Landsat Thematic Mapper Data Production: A History of Bulk Image Processing

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ABSTRACT: Image processing for the Landsat TM is robust. The ground system was built by NASA, handed over to NOAA for operations in 1984, and made a commercial venture in 1985 when EOSAT was selected for operations for Landsats 4 and 5. International experiments, enhanced operations, and consistent quality standards for both old and new products are responsible for continued capabilities in this area. Multiple upgrades include new data products and data quality standards commensurate with changes in the philosophy from build to operation to commercial operation. The results of these tasks are integral elements of the capability today to be more responsive to customer requests than was the case at the time of launch of Landsat 5. This paper will discuss the initial production of TM data, the upgrades made by NOAA and EOSAT, and the current configuration for bulk image processing.

INTRODUCTION

LANDSAT 5 WAS LAUNCHED 1 March 1984. Prior to launch, Webb (1983) and Webb and Watt (1984) presented invited papers that described the projected image processing capabilities of the Landsat Thematic Mapper Image Processing System (TIPS). Their papers laid out the NASA design for TIPS and its expected functionality. When the image production system was transferred from NASA to NOAA in September 1984 it had been tested and declared operational by NASA. However, because its sustained production capabilities had not been tested due to monetary constraints, the last quarter of 1984 was spent in a day to day operations test mode to acquire system throughput statistics. After working through all test configurations, the ground processing system was declared operational by NOAA in January 1985. A brief summary of the final operational system's functionality was provided in a later paper (Clark, 1986). This paper contains the production flow for Landsat MSS and TM data processing used immediately after NOAA had declared the system to be operational. Since then it has been necessary to modify daily operations due to aging of both the flight and ground segments. This paper will discuss the original production flow, its changes after acceptance testing by NOAA, and later changes introduced by EOSAT to make the system more responsive to customer requirements.

BACKGROUND

The standard image production flow requires that the downlinked bit-serial data stream be converted into user products in the form of both film and Computer Compatible Tapes (CCT). Early in the program it was decided that the best production system for TM would be highly flexible. This meant that the system would be modular, would be serial in nature, and would use the most current technology available. This led to a configuration wherein the raw data could be ingested and radiometrically calibrated as the first step of production, the radiometrically corrected data could be geometrically corrected in the second step of production, and user products would be generated in the third step. In order to communicate the success or failure of any part of this process flow to a production control group, a separate system was needed that carried the database, generated product work orders, and interfaced with both the operation control center of the satellite for scheduling and with the outside world to provide production status for any scene of interest. This combination database and processing control center was called the Mission Management Facility (MMF). Finally, there had to be a method for archiving the imagery. Given the past interface with the EROS Data Center (EDC) and the successful operational interface for earlier Landsats, NASA selected EDC to act as archive for Landsats 4 and 5.

Early in the procurement cycle it was recognized that very few computers on the market could accept or ingest the 84.9 Megabit per second (Mbs) TM downlink data stream for near real time image processing. This was further complicated by the use of the Tracking Data and Relay Satellite System (TDRSS). Because Landsats 4 and 5 had no video tape recorders, the operational scheme required that, when non-USA sites were to be imaged by TM, image data were to be uplinked from Landsat to TDRSS and then downlinked to the TDRSS ground station in White Sands, New Mexico. Upon receipt in New Mexico these data were to be reformatted, uplinked to the DOMSAT satellite, and then downlinked to the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland for processing. DOMSAT linkage was to be accomplished at one-half the full bandwidth of the real time TM downlink. Thus, the designers of the image processing system were faced with the problem of accepting raw data at both the full data rate and half that rate. These communications constraints led to the hardware configuration mentioned by Webb and Watt (1984).

At the time of build of the ground segment, there were no high speed computers capable of ingesting the raw data at either the one-half or full data rates. This made the configuration for image processing unique in its architecture. The Digital Equipment Corporation's Vax 11/780 computer was selected as the primary hardware device. In addition, a special interface called the Federation of Functional Processors or FPP was designed. This FPP was constructed from the best technology available at the time, i.e., an array processor was purchased and reworked to handle the data ingest rates, image calibration, image rectification, and output rates necessary to produce image data in volume in near real time.

IMAGE PROCESSING PRODUCTION FLOW

The data flow for TM image processing illustrates how the conceptual design functioned as a working system in 1984. As illustrated in Figure 1, the user request is passed to the user services group at EDC. Periodically the Acquisition Requirements Order Tape (AROT) containing requests for data capture and image processing is transmitted to Goddard Space Flight Center (GSFC). The AROT contains delimiters such as user defined cloud cover maximum, minimum allowed sun angle, time span for acquisition, types of products desired, etc., required to drive image acquisition and production. Upon receipt of the AROT, the MMF splits out data relative to new acquisition re-

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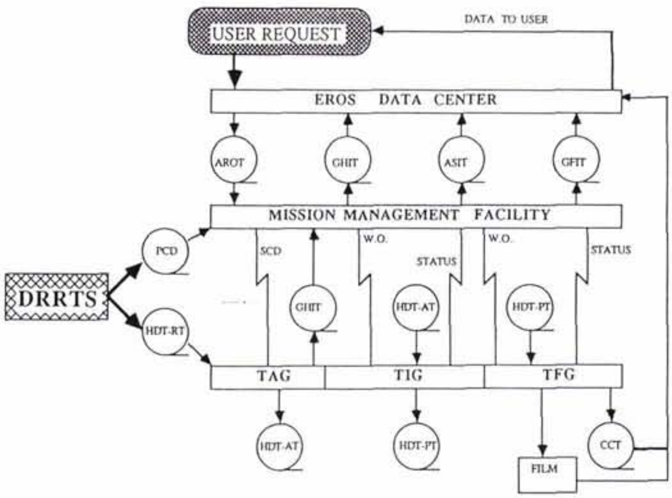

FIG. 1. Thematic Mapper image data production schematic.

quests. These are sent to the Control and Simulation Facility (CSF) where they are used as input to a model that schedules imaging for each satellite. Every day a fresh command load is uplinked. Downlinked image data are received by the Data Capture System (DCS). The DCS consists of a ten-metre antenna and multiple tape recorders. Video data are recorded on 28-track High Density Tapes (HDT). The subset of the DCS responsible for data recording is called the Data Receive Record Transmit System (DRRTS).

The downlink of video data was initially accompanied by the simultaneous downlink of a 32-kbs payload correction data (PCD) data stream. Upon receipt of the PCD, the MMF performs two stages of processing that results in scene correction data (SCD) that can be merged with the raw video. When the SCD is transmitted from MMF to the Image Processing Facility, it has associated with it a work order and a unique HDT-RT tape ID. The operator captures the SCD file and then mounts the HDT to perform the first step of image processing.

This first step – called the TM Archival Generation or TAG step – extracts video from the raw data tape, places it into a Band Interleaved by Line (BIL) format, and performs the radiometric calibration. The output from this step (the HDT-AT) consists of processed video in a swath format, i.e., framing has not yet been performed. This allows a quick evaluation of the quality of the data prior to the expenditure of the computer time required for geometric correction and framing of unwanted imagery. During TAG, geometric correction coefficients are calculated either using ground control points (GCP) or using a systematic correction. Geometric parameters and correction coefficients are appended at the end of the tape as a trailer record. At the end of this step, the MMF is notified that the scenes acquired have completed the first step of processing.

At the end of the TAG process, the Goddard HDT Inventory Tape (GHIT) file is generated for transmittal to EDC. It is read into their database and can be used by their user services group to respond to customer requests for retrospective data. The MMF then checks the completion records against quality criteria and cloud cover to determine which of the archive scenes are to be made into user products. This results in the generation of work orders for the next step in image processing.

When the work order generated by MMF is sent down to the image processing area, the operator is instructed to mount the HDT-AT and perform the second phase of processing. During this TM Initial Product Generation (TIG) step, the data are converted from their BIL format into a framed or band sequential (BSQ) format, after which geometric corrections are applied for image rectification. Each frame is designed so that the World Reference System (WRS) scene center lies somewhere along the middle mirror sweep. East and West offsets from nadir are allowed. However, they are managed by the combined satellite control and image production systems to be no larger than a nominal five kilometres. Any deviation from this range makes the use of GCPs difficult.

After geometric corrections are applied, the data are laid out on the map projection selected by the user. When no special projection is selected, the system defaults to a Space Oblique Mercator (SOM) projection. At user request, TIPS can place the image data in either a UTM or Polar Stereographic projection, dependent on scene center latitude.

It is during the TIG step that the data are resampled. During resampling either Cubic Convolution (CC) or Nearest Neighbor (NN) resampling can be applied. The default resampling scheme for products delivered to the archive at EDC is cubic convolution. Nearest neighbor resampling is performed only at user request. It should be emphasized that, after resampling, the detector to line mapping is lost. Users that want to apply their own corrections to the digital data for either radiometry or geometry are requested to order the CCT-AT. This CCT is generated from the HDT-AT immediately after the TAG processing step and is produced for the user in a unique format (EOSAT, 1985).

The output from TIG processing is a fully corrected set of images resident on the HDT-PT. Data on this tape have been framed, resampled, rectified, and registered to a map when GCPs are available. Data resident on the HDT-PT can therefore be used as input for the generation of user products. At the end of this step, the MMF is notified of scene completion status.

The scene completion status information passed to MMF after TIG processing is merged with user requests for products resident in the MMF data base. The MMF then creates work orders for the third step of production, i.e., user product generation.

User products are created during the TM Final product Generation (TFG) step of data processing. During this step product work orders and the HDT-PT are used as input. Output products include both film and CCT. Products that meet quality standards are mailed to the archive at EDC for dispersal to the user community.

Throughout this discussion of TAG, TIG, and TFG, the operational scenario has called for feedback of completion status to the MMF database at the end of each step of data processing. This feedback information consists of data relative to the unique HDT identifiers for input and output tapes, the scene IDs on each HDT, the type of processing performed for each scene, quality information for each scene, and an identifier that indicates which of the two TIPS computers processed the data. Through standard access to this database, it is possible to generate an Acquisition Status Information Tape (ASIT) file. This file can be accessed either by User Services or by the archive at any time to check the status of production for any scene in the production queue. In normal operations, the ASIT is created weekly and transmitted to EDC.

In the initial production system the philosophy was that all data would go to film that had been processed to the HDT-PT. This philosophy was altered with time, as will be discussed in later paragraphs. When operations were studied by NOAA and its contractors, it was determined that there was a volume of film that could be processed daily with up to 80 percent assurance of completion within the desired quality standards. There was also to be a smaller volume of CCT production. The lower production for CCT came from the fact that the system time needed for this step was larger than that required for any other scene production activity.

NOAA MODIFICATIONS TO PRODUCTION

PCD EXTRACTION

One of the early modifications to the image production system dealt with the production of imagery using the combined HDT-RT and the downlinked 32 kbs PCD. Due to the complexity of the instrument and the enlarged memory of the On-Board Computer, it was determined prelaunch that the imaging system could benefit by embedding the real time payload correction data in the raw image telemetry. This was the first imaging system built by NASA with this feature. It was designed to minimize cost at each ground station. All non-USA ground stations were to read in the HDT-RT, extract the PCD, perform the PCD processing step, and then go into the image production activity analogous to TAG.

During early Landsat Technical Working Group (LTWG) interface meetings and at the Landsat Image Data Quality Assessment (LIDQA) symposia, it was determined that the European and Canadian ground stations were to be the first non-USA systems capable of processing TM data. Furthermore, both were to go into production during the same year. Prior to the onset of production at either site, a joint international experiment was performed. Members of the staff of the Canadian Centre for Remote Sensing (CCRS) and the European Space Agency (ESA) were sent raw data on an HDT-RT for processing. The experimental design called for them to ingest the RT and generate user products using their new computer systems. The resulting data were then to be compared with the same imagery resident in the USA archive. The USA imagery had been generated using the downlinked 32-kbs data stream captured independently of that resident in the video. ESA was able to complete the generation of a CCT using their system within one month of data receipt. After generation of this CCT, members of staff from each of the facilities were allowed by NASA to use their Landsat Assessment System (LAS) to read in the tapes and cross-compare the data both visually and using special software. The ESA data matched that generated by the USA when factors such as the relative pixel size and the type of resampling kernel were entered into the experiment. For example, the USA standard product is resampled using cubic convolution. In addition, the 30-metre pixel — or Instantaneous Field of View (IFOV) — acquired by the TM optics is resampled during processing to 28.5 metres. Europe uses Nearest Neighbor resampling with a 30-metre pixel. This led to some misregistration due to pixel size and some due to the resampling methodology. In order to make a real comparison between the common data sets, map based ground feature points were selected and compared. Details are carried in the paper given at the XVth international congress meeting of the ISPRS by Clark *et al.* (1984) and by Fusco *et al.* (1985).

Direct comparison of the USA generated data with those of CCRS was also performed. However, the evaluation of data was not as extensive as that in the initial experiment. Instead, photographic images generated at the two sites were overlaid with no visible differences in image content feature location. As a result of the success of this experiment and the need to operate Landsat 5 in a very specific mode for non-USA ground stations, a special hardware/software system was built at GSFC for the extraction of the imbedded PCD. This system, called the PCD Extraction and Recording System (PERS), is in use today. Acceptance tests for PERS illustrated that, when the new hardware and software system extracted the imbedded PCD from the HDT, it was possible to use the extracted data to generate an SCD file compatible with TIPS. When the HDT and SCD were input to TIPS, imagery was generated that was equivalent to that produced using the downlinked PCD data. After integration of this PCD extraction system, data from the National Space Development Agency (NASDA) of Japan were passed to the USA in raw video form, the imagery were processed both at NASDA and in TIPS, and the data were then compared. The results indicated that the NASDA ground processing system and TIPS produced equivalent image data with less than one pixel misregistration. Both images were processed using the imbedded PCD. This test confirmed further that there could be compatibility in TM data processed at different ground stations around the world. Therefore, in today's production system, raw data are downlinked from the satellite and captured on HDT. The HDT is read into the PERS, the PCD are extracted, and the remainder of the production flow is unaltered. This gives the USA ground station operational compatibility with the remainder of those in the world.

INTERFACE BETWEEN GSFC AND EDC

Early in the design for the image production facility, it was felt that processing status data should be transferred from the GSFC site to EDC using nine-track tapes. These were to be used for both the AROT and ASIT. In addition, a third tape, the Goddard Film Inventory Tape (GFIT), was to be generated and mailed to EDC with each film shipment. The GFIT was to be used to load the film database at that facility. These three tape types were to be implemented at the time of production startup. However, due to time, improved technology, and cost, the operational scheme was changed. Multiple conferences between operations personnel at GSFC and EDC led to a format amenable for data transfer using Decnet rather than tape for the AROT/ASIT pair. The GFIT remained a tape. Both film and GFIT were mailed daily to EDC.

FILM PRODUCT CHANGES

Early film products for the Landsat 5 TM were not compatible with standard MSS infrared false-color composites. Therefore, an experiment was carried out (Clark and Johnson, 1985) that assured that film products made from MSS equivalent bands for the TM matched those generated for MSS. This encompassed the collection of data from both instruments simultaneously, the evaluation of common features in each image, and the remapping of the digital values for TM onto film response curves that matched those used for MSS. The film study was done to satisfy the largest customer group, namely, those that were used to the imagery in infrared false-color hues. It also was performed with no impact to the TM digital radiometry.

VOLUME THROUGHPUT REDUCTION

The initial system was designed with specific production goals. These were to produce 100 HDT-AT scenes per day, 50 HDT-PT scenes per day, 50 scenes to film each day, and ten CCTs each day. The analysis of production over a three-month period indicated that this level of production left no room for rework and very little time for standard engineering preventative maintenance. Therefore, the volumes were reduced to emphasize the production of the HDT-AT for all acquisitions, the production of HDT-PT only for those data that met cloud cover constraints, the production of no more than 30 scenes to film each day, and no more than ten CCTs daily. CCT production was to be driven by the user community.

EOSAT CHANGES TO PRODUCTION

The system was transitioned from NOAA to EOSAT in 1985. After NOAA transferred the system over to EOSAT, further changes in the production system were implemented. These efforts were designed to streamline the production flow and make the system respond in a more timely fashion to customer requests.

CUSTOMER SERVICES

One of the first activities designed to make the system more responsive to user requests was to implement a user services group that operated from the EOSAT headquarters building in Lanham, Maryland. This group took over the function of the EDC group and leads its activities today. At the current time it is possible for customers to order data from the archive at EDC or directly from the production facility through the EOSAT User Services organization in Maryland.

COMMUNICATIONS PROBLEMS (LANDSAT 4/5)

Early in the life of Landsat 4 it was determined that there was a problem with the solar array. Due to thermal stress fractures in the cables connecting elements of the array, two panels of the array were lost before an operational scheme was developed that saved the satellite. Because there was no knowledge relative to the expected lifetime for this satellite, Landsat 5 was launched in 1984, two years ahead of schedule. Prior to this loss, which impacted the daily power available for imaging, it had been determined in February 1983 that both the primary and redundant X-band transmission electronics had failed. Therefore, in 1983 Landsat 4 was viewed as a system capable of the generation of MSS data and downlink via S-Band but capable of Ku-band only activities for TM. Non-USA stations could not receive TM, the MSS data was noisy at some digital levels, and the length of the mission was in doubt. Because the total power available due to solar panel damage was below that required for a full TM mission, the user community was told by NOAA that the system could not image using this instrument. This left Landsat 4 in an "MSS only" configuration relative to imaging.

After the successful launch of Landsat 5 in 1984, the user community had the capability to view the same point on the Earth using both MSS and TM simultaneously. The quality of the MSS data for Landsat 5 was better than that for Landsat 4 due to upgraded electronics that removed the noise in MSS data. TM data acquired by Landsat 5 were also of better quality. The imagery was brighter and some of the Landsat 4 anomalies were not present. However, TM for Landsat 5 did have some radiometry problems that were corrected by NASA prior to the turnover to NOAA (Markham and Barker 1985).

At the time of launch, NOAA had declared that the TM would be operational for Landsat 5 only. Because the quality of the MSS data for Landsat 5 was superior to that of Landsat 4, worldwide requests for MSS imagery using Landsat 5 quickly outpaced those for Landsat 4. This left the production staff with a Landsat 4 satellite capable of imaging with MSS yet facing decreasing demands for Landsat 4 MSS data from users worldwide. This decrease in demand allowed time for a systems engineering evaluation of the on-board electronics and the potential of reviving the Landsat 4 TM for emergency situations.

It was known at the outset that the power balance was critical. The energy received by the remaining panels of the solar array was just enough to operate the TM – but in a degraded mode. In this mode the instrument design temperature could not be maintained and the data captured was initially suspect. Evaluation of the data illustrated that the difference was as much subjective as it was scientific. However, for daily operations, the charge/discharge cycle used for the on-board batteries could not be maintained with the solar array in its standard position. For this reason special computer code and new instructions for the On-Board Computer (OBC) were developed and tested using a simulator. After one year of experimentation, it was determined that the Landsat 4 system for imaging using TM could be brought back on-line at a very much reduced imaging rate. This mode was attempted several times during the following year to gather data that was of special importance to Landsat data users. With each attempt new information was gathered relative to the on-board electronics, the depth of charge allowed for operations, and other factors. Eventually, through the integration of new software and improved operations, it became possible to collect up to 50 combined MSS and TM scenes each day. As these data were in their final stages of evaluation, it was determined that the Ku band for Landsat 5 was not functioning as designed. Multiple experiments led to the conclusion that the operational Traveling Wave Tube Amplifier (TWTA) was functional but had a problem with overheating. This led to a series of experiments illustrating that the use of Landsat 5 Ku band was not as stable as desired. For this reason the number of scenes taken daily was decreased and extra efforts were expended to understand how to bring Landsat 4 back on-line.

When the Landsat 5 Ku band started to fail with increasing frequency, a new operational scenario was developed. The X band for Landsat 4 was not operational but Ku band was functioning as designed. The X band for Landsat 5 was operational. However, the Ku band was only marginally functional. Therefore, in order to satisfy the largest contingent of EOSAT customers, it was decided that the operational scenario would use Landsat 4 for non-USA scenes and Landsat 5 for direct downlink data. This was accomplished with no impact to worldwide operations.

PHOTO PROCESSING

In 1987 it was known that there would be a potential problem with photo production. By that time the Laser Beam Recorders had gone through multiple upgrades yet were unable to maintain the original specification for all data at the desired throughput rate. Furthermore, the quality of the image data was not compatible with that available from newer systems such as the MacDonald, Dettwiler and Associates Ltd. Color Fire 240. When NASA announced that its photographic laboratory would close in 1989, operations steps were taken by EOSAT to transfer this function to an outside vendor. In today's production flow for photographic products, TIPS is used to generate a CCT, the CCT is used to drive the Fire 240, and the user receives first generation color film products. Although this increases the total image processing time for film products, it has consistently produced a product that is superior to that generated using the older method.

NEW CCT PRODUCTS

The original format for the CCT was defined in 1983. In this format a full TM scene is broken into four quadrants with non-overlapping video. Four 6250 bits per inch (bpi) tapes are created for the full scene. Each quadrant contains the full seven bands of video data and ancillary information in a format designed by the LTWG (EOSAT, 1985). In the EOSAT era it was determined that the CCT were not serving the user community as well as desired with this single format. Therefore, a full frame format was designed that conforms to the LTWG format standard but places the data on three 6250 bpi tapes. Each tape contains up to three bands of full frame image data. Details relative to the new format are available from EOSAT.

SUMMARY

The ground processing system remains robust. However, today's configuration for image processing differs from that designed by NASA, accepted by NOAA, and initially implemented by EOSAT. The current production system is user driven and maintains data quality at or above that delivered in the initial system. This has been accomplished through multiple changes in the day-to-day operational scenario. As the system ages further, other changes can be expected to be necessary. Response to future change requirements will be designed to assure that the worldwide group of Landsat data users continues to receive the best quality products available.

REFERENCES

Clark, B. P., 1986. Landsat Data Production Past, Present, and Future; *International Archives of Photogrammetry*, Vol. 26-2, pp. 241–250.

Clark, B. P., L. Fusco, and J. Murphy, 1984. Comparison of TM Ground Stations: Similarities and Differences in Image Products; Invited Paper, XV Congress Meeting, International Society for Photogrammetry and Remote Sensing.

Clark, B. P., and A. J. Johnson. 1985. Creating an Optimized Color Balance for TM and MSS Imagery, *1985 ACSM-ASPRS Fall Convention, Technical Papers*, pp. 821–832.

EOSAT, 1985. *User's Guide for Landsat Thematic Mapper Computer-Compatible Tapes*, Earth Observation Satellite Company, 4300 Forbes Blvd., Lanham, Md.

Fusco, L., U. Frei, and A. Hsu, 1985. Thematic Mapper: Operational Activities and Sensor Performance at ESA/Earthnet; *Photogrammetric Engineering and Remote Sensing*, Vol. 51, pp. 1299–1314.

Markham, B. L., and J. Barker (Editors), 1985. *Photogrammetric Engineering and Remote Sensing*, Volume 51, Special LIDQA Issue.

Webb, W., 1983. The Landsat Program: An Overview: *Landsat 4 Science Investigations Summary*, Volume I, NASA Conference Publication 2326, pp. 1–14.

Webb, W., and W. M. Watt, 1984. The Landsat 5 System: Description and Preliminary Assessment; *International Archives of Photogrammetry and Remote Sensing*, Volume XXV, Part A2, Commission II, pp. 506–532.