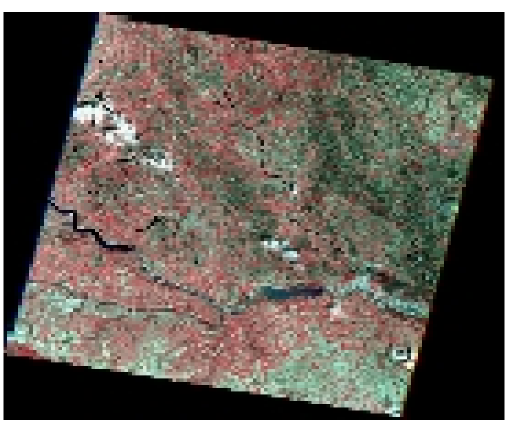
LANDSAT 7 PROGRAM REPORT

FY 2000

U.S. Department of the Interior
U.S. Geological Survey

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EXECUTIVE SUMMARY

On April 15, 1999, after six years of development, Landsat 7 was successfully launched from Vandenberg Air Force Base in California. The launch marked a new era in land remote sensing and, building on nearly thirty years of observation, offers the global science community a valuable information resource.

Four days after the launch of Landsat 7, the first image, of the southeastern South Dakota area, was acquired. The data were sent directly from the satellite to the receiving capability at the USGS' EROS Data Center near Sioux Falls, SD, and fulfilled the long-standing goal of real time reception of data over North America.

Landsat 7 was declared operational for data acquisition on June 29, 1999. Additional time was required to complete testing and implementation of the customer information and product generation systems, and product generation and distribution to users began in mid-September 1999.

The sensor aboard Landsat 7 (the Enhanced Thematic Mapper+ [ETM+]) is compatible with those from previous Landsat satellites. The 15m panchromatic band of data from Landsat 7 offers additional capability to the science community.

The tremendous success of Landsat 7 as a data source for earth science became clear during its first fifteen months of operation. The 250 scenes per day delivered to the U.S. archive, plus the 300 scenes transmitted to the international ground station network, represent a major source of quality earth science observations.

The Landsat 7 program produces and distributes two levels of Landsat 7 data products. Level 0R data are essentially unprocessed image data. These images have been reformatted to perform scan line reversal, but no radiometric or geometric corrections have been applied. Level 1 data products have had radiometric (Level 1R) or radiometric and geometric (Level 1G) corrections applied. User access to the Landsat 7 archive can be accomplished through two search and order systems, the Earth Data Gateway (EDG) and Earth Explorer.

From the very beginning, coordination with international ground receiving stations has been an integral element of the Landsat Program. During the first fifteen months of Landsat 7 operations, seven International Cooperators, representing 13 ground stations, signed agreements with the USGS for the reception, archiving and distribution of Landsat 7 data. These agreements require each cooperator to support a bi-lateral data exchange. As of September 30, 2000, the end of the first fifteen months of Landsat 7 operations, more than 138,000 Landsat 7 scenes were received by the operational ground stations. In fiscal year 2001, 4 International Cooperators, representing five ground stations, are expected to sign agreements with the USGS.

In recognition of the delegation of the Landsat program to promote private sector capabilities in remote sensing, the managers of the Landsat 7 Program are working closely with the private sector to assure users the best possible access to Landsat 7 data archives. In that spirit, through workshops, conferences, and partnership agreements, Landsat 7 Program managers have solicited advice and critiques from their private sector colleagues. Twenty-one organizations have signed agreements to serve as USGS Business Partners to facilitate user access to Landsat 7 data and to higher order derivative image and information products.

Landsat 7 has proven, in just over a year of operation, to be an important resource and a success. The data quality remains high, the acquisition rate is superb, and the global science community has welcomed this robust source of quality data.

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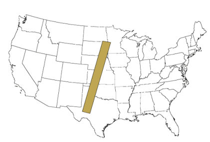

Image 1: This continuous strip of data represents the first pass of data collected by Landsat 7 on April 18, 1999.

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INTRODUCTION

The Landsat Program was established in 1969 through a joint initiative of the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA). NASA was assigned responsibility for developing and launching the spacecraft and sensor and operating the spacecraft, while the USGS was assigned responsibility for archiving the images acquired and for producing and distributing data products. In July 1972, the first "land sensing satellite" (originally the Earth Resources Technology Satellite, later renamed Landsat 1) was launched. Landsat 1, with the Multi-Spectral Scanner (MSS) instrument, was highly successful, and Landsats 2 and 3 were launched in 1975 and 1978, respectively, to provide data continuity for Earth science research and resource monitoring.

After seven years of operation, program management changes were directed by issuance of a Presidential Decision Directive in 1979. The National Oceanic and Atmospheric Administration (NOAA) was assigned responsibility for overall program oversight, and for transferring management and operation of the Landsat Program to the private sector. Landsats 4 and 5, launched in 1982 and 1984, respectively, brought a new sensor to the program, the Thematic Mapper. In 1985, to initiate transfer to the private sector, NOAA implemented a government contract with a commercial operator (EOSAT, Inc.) to operate the on-orbit Landsat 4 and 5 satellites and to build and launch two additional satellites, Landsats 6 and 7, to ensure data continuity. In addition to the well-established sensors on previous Landsats, the new generation would carry the Enhanced Thematic Mapper (ETM) instrument.

By 1989, with Landsats 4 and 5 operational for both MSS and TM instruments and Landsat 6 still in the development phase, EOSAT determined that it was not commercially viable to develop and operate a Landsat 7 mission. The resulting Congressional debate over the future of the Landsat Program resulted in the Land Remote Sensing Policy Act of 1992 (Public Law 102-555), which returned responsibility for development and operation of Landsat 7 to the Government under a tri-agency management team consisting of NASA, the Department of Defense (Air Force) and the USGS. In the fall of 1993, Landsat 6 failed to reach Earth orbit, exacerbating the issue of data continuity, since the likelihood of continued operation of Landsat 4 and 5, already well beyond their design life, was regarded as doubtful. In 1994, the Department of Defense withdrew from the Landsat Program and NOAA was reinstalled as the operational manager of Landsat 7 (Presidential Decision Directive NSTC-3, May 5, 1994).

In late 1998, NOAA, NASA, and the USGS agreed to revise the Landsat Program management team to include only NASA and the USGS. NASA retained responsibility for completing the development and launch of Landsat 7. The USGS assumed responsibility for management of all ground data reception, processing, archiving, product generation, and distribution. Additionally, the USGS agreed to assume Landsat 7 flight operations beginning October 1, 2000. The Presidential Decision Directive reflecting this management agreement was signed on October 16, 2000.

On April 15, 1999, Landsat 7 was successfully launched from Vandenberg Air Force Base. Shortly thereafter the first Landsat 7 image was acquired at the EROS Data Center. By June 29, on-orbit checkout was completed, and Landsat 7 was declared operational for data acquisition. Product generation and distribution to users began in mid-September 1999.

Image 2: Landsat 7 launch, April 15, 1999

This report documents the accomplishments of the Landsat 7 Mission during the first fifteen months of production operations, nominally October 1, 1999 through September 30, 2000, plus the initial data acquisition period that began July 1, 1999.

MISSION GOALS

The primary objective of the Landsat 7 Mission is to ensure collection of consistently calibrated Earth imagery throughout its five-year design life. Landsat 7, true to its design characteristics, has successfully satisfied the following goals during the first year of operation:

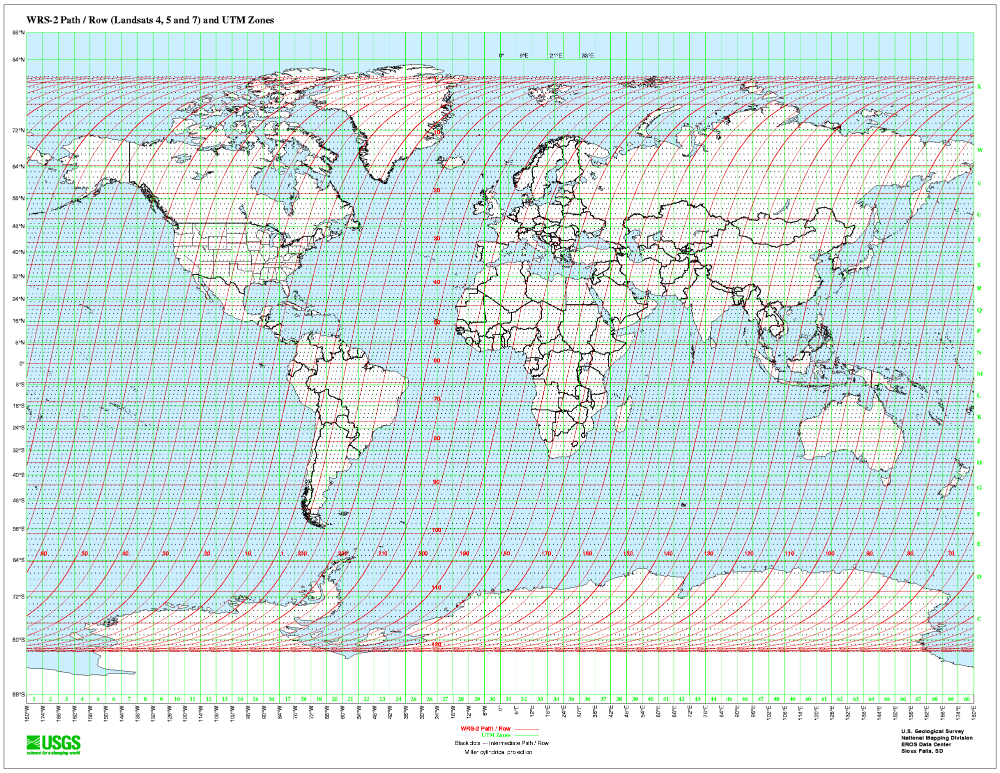


Figure 1: WRS 2 path/row grid

Global Survey Mission: To establish and execute a data acquisition strategy that ensures repetitive acquisition of observations over the Earth's land mass, coastal boundaries, and coral reefs; and to ensure the data acquired are of maximum utility in supporting the scientific objectives of monitoring changes in the Earth's land surface and associated environment. The Landsat 7 Program is continuing to use the Worldwide Reference System (WRS), originally developed to serve as a data indexing and access aid for preceding Landsats. However, in addition to its use as a customer aid for data searching, the Landsat 7 Program uses the WRS grid (Figure 1) as an index to the data base to maintain the historical acquisition history for each scene location of the world, and to plan future acquisitions, in order to execute the Landsat 7 global mapping objective. ***Landsat 7 has acquired, processed, and archived approximately 250 scenes per day for the U.S. Landsat archive and has delivered approximately 300 scenes per day to the international cooperator network.***

- **Data Continuity:** To ensure that Landsat 7 data are acquired, characterized, and processed to ensure compatibility and consistency of application with Landsat data provided by previous missions. ***Shortly after launch Landsat 7 was maneuvered to underfly Landsat 5 in order to collect nearly simultaneous observations of several test sites worldwide.***

Subsequent comparison of these data indicates that Landsat 7 images are clearly consistent with those acquired by Landsat 5.

- **Product Availability:** To ensure that products derived from the global archive are produced and distributed in a timely manner at the lowest possible cost, nominally at Cost of Fulfilling User Requests (COFUR), as mandated by the Land Remote Sensing Policy Act of 1992**.** ***The Landsat 7 Program distributed more than 12,000 full scene products in the first fifteen months of operation, typically shipping the requested product in less than 48 hours after receipt of order.***

- **Data Calibration and Characterization:** To provide Landsat data products that exhibit improved calibration characteristics, and ensure that data collected are closely evaluated and monitored in order to detect any anomalies in instrument, spacecraft, or ground processing systems performance*.* ***Through the work of the image data quality team, the availability of the Image Assessment System, and the support of the Landsat Project Science Office, Landsat 7 data are more completely and thoroughly calibrated and characterized than for any previous Landsat.***

- **International Cooperator Network:** To continue the United Nations "open skies" policy adopted by previous Landsat missions by acquiring Landsat 7 observations of non-U.S. landmasses and delivering those data to ground stations operated and managed by international cooperators. ***Agreements were negotiated and signed with International Cooperators, and twelve associated ground stations became operational by October 1, 2000***

PROGRAM MANAGEMENT

The Landsat 7 Program is managed under guidelines established by the Management Plan for the Landsat Program, signed March 21, 2000 by the Associate Administrator, Earth Science Enterprise, NASA and the Director, USGS.

Under the terms established by this agreement, NASA was responsible for the development and launch of the Landsat 7 satellite and the development of the associated ground system. Hughes (now Raytheon) Santa Barbara Remote Sensing (SBRS) developed the ETM+ instrument, while Lockheed Martin Missiles and Space (LMMS) developed the Landsat 7 spacecraft. Computer Sciences Corporation, Honeywell, and Raytheon personnel developed various elements of the Landsat 7 Ground System. The USGS is responsible for the operation and maintenance of the Landsat 7 program and for transition of Landsat 7 data to the National Archive upon completion of the mission. Honeywell and Raytheon provide operational support of spacecraft flight operations, ground data reception, archival processing, and production elements of the ground system, respectively.

Image 3: Building 32, Goddard Space Flight Center, Greenbelt, Maryland, home of the Landsat 7 Mission Operations Center

The Landsat Project Office at the NASA Goddard Space Flight Center (GSFC), Greenbelt, Maryland managed Landsat 7 development. NASA also established the position of Landsat Project Scientist at GSFC and supports the Landsat Science Team, consisting of principal investigators responsible for scientific investigation and application of Landsat 7 data. In addition, to facilitate USGS assumption of mission operations responsibility, an agreement was reached for NASA to provide interim mission operations support for FY 2000 until the USGS could secure appropriations to support spacecraft operations. Shortly after launch, operations responsibility was transferred to the Earth Science Missions Operations Office.

Image 4: U.S. Geological Survey's EROS Data Center

The Landsat 7 Program provides oversight for the Landsat 7 Data Handling Facility (data reception and processing), the Land Processes Distributed Active Archive Center (Level 0R data archiving and product distribution), and product generation systems (Level 1 data archiving and product distribution). Figure 2 illustrates the complex, yet effective, mission configuration and the wide-ranging organizations with major data handling responsibilities

SCIENCE SUPPORT

Landsat observations have contributed to a virtual revolution in earth science research, revealing the importance of remotely sensed images for monitoring the patterns and processes that define the Earth's land areas. In fact, the science and technology introduced by continuing Landsat missions have provided a primary stimulus for current interest in earth system science and global change investigations, in particular the role of land conditions and dynamics in the Earth system.

The quantity and geographic extent of data acquired during the first fifteen months in orbit, nearly 40% of which are virtually cloud-free, combined with the quality of the imagery, represents a major source of quality data for Earth science research. Early scientific investigations suggest that Landsat 7 has indeed emerged as a cornerstone for the U.S. land remote sensing program.

Beginning with the inception of the Landsat 7 Project in 1993, the Landsat Project Science Office spearheaded the specification and development of both the scientific characteristics of the Landsat 7 mission, and the creation of monitoring tools required to evaluate and quantify those characteristics. In addition to overseeing development of the ETM+ instrument and its various calibration features, the Science Office initiated design and development of an Image Assessment System to provide tools for quality assessment of Landsat 7 images. The Science Office also initiated and managed development of a strategy for planning and executing acquisition of Landsat 7 images required to support the Landsat 7 global mapping objective. Science Office personnel work in conjunction with quality assessment personnel at EDC to monitor, analyze and report on the performance of the ETM+ sensor and provide improved calibration parameters and algorithms for the ground processing system. The principal focus of their activities during this reporting period included characterizing the performance of the Internal Calibrator, the Partial Aperture Calibrator, and the Full Aperture Calibrator, as well as enhancing the calibration of all of the ETM+ spectral bands. Specific contributions of these calibration features are discussed later in this report.

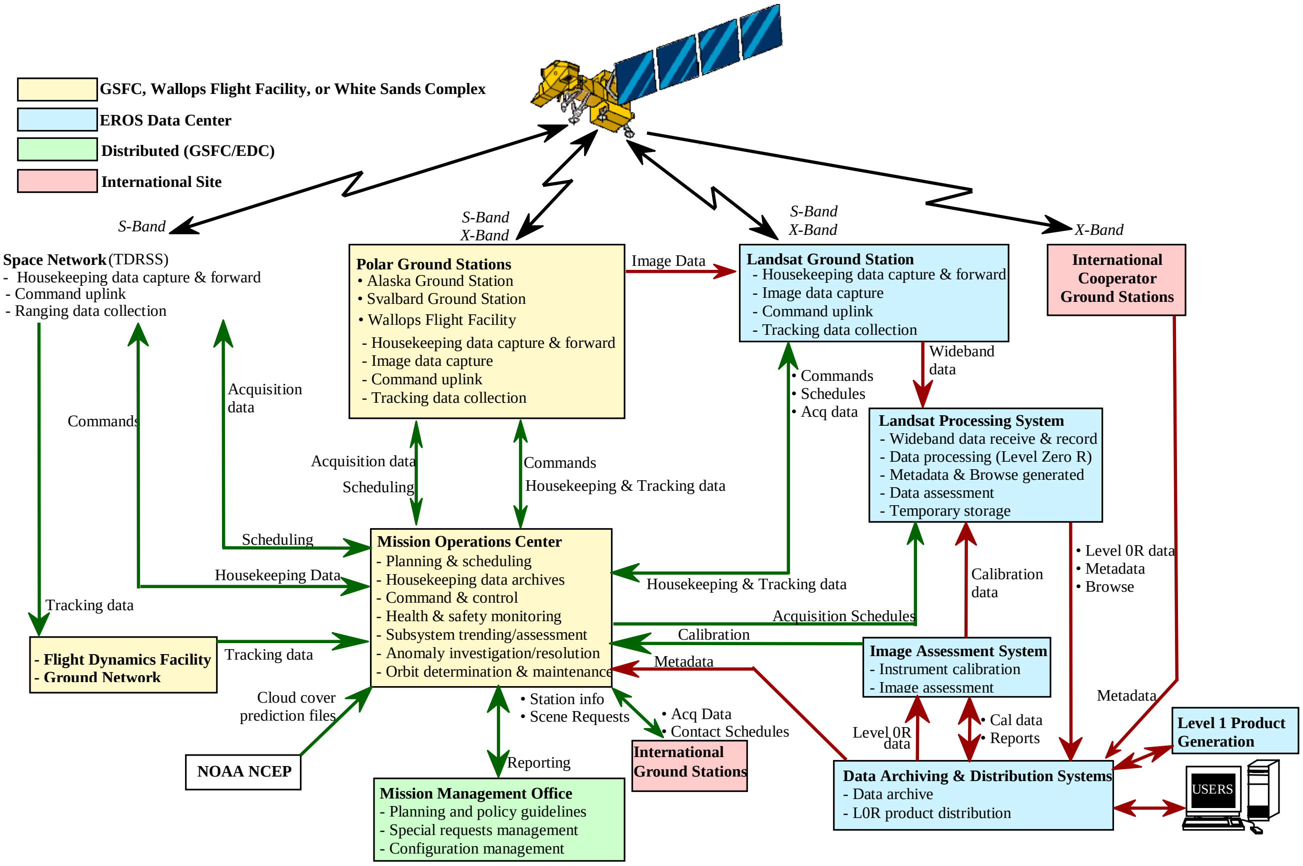


Figure 2: Landsat 7 Mission Configuration

SYSTEM COMPONENTS

Spacecraft

The spacecraft is, in itself, a complete system that transmits and receives data required to carry out the primary mission of land observation imaging, provides power to onboard hardware components, and maintains attitude. These functions are managed in conformance with the specifications of the World Wide Reference System, under control of the onboard spacecraft control processor. These functions operate as separate subsystems for nominal control of the spacecraft during normal, special, and contingency operations**.** During the first year of operation, all subsystems performed nearly flawlessly. All performance parameters indicate that the spacecraft will meet or exceed its design life of five years.

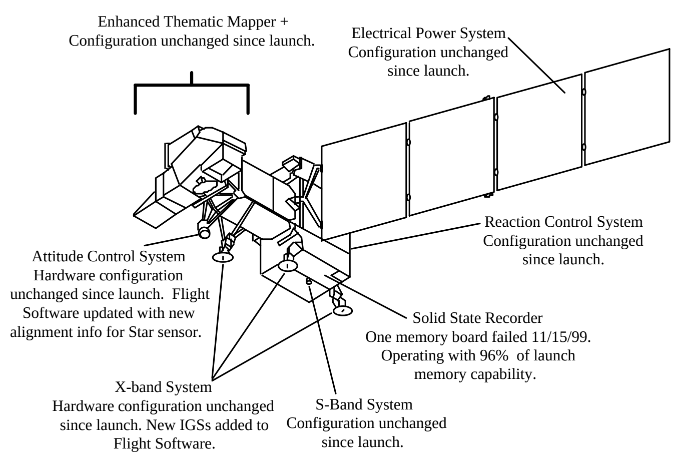


Figure 3: Landsat 7 Subsystem Status

Landsat 7 is commanded to execute orbital maintenance maneuvers as necessary in order to maintain the appropriate Landsat Worldwide Reference System (WRS) ground track for successful imaging. A typical orbital maneuver, referred to as a "delta velocity" or Delta V maneuver, is required to ensure that Landsat 7 maintains the proper orbital altitude**.** Delta V maneuvers were executed at (nominally) two-week intervals.

Another, more significant maneuver is referred to as a "delta inclination" (or Delta I) maneuver, required approximately once per year to ensure that the Landsat 7 spacecraft maintains its proper position with respect to the WRS ground track. The first Delta I maneuver was performed in November 1999.

Image 5: Mission Operations Center, Maryland

To ensure that all Landsat 7 spacecraft subsystems continue to operate within nominal conditions, several investigations were initiated to continually monitor and analyze specific performance characteristics observed in the first years of operation of the Solid State Recorder, ETM+, and spacecraft power subsystems.

All systems within the satellite are in their original post launch configuration and all Failure Detection and Correction System elements are active. The solar array and batteries in the Electrical Power Subsystem are performing well within expected limits. Attitude control and determination have exceeded the specific values by a wide margin and propulsion usage is consistent with mission specifications.

While the overall satellite performance has been excellent, there have been a limited number of noteworthy anomalies. The Solid State recorder, the first of its size to fly, has performed extremely well but has caused some concern. One memory board has been turned off (one of twenty four) because it malfunctioned. Also, a number of unexpected 'features' have required changes in operational procedures. Another area of concern is an intermittent interruption in the Electrical Power System. For a period of a week, telemetry showed a drop in current equivalent to the loss of one solar array string. As suddenly as the anomaly appeared it disappeared. It is believed that there was a short in the system that burned through, though no definitive answer has been found.

Enhanced Thematic Mapper Plus (ETM+)

The ETM+ instrument has performed exceptionally well, from the acquisition of the first image within four days after launch, through the on-orbit initialization and verification phase, and throughout the first fourteen months of data acquisition. Execution of the image acquisition strategy described under Data Acquisition and Archiving later in this report has demonstrated virtually error-free instrument performance. In addition, the ETM+ instrument has provided high quality data in quantities that exceed any of the previous Landsat missions.

Mission Operations

The Mission Operations Center (MOC) is located in Building 32 on the campus of the Goddard Space Flight Center. MOC personnel are responsible for planning and scheduling functions required for command and control of the Landsat 7 spacecraft and instrument, both to ensure health and safety of the on-orbit asset and to execute the global data acquisition plan for the mission.

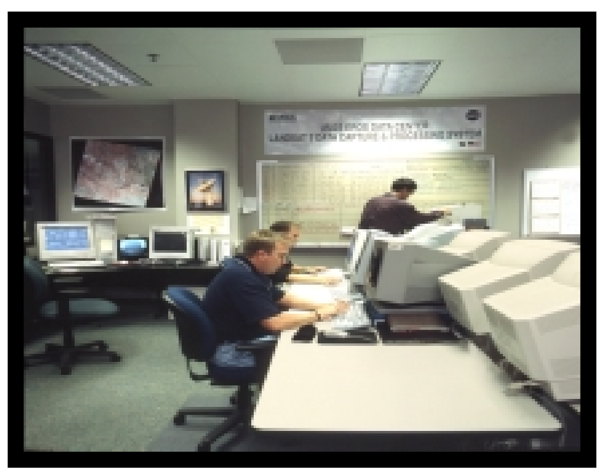


Image 6: Landsat 7 Data Handling Facility, SD

Image 8: EDC Distributed Active Archive Center

Image 9: Landsat secondary archive

Landsat Data Reception and Processing
The Data Handling Facility (DHF) is located at the EROS Data Center. DHF personnel are responsible for supporting the EDC ground station as well as ensuring the acquisition and processing of all data downlinked to EDC and processing of all data downlinked to other U.S. ground stations that are shipped to EDC.

Data Archiving
The EDC Land Processes Distributed Active Archive Center (DAAC), located at the EROS Data Center, is responsible for Landsat 7 data archiving. DAAC personnel are responsible for ingesting and managing all images acquired by Landsat 7 and processed by the DHF, and for managing the inventory metadata and browse image files for access by the user community.

Archive Management
The Landsat Archive Manager (LAM) at EDC is used to provide storage for the backup archive of raw Landsat 7 subinterval files, and to provide a secondary production archive. LAM personnel are responsible for ingesting and preserving the backup archive of unprocessed Landsat 7 data, and for providing Landsat 7 data files to USGS National Archive systems for product generation.

Product Generation
Both the Landsat Product Generation System (LPGS) and the National Landsat Archive Production System (NLAPS) produce Level 1 products. The LPGS is capable of producing up to 100 full scene products per day, either radiometrically corrected only, or both radiometrically and systematically corrected for geometry. NLAPS is capable of producing an additional 100 full scene products per day, but also includes precision and terrain correction features for added geometric accuracy.

OPERATING CONSTRAINTS

Landsat 7 operations management requires a significant amount of planning to maximize global acquisition of Landsat scenes. The ETM+ instrument duty cycle, the three steerable downlink antennas, the capacity of the Solid State Recorder, and the capacity of the ground data processing system must be considered when determining the amount of data that can be downlinked to U.S. and international ground receiving stations.

Duty Cycle: The design specification for the Landsat 7 ETM+ sensor duty cycle allows a maximum of 300 minutes of operation within a 24-hour period. The current operational duty cycle has been reduced to 240 minutes for a 24-hour period in order to ensure that no negative effects occur due to heat build-up on the spacecraft. In addition, the following duty cycle constraints also apply:

(1) limit of 34 minutes for a single orbit, including night time acquisitions;
(2) limit of 52 minutes for any two consecutive orbits;
(3) limit of 131 minutes for any six orbits; and
(4) limit of 15 minutes per orbit for nighttime operations.

These limitations on duty cycle are the most significant of the operational constraints that must be managed. Landsat 7 Program Management personnel are investigating, with the manufacturer, options for increasing the available duty cycle, and therefore the amount of data that can be captured and downlinked to the ground station network.

Solid State Recorder (SSR): The SSR provides the unique capability for the Landsat 7 mission to acquire multiple observations of virtually every element of landmass in the world, except for the Polar Regions, and return these observations to the U.S. archive. The SSR is designed to store a maximum of 100 Landsat scenes at any given time. However, in any given day as many as 210 scenes may be incrementally acquired and stored temporarily while awaiting the opportunity to playback data to one of the U.S. ground stations**.** Recorded data are not available for downlink to International Cooperators.

GXA Antennae: Landsat 7 data are transmitted, either during real-time data acquisition or when playing back the contents of the SSR (or both), to ground stations using one or more of the three gimbaled X-band antennas (GXAs) on board. Generally, two data streams, one for real-time acquisition and one for SSR playback, or two for SSR playback, are downlinked simultaneously when the spacecraft is within the coverage circle of a U.S. ground station. Any or all of the three X-band antennas can also transmit to International Cooperator ground stations, depending on the receiving frequency (ies) of the respective ground station(s), and assuming lack of any conflict with a U.S. ground station. To date there have been very few examples of data lost due to antennae conflicts.

Ground Data System: The U.S. ground data capture system is designed to ingest and archive, throughout the five year design life of the mission, an average 250 full scenes each day, plus the associated partial scenes at the beginning and end of each subinterval. While actions are underway to remove or relax this restriction, current planning and scheduling parameters are applied to adhere as closely as possible to this limitation.

ETM+ MTF Characterization: The Modulation Transfer Function (MTF) of the ETM+ has been closely monitored. Discoveries made during pre-launch testing indicated that the MTF of the instrument, although within specifications at the time of launch, might slowly drift out of specification as the telescope structure outgases and ages on-orbit. Using the long causeway bridge across Lake Ponchartrain, Louisiana, as a test target, successive images of the bridge have been analyzed and trended to monitor the minor changes to MTF that have occurred since launch.

Results have determined that all bands were within or right at the MTF specification limits during the monitoring period. Band 8 appears to have very little margin, and is in the most danger of slipping past the MTF specification limits. Comparisons indicate that initial on-orbit analyses are consistent with the findings of prelaunch thermal vacuum measurements. To date the general trend has been in the direction predicted by Santa Barbara Remote Sensing, the builders of the system, although the magnitude of the degradation has been smaller than initial predictions. It also should be noted that relative performance of bands are generally the same. The on-orbit MTF estimates are slightly higher (better) for most bands (except band 8). A comparison to Landsat 5 shows similar performance. Some bands (1, 2 and 3) are about the same; some (4) are better on L5, and some (5 and 7) better on L7. The present models suggest that half of the total degradation has already occurred in the first year of on-orbit life. By the end of life, bands 4 and 8 are predicted to be out of spec.

These operating constraints, when combined with the requirement for satisfying the U.S. data acquisition plan, require a significant amount of planning and management attention to maximize the quantity of Landsat 7 scenes to be delivered to the combined receiving capabilities of both the U.S. and International Cooperator ground stations. During the first fifteen months of operations, no significant conflicts have been encountered while delivering data to the currently operating ground stations. However, as additional requirements for ground station support materializes, the Landsat 7 Program will most likely be required to limit support for additional ground stations. The Landsat 7 Program will continue to investigate the actual and potential management tradeoffs of duty cycle, SSR capacity, antenna availability, and ground data system capacity, and the impact of these factors on the amount of Landsat 7 data that can be delivered to the ground station network.

DATA ACQUISITION AND ARCHIVING

The goal of the Landsat 7 Mission is to maximize the acquisition of Landsat 7 images of the world, while equitably balancing the mission requirements of the U.S., the interests of international cooperators, and opportunities for the private sector. To satisfy the global mapping objective of the Landsat 7 Program, approximately 14,000 individual scene areas (or path-rows) are considered candidates for repetitive observation. During any given day, approximately 850 of these scenes can be considered as candidates for acquisition. Based on the operating constraints described earlier, the ETM+ is able to image approximately 450 candidate scenes in a typical day.

During a typical day of operations, approximately 250 scenes are delivered to the U.S. archive, while approximately 300 scenes are delivered to international ground stations (approximately 100 scenes are directed to both the U.S. archive and the international ground station community each day). To manage this complex acquisition strategy, the Landsat 7 Program utilizes the WRS grid (see Figure 1) as an index to a database of areas to be imaged and employs a modeling strategy to determine which 250 scenes to collect each day for the U.S. archive**.** This strategy is embodied in the Landsat 7 Long Term Acquisition Plan (LTAP).

The goals of the LTAP are, to the maximum extent possible, to ensure annual global land coverage, capture seasonal change, and avoid acquiring cloud-contaminated imagery. To achieve these goals a scheduler algorithm is used to select the "best" 250 scenes each day. The scheduler determines which scenes to acquire by assigning a priority ranking to each candidate scene area. The priority is calculated using

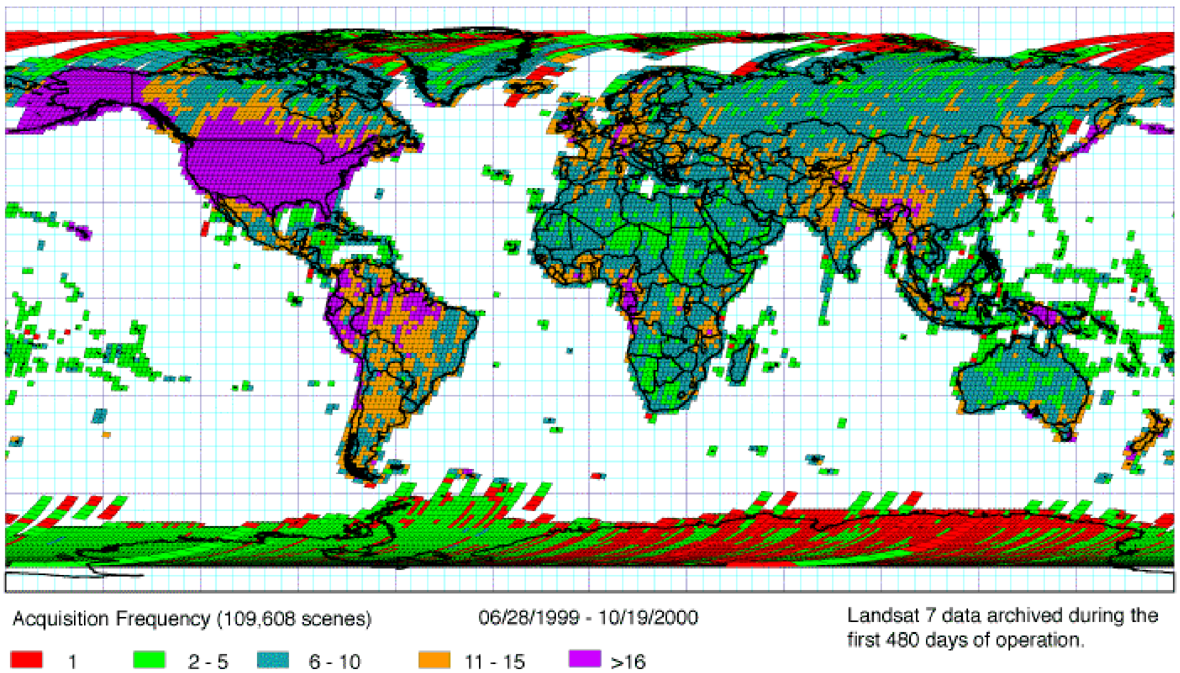


Figure 4: Density of Landsat 7 data acquired by the U.S. archive during the first fifteen months of operation.

information that includes when the scene was last acquired, the quality of the last acquisition, how the cloud cover predicted for that scene compares with the historical norm and how well an acquisition captures seasonal change. In addition to this overall global mapping objective, the operating constraints described earlier in this report (duty cycle, GXA antenna availability, SSR capacity, and ground data system capacity) must also be factored into the acquisition strategy. Over the course of this reporting period, even while absorbing the impacts of initiation of operations, this process populated the U.S. archive with approximately 109,000 scenes. Figure 4 illustrates the success of the LTAP strategy in acquisition of imagery of the landmasses of the world.

Scenes acquired through the LTAP strategy are received from Landsat 7 by a network of three U.S.-operated ground receiving stations. The primary US ground station is located in Sioux Falls, South Dakota. Two other U. S. stations are located at Poker Flat, Alaska and Svalbard, Norway. All three stations receive both real-time imagery and recorded imagery.

During normal operations, the station in Sioux Falls receives an average of 140 scenes per day. Approximately 40 of those are of the conterminous U.S.

Figure 5: U.S. ground receiving stations for Landsat 7 data downlink.

The polar stations (Poker Flat and Svalbard) receive the remaining 110 scenes, representing real-time acquisition of Alaska and international coverage acquired by the SSR.

The scenes received in Sioux Falls are typically added to the archive in less than 24 hours. Scenes received at the polar stations are captured on magnetic tape and shipped to Sioux Falls for processing and archiving, typically resulting in a three-to-five day delay in processing and archiving.

INSTRUMENT CALIBRATION

The ETM+ Internal Calibrator provides data regarding both short-term and long-term radiometric stability. Short-term stability, i.e., within an ETM+ turn on cycle (maximum of 31 minutes), has been studied using several special acquisitions where the instrument and calibration lamp are on continuously and data are acquired regardless of cloud cover. The ETM+ lamp should be warmed up and stable within 1 minute of turn on; however the data show that the response to the lamp continues to decrease well after the nominal 1 minute warm up and never totally stabilizes. This lack of stabilization is one limitation on the use of the internal calibrator for calibrating ETM + data. A model of the lamp that includes current and temperature effects is being developed to correct an Internal calibrator lamp sample that has been acquired anywhere along the warm up curve to “constant” conditions. Another limitation of the Internal Calibration for ETM+ calibration is its long-term stability. For example, initially the response of the ETM+ band 1 channel dropped by about 15%, however, once the instrument was in its normal operational mode, the response to the Internal Calibrator stabilized. Again, the intent of the ongoing effort is to understand the behavior of the Internal Calibrator so that it will be useful for providing calibration information for the ETM+ over the mission lifetime.

The Partial Aperture Solar Calibrator (PASC) is least understood of the on–board calibration systems. This device reflects the direct sunlight through a small (4 mm diameter) aperture into the ETM+ system allowing the ETM+ to image the Sun. The Landsat Project Science Office (LPSO) has studied several aspects of the PASC. First, these images were not appearing in the imagery at the locations they were expected. An analysis of the data indicated that a minor misalignment of the PASC could account for the discrepancy, and an adjustment was made to the processing software to correct the problem. The major problem with the PASC, however, is that the signal responses have increased over time to such an extent that the center of the solar disk now saturates, even in the low gain state for bands 1-3, 8. This increase has been as large as 60% and clearly does not reflect a change in ETM+ response. Band 4, though it does not saturate, has increased about 60% in response to the PASC. Band 5 and 7 responses vary widely in response and trends between detectors. The extent of the variation has rendered the PASC data currently unusable for ETM+ calibration. Studies continue in cooperation with SBRS, the instrument manufacturer, to understand the source of the failure. The current hypothesis is that the front surface of the uncoated silica plate that reflects sunlight into the reduced aperture has become contaminated.

The Full Aperture Solar Calibrator (FASC) is a diffuser panel that can be deployed in front of the ETM+ aperture. Data from this device are acquired approximately monthly. Figure 6 shows band 1 results to date. Two anomalies are evident in the data: (1) there is about a 5% discrepancy between the initial calibration achieved with the FASC in band 1 post launch relative to the pre launch calibration, and (2) the response to the FASC has decreased with time. The 5% discrepancy can be explained by a deviation of about 1 degree in the angle of deployment of the FASC relative to the angle measured prior to launch. The time location of the sunrise on the FASC panel is also consistent with a 1-degree deviation. The change in response with time is evident in bands 1-4 and 8 and appears related to some change in the surface of the FASC panel, with the change larger on one side of the panel than the other. The change in band 1 is about 2%/year; the maximum occurs in band 4 at about 4%/year. These changes are again believed related to the FASC, not the instrument response itself, but they do provide a bound for the amount of instrument change that could be occurring. The LPSO staff are working with the contamination engineering group at GSFC to try to understand these changes.

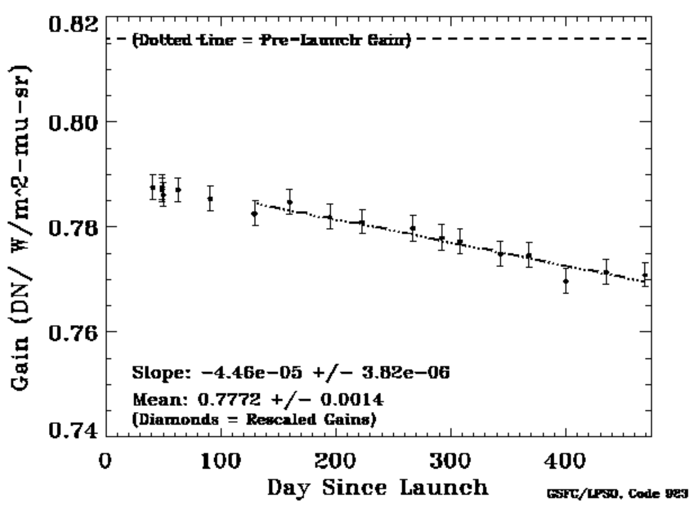


Figure 6: ETM+ Band 1:FASC low gain average

Band 6 (thermal band) calibration has been analyzed by two of the Landsat 7 Science Team investigators using vicarious calibration methods. Science Office personnel and EDC data quality team members have been involved in these analyses, and have also performed analyses of the calibration using the Internal Calibrator. The ETM+ band 6 response to the Internal Calibration system (blackbody and shutter) has been extremely stable over time. This contrasts with the behavior of the Landsat-5 band 6 sensor, where response to the Internal Calibrator decreased rapidly, and required outgassing at periodic intervals to maintain adequate sensitivity. The overall stability of ETM+ band 6 is valuable as scientists attempt to understand its calibration. The results of the vicarious calibration indicate that though the instrument may be quite stable, there is a consistent bias of about 0.31 W/m^2 sr microns in the absolute calibration. The user community has been alerted to this bias. The LPSO and the Image Assessment System team are working to remove this bias from the calibration processing and to improve the residual striping in the band 6 imagery.

The ultimate goal of the analysis of the various on-board calibration devices (IC lamps, PASC, and FASC) is the radiometric calibration of the reflective bands (bands 1-5, 7, and 8). To date all indications are that the instrument is more stable than any of the calibrators. This is inferred by the lack of consistency in the trends of the ETM+ response to the various calibrators; however, the confidence in the stability of the ETM+ is limited by the stability of the calibrators**.** The calibration of the ETM+ reflective bands has been updated several times since launch. First, the pre-launch absolute calibration of bands 1–4, based on an analysis of the Landsat Transfer Radiometer calibration data, was updated with the July 1, 2000 release of the calibration parameter file. Second, pre-launch calibration of all reflective bands was updated to bring the ratio of the high to low calibration coefficients into agreement with post launch measurements of this ratio. Finally, the relative detector-to-detector gains within a band were adjusted to reduce striping. A one-day workshop was held in May 2000, where the results of various scientific investigations were compared with the pre-launch and post-launch calibrations performed by LPSO and quality assessment personnel. Results of these comparisons were generally consistent to within about 5% of the pre-launch calibration coefficients currently used for data processing and are suggestive that the instrument is being calibrated to this level of accuracy and stable with time.

DATA QUALITY

The overall radiometric and geometric quality of Landsat 7 data are superb. The data delivered to users from EDC meets or exceed all quality requirements expected from this satellite. Due to improved ground pointing of the satellite, and excellent ground processing and calibration tools in the Image Assessment System (IAS), the geometric characteristics of Landsat 7 data dramatically exceed specifications. The requirement for 250 meter absolute geodetic accuracy (one sigma) levied on Landsat 7 Level 1 systematic products before launch has been exceeded by up to a factor of five for most products produced by the Program to date, with typical geodetic accuracies on the order of 50 meters (one sigma).

Data quality analysts at EDC have responsibility for monitoring the quality of data entered into the Landsat 7 archive. The analysts work closely with the science staff to investigate and detect anomalies. The team carries out this responsibility through several work activities, using the IAS as the primary suite of analysis tools. Data quality analysts routinely examine approximately 10 scenes per day, randomly selected from the data entering the archives. Analysts also evaluate specific calibration scenes acquired over known ground targets**.** Finally, special imaging opportunities are requested to support calibration purposes using the calibration results described in the ETM + Instrument Calibration section of this report**.** The results of these calibrations are stored in a large trending database that extends over the life of the mission. This database is then used to analyze trends in the sensor's performance, develop ongoing calibration coefficients for the data, and predict sensor performance in the future.

In addition to the subset of Landsat 7 scenes analyzed and trended by the IAS team, the trending database receives similar data from each scene selected for generation of a customer product. The extraction of performance parameters from the combination of IAS sampling and the much larger volume of production scenes populates the database with sufficient data to support a thorough characterization of the Landsat 7 archive. To date, detailed calibration has been performed on more than 3,000 individual Landsat 7 scenes, and trending data have been extracted and archived from the 12,000 scenes produced for customers. These data are continuously monitored by LPSO and EDC quality analysts. As a result, Landsat 7 is by far the most completely characterized instrument of the Landsat program. Figure 7 illustrates the geographic extent of this quality management database.

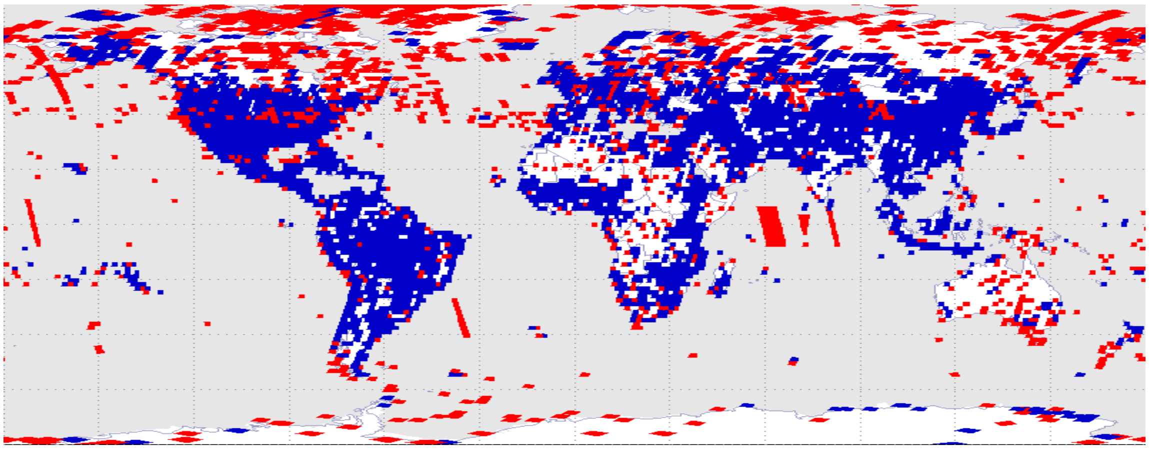


Figure 7: All scenes trended in the IAS Database - IAS scenes in red, Level 1 product scenes in blue

From these detailed data, the IAS team produces up-to-date calibration parameters used to produce final products for users of Landsat 7 data. Each Calibration Parameter File (CPF) contains over 15,000 individual coefficients used to calibrate and control the Landsat 7 image and associated metadata, ensuring that the data delivered to customers is of the highest scientific quality, reliability and usability. An updated CPF is released quarterly (or more often if required) to reflect any subtle changes in instrument performance. Nine "current" CPFs are archived, representing nine periods since launch, and are used when products from the respective period of acquisition are requested. Each period-specific CPF may be updated as better understanding of instrument performance allows improved calibrations to be issued. Each CPF release is also provided to each international ground station for utilization in its local image processing systems.

Anomaly Investigations: Several data anomalies have been detected that originate on board the satellite. The IAS Team at EDC assisted scientists in the LPSO and satellite engineers at the MOC in the investigation and analysis of these various anomalies. Short descriptions of these anomalies are given below. It must be noted that the overall effect of these anomalies on the total Landsat 7 data archive is exceedingly small, given that less than one tenth of one percent of the scenes acquired are affected.

Scan Mirror Anomaly: This anomaly is caused by a loss of synchronization between the various scanning mechanisms in the ETM+ instrument. The anomaly has been investigated by a team of engineers from the Science Office, EDC, the MOC, and Santa Barbara Remote Sensing. The example at right shows the effects on imagery that can occur from these anomalies. This anomaly has occurred approximately 82 separate times since launch, representing less than .05 % of the scenes acquired.

Clearly, this scene is not usable; however**,** due to its infrequent occurrence, this anomaly is not believed to pose any long-term problems to the ETM+ or the Landsat 7 mission.

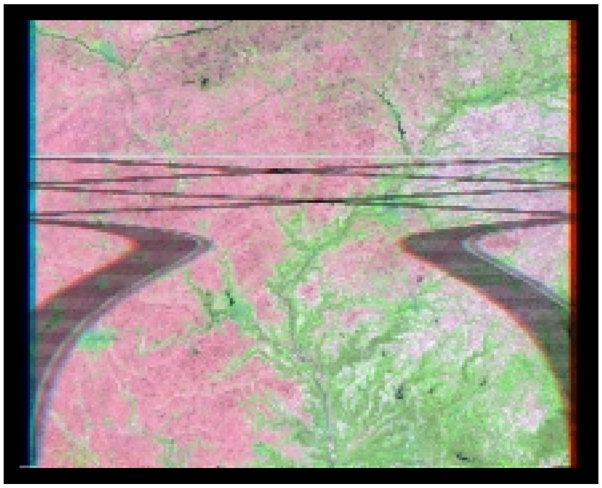


Image 9: Scan Mirror Anomaly

This anomaly has been replicated on the ground using engineering systems at the instrument manufacturer's facility. The cause is still unknown, but is believed to be related to solar particles in the exoatmosphere at Landsat 7's orbital altitude. This was most dramatically confirmed on July 14, 2000, when an exceptionally large eruption on the surface of the sun bombarded the Earth with a sudden particle flux 10,000 times higher than normal in a matter of minutes. No less than twelve scan mirror anomalies resulted from this massive radiation spike over the next 24 hours, an extraordinary rate of occurrence. Virtually all scan mirror anomalies have occurred in areas near the Polar Regions or over the South Atlantic Anomaly, all areas of higher space radiation due to the distribution of the Earth's magnetic field. The South Atlantic Anomaly is centered off the southeastern coast of Brazil where the Earth's magnetic fields dip unusually low, allowing the Van Allen Radiation belts to dip much closer to the Earth, resulting in a region of high concentration of solar protons.

Late-Start Anomaly**:** First witnessed on August 28, 1999, a succession of twenty-three anomalies occurred through January 20, 2000 and then inexplicably stopped. The anomaly involved an abnormally long start-up time for the ETM+ instrument. Typically the ETM+ is commanded "ON" nearly a minute before imaging begins to allow the scanning mechanisms to all come into synchronization, and allow electronics and calibration lamps to warm up. For some unknown reason during each of these anomalies the ETM+ had not achieved synchronization before actual imaging began, sometimes requiring up to a full minute to achieve lock and normal operations. This initial imagery during this "unstart" period resembled the loss of synchronization shown in Image 9, and rendered these scenes unusable also. Although investigated by

SBRS, IAS, and MOC personnel, there is still no understanding as to what may have caused this problem. Further investigations are on hold until such time that this anomaly reappears.

Detector-Specific Noise Spikes: Although quite minor in their effect on data (so far only seen in Band 1, Detector 9 and the Pan Band, Detector 14), these noise spikes may offer a clue into other low-level noise sources in Landsat 7 data. The profile of an example noise spike affecting one detector along one scan is illustrated in Figure 8.

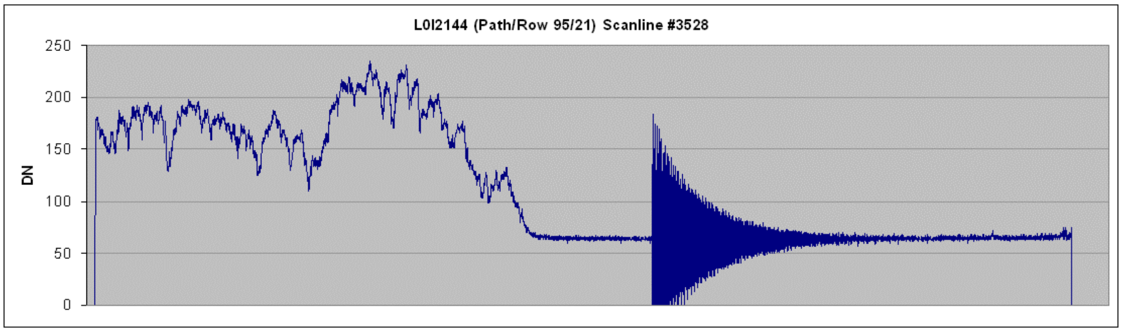


Figure 8: Example of Detector-Specific Noise Spike

This sudden noise spike contains an internal frequency that may offer clues to other areas of instrument performance and may actually help better understand the performance of the ETM+. These spikes do not represent a significant impact or threat to Landsat 7 data.

Solar Proton Noise: This is another effect on Landsat imagery caused by "space weather" and charged particles from the Sun. These tiny spikes of noise affect only a handful of pixels and were not even detected by the IAS until almost a year after launch. Further in-depth searches of the IAS database revealed more examples and an obvious geographic clustering of these anomalies around the South Atlantic Anomaly.

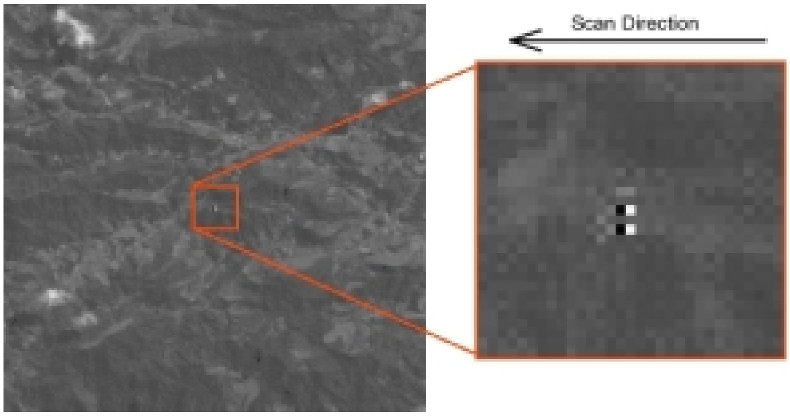


Image 10: Example of proton noise in image.

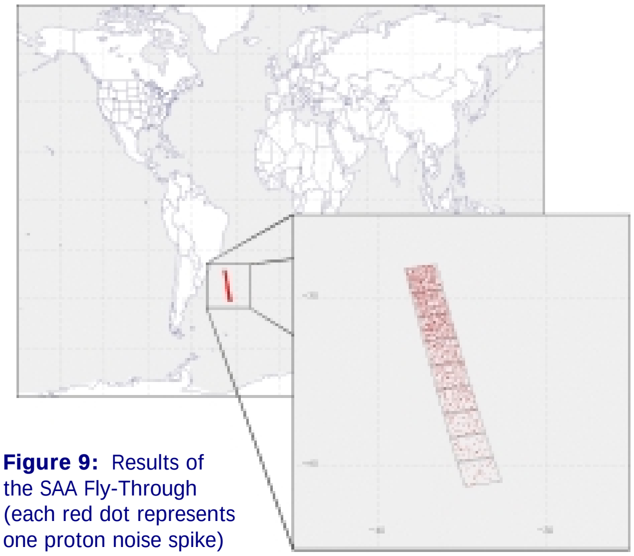


Figure 9: Results of the SAA Fly-Through (each red dot represents one proton noise spike)

To test this theory the data quality team requested a special imaging collection at night through the heart of the South Atlantic Anomaly. The results mapped very well with known levels of proton flux in these regions and confirmed that these are indeed the results of protons affecting the ETM+ system over this region of the globe. These tiny spikes are quite minor and are not anticipated to have any lasting effect on the satellite or the mission. The effect on the data is quite minimal and expected to have little or no impact on the scientific usability of the data.

Scan Mirror Life Expectancy: The data quality team also monitors the wear on the scanning mechanism within the ETM+. The scanning mirror bumpers that stop mirror travel at the end of each scan are known to wear as they have in previous Landsats. Due to the heavier imaging load placed on Landsat 7, the bumpers are predicted to wear faster than those on Landsat 5 and be a potential limiting factor to the life of the mission when synchronization with the scanning mechanisms is no longer possible. The IAS Team monitors the scan mirror and corresponding bumper wear and maintains a prediction for the possible end-of mission date due to permanent loss of synchronization. Recent data predicts an end-of-life near the end of 2007.

DATA ACCESS, PRODUCTS, AND DISTRIBUTION

User access to the Landsat 7 archive for identifying and ordering products can be accomplished through either of two systems. The Earth Data Gateway (EDG), developed under contract to access NASA's Earth Observing System (EOS) archives, allows searching for Landsat 7 data as well as multiple EOS data types in multiple EOS Distributed Active Archive Centers (DAACs) around the country. Level 1 products ordered through EDG are processed using the Level 1 Product Generation System (LPGS), also developed under contract to NASA.

The second search and order system, developed under contract to the USGS around a commercial off the shelf software product, is called Earth Explorer. Earth Explorer allows cross-inventory searches of multiple date sets in the USGS archive, including Landsat 7, Landsats 1 through 5, and other satellite and non-satellite USGS data collections. Level 1 products ordered using Earth Explorer are processed through the National Landsat Archive Processing System (NLAPS), also developed under contract to the USGS.

Table 1: Landsat 7 Product Suite

Product	Description	Format	Media	Price
Level 0R	Image data as transmitted from the satellite, processed into "pixels"	HDF	8mm, ftp	$475
Level 1R	L0R data input, radiometrically corrected, gain and bias applied, no scan correction applied	HDF	8mm, ftp, CD	$600
Level 1G	L0R data input, radiometrically and geometrically corrected, map projection applied	HDF, GeoTIF, FastL7a	8mm, ftp, CD	$600

The Landsat 7 program produces and distributes two levels of Landsat 7 data products. Level 0R data are essentially unprocessed image data. These images have been reformatted to perform scan line reversal, but no radiometric or geometric corrections have been applied. Level 1 data products, on the other hand, have had radiometric (Level 1R) or radiometric and geometric (Level 1G) corrections applied.

In addition to the "standard" product described above, the Landsat Program also has the capability to develop precision-corrected (using ground control) and terrain-corrected (using terrain models) products to improve image geometry. These systems are used only to develop a limited suite of products, and only for selected research and applications projects, as additional processing is widely available from the value-added community.

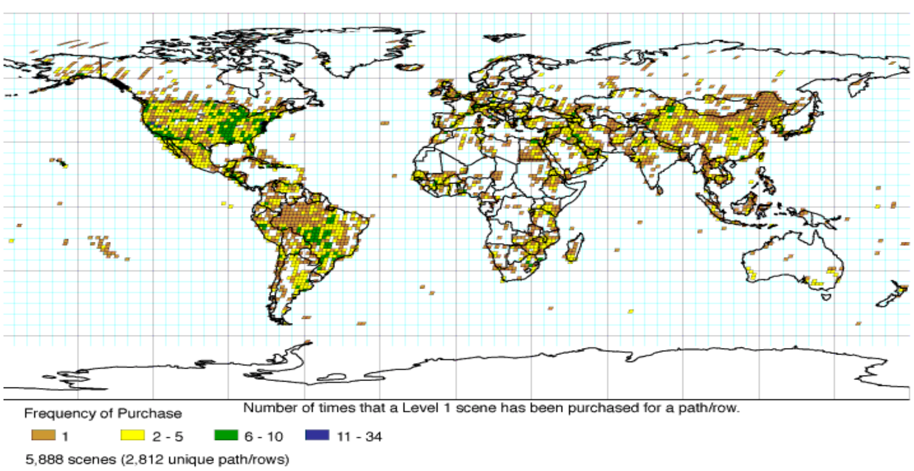


Figure 10: Frequency and distribution of product order by WRS Path/Row through 6/2/00.

During the first fifteen months of operations over 12,000 scenes were distributed from the U.S. archive. The distribution of geographic location of the scene products ordered during the first nine months of production, illustrated in Figure 10, clearly shows the global interests of the Landsat 7 user community. In this first fifteen months of operation, U.S. Government agencies have been the leading consumers of Landsat 7 data. The general category of "international users," defined as having a shipping address outside the United States, is second; however, a large number of users in academia and private industry have exhibited an interest in Landsat 7 data, purchasing one or two scenes each. It is this emerging user community that has given rise to an optimistic future for broader distribution and application of Landsat 7 data products.

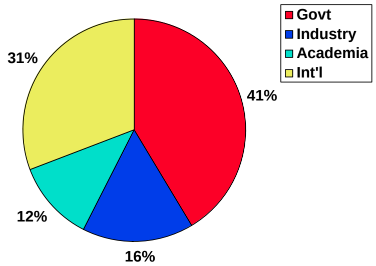


Figure 11: Distribution of product orders by customer category

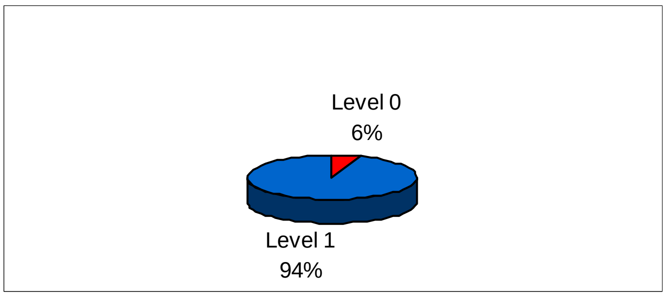


Figure 12: Product Preference

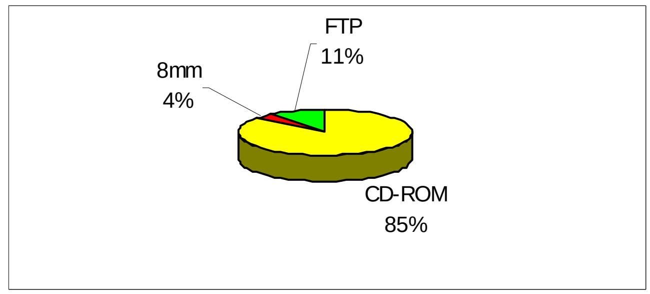


Figure 13: Product Format Preference

INTERNATIONAL COOPERATION

From the very beginning, coordination with international ground receiving stations has been an integral element of the Program. International Cooperators (IC) have been receiving, archiving and distributing Landsat data since the first Landsat, partnering initially with NASA for Landsats 1, 2, and 3, with NOAA during the Landsat commercialization period (Landsats 4-5), and now with the USGS for Landsat 7. During

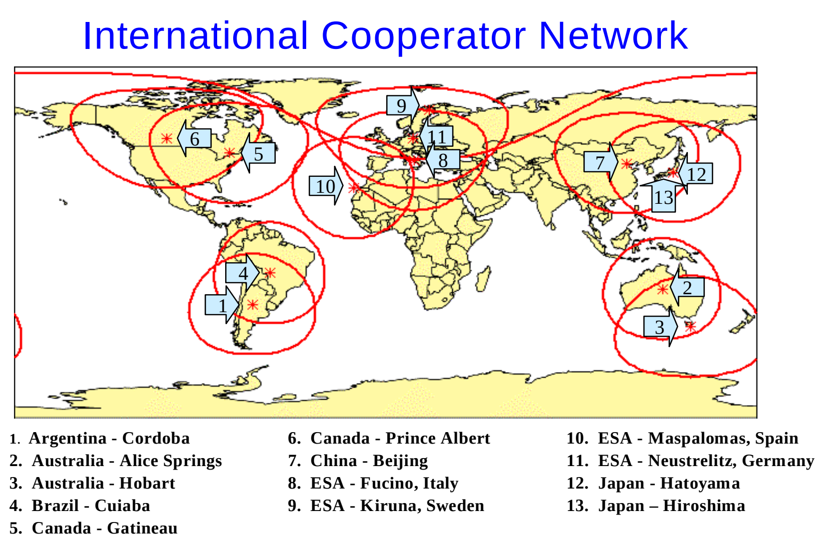


Figure 14: Landsat 7 International Cooperator receiving station locations.

the first fifteen months of Landsat 7 operations seven International Cooperators, representing 13 ground stations, arranged with the USGS to receive, archive and distribute Landsat 7 data. (Note: The Brazilian station did not remain operational during the full fifteen months). Distribution of the existing operational receiving stations is illustrated in Figure 14.

Within the next year of Landsat 7 operations, four International Cooperators are expected to sign agreements with USGS, and five additional ground stations, including Brazil, will become operational, bringing the international ground station network to a total of 17 stations. Stations are anticipated in Brazil, Indonesia, South Africa, and Thailand.

As of October 2000, the end of the first fifteen months of Landsat 7 operations, more than 138,000 Landsat 7 scenes, averaging approximately 300 scenes per day, were downlinked to the 12 operational ground stations. Table 2 provides a list of the countries, cooperating agencies, ground station location, acquisition statistics, and operational readiness dates for all International Cooperators for which commitments have been signed by October 2000.

During this first fifteen months of operations, most of the interaction with the International Cooperator group has focused on defining and establishing an appropriate agreement with each cooperator. The initial requirement was to reach agreement on and secure signatures for the governing Memorandum of Understanding (MOU) between the USGS and the respective cooperators for Landsat 7 data reception and distribution.

Table 2: International Cooperator Data Acquisition History

Ground Station	FY 1999 4th Qtr	FY 2000 1st Qtr	FY 2000 2nd Qtr	FY 2000 3rd Qtr	FY 2000 4th Qtr	Total Scenes	Scenes by Cooperator	Start of Operations
Argentina - Cordoba Nat'l. Commission for Space Activities (CONAE)	1,456	2,297	2,327	2,397	2,420	10,897	10,897	July 18, 1999
Australia ASA - Alice Springs Australia Centre for Remote Sensing (ACRES)	2,856	3,469	3,236	2,851	2,906	15,318	17,225	July 6, 1999
Australia HOA - Hobart Australia Centre for Remote Sensing (ACRES)	404	425	427	333	318	1,907		July 14, 1999
Brazil CUB - Cuiaba Nat'l. Institute for Space Research (INPE)	2,418	3,150	2,097	0	0	7,665	7,665	July 8, 1999
Canada GNC - Prince Albert Canada Centre for Remote Sensing (CCRS)	1,345	1,362	1,269	2,229	2,208	8,413	31,799	July 6, 1999
Canada PAC - Gatineau Canada Centre for Remote Sensing (CCRS)	5,170	3,630	1,726	6,444	6,416	23,386		July 6, 1999
China BJC - Beijing China Academy of Science Remote Sensing Satellite Ground Station (RSGS)	0	0	1,714	2,412	2,960	7,086	7,086	March 1, 2000
ESA FUI **-** Fucino, Italy European Space Agency	2,460	3,169	3,088	3,148	2,868	14,733	58,945	July 8, 1999
ESA KIS **-** Kiruna, Sweden European Space Agency	4,703	2,633	3,337	3,917	3,919	18,509		July 8, 1999
ESA MPS **-** Maspalomas, Spain European Space Agency	0	385	1,098	692	83	2,258		Dec. 14, 1999
ESA NSG - Neustrelitz,Germany European Space Agency	4,512	5,147	5,185	4,829	3,772	23,445		July 15, 1999
Indonesia DKI - Parepare Indonesia Nat'l. Institute of Aeronautics & Space (LAPAN)								Anticipated Oct.-Nov. 2000
Japan HIJ - Hiroshima Nat'l. Space Development Agency (NASDA)	0	0	425	1,992	1,240	3,657	5,214	March 1, 2000
Japan HAJ - Hatoyama Nat'l. Space Development Agency (NASDA)	0	0	0	483	1,074	1,557		May 1, 2000
TOTALS	25,324	25,667	25,929	31,727	30,184	138,831	138,831	

A secondary activity was devoted to establishing and testing the interfaces between each ground station and the appropriate elements of the Landsat 7 Program. Operational interfaces are required between each ground station and the Mission Operations Center and the Landsat 7 Program Office. Requirements for each of these interfaces are documented in the Landsat 7 to International Ground Station Interface Control Document (ICD), Revision D, April 2000.

Finally, significant effort was directed to defining and implementing other terms and conditions required by the MOU, particularly the procedures required for data exchange, metadata/browse exchange, and customer referral.

MOC Interface: The ground station-to-MOC interface is required for the ground station to submit requests for data acquisitions within the coverage circle of each ground station, and for the MOC to provide information to the station regarding acquisition schedules, calibration parameters, and health/status information about the spacecraft and sensor. In this first reporting period, requests for data acquisition were supported with highest priority assigned to the land area of the Cooperator's host country. Investigations were initiated to evaluate a three-tiered prioritization system that would be more equitable and provide for a higher probability of obtaining the highest priority scenes requested by the ground stations.

DAAC Interface: The ground station-to-DAAC interface is required for exchange of metadata and browse imagery. ICs are required, under the terms of the MOU, to provide, at monthly intervals, the metadata describing all Landsat 7 data acquired and archived by their station(s). The requirement to provide browse imagery is optional if the IC maintains an on-line web system whereby users can access browse imagery for the respective archive. Procedures for testing and exchanging metadata were developed in the latter portion of this period, and are now being implemented. When these interfaces are fully operational, all users will be able to view metadata and browse imagery for international archives, either on the U. S. Landsat 7 data access system, or by contacting the respective international archive system directly via the Internet.

Data Exchange: The terms and conditions of the MOU call for the USGS and the ICs to exchange data in common formats and media for key government programs, validating data quality, short term IGS outages, and temporary or long term loss of spacecraft capability. The specific conditions for exchange are documented in a draft Data Exchange Annex to the MOU and in a Data Exchange Implementation Plan. Approval of the Annex and Plan and encouragement to move quickly to implementation was given at the Landsat Ground Station Operations Working Group meeting in Beijing, China in September 2000. Testing for readability of data to be exchanged is currently ongoing.

Customer Referral: The USGS/IGS MOU states that the USGS will "make every reasonable effort to avoid competition with the ICs in filling orders for Landsat 7 data products from customers within the IC area of coverage". Several actions under the term "customer referral" are being implemented to address this condition of the MOU. For example, a customer referral letter has been sent out to all international customers making them aware of the USGS customer referral policy, and providing contact information for each of the customer services activities at each ground station. In addition, information about the customer services departments at each ground station is also provided on the USGS Landsat 7 website.

Coordination Activities: Coordination of International Ground Station activities is provided through the office of the USGS Landsat 7 Program Manager. The primary coordination mechanism is through the Landsat Ground Station Operations Working Group (LGSOWG), which meets annually to discuss policy issues and IC concerns regarding their participation in the Program. The LGSOWG has also chartered a sub-group, the Landsat Technical Working Group (LTWG), which meets semi-annually to coordinate and discuss a variety of technical issues of the Landsat Program. The focus of these meetings is to share initial operational data capture experiences, to understand ground station configurations of the various ground stations, and to discuss technical approaches for supporting data exchange. Both the LGSOWG and LTWG

Table 3: Landsat 7 International Coordination Meetings

Meeting	Location	Date
Landsat Technical Working Group #6	Sioux Falls, SD, USA	June 30-July 2, 1999
Landsat Ground Station Operations Working Group #28	Neustrelitz, Germany	September 13-15, 1999
Landsat Technical Working Group #7	Williamsburg, VA, USA	January 25-27, 2000
Landsat Technical Working Group #8	Ottawa, Ontario, Canada	July 17-21, 2000
Landsat Ground Station Operations Working Group #29	Beijing, China	September 18-22, 2000

meetings are chaired by USGS Landsat 7 Program management personnel. Table 3 summarizes international coordination meetings conducted since launch.

COMMERCIAL SECTOR COOPERATION

Public Law 102-555, the Land Remote Sensing Policy Act of 1992, requires the USGS to promote development of remote sensing capabilities within the private sector. In recognition of this requirement, the Landsat 7 Program is working closely with the private sector to provide users efficient access to Landsat 7 data archives and data products. In that spirit, through workshops, conferences, and partnership agreements, the USGS has solicited ideas, critique, and guidance from private sector users and value-added processors of Landsat products.

One vehicle for maintaining a responsive relationship between the private sector and the Landsat 7 Program is the USGS Business Partner Program, established several years ago by the USGS to facilitate private industry access to a variety of USGS data archives and products. The Landsat 7 Program modified the Program with an addendum to the Business Partner agreement that allows business partners ready access to Landsat 7 data products. Business partners receive bulk purchase prices (dependent on volume of business), customer referrals, links to business partner Internet sites from USGS Internet home pages, rapid turnaround for orders, and dedicated USGS customer services points of contact.

Table 4: Digital Satellite Data Partners

Name	Location
Applied Analysis Incorporated	Billerica, MA
Bio-Geo Recon	Sonora, CA
Cooper Aerial Surveys Company	Phoenix, AZ
CSIR/Satellite Applications Center	Pretoria, South Africa
Earth Imaging Center	Stennis Space Center, MS
EARTHWATCH	Longmont, CO
Earth Satellite Corporation	Rockville, MD
Eurimage S.P.A.	Rome, Italy
GEOSYS, Incorporated	Plymouth, MN
GIS Integrated Solutions	Laurel, MD
I-cubed	Fort Collins, CO
Image Links, Incorporated	Melbourne, FL
ISTAR	Sophia Antipolis, France
Natural Systems Analyst, Incorporated	Winter Park, FL
Pacific Geomatics Limited	Surrey, BC
Prosis S. A.	Bogota, Columbia
Silvana Import Trading, Incorporated	Montreal, QU
SPOT Image Corporation	Reston, VA
Terra Space C.A.G.	Moscow, Russia
TMS Communications Limited	Kobe, Japan

Business Partners active as of the end of this report period are included in Table 4.

Another means of involving the private sector in Landsat 7 data distribution is a series of workshops, initiated by the Landsat 7 Program, to engage in discussion of opportunities with the value-added processor community for Landsat 7 data exploitation.

A March 1999 workshop held in Reston, Virginia prior to the launch of Landsat 7 was designed to brief participants on operational plans, policies, and data availability for the Landsat 7 mission, and to listen to the value-added community's expectations, concerns, and advice regarding Landsat 7. A December 1999 workshop, held in Denver, Colorado in conjunction with the Pecora14/LandSatellite II conference, continued the dialog and included a report on the status of the Landsat 7 system and discussion of Landsat 7 data policy. The May 2000 workshop, offered as part of the ASPRS 2000 annual conference in Washington, D.C., reflected the growing maturity of the Landsat 7 distribution process, with additional discussion on data policy and presentations by selected value-added processors.

While there still are questions about the role of the government in data processing and distribution, new markets are emerging that focus on information that can be derived from the data rather than data itself. Again, the perspectives of the commercial and government sectors continue to change and these value-added workshops will continue to provide a forum for discussing this evolution.

OUTREACH

From the beginning, NASA and the USGS have been partners in the Landsat 7 Program. Each agency has accepted responsibility to explain to the science user, as well as the general public, the capabilities of the Landsat 7 system. Each agency supports outreach activities for the Program in a variety of ways. NASA staff members are dedicated to monitoring data quality as well as development of scientific research and applications of the data. USGS outreach activities focus on communicating with the user community regarding data acquisition, processing, archiving, and distribution of data products.

The user community, accustomed to the distribution policies of the Landsat commercialization effort for the preceding 15 years, needed to be informed about the significant changes in pricing structure, distribution rights, and relaxation of re-use restrictions. Technical awareness (designed for the science users) and outreach (directed toward the education and general public groups) were carried out by many Program participants through press releases, handout materials, education packages, and presentations. NASA and the USGS have established web sites as important means of communicating capabilities and changes to the program:

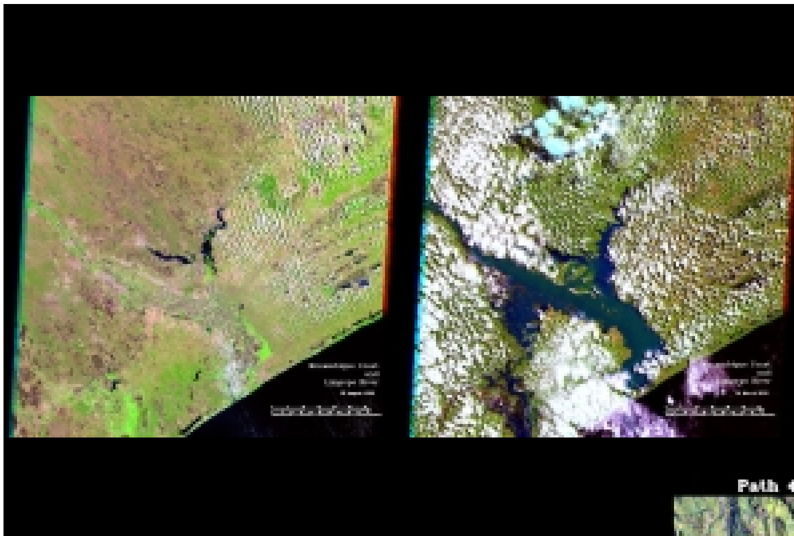
The NASA web site: **http://landsat.gsfc.nasa.gov**
The USGS web site: **http://landsat7.usgs.gov**

Media contacts brought a great deal of attention to the program. Over two dozen national publications and all of the major national television networks used Landsat 7 data to illustrate science issues. Specifically, news stories on the flooding caused by Hurricane Floyd in North Carolina and stories on the major fires in the western United States were illustrated by Landsat 7 data. Landsat 7 data were also used to illustrate volcanic activity in Japan and atmospheric phenomena in the South Pacific.

The Landsat teams from the USGS and NASA have aggressively pursued opportunities to encourage the examination and applications of Landsat 7 data. Science team members are encouraged to present their results at Landsat Science Team meetings, Landsat Working Group meetings and International Scientific meetings Recent special workshops were held on Landsat TM calibration in an attempt to solidify the calibration record for the earlier Landsat TM sensors, the Landsat ETM+ calibration workshop mentioned above and a tutorial on Landsat 7 performance was held as part of the Pecora 14/LandSatellite II symposium in December 1999. The Landsat Project Science Office has supported the Landsat Technical Working Group meetings in Williamsburg, VA and Ottawa, Ontario, CA and LGSOWG meeting in Neustralitz, Germany with instrument performance updates. Key scientific meetings where presentations were made included: IGARSS'99 in July 1999, SPIE/EUROPTO in September 1999; CALCON'99, in November 1999; American Geophysical Union in December 1999; and SPIE/ AEROSENSE in April 2000, ASPRS, May 2000.

The majority of scenes requested by users, commercial, science or otherwise, were satisfied from the archive with exceptional global coverage provided by the long-term acquisition plan and the high quality of the data characterized by the use of cloud cover predictions. Some special requests that were not covered by the long-term acquisition plan, for field campaigns and calibration efforts, or in response to natural disasters, were handled through the Landsat Project Science Office. Scenes were acquired, ordered, processed and analyzed for use by the science community and the public at large. Examples of these efforts included processing scenes of the drought in the eastern United States that affected much of the area during the summer months of 1999. The Science Office ran land cover classifications on Landsat 7 scenes to determine the reduction in water levels of various reservoirs in the region.

On the other side of the drought, extensive flooding occurred in North Carolina in September 1999, after Hurricane Floyd, providing opportunities for the Science Office to process scenes for public access and dissemination. Severe flooding in the Outer Banks of North Carolina caused major damage in the region. In order to assess the geographical impact of the flooding, Landsat 7 scenes of the region, acquired both before and during the flooding, were processed and shared with the public. Landsat 7 images were used extensively by national publications and electronic media outlets, including the National Geographic Magazine, Space News, the New York Times, CNN, NBC, and CBS.



In March 2000, massive flooding of the Limpopo River in Mozambique caused great destruction and loss of life. Landsat 7 data were used to measure the extent of flooding and to monitor upstream river and impoundment conditions.

Image 11: 2000 Flooding along the Limpopo River, Mozambique, Africa.

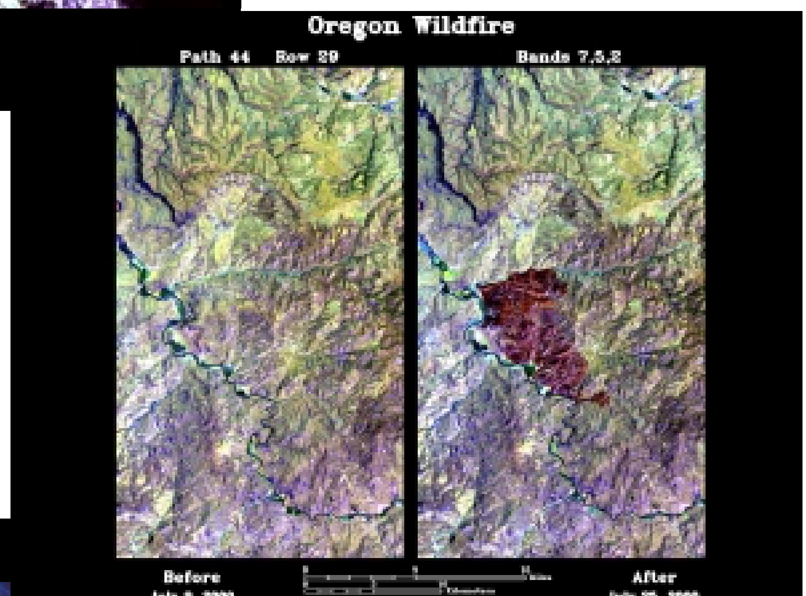


Image 12: Midsummer wildfires caused extensive damage to forests in north central Oregon. Landsat 7 data captured the conditions shortly before the fire and shortly after it was contained.

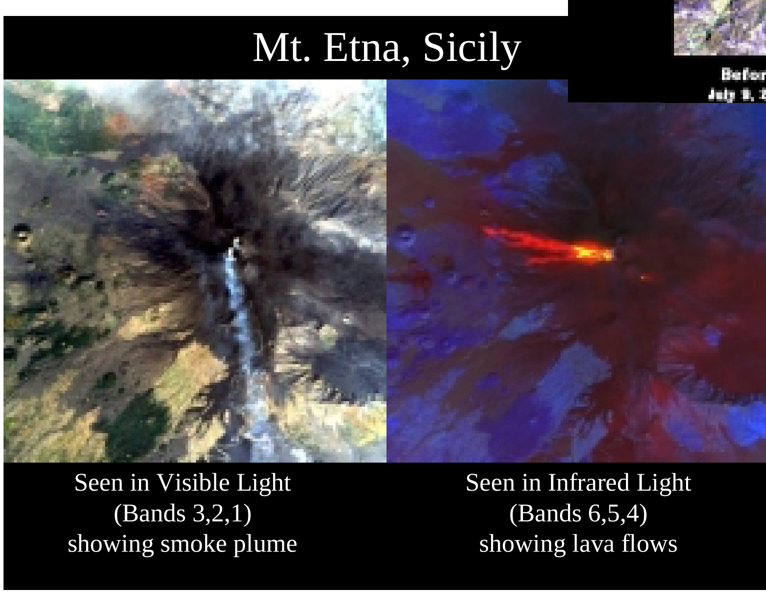


Image 13: Thermal infrared measurements were tested by examining the data over Mt. Etna, Sicily when the volcano erupted in 1999.

Multi-Spectral Scanner (MSS) - September 13, 1972

Enhanced Thematic Mapper (ETM) - June 15, 1999

Image 14: Landsat 1 MSS data (left), compared with Landsat 7 data (right), illustrate the growth in the Las Vegas, Nevada area.

Urban change detection was illustrated using historic Landsat data and Landsat 7 data. Image pairs or triplicates over Las Vegas, Nevada, Denver, Colorado, and Beijing, People's Republic of China showed the expansion of those metropolitan cities.

Educational materials developed in partnership with NASA included a Landsat 7 Teacher's Kit, a poster showing the Washington, D.C. area, four Landsat lithographs (Chesapeake Bay, Baltimore, Washington, and Outer banks, North Carolina). Teacher workshops, presentations at graduate seminars, at conferences on Remote Sensing Education, and at national discipline meetings were designed to make educators aware of the significance Landsat 7 data may have in teaching.

Presentations were also given to state and regional government agency representatives, calling attention to the NASA/USGS responsibilities for the program.

LANDSAT 7 SCIENCE TEAM

A new element of the Landsat 7 mission is the NASA Landsat Science Team, a consortium of 14 investigations chartered to use Landsat 7 data for global change research. Team members represent universities, research laboratories, and federal agencies interested in objective evaluation of Landsat 7 data. Their research includes evaluation of the sensor capability, the data characteristics, and the relevance of the data to global environmental measurement issues. These projects, based at universities and national laboratories across the United States, are investigating topics as diverse as volcanic hazards, tropical deforestation, and Antarctic ice sheet dynamics. Investigators are also focusing on robust approaches for instrument calibration and atmospheric correction, key prerequisites for successful Earth science. The science team carefully examined early Landsat 7 data by testing the data in relation to known factors. For example, the radiometric performance of the thermal infrared measurements was compared to the pre-flight specifications. The results lead researchers to conclude this sensor is the first civilian satellite sensor to produce thermal infrared measurements at such a fine spatial resolution

Information on the goals of specific projects can be found on the Science Team web site:
http://www.geog.umd.edu/Landsat

At two meetings held in October 1999 and May 2000, the Landsat Science Team gave preliminary assessments of the Landsat 7 mission and the quality of the ETM+ imagery. The findings were uniformly positive. Team members, institutional affiliation and study topics, include:

Robert Bindschadler
Goddard Space Flight Center
Enhanced Antarctic Research with Landsat: Ice-sheet Dynamics, History, and Cartography

Robert F Cahalan
Goddard Space Flight Center
Clear Sky and Cloud: Characterization and Correction for Landsat

Luke P. Flynn
University of Hawaii, Manoa
Analysis of Volcanic Eruptions and Fires Using Landsat 7

Alexander Goetz
University of Colorado, Boulder
Land and Land-Use Change in the Climate Sensitive High Plains: An Automated Approach with Landsat

Samuel N. Goward
University of Maryland, College Park
Terrestrial Monitoring at High Spatial Resolution: The Role of Landsat-type Sensors in Mission to Planet Earth

Susan Moran
US Department of Agriculture
LANDSAT TM and ETM+ Data for Resource Monitoring and Management

Frank Mueller-Karger
University of South Florida
Bottom-Assessment and Water-Constituent Algorithms for the ETM in the Coastal Zone

Frank D. Palluconi
Jet Propulsion Laboratory
Landsat 7: Calibration and Atmospheric Correction for Thermal Band 6

John Price
US Department of Agriculture
Surface Classification for MODIS, Radiometric Calibration and Project Support

John R. Schott
Rochester Institute of Technology
Absolute Calibration, Atmospheric Correction and Application of LANDSAT ETM= Thermal Infrared Data

David L. Skole
University of New Hampshire
Acquisition and Analysis of Large Quantities of Landsat 7 Data for Measuring Tropical Land Cover Change

Kurtis J. Thome
University of Arizona
Absolute Radiometric Calibration and Atmospheric Correction of Landsat 7 Thematic Mapper

James E. Vogelman
US Geological Survey
Characterization of Landsat 7 Geometry and Radiometry for Land Cover Analysis

Curtis E. Woodcock
Boston University Monitoring Changes in Temperate Coniferous Forest Ecosystems

LESSONS LEARNED

This first fifteen months of operation of the Landsat 7 mission has proved to be enlightening with respect to consideration of the various parameters that should be considered in designing a global land observing and mapping mission. The following comments illustrate some of these lessons.

Instrument Duty Cycle: The Landsat 7 duty cycle (the amount of time the instrument can be imaging during a specified window of time, i.e. an orbit, multiple orbits in sequence, a 24-hour day, etc.) is significantly more constrained than has been experienced in previous Landsat TM instruments. The Landsat 7 duty cycle specification, nominally an aggregated number of minutes representing approximately 16.7 percent of the available on-orbit time, places a constraint on the ability of the ETM+ to satisfy the acquisition requests resulting from execution of the Long term Acquisition Plan (LTAP) and the acquisition requests submitted by the network of International Cooperators. This constraint has become sufficiently critical during the first year of operation that serious consideration is already being directed to limiting commitments regarding support for additional international ground stations. Limiting the growth of the international network has both short term and long-term consequences. In the short term, limitation on network growth impacts income estimates projected to offset costs of operation. In the long term, restriction on network growth results in less flexibility for managing global data acquisition, particularly in the event of the loss of spacecraft data storage or communications capacity, since an incomplete network would not provide the necessary flexibility for continued global data collection of land observations. Future missions should be designed to mitigate, to the maximum extent possible, any limitations on instrument duty cycle.

Data Downlink Capacity: An important element of the Landsat 7 Program is to continue to deliver Landsat data to a network of international ground stations under agreements signed with International Cooperators. This International network is an important element of the Program; however, Landsat uses three directional x-band antennae to deliver image data to the ground receiving stations, thus limiting the number of ground stations that can be serviced simultaneously to three, or perhaps even fewer than three, depending on requirements for antenna re-positioning. After only fifteen months of operation, with 13 receiving stations operational for all or part of the year and several more locations in the implementation stage, the Program must become very selective with regard to making future commitments for additional stations. This concern is particularly important in east and southeast Asia, where as many as six existing or potential cooperators have expressed interest in receiving Landsat 7 data. If the Landsat Program wishes to continue to service a viable international network, future mission design should provide a more flexible data downlink resource.

Solid State Recorder Capability: The Landsat 7 Mission has demonstrated a marvelously effective capability for collecting global observations and returning them to the U.S. archive through implementation of a state-of-the-art Solid State Recorder (SSR.) Without this resource, acquisition of global land observations would be significantly more complex and difficult, since data would have to be delivered to stations within line of sight of the spacecraft and shipped to the U.S. The potential for reduction in capacity or total loss of the SSR capability has prompted Program management to devote significant attention to alternative means of collecting these global data; however, the SSR has performed extremely well. Future missions, assuming that a mission objective is to populate a robust U.S. archive of data, should certainly note the success of the Landsat 7 mission and seek to implement a comparable on-board recorder resource.

International Cooperator Relationships: The Landsat Program in the U.S. has for many years encouraged participation by International Cooperators through execution of agreements for delivering imagery of the respective receiving footprint, while in turn receiving a fee for providing that access. Early agreements, executed when the Landsat Program was managed as a "public good" program engendered significant international "goodwill" through sharing of this new use of space-based technology. Upon transition of the Landsat satellites to a commercial operator the "goodwill" motive was replaced by a commercial profit motive, and access fees were generally increased by a factor of three or four. Upon implementation of the Landsat 7 Program under U.S. Government management, access fees were again reduced to near the level of the early days of Landsat. As a condition of the reduced access fee, however, additional operating guidelines have been included in each international agreement requiring each of the Landsat 7 ground stations to support a capability to exchange data both with the U.S. and with each other. As the International Cooperator network has grown and stabilized, we have experienced a tangible evolution of a spirit of teamwork and cooperative interests that has been absent for many years within the ground station community. In summary, effective cooperation and teamwork among a group as diverse as the Landsat International Cooperator group are at best a fragile relationship, requiring considerable work and attention to ensure its viability. The participants of this network represent a major international asset to Landsat Program stability and evolution; it is important; therefore, that they are appropriately informed and they have opportunities to participate in the debate regarding the future of this highly successful program of international benefit.

Ground Data System Capacity: The primary archive for Landsat 7 observations is provided by the EDC Distributed Active Archive Center (DAAC). The EDC DAAC, in turn, has additional responsibility for ingesting and archiving several other large data sets from other instruments and missions, necessitating that the boundary conditions (data volume, timeliness of processing, product requirements, etc.) for managing the data flow from each mission be well defined and constrained, to avoid competition or conflict between the various requirements that must be supported. Even though the defined boundary conditions include provisions for some amount of contingency, mission-specific constraints have on occasion resulted in limitations that influence the data acquisition strategy for the Landsat 7 Program. The Landsat 7 Program is re-engineering the system to de-couple the data ingest limits from the data capture capability. The Landsat 7 experience has provided an excellent opportunity to plan for future ground data system capacity. In the design for ground data systems for future missions, consideration should be given to providing ingest and archive capacity for the maximum quantity of data that the on-orbit asset can be expected to support under maximum load.

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Landsat 7 has proven, in just over a year of operation, to be an outstanding success for acquisition of data for earth science and resource management. The data quality remains superb, the acquisition rate is very high, the international ground station network continues to grow, and the global science community is pleased with the quality and quantity of data.

Useful partnerships have been formed and extended. NASA and the USGS worked together to establish an efficient data acquisition, archiving, and distribution system; a system that the user community has found to be readily accessible. The commercial sector has greatly expanded options for value-added products, thus providing key information packages to the broader user community. Since July 1999, a steady stream of observations of the landmass of the planet has given scientists, educators, managers, and the public new and important views of the changing world.

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