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LANDSAT-D DATA ACQUISITION AND PROCESSING

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I. INTRODUCTION

A series of evolutionary changes have taken place since the early beginnings of the Landsat (Earth Resources Technology Satellite) program. Since the first satellite launch on July 23, 1972, many tens of thousands of multispectral views of the Earth have been taken and processed at the NASA/Goddard Space Flight Center (GSFC) data processing facility located at Greenbelt, Maryland. This satellite and the subsequent Landsats 2 and 3 have supplied a continuous flow of data to a widely diverse number of users for the past 6.5 years.

For the first 6 years of operation, all multispectral images were processed as photographic imagery with only a very small percentage processed digitally in the form of computer compatible tapes (CCT's). Photographic imagery was chosen originally to accommodate the use of existing experience in using photo-interpretation techniques to extract information.

For the last 6 months, the GSFC Image Processing Facility has been experimenting in the production of Landsat MSS data in digitally processed form. These data consist of fully radiometrically and geometrically corrected scenes on high-density digital tapes. This change to a digitally processed product was made to accommodate the rapid emergence of a more sophisticated user and his reliance on automated digital data correlation and extraction techniques. Although the recent work in digital domain processing of MSS data at GSFC is still in its infancy, much has already been learned that can be applied to the new Landsat-D system.

For the Landsat-D mission, NASA is developing a separate and dedicated facility at GSFC to support ground data processing. This separate development will provide for autonomous development and integration of the new system while permitting ongoing Landsat operations to continue without conflict in time or concepts. The system developed will use digital processing techniques and communications satellites to minimize

the loss of information between the sensor output and the ultimate user. This is to be accomplished by providing timely delivery of master data products to a public domain facility located at Sioux Falls, South Dakota.

II. SYSTEM OVERVIEW

The total Landsat-D system concept utilizes many components to bring a data user together with his data. These data are to be put in the most universally accepted form with the least amount of delay. As shown in Figure 1, the system functions are as follows.

A. OPERATIONS CONTROL CENTER (OCC)

All requests for data acquisitions reside in a data base shared between the OCC and the Data Management System (DMS). From this data base, both the thematic mapper (TM) and the multispectral scanner (MSS) operations are scheduled, using daily cloudcover predictions, spacecraft power limitations, and pre-established priorities. This schedule is then transferred to the Landsat spacecraft by either the Tracking and Data Relay Satellite (TDRS) or a conventional GSFC tracking station for later spacecraft execution.

B. DATA RELAY BY SATELLITE

In place of the onboard recorder, used in the previous Landsat series, a real-time satellite-to-satellite-to-ground relay will be used, utilizing the Tracking and Data Relay Satellite (TDRS) system. All sensor data will be received and recorded in real time at a single ground receiving site located at White Sands, New Mexico. This satellite relay system will provide coverage for all areas of the world except for a small zone over India.

A second satellite relay system, called the Domestic Communication Satellite (Domsat), will relay the recorded data from the White Sands facility to GSFC with less than 8 hours delay. The Domsat system will

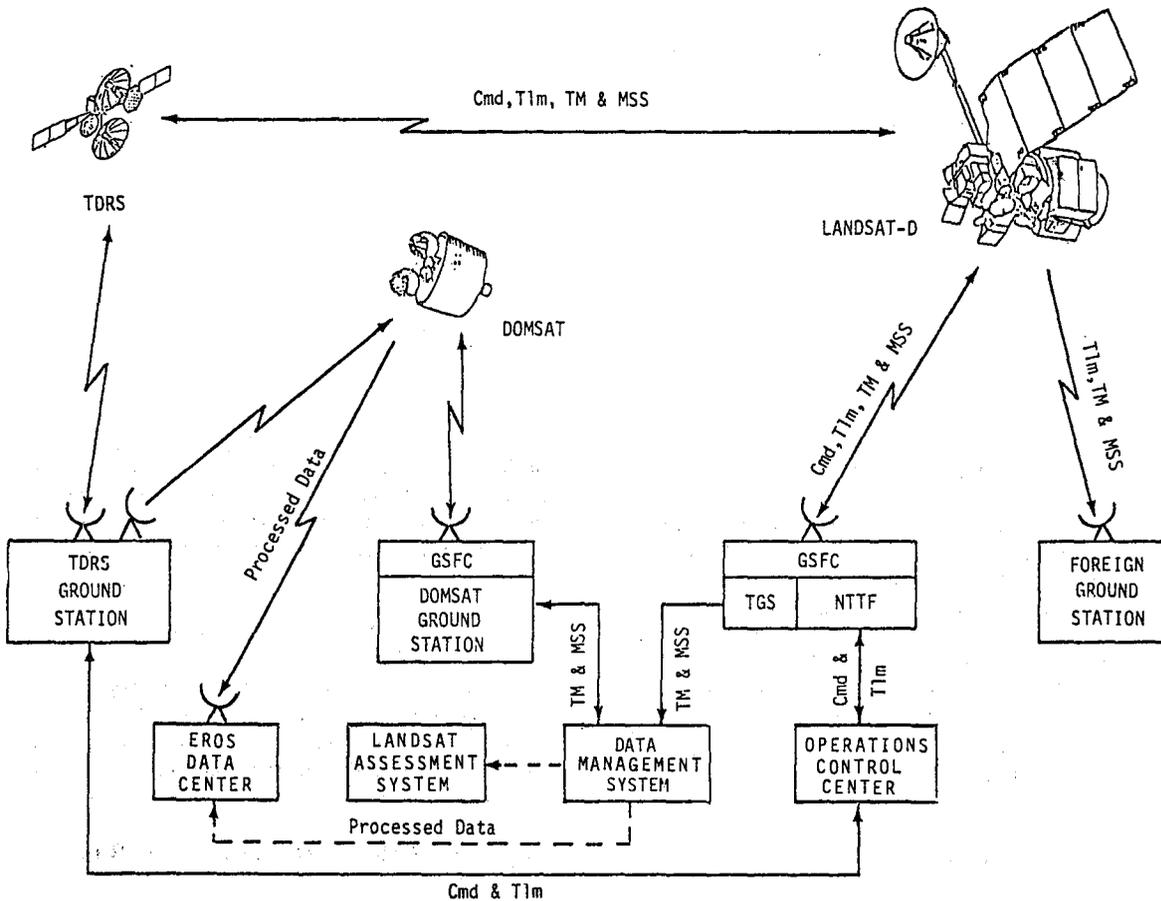


Figure 1. Landsat-D System Overview

also be used to relay fully processed data between GSFC and the public domain facility (the EROS data center) located at Sioux Falls, South Dakota.

C. DATA MANAGEMENT SYSTEM

The DMS will provide all image processing and archival data distribution for the Landsat-D mission. The primary outputs of the DMS are high-density tapes (HDT's) for MSS sensor data and 241-mm film masters for TM sensor data. Selected scenes can be requested and products produced in CCT form for both TM and MSS sensor data. The facility is capable of processing, in a pipeline mode, 2.6×10^{11} bits of sensor data per day. This data volume can be achieved with a 48-hour turnaround time (averaged over 10 days) from receipt of input data within the DMS for master data products. A 7-day turnaround time is required for CCT products when ordered retrospectively.

D. THE LANDSAT ASSESSMENT SYSTEM (LAS)

This facility, which is separate from the pipeline processing functions, functions as the research

and development arm of the total system. In this capacity, it must perform two primary functions:

1. With the formation of several selected discipline teams, develop and refine new data extraction and correlation techniques.
2. Evaluate and refine the pipeline processing techniques and algorithms, such as resampling, map projections, radiometric adjustments, etc., that are in use within the DMS.

E. TRANSPORTABLE GROUND STATION (TGS)

This portable ground station, located at GSFC, is capable of receiving both X-band and S-band data. The purpose of this system is twofold:

1. To support engineering evaluation of both the spacecraft and its sensors through the direct-transmission capabilities, independent of the data-relay communications links or other data-gathering operations in process.

2. To transport the ground station to another remote location in support of real-time data acquisition if a data-relay link failure occurs or if a spacecraft failure prevents acquisition of the TDRS system.

F. FOREIGN GROUND STATION SUPPORT

The Landsat-D Mission, as in the previous mission, is committed to supporting other foreign ground receiving stations. For this purpose, the S-band and X-band data links provide real-time direct transmission of sensor data. The S-band link will support MSS data only and will be used for the stations that are not converted to X-band reception. This link is compatible with present Landsat MSS transmission. The X-band will support simultaneous TM and MSS data transmissions. The Landsat-D spacecraft is required to support a total of 660 scenes/day of MSS data and 250 scenes/day of TM data. Table 1 shows the distribution of these data.

4. Product generation subsystem (PGS)

The IMS provides the scheduling, annotation data, and ancillary data required for supporting all DMS production processes. It also performs user order processing, inventory control, and mission/production status reporting. Data processing in the DMS is performed in six fundamental steps within these four elements. These six steps (Figure 2) are discussed in the following paragraphs.

A. STEP 1. CAPTURE RAW SENSOR DATA (TM AND MSS)

Sensor data, which are acquired and recorded at White Sands, are relayed to the GSFC by Domsat service three times daily at 8-hour intervals. This will support raw sensor data availability at GSFC within approximately 8 hours from acquisition by the spacecraft. The data received at GSFC are captured on high-data-rate

Table 1. Landsat-D Required Scene Rate

INSTRUMENT USERS	MSS			TM		
	SCENES/ DAY	SCENES/ NIGHT	SCENES/ 24 HRS.	SCENES/ DAY	SCENES/ NIGHT (THERMAL BAND)	SCENES/ 24 HRS.
NASA STATIONS	200	0	200	70	30	100
FOREIGN STATIONS (REAL TIME)	460	0	460	100	50	150

III. DATA PROCESSING FLOW

This section describes the Data Management System (DMS) at its present state of design and its mission objectives and processing capability for Landsat-D. The end-to-end major data flow for Landsat-D is shown in Figure 1 with the GSFC ground-segment subsystems and is described briefly in Section II, System Overview. The DMS consists of the following major elements:

1. Information management subsystem (IMS)
2. Data receive, record, and transmit subsystem (DRRTS)
3. Image-processing subsystem (IPS)

recorders (HDT-R) within the DRRTS. These recorders have a record/reproduce capability for handling data rates of greater than 85 megabits per second. During the data-capture process, data quality and inventory information are extracted and forwarded by data link to the IMS and the OCC for use in evaluating flight and ground recording performance and for later use in supporting pipeline data-processing functions performed within DMS.

B. STEP 2. CONVERSION OF RAW SENSOR DATA

The conversion of raw sensor data to a partially processed archival format takes place within the IPS. The HDT-R tapes are input to the IPS, which performs

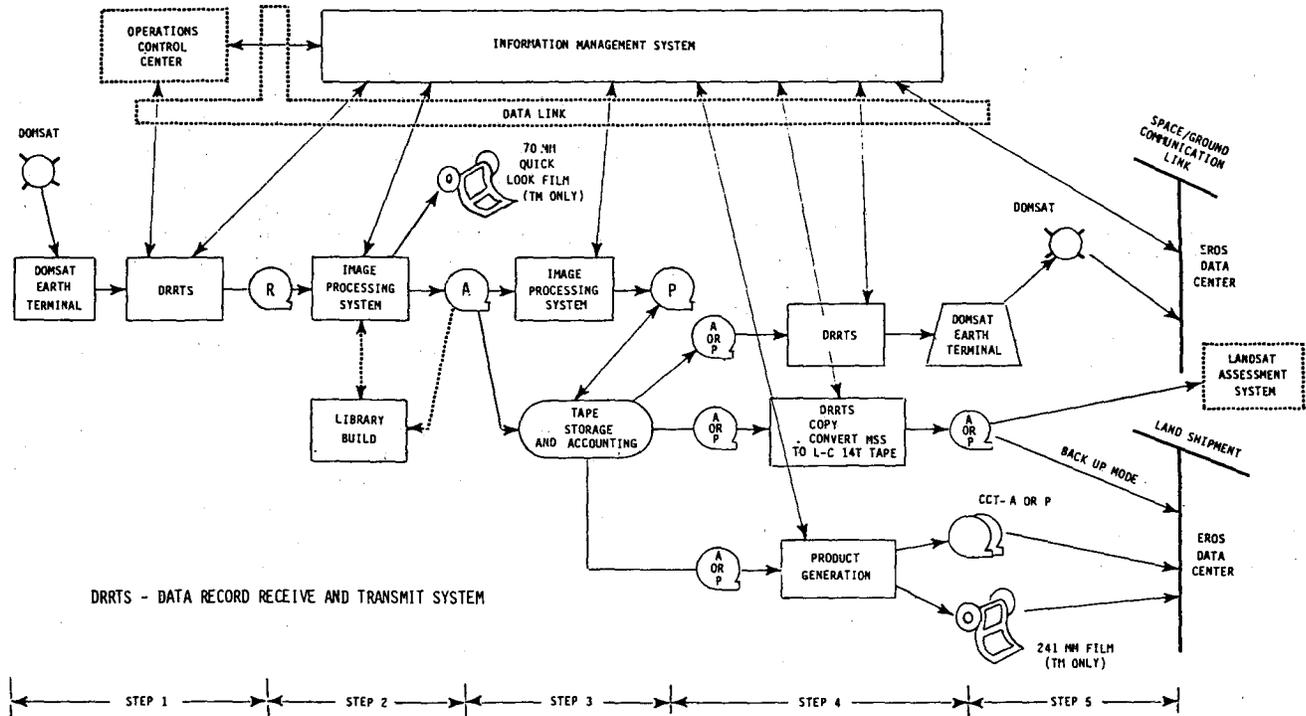


Figure 2. Data Flow Within the Landsat-D Data Management System

the following processing on the data to generate partially processed output tapes (HDT-A):

1. Reformat raw data from band interleaved by pixel (BIP) to band interleaved by line (BIL) for TM or band sequential (BSQ) for MSS.
2. Alternate scan line reversal (TM only)
3. Cloudcover assessment
4. Line dropout adjustments
5. Radiometric data correction
6. Computation of geometric correction matrices (GCM) for space oblique mercator (SOM), universal transverse mercator (UTM), polar stereographic (PS), and Lambert conformal conic (LCC) map projections.
7. Generate partially processed output high-density tapes containing radiometrically corrected data with GCM's annotated on tape but not applied to the data.
8. Generate 70-mm quick-look film of two bands of TM (band 7 plus one visible band) for quality control purposes only.
9. Extract ground control points from sensor data and load into a disc library. This process can also be performed offline.

C. STEP 3. CONVERSION OF PARTIALLY PROCESSED HDT-A TO FULLY PROCESSED HDT-P

The geometric correction process takes place within the image processing system (IPS). The HDT-A tapes are input to the IPS, which performs the following processing on the data to generate fully processed output high-density tapes (HDT-P):

1. Reformat BIL to BSQ
2. Geometrically correct data to a selected map projection using a selected resampling algorithm. Options include SOM, UTM, PS, and LCC projections and cubic convolution (CC) and nearest-neighbor (NN) resampling. The standard pipeline product that the DMS generates is in the SOM projection with CC resampling.
3. Produce fully corrected HDT-P output (geometric corrections applied).

D. STEP 4. GENERATION OF OUTPUT PRODUCTS FROM HDT-A OR P INPUTS

The PGS converts the partially processed and fully processed HDT's to output products and supports both pipeline and nonstandard product generation. The PGS performs the following processes:

1. Conversion of TM pipeline HDT-P's to 241-mm negative film masters in whole-roll form

2. Selective editing of HDT-A and P inputs to produce CCT's

3. Selective editing of HDT-A and P inputs to produce 241-mm film imagery for internal project use

4. Support routine performance analyses of DMS processing

E. STEP 5. DELIVERY OF PRODUCTS TO USERS

The current specifications for pipeline output products consist of 241-mm negative whole-roll film masters for TM data and fully processed HDT-A for MSS data. Film and HDT products are delivered as follows:

1. The 241-mm negative whole-roll film master is forwarded to the EROS Data Center (EDC) at Sioux Falls, South Dakota, where it is archived and used to support generation of a full complement of user photographic products for the Landsat user community at large.

2. MSS HDT-A tape data are transmitted to EDC by Domsat. The DRRTS element interfaces with the Domsat Earth terminal to effect this transfer. Air shipment of HDT-A tapes is provided as a contingency backup to the Domsat link.

3. Inventory data describing the contents of MSS HDT-A's and TM film rolls are transmitted to EDC by a 9.6-kbs leased data link.

4. CCT's for satisfying EDC orders for TM CCT's are delivered by air shipment.

5. Present plans are to routinely transfer the GSFC archive of MSS HDT-A tapes to EDC 6 months after acquisition.

6. Generation of nonstandard user products. User requirements for products other than standard pipeline products will require repeating either part or all of preceding processing series 3 through 5, depending on the type of product requested.

IV. DATA PROCESSING TECHNIQUES

Because of space limitations, this section will cover only those data processing techniques that are new or different from those used by the present GSFC digital image processing for Landsat-3. The processes that fall into this category are automated cloudcover assessment, control point library build, radiometric correction, and geometric correction. The following paragraphs discuss these processes.

A. AUTOMATED CLOUDCOVER ASSESSMENT

Automated cloudcover assessment is planned for TM data only, using bands 4, 5, and 7. The specific classification characteristics of these three bands that will be used in cloudcover assessment appear in Table 2.

Expected performance from the classifier in cloud/snow differentiation is summarized as follows:

<u>True State</u>	<u>Classify as Cloud</u>	<u>Classify as Snow</u>
Cloud	97.4% correct	±2.6% error
Snow	±3.6% error	96.4% correct

The predicted number of samples required for achieving 99.7-percent confidence of 5-percent accuracy in assessed cloudcover is 12,288 compares per quadrant. Cloud classification is performed on each element of subsampled 128 by 128 arrays extracted from TM bands 4, 5, and 7. The percentage of cloudcover for each quadrant is computed from this classification process. This design permits an operator to monitor the automated cloudcover assessment process and override the procedure when necessary.

B. CONTROL POINT LIBRARY BUILD SYSTEM

Library build can be supported either during pipeline processing or as an offline function. Because the library-build procedure is the same for both functions, only the offline process is explained herein. For the offline library-build process, the IPS uses as inputs the partially processed HDT-A tapes, maps, geodetic coordinates for ground-control point (GCP) location, and altitude of the control points to be entered into the library. These data are put into the computer and the library-build process takes place. Control points are selected and entered in the following manner:

1. The reference swath or orbit is input from the HDT-A, and control-point neighborhoods (CPN's) are extracted for the candidate control points to be processed. The CPN's are large enough to ensure that the candidate control points are not missed because of orbital altitude or longitudinal uncertainties.

2. By using a cursor and an interactive cathode-ray-tube (CRT) image display, CPN's are displayed one at a time for the operator to select the exact location of the candidate GCP's. All candidate GCP's are processed for the reference swath in this manner.

3. After the candidate points have been entered, the system geometrically corrects the swath. A recursive distortion estimator (RDE) is then used to prompt the operator to select additional relative control points (RCP's) to bring the total number of control points per

Table 2
Classification Characteristics

TM Band	Bandwidth (μm)	Threshold	Identifies
4 (visible)	0.76 to 0.9	Rad $\geq 2.5 \text{ mW/cm}^2\text{-sr}$	Cloud, snow, sand
5 (near infrared)	1.55 to 1.75	Rad $\geq 0.4 \text{ mW/cm}^2\text{-sr}$	Cloud, sand
7 (infrared)	10.4 to 12.5	Temp $< 5^\circ\text{C}$	Cloud

scene up to approximately 12. The geodetic location of the RCP's is computed by the RDE.

4. A 32- by 32-element array of pixels, centered about each control point (CP), is extracted from the "A" tape for each control point that is processed. These pixel arrays, referred to as chips, and their corresponding geodetic coordinates are entered into the library for use in correcting any future imagery. The retrospective library-build process is shown pictorially in Figure 3.

C. RADIOMETRIC CALIBRATION

Radiometric correction of MSS and TM sensor data is performed by using calibration data derived from a combination of the internal sensor-detector calibration system and scene content. Calibration is computed and applied independently for each detector on an image-pass segment basis. An image-pass segment is equal to a full scene. The following correction takes place for each image-pass segment:

1. Each detector response function is derived from internal calibration data (gain and bias).

2. Histograms of raw image data are generated for each detector. Using calibration data, a common radiance range is determined for all detectors in a band as shown in Figure 4. This range (e.g., RH in Figure 4) is used to truncate histograms and to avoid saturation effects.

3. Calibration gains and bias are used to adjust each detector's histogram parameters (e.g., mean and standard deviation). An average of these adjusted parameters is then determined as a calibration reference. (It is assumed that, on the average, the internal calibration is correct.)

4. By comparing each detector's adjusted parameters to the band-averaged parameters, adjustments to detector gain and bias values are determined to minimize histogram differences.

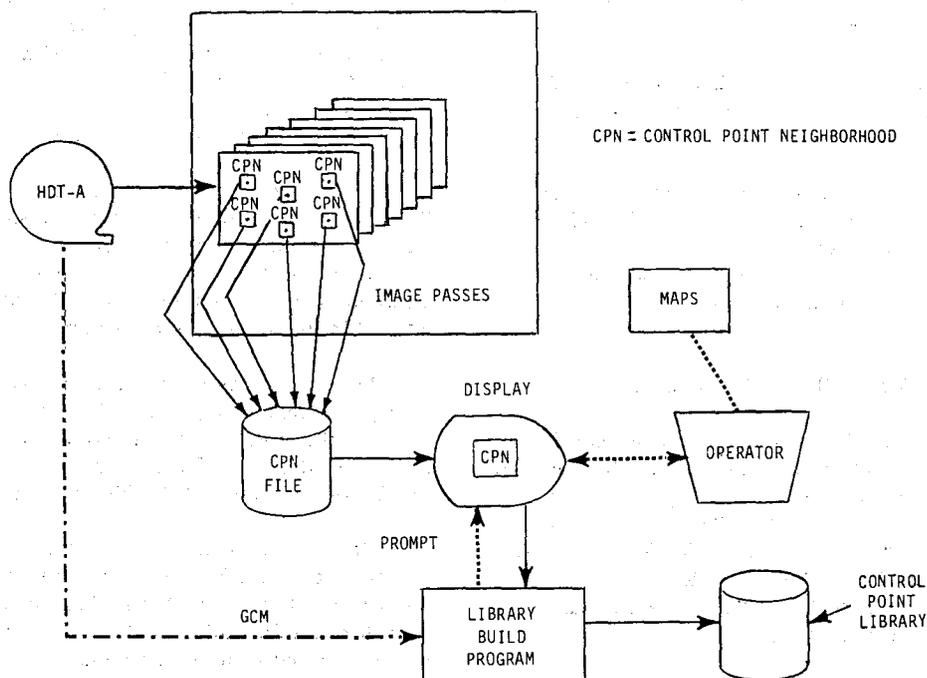


Figure 3. Library Build Offline Operations

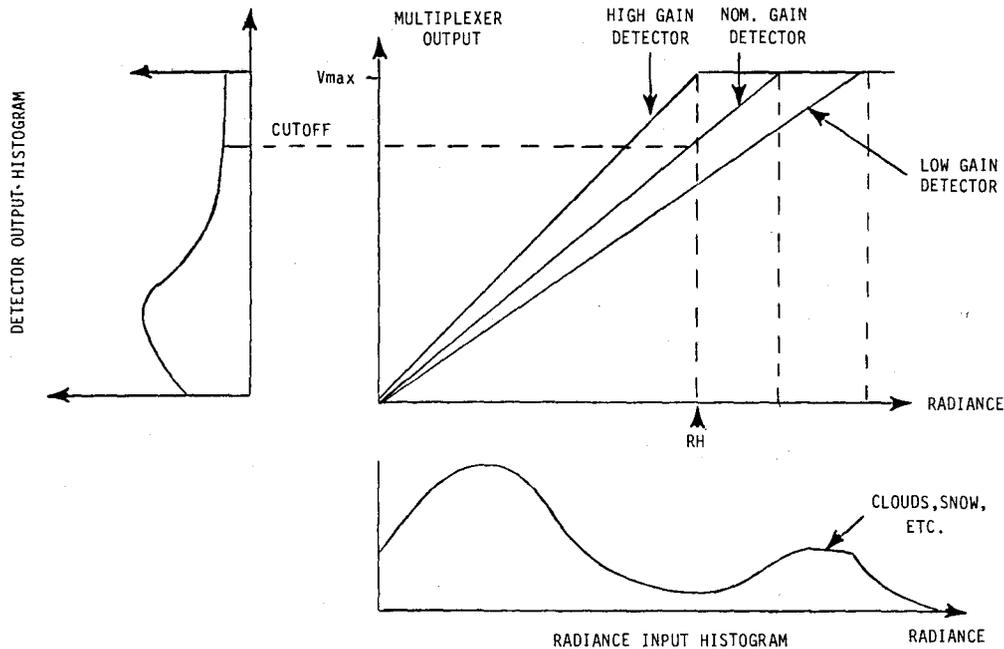


Figure 4. Detector Saturation

5. These adjusted gain and biases are then applied to the image data in producing HDT-A outputs.

The foregoing procedure is performed on an image-pass segment to avoid radiometric discontinuities between image-pass segments (especially overlap area). The gains and bias values can be filtered between image-pass segments to provide continuously variable gains and biases.

D. GEOMETRIC CORRECTION

Geometric accuracy of image data is determined by the ability to reference the location of each pixel relative to the surface of the Earth. This location reference requires an image-data to Earth-surface transformation that includes:

1. Ellipsoidal model of the Earth's surface, plus Earth rotation.
2. Location of spacecraft relative to the Earth (ephemeris data).
3. Pointing of the imaging sensor axis
 - (a) Spacecraft attitude
 - (b) Boresight of sensor axis to spacecraft axis
 - (c) Relative location of detectors and bands

4. Definition of scanning mechanism (e.g., scan angle as a function of time)

Item 1 is satisfied by standard Earth models (e.g., map geoids). Items 3(b), 3(c), and 4 are assumed to be sufficiently stable so that prelaunch measurement with minimal postlaunch adjustment will permit definition suitable to achieve desired geometric accuracy. Uncertainties in location and attitude data (Items 2 and 3(a)) are dynamic sources of error. These errors are reduced by locating points in image data for which accurate Earth locations are known ground-control points (GCP).

The location and attitude adjustment based on GCP's will be implemented by using a Kalman filter over a swath, followed by optimal smoothing. A realizable distribution of GCP's (e.g., two per frame) over a swath permits the correction of low-frequency errors in these parameters.

The accurate determination of location and attitude can then be used to identify the location of each image pixel on the surface of the Earth. From these data, image corrections required for resampling the data and producing UTM/PS, SOM, and LCC are computed. This process produces a geometric correction matrix (GCM) of points in the desired output array (e.g., TM matrix spaced 32 lines by 127 pixels). Correspondence between output and input pixel locations for all other points is determined by bilinear interpolation.

The GCM grid of pixel locations is provided on an HDT-A for each of the specified map projections. Resampled data can then be produced by using nearest neighbor (NN) or 4- by 4-cubic convolution based on the GCM mapping from input to output.

ACKNOWLEDGMENT

Special recognition is given to William Watt and Gerald Grebowsky of NASA/GSFC, who provided many of the details concerning geometric and radiometric correction techniques.

V. SUMMARY

At this writing, the Landsat-D system is in the design phase. The overall performance objectives are ambitious and, if realized, will be a giant step beyond existing programs. The viability of any program of this magnitude will lie in its ability to deliver abundant, useful, and timely data to the user community. The system performance objectives for Landsat-D are:

<u>Function/Operation</u>	<u>Performance Objective</u>
Input data quantity	200 MSS scenes/day by Domsat 100 TM scenes/day by Domsat
Radiometric error correction (relative inter-detector)	1 quantum level over full range
Geometric error correction (nominal conditions with GCP's)	0.5 sensor pixel (90% of the time)
Temporal registration error	0.3 sensor pixel (90% of the time)
Map projections	Space oblique mercator (SOM) Universal transverse mercator (UTM)/Polar Stereographic (PS) Lambert conformal conic (LCC)
Resampling	Cubic convolution (CC) Nearest neighbor (NN)
Output data media	High-density digital tape Computer-compatible tape 241-mm film
Processing throughput	2.6×10^{11} input bits per 16-hour day

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Author has been associated with the Landsat (Earth Resources Technology Satellite) project since June 1969. He was responsible in the original Landsat system design and served as Flight Operations Manager from the launch of Landsat-1 in July 1972 until August 1975 when he became Landsat Mission Operations Manager responsible for all flight and data operations. Presently serves as Landsat-D Ground Segment Manager responsible for the design and integration of the ground based systems for flight control and data processing functions.

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Author has been involved in design, operations, and management of Landsat (Earth Resources Technology Satellite) Image Data Processing since July 1972. In November 1978, he became associated with the Landsat-D project assuming the capacity of Data Systems Engineer responsible for systems design of the ground based data capture, image data processing, and Domsat relay functions for Landsat-D.