometry and Geometry Session, Continued

3:30 p.m. Adjourn

**4:00 p.m. Fourth General Session
Research Plans and Panel Discussion**

5:00 p.m. Adjourn

Bldg. 3, Auditorium

8:30 a.m. TM Applications Session

12:10 p.m. Lunch

1:30 p.m. TM Applications Sessions, Continued

3:30 p.m. Adjourn

Landsat-4 Scientific Characterization Early Results Symposium

**First General Session
Introduction, Description and Highlights
Tuesday, 22 February**

**Bldg. 8, Auditorium
John Barker, Moderator**

- 9:30 a.m. Welcome and Introduction**
Vince Salomonson
Landsat-4 Project Scientist, Goddard Space Flight Center
- 9:50 a.m. Landsat-4 Program**
William Webb
Landsat-4 Mission Operations Manager, Goddard Space Flight Center
- 10:20 a.m. NOAA's Landsat Program**
Russell Koffler
Director, Office of Satellite Data Processing and Distribution, National Oceanic and Atmospheric Administration
- 10:30 a.m. Landsat-4 System Description**
Ted Aepli
Manager, Landsat Systems Engineering, General Electric
- 11:00 a.m. Instrument Descriptions**
Jack Engel
Manager, Thematic Mapper Program, Santa Barbara Research Center
- 11:30 a.m. Landsat-4 Highlights**
Darrel Williams
Landsat-4 Assistant Project Scientist, Goddard Space Flight Center
- 12:00 Noon Adjourn**
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Landsat-4 Scientific Characterization Early Results Symposium

**Second General Session
Representative Early Results
Tuesday, 22 February**

**Bldg. 8, Auditorium
John Barker, Moderator**

- 1:30 p.m. Earth Imaging and Data Processing for Mapping and Analysis — A Technological Assessment**
Ralph Bernstein
IBM Corporation
- 2:00 p.m. Interpretability of California's Agricultural Resources on Landsat-4 TM and MSS Imagery — An Early Appraisal**
Stephen DeGloria
University of California, Berkeley
- 2:30 p.m. Evaluation of TM Performance as Applied to Hydrocarbon Exploration**
Jon Dykstra
Earth Satellite Corporation
- 3:00 p.m. Geologic Utility of Landsat-4 TM Data — Death Valley, California**
Mike Abrams
NASA, Jet Propulsion Laboratory
- 3:30 p.m. Break**
- 4:00 p.m. An initial Analysis of Landsat-4 Thematic Mapper Data for the Discrimination of Agricultural Forested Wetland and Urban Land Cover**
Dale Quattrochi
NASA, Earth Resources Laboratory
- 4:30 p.m. Canadian Plans for TM Data**
W. Murray Strome
Canada Centre for Remote Sensing
- 5:00 p.m. Landsat-4 Image Data Analysis**
Robert MacDonald
NASA, Johnson Space Center
- 5:30 p.m. Adjourn**
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Landsat-4 Scientific Characterization Early Results Symposium

**Third General Session
Scientific Characterization
Wednesday, 23 February**

Bldg. 8, Auditorium

- 8:00 a.m. Landsat-4 Evaluation Program and Scientific Characterization Activities**
John Barker
Landsat-4 Associate Project Scientist, Goddard Space Flight Center
- 8:15 a.m. MSS Report**
William Alford
Landsat-4 Senior Systems Programmer, Goddard Space Flight Center
- 8:30 a.m. TM Report**
John Barker
Landsat-4 Associate Project Scientist, Goddard Space Flight Center
- 9:00 a.m. Analysis of TM Data from Geologic Terrain in a California-Nevada Scene**
Nicholas Short
Goddard Space Flight Center
Rupert Haydn
Ventralstelle fur Geo-Photogrammetrie w. Fernerkundung, Federal Republic of
Germany
- 9:30 a.m. Adjourn**
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Landsat-4 Scientific Characterization Early Results Symposium

**TM Introductory Session
Wednesday, 23 February**

**Bldg. 8, Auditorium
John Barker, Moderator**

- 10:00 a.m. Sensor Radiometry**
J. Barker
Goddard Space Flight Center
- 10:30 a.m. Sensor Geometry**
J. Engel
Santa Barbara Research Center
- 11:00 a.m. Radiometric Processing**
J. Barker
Goddard Space Flight Center
- 11:30 a.m. Geometric Processing**
E. Beyer
General Electric
- 12:00 Noon Image Data Quality**
J. Lyon
Goddard Space Flight Center
- 12:30 p.m. Adjourn**
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Landsat-4 Scientific Characterization Early Results Symposium

**MSS Session
Wednesday, 23 February**

**Bldg. 3, Auditorium
William Alford, Moderator**

MSS Investigations Results

- 10:00 a.m. MSS Radiometric Accuracy Assessment**
W. Alford
Goddard Space Flight Center
- 10:15 a.m. Spectral Characterization of the Landsat-4 MSS Sensors**
B.U. Markham
Goddard Space Flight Center
- 10:30 a.m. Investigation of Radiometric Properties of Landsat-4 MSS**
W.A. Malila
Environmental Research Institute of Michigan
- 10:50 a.m. Evaluation of Landsat-4 Multispectral Scanner Ground Segment Performance**
A. Zobrist
NASA, Jet Propulsion Laboratory
- 11:10 a.m. Radiometric Calibration and Geocoded Precision Processing of Landsat-4 MSS
Products by the Canada Centre for Remote Sensing**
J. Murphy
Canada Centre for Remote Sensing
- 11:30 a.m. Landsat-4 Multispectral Scanner Radiometric Intraband Performance**
E. Eliason
U.S. Geological Survey, Flagstaff
- 11:45 a.m. Landsat MSS Scene-to-Scene Registration Assessment**
J.E. Anderson
NASA, Earth Resources Laboratory
- 11:55 a.m. Geometric Accuracy of Landsat-4 Image Data**
R. Welch
Department of Geography, University of Georgia
- 12:15 p.m. Geodetic Accuracy of Landsat-4 MSS Data**
L. Oleson
U.S. Geological Survey, EROS Data Center
- 12:30 p.m. Lunch**
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Landsat-4 Scientific Characterization Early Results Symposium

**MSS Session, Continued
Wednesday, 23 February**

**Bldg. 3, Auditorium
William Alford, Moderator**

MSS Investigations Results

- 1:30 p.m. MSS Geometric Accuracy Assessment**
M. Imhoff
Goddard Space Flight Center
- 1:45 p.m. MSS Geometric Performance: Line-to-Line Displacement Analysis**
L. Fusco
Earthnet Program Office, Frascati, Italy
- 2:00 p.m. Impact of Landsat MSS Sensor Differences on Change Detection Analysis**
W. Likens
NASA, Ames Research Center
- 2:15 p.m. Comparison of Land Cover Information from Landsat MSS and Airborne TMS for Hydrological Studies**
J. Gervin
Goddard Space Flight Center

MSS Methods and Results

- 2:30 p.m. Landsat-4 MSS Radiometric Correction**
A. Singh
General Electric
- 3:30 p.m. Break**
- 4:00 p.m. Landsat-4 MSS Geometric Correction**
J. Brooks
General Electric
- 5:30 p.m. Adjourn**
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Landsat-4 Scientific Characterization Early Results Symposium

TM Radiometry and Geometry Session Wednesday, 23 February

**Bldg. 8, Auditorium
John Barker, Moderator**

- 1:30 p.m. Spectral Characterization of the Landsat Thematic Mapper Sensors**
B.L. Markham
Goddard Space Flight Center
- 1:50 p.m. Prelaunch Absolute Radiometric Calibration of Reflective Bands on Landsat-4
Photoflight Thematic Mapper**
J. Barker
Goddard Space Flight Center
- 2:05 p.m. Characterization of Radiometric Calibration of Landsat-4 Thematic Mapper Reflective
Bands**
J. Barker
Goddard Space Flight Center
- 2:25 p.m. Evaluation of the Radiometric Integrity of Landsat-4 Band 6 Data**
J. Schott
Rochester School of Technology
- 2:45 p.m. Break**
- 3:15 p.m. Thermal Band Characterization of Landsat-4 Thematic Mapper**
J. Lansing
Santa Barbara Research Center
- 3:40 p.m. A Preliminary Assessment of Landsat-4 TM Data Processing by NASA**
D. Goodenough
Canada Centre for Remote Sensing
- 4:00 p.m. Preliminary Evaluation of Radiometric Calibration of Landsat-4 TM Data by the
Canada Centre for Remote Sensing**
J. Murphy
Canada Centre for Remote Sensing
- 4:20 p.m. Evaluation of the Radiometric Quality of the TM Data Using Clustering and
Multispectral Distance Measures**
L. Bartolucci
Purdue University
- 4:40 p.m. Analysis and Evaluation of the Landsat-4 MSS and TM Sensors and Ground Data
Processing Systems — Early Results**
R. Bernstein
IBM Corporation
- 5:20 p.m. Adjourn**
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Landsat-4 Scientific Characterization Early Results Symposium

**TM Radiometry and Geometry Session, Cont.
Thursday, 24 February**

**Bldg. 8, Auditorium
John Barker, Moderator**

- 8:45 a.m. In Progress Report: Absolute Radiometric In-Flight Calibration of Landsat-4 Sensors**
P. Slater
University of Arizona, Optical Science Center
- 9:00 a.m. Landsat-4 TM Calibration and Atmospheric Correction**
W. Hovis
NOAA/NESDIS
- 9:20 a.m. Scan Angle and Detector Effects in TM Radiometry**
M. Metzler
Environmental Research Institute of Michigan
- 9:45 a.m. TM Spectral Dimensionality and Data Structure**
E. Crist
Environmental Research Institute of Michigan
- 10:00 a.m. Break**
- 10:30 a.m. MTF Analysis of Landsat-4 TM**
R. Schowengerdt
University of Arizona
- 10:50 a.m. Thematic Mapper Intraband Radiometric Performance**
H. Kieffer
U.S. Geological Survey, Flagstaff
- 11:10 a.m. Evaluation of Radiometric and Geometric Characteristics of Landsat-4 TM**
M. Podwysocki
U.S. Geological Survey
- 11:30 a.m. JSC TM Scrounge Data Preprocessor**
J. Gilbert
NASA, Johnson Space Center
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Landsat-4 Scientific Characterization Early Results Symposium

**TM Radiometry and Geometry Session, Cont.
Thursday, 24 February**

**Bldg. 8, Auditorium
John Barker, Moderator**

- 11:50 a.m. Processing of Thematic Mapper Simulator Data**
S. Unger
Goddard Space Flight Center
- 12:00 Noon Lunch**
- 1:10 p.m. Evaluation of Landsat-4 Thematic Mapper Ground Segment Performance Without Ground Control**
A. Zobrist
NASA, Jet Propulsion Laboratory
- 1:30 p.m. Early Evaluation of TM Geometric Correction System**
E. Beyer
General Electric
- 2:00 p.m. The Use of Linear Feature Detection to Investigate TM Data Performance and Processing**
C. Gurney
Systems & Applied Sciences Corp.
- 2:20 p.m. Spatial Resolution Estimation of Landsat-4 TM & MSS Data**
K. Yu
Virginia Tech.
- 2:40 p.m. An Analysis of the High Frequency Vibrations in Early TM Scenes**
J. Kogut
Research & Data Systems
- 2:50 p.m. Assessment of TM Band-to-Band Registration by the Block Correlation Method: Preliminary Results**
R.C. Wrigley
NASA, Ames Research Center
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Landsat-4 Scientific Characterization Early Results Symposium

**TM Radiometry and Geometry Session, Cont.
Thursday, 24 February**

**Bldg. 8, Auditorium
John Barker, Moderator**

- 3:05 p.m.** **Investigation of TM Band-to-Band Registration Using the JSC Registration Processor**
S.S. Yac
Lockheed-EMSCO
- 3:15 p.m.** **Geodetic Accuracy of Landsat-4 TM Data**
L. Oleson
U.S. Geological Survey, EROS Data Center
- 3:30 p.m.** **Adjourn**
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Scientific Characterization Landsat-4 Early Results Symposium

TM Applications Session Thursday, 24 February

Bldg. 3, Auditorium
Darrel Williams, Moderator

- 8:30 a.m.** **TM Quick-Look Analysis of the Washington, D.C. Area**
D. Williams
Goddard Space Flight Center
- 8:45 a.m.** **Preliminary Comparisons of Information Content Utility of TM vs MSS Data**
B.L. Markham
Goddard Space Flight Center
- 9:00 a.m.** **Information Content of Data from the Landsat-4 TM and MSS**
J. Price
U.S. Department of Agriculture, ARS Hydrology Laboratory
- 9:15 a.m.** **Landsat-4 Investigation of TM and MSS Applications**
D. Lauer
EROS Data Center
- 9:45 a.m.** **Break**
- 10:00 a.m.** **Preliminary Evaluation of TM Data for Renewable Resources**
D. Pitts
NASA/Johnson Space Center
- 10:20 a.m.** **TM Data Quality and Performance Assessment in Renewable
Resources/Agriculture/Remote Sensing**
R. Bizzell
Johnson Space Center
- 10:50 a.m.** **Remote Sensing Investigations of Wetland Biomass and Productivity for Global
Biosystems Research**
M. Hardisky
College of Marine Studies, University of Delaware
- 11:10 a.m.** **Assessment and Comparison of Landsat TM and MSS Data for Detecting Submerged
Vegetation**
S. Ackleson
College of Marine Studies, University of Delaware
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Landsat-4 Scientific Characterization Early Results Symposium

TM Applications Session, Continued Thursday, 24 February

**Bldg. 3, Auditorium
Darrel Williams, Moderator**

- 11:30 a.m. A Preliminary Evaluation of Thematic Mapper Data to Measure Suspended Sediments
in Lake Chicot, Arkansas**
J. Ritchie
U.S. Department of Agriculture
- 11:50 a.m. Snow Reflectance from the TM**
J. Dozier
University of California, Santa Barbara
- 12:10 p.m. Lunch**
- 1:30 p.m. Preliminary Evaluation of TM Soils**
D. Thompson
NASA, Johnson Space Center
- 1:50 p.m. Spatial Analysis of Thematic Mapper Products**
M. Jackson
NERC, Experimental Cartography Unit, U.K.
- 2:10 p.m. Geologic Utility of Landsat-4 TM Data - Death Valley, California**
M. Abrams
NASA, Jet Propulsion Laboratory
- 2:30 p.m. Preliminary Study of Information Extraction of TM Data for a Suburban/Regional
Test Site**
D. Toll
Goddard Space Flight Center
- 2:50 p.m. Comparative Techniques Used to Evaluate TM Data for Land Cover Classification in
Logan County, West Virginia**
H. Blodget
Goddard Space Flight Center
- 3:10 p.m. A Relative Accuracy Assessment of Landsat-4 MSS and TM Data for Land Cover
Inventory**
Y. C. Lu,
Computer Science Corp.
- 3:30 p.m. Adjourn**
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Landsat-4 Scientific Characterization Early Results Symposium

Fourth General Session Research Plans and Panel Discussion

Thursday 24 February

**Bldg. 8, Auditorium
Mark Settle, Moderator**

This session makes available to the public a panel of Landsat-4 personnel to respond to questions on scientific, technical and policy topics.

4:00 p.m. Thematic Mapper Research Plans

Mark Settle
Landsat-4 Program Scientist, NASA Headquarters

4:20 p.m. Panel Discussion

Panel members are:

John Barker
NASA, Goddard Space Flight Center

Russ Koffler
NOAA, National Environmental Satellite Information and Data Service

Vince Salomonson
NASA, Goddard Space Flight Center

Mark Settle
NASA Headquarters

5:00 p.m. Adjourn

First General Session

Landsat-4 Introduction, Description and Highlights



LANDSAT-4 PROGRAM

William Webb
Landsat-4 Mission Operations Manager
Goddard Space Flight Center

The Landsat-4 program is described in terms of its history, project objectives, mission requirements and system design. Accomplishments, as well as future plans are outlined, including the transition of the program to NOAA.

NOAA's LANDSAT PROGRAM

Russell Koffler
Office of Satellite Data Processing
and Distribution
National Oceanic and Atmospheric Administration

An introduction to the National Oceanic and Atmospheric Administration's activities as the organization changed with the responsibility of managing the nation's operational civil remote sensing satellites. Emphasized will be NOAA's role in the Landsat Program.

Discussion of related questions will take place at the Symposium Wrap-Up Panel Session, 4:00 p.m., Thursday, 24 February.

LANDSAT-4 SYSTEM DESCRIPTION

T. C. Aepli
Manager, Landsat Systems Engineering
General Electric Co.

The operation of the next generation Landsat system began following the launch of Landsat-4 on July 16, 1982. Involved are a new satellite design, a new Thematic Mapper instrument, new and varied data return paths and a new ground segment. The system has been operating for over six months during which time initial assessments have been made of the performance of these new elements. This paper summarizes the Landsat-4 system, highlights the new and different elements of interest to data users and summarizes early results.

INSTRUMENT DESCRIPTIONS

Jack Engel
Manager, Thematic Mapper Program
Santa Barbara Research Center

LANDSAT-4 HIGHLIGHTS

Darrel Williams
Goddard Space Flight Center

The first Landsat satellite was launched in July 1972. It carried an Earth-viewing sensor known as the Multispectral Scanner (MSS) that obtained imagery of the Earth's surface in four discrete spectral bands. Landsat 1 was followed by Landsats 2 and 3 in 1974 and 1978, respectively. Research conducted during the 1970's demonstrated that unique types of information could be derived from MSS imagery. For example, multispectral Landsat data has been used for geological mapping, crop forecasting, urban studies, land use planning, water management, map making, and a wide variety of other applications. More than one million images of the Earth's surface have been collected by the first three Landsat satellites. This image collection represents the first historical record of global surface conditions on our planet. The value of this image collection has grown significantly during the first decade of Landsat operations, and it will continue to grow in the future.

Our ability to conduct routine observations of the Earth's surface on a repetitive, global basis has been considerably expanded with the successful launch of Landsat 4 in July 1982. Landsat 4 carries a new sensor known as the Thematic Mapper (TM) that is far more sophisticated than the previous MSS instruments. The TM measures the intensity of surface radiation in seven discrete spectral channels (six of these channels are sensitive to variations in reflected sunlight and the other channel, commonly referred to as the "thermal band", is sensitive to surface temperature). Individual picture elements in a TM image cover an area of 30x30 meters, except for the thermal channel which has a spatial resolution of 120x120 meters. Incoming radiation is assigned to one of 256 gray levels in each spectral channel by the TM. In comparison, the MSS is less sensitive with an overall range of 64 gray levels in each band. In summary, the TM possesses approximately twice the spectral resolution, three times the spatial resolution, and four times the sensitivity of the earlier MSS sensors. Considered together, the TM represents an order of magnitude increase in our Earth observation capabilities from space.

More than 100 Thematic Mapper images have been fully processed and distributed to scientific investigators. The preliminary results of current data analysis activities are described below.

Agriculture

The TM spectral bands were selected in part for classifying crops and monitoring conditions. One of the earliest TM scenes was acquired over the Mississippi River in the central U.S. on August 22, 1982. A wide variety of crops are grown in this region, which encompasses portions of Arkansas, Missouri, Kentucky, and Tennessee. Analysis of this scene has demonstrated that several of the new spectral bands on the TM (particularly those at wavelengths of 1.6 and 2.2 micrometers) are particularly useful for distinguishing crops such as rice and soybeans, which were difficult to differentiate in earlier MSS imagery. Overall crop classification accuracy for this scene was improved by roughly 25% using TM data. Early results suggest that a TM image acquired at a single point in time may achieve the same accuracy in crop classification that has been achieved with multiple MSS images obtained throughout an entire growing season. The improved spatial resolution of the TM is particularly useful for crop assessment because a greater number of the TM picture elements fall within individual fields. Picture elements (pixels) in single fields produce a more accurate measurement of the spectral characteristics of individual crops than do "mixed pixels" which straddle field boundaries and contain mixed spectral signatures of crops, roads, trees, water, etc. One of the early TM scenes acquired over the central plains of Canada has graphically demonstrated the utility of TM data for surveying areas that are cultivated in a "strip crop" fashion with alternating rectangular fields of cultivated and fallow land. Many portions of Europe, China, India, and South America contain agricultural fields that range in size from 10-40 acres. TM data should be particularly useful for crop surveys in these areas.

Geology

One of the other major factors in selecting the spectral channels on the Thematic Mapper was the desire of geologists to map variations in the abundance of clay minerals in semi-arid regions. Clay minerals generally possess diagnostic spectral absorption features at wavelengths of 2.0-2.5

micrometers, and the TM band at 2.2 micrometers was specifically included for this purpose. Geological evaluation of TM data has initially concentrated upon a scene of Death Valley, California that was acquired November 17, 1982. Mineralogical variations between major classes of rocks such as granites, quartzites, and volcanic lavas can be clearly detected in the TM imagery. Furthermore, subtle variations in clay mineralogy and abundance have been detected in the gravel fans that lie along the edges of the valley. These clay variations cannot be detected in aerial photography of the Death Valley area, demonstrating the utility of the new spectral channels at 2.2 and 1.6 micrometers for rock classification. A second major study site situated near Tucson, Arizona has also been examined. An area of copper mineralization known as Silver Bell, Arizona has been studied in the past using airborne sensors that simulate the measurement capabilities of the TM. These TM simulator studies showed that certain types of clay minerals commonly associated with metal deposits could be spectrally detected. A TM scene acquired over the Tucson area by Landsat 4 has confirmed the results of this earlier study, and an alteration "halo" of clay minerals associated with the Silver Bell deposit has been identified in the orbital TM imagery. Airborne TM simulator studies performed in the past were conducted over localized test sites roughly 15x15 kilometers in size. The confirmation of these experimental results using early Landsat 4 data implies that similar mineral evaluation studies can now be conducted routinely in semi-arid portions of the world, over areas of 185x185 kilometers or greater.

Water Resources

The improved spatial resolution of the TM will lead to significant improvements in our ability to map natural watersheds. It will improve estimates of urban runoff and lead to better management of storm water in metropolitan areas as well. Snow and cloud-covered areas can be more accurately differentiated with TM data due to the unique spectral properties of snow and clouds at wavelengths of 1.6 and 2.2 micrometers. These spectral channels will also provide a new capability for differentiating nutrients and sediments that are commonly found in coastal waters. Preliminary analysis of TM data acquired over the southeastern

coastline of the U.S. near Charleston, South Carolina has demonstrated that suspended sediments can be distinguished from plankton in near-shore waters. Furthermore, the improved spatial resolution of the TM should prove useful for longer term studies of topsoil erosion and sediment transport in coastal environments. The new thermal infrared band on the TM will provide an important new capability for monitoring soil moisture conditions and evaluating the effectiveness of crop irrigation practices. Preliminary analysis has shown that surface temperature differences as small as 0.5^o Centigrade can be detected in TM thermal imagery. Large scale surveys of thermal conditions in vegetated regions will be useful for detecting water stress conditions in both natural and cultivated areas.

Urban Studies/Land Use Planning

The Thematic Mapper can be used to identify surface features 30 meters on a side, which roughly corresponds in size to a standard city lot. Highway construction, land excavation, urban growth, the health and extent of vegetation, etc. can be delineated in Thematic Mapper imagery. Repetitive observations of these features is an important source of data for land use planning and resource management. The TM is ideally suited for collecting this type of data in a quantitative fashion at uniform scales and accuracies. Comparative analysis of TM imagery acquired over large metropolitan areas such as Washington, DC and small rural towns such as Union City, Tennessee have demonstrated that a wide range of man-made features have unique spectral expressions in TM imagery.

In summary, initial analysis of TM imagery has produced highly encouraging results in a wide variety of disciplines. The TM possesses a unique set of measurement capabilities that will not be duplicated or surpassed by any orbital sensor system planned for the 1980's. Earth imagery acquired by the TM will extend and enlarge the value of the existing Landsat data collection. At the same time, the TM opens new avenues of Earth-related research that could not be addressed by earlier sensor systems. Evaluation and analysis of Landsat 4 TM data for NASA R&D purposes will continue during the next two years. The TM sensor will be transferred to NOAA in 1985 for operational data collection.

Dr. Mark Settle
Landsat 4 Program Scientist
NASA Headquarters

Dr. Vincent Salomonson
Landsat 4 Project Scientist
Goddard Space Flight Center

Second General Session

Representative Early Results



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EARTH IMAGING AND DATA PROCESSING FOR MAPPING AND ANALYSIS,
A TECHNOLOGICAL ASSESSMENT

Ralph Bernstein
IBM Palo Alto Scientific Center
1530 Page Mill Road
Palo Alto, CA 94303 0821 USA

ABSTRACT

Early observations of the earth used balloons and cameras. These platforms provided limited geographical coverage and small area images. The platforms were replaced by rockets and aircraft platforms, but did not provide repeat coverage or cost effective data. These imaging systems used film, the processing was chemical, and the interpretation involved primarily human analysis of the photographic images. The current Landsat NASA/NOAA Landsat satellite program has the potential of providing users with data of exceptional spectral and dynamic range, and data of high resolution at nominal costs. In addition, the repeat coverage under controlled conditions provide data of significant scientific utility. Current sensor technology utilizes solid state detectors, and the data can be provided to users in a digital form. Thus, information extraction and interpretation can be aided by digital processing of the data.

This paper describes early earth observation imaging systems and compares the quality and utility of the previous data with the current Landsat-4 Thematic Mapper data. In particular, the ability of the TM sensor to discern small natural and cultural features will be discussed and described with emphasis on land use analysis and mapping. The TM has a thermal band, capable of both day and night imaging. Both B&W and color products have been produced and will be presented and discussed. In addition, the wide spectral range of the TM data allow for new presentations of data to the users. Various band combinations in red/green/blue and intensity/hue/saturation will be presented, as well as experiments to attempt to display six bands in one presentation.

Digital data processing was at one time the domain of data processing centers. This technology has not progressed to the point that individuals now have their own computers. The paper will also describe an experiment that involves the use of an IBM Personal Computer to process the new Landsat-4 Thematic Mapper data. This computer has been programmed to do statistical analysis of the data, produce graphical results, and perform limited image processing and display operations. This capability may be of importance to users who do not have access to larger computers. Future satellite communications technology, combined with the digital processing technology presents the possibility that future earth observation systems will provide data directly to the users, with a concurrent reduction in both time for data acquisition and data costs.

"INTERPRETABILITY OF CALIFORNIA'S AGRICULTURAL RESOURCES
ON LANDSAT-4 TM AND MSS IMAGERY--AN EARLY APPRAISAL"

R. N. Colwell
S. D. DeGloria

Remote Sensing Research Program
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ABSTRACT

The purpose of this presentation is to provide an early appraisal of the interpretability of Landsat-4 TM and MSS image products for determining the extent to which major agricultural resources and conditions can be detected and identified. An evaluation of the quality of various spectral band combinations and transformations for a scene of the Central Valley of California (Scene ID #84014518082X0, P: 43, R:34, 12/8/82) is accomplished through systematic image interpretation using photographic displays of the digital data, provided in part by IBM, in combination with low altitude oblique and ground photography and ground data provided in part by ongoing agricultural research projects in California under USDA sponsorship. Evaluation of the quality of the thermal band (TM6) for assessing agricultural resources is also included in the interpretation process. The evaluation includes (1) a quantitative and qualitative interpretation of crop types, primarily small grains and fields under double cropping regimes; (2) an assessment of the within-field, or feature, variability for assisting the interpretation process, and (3) an assessment of interpretation errors as influenced by image quality.

ABSTRACT FOR LANDSAT-4 EARLY RESULTS SYMPOSIUM

EVALUATION OF THEMATIC MAPPER PERFORMANCE AS APPLIED TO HYDROCARBON EXPLORATION

By Dr. John R. Everett, Dr. Charles Sheffield, Dr. Jon Dykstra
Earth Satellite Corp., 7222 47th Street, Chevy Chase, MD 20815

Results from a limited sample of Landsat-4 TM scenes demonstrate that the greater number of spectral bands and the increased spectral and spatial resolution over previous satellite data greatly expand, improve and refine the geological inferences possible from space. The number and narrower width of available spectral bands, coupled with digital processing techniques such as band ratioing, principal component analysis and hue-saturation-intensity presentation, allow the differentiation and mapping of a large number of geologic units and the identification of altered rock associated with intrusions in the Death Valley, California, area. These capabilities will contribute greatly to geologic exploration in arid areas.

The increased spatial resolution also assists in distinguishing glacial from tectonic features (difficult on previous imagery) in the Detroit area. Several of the Ordovician oil and gas fields of Ontario lie on fracture zones clearly visible on Landsat-4 TM imagery. All of these fields rely on fracture-related porosity and permeability for production. The current-borne sediment plumes in Lake St. Clair and Erie demonstrate that Landsat-4 will contribute to our understanding of lacustrine, riverine and marine depositional and erosional patterns and processes.

Digitally enhanced Landsat-4 TM imagery reveals geological features of the Anadarko Basin, Oklahoma, in greater numbers and detail than previously possible. Comparison with existing work suggests that some of the subtle spectral differences detected are related either to changes in chemical composition or resultant changes in vegetation related to micro-seepage of hydrocarbons adjacent to oil fields in the area.

There seem to be several categories of features (throughgoing structures, large area subtle tonal contrasts, etc.) that are still best seen on older Landsat imagery. Thus, Landsat-4 does not make earlier systems obsolete; rather it provides a powerful new tool to exploration geologists.

GEOLOGIC UTILITY OF LANDSAT-4 TM DATA:
DEATH VALLEY, CALIFORNIA

Michael Abrams, Anne Kahle, Alan Gillespie,
James Conel, Harold Lang
Jet Propulsion Laboratory
Pasadena, CA

The present LIDQA study is being conducted in several phases to quantify the performance of the TM vis-a-vis various geological applications. These phases include: (1) analyses of the geological utility of the data with respect to the increased spatial resolution and number of bands (compared to the MSS); (2) analysis of geometric accuracy; (3) analysis of radiometric performance of the TM scanner.

This report presents some preliminary results of geological analysis of TM data for Death Valley, California, and observations on TM data quality. Geometrically and radiometrically corrected data (CCT-PT) have been examined for scene E-40124-17495, acquired November 17, 1982. Overall, the TM data appeared to contain a marked increase in geologically useful information; however, a number of instrumental or processing artifacts may well limit the ability of the geologist to fully extract this information.

A 27 by 18 km area was extracted from the scene for detailed analysis. Color-enhanced band composites, principal components composites, and color ratio composites were produced from the TM data. Lithologic interpretation maps were prepared and compared to detailed published geologic maps. More detail and delineation of alluvial fan units was evident on the TM data; most of the salt/silt/evaporite units in the Death Valley playa were apparent on the images; many of the outcropping volcanic and sedimentary rock types were separable based on differences in their spectral response. However, substantial shadowing due to the combination of low sun angle and severe topographic relief limited the ability to interpret information in the mountainous areas. High sun angle, summer scenes would greatly reduce this problem.

The same region was extracted from Landsat-2 MSS data and also from aircraft multispectral thermal data. Displayed as color composites and principal component images, the TM data were superior to the MSS data in all respects. The multispectral thermal data, however, allowed separation of alluvial units and lithologic units not seen on the TM data. This indicates the complementary nature of the two data sets for providing lithologic separations based on sensing different physical properties.

Two significant radiometric problems were observed in the TM data. The mean signal levels differ appreciably between the forward and reverse scan directions, possibly due to inaccuracies in the radiometric calibrations. This effect manifests itself as banding in harshly contrast-enhanced images. The second problem is most pronounced in ratio images and appears as striping, most severe at the edges of the scenes. The striping consists of paired lines of high-variance noise, with a 17-line periodicity. They

occur at the seams between the forward and reverse scan swaths, where extension scan lines have been interpolated to fill data gaps. It appears that the interpolation procedure used to process this scene was faulty.

The TM data were registered to a topographic base map. Results of the registration procedure indicate that the error in geometric accuracy of the CCT-PT data is less than 2 pixels. A more rigorous test of accuracy is planned.

AN INITIAL ANALYSIS OF LANDSAT-4 THEMATIC MAPPER DATA
FOR THE DISCRIMINATION OF
AGRICULTURAL, FORESTED WETLAND, AND URBAN LAND COVERS

By: Dale A. Quattrochi

NASA/Earth Resources Laboratory
Code HA30
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ABSTRACT

An initial analysis of Landsat-4 Thematic Mapper (TM) data for the discrimination of agricultural, forested wetland, and urban land covers was conducted using a scene of data collected over Arkansas and Tennessee on August 22, 1982. A study area in Poinsett County, Arkansas was used to evaluate a classification of agricultural lands derived from multi-temporal Landsat Multispectral Scanner (MSS) data in comparison with a classification of TM data for the same area. Results indicated that the TM performed significantly better than the MSS in overall classification accuracy. Data over Reelfoot Lake in northwestern Tennessee were used to evaluate the TM's capabilities for delineating forested wetland species. A classification derived for the study area yielded an overall accuracy of 95% correct in discriminating five categories of forested wetlands. Additionally, the TM data were used to identify urban features within a small city in northwest Tennessee. A classification of Union City, Tennessee was evaluated for accuracy in discriminating urban land covers. This classification produced an overall accuracy of approximately 90% correct when compared with

ground truth information for the study area. An assessment of digitally enhanced TM data was also performed using principal components analysis to facilitate photointerpretation of urban features of the Union City area.

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Canadian Plans for Thematic Mapper Data

Authors W.M. Strome, F.E. Guertin, A.B. Collins and D.G. Goodenough

Presented by W.M. Strome
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ABSTRACT

Canada was the first country outside the U.S.A. to receive, process and distribute data from the original LANDSAT series. The data from these satellites have been used to improve the state-of-the-art of resource management and environmental monitoring in Canada over the past decade. The utility of MSS data has been proven in a wide range of applications, from ice reconnaissance, through agriculture and forestry to geological exploration, to name a few. Despite the usefulness of MSS, its limitations prevented full use of satellite remote sensing technology for some purposes. Thus, it was decided to upgrade the Canadian facilities to receive and process the data from LANDSAT-4.

The modifications to the existing equipment for processing MSS data from the new satellite were relatively straightforward and are now complete. The Prince Albert Satellite Station has been modified to permit reception and recording of TM data for western North America. A small scale system has been built to transcribe TM data from the high density station tapes to computer compatible tape. The throughput of this system is very low - two to five scenes per week. However, it does enable us to develop and test the algorithms to be used in our Thematic Mapper Bulk Processing system and our Multi Observation Satellite Image Correction System (MOSAICS). These will be operational in 1984 and 1986 respectively. The latter system will provide geocoded image data, keyed to maps and independent of satellite orbit and sensor resolution. To analyze the TM imagery a new facility called the LANDSAT-D Image Analysis System is being developed and will be phased gradually into operation starting in 1983.

LANDSAT-4 IMAGE DATA ANALYSIS

Robert B. MacDonald
NASA/Johnson Space Center
Houston, Texas

Researchers at the Johnson Space Center have completed a preliminary analysis of data acquired by the Thematic Mapper over several test sites. These data were analyzed, together with "site ground truth measurements" to evaluate various performance characteristics of the Thematic Mapper. The results of this analysis are presented.

Third General Session

Scientific Characterization



LANDSAT-4 EVALUATION PROGRAM AND SCIENTIFIC
CHARACTERIZATION ACTIVITIES

John L. Barker
Landsat-4 Associate Project Scientist
Goddard Space Flight Center

As part of the Landsat-D program, NASA committed to the following objectives:

- 1) Thematic Mapper (TM) Capability Assessment
- 2) Multispectral Scanner (MSS) to TM Transition
- 3) Operational System Feasibility Demonstration
- 4) Continuity of MSS Imagery
- 5) Continued Foreign Access

With the turnover of Landsat-4 MSS operations to NOAA on January 31, 1983, NASA has effectively accomplished 3 of the 4 engineering objectives, namely 3, 4 and 5. Objective 2 is being addressed with the development of the TM Image Processing System (TIPS). Objective 1 falls primarily into the perview of scientific characterization rather than engineering verification of reliability, specifications and quality assurance. The characterization objectives of the Landsat-4 Science Office at Goddard Space Flight Center are:

- 1) Characterize Accuracy and Precision of Sensor and Spacecraft Performance
- 2) Characterize Accuracy and Precision of Image Data Quality
- 3) Characterize Accuracy and Precision of Derived Information
- 4) Recommend Landsat-4 System Improvements
- 5) Communicate Results to Research Community

In order to accomplish these objectives, NASA has embarked on a three pronged effort. Firstly, in-house activities at Goddard have been directed toward full access and utilization of the pre-launch and in-orbit engineering test data on the sensor and spacecraft. Secondly,

the principle scientists in land remote sensing have been gathered together as part of a major scientific characterization effort following the LIDQA Application Notice (AN) in 1981. Two Landsat-4 Workshops have already been held for these investigation teams, namely in May, 1981 and January, 1982. Most of the investigators are now under contract. Investigators who have already received imagery are presenting at this Landsat-4 Early Results Symposium. A final symposium is scheduled for the Fall of 1984, prior to the turnover of TM to NOAA. In a third phase, NASA intends to move from an emphasis on sensor and spacecraft performance and image data quality into a more extensive scientific investigations program.

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MSS EVALUATION REPORT

William Alford
Landsat-4 Senior Systems Programmer
Goddard Space Flight Center

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TM REPORT

John L. Barker
Landsat-4 Associate Project Scientist
Goddard Space Flight Center

In this TM summary report, emphasis is placed on the key spectral, radiometric and geometric characteristics of the sensor. Future editions will emerge from the studies of the Landsat-4 LIDQA investigations team and will result in an expanded emphasis on image data quality and applications information.

Spectrally the key findings of importance to scientific use of TM in the visible (VIS) and near infrared (NIR) included narrower bands, and new bands in the shortwave and thermal infrared (SWIR and TIR). Band 5 is slightly wider than specified and its upper edge at 50% of maximum of 1784 nm (nanometers) includes some unintended overlap with water absorption bands. The thermal Band 6 is half the expected width, which causes no foreseeable scientific problems, especially since it has nearly twice the expected signal-to-noise ratio.

Radiometrically, the TM sensor is characterized by extreme linearity and stability in comparison to previous MSS photomultiplier systems. The forward and reverse scans on TM have shown some unexplained radiometric differences of up to four digital levels, especially in the four bands on the primary focal plane (PFP). Intraband variability between detectors has been less than about $\pm 0.3\%$ for the four PFP bands and about $\pm 1\%$ for Bands 5 and 7. This means that radiometric calibration of Bands 5 and 7 is more important for within image destriping. PFP bands, as monitored by the internal calibration (IC) have shown a monotonic decrease in gain of about 5% in the five months since launch. On the other hand, the relative internal gains of Bands 5 and 7 have varied with a period of about 60 days and an amplitude of about 6%. This difference in pattern between PFP and the cold focal plane (CFP) bands suggests a band-dependent gain change that is independent of possible IC changes with time. This indicates that it is essential to apply IC radiometric calibration before any histogram equalization algorithms in order to

preserve both relative and absolute interband radiometric accuracy. Signal-to-noise ratios exceed specifications by nearly a factor of two in all bands. Observed background noise is ± 1 count in Bands 1, 5 and 7 and about $\pm .5$ counts in the other three bands. Detector 3 in Band 5 is dead. In general, the first detectors are the noisiest. Channel 7 in Band 7 is more than a factor of two noisier than other detectors, and has shown a 20% gain increase since pre-launch calibration in system-level thermal vacuum testing. Thermal Band 6 showed a loss in gain of approximately 40% from August to January, when the CFP cooler was outgased and Band 6 regained its initial in-orbit gain sensitivity. This gain loss corresponds approximately to a change of from 0.3 to 0.45^oC per digital count. There appears to be a mislabeling of the Band 6 channels for the calibration data. Assuming that there is no significant limitation from quantization, dynamic ranges may be too large for typical scenes, especially in Bands 6 and 7.

Geometrically, pre-launch tests indicated compliance with most specifications. Channel 4 in Band 2 has a smaller modulation transfer function (MTF) than desired and is being replaced by its neighbor prior to geometric resampling. There is an apparent PFP-CFP misregistration of .75 pixels along scan and 0.2 pixels across-scan. An intermittent geometric discontinuity of up to 2 pixels between forward and reverse sweeps has been observed and is under investigation. Peak-to-peak attitude deviations are being measured by the angular displacement sensor (ADS) at less than 0.5 pixels and are removed during systematic geometric preprocessing.

MIT

ANALYSIS OF THEMATIC MAPPER DATA FROM GEOLOGIC
TERRAIN UNITS IN A CALIFORNIA-NEVADA SCENE

Rupert Haydn
Zentralstelle fur Geo-Photogrammetrie w. Fernerkundung
Luisenstrasse 37, 8000 Munchen 2
Federal Republic of Germany

and

Nicholas M. Short
Geophysics Branch
NASA/Goddard Space Flight Center
Greenbelt, MD 20771

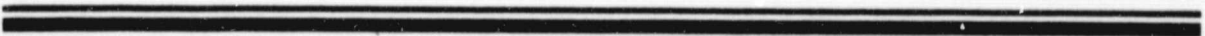
Abstract

Thematic Mapper data from the Death Valley scene (Landsat 40124-17495; November 17, 1982) have been processed for a variety of output products. Edge-enhanced natural and false color composites of the full and partial scene(s), using the intensity, hue, saturation (IHS) color system, were produced on a DEC PDP-11.

Ratios of selected reflectance bands including the Short Wave Infrared bands 5 and 7, can be displayed in combinations in which two or three ratios are expressed in the IHS color scheme and another ratio is used to calculate pixel shifts by which an image pair is created to generate a 3-D stereo effect. This approach can also depict variations in temperature, from band 6 data, as the stereo component. Examples of these experimental products will be displayed in 3-D to the audience.

A data subset from the northern Death Valley area was analyzed on Goddard's IDIMS computer. Unsupervised classifications, based on a maximum likelihood classifier, yielded nine separable classes from TM bands 2, 3 and 4 (roughly equivalent to the MSS interval) and 11 classes for bands 1, 2, 3, 4, 5 and 7 combined. Discrimination of rock types in the mountain terrain was poor but recognition of discrete units in the valley was notably improved. A supervised classification based on twelve defined classes including five rock units present in the mountains was superior to the unsupervised ones. Better definition of valley units was achieved with color composites made from several image combinations of principal components derived from the Karhuenen-Loeve transformation function developed by ERIM to specify brightness and greenness.

TM Introductory Session



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TM SENSOR RADIOMETRY

John L. Barker
Landsat-4 Associate Project Scientist
Goddard Space Flight Center

An overview of the pre-launch and in-orbit radiometric calibration procedures is provided, including both absolute and relative calibration.

SENSOR GEOMETRY

J. Engel
Santa Barbara Research Center

TM RADIOMETRIC PROCESSING

John L. Barker
Landsat-4 Associate Project Scientist
Goddard Space Flight Center

An overview of the SCROUNGE-Era TM radiometric digital processing is provided from abstraction of calibration data in ADDS through radiometric calibration of the CCT-BT to CCT-AT tapes and subsequently through geometric resampling to CCT-PT tapes.

TM INTRODUCTORY SESSION

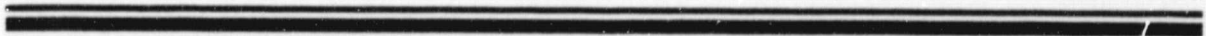
GEOMETRIC PROCESSING
Eric Beyer
General Electric Co.

An overview of TM Geometric Processing is provided. The description of the Flight Segment includes the TM, attitude measurement sensors, attitude control system and payload correction data. The ground processing description includes payload correction processing (in which Flight Segment telemetry is converted into geometric distortion information), ground control point processing and image data reformatting and resampling.

IMAGE DATA QUALITY

J. Lyon
Goddard Space Flight Center

MSS Session



MSS RADIOMETRIC ACCURACY ASSESSMENT

William Alford
Landsat-4 Senior Systems Programmer
Goddard Space Flight Center

Spectral Characterization of the Landsat-4 MSS Sensors

Brian L. Markham and John L. Barker
NASA/Goddard Space Flight Center
Earth Resources Branch
Greenbelt, MD 20771

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ABSTRACT

Relative spectral response data for the Landsat-4 and Landsat-4 backup multispectral scanner subsystems (MSS), the protoflight and flight models, respectively, are presented and compared to similar data for the Landsat 1, 2, 3 scanners. Channel-by-channel (six channels per band) outputs for soil and soybean targets were simulated and compared within each band and between scanners. The two Landsat-4 scanners proved to be nearly identical in mean spectral response, but they exhibited some differences from the previous MSS's. Principal differences between the spectral responses of the Landsat-4 scanners and previous scanners were: (1) a mean upper-band edge in the green band of 606 nm compared to previous means of 593 to 598 nm, (2) an average upper-band edge of 697 nm in the red band compared to previous averages of 701 to 710 nm, and (3) an average bandpass for the first near-IR band of 702-814 nm compared to a range of 693-793 to 697-802 nm for previous scanners. These differences caused the simulated Landsat-4 scanner outputs to be 3 to 10 percent lower in the red band and 3 to 11 percent higher in the first near-IR band than previous scanners for the soybeans target. Otherwise, outputs from soil and soybean targets were only slightly affected. The Landsat-4 scanners were generally more uniform from channel to channel within bands than previous scanners. One notable case of poor uniformity was the upper-band edge of the red band of the protoflight scanner, where one channel was markedly different (12 nm) from the rest. For a soybeans target, this nonuniformity resulted in a within-band difference of 6.2 percent in simulated outputs between channels.

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INVESTIGATION OF RADIOMETRIC PROPERTIES OF LANDSAT-4 MSS

Daniel P. Rice

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Ann Arbor, Michigan 48107

Summary

Objectives

The objectives of our investigation are to characterize Landsat-4 multispectral scanner (MSS) image data quality relative to:

(a) Detector calibration: Study the calibration of the six detectors in each band in order to determine the magnitude of any calibration differences that remain after ground processing, and, if needed, provide information that would support corrective techniques.

and (b) Satellite-to-satellite calibration: Study calibration differences between Landsat-4 and previous Landsat satellites and, as needed, develop a method to adjust Landsat-4 multispectral scanner (MSS) signals, in all four spectral bands, to match the calibration of previous MSS sensors.

General Approach

Two full frames of radiometrically corrected (Type A) Landsat-4 MSS data were analyzed digitally and visually for evidence of residual calibration differences between detectors, quantization effects, and other sensor-related artifacts. Both standard statistical and Fourier analysis techniques were employed.

Opportunities for coincident coverage by Landsats 3 and 4 were identified in the contiguous 48 states. Paired acquisitions for two scenes have been obtained to date and analyzed to establish relationships between signal values from common areas imaged by the two MSS systems.

Initial Findings

General Radiometry. We found that the Landsat-4 MSS produces data of generally good quality with dynamic ranges and target responses similar to those of previous Landsat systems (See Figure 1). Clouds often caused saturation in all bands. The extent of specific system artifacts are discussed individually below.

Detector-to-Detector Differences. Striping caused by residual differences in detector calibration and quantization effects appears to be quite well corrected. The histogram equalization algorithm used to adjust radiometric look-up tables appears to be working as intended. Residual rms differences of 0.3 digital counts or less were measured between detector means from a variety of scene areas. Fourier analysis of a down-track profile obtained by averaging the pixels in each scan line showed amplitudes attributable to the residual detector differences that were also approximately 0.3 digital counts or less. These differences were indicated by disturbances in the transforms at wavelengths of two, three, and six scan lines.

Coherent Noise. A low-level coherent noise effect was found in all bands, appearing in uniform areas as a diagonal striping pattern. The principal component of this noise was found by Fourier analysis to be at a consistent wavelength of 3.6 pixels along the scan line (See Figure 2), corresponding to a noise frequency of about 28 KHz. The magnitude varied from about 0.75 of one count in the worst case (Band 1) to 0.25 counts in the best case (Band 4). This noise pattern was visually discernable in water areas of a Landsat-4 image but not discernable in a simultaneous Landsat-3 image of the same area.

Landsat-4 to Landsat-3 Calibration. Initial regression relationships were computed between average signal amplitudes from a number of areas in common between Landsat-3 and -4 images of the two scenes with paired acquisitions. Linear fits with R^2 values exceeding 0.99 were obtained (See example in Figure 3). Letting

$$\text{Landsat 3} = \text{Gain} \times (\text{Landsat 4}) + \text{Offset}$$

we computed gains that were higher (by approximately 10% in Bands 1, 2, and 4) than ones based on prelaunch calibration values for the two sensors. While 23 points were used to determine this initial result, updated relationships based on more data points will be presented in the complete paper.

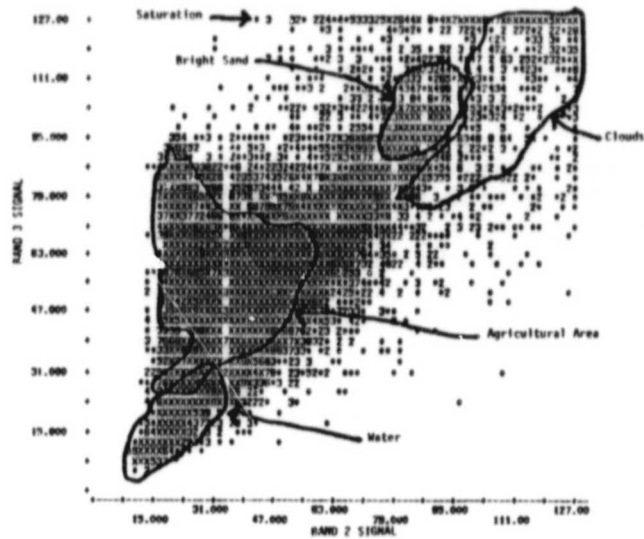


FIGURE 1. EXAMPLE OF LANDSAT-4 SIGNAL DISPERSION FOR A DIVERSE SCENE

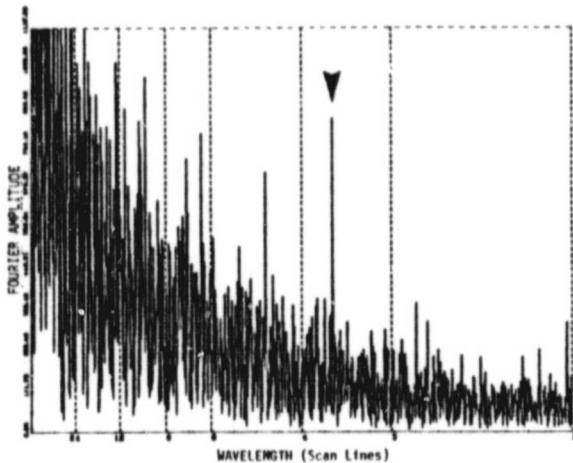


FIGURE 2. ILLUSTRATION OF THE COHERENT NOISE FREQUENCY IN A FOURIER SPECTRUM (BAND 3)

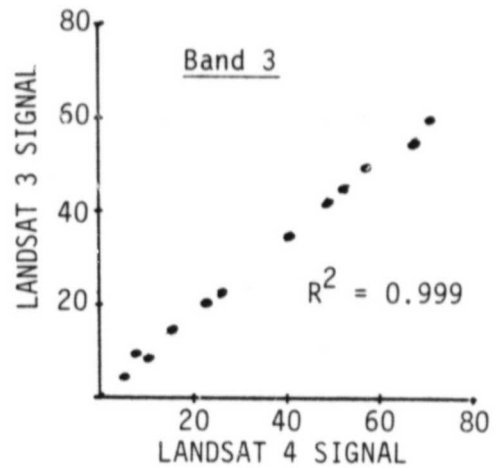


FIGURE 3. EXAMPLE REGRESSION RELATIONSHIP BETWEEN LANDSAT 3 AND 4 (BAND 3)

ABSTRACT

Evaluation of Landsat-4 Multispectral
Scanner Ground Segment Performance*

N. A. Bryant, A. L. Zobrist, F. C. Billingsley,
S. Z. Friedman, B. Gokhman, T. L. Logan

An analysis was performed on the P-Format computer compatible tapes for the Landsat-4 Multispectral Scanner (MSS) scene 40109-15140 acquired November 2, 1982 over Washington, D. C. and environs. Three tests of sensor geometry were undertaken: a) band-to-band registration, b) line-to-line registration between swaths, and c) geometric correction of sensor and spacecraft/ephemeris characteristics. The band-to-band and line-to-line registration was measured at one hundred pixel spacings along a line using the phase correlation image alignment method developed by Kuglin and Hines and adapted to a one-dimensional FFT correlation technique. The sensor and spacecraft geometric calibration analysis was checked by registering ground control point chips developed under the Landsat-3 Master Data Processor program. Twenty four ground control points (gcp) were located in the scene using the phase correlation image alignment method. (Note: this contrasts with 2 gcps being found by the Landsat-4 ground data processing segment using an autocorrelation technique.) A least squares fit of the gcps was computed and the vector offsets of the residuals was tabulated and plotted.

An analysis of the tabulated and plotted results revealed the following characteristics: a) There is no measurable swath-to-swath misregistration in the P-format imagery. b) Band-to-band registration is 0.1 pixel or less on the average. c) Line-to-line jitter effects may be occurring, but could not be more than one half pixel offset in any instance. d) It is apparent from the line-to-line plots that approximately 1/8 pixel shift to the right predominates. This may be a scene dependent artifact associated with the eleven degree off-polar orbit, an artifact of our phase correlation algorithm, or indicate a need to tune the estimate of spacecraft velocity for the geometric calibration. e) There appears to be a brightness modulation with a pseudo coherent pattern that gives a false impression of swath-to-swath misregistration. The brightness modulation is more severe on the right than left side of the frame, and may be associated with jitter impacting dwell time rates over pixels. f) Ground control point offsets from the residual surface fit are generally good (RMSE of 2.5 pixels or 142.5 meters), although some points are off to a significant degree. An analysis of the TM P-data revealed a slow spacecraft roll condition under one hertz in this scene. As only two gcps were found by the Landsat-4 ground processing system, this systematic distortion was not adequately removed.

*This abstract presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract No. NAS7-100, sponsored by the National Aeronautics and Space Administration.

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RADIOMETRIC CALIBRATION AND GEOCODED PRECISION PROCESSING
OF LANDSAT 4 MULTISPECTRAL SCANNER PRODUCTS
BY THE CANADA CENTRE FOR REMOTE SENSING

AUTHORS: J. MURPHY, D. BENNETT, F. GUERTIN

PRESENTED BY JENNIFER MURPHY

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ABSTRACT

The method used by the Canada Centre for Remote Sensing (CCRS) for the radiometric calibration of Landsat 4 Multispectral Scanner (MSS) data is reviewed, with reference to the methodology used by the Centre for Landsat 1 2 and 3 MSS data. Inherent in this technique is the possibility for the user to convert the corrected digital values to the absolute scene radiance of the target under observation. The generation of the constants needed for this final conversion requires both the pre-launch and post-launch radiometric calibration constants as supplied by NASA. Results of some preliminary comparative studies of the radiometric properties of the Landsat 4 MSS versus earlier satellites in the Landsat series are presented. In addition, early observations on the stability of the calibration data, firstly, within one scene, secondly, within one orbit, and thirdly, over a period of several months, are presented. Quantitative estimates of residual striping in the corrected products are also presented.

The method used by CCRS, to perform precision processing of Landsat MSS data to generate geocoded or map compatible Landsat MSS products in the Universal Transverse Mercator projection, is reviewed. Landsat 4 MSS precision processed products are evaluated for geodetic accuracy, and are compared to similar products from the previous Landsat satellites to assess the orbit independent registration accuracy.

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Landsat-4 Multispectral Scanner Radiometric Intraband Performance
Eric Eliason, Hugh Kieffer & Kay Edwards
U. S. Geologic Survey, Flagstaff, Arizona 86001

A geometrically raw image of Washington D.C. was aquired from EROS Data Center. These data have been radiometrically corrected by GSFC; radiometrically raw data are not available. The data aquired show little of the detector striping common in earlier Multispectral Scanner images.

The radiometrically corrected data have uniform means and standard deviations for the detectors in each band; however, the data for different detectors utilize a different pattern of DN levels, (typically 1 DN level out of 3 is not used), resulting in ubiquitous striping of 1 DN amplitude.

All bands have pronounced coherent noise obvious in contrast enhanced images, and evident in natural color composites. One-dimensional Fourier transforms of a flat field show a sharp peak with a period of 3.5 samples. There is evidence of weaker period noise at other frequencies. We have attempted to remove the coherent noise by both transform techniques and by a specially designed sequence of "box" filters.

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LANDSAT-4 SCENE-TO-SCENE
REGISTRATION ACCURACY ASSESSMENT

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By: James E. Anderson

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Code HA20, Bldg 1100
NSTL Station, MS 39529

ABSTRACT

This report documents initial results obtained from the registration of Landsat-4 MSS data to Landsat-2 MSS data. A comparison is made with results obtained from a Landsat-2 MSS-to-Landsat-2 MSS scene-to-scene registration (using the same Landsat-2 MSS data as the "base" data set in both procedures). RMS errors calculated on the control points used in the establishment of scene-to-scene mapping equations are compared to errors computed from independently chosen verification points. Models developed to estimate actual scene-to-scene registration accuracy based on the use of electrostatic plots are also presented. This project will include analyses of TM data at a later date, and both SCRUNGE and TIPS era products will be evaluated.

GEOMETRIC ACCURACY OF LANDSAT-4 IMAGE DATA

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Landsat-4 MSS digital data received from the EROS Data Center (EDC) in CCT-P formats are being rectified with the aid of a modified version of the Digital Image Rectification System (DIRS) originally developed at the NASA Goddard Spaceflight Center. The rectification procedure involves the digitization of ground control points (GCP's) from U.S. Geological Survey 1:24,000 scale topographic maps and the determination of image locations with the aid of an interactive image processing system. Once the coordinates of the GCP's are determined in both the map (UTM) and image (pixel and line) coordinate systems, these data are transferred to an IBM 370/158 mainframe computer on which the DIRS software is resident. Corrections based on a least-squares fit of polynomials of the 2nd to the 5th degree are developed and applied to the image coordinates. Accuracy checks are performed by two methods: 1) point pair distance checks involving the comparison of distances computed from the map and image coordinates; and 2) vector plots of the errors of withheld GCP's to which the least squares polynomial equations have been applied.

Results of analyses of an MSS scene of a rugged area in North Georgia have provided the following results. Distances between point pairs of GCP's computed from the (raw) CCT-P data provided by EDC produced errors of approximately 120-130 m. This indicates a relative positional error of about 50-60 m at well-defined points. After rectifying the full scene using 42 GCP's and 5th degree polynomials, a root-mean square error (RMSE) of +40 m in planimetric position was obtained. Subscene areas of single 1:24,000 scale quadrangles which have been rectified produce errors of about 30 m between point pairs.

The procedures for locating the GCP's with the interactive image processing system are being revised to allow sub-pixel determination of image coordinates. This refinement should yield higher accuracies. Work to-date indicates that the largest error source is the difficulty in locating the GCP's in the MSS scenes, and not defects in image geometry.

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GEODETIC ACCURACY OF LANDSAT-4 MULTISPECTRAL SCANNER AND THEMATIC MAPPER DATA

Principal Investigator: June M. Thormodsgard

EROS Data Center, U.S. Geological Survey

The EROS Data Center, as the primary facility for generation and dissemination of Landsat data products, is evaluating the geodetic accuracy of data from both the Multispectral Scanner (MSS) and Thematic Mapper (TM) processing systems.

The standard Landsat-4 MSS and TM digital tapes contain information which relates the map projection coordinate system to the image coordinate system. Therefore, by converting the latitude and longitude of a given location to the map projection coordinates, the image coordinate location can be calculated. Verification of the image's geodetic accuracy can then be accomplished by comparing the calculated image coordinates with the visually determined image location.

Landsat-4 digital images produced by NASA are either system-corrected or precision-corrected (ground control points applied). This method of geodetic verification has been applied to images of both precision-corrected and system-corrected MSS and TM data.

MSS GEOMETRIC ACCURACY ASSESSMENT

M. Imhoff
Goddard Space Flight Center

MSS GEOMETRIC PERFORMANCE:
LINE-TO-LINE DISPLACEMENT ANALYSIS

L. Fusco
Earthnet Program Office
Frascati, Italy

Impact of Landsat MSS Sensor Differences
On Change Detection Analysis

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INTRODUCTION

This work examines MSS sensor radiometric and geometric differences for their impact upon change detection. Comparative response of various MSS sensors becomes a consideration in change detection analysis. Differences in overall sensor response, due to both factors within the sensor system, and external factors such as atmospheric effects, must be dealt with before change detection techniques using image differencing can be successfully implemented.

To date three MSS scenes have been acquired and compared for the San Francisco area: 1) October 12, 1982 Landsat 4, 2) October 8, 1982 Landsat 3, and 3) October 4, 1981 Landsat 2 data. These data comprise a common set that has been intercompared. Three additional comparison sets have been ordered and will soon be examined: 1) Landsat 2 and 4 data of Artesia, New Mexico, both acquired on October 9, 1982, 2) Landsat 3 and 4 data of Rhode Island, both acquired on December 22, 1982, and 3) Landsat 3 and 4 data of New Hampshire, both acquired on December 22, 1982. All the data are being acquired in the EDIPS A-Tape (radiometric corrections only) format. While verbal communication with Goddard and EROS staff had given the impression that data for the same area would not be acquired concurrently from Landsat satellites, a search of the EROS Landsat data base showed that of the approximately one dozen possible instances of concurrent coverage over the United States between September and December, two instances existed where concurrent coverage was aquired. The imagery ordered were those scenes having the least cloud cover for the two orbit paths for which concurrent coverage existed. The most useful results of this investigation are expected from examination of the concurrently acquired image pairs, rather than from examination of the San Francisco data.

ANALYSIS TO DATE

The method of MSS comparison being used here is to coregister the data to a base, followed by between image scattergram generation and evaluation, and image differencing. In this case the Landsat 2 and 3 data have been registered to the Landsat 4 data. The area coregistered was limited to a small portion of the scene

near the city of Santa Cruz because this was the only area cloud and haze free on all the images. Visual examination of each image, as well as of the between image scattergrams, are intended to provide information of the radiometric characteristics of each sensor. The image differencing, after normalizing for radiometric differences, provides a visual depiction of geometric distortions.

Comparison of the San Francisco data sets show that Landsat 4 appears to have no problems that would preclude comparison to other MSS data for change detection, though there are comparison considerations that are common to comparison of any MSS data that must be considered. The Landsat 4 data was noted to have diagonal banding in bands 1, 2, and 3. This type of banding, or "woodgrain" effect has been noted to occasionally occur with the other MSS sensors. A subjective conclusion was that in this instance the magnitude of the effect was not great enough to pose a significant problem, though this requires and will receive further evaluation when additional image pairs are examined. Empty bins, as a result of the signal decompression process, were noted in Band 4, though NOAA now reports this has now been corrected. Malila and Rice have previously reported both the diagonal banding and the empty bin effects at the LIDQA meeting held in January 1983 at GSFC. Band 2 of the Landsat 3 data was misregistered with respect to the other bands in the bottom portion of the scene. We believe this to be a ground processing rather than a sensor problem, and have noted this effect once before in Landsat 3 EDIPS processed data set (described then as a "dogleg"; both a stretch and a leftward shift increasing towards the bottom of the image). Detector banding (horizontal) was also noted in band 1. The Landsat 2 data evidenced banding in bands 1, 2, and 3. The banding effects, both horizontal and diagonal, can be removed from all data sets using commonly available detector normalization and/or frequency filtering algorithms, and need not adversely impact use of the data for change detection. The banding did appear more severe in the Landsat 2 and 3 data, with interdetector banding appearing to be completely corrected for interdetector histogram equalization processing applied by Goddard to the Landsat 4 MSS data. We feel further conclusions of the radiometric and geometric properties of each sensor based upon scattergram and image differencing can not be made until the additional scene pairs are received and compared.

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COMPARISON OF LAND COVER INFORMATION FROM
LANDSAT MSS AND AIRBORNE TMS FOR HYDROLOGICAL
APPLICATIONS

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ABSTRACT

In a cooperative program with the US Army Corps of Engineers, NASA is evaluating the capabilities of Landsat-4 Thematic Mapper (TM) data for environmental and hydrologic applications. Several sites already under study by the Corps were selected for this program. This paper will report results for one of these sites, the Clinton River Basin in Michigan.

Land cover information for the Clinton River Basin derived from Landsat Multispectral Scanner (MSS) data was compared with that from airborne Thematic Mapper Simulator (TMS) to investigate the probable capabilities of the Thematic Mapper (TM) launched aboard Landsat-4 in July 1982. This paper reports the findings for two 7.5 minute topographic maps. Significant improvements in land cover classification accuracy were obtained using TMS data as compared with MSS data. Overall mapping accuracy increased from 44 to 58 percent with an improvement from 62 to 82 percent in the residential category. A combination of four bands with one band in each major region of the spectrum (visible, near IR, middle IR and thermal IR) provided nearly as good a discrimination of land cover as all seven bands. Based on the improved land cover classification accuracy of TMS, TM data has the potential to provide more useful and effective input to US Army Corps of Engineers flood forecasting and flood damage prediction/assessment models.

LANDSAT-4 MSS RADIOMETRIC CORRECTION:
METHODS AND RESULTS

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ABSTRACT

Radiometric correction for the Landsat-4 MSS system consists of two parts. The first is the prelaunch calibration of the internal lamps. The sensors are exposed to the known radiances of the integrating sphere, which allows for the calibration of the lamps. The results of this process are the regression coefficients (C_i 's & D_i 's). These coefficients are used in the second part - the on-line correction of the data. In this step the detector voltage samples are converted into values representing the input radiance. The step consists of estimating Gains and Biases of the detector transfer curves, modifying them using scene content information, and generating the Radiometric Look Up Tables (RLUTs). These tables are then applied to the raw data (voltage samples) to yield the input radiance estimates (archival tape data).

This presentation will review the on-line correction process, and the fine tuning of the parameters that are necessary to accommodate for sensor drifts. It will also contain a chronological summary of the parameter updates that were made during the first six months of operation. Finally, it will examine the Radiometric Quality Indicators (RQI) that were developed to evaluate the radiometric correction process, and present performance results.

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LS-4 MSS GEOMETRIC CORRECTION:
METHODS AND RESULTS

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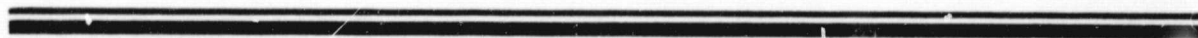
ABSTRACT

LS-4 MSS Geometric Correction data are generated in a two step process. The first step utilizes models of the spacecraft-scanner-spinning earth system, with smoothed ephemeris and attitude data as input, to deduce systematic correction data. The systematic correction data therefore suffer from random system pointing and spacecraft location errors. If control points are available for the subject scene, the second step - automatic correlation of control point chips to control point neighborhoods - is performed to develop input to the MSS control point location error filter. The output of the filter is the state error vector, which is used to upgrade the systematic correction data to geodetic correction data.

An important offline subsystem of the LS-4 MSS Image Generation Facility is the Control Point Library Build (CPLB) subsystem. This hardware and software complex is used to generate control point chips and support data for use in online upgrade of correction data. Control point chips that represent ground truth are called geodetic or supplemental, depending on whether they are used to establish the model surface (with the same filter that is used online) or are selected from the fully corrected imagery. Relative control points are designated in systematically corrected imagery, have no ground truth and can therefore be used only for temporal registration.

During the last six weeks before the NASA/NOAA turnover of the system, an intensive effort was carried out to fine-tune both software and data base and to evaluate the geometric performance of the calibrated system. The online processing and the CPLB process provided all the tools necessary for the verification, calibration (including initial scan profile correction) and evaluation of LS-4 geometric processing. In this presentation, we will describe the methods and results of that effort, including changes to system and data base that will affect the LS-4/EDC products.

TM Radiometry and Geometry Session



Spectral Characterization of the Landsat-4 Thematic Mapper Sensors

by

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A summary and analysis of data collected by Hughes/SBRC* on the spectral characteristics of the Landsat-4 and Landsat-4 backup Thematic Mapper instruments, the protoflight (PF) and flight (F) models, respectively, is presented. Tests were conducted on the instruments and their components to determine compliance with two sets of spectral specifications: Band-by-band spectral coverage and channel-by-channel within-band spectral matching.

Spectral coverage specifications were placed on: (1) band edges--points at 50% of peak response, (2) band edge slopes--steepness of rise and fall-off of response, (3) spectral flatness--evenness of response between edges, and (4) spurious response--ratio of out-of-band response to in-band response. Compliance with the spectral coverage specifications was determined by analysis of spectral measurements on the individual components contributing to the spectral response: filters, detectors, and optical surfaces. The protoflight and flight model TM's used filter pieces cut from the same substrate and detectors from the same batch (except band 6); any differences between the calculated relative spectral responses (RSR) resulted from optics differences (except band 6).

The RSR's for the reflective bands were similar between PF and F except for the within-band flatnesses. Both the PF and F reflective band calculated spectral responses were within specifications except for bands 2, 3 and 7 spectral flatnesses and the band 5 upper band edge: specification, 1750 \pm 20nm; calculated as 1784 nm. In band 6, the PF and F showed fundamentally different spectral responses. The PF upper-band edge was detector determined at 11.66 μ m (varying with temperature); the F upper band edge was filtered determined at 12.43 μ m. The PF band 6 was spectrally out-of-specification, but its detectors' sensitivities were better than the F, which was basically within specifications spectrally.

Out-of-band responses for all bands were within specification. Bands 1 and 3 had some sensitivity to near-IR radiation. Band 1 filters had transmission peaks at 800 and 885 nm of 0.5% and 0.7% respectively. When measured on the flight model, an approximately 1 count contribution to band 1 resulted when the radiance between 776 and 905 nm resulted in 100 counts in band 4. Band 3 filters had peaks in out-of-band transmission at 945 and 1000 nm, of 2.8% and 1.2% respectively. The impact of this on the band 3 response has not been determined.

*Data and assistance in interpretation were provided by Hughes/SBRC personnel:
 Richard W. Cline--spectral coverage determination
 Jack C. Lansing--spectral matching
 Donald G. Brandshaft--out-of-band response, light-leaks

The spectral matching specification stated that "after system calibration, the peak-to-peak signal variations between channels within any of the first five bands and band seven, when all channels are viewing the same scene radiance, shall be less than 0.5 percent of the minimum saturation levels for the two test conditions whose parameters are given in . . . [a linearly varying spectral radiance and a flat spectral radiance]." Initial test plans called for using channel-by-channel relative spectral response curves to determine compliance with the spectral matching specification. As channel-by-channel relative spectral responses were not measured for the TM's, an alternative test was devised to assess the spectral mismatch between channel in a band. This test involved calibrating the individual channels on the 1.2 meter integrating sphere and then recording the mismatch in their outputs to a spectrally different source, the TM calibrator (modified by filters). The protoflight test gave out-of-specification results which appeared to be attributable to spatial non-uniformity of the calibrator source. A refined test was used for the flight model testing, using the calibrator source with and without filters for the two targets. With the exception of band 4, which showed a 1.7% mismatch, all bands were within specifications. Calculations using the relative spectral response data for the 5 MSS sensors (MSS 1, 2, 3, 4 and 4-backup) showed that the flight model TM had comparable or better spectral matching than the MSS sensors.

An examination of the along-scan line spread function for the flight model TM revealed several minor white light leaks in the primary focal plane bands (1-4)--i.e., light getting to the detectors without passing through the spectral filters. The magnitude of these light leaks is dependent on the spectral character of the illumination. For the odd channels of band 1 (magnitude of the light leaks comparable for all detectors in a half-band), which was the worst observed, with the TM calibrator 'white' light source, a light leak at 13.1 IFOV off the detector center made about a 1% contribution to the signal. The location and shape of the light leaks suggests they are associated with the slots at the sides of the individual band assemblies. It is believed the protoflight model has comparable light leaks.

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Prelaunch Absolute Radiometric Calibration of the Reflective Bands on
Landsat-4 Protoflight Thematic Mapper

J. L. Barker (NASA/GSFC), D. L. Ball and K. C. Leung (CSC)
and J. A. Walker (SBRC)

Abstract

Landsat-4 Early Results Symposium (23 Feb 83)

We present results on the absolute radiometric calibration of the Landsat-4 Thematic Mapper (TM) as determined during prelaunch tests with a 122-cm Integrating Sphere (IS). Discussions of the radiometric requirements specified for the TM reflective bands, the equipment used to calibrate the instrument and the procedures used are included. Unlike the photomultiplier tubes used on the Multispectral Scanner, the solid state detectors on the TM are linear in their response to radiance. The sample response shown in the accompanying figure is linear to 0.4 percent of full scale in the standard error of the estimate for a linear fit.

In the table below we summarize results for the dynamic range, average gain and offset and signal-to-noise ratio (SNR) for the TM reflective bands.

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Band	Dynamic Range		Gain (counts/(mWcm ⁻² sr ⁻¹ μm ⁻¹))	Offset (counts)	Signal-to-Noise Ratio	
	RMIN (mWcm ⁻² sr ⁻¹ μm ⁻¹)	RMAX			Spec (MSL) ³	Obs (MSL) ³
1	-0.152	15.842	15.78±0.54%	2.58±0.18	85	152±9%
2	-0.284	30.817	8.10±0.89%	2.44±0.16	170	281±17%
3	-0.117	23.463	10.62±0.76%	1.58±0.20	143	235±6%
4	-0.151	22.432	10.90±1.23%	1.91±0.22	240	341±9%
5	-0.037	3.242	77.24±0.53%	3.02±0.11	75	180±6%
7	-0.015	1.700	147.12±0.72%	2.41±0.20	45	175±14%

¹RMIN is the largest minimum radiance observed in the band (0 counts).

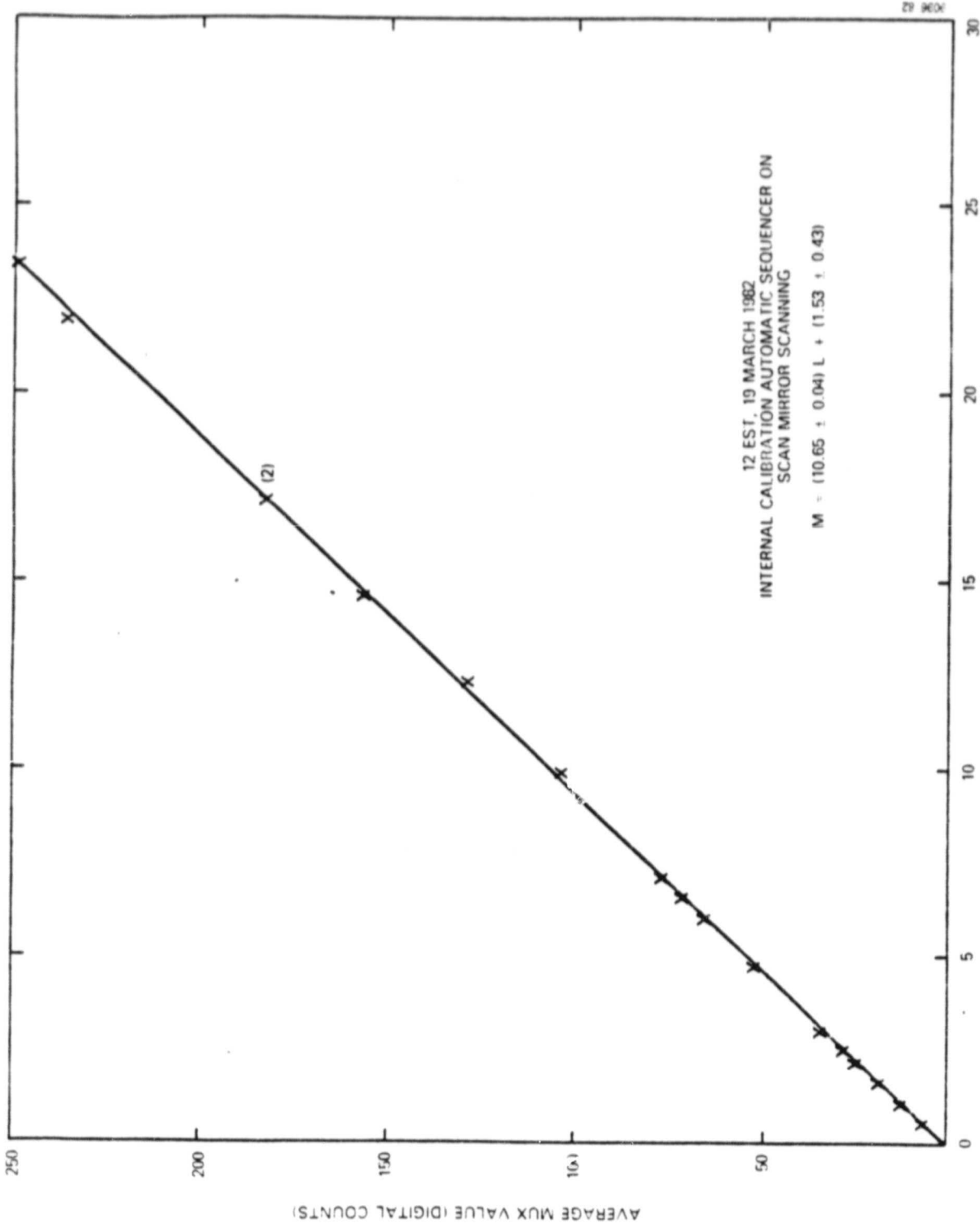
²RMAX is the smallest maximum radiance observed in the band (255 counts).

³MSL is the minimum saturation level radiance for the band.

Three detectors failed to pass the minimum SNR specified for their respective bands; band 5, channel 3 (dead), band 2 channels 2 and 4 (noisy or slow response).

Estimates of the absolute calibration accuracy for the TM show that the detectors are typically calibrated to five percent absolute error for the reflective bands; ten percent full scale accuracy was specified. Ten tests performed to transfer the detector absolute calibration to the internal calibrator show a five percent range at full scale in the transfer calibration; however band 5 in two cases showed a ten percent difference and a seven percent difference. These errors are given under the assumption of identical operating conditions for all transfer tests; known temperature sensitivities for the TM have not yet been included.

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INTEGRATING SPHERE SPECTRAL RADIANCE, L ($\text{mW cm}^{-2} \text{sr}^{-1} \mu\text{m}^{-1}$)

**ILLUSTRATIVE TM/PF RADIOMETRIC ABSOLUTE DETECTOR CALIBRATION FOR
CHANNEL 9 OF BAND 3 (624-693 nm)**

Characterization of Radiometric Calibration of LANDSAT-4
TM Reflective Bands

J. L. Barker, R. B. Abrams, D. Ball, and K. C. Leung

Knowledge of the absolute radiometric accuracy of Thematic Mapper (TM) LANDSAT-4 data is critical for arithmetic spectral transforms such as those used to determine atmospheric correction path radiance. In this paper the radiometric performance of the Landsat-4 TM is characterized. Radiometric calibration using nominal gains and offsets versus using the internal calibration system (IC) is discussed. Prelaunch and postlaunch IC, image and background data are examined. Early results indicate that IC lamp 2 has changed relative to prelaunch. For any given band, the change in counts relative to November 2, 1982, for each single-lamp IC state is the same for all three states within .5 percent. When prelaunch March 9, 1982 data is used as a reference, lamps 1 and 3 have the same change in counts within .8 percent while lamp 2 differs from lamp 1, on the average, by 2.2 percent. All but two channels have performed normally. Band 5, channel 3 and band 2, channel 4 have been replaced with data from band 5, channel 4, and band 2, channel 5 respectively. Gain changes relative to November 2, 1982, for channels within a band vary as a group within .5 percent. Change in gain of primary focal plane channels was 1 percent for bands 2 and 4 and 2 percent for bands 1 and 2 from August to October, and less than .8 percent from October through December (see Table 1). The variability in the cold focal plane of up to 7 percent in band 5 and 4.5 percent in band 7 indicates a need for IC correction. The gain in band 1/channel 1 was under valued by approximately 5 percent on all data processed prior to December 22, 1982, due to clipping of the calibration pulse in the ground-processing system.

Background noise ranges from .5 to 1.27 digital counts depending on the band (see Table 2). Noise in image data from flooding lamp (prelaunch calibration) and water scenes is slightly higher, .5 to 1.7 counts (see Table 3). Discrete fourier transforms of data from all 96 reflective channels (first scan) in a scene from Memphis, Tennessee, August 22, 1982, show coherent noise at 32.7 kHz in band 1/channels 2, 3, 4, 5, 6, 8, 14, and 16; band 3/channels 4 and 8, and band 4/channels 4 and 5 with peak-to-peak amplitudes ranging from .7 to 1.4.

Possible improvements in calibration processing are presented. Forward and reverse average differences for background flooding lamp and water scenes are erratic up to one digital count. This might indicate a need for recalibration of forward and reverse prelaunch absolute radiometry. Precision is improved typically by 50 percent by increasing the pulse integration width from 31 to 31-41 minor frames depending on the band. Dropping 4 minor frames preceding a transition improves precision for cold focal plane bands by 35 percent.

Table 1
 Postlaunch Change in Gain in Parts Per Thousand Relative
 to March 9, 1982 Prelaunch Values

Odd Detectors						
	1	2	3	4	5 ²	7 ³
3/9/82 ¹	15.49	7.97	11.09	11.35	74.88	141.82
7/20/82	.6	5	0	19	--	--
8/22/82	-33	-23	-29	-8	1	8
8/25/82	-31	-21	-26	-8	8	2
9/10/82	-40	-31	-36	-15	87	-1
9/24/82	-47	-32	-47	-18	48	4
10/24/82	-50	-33	-49	-24	23	28
11/2/82	-50	-36	-50	-25	55	18
11/24/82	-51	-33	-48	-26	26	-7
12/8/82	-50	-34	-50	-28	-1	0
12/20/82	-55	-35	-55	-31	31	16

Even Detectors

	10.92	11.56	74.33	146.86
3/9/82 ¹	8.17 ⁴	11	6	4
7/20/82	-17	-9	14	-2
8/22/82	-30	-27	69	-18
8/25/82	-35	-26	56	-5
9/10/82	-42	-35	29	18
9/24/82	-51	-46	61	10
10/24/82	-54	-48	32	-15
11/2/82	-53	-49	3	-10
11/24/82	-54	-47	36	5
12/8/82	-53	-49		
12/20/82	-59	-53		

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¹prelaunch gains in counts/mW cm⁻² r⁻¹ μm

²Excludes channel 3

³Excludes channel 7 which is excessively noisy

⁴Excludes channel 4

Table 2

Noise in Background Data

	1	2	3	4	5	7
Odd Ch.	1.24	.450	.539	.333	.948	1.25
Even Ch.	1.27	.557	.669	.405	.939	1.13
Odd Ch.	1.12	.393	.518	.496	.872	1.03
Even Ch.	1.33	.523	.657	.575	.818	1.01
Flooding Lamp ¹						
Flooding Lamp						
Water ²						
Water ²						

Table 3

Noise in Image Data

	1	2	3	4	5	7
Odd Ch.	1.45	.606	.859	.483	1.19	1.67
Even Ch.	1.50	.684	.952	.532	1.19	1.40
Odd Ch.	1.51	.589	.842	.462	.921	1.13
Even Ch.	1.71	.655	.942	.461	.840	1.06
Flooding Lamp ¹						
Flooding Lamp						
Water ²						
Water ²						

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¹Flooding Lamp, March 1982.

²Boston Water Scene, September 10, 1982

EVALUATION OF THE RADIOMETRIC INTEGRITY
OF LANDSAT-4 BAND 6 DATA

J. Schott
Rochester School of Technology

THERMAL BAND CHARACTERIZATION OF LANDSAT-4
THEMATIC MAPPERJack C. Lansing/Santa Barbara Research Center
and
John L. Barker/Goddard Space Flight Center

ABSTRACT

Observations With Time

A quick-look monitor in the spacecraft control center was used to measure the TM Band 6 shutter background and the 34.7°C internal block body signal on over 50 dates. Variability of the shutter background temperature varied from 7 to 11°C. For ten specific images the digital counts of the calibration data were measured. The average pulse value of the block body peak, CB, decreased from 174 to 149 counts while the shutter background counts, CS, varied as a function of shutter temperature, TS, from 77 to 85 ($CS = 3.05 TS(^{\circ}C) + 53.27$). The net calibration peak, CB-CS, decreased from 95 to 64 between August 22nd and December 20th. Relative internal gains between the four channels were calculated and compared to pre-launch values; they showed changes over 9 months of up to 5%. 512 x 512 subsections of the original ten daytime scenes showed target counts, TS, that ranged from 135 down to 62, with a range of standard deviations from as low as ± 0.5 for a pure water scene off Boston to as high as ± 4.1 for an August 22nd scene over Arkansas.

Image Destriping

Frequency histograms of numbers of pixels vs. digital counts from a night scene of the Buffalo area of 22 August 1982 were used to determine channel gain relative to the mean and to discern a systematic along-scan pattern in a difference between forward and reverse scan counts of up to 0.5. These results were used to produce a corrected digital image, which, in turn, exposed minor adjustments necessary to further correct the channel gains and offsets. Individual gains and offsets were calculated for the four channels. The final values may be used to produce a destriped image of Band 6.

At-Satellite Radiance

An illustrative thermal band radiometric calibration graph was produced to relate known spectral radiance to digital counts. Calibration lines were calculated for initial turn on of the cold focal plane in August through the 60% gain loss in Band 6 over 5 months until outgassing of the cooler in early January, when the gain was restored to its original value.

The specified range of 260K to 320K corresponds to a range of approximately 50 to 195 counts, which is centered in the 0 to 255 counts available.

Noise Equivalent Temperature

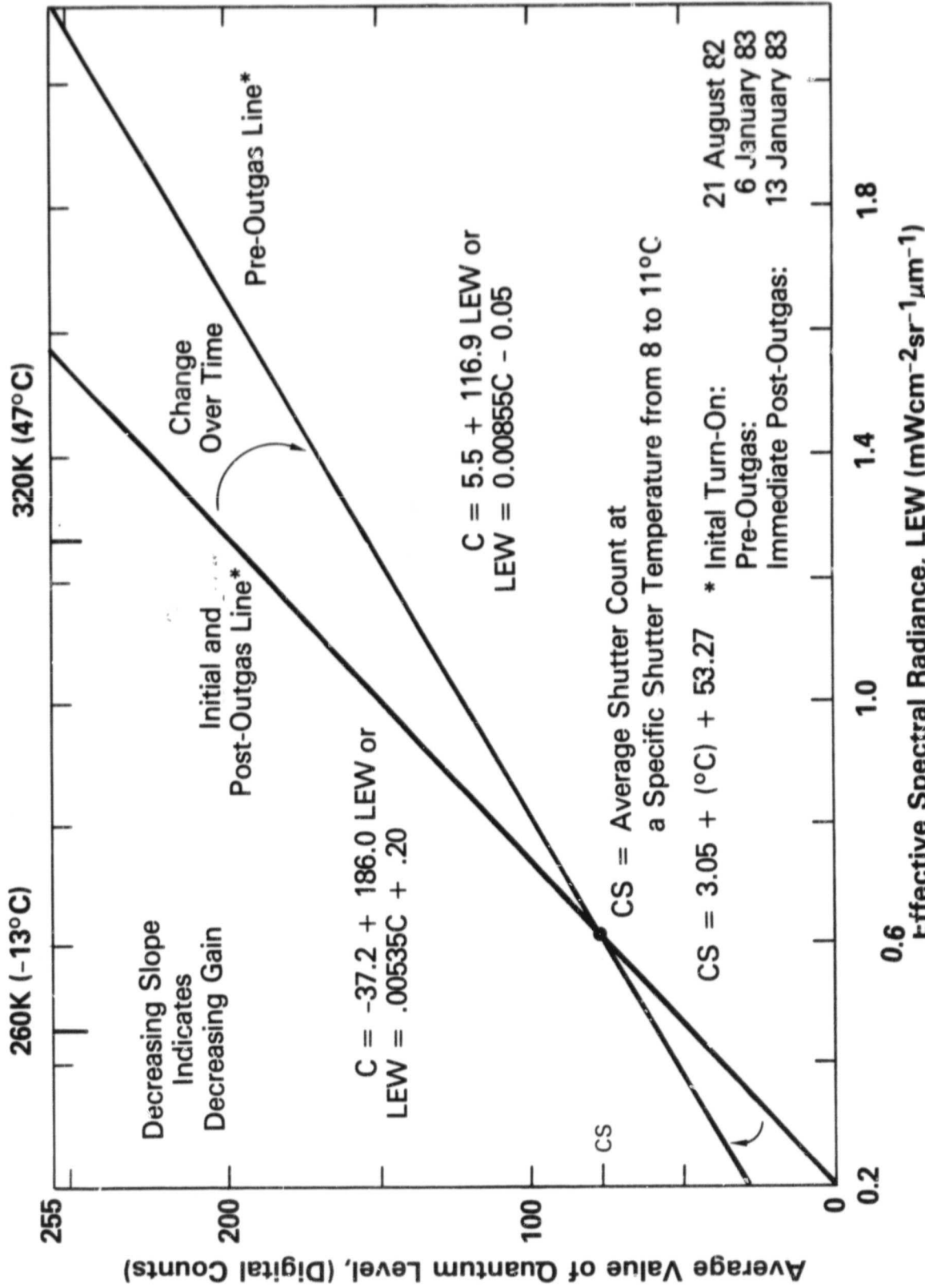
An area of 600 120m pixels in Lake Erie was used to calculate noise equivalent temperature difference, which was 0.10 K at 300 K, neglecting the forward to reverse scan difference.

Target Temperature After Atmospheric Correction

The calibration data and the Buffalo scene with the corrections mentioned and with preliminary estimates of the atmospheric transmission and radiance were used to make a temperature estimate for an area of Lake Erie, of 18.5 to 19.9°C. Local records of the temperature showed 21°C.

Landsat-4 TM Thermal Band 6 Radiometry Channel 4

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A PRELIMINARY ASSESSMENT OF LANDSAT-4
TM DATA PROCESSING BY NASA

D. Goodenough
Canada Centre for Remote Sensing

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PRELIMINARY EVALUATION OF THE
RADIOMETRIC CALIBRATION OF LANDSAT 4 THEMATIC MAPPER DATA
BY THE CANADA CENTRE FOR REMOTE SENSING

AUTHORS: J. MURPHY W. PARK, A. FITZGERALD

PRESENTED BY: JENNIFER MURPHY

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ABSTRACT

The technique being evaluated by the Canada Centre for Remote Sensing (CCRS) for the radiometric correction of Landsat 4 Thematic Mapper (TM) data is discussed. Preliminary results on the removal of radiometric striping, caused by inequalities in the calibration of individual detectors within each band, are presented. The destriping method was originally developed by CCRS for processing Landsat Multispectral Scanner (MSS) data and uses the scene histograms to equalize the responses of the individual detectors within each band. For the TM case, it may be applied to the forward and reverse scans either separately or in combination. CCRS is also evaluating the radiometric calibration of test scenes using the absolute pre-launch calibration tables supplied by NASA. Quantitative estimates of residual striping in the radiometrically corrected TM data are provided.

EVALUATION OF THE RADIOMETRIC QUALITY
OF THE TM DATA USING CLUSTERING AND
MULTISPECTRAL DISTANCE MEASURES

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NASA CONTRACT NAS5-26859

FEBRUARY 22, 1983

Evaluation of the Radiometric Quality
of the TM Data Using Clustering and
Multispectral Distance Measures

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Introduction

The primary objective of this investigation was to evaluate the radiometric quality of the Thematic Mapper (TM) data for classification and identification of earth surface features. In addition, a comparison of the information content between TM and MSS data sets was carried out. Finally, the TM data were utilized to map the thermal effluent discharge into a river ecosystem from a nuclear power plant, an application only possible until now through the acquisition of thermal infrared scanner data from aircraft altitudes.

Procedures

Radiometrically corrected (A-tape) and geometrically corrected (P-tape) TM data from three different geographic locations were utilized in this investigation. A description of these data sets is given in Table 1.

Table 1. TM Data Sets

<u>Scene ID</u>	<u>Date</u>	<u>Location</u>
40037-16031	8/22/82	Arkansas
40049-16264	9/03/82	Iowa
40101-16025	10/25/82	Illinois

The initial examination of the TM data consisted of an inspection of the histograms for each band to determine the dynamic range of the data, the shape of the distributions, and to verify whether empty bins were introduced by the radiometric correction process.

In order to assess the effect of the geometric correction process (resampling effects) on the radiometry of the new resampled pixels, the means and variances for homogeneous and heterogeneous areas on the ground scene were calculated using both the A and P tape data sets. Furthermore, to determine the influence of resampling on the structure of the data, clustering of the A and P tape data sets of the same areas on the ground were performed. The resulting cluster classes from the original and resampled data sets were then compared using a transformed divergence measure. The results of this multispectral distance measure were also used as a feature selection criterion to obtain the optimum combinations of spectral bands for dimensionality reduction purposes.

The intrinsic dimensionality of the TM data was also studied by means of a principal components analysis. A Karhunen-Loeve transformation was applied to both the MSS A and P and to the TM P data tapes of the Chicago O'Hare airport test site. Statistics used to generate the

transformation matrices for each of these data sets were calculated from samples of the data taken from every 5th line and 5th column in the scene. The resulting transformed components were scaled to be proportional to the square root of their respective eigenvalues, with the first component set equal to a range of 0-255.

In multidimensional space, such transformations will not alter the Euclidean distance between data points. However, if the resulting components are given some relative magnitude or length other than values which are proportional to the square roots of their respective eigenvalues, then the Euclidean distance between data points will be altered. Clustering algorithms are often highly sensitive to such movements or changes in position of data points with respect to each other. Therefore, it is important for clustering and classification purposes that the resulting transformed components of such orthogonal transformations be (each) correctly scaled.

To assess the utility of high (spatial) resolution thermal infrared data for thermal pollution studies, TM data over an area south of Chicago, Illinois, were classified using a layered classifier to first discriminate water from everything else with the aid of the reflective infrared bands, and then to perform a level slicing of the thermal band for only the resulting water pixels, thus producing a temperature map of the thermal plume. The linearity of the calibration of the thermal band was also studied for various temperature ranges.

Results

An evaluation of the histograms from the A and P tape TM data sets shows that the data in the three reflective infrared bands have a larger dynamic range than the data in the visible and thermal bands. It was also observed that the shape of the distributions in the three visible bands, especially in the blue band, deviated considerably from a normal curve, approximating a distribution highly skewed towards the higher response values. This phenomenon was not observed in the Landsat 4 MSS bands corresponding to the visible portion of the spectrum. This histogram also showed that the A tape data from both the MSS and TM systems contained a number of empty bins. As it would be expected, empty bins were not found in either the MSS or TM P tapes, since the gray level interpolation applied to the geometrically corrected data would eliminate such effects.

From past experience at LARS, there was concern about the magnitude of the radiometric changes that would occur on resampled (gray level interpolated) pixels. To determine quantitatively the effect of the interpolation, individual pixels and sets of pixels representing the same features on the ground were examined. The results indicate that the interpolation did not affect the means and variances of the spectral response of ground cover types. In fact, the smoothing effect that the cubic convolution was expected to have on the radiometry of the data was not evident in these results as illustrated in Table 2.

In order to further evaluate the effects of the cubic convolution on the structure of the geometrically corrected TM data, the same areas on the

Table 2. Means and Standard Deviations for Homogeneous and Heterogeneous Areas in the TM A and P Data Sets.

		<u>Bright Homogeneous Target</u>						
		1	2	3	4	5	6	7
TM A-tape	Spectral Band							
	Mean	72.64	33.75	37.93	64.59	119.95	57.23	136.77
	Standard Deviation	2.27	1.45	2.85	2.49	6.37	3.28	3.74
TM P-tape	Spectral Band	1	2	3	4	5	6	7
	Mean	72.88	33.95	38.30	64.34	120.80		137.75
	Standard Deviation	2.18	1.42	2.83	2.52	6.54		3.46
		<u>Heterogeneous Area</u>						
TM A-tape	Spectral Band	1	2	3	4	5	6	7
	Mean	68.31	29.56	26.94	89.58	75.75	27.94	127.78
	Standard Deviation	15.31	8.91	13.12	21.30	16.35	12.62	4.53
TM P-tape	Spectral Band	1	2	3	4	5	6	7
	Mean	68.28	29.56	26.90	89.77	75.92		127.83
	Standard Deviation	15.36	8.94	13.10	21.80	16.42		4.65

ground were selected in the A and P TM images and both data sets were clustered. The statistical parameters (means and covariance matrices) that describe the resulting cluster classes from both the A and P TM data sets were found to be virtually identical; but to determine more quantitatively the similarity between corresponding class pairs, a Transformed Divergence (Spectral Separability) algorithm was used. Table 3 illustrates the results of this separability analysis. The Transformed Divergence values range from zero (identical spectral classes) to 2000 (completely different spectral classes).

The same spectral separability measure was also used as a feature selection function in order to determine the best combination (subset) of bands that would provide the most accurate multispectral classification results. Also, the MSS data for the same areas on the scene were clustered and the results were compared with the resulting cluster classes from the TM data in an attempt to learn more about the information content from the two multispectral scanner systems.

Finally, a temperature map of a nuclear power plant cooling pond and the thermal plume discharged into the Illinois river was produced using a Layered Classifier and calibrating the relative digital counts in the thermal IR band into degrees Celcius. It will also be shown that the relationship between the thermal IR radiation and the corresponding radiant temperature is not a linear function for the 10.4-12.5 μm band and for the range of temperatures from 260K to 320K.

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Table 3. Separability for the Merged A and P Tape Cluster Classes.

<u>Classes Considered</u>		<u>Class Pairs</u>	<u>D_T</u> (Combination of all bands)	
A Tape	Symbol			
		Class		
	A	TM- 1/16	AQ	59.
	B	TM- 2/16	BR	53.
	C	TM- 3/16	CS	164.
	D	TM- 4/16	DT	85.
	E	TM- 5/16	EV	35.
	F	TM- 6/16	FU	150.
	G	TM- 7/16	GW	60.
	H	TM- 8/16	HX	99.
	I	TM- 9/16	IY	108.
	J	TM-10/16	JZ	262.
	K	TM-11/16	K\$	63.
	L	TM-12/16	L+	62.
	M	TM-13/16	M=	22.
	N	TM-14/16	N/	37.
	O	TM-15/16	OA	168.
P	TM-16/16	PB	75.	

P Tape	Symbol			
		Class		
	Q	TM- 1/16		
	R	TM- 2/16		
	S	TM- 3/16		
	T	TM- 4/16		
	U	TM- 5/16		
	V	TM- 6/16		
	W	TM- 7/16		
	X	TM- 8/16		
	Y	TM- 9/16		
	Z	TM-10/16		
	\$	TM-11/16		
	+	TM-12/16		
	=	TM-13/16		
	/	TM-14/16		
	A	TM-15/16		
B	TM-16/16			

ANALYSIS AND EVALUATION OF THE LANDSAT-4 MSS AND TM SENSORS AND
GROUND DATA PROCESSING SYSTEMS-EARLY RESULTS

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ABSTRACT

This investigation deals with the analysis of the new Landsat-4 sensor data and ground data processing. The analysis involves the assessment of the data radiometric calibration accuracy, geometric correction accuracy, data resolution and data quality. In addition, image research dealing with advanced information extraction techniques are planned. Both Landsat-4 Multispectral Scanner and Thematic Mapper data have been acquired and processed. The data processed to date include both raw and processed data from three geographic areas of interest. Several digital image processing techniques have been applied to the data to improve data radiometry and quality.

In the area of radiometry, although the quality of the data is very good, incomplete radiometric calibration processing is evident from the data statistics and image products. Improved radiometric calibration results have been developed, and consistently demonstrate less than one quantum level of relative radiometric error for all detectors signals. This processing has substantially reduced the striping evident in the original data. To assess the information content and quality of the data, entropy analysis and principal component processing of the data have been performed. Also intensity, hue, and saturation data presentation experiments have been conducted. The data exhibit excellent information potential, although data entropy studies show that the full range of the sensor performance has not yet been achieved. In the area of data quality, some problems are evident, due to failed detector compensation. Improved techniques have been developed to compensate for these failures, and the results are presented. These show that better techniques than the line repeat procedure should be used. Some sub-pixel band-to-band misregistration is evident, and registration statistics are presented.

Resolution studies using subimage areas of well defined features were performed using precise ground truth data. In addition, data edge analyses studies have been conducted. These results are presented in image and statistical form, and have shown that the TM data exhibits very good data quality and reliability, and can be used for accurate mensuration studies at a suitable scale.

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**In-progress Absolute Radiometric
Inflight Calibration of the Landsat-4 Sensors**

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Abstract

We describe our approach to providing periodic inflight absolute radiometric calibrations of the Landsat-4 sensors by reference to selected, instrumented ground areas, and we present the results of some early ground measurements and computer simulations.

In pursuing such a calibration approach, the first step is the selection of a suitable ground reference site. The requirements are that the site should contain areas that are (1) large, of the order of several square kilometers to minimize atmospherically induced adjacency effects; (2) flat, diffuse and of uniform reflectance, to minimize the difficulty of accurately mapping surface spectral radiance variations; (3) of different reflectances, to provide several points on the calibration curve; (4) in a region where the sky is often clear and the aerosol content of the atmosphere is low; (5) within convenient travelling distance for the measurement team. The White Sands Missile Range in New Mexico is such a site, containing an extensive white "alkali flats" area of gypsum and other areas of dark soil and water.

The second step is the accurate measurement of the spectral reflectance of the selected ground areas and the determination of certain atmospheric characteristics (the Rayleigh, Mie, O_3 spectral extinction coefficients, and H_2O vapor concentration) during the morning of the sensor overpass. This involves

the accurate absolute calibration of the instruments used and the aerial mapping of spectral variations over the selected ground areas. In preliminary measurements we are using a manually operated solar radiometer, two transportable Barnes Model 1200 MMK radiometers, an Exotech Model 100A, and an RMR-10 Radiometer.

The third step is the reduction of the measured data and the use of these data in an appropriate atmospheric radiative transfer program to predict the radiance levels at the entrance pupil of the sensors across each of their spectral bands.

The last step is the comparison of the radiance level data with the digital counts for the images of the selected ground areas. This comparison will be made first for the raw data in CCT-B form, then for data to which the internal calibration and the histogram equalization procedure has been applied (CCT-A) and finally to the radiometrically corrected and cubic convolution resampled data in CCT-P form.

At this writing, attempts have been made to collect data at White Sands on 18 December 1982, 3 and 19 January 1983, and 4 February 1983. Because of cloud cover, only data for 3 January 1983 were collected. On that date the ground had a 80 mm snow cover which provided a very uniform high reflectance surface in bands 1 through 4 and a low uniform reflectance in bands 5 and 7. These data have been reduced together with field and laboratory measurements of gypsum and are presented at this symposium together with Langley plot data.

These preliminary measurements are being made partly as an aid to defining the characteristics of field equipment to be constructed and calibrated for later use on this program. Computer simulations are also being

made to predict the periods of the year for which the various TM bands will be unsaturated by the radiance of the main gypsum reference area at White Sands and to determine the accuracy to which the various ground-based measurements have to be made. Some of these results are presented at this symposium.

Acknowledgements

We wish to acknowledge the financial support provided by contract NAS5-27382, J. L. Barker, NASA/Goddard Space Flight Center, Project Scientist. In addition we wish to acknowledge the following organizations who are supporting or who plan to support our measurement program at White Sands: Atmospheric Sciences Laboratory, Canadian Center for Remote Sensing, NASA/Ames Research Center, NASA/Johnson Space Center, Purdue University, and U.S. Department of Agriculture.

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Landsat-4 Thematic Mapper Calibration and Atmospheric Correction

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ABSTRACT

The Landsat-4 Thematic Mapper, with its wide spectral coverage and digitization to 8 bits per word, is a large step forward in the direction of quantitative radiometry from the Multi Spectral Scanner (MSS) flown on all four Landsats launched to date. In order to utilize the quantitative accuracy built into the Thematic Mapper effectively, more attention must be paid to calibration before launch, changes of calibration with time in orbit, and atmospheric interference with the measurements, especially in the 450 to 520 nanometer band. All of these factors are important if we are to realize the goal of such an instrument; namely, determining the upwelled radiance that would be measured at the surface. Recent experience with the Coastal Zone Color Scanner (CZCS) program has led to procedures wherein Rayleigh correction factors can be generated utilizing simultaneous surface truth data that empirically give correct upwelled surface radiances, despite errors in sensor calibration, solar spectral irradiance measurements, and reported values of Rayleigh optical depth. These techniques also offer sensitive tests for change in calibration, especially at shorter wavelengths. Previously launched instruments, such as the CZCS, have shown that calibration changes first and to the largest degree at the shorter wavelengths, with lesser changes as wavelength increases. These techniques, applied to Thematic Mapper data, are utilized to calculate a Rayleigh correction factor that, together with geometric terms, will give an accurate correction for this portion of the atmospheric contribution to the signal. Long term observation of the Rayleigh corrected radiance over clear water will be a sensitive indicator of any change in calibration as the sensor ages in orbit.

SCAN-ANGLE AND DETECTOR EFFECTS IN
THEMATIC-MAPPER RADIOMETRY

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Summary

Objective

The objective of our investigation is to quantify the performance of the Thematic Mapper (TM) as manifested by the quality of its image data, in order to suggest possible improvements for data production and assess the effects of data quality on its utility for land resources applications. The major emphasis of our work thusfar has been on the radiometric characteristics of TM data.

Approach

Computer-compatible tapes of raw data (CCT-B), radiometrically corrected data (CCT-A), and geometrically corrected data (CCT-P) have been examined for two scenes, 40049-16262 (Iowa) and 40037-16031 (Arkansas), with concentration on the CCT-B and CCT-A data. Histograms, scan-line (across-track) and along-track averages, Fourier transformations, and gray maps have been produced and analyzed, for each band, each detector, and each scan direction.

Initial Findings

Our initial examination of Thematic Mapper data yielded an overall positive reaction to its quality and information content. We did, however, observe and quantify some relatively low-level artifacts relatable to the sensor and data processing stages. We also have noted and quantified scene-related scan-angle effects that could be important in analysis of full scenes and in comparing data from different portions of a scene.

Horizontal stripes and discernable banding are common artifacts in image data from sensors that scan arrays of detectors. We found evidence of striping in corrected TM data due to residual between-detector calibration differences and quantization effects like those found in MSS data. Figure 1 illustrates one pattern of differences found in Band 2 between averages of successive scan lines across a homogeneous scene. Effects

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of unequal analog-to-digital conversion bin sizes in CCT-B data and empty quantization levels in CCT-A data are largely masked by the interpolation process used to produce CCT-P data.

In addition, we detected a new type of banding caused by the combination of bidirectional scanning by the 16-detector arrays and a systematic droop of signal values during the active portion of each scan. The resulting differences between forward and reverse scans are illustrated in Figure 2, as a function of scan angle for TM Band 1. This effect produces swaths or bands of differing signal levels that are most pronounced near the frame edges and minimal at the frame center. Similar behavior was detected in Bands 2, 3, and 4, relatively little effect in Bands 5 and 7, and a substantially different behavior in the thermal band (Band 6). The markedly different full-frame averages for forward and reverse scans in the thermal band are shown in Figure 3.

The scan-related banding in the reflective bands was superimposed on substantial scene-related scan-angle effects in the data. Again for Band 1, the full-frame averages for forward and reverse scans are presented in Figure 4. The dominant scan-angle effect here is due to differential backscattering by the atmosphere, differing path lengths, and bidirectional reflectance effects on the ground. It was expected to be greater than seen before in Landsat MSS data due to the larger scan angles for all bands and the shorter wavelength of Band 1. Differences were observed between bands due to spectral phenomena.

An empirical first-order model to correct for the scan-direction banding effect was derived for the reflective bands. Refinement of the model awaits further understanding of the sensor phenomena driving the effect and other scene data for validation. We also recommend that procedures be investigated to normalize the scene-related scan-angle effects, as has been done previously for aircraft and Landsat MSS data.

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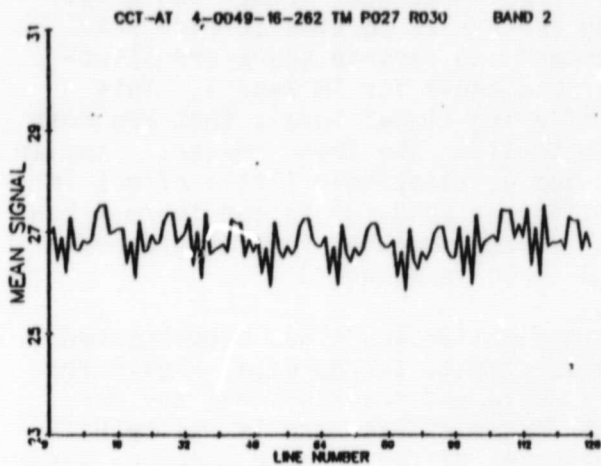


FIGURE 1. DOWN-TRACK MEAN SIGNAL, BAND 2, ILLUSTRATING DETECTOR CALIBRATION DIFFERENCES

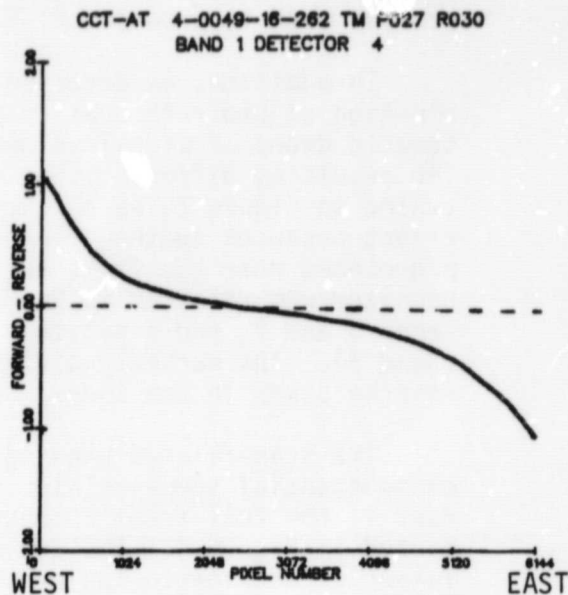


FIGURE 2. DIFFERENCE IN CROSS-TRACK MEAN SIGNAL BETWEEN FORWARD AND REVERSE SCANS, BAND 1

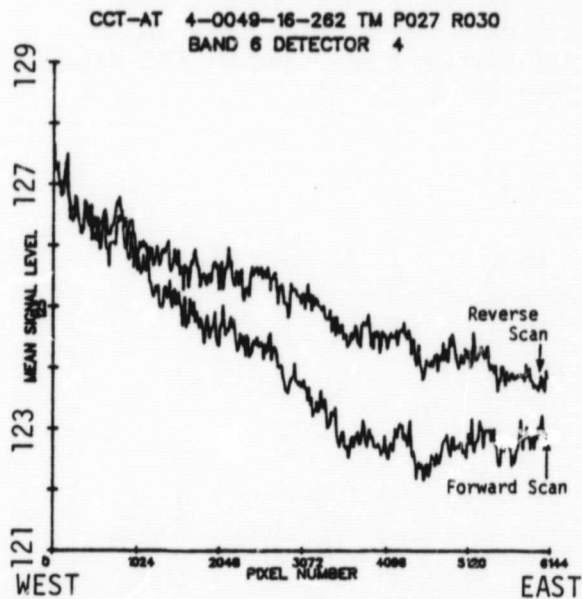


FIGURE 3. CROSS-TRACK MEAN SIGNAL, BAND 6, ILLUSTRATING SCAN DIRECTION EFFECT

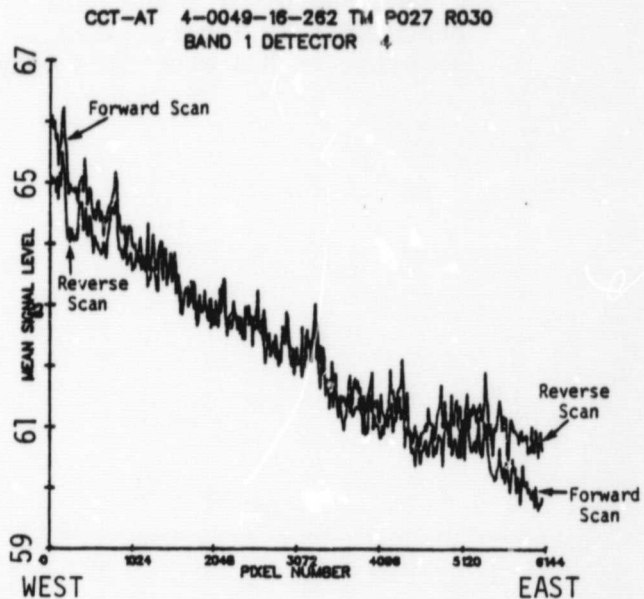


FIGURE 4. ILLUSTRATION OF SCAN-ANGLE EFFECT, ACROSS A FRAME (BAND 1)

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THEMATIC MAPPER SPECTRAL DIMENSIONALITY AND DATA STRUCTURE*

E. P. Crist and R. C. Cicone

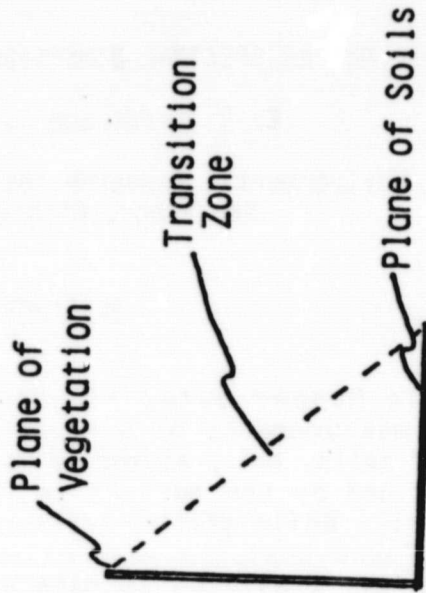
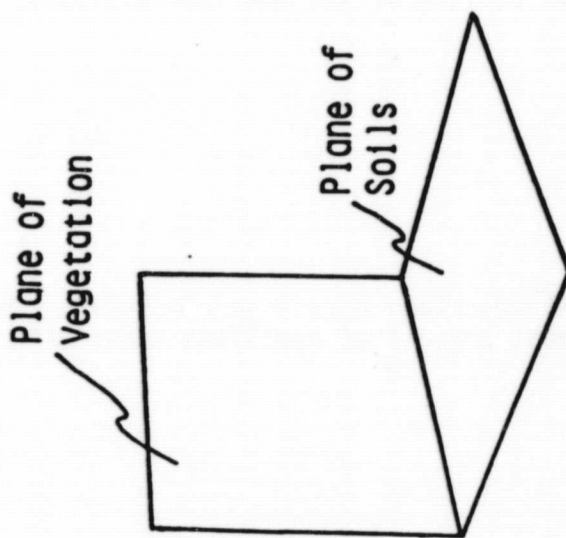
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Abstract

Thematic Mapper data, simulated from field and laboratory spectrometer measurements of a variety of agricultural crops and a wide range of soils, are analyzed to determine their dispersion in the six-space defined by the reflective TM bands (i.e., excluding the thermal band). While similar analyses of MSS data from agricultural scenes have found that the vast majority of the MSS data occupy a single plane, the simulated TM data are shown to primarily occupy three dimensions, defining two intersecting planes and a zone of transition between the two (see Figure). Viewing the "Plane of Vegetation" head-on provides a projection equivalent to the single plane of MSS data. The "Plane of Soils" and transition zone represent new information made available largely as a result of the middle-infrared bands included on the Thematic Mapper. Variation in this transformed data space is described in terms of the physical properties of the vegetation and soils in the data set, and the potential utility of the new information sources is highlighted.

*The work described herein was supported by the Inventory Technology Development project of AgRISTARS under NASA contract NAS9-16538.

DIMENSIONAL RELATIONSHIPS IN 6-BAND
THEMATIC MAPPER DATA



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MTF Analysis of Landsat-4 Thematic Mapper
Robert Schowengerdt
University of Arizona

A research program to measure the Landsat-4 Thematic Mapper (TM) modulation transfer function (MTF) is described. The research is being conducted by the University of Arizona and NASA Ames Research Center under the contract "An Investigation of Several Aspects of Landsat-D Data Quality."

Measurement of a satellite sensor's MTF requires the use of a calibrated ground target, i.e. the spatial radiance distribution of the target must be known to a resolution at least four to five times greater than that of the system under test. Any radiance structure smaller than this will have a small effect on the calculated MTF. Calibration of the target requires either the use of man-made special purpose targets with known properties, e.g. a small reflective mirror or a dark-light linear pattern such as line or edge, or use of relatively high resolution underflight imagery to calibrate an arbitrary ground scene. Both approaches will be used in this program; in addition a technique that utilizes an analytical model for the scene spatial frequency power spectrum will be investigated as an alternative to calibration of the scene. The test sites and analysis techniques to be used in this program are described in this paper.

Thematic Mapper Intraband Radiometric Performance
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In this early report, we have concentrated on a radiometrically corrected, geometrically raw (A data) and a fully processed (P data) images of the Washington D.C. area (ID 40109-15140). In A-data, every 16th image line is from a single detector. To allow recognition of features in A data, a first order geometric correction consisting of a 46 sample shift between forward and reverse scan directions was applied. The radiometric correction incorporated in A-data consists of applying a Radiometric look-up table (RLUT) constructed to equalize throughout a scene the mean and standard deviation of each detector, with the constraint of never compressing two DN levels into one. The same RLUT is used for the forward and reverse scan directions.

For our statistical study, we used a set of lines (512 A, 1024 P) across the center of the scene. A sub-scene centered over Chesapeake Bay and approximating a flat field was used for characterizing subtle radiometric differences and noise problems.

There are small differences between the average DN for the 16 detectors in each band, typically 0.8 DN; the standard deviations also differ typically by 0.4 DN. Differences of mode in a band are as large as 6 DN. Some DN levels appear to be strongly favored over adjacent levels. Differences between forward and reverse scans are approximately 0.1 DN in the mean, and 0 to 0.6 DN in the standard deviation. Geometrically resampled images (P data), in which the fixed correspondance between lines and single detectors is lost, are statistically similar to the ensemble of detectors in each band in A data.

The magnitude of inter-detector variation is readily seen by making an image of the first derivative in the vertical (line) direction of a flat field and stretching progressively wider ranges to gray; most detectors differ from their neighbors by 1 to 2 DN.

The effective resolution in radiance is degraded by a tendency for the TM to avoid certain DN levels by about a factor of two. These levels are consistent over all bands and detectors, and are spaced by an average of 4 DN. In band 6, level 127 is avoided by a factor of 30. This behavior is masked by resampling in the P data.

At high contrast boundaries, some of the detectors in Band 5 commonly over- or under-shoot by several DN and require on the order of 50 samples to recover; this behaviour occurs erratically.

A coherent sinusoidal noise pattern is evident in Detector 1 of Band 3. One-dimensional Fourier transforms show that this "stitching" pattern has a period of 13.8 samples with a peak-to-peak amplitude ranging from 2 to 5 DN. Oscillations of the same frequency, but about half this amplitude, occur for one other detector in this Band. Noise with a period of 3.24 samples is pronounced for most detectors in Band 1 and for 2 detectors in band 3, insignificant in Band 2, weak in Band 4, and obscured by noise in Bands 5 and 7.

A set of adjacent detectors in Band 1 has a change of response with a period of several scans. These detectors will have a reponse similar to their neighbors for several scans, then for several scans will have higher or lower DN numbers than their neighbors. There is no apparent pattern to this drift.

The random noise level of each detector was characterized by the standard

deviation of the first derivative in the sample direction across a flat field. By this measure, the noise level is: Band 1, 1.8 to 2.8 DN; Band 2, 0.74 DN representative, one detector each at 1.1 and 1.7; Band 3, 0.8 representative, 4 detectors at 1.0 to 1.3; Band 4, 1.0 representative, Band 5, 1.5 to 2.1; Band 7, 1.8 representative, one detector at 3.1.

The resampling algorithm used in generation of P data incorporates the 0 DN values which occupy non-data areas along the left and right edges of a frame. This causes 'fuzzy' frame edges and adds anomalous low and high DN values in the resulting frame histogram. In order to avoid adverse effects in applications involving scene statistics, such as clustering techniques, these values should be reset to zero after the resampling.

A principal component analysis indicates that a composite of the first component of Bands 1, 2, and 3; of Band 5 and 7; and Band 6 contain 97% of the information and has reduced the effect of noise.

A periodic noise removal algorithm developed by Chavez, et. al. has been adapted and applied to the coherent noise of Band 3, detector 1; the technique appears to work quite well.

The geometric fidelity of the GSFC filmwriter used for Thematic Mapper images was assessed by measurement with accuracy better than 3 micrometers of a test grid. The film output has scale errors in both the sample and line directions corresponding to 4 pixels in a TM image, and skew corresponding to 3 pixels.

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An evaluation of Landsat-4 Thematic Mapper data for
their geometric and radiometric accuracies and their relevance
to geologic mapping

by

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Landsat-4 Thematic Mapper (TM) scenes for Washington, D.C. (40109-15140, November 2, 1982) and Macon, Georgia (40050-15333, September 4, 1982) have been examined to determine their radiometry and geometric accuracy. In addition, these two scenes also are being analyzed to determine the ability to identify specific rock types with the added near infrared TM bands located at 1.6 and 2.2 μm .

Each of the seven TM bands of the geometrically corrected (P-tape) Washington, D.C. scene were contrast stretched and recorded on film using an Optronics P-1500 film writer. Thirty-eight control points were visually identified from 1:24,000-scale topographic maps and a 40-micrometer circular hole was drilled at each control point on the images of bands 1, 3, 5 and 7. Subsequently, rectangular coordinates of each control point were measured with a photogrammetric comparator with a resolution of 1 micrometer. Two transformations, the similarity and the affine, were fit by the least squares method to the comparator coordinates and to their respective UTM coordinates as taken from the maps. The similarity transformation only allows the data points to be translated, scaled and/or rotated about the coordinate system whereas the affine translation also allows for separate linear scaling of each

coordinate axis. Table 1 shows the vector residuals resulting from each transformation for several of the bands.

Table 1 Root Mean Square Error of Vector Residuals

TM Band	Similarity	Affine
1	72 m	45 m
3	70 m	45 m
5	68 m	48 m
7	69 m	45 m

It is apparent that the application of the affine transformation significantly reduces the root mean square error in all cases. One possible cause may be the film writing device. A highly significant skewness was observed in previous tests of grids printed from the same device as used in this study. This was possibly caused by lack of parallelism between the axis of the rotary drum and the axis of travel of the light source.

Band to band registration was checked for the Washington, D.C. scene viewing several small portions of the scene on an interactive video display device. Several strongly contrasting targets, such as airport runways and small ponds, were used to visually determine the offsets. TM bands 1-4 were perfectly coregistered. Using channels 1-4 as references, bands 5 and 7 were found to be displaced 1-2 pixels eastward. Band 6 was displaced 4 pixels eastward, which effectively means it is displaced by one of its 120m resolution units.

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A geometrically uncorrected version (A-tape) of the Macon, Georgia scene was examined to determine some of the radiometric characteristics of the data. This included analysis of the 16 individual detectors in bands 1-5 and 7 and each of two detectors of channel 6. Systematic gaps were found within the limited range of digital numbers recorded for the scene. These can be attributed to the integer truncation of decimal numbers involved in the calibration procedure during production of the computer compatible tapes.

The potential of sensor striping caused by the separate gains and offsets required for each of the 16 sensors of the visible and near infrared TM bands was investigated using the A-tape of the Macon scene. The two sensor thermal infrared band also was examined. Means and standard deviations were calculated on a modulo-16 basis. The results are summarized in table 2. The range of means is typically less than that of Landsat MSS values when the MSS data are scaled into 8-bit space. Contrast stretched images of portions of the Macon scene were recorded onto film and visually examined for evidence of striping. Striping is not evident in channels having sensors with a range of mean differences less than 0.4 between their high and low values. Striping becomes apparent when difference values reach 0.5 and becomes objectionable with values greater than 0.6. The means and standard deviations of TM band 1 appear excessively high in comparison with TM channels 2 and 3, suggesting that gain and/or offset values for these sensors may be set too high. It is unlikely that these increased values in TM channel 1 can be accounted for by atmospheric scattering alone.

A modulo 32 striping also was noted for some of the TM bands over homogeneous targets such as water bodies. The striping appears clustered in two groups of 16 adjacent scan lines and probably is related to the alternate back and forth sweeps of the pushbroom scanner. Additional analysis is underway.

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Table 2-Comparison of Digital Number Statistics for Modulo-16 Striping
of TM data

<u>TM Channel</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>
range of	85.5	34.2	30.6	74.5	66.8	126.0	22.7
sensor means	86.4	34.8	31.2	74.9	67.1	126.7	23.1
difference	0.9	0.6	0.5	0.4	0.3	0.7	0.4
range of							
standard	17.649	9.067	11.295	16.665	23.449	15.527	11.679
deviations	18.076	9.504	11.661	17.026	23.931	15.980	12.271
difference	0.427	0.437	0.366	0.361	0.482	0.453	0.592
median							
sensor value	86.0	34.6	30.95	74.6	67.0	126.7	22.9
standard							
deviation	17.85	9.24	11.468	16.897	23.565	15.963	11.979

Band ratioing of specific TM bands was done for both the Macon, Georgia and Washington, D.C. scenes. Specific band ratios were used to determine their effectiveness in defining vegetation and rock mineralogy. The TM 3/4 band ratio was selected to define vegetation and the 5/2 band ratio was used to define limonitic rocks. The 5/7 band ratio was evaluated to test the effectiveness of the new 1.6- and 2.2- μ m bands in detecting clay and carbonate

bearing rocks. Preliminary results show that clay minerals containing absorption bands at $2.2 \mu\text{m}$, which are centered in TM band 7, can be readily detected when the band ratio images are suitably contrast stretched. Bright rocks containing carbonates, such as marbles, which contain absorption bands in the $2.33\text{-}\mu\text{m}$ region, near the long wavelength cutoff of TM band 7, are only evident upon harsher contrast stretching of the 5/7 band ratio.

Geobotanical studies using the early November Washington, D.C. scene show that monospecific forest canopies can be differentiated. A false-color composite image of TM bands 1, 4 and 7 allowed the photointerpreter to distinguish between relatively pure stands of Virginia pine (*Pinus virginica*), loblolly pine (*P. taeda*) and white pine (*P. strobus*), although dense stands of Virginia cedar (*Juniperus virginica*) could not be distinguished from the Virginia pine. All groups of coniferous trees could be distinguished from deciduous canopies.

omit

JSC THEMATIC MAPPER SCROUNGE DATA PREPROCESSOR

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ABSTRACT

With the launch of Landsat-D in July 1982, the remote sensing community has been provided a near Earth-orbiting multispectral sensor which has increased spatial resolution and superior spectral discrimination than any previously launched Landsat instrument. This new instrument, the Thematic Mapper, is a forward step in the progression of remote sensing technology, incorporating the knowledge and experience gleaned from early scanning instrument endeavors as well as utilizing the latest available satellite stability and pointing capability.

The immediate concern of Landsat ground processing segments became the accommodation of a data volume output from the Thematic Mapper which is seven times as great as multispectral scanner output for the same scene coverage. Often, existing multispectral scanner processors were in-place since the early 1970's and were not capable of handling such volumes of data. The problem consequently became a manifestation of the adaptation of existing systems, wherever feasible, and in many instances, the implementation of new processors for increased data volume handling.

This paper presents the development of the Thematic Mapper ground pre-processing capability of the Earth Observations Data Laboratory (EODL) at Johnson Space Center. The implementation of new processing elements and the utilization of existing systems in the EODL to handle Thematic Mapper data are reviewed in detail. The EODL Thematic Mapper preprocessor has been designed to provide AgRISTARS researchers with satellite imagery data over selected areas of interest in data sets which are sized to be computationally manageable. In addition, the EODL Thematic Mapper preprocessor includes the capability to provide image products in support of research activity.

Processing of Thematic Mapper Simulator Data

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With the advent of advanced satellite-borne scanner systems, the geometric and radiometric correction of aircraft scanner data has become increasingly important. These corrections are needed to reliably simulate observations obtained by such systems for purposes of evaluation. This paper reviews two approaches to reducing distortion in aircraft scanner data: by a combination of local and global "rubber sheet" polynomial transformations based on ground control points; and by modelling the effect of aircraft motion on the scanner scene.

ABSTRACT

Evaluation of Landsat-4 Thematic Mapper Ground Segment Performance Without Ground Control*

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S. Z. Friedman, B. Gokhman, T. L. Logan

An analysis was performed on the P-format computer compatible tapes for the Landsat-4 Thematic Mapper (TM) scene 40109-15140 acquired November 2, 1982 over Washington, D. C. and environs. Three tests of sensor geometry were undertaken: a) band-to-band registration, b) line-to-line registration between swaths, and c) geometric correction of sensor and spacecraft/ephemeris characteristics. The band-to-band and line-to-line registration was measured at one hundred pixel spacings along a line using the phase correlation image alignment method developed by Kuglin and Hines and adapted to a one-dimensional FFT correlation technique. The sensor and spacecraft geometric calibration analysis was checked by identifying 75 ground control points in the TM scene and on 1:24,000 topographic maps. A least squares fit of the gcps was computed and the vector offsets of the residuals was tabulated and plotted.

An analysis of the tabulated and plotted results revealed the following characteristics: a) Band-to-band registration in the primary focal plane (bands 1-4) is less than 0.1 pixel with the possible exception of band 4, which may be slightly above 0.1 pixel. b) Band-to-band registration in the secondary focal plane (bands 5 & 7) is less than 0.1 pixel. c) Band-to-band registration between bands in the primary and secondary focal planes varies between minus 0.1 and minus 0.35 pixels on the average where good correlations could be obtained (note the different spectral responses for each band made a comparison difficult sometimes). d) Line-to-line mis-registration averages less than 0.1 pixel, with some apparent local mis-registration of 0.3 pixel. Plots failed to show any systematic mis-registration effects that can be directly associated with local jitter. e) Ground control point offsets from the residual surface fit are generally good (RMSE of 4.43 pixels or 132.77 meters), although some points are off to a significant degree. An analysis of the TM P-data shows that a slow spacecraft roll condition of under one hertz exists in this scene. It is expected that an even distribution of gcps could effectively remove the roll distortion encountered.

*This abstract presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract No. NAS7-100, sponsored by the National Aeronautics and Space Administration.

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TM RESULTS SESSION

EARLY EVALUATION OF TM GEOMETRIC CORRECTION SYSTEM
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Results of available Thematic Mapper Geometric Correction System evaluations are given. The early mission attitude control performance is described. This includes attitude deviations which result from Thematic Mapper, Multi-spectral Scanner, solar array and TDRSS antenna operations. Thematic Mapper performance is given with respect to active line length, total scan time and scan nonlinearity. As ground control points are not yet used in processing, evaluations of the processed imagery is limited to forward-to-reverse scan continuity and band-to-band registration.

**The Use of Linear Feature Detection to Investigate Thematic
Mapper Data Performance and Processing**

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Abstract

Linear features are defined as long, narrow features such as roads, rivers and bridges. In addition to applications utility for mapping, they may be used to investigate the geometric properties of remotely sensed data.

Data suitability for feature detection is investigated by considering the contrast between typical feature and background materials.

Applications of the detector model at a series of thresholds, and estimation of the resulting detection accuracies for features of known width and composition, allows estimation of the ground IFOV (pixel size).

Band to band registration is estimated by considering the relative positions of features between bands. Results indicate an off-set of about .75 pixels along scan and .5 pixels across scan between features detected in the primary focal plane (bands 1 - 4) and those in the cold focal plane (bands 5 - 7).

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SPATIAL RESOLUTION ESTIMATION OF LANDSAT-4
TM AND MSS DATA

By

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SPATIAL RESOLUTION ESTIMATION OF LANDSAT-4
TM and MSS DATA

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SUMMARY

In order to verify that the Landsat-4 sensors are operating within specifications, it is useful to estimate the system parameters by analysis of the measured data. One parameter of particular interest is the sensor point-spread function (PSF) which determines the resolution of the system.

A method of estimating the PSF has been developed that utilizes data obtained during scanning of ground elements having identifiable geometric and radiometric structure. These data are then processed in such a manner as to recover either the PSF itself or to estimate the parameters of an assumed functional representation of the PSF.

The measured data can be expressed in the spatial domain as a convolution of the scene with an overall point-spread function:

$$g(x,y) = h(x,y) * f(x,y)$$

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where $f(x,y)$ is the earth scene
 $h(x,y)$ is the overall point-spread
 function of the sensor system
 $g(x,y)$ is the resulting image

Given $g(x,y)$, we wish to determine $h(x,y)$ or its Fourier transform $H(u,v)$. To do this, some deterministic element of the input $f(x,y)$ must be known or assumed. Although the theory takes into account the two-dimensional nature of the element, the initial experiments have been limited to the one-dimensional case. Three useful elements of this type are:

1. A step function represented by an abrupt change in gray level along a row or column of the data.
2. An impulse represented by a narrow-width discontinuity along a row or column of the data.
3. A rectangular pulse represented by a sequence of two steps in opposite directions along a row or column of the data.

The point-spread function estimation method described in the paper uses horizontal and vertical roads in Landsat-4 MSS and TM images. The two-dimensional function is solved as two one-dimensional functions under the assumption that the PSF is separable; i.e.,

$$h(x,y) = h_x(x) h_y(y)$$

The steps in carrying out the solution are:

1. Each scan line across a road is modeled as an ideal point response

$$f_i p_i = p_i \delta(x-x_i)$$

p_i = magnitude of the ideal point source

x_i = location of the point source

2. Each point response is adjusted such that the locations of the point sources align with each other and an average point response is computed.

$$g_1(x) = p_1 \delta(x-x_1) * h(x) = p_1 h(x-x_1)$$

$$\bar{g}(x) = \frac{1}{M} \sum_{i=1}^M g_1(x+x_i) = \frac{1}{M} \sum_{i=1}^M p_i h(x) = \left[\frac{1}{M} \sum_{i=1}^M p_i \right] h(x)$$

Therefore:

$$h(x) = K \bar{g}(x)$$

$$\text{where } K = 1 / \left[\frac{1}{M} \sum_{i=1}^M p_i \right]$$

Once an estimate for the PSF has been obtained to within an (unknown) constant factor K, a quantification of the width of the function can be made. Three methods are of general interest and are defined in one dimension, as follows:

1. Half amplitude width $W_{1/2}$ = width at which the magnitude of $h(x)$ falls to one-half of its value at the origin.

2. Equivalent width $W_e = \frac{\int_{-\infty}^{\infty} h(x) dx}{h_{\max}}$

3. rms width $W_{\text{rms}} = 2 r$

$$r^2 = \frac{\int_{-\infty}^{\infty} x^2 h(x) dx}{\int_{-\infty}^{\infty} h(x) dx}$$

Similar quantities can be defined to estimate the bandwidth of the modulation transfer function (MTF) and are represented by $B_{1/2}$, B_e , and B_{rms} .

The method was applied to Landsat-4 MSS and TM images from the Webster County, Iowa area and the Chicago, IL area using interstate highways and major roads

as test inputs. The results for these tests are obtained in the form of both spatial widths of the estimated PSF in pixels and the bandwidth of the modulation transfer function in cycles per pixel and by plots of the estimated PSF and MTF.

One result using 50 scan lines across a north-south road in Webster County, Iowa (TM data) is shown in Figure 1. The PSF width results are listed below:

Vertical road in Webster Co., Iowa area:

$$W_{\frac{1}{2}} = 2.0$$

$$W_e = 3.58$$

$$W_{rms} = 5.23$$

Evaluation of the method using an assumed step response will also be presented, along with results from the MSS and using data both from Iowa and the Chicago areas.

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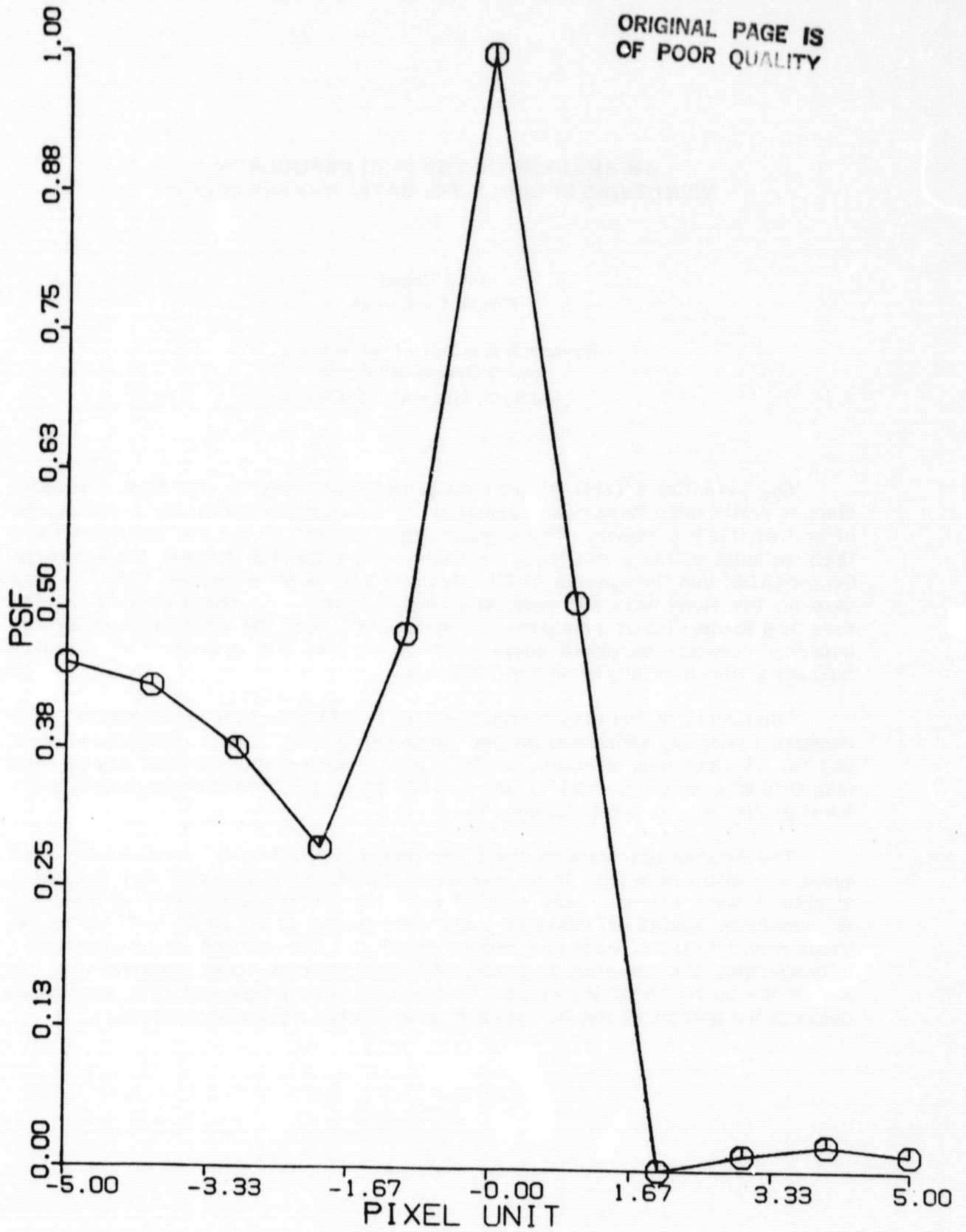


Figure 1. PSF using 50 location-adjusted scan lines.

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**AN ANALYSIS OF THE HIGH FREQUENCY
VIBRATIONS IN EARLY THEMATIC MAPPER SCENES**

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The potential effects of high frequency vibrations on the final Thematic Mapper (TM) image have been evaluated for 26 scenes between day 4 and day 50 after LANDSAT-4 launch. The angular displacements of the TM detectors from their nominal pointing directions as measured by the TM Angular Displacement Sensor (ADS) and the spacecraft Dry Rotor Inertial Reference Unit (DRIRU) give data on the along scan and cross scan high frequency vibrations present in each scan of a scene. These measurements were used to find the maximum overlap and underlap between successive scans, and to analyze the spectrum of the high frequency vibrations acting on the detectors.

The history of the scan overlap and underlap for this time period shows that a consistent underlap which was present immediately after launch disappeared after day 10. The maximum overlap/underlap within a scene stabilized after day 15 from launch to an average of -0.337 pixels / $+0.358$ pixels for the reflective bands, and -0.034 pixels / $+0.141$ pixels for band 6.

The Fourier spectrum of the along scan and cross scan vibrations for each scene was also evaluated. In the scenes analyzed, the along scan high frequency vibrations were strongly concentrated at 7 Hz and had amplitudes of about 80 microradians. Additional vibration peaks were present in the 56 Hz to 77 Hz range. Cross scan vibrations were also concentrated at 7 Hz and had amplitudes near 7 microradians. For the cross scan data additional spectral peaks occurred at 21 Hz and in the 56 Hz to 67 Hz range. Differences in structure and peak amplitudes between the spectra of the forward and reverse scans were also observed.

**Assessment of Thematic Mapper Band to Band Registration by the
Block Correlation Method: Preliminary Results**

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A Thematic Mapper Arkansas scene (August 22, 1982) is being processed on Ames Research Center's block correlation program to assess band to band registration. This is a Fast Fourier Transform based program implemented on a CDC 7600 computer that correlates spectral values between bands using a 64 X 64 pixel block in the primary band image versus a moving 32 X 32 pixel block in the secondary band image. Correlations are performed on gradient images in order to minimize radiometric differences between bands. Initial results on band 3 versus band 5 indicate an approximate 1/2 pixel offset in the vertical direction and 1/4 pixel offset in the horizontal direction, with standard errors of .3 pixel in each direction. Further results with other band comparisons will be presented.

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INVESTIGATION OF TM BAND-TO-BAND REGISTRATION USING THE
JSC REGISTRATION PROCESSOR

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SUMMARY:

Several TM scenes from the Goddard "SCROUNGE" processing system were available at JSC for a quick-look investigation. One topic of interest is the accuracy of the TM band-to-band registration. It is known that the detectors for the seven-band TM system are placed in two groups aboard the spacecraft. Located at the primary focal plane are detector arrays for band one to band four, while the remaining detectors are placed at the cold focal plane. Software in the SCROUNGE system is used to register the bands together to an accuracy of less than one-fifth of a pixel, or six meters on the ground. It is expected, therefore, that the data from the first four bands are well registered to each other. In the current investigation, the JSC registration processor is used to study the registration between all TM bands, with special attention given to band 6, the thermal band, which has a four-times coarser resolution compared to the other bands.

The JSC registration processor is an improved offspring of Goddard's Master Data Processor and the LACIE processor. It performs scene-to-scene (or band-to-band) correlation based on edge images, which are derived from a percentage of the edge pixels calculated from the raw scene data, excluding clouds and other bad data in the scene. Correlations are performed on patches of the edge images, and the correlation peak offset in each patch is estimated iteratively to fractional pixel location accuracy. Peak offset locations from all patches over the scene are then considered together, and a variety of tests are made to weed out outliers and other inconsistencies before a distortion model is formed. Thus, the correlation peak offset locations in each patch will indicate quantitatively how well the two TM bands registered to each other over that patch of scene data.

When multitemporal acquisitions of TM data over the same ground track were made available, the JSC registration processor was also used to multitemporally register one acquisition to the other. Some multitemporal TM registration results together with the preliminary evaluation of single acquisition band-to-band registration results will be presented.

GEODETIC ACCURACY OF LANDSAT-4 MULTISPECTRAL SCANNER AND THEMATIC MAPPER DATA

Principal Investigator: June M. Thormodsgard

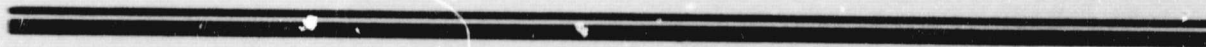
EROS Data Center, U.S. Geological Survey

The EROS Data Center, as the primary facility for generation and dissemination of Landsat data products, must evaluate the geodetic accuracy of data from both the Multispectral Scanner (MSS) and Thematic Mapper (TM) processing systems.

The standard Landsat-4 MSS and TM digital tapes contain information which relates the map projection coordinate system to the image coordinate system. Therefore, by converting the latitude and longitude of a given location to the map projection coordinates, the image coordinate location can be calculated. Verification of the image's geodetic accuracy can then be accomplished by comparing the calculated image coordinates with the visually determined image location.

Landsat-4 digital images produced by NASA are either system-corrected or precision-corrected (ground control points applied). This method of geodetic verification has been applied to images of both precision-corrected and system-corrected MSS and TM data.

TM Applications Session



Thematic Mapper Quick-Look Analysis of the Washington, DC Scene (11/2/82)

by

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ABSTRACT

Preliminary analysis of the Landsat-4 Thematic Mapper (TM) scene of Washington, DC (November 2, 1982) has been completed. The objective of this effort was to provide very near term quantitative results on assessment of the increased information content provided by the improved spatial, spectral, and radiometric resolution of the TM relative to the Multispectral Scanner (MSS).

Four different "data sets" were analyzed. These consisted of: (a) the original TM data (28.5 meter pixel, 8 bits, 6 channels), (b) the original data degraded to 6 bit quantization, (c) a 3 channel subset of the original data (TM bands 2, 3, and 4 which are similar to MSS bands 1, 2 and 4), and (d) the original data degraded to MSS spatial resolution. [The thermal data (band 6) were excluded from this study due to the difference in spatial resolution (120 meters.)] Nine different study sites, 256 by 256 pixels in size, were randomly selected from the full scene for analysis. Recent aerial photography was available and all sites were visited during the last week of October to collect ground reference data. All nine study areas for each of the four data sets were classified using a per-point gaussian maximum likelihood classifier.

The following results were obtained: (a) the reduction of quantization level from 8 bit to 6 bit caused a decrease in overall accuracy (7%), (b) the use of only three bands (TM 2, 3 and 4) covering the visible and near infrared portion of the spectrum, caused a decrease in overall accuracy (7%), and (c) the decrease in spatial resolution resulted in an increase in overall accuracy (4%). Results (a) and (b) indicate that the increased radiometric and spectral resolution of the TM instrument do provide increased information content. The results of the spatial resolution degradation is somewhat misleading, in that the result is more a function of the type of classifier used (i.e., per-point), rather than a function of spatial resolution. This result points to the need for new classifiers, such as contextual classifiers, which take into account the increased spectral heterogeneity in higher resolution data.

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Preliminary Comparisons of the Information Content and Utility
of TM Versus MSS Data

by

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Comparisons were made between comparable subscenes from the first TM scene acquired of the Washington, DC area (July 29, 1982-4 bands only) and a MSS scene acquired approximately one year earlier (July 11, 1981). The Landsat-4 MSS scene of July 29, 1982 was never made available. Three types of analyses were conducted: a water body analysis, a principal components analysis and a spectral clustering analysis.

The water body analysis compared the capability of the TM to the MSS for detecting small uniform targets. All water bodies (>10 meters) were located on aerial photographs collected July 13, 1982 and categorized by the size of the maximum inscribable circle. Each scene was independently clustered and the clusters assigned to water or non-water. Each water body was said to be detected for the MSS or the TM if a minimum of one pixel at its location was classified into a water cluster. Of the 59 ponds located on the aerial photographs 34 (58%) were detected by the TM with six commission errors (15%) and 13 (22%) were detected by the MSS with three commission errors (19%). The smallest water body 'detected' by the TM was 16 meters; the smallest 'detected' by the MSS was 40 meters.

For the principal components analysis, means and covariance matrices were calculated for each subscene, and principal components images generated and characterized. The 4-band TM image had slightly higher dimensionality than the MSS in this rural-suburban area, with 2.6% of the variance in the third component as compared to 1.2%. The first two principal components of the TM and MSS were similar, containing brightness-like and greenness-like features. The MSS third and fourth principal components were dominated by noise and striping whereas the third TM principal component (a red to blue-green contrast) was less noisy and appeared to contain information useful for separating built-up features from bare soil. This third component detected the spectral flatness of construction materials in the visible spectrum as opposed to the sloping response of bare soils.

In the spectral clustering comparison each scene was independently clustered and the clusters were assigned to informational classes. The clusters were assignable to the same classes on the 4-band TM as on the MSS data with the exception that the TM data provided separation of bare soil areas from areas of buildings that MSS data did not provide. The TM band 1 contributed to this improved separation.

The preliminary comparisons indicated that TM data provides enhancements over MSS in terms of (1) small target detection and (2) data dimensionality (even with 4-band data). The extra dimension, partially resultant from TM band 1, appears useful for built-up/non-built-up area separation.

INFORMATION CONTENT OF DATA FROM THE LANDSAT 4 THEMATIC
MAPPER AND MULTISPECTRAL SCANNER

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The word "information" has both a popular and a technical meaning, the latter referring to the statistical variability associated with a data set. This study addresses the question of the quantitative increase in the information content (in the technical sense) of Landsat 4 Thematic Mapper (TM) data as compared to data from the Multispectral Scanner (MSS).

An intuitive concept of the information content of image data may be gained from several examples: 1) A uniform featureless scene, such as a desert area, has a low information content while a "busy" scene, such as a city, contains more information; 2) A scene having no spectral variability, i.e. all wavelength channels having a common brightness value at each point - a black and white scene, has a lower information content than one in which brightness values differ from one spectral channel to another in a spatially varying way - a multicolored scene; 3) A data set obtained at low spatial resolution has many features blurred or averaged out, and thus has a lower information content than the equivalent scene observed at higher resolution.

In the present case, the TM data contain more information than the MSS data because of 1) the greater number of spectral channels, 7 versus 4, 2) the improved spatial resolution, 30m versus 82m, and 3) the increased precision resulting from better detector response and decreased quantization intervals, e.g., 8 bit versus 6 bit data.

The analysis procedure consists of the application of standard mathematical methods (principal components, autocorrelation, delta transformation, etc.) to data sets from the MSS and TM. The subject area, information theory, as well developed and software already has been developed to support the study.

Computer runs have been carried out for several subareas from a data set acquired simultaneously by TM and MSS over a test area in northeast Arkansas. (Scene center North $36^{\circ}02'$, West $90^{\circ}02'$, date, August 22, 1982) This scene is one of the most agriculturally diverse areas in the U.S. As one would expect, the 6 visible-near IR channels of the thematic mapper provide more information than the 4 channels of the multispectral scanner. A rough estimate of 20 bits per pixel for TM, 10 bits per pixel for MSS has been computed for these subareas. These numbers will be revised downward when allowance is made for noise in the data.

Since the 6 reflective channels of the TM have a capacity of 48 bits per pixel (6 channels x 8 bits per channel) while the 4 MSS channels have a capacity of 27 bits per pixel (3 x 7 bits + 1 x 6 bits) one can readily compare the information gathering efficiency of the two instruments. It appears that the ratios (information per pixel)/(possible information per pixel) are approximately equivalent - $20/48 \approx 10/27$, with noise not yet accounted for. If data utility is related to the quantitative estimate of information then the greater spatial and spectral capability of the TM represents a substantial improvement in remote sensing technology. However, the present assessment is preliminary and study of additional data sets is required.

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LANDSAT 4 INVESTIGATION OF THEMATIC MAPPER
AND MULTISPECTRAL SCANNER APPLICATIONS

By D. T. Lauer^{1/} and F. A. Waltz^{2/}

ABSTRACT

The objective of this experiment was to determine the incremental value of Landsat 4 thematic mapper (TM) data over multispectral scanner (MSS) data for acquiring resource information from selected test sites. Only data collected on November 2, 1982, over the Washington, D.C., test site have been analyzed.

Data from the six visible bands (1, 2, 3) and near-infrared spectral bands (4, 5, 7) of the TM data were used for several land use applications. The statistical characteristics of the information obtained from the various bands were determined by principal component analysis, correlation analysis, and feature classification. Preliminary results of these analyses showed that the most informative combination of bands includes the near-infrared band 4 with at least two other bands, either visible or infrared. This information was used to select bands to be used in a hue-intensity, saturation-image transformation algorithm.

A second approach based on the relative interpretability of features in the black-and-white products was used to make optimum band selections for false-color image products.

Work was begun building a multilayered digital data base covering the Washington, D.C., area. TM and MSS data were registered with digital elevation data (digital terrain tape), and TM conjugate stereoscopic images were then made by introducing parallax via the digital elevation data, into all seven bands. Both true and false color stereoscopic image products were made for the Washington, D.C., test site. Also, the digital data were used to make three-dimensional perspective views in which the azimuth (viewing angle) and location (height) of the observer were varied.

Digital products were statistically analyzed and photographic products manually interpreted by experienced EROS Data Center scientists to determine the incremental value of Landsat 4 TM over MSS data. This value was then related to the physical parameters of the two systems.

^{1/} U.S. Geological Survey

^{2/} Technicolor Government Services, Inc. Work performed under U.S. Geological Survey contract 14-08-0001-20129.

PRELIMINARY EVALUATION OF THEMATIC MAPPER
DATA FOR RENEWABLE RESOURCES

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ABSTRACT

The Thematic Mapper data are being used to empirically determine the effect of atmospheric scattering on spatial resolution. The response of the Thematic Mapper to discontinuous changes in scene reflectance was used to estimate the system optical transfer function. These estimates are being compared with protoflight measurements to determine if the observed spatial response is consistent with atmospheric scattering model predictions of spatial resolution.

In order to evaluate the effect of increased resolution on classification, an unsupervised clustering algorithm (CLASSY) was applied to the TM data and to simultaneously acquired MSS data. By observing features which were not resolved into separate clusters using TM data, an indication of how the increased TM resolution would affect classification was obtained. The results of this evaluation indicated that using TM data would produce separate classes for small features such as roads and homesteads, while using MSS data would not separate these small features.

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THEMATIC MAPPER DATA QUALITY AND PERFORMANCE
ASSESSMENT IN RENEWABLE RESOURCES/AGRICULTURE
REMOTE SENSING

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For the past decade the Johnson Space Center has been involved in the research and development of technology that utilizes satellite based remotely sensed data to perform global crop inventories. The Large Area Crop Inventory Experiment (LACIE) established the proof-of-concept with the LANDSAT MSS. The fundamental understanding gained with the LACIE formed the basis for the development of these techniques in the framework of a systems approach that has been evaluated in the Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) project. The successes with these joint projects have been manifest by the installation and periodic upgrade by the Foreign Agriculture Service (FAS) of the USDA within their ongoing operational forecasting system.

The limits reached with the MSS emphasized the need for the Thematic Mapper (TM) to further expand the progress made to date. It is believed that the increased spatial resolution will provide solutions to proportion estimation error due to mixed pixels, and the increased spectral resolution will provide for the identification of important agricultural features such as crop stage, and condition.

This paper will describe the results of analyses conducted relative to these hypothesis from sample segments (approximately 30 sq. miles) extracted from the 4-band Detroit scene and the 7-band Mississippi, Ar engineering test scene. Several studies were conducted to evaluate the geometric and radiometric performance of the TM to determine data viability for the more pertinent investigations of TM utility. In most cases this requirement was more than sufficiently satisfied. This allowed the opportunity to take advantage of detailed ground observations for several of the sample segments to assess class separability and detection of other important features with TM.

The results presented regarding these TM characteristics show that not only is the increased definition of the within scene variance captured by the increased spatial and spectral resolution, but that the mid-IR bands (5 and 7) are necessary for optimum crop type classification. Both qualitative and quantitative results are presented that describe the improvements gained with the TM both relative to the MSS and on its own merit.

REMOTE SENSING INVESTIGATIONS OF WETLAND BIOMASS AND
PRODUCTIVITY FOR GLOBAL BIOSYSTEMS RESEARCH

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ABSTRACT

Wetland ecosystems constitute a minor portion of the earth in an areal sense, yet they are probably one of the most important ecosystems when considering the global cycling of some elements having major reserves in the atmosphere. Among the outstanding characteristics of wetlands are the anaerobic sediments associated with these areas. Within the anaerobic zone, fermentation, denitrification, sulfate reduction and methanogenesis provide the mechanisms for C, N and S to be returned to the atmospheric reservoir (Odum 1979). Considering that wetlands ecosystems are among the most productive (per unit area) on earth and that they maintain an environment favorable to the nutrient transformations necessary to return C, N and S compounds to the atmospheric reservoir, it is critical that wetland ecosystems be evaluated as extremely important areas in global ecology models.

Systems analysis on a global scale will necessitate information gathering from orbiting platforms. The vegetation of wetlands will be the most measurable surface feature. Since plants are good indicators of edaphic conditions, they can serve as monitors of the anaerobic conditions in the soil. Therefore, monitoring biomass of wetlands ecosystems can provide information on net primary production and on the chemical and physical status of wetland soils relative to anaerobic microbial transformation of key elements.

Multispectral remote sensing techniques have been successfully used to estimate macrophytic biomass in wetlands systems (Jensen 1980, Hardisky et al. 1983a). The improved spatial, radiometric and spectral resolution of the Landsat-4 Thematic Mapper over the Landsat MSS will greatly enhance multispectral techniques for estimating wetlands biomass over large areas. These techniques can provide the biomass data necessary for global ecology studies.

Approach

A data base of spectral and biomass information has been compiled for the dominant salt marsh plant *Spartina alterniflora*. Spectral data were collected with a hand-held GSFC Mark II radiometer (Tucker et al. 1981). The radiometer was configured with three spectral bands deemed most useful for studying plant canopies. A red band (0.63-0.69 μm) sensitive to chlorophyll density, a near infrared band (0.76-0.90 μm) sensitive to tissue structure or biomass and a middle infrared band (1.55-1.75 μm) sensitive to leaf moisture were used. These spectral bands correspond to bands 3, 4 and 5, respectively, of the Thematic Mapper.

This initial data acquisition was designed to accomplish the following objectives:

1. To determine the range of biomass density for naturally occurring S. alterniflora which can be discriminated using spectral data.
2. To evaluate normal seasonal changes in several S. alterniflora stands with respect to spectral discrimination of these changes.
3. To develop regression models equating spectral radiance and aboveground biomass of S. alterniflora for use as predictive models in future nondestructive estimates of biomass.

If nondestructive biomass estimation of tidal wetlands using remote sensing is to be a viable operational methodology, many of the plant species and plant associations other than S. alterniflora must be investigated. By developing regression models for estimating biomass of the major salt marsh plant species and for the major plant associations of typical brackish marsh systems, realistic estimates of total marsh biomass and production can be derived from remotely sensed spectral data.

The central theme of future research is to develop the methodology necessary for spectral estimation of marsh plant biomass and to use this methodology for the estimation of net primary productivity of tidal wetlands. Both ground-based and airborne platforms for spectral data collection will be tested and marshes experiencing different salinity regimes will be investigated. The principal goals of this research can be summarized as follows:

1. To develop predictive regression models equating spectral radiance and plant biomass for a variety of marsh plants exhibiting different leaf morphology, growth form and phenology.
2. To employ the regression models to estimate aboveground plant biomass temporally for salt and brackish marshes and to estimate, solely from radiance data, the net primary production of the marshes.
3. To compare biomass estimated using spectral data collected from the ground, from low altitude aircraft and from Landsat MSS and Thematic Mapper with biomass estimated using harvest techniques.
4. To expand the spectral estimation technique to coastal mangrove swamps.

Results

Results from earlier studies suggest that using spectral data, one can successfully detect changes in S. alterniflora biomass (Hardisky et al. 1983b,c). In addition to monitoring perturbation, regression models have also been developed for predicting S. alterniflora biomass over an entire growing season from spectral data (Hardisky et al. 1983d). Models developed over the growing season include seasonal variations in biomass density and illumination intensity.

Using the models, we then collected an independent set of biomass and spectral data for S. alterniflora. We estimated standing crop biomass and net primary productivity using the regression model and then compared the remote sensing estimates to the harvest estimates of biomass (Hardisky et al. 1983a). The results suggest biomass and net primary productivity estimates for S. alterniflora marshes using multispectral data are possible. Albeit these initial investigations have relied solely on spectral data collected from the ground, the spectral regions and algorithms suggest that successful estimation of wetlands biomass and production from the Thematic Mapper will be possible.

Preliminary data are now being collected for wetland plant species other than S. alterniflora. Initial trends suggest that plants with different morphologies and canopy structure yield a different association between spectral data and biomass. For example, gramineous canopies (like S. alterniflora), leafless stem canopies (like Salicornia sp.) and broadleaf canopies (like Iva frutescens or Solidago sp.) exhibit differing reflectance per unit leaf biomass density. Canopy structure (orientation of leaves) plays an important role in determining spectral response. Adjustments to models must be made such that biomass estimations are possible for the variety of plant types inhabiting wetland systems.

Implications

Based on spectral data similar to the Thematic Mapper and collected from the ground, we can suggest the following:

1. The spectral configuration of the Thematic Mapper is such that estimates of wetlands biomass and/or productivity can be made using spectral data.
2. Wetland plant communities having different canopy configurations will require different biomass-spectral data algorithms. Thus plant species having similar canopy structure can probably be incorporated into a single model for biomass estimation.
3. With algorithms for the major plant types, large area estimates of biomass and productivity will be possible from the Landsat-4 Thematic Mapper.

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ASSESSMENT AND COMPARISON OF LANDSAT TM AND MSS
DATA FOR DETECTING SUBMERGED VEGETATION

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ABSTRACT

The objective of this research is to assess the spacial, spectral, and radiometric resolution of LANDSAT TM and MSS data for detecting submerged grass beds in Chesapeake Bay. Preliminary results show the relative effectiveness of TM bands 1, 2, and 3 and MSS bands 4 and 5 for discriminating between submerged vegetation and mud or sand. Only the spectral characteristics of each band are considered. A single-scattering radiative transfer model was used to generate a spectral quality index (SQI) for shot-noise-limited detectors. As SQI increases, so does the apparent contrast between target reflectance and background reflectance.

TM band 3 (630nm - 690 nm) and MSS band 5 (600nm - 700nm) were found to best discriminate between vegetation and sand in turbid water. Corresponding SQI values representing a water depth of 0.5 meters were 174.3 and 154.8 respectively. TM bands 1 and 2 and MSS band 4 were all of significantly lower quality, with SQI values of 69.4, 70.6 and 71.7, respectively. Similar results were obtained using mud as the background. The major difference was that all SQI values decreased.

For each of the two situations, sand background and mud background, the optical properties of the water column appeared to have a minimal effect upon the relative usefulness of each band with respect to increasing water depth. The optimum band for detecting vegetation in shallow water remained optimum for deeper water. An example is presented in which the optimum band does change with increasing depth.

A Preliminary Evaluation of Thematic Mapper Data to
Measure Suspended Sediments in Lake Chicot, Arkansas

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A comparison was made between ground data collected from Lake Chicot, Arkansas and thematic mapper data collected on September 23, 1982. A preliminary analysis of limited data indicates that thematic mapper data may be useful in monitoring suspended sediments and chlorophyll in lake with high suspended sediment loads. Total suspended loads ranged from 168 to 508 ppm. TM band 3 appears to be most useful to measure suspended loads. Bands 1, 2, and 4 also have useful information on suspended sediments. Digital data from band 2 is correlated with chlorophyll concentration. The ratio of band 1 - band 2 / band 1 + band 2 is also correlated with chlorophyll concentration. Looking at water data only, bands 1, 2, and 3 appear to have similar information. Band 3 is also related to band 4. Bands 5, 6, and 7 appear to have independent information content but it was not related to any of the ground data we collected.

Snow Reflectance from Thematic Mapper

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Calculations of snow reflectance in all 6 TM reflective bands (i.e. 1, 2, 3, 4, 5, and 7), using Wiscombe and Warren's (1980) delta-Eddington model, show that snow reflectance in bands 4, 5, and 7 is sensitive to grain size. An objective in our investigation is to interpret surface optical grain size of snow for spectral extension of albedo. Our results so far are encouraging. It also appears that the TM filters resemble a "square-wave" closely enough that we can assume a square-wave in our calculations. We calculated integrated band reflectance over the response functions, using sensor data supplied by Santa Barbara Research Center. Differences between integrating over the actual response functions and the equivalent square wave were negligible.

Table 1 gives characteristics of the Thematic Mapper, and, for background information, the Multispectral Scanner and NOAA Advanced Very High Resolution Radiometer. In the radiance columns of the table, the quantization errors and saturation radiances of the sensor bands are compared with the solar constant, integrated through the sensor response functions. Solar constant spectral distributions are from Thekaekara (1970), adjusted to fit the integrated values of Hickey et al. (1980). The last column in the table expresses the sensor saturation radiance as a percentage of the solar constant, integrated through the band response function. While snow will still saturate in band 1, bands 2 and 3 will saturate only for nearer-normal illumination angles and bands 4, 5, and 7 will not saturate. The saturation problem is not nearly as severe as with the MSS, so the TM can be used to measure snow albedo and thus allow basin-wide energy budget snowmelt calculations.

Table 2 shows calculations of integrated reflectance for snow over all reflective TM bands, and water and ice clouds with thickness of 1mm water equivalent over TM bands 5 and 7. In the blue and green bands (1-2) snow reflectance is not sensitive to grain size, so measurements in these wavelengths will reveal the extent to which snow albedo is degraded by contamination from atmospheric aerosols, dust, pine pollen, etc. In the red and near-infrared, snow reflectance is sensitive to grain size but not to contaminants, so grain size estimates in these wavelengths can be used to spectrally extend albedo measurements. In bands 5 and 7, snow is dark and clouds are bright. Initial frames with both snow and clouds from the western United States show that the TM can distinguish between them.

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PRELIMINARY EVALUATION OF TM FOR SOILS

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Thematic Mapper data acquired over Mississippi Country, Arkansas, were examined for utility in separating soil associations within general level alluvium deposited by the Mississippi River. The 1.58-1.79 μ m (Band 5) was found to separate the different soil associations fairly well when compared to the USDS-SCS general soil map. The thermal channel also appeared to provide information at this level. A detailed soil survey was available at the field level along with ground observations of crop type, plant height, percent cover and growth stage. Soils within the fields ranged from uniform to soils that occur at patches of sand that stand out strongly against the intermingled areas of dark soil. Examination of the digital values of individual TM bands at the field level indicates that the influence of the soil is greater in TM than it was in MSS bands. TM appears to provide greater detail of within field variability caused by soils than MSS and thus should provide improved information relating to crop and soil properties. However, this soil influence may cause crop identification classification procedures to have to account for the soil in their algorithms.

SPACIAL ANALYSIS OF THEMATIC MAPPER PRODUCTS

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GEOLOGIC UTILITY OF LANDSAT-4 TM DATA:
DEATH VALLEY, CALIFORNIA

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The present LIDQA study is being conducted in several phases to quantify the performance of the TM vis-a-vis various geological applications. These phases include: (1) analyses of the geological utility of the data with respect to the increased spatial resolution and number of bands (compared to the MSS); (2) analysis of geometric accuracy; (3) analysis of radiometric performance of the TM scanner.

This report presents some preliminary results of geological analysis of TM data for Death Valley, California, and observations on TM data quality. Geometrically and radiometrically corrected data (CCT-PT) have been examined for scene E-40124-17495, acquired November 17, 1982. Overall, the TM data appeared to contain a marked increase in geologically useful information; however, a number of instrumental or processing artifacts may well limit the ability of the geologist to fully extract this information.

A 27 by 18 km area was extracted from the scene for detailed analysis. Color-enhanced band composites, principal components composites, and color ratio composites were produced from the TM data. Lithologic interpretation maps were prepared and compared to detailed published geologic maps. More detail and delineation of alluvial fan units was evident on the TM data; most of the salt/silt/evaporite units in the Death Valley playa were apparent on the images; many of the outcropping volcanic and sedimentary rock types were separable based on differences in their spectral response. However, substantial shadowing due to the combination of low sun angle and severe topographic relief limited the ability to interpret information in the mountainous areas. High sun angle, summer scenes would greatly reduce this problem.

The same region was extracted from Landsat-2 MSS data and also from aircraft multispectral thermal data. Displayed as color composites and principal component images, the TM data were superior to the MSS data in all respects. The multispectral thermal data, however, allowed separation of alluvial units and lithologic units not seen on the TM data. This indicates the complementary nature of the two data sets for providing lithologic separations based on sensing different physical properties.

Two significant radiometric problems were observed in the TM data. The mean signal levels differ appreciably between the forward and reverse scan directions, possibly due to inaccuracies in the radiometric calibrations. This effect manifests itself as banding in harshly contrast-enhanced images. The second problem is most pronounced in ratio images and appears as striping, most severe at the edges of the scenes. The striping consists of paired lines of high-variance noise, with a 17-line periodicity. They

occur at the seams between the forward and reverse scan swaths, where extension scan lines have been interpolated to fill data gaps. It appears that the interpolation procedure used to process this scene was faulty.

The TM data were registered to a topographic base map. Results of the registration procedure indicate that the error in geometric accuracy of the CCT-PT data is less than 2 pixels. A more rigorous test of accuracy is planned.

Preliminary Study of Information Extraction of Landsat TM Data
for a Suburban/Regional Test Site

by

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Objectives

The primary objective is to quantify the information extractable from TM data for a suburban/regional test site. Specific objectives include (1) quantifying information in processed TM data of land cover classes, and (2) assessing important TM sensor parameters affecting cover class discrimination.

Approach

Landsat TM (July 29, 1982 4 band; and November 2, 1982 7 band) and MSS (Landsat-2, July 11, 1981; and Landsat-4, November 2, 1982) P-data were registered scene to scene for a 15 km² study area encompassing Beltsville-Laurel, MD. The MSS data was analyzed for comparisons to TM. In order to study the effects of improved TM sensor parameters--spatial resolution, quantization level, and spectral regions--on land use/land cover discrimination, the TM data was preprocessed. For both of the July and November TM scenes the data was degraded from 28.5m to 85m spatial resolution, compressed from 8 bits to 6 bits quantization, and spectrally subset from 6 bands (4 bands in July) to 3 bands (TM2, 0.52-0.60 μ m; TM3 0.63-0.69 μ m; and TM4 0.76-0.90 μ m). Thus for each of the two dates there are three factors (spatial resolution, quantization, and spectral regions) yielding a 2x2x2 combinatorial design of eight possible data arrangements (i.e., 6 bands, 28.5m, and 8 bits; 6 band, 28.5m, and 6 bits; . . .; 3 bands, 85m, and 6 bits). To assist evaluations, CIR (1:40,000) of July 13, 1982, was photointerpreted to seven land use/cover classes: water, forest, agriculture, extractive, transportation, commercial/industrial, and residential. For cover class evaluations, pixels of TM and MSS were selected through a stratified-systematic sample in order to obtain independent and unbiased observations. Results from correlations, histograms, two-dimensional spectral class plots, clustered maps, principal components, transformed divergence, and per-pixel classifications were evaluated.

Findings

Results from the TM sensor parameter study indicate a significant increase in classification accuracy and transformed divergence for the improved 8 bit quantization level and added spectral regions TM1 (0.45-0.52 μ m), TM5 (1.55-1.75 μ m), and TM7 (2.08-2.35 μ m). However, results from the spatial degradation procedure exhibited a significant improvement in classification accuracy and transformed divergence when using 85m vs 28.5m spatial resolution TM data. The additional spectral heterogeneity in the higher resolution data, produced higher variability or class overlap about class means, resulting in worsening cover class confusions. New classifiers or approaches should be investigated which take into account the increased spectral heterogeneity of higher resolution data.

Analysis of transformed divergences for all possible 2-band and 3-band combinations indicated a general trend of including spectral bands from the four major spectral regions (visible, near-infrared, middle-infrared, and thermal-infrared) in order to maximize cover class discriminations. Assessment of principal components for TM and MSS data indicated approximately two additional components of information in TM vs MSS. As evidenced by an increase in classification accuracy from 78.7% to 83.2%, the addition of the thermal-infrared band (TM6, 10.4-12.5 μ m) to the other 6 channels in a classification provides for a significant improvement in cover class discrimination.

COMPARATIVE TECHNIQUES USED TO EVALUATE THEMATIC MAPPER DATA
FOR LAND COVER CLASSIFICATION IN LOGAN COUNTY, WEST VIRGINIA

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The Eastern Regional Remote Sensing Applications Center (ERRSAC) and Marshall University (West Virginia) are conducting a joint evaluation of Thematic Mapper (TM) data for mapping abandoned lands and stages of revegetation in conjunction with the West Virginia Department of Natural Resources (WVDNR). The study area for the project is Logan County, West Virginia, a predominantly rural county that contains a variety of land cover types, including many active and abandoned surface mines. The objectives of the research are to identify and map active, abandoned, and reclaimed/revegetated mine areas, and to test a variety of digital data processing techniques. The following data extraction and data reduction procedures are being compared: canonical analysis, principal components analysis, and band selection.

A subset of the 4 November 1982 data set (TM seven bands) corresponding to the central area of Logan County was created. This subarea was then subjected to the above transformations, before being input to an unsupervised clustering algorithm which generated classifications for each technique. These classifications were labelled with the aid of USGS 7.5' topographic quadrangles.

The WVDNR is in the process of photointerpreting three of the quads (Holden, Henlawson, Clothier) to provide ground truth information for comparison. It is expected that preliminary results for the Holden quadrangle will indicate that the canonically transformed data set yields the highest accuracies for surface mine categories when compared with the photointerpreted and digitized ground truth data from WVDNR.

RELATIVE ACCURACY ASSESSMENT AND SPECTRAL
COMPARISON OF LANDSAT-4 MSS AND TM
DATA FOR LAND COVER INVENTORY

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A study was undertaken to compare digital data for the Washington, DC scene from: a) the Landsat-4 Multispectral Scanner (MSS) acquired 11/02/82 (ID: 40109-15140); b) the Landsat-4 Thematic Mapper (TM) (ID: 40109-15140), simultaneously acquired; and c) the Landsat-3 MSS from 7/11/81 (ID:22362-1504). Level I mapping accuracy was determined by a per pixel comparison of each remotely sensed data set with digitized ground truth for four USGS 7.5 minute topographic quadrangle maps. The overall mapping accuracy was computed as the sum of all correctly classified pixels (for all cover types and 4 quads) divided by the total number of pixels for the 4 quads. Preliminary results indicate comparable overall mapping accuracies from L-3 and L-4 MSSs. An apparent improvement in mapping accuracy from L-4 TM is being quantified. In addition, the statistical variation in the spectral data from the three sensors associated with each cover type were also evaluated.

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Fourth General Session

Research Plans and Panel Discussion



Thematic Mapper Research Plans

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Thematic Mapper (TM) data collected during the first two and one-half years of Landsat 4 operations will be primarily used by NASA for purposes of research and development. NASA's R&D objectives during this period are: (1) to evaluate the quality of TM data from an engineering perspective; (2) to verify the results of airborne TM simulator studies conducted in the past; (3) to evaluate the utility of TM and MSS (Multispectral Scanner) data for conventional remote sensing applications; and (4) to explore new avenues of scientific research that can be addressed for the first time with the TM. The quality of TM data is currently being evaluated by thirty-two scientific investigators who were selected by NASA to participate in the Landsat 4 Image Data Quality Analysis (LIDQA) program. This program was initiated in 1982 and will be largely completed in 1984. At the same time, investigators at various NASA field centers are attempting to verify the results of earlier experiments that were performed with airborne sensors that simulated the measurement capabilities of the TM. Airborne TM simulators developed by NASA have been used to conduct experimental multispectral surveys of local test site areas from elevations of 8 to 15 kilometers. Orbital TM imagery is now being analyzed to verify that similar results can be achieved over broad areas based upon multispectral measurements of surface radiance obtained at an altitude of 705 kilometers.

The third major element of NASA's TM research program involves comparative studies of TM and MSS imagery to evaluate the relative utility of each sensor system for conventional applications such as crop monitoring, lineament mapping, and regional watershed analysis. The measurement capabilities of the TM are considerably more sophisticated than those of the MSS. Comparative studies of both data sets will be conducted to determine how the improved measurement capabilities of the TM enhance the quality and quantity of physical information that can be derived from orbital multispectral imagery. This research will attempt to relate incremental improvements in the information content of TM imagery to specific improvements in resolution and sensitivity that were incorporated in the design of the TM sensor. The results of this research will assist NASA and others in evaluating the relative utility of further improvements in the resolution and sensitivity of imaging sensor systems.

Finally, the successful launch of Landsat 4 represents the beginning of a new era in land remote sensing research. Analysis of MSS data collected by Landsats 1, 2, and 3 during the 1970's revealed that unique types of useful information concerning the surface conditions on our planet could be derived from orbital multispectral surveys. The decade of the seventies was primarily a period of technique development that resulted in a wide variety of new methods for analyzing and interpreting digital Earth imagery. With the advent of the TM, we now have a unique opportunity to build upon the results of this earlier research and apply multispectral imaging methods to the study of a wide variety of terrestrial phenomena. During the decade of the 1980's these methods have matured to the point where they can be meaningfully employed to study surface conditions and processes on a global scale. NASA currently plans to enlarge the scope of ongoing TM investigations and explore innovative scientific applications of TM data during 1984 and 1985.