

2003 Landsat Updates

January 2003

Landsat 7

Landsat 7 Flight Operations Team (FOT) had an outstanding year in 2002, capping it off with the celebration of 366 days without an operator error. This performance is well above the Six Sigma standard of proficiency the Landsat 7 Flight Operations Team holds to, and this is the second time their record has exceeded one year without an error.

Landsat 7 Flight Operations is a complex arena, presenting nearly 940 thousand “opportunities” a year to succeed. Apart from the daily rigors of normal operations, Landsat 7 Flight Ops enhanced the spacecraft’s star catalog, performed 22 delta velocity maneuvers, executed a detailed dual-burn delta inclination maneuver, performed special instrument cool-down imaging, addressed several spacecraft anomalies, dodged the Leonid meteor shower, and successfully performed calendar-year-end rollover operations. In conjunction with all of these challenging spacecraft activities, the team re-engineered all of the control center interfaces in order to implement the Landsat 7 backup Mission Operations Center (bMOC), and also helped to integrate a new ground station into its network.

Tegan Collier, Landsat 7 Project Manager, presents the “Six Sigma Error- Free Operations” award to Ed Callaway, Landsat 7 Realtime Operations Supervisor and Rich Lonigro, Landsat 7 FOT Manager.

Acting International Coordinator

Mr. Steve Covington has been appointed Acting Coordinator for the Landsat 7 International Activities. Mr. Covington works in the Landsat Program as Senior Project Leader for the Aerospace Corporation at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center, Code 428.1, Greenbelt, MD 20771. He can also be reached by phone at 301-614-5211, fax 301-614-5263, or e-mail steven.covington.1@gsfc.nasa.gov.

International Ground Station (IGS) Metadata

International Ground Station (IGS) Metadata from Canada, Australia, South Africa, China, Argentina, and Europe continue to be archived successfully. Matera, Italy began archiving metadata at the U.S. Geological Survey (USGS) EROS Data Center (EDC) on December 27, 2002. Metadata and browse from Brazil (CUB) were successfully archived from 8mm tapes on January 23, 2003. Thailand (BKT) stopped metadata production January 1, 2003, to perform system updates. As of January 31, 2003, there were 14,582 Landsat 7 IGS subintervals archived for 238,037 Landsat 7 Worldwide Reference System (WRS) scenes. Japan (HAJ) plans to resume transferring metadata to EDC sometime this Spring.

Data Validation

The Maspalomas, Spain ground station provided the USGS with Raw Computer Compatible (RCC) data for their scheduled biannual revalidation. The RCC data was successfully revalidated and found to be of equivalent quality to the corresponding USGS data.

Landsat 5 Radiometry Notice

During the latest analysis of the National Land Archive Production System (NLAPS) Landsat 5 Thematic Mapper (TM) processing capability, radiometric differences were discovered which vary according to band and acquisition date. Please note that these differences would primarily impact users who are converting to absolute scale (e.g. radiance, reflectance, etc.) and in many cases this should not affect the scene's usability for image interpretation, classification, or other purposes.

Landsat 5 TM data acquired after 1988 was found to have a linearly increasing radiometric difference due to changing lamp response. This difference affects bands 2, 3, and 4 in particular, and increases over time for all bands. In addition, a separate error appears to have been introduced into the processing of recently acquired scenes, due to an apparent light leak. This second error particularly affects bands 1, 2, and 3 and was found to occur within TM scenes that were acquired between 2000 and 2002.

Staff are currently working to implement an enhancement to the NLAPS radiometric processing that will allow the data to be processed to within an acceptable tolerance. This new enhancement is expected to be in place by the end of March 2003.

For the interim period (12/31/02 to 3/31/03), please be aware that all Landsat 5 TM data can only be purchased on an "as is" basis, because product returns will not be accepted if the user encounters problems with the radiometric results. (<http://edc.usgs.gov/products/satellite/tm.html>)

LTWG-13

The Landsat Technical Working Group (LTWG-13) meeting will be held in Cordoba, Argentina on March 31- April 3, 2003. The Comision Nacional de Actividades Espaciales (CONAE) will host the sessions. Coordination and planning for the meeting is being done by Mr. Steve Covington (see previous article for contact information.) Further information and registration can be arranged by contacting him.

February 2003

Sharpening Landsat with SPOT

Editor's note: Landsat data have provided opportunities for creative applications and merging of data sets. Mr. Ahern has offered the following example for illustration and discussion. For details, please contact Mr. Ahern at [f-ahern@nrtco.net](mailto:ahern@nrtco.net).

Many splendid images have been produced by sharpening Landsat 30 m data with 10 m panchromatic imagery from the SPOT series of satellites. Recently, SPOT-5 was launched with an improved panchromatic sensor that has a spatial resolution of 5 m and a pixel spacing of 2.5 m. What happens when one sharpens a Landsat image with these new panchromatic data? The results are stunning! TerreVista Earth Imaging has pioneered the use of SPOT-5 panchromatic data to sharpen Landsat imagery. In Figure 1 we see an image that was created by merging these two data types, using Bands 1,2 and 3 of the Enhanced Thematic Mapper Plus (ETM+) to produce a natural color image. The image is 47 x 40 km in size, with a pixel spacing of 2.5 m. When reproduced in a small size, as shown here, it looks like a familiar Landsat February 2003 2 scene. But when we zoom in to the area of downtown Ottawa covered by the red rectangle, we see far more detail than ever before, as shown in Figure 2. Roads, city blocks, and large buildings are all clearly

seen. We even see a tour boat cruising around a bend in the scenic Rideau Canal. The image is even more spectacular when viewed on a computer enough processing power to allow one to roam and zoom at will over the full area. We expect that this capability will open up new commercial and non-commercial opportunities for earth observation technology.

Figure on left: Landsat 7 ETM+ image acquired July 5, 2000 merged with SPOT-5 HRG panchromatic image acquired September 12, 2002. SPOT image © 2002 CNES, licensed by Iunctus Geomatics Corp, Lethbridge, Alberta, Canada.

Figure on right: Enlargement of downtown Ottawa showing the level of detail that is present throughout the full scene. The anomalous red and blue colors appear to be caused by residual misregistration of the two images, and will be removed with improved registration.

International Ground Station (IGS) Metadata

International Ground Station (IGS) metadata from Brazil, Canada, Australia, South Africa, China, Argentina, and Europe continue to be archived successfully. Matera, Italy began sending metadata collected by their retired ground station in Fucino, Italy (FUI) on February 5, 2003. As of February 28, 2003, there were 16,092 Landsat 7 IGS subintervals archived for 260,330 Landsat 7 Worldwide Reference System (WRS) scenes. Maspalomas, Spain (MPS) is expected to begin archiving their metadata at EROS Data Center (EDC) very soon. Hatoyama, Japan (HAJ) is expected to resume sending metadata to EDC by this spring.

Data Validation

During the month of February, the Cordoba Argentina station provided the U.S. Geological Survey (USGS) with Raw Computer Compatible (RCC) data for their scheduled biannual revalidation. The biannual revalidation was successful. Preliminary testing continues with the L1G Product Validations. At this time initial product validations have been completed for Japan (Hiroshima), Argentina, Australia (Alice Springs), China and Thailand.

Landsat Web Site

Recent updates to the Landsat web site (<http://landsat7.usgs.gov>) are popular with web users. In January 2003, the Landsat web site averaged over 20,000 hits and 906 visitors per day. The most popular area of the web site is the improved Image Gallery (<http://landsat7.usgs.gov/gallery>). Landsat staff are continually adding interesting images from Landsat with descriptions of the area. Recently, several change-over-time sequence images were added to the gallery. An interactive map is also now available to help viewers choose an image geographically. Watch this site for more interesting Landsat images!

This series demonstrates the amount of change we can identify over a short four-year period. Fire has the ability to change our landscape tremendously, and a good example is the Black Hills of South Dakota. Compare the landscapes as each fire season profoundly influenced the ecology of the Black Hills. The fire scars are clearly visible in dark red. Using the short-wave infrared (Bands 543), we can more clearly discern the fire scars from the green coniferous forests surrounding them.

LTWG-13

The Landsat Technical Working Group (LTWG-13) meeting will be held in Cordoba, Argentina on March 31- April 3, 2003. The Comision Nacional de Actividades Espaciales (CONAE) will host the sessions. Mr. Steve Covington is coordinating and planning for the meeting. Further information and registration can be arranged by contacting him at steven.covington.1@gsfc.nasa.gov.

QMM #19

The 19th Quarterly Management Meeting (QMM) with USGS and NASA management personnel was held on February 26, 2003. Flight operations and USGS EDC management staff attended the meeting in Sioux Falls as well as NASA management via telecon. This meeting focused on interagency issues and other status reports for U.S. operations of Landsats 5 and 7.

March 2003

Fourth Anniversary

April 15, 2000, marks the fourth anniversary of Landsat 7 on-orbit operations. The U.S. Geological Survey (USGS) and National Aeronautics and Space Administration (NASA) take great pride in the success of the Landsat 7 mission. The Landsat 7 satellite has performed flawlessly and provides the highest quality, best characterized data in the 30-year Landsat data acquisition history.

The U.S. archive of Landsat 7 data contains a wealth of cloud-free land observations, with over 30 percent of the more than 300,000 archived scenes having less than 10 percent cloud cover. The extensive network of Landsat International Cooperator (IC) stations has augmented the global archive of Landsat 7 data with a great depth of unique coverage over their individual geographic regions. Over the last four years, the U.S. Landsat project has produced and distributed over 55,000 scenes for the Landsat user community. For the first time in Landsat history the network of stations producing Landsat products provides data in both unique and common formats. The common formats are validated twice per year to ensure that a Landsat user anywhere in the world can acquire Landsat 7 data in a common format from multiple receiving stations.

The Landsat 7 mission has been an enormous success because of the tireless effort of many dedicated individuals. To the many people in the U. S. and around the world who work on the Landsat 7 mission and infuse it with their passion for excellence, we say thank you. May we all look forward to many more years of Landsat 7 operations.

Tracy Zeiler, Landsat Project Chief

International Ground Station (IGS) Metadata

International Ground Station (IGS) metadata from Argentina, Australia, Brazil, Canada, China, Europe, and South Africa continue to be archived successfully. Hatoyama, Japan (HAJ) resumed sending metadata to EROS Data Center (EDC) in early March. Bangkok, Thailand is expected to resume sending metadata to EDC very soon. As of March 31, 2003 there were 18,468 L7 IGS subintervals archived for 288,338 Landsat 7 Worldwide Reference System (WRS) scenes. Italy finished sending EROS Data Center (EDC) their backlogs from FUI and MTI. Sweden (KIS), Brazil (CUB), and Japan (HAJ) are in the process of doing the same.

L5 Mission Operations Center (MOC)

The Landsat 5 Mission Operations Center (MOC) Contractor transition is proceeding on schedule. Effective April 1, 2003, Computer Sciences Corporation will assume the daily operational responsibility for the Landsat 5 satellite and Space Imaging operational support will conclude. The USGS wishes to thank Space Imaging for the service and support they have provided during the continuing mission of the Landsat 5 satellite.

Landsat 7 Introduces Automated Operations to the bMOC

In March, the Landsat team implemented the Landsat 7 On-Orbit Flight Automation (LOOFA) system in the backup Mission Operations Center (bMOC). Ever since USGS assumed program management in late 2000, LOOFA has been successfully "flying" Landsat 7 in the primary MOC fourteen hours of every day, monitoring spacecraft and ground systems status and paging Flight Ops personnel when problems arise. Automated operations in the bMOC avoid the costs of staffing the bMOC 24x7 in the event of an operations transfer, and greatly enhances the programs' ability to respond to a contingency situation.

Landsat 7 Flight Ops Responds to Increased Homeland Security Alert Level

Landsat 7 Flight Operations enhanced its readiness to respond to an emergency by expanding its procedures to escalate a problem or threat to USGS flight operations capability at Goddard Space Flight Center (GSFC). As the war in Iraq became imminent, Landsat 7 Flight Operations put in place additional procedures to alleviate potential confusion that could arise from the loss of communications at GSFC or in the local area. In addition, Flight Operations conducted its first rehearsal to simulate a loss of functionality in the MOC that would warrant the transfer of operations to the backup MOC. This is the first part of an on-going plan to rehearse failure scenarios at all levels to maintain the team's readiness and exercise the bMOC to ensure seamless Landsat 7 image acquisition.

Data Validation

During the month of March, the Japan (Hiroshima) station provided the USGS with Raw Computer Compatible (RCC) data for the biannual revalidation. The RCC data from Hiroshima was found to be of equivalent quality to the corresponding USGS data, and the revalidation was a success. Also, the Australian stations (Alice Springs and Hobart), the Canadian stations (Gatineau and Prince Albert), and the Beijing China station all provided the USGS with Level 0 Reformatted Distribution Product (L0Rp) data for biannual revalidations. All L0Rp data revalidations were successful.

Testing of the IGSs Level 1 (L1) Products and the validation techniques continue. Eight of the eleven L1 products received from the IGS have been analyzed for conformance to the product format and specifications document. These data are also compared to the corresponding USGS L1 product. Use of these IGS data for testing of the procedures and methodologies has been of tremendous value for these initial L1 product validations. All of the IGS are being notified of these results as these preliminary validations are completed.

Landsat 5

Landsat 5 is being successfully maintained within plus/minus 3 km of the nominal Worldwide Reference System (WRS). This tolerance is a reduction of plus/minus 6 km, historically set for Landsat 5.

Landsat Documentation

Recently two documents have been updated by the Landsat team at the USGS EDC. The Landsat 7 Data Quality Validation Plan changes reflect the new document template, new approved media options, and changes made to the RCC data flow since the accomplishment of the re-engineering. Changes to the Landsat 7 Data Exchange Implementation Plan update include the use of the new document template. The majority of the changes made were necessary to reflect better sentence structure and word usage.

Revision F of the Landsat 7 to IGS Interface Control Document (ICD) was published in January 2003. Updates include further details on the IGS Priority/Service Request Map Editor (IPM) online tool, and new online locations for the reference documents. Revision A of the Landsat 7 to IGS Operations Agreement (OA) was published in March 2003.

This was the first update since launch of the atellite, and revisions were major in order to bring the document into line with current operations. Both documents are available at the IGS web site: <http://landsat7.usgs.gov/igsdocs.html>.

The IGS Priority & Service Request Mask Editor (IPM) online tool is ready for operational use. Tutorials on how to use the tool have been posted at the IGS web site: <http://landsat7.usgs.gov/igsdocs.html>. Testing was successfully completed in February with Australia, and in March/April with China, on use of the IPM to submit both priorities and service requests. Testing will begin soon with European Space Agency (ESA) on the manual submission of both priorities and service requests using the Priority/Service Request Mask (PSR) file. Testing will continue with the rest of the stations, a few at a time, over the coming year. Stations are encouraged to contact the MOC mission planners at L7MPT@LISTSERV.GSFC.NASA.GOV with dates that are convenient to them for testing and transition to the IGS Priority Mask Online Tool (IPM) for priority mask and service request submission.

Landsat Technical Working Group (LTWG)-13

This month, in light of the recent increase in world tensions, the Landsat project reluctantly decided that it was in the best interest of all participants that Landsat Technical Working Group (LTWG)-13 be cancelled. There was no specific cause for the cancellation - more a preponderance of smaller concerns that led to the conclusion that the benefits of holding the meeting did not justify the resulting anxiety to those traveling and their families. It was decided to cancel rather than postpone the meeting, as it is unclear when the situation in Iraq will conclude and world tensions subside. As such, the next meeting is scheduled to be the Landsat Ground Station Operator's Working Group (LGSOWG) to be held in Hiroshima, Japan in early October 2003. The Landsat Project extends sincere thanks to our friends at CONAE for all the effort expended in preparation for LTWG-13. It is our sincere hope to hold the next LTWG in Argentina if circumstances allow.

April 2003

International Ground Station (IGS) Metadata

International Ground Station (IGS) metadata from Argentina, Australia, Brazil, Canada, China, Europe, Japan, and South Africa continue to be archived successfully. Maspalomas, Spain (MPS) began archiving their metadata at the U.S. Geological Survey (USGS) EROS Data Center (EDC) on April 28, 2003. As of April 30, 2003, there were 19,572 L7 IGS subintervals archived for 302,512 Landsat 7 Worldwide Reference System (WRS) scenes.

Data Validation

The Matera, Italy ground station provided the USGS with Raw Computer Compatible (RCC) data for biannual revalidation. These data were successfully revalidated and found to be of equivalent quality to the corresponding USGS data. The Hatoyama, Japan ground station provided the USGS with Level Zero Reformatted Distribution Product (L0Rp) for biannual revalidation and was also found to be of equivalent quality to the corresponding USGS data.

System tests (LAM 4.3.0) are currently under way and will conclude May 2003. This Landsat Archive Manager (LAM) release will allow the USGS to provide the International Ground Stations (IGSs) with subsetted RCC data on an operational basis. All IGSs involved in the validation and exchange of RCC data will be provided with a subsetted RCC data within their acquisition circle to confirm that each IGS is able to extract, process and validate the USGS RCC data.

All L1G product data received from the IGS for preliminary testing has been analyzed and reported to each IGS. Level 1 Geometrically Corrected (L1G) products are expected from Brazil, Indonesia, Italy, and South Africa for initial testing.

Landsat Coverage

Editor's Note: A number of inquiries have come in asking about the coverage extent of Landsat data. The following chart documents the extensive coverage collected as of April 2003. The color codes represent the number of acquisitions over areas. Future issues will provide updates of scenes acquired by the U.S. managed stations.

Revised Procedure & Calibration Parameters

Effective May 5, 2003, Landsat 5 Thematic Mapper (TM) data processed and distributed by the USGS EDC will be radiometrically calibrated using a new procedure and revised calibration parameters. The modified approach involved discontinuing use of the internal calibrator for the reflective bands (with the exception of the thermal band), implementing instead a time-dependent calibration Look-up Table (LUT). This change will improve absolute calibration accuracy, data consistency over time, and consistency with Landsat 7 Enhanced Thematic Mapper Plus (ETM+) data. It is expected that radiometric accuracy of five percent could be obtained with reprocessing of raw archival data with these lifetime calibration updates. The full implementation of these processing changes, will lead to a superior Landsat 5 TM data product that will be comparable to Landsat 7 ETM+ radiometry, and will provide the basis for continued long-term studies of the Earth's land surfaces.

Please contact Gyanesh Chander gchander@usgs.gov for extensive documentation on this matter.

May 2003

International Ground Station (IGS) Metadata

International Ground Station (IGS) metadata from Argentina, Australia, Brazil, Canada, China, Europe, Japan, and South Africa continue to be archived successfully. Bangkok, Thailand (BKT) resumed sending metadata to EROS Data Center (EDC) on May 27, 2003. On May 28, Kiruna, Sweden (KIS) finished sending their historic metadata records to EDC for the years 1999 through 2001. We expect to receive similar metadata from Maspalomas, Spain (MPS) and Neustrelitz, Germany (NSG) very soon. As of May 31, 2003 there were 22,062 L7 IGS subintervals archived for 330,196 Landsat 7 Worldwide Reference System (WRS) scenes.

Data Validation and Exchange

In the month of May, the Brazil and Thailand stations provided the U.S. Geological Survey (USGS) with Level Zero Reformatted Distribution Product (LORp) data for their biannual revalidations. The Brazil and Thailand LORp data were found to be of equivalent quality to the corresponding USGS LORp data.

Although Canada is not responsible to provide Raw Computer Compatible (RCC) data for validation or exchange purposes, they were successfully validated to be of equivalent quality to the USGS data. The USGS is now able to recover approximately five scenes that were lost at EDC due to a downlink anomaly. Thanks very much to the Beijing, China station for sending the USGS RCC data in support of anomaly investigations. These are excellent examples of the value of data validation and exchange.

The Landsat Archive Manager (LAM) 4.3.0 release will allow the USGS the capability to provide the IGS with subsetted RCC data on an operational basis. The IGS that provide the USGS with RCC data will receive subsetted data within their acquisition circle as part of the two-way validation process during the month of June.

Editor's note: From time to time, techniques in using Landsat data will be described in this update. The objective is to keep the science community aware of the possibilities Landsat offers. For more information about this example please contact Clyde Spencer of Bio-Geo-Recon (bgr@jps.net).

Data Fusion Example

Landsat thermal imagery has produced coarse resolution. The resolution is nominally 120 meters per pixel with Landsat Thematic Mapper (TM); while it has been improved to 60 meters per pixel with the Enhanced Thematic Mapper Plus (ETM+) sensor, it is still twice as coarse as the other multispectral bands. This coarse resolution can be reduced with the example shown, using a variation on the "pan sharpening" approach.

For this example, a Landsat 7 ETM+ data set (27 July 2000) of the central Sierra Nevada (California) was used. This had been re-sampled to 25 meters per pixel for the multispectral imagery, 50 meters per pixel for the thermal imagery, and projected to Universal Transverse Mercator (UTM) zone 11 by the EDC. A region of interest (2500 X 2250 pixels) centered on Long Valley Caldera was cut out for all bands including the thermal band. However, the thermal band was first re-sampled with cubic convolution to the same resolution (25 m per pixel) as the other bands. A simulated natural-color image was composited from Bands 7,4, and 2 (RGB) by visually adjusting the histograms to remove the magenta tones commonly observed in this combination. This was draped over a mosaicked DEM and is file "LV_Caldera_surface.JPG". This is looking East.

The thermal band (ETM+ band 6, low-gain) was converted from an 8-bit byte image to an inverse Floating-Point (FP) image with values from 0 to 360 (equivalent to degree angles), corresponding to the 'hue' image produced by the Environment for Visualizing Images (ENVI) (RSI, Boulder, CO) software package's Red Green and Blue (RGB) to Hue, Saturation, and Value (HSV) color transform. The thermal band was also converted to a floating-point image with a range from 0.0 to 1.0, corresponding to the range of the ENVI 'saturation' image. The RGB to HSV transform was performed on the 7,4,2-band combination. Then, the inverse HSV to RGB transform was performed using the FP 'value' image produced, the 0-360 FP inverse-thermal image as the 'hue,' and the 0-1.0 FP thermal image as the 'saturation' image. The resulting image was then stretched with a 2% linear stretch to improve the contrast and saturation for display. No corrections were made for elevation or emissivity. The first image (LV_Caldera_thermal1.JPG) is the final result, with a standard ROYGBIV rainbow-color range, with reds being hot and blues being cold. Water displays as black, regardless of temperature, and the snowfields along the crest of the Sierra Nevada show white. The temperatures are clearly modulated by elevation, although this affect could be removed easily if desired. What is interesting are the hot spots that are at the intermediate elevations, and are unremarkable in the simulated natural-color image - many of them correspond to well known hot springs. The detail on agnification is visually equivalent to the 7,4,2-band combination. File "LV_Caldera_thermal2.tif" is an 800 X 600 pixel, full-resolution area from the center of the caldera.

Update on Landsat Acquisitions

LGSOWG #32

The Landsat Ground Stations Operations Working Group (LGSOWG) #32 meeting is scheduled to be held in Hiroshima, Japan from October 13 - 17, 2003. The Hiroshima Institute of Technology, NASDA, HIT, RESTEC, and HEEIC will co-host the event. More information on meeting preparations and logistics will be coming out over the next several months.

June 2003

Landsat 7

The problem with Landsat 7, first noticed in early June, has had a major impact on the global Earth science community. While engineers are studying the cause of the problem, the global user community has recognized the immediate impact of lost data and has shown great concern over the plans for future systems.

We feel it is important to keep the Landsat User community aware of latest developments: hence, the Landsat Monthly Update subscription list was used to send out early notification of the data anomaly. In that spirit, this issue of the Update will be devoted to a summary of the problem, a description of plans, and resources that will allow you to stay informed, on a regular basis, of developments.

The Problem

In May 31, 2003 at approximately 21:45 GMT unusual artifacts began to appear within image data collected by the Enhanced Thematic Mapper Plus (ETM+) instrument on board the Landsat 7 spacecraft. These artifacts are consistent with a failure of the instrument's Scan Line Corrector (SLC). The SLC is an electromechanical device that compensates for the forward motion of the spacecraft. Further analysis has confirmed that there is a problem with the SLC.

The spacecraft itself appears to be in no danger; however, it is believed that all data collected by the ETM+ since the initial failure contain the defect. The affected data have been archived and removed from the publicly accessible data ordering systems. Operations, other than those required to support the current investigation, have been limited to routine housekeeping procedures since the data anomaly was discovered. At this time, the root cause of the anomaly – why the SLC ceased functioning – is unknown.

A joint U.S. Geological Survey - National Aeronautics and Space Administration (USGS-NASA) anomaly resolution team has been put into place under the leadership of the USGS Flight Operations Manager. The team, including the instrument manufacturer, Raytheon Santa Barbara Remote Sensing, is actively investigating both possible causes and remedial actions.

This is the fourth incident during the life of the mission that has had the potential to jeopardize the spacecraft's ability to meet its performance requirements. Each of the other incidents was investigated and resolved without significant impact to the Landsat 7 mission. The drawing shows the SLC and scan mirror optics.

The SLC compensates for the forward motion of the spacecraft. The following drawing illustrates the results with the scan line corrector functioning versus non-functioning. The following three images show the results in actual data sets. In Figure 1, the scan line problem can be seen; in Figure 2, a close-up of the scene shows the affected scene; in Figure 3, the middle section of a scene, less affected by the problem is marked.

Teams, led by the USGS Landsat Flight Operations Manager, are evaluating probable causes of the problem. Through the use of a 'fault tree', potential causes are compared to the technical data in hand. Through a methodical process of elimination likely causes of the problem will be identified and remedial actions will be considered. Only when the anomaly team has concluded, with confidence, the most probable cause of the problem will appropriate action take place.

Secondly, test data are being evaluated by a team of experienced users. They are evaluating data collected for test purposes since May 31 to determine the viability and scientific integrity of data with the scan line corrector information. While early reports are encouraging, no data collected since May 31 have been processed for wide distribution.

In place of Landsat 7, Landsat 5 acquisitions have increased. A number of International Cooperators are preparing to acquire and process Landsat 5 data. The Landsat 7 scan line collector problem is unique. Causes and remedial actions are under careful review and evaluation. Daily updates are posted on the landsat7.usgs.gov web site. Users and interested parties are encouraged to check that site regularly for the latest developments.

July 2003

The Anomaly Resolution Team

The Anomaly Resolution Team (ART), which is composed of representatives from the U.S. Geological Survey (USGS), National Aeronautics and Space Administration (NASA), and the instrument manufacturer, is now finishing the Scan Line Corrector (SLC) Anomaly Investigation and is preparing for the recovery phase. The ART is preparing their recommendation to USGS and NASA as to the probable failure mode(s) and the next corrective action. The ART will formalize their recommendation to USGS and NASA in early September and request approval for taking the next steps toward the resumption of operations of Landsat 7.

At this time no specific failure mode has been identified. The leading failure theories are:

- The SLC motor is jammed somewhere within the mechanism, restricting freedom of movement. This jam may have been caused by some form of electronics failure resulting in the motor cage to overdrive into a hard stop. If this happened it might be possible that the beryllium motor housing cracked, creating debris that found its way into an area that restricts the free movement of the motor. The signatures from the anomaly have revealed that this is the most likely failure scenario; however, testing with an Engineering Test Unit (ETU) has shown that this would be very unlikely.
- The motor and the mirror cage are attached by a glue or epoxy to a small shaft. A possibility is that the bond was broken. This failure theory fits most of the anomaly signatures but not all. This theory could not be tested with the ETU; however, should the decision be made to test with the redundant electronics and if a de-bonding did occur, then the redundant tach would provide a signature to support this.
- A failure of the electronics has not been completely ruled out even though a particular failure cannot be identified to explain all of the anomaly signatures. Re-enabling the SLC on the primary electronics (A-side), or the redundant side (B-side), or both, will be necessary to vindicate the electronics.

The team is evaluating the possible test scenarios. Pending the ART's final recommendation and USGS and NASA approval, this testing will likely take place in mid-September. Once the test data have been evaluated, future operations plans will be formulated and communicated.

Anomaly Data Testing

A diverse group of scientists, with ongoing experience using Landsat 7 data, evaluated the scientific usability and validity of Landsat 7 products containing the SLC anomaly. The disciplines represented by these scientists include Geography, Agriculture, Forestry, Rangeland Ecosystems, Glaciology and Ice Cap Monitoring, Ecological Remote Sensing, Phenological Characterization, Coastal/Oceanographic Remote Sensing and Coral Reef Monitoring, Tropical Forest Monitoring, Water Quality Monitoring, Remote Sensing Methodology and Techniques Development, and Global Change Monitoring. EROS Data Center (EDC) scientists and engineers also performed evaluations of the radiometric and geometric validity of these products. While it is not possible to correct for the missing data caused by the scan line corrector malfunction, it is possible to modify the processing algorithms to produce imagery containing

roughly 80 percent of the expected pixels. Initial evaluation indicates that the processed post-anomaly data maintain expected radiometric and geometric fidelity. It is also possible, using basic interpolation algorithms, to “fill in” some of the missing pixels; however, the data produced with interpolation techniques require further research and may not be useful for all science applications.

Anomalous Landsat 7 data products retain significant and important utility for scientific applications. The presence of the anomaly and associated missing pixels does degrade the usefulness of the imagery; however, the majority of scientists who have examined these anomalous data concluded that the data were still quite useful for their particular application. Additionally, the potential to develop new tools or methods of compensation for this anomaly, may enable even more scientific use of these data (for example, developing a mosaic of overlapping scenes or data from subsequent imagery to “fill in” missing pixels.)

LGSOWG-32

The Landsat Ground Station Operators Working Group (LGSOWG)-32 meeting is scheduled to take place the week of October 13, 2003 in Hiroshima, Japan. Meeting participants will spend considerable time discussing the activities surrounding the Landsat 7 SLC anomaly and the efforts to recover the mechanism.

Depending on the status of the SLC at that time, USGS will discuss the effects to the Landsat 7 Project, International Cooperators (ICs), and expectations for the coming year. Also, given the resurgence of interest and importance of the Landsat 5 operation, presentations will be made on that mission's status, future plans and the opportunities for International Cooperators to participate.

The hosting team, National Space Development of Japan (NASDA), Remote Sensing Technology Center of Japan (RESTEC), Hiroshima Institute of Technology (HIT), and Hiroshima Earth Environmental Information Center (HEEIC), have been working very hard to put together the meeting site and some wonderful group events. Specific information regarding the meeting and logistics will be sent out in the next several weeks.

August 2003

SLC Update

On Wednesday, September 3, 2003, the U.S. Geological Survey (USGS) Director authorized the Landsat Project Chief to attempt recovery of the Scan Line Corrector (SLC), which malfunctioned on May 31, 2003.

Supported by several National Aeronautics and Space Administration (NASA) Tracking and Data Relay Satellite System (TDRSS) satellites as well as the USGS's own Landsat ground station at EROS Data Center (EDC) in Sioux Falls, South Dakota, a series of commands directed the instrument to operate using its redundant electronics. Additionally, several spacecraft subsystems associated with Enhanced Thematic Mapper Plus (ETM+) operations and data transmission were moved to their ‘Side-B’ configurations. These are systems that had never been powered during the 4+ years since launch of Landsat 7 on April 15, 1999.

On Sunday, September 5, the Landsat 7 SLC was energized using the ‘Side-B’ redundant electronics in an attempt to restore the functionality lost when that system failed on May 31. While both the USGS flight operations team located at the NASA Goddard Space Flight Center (GSFC) in Greenbelt, Maryland and the ground operations team located at the EDC performed their roles in the test without error, the SLC failed to operate correctly.

Analysis will be carried out on both the spacecraft telemetry and the image data collected during the test in an attempt to gain additional insight into the exact nature of the mechanism's failure. However, the negative results of this test leave little hope that it will ever be possible to recover the SLC. The data collected without the SLC are still of very high radiometric and geometric fidelity, but leave a gap between some scans, resulting in about 25% less coverage.

In the coming days, the flight operations team and the ground operations team will report on the results of their analysis to the USGS and NASA. In addition, the flight operations team will begin preparations for returning the ETM+ and spacecraft components back to their primary 'Side-A' operational configuration. Once back on Side-A, the mission will resume collection of global imagery with the SLC powered off, as it has been doing since July 14.

Extensive work has already been done to develop processing systems for general distribution of the affected data (data without the benefit of the scan line correction.) The Landsat Project team is now turning its efforts towards reestablishing normal baseline operations with the "new" SLC-off data, with an objective of providing L1G SLC-off products to the user community by November 1st. Also, the team will work with the International Cooperator (IC) network to begin SLC-off data downlinks to their stations in the near future. Finally, an evaluation of "new" products will be initiated to determine if the Landsat can make the SLC-off data even more useful to customers.

LGSOWG-32

The Landsat Ground Station Operators Working Group (LGSOWG)-32 meeting is scheduled to take place the week of October 13, 2003 in Hiroshima, Japan. Meeting participants will spend considerable time discussing the activities surrounding the Landsat 7 SLC anomaly and the efforts to recover the mechanism of the SLC. The USGS will lead discussions concerning the effects of the scan line problem to the Landsat 7 Project, ICs and expectations for the coming year. Also, given the resurgence of interest and importance of the Landsat 5 operation, presentations will be made on that mission's status, future plans and the opportunities for ICs to participate.

October/November 2003

Scan Line Corrector-off (SLC-off) Products Available

The U.S. Geological Survey (USGS) is pleased to announce that Landsat 7 Scan Line Corrector-off (SLC-off) data acquired since July 14, 2003 are now available for purchase. The initial SLC-off product release includes Level 0Rp (L0Rp), Level 1R (L1R), and Level 1G (L1G) data products. The SLC-off data are being distributed as standard Landsat 7 single scene (Worldwide Reference System 2 (WRS-2)) and multi-scene ("floating scene") products. The feasibility for future additional data products and/or product access is still being determined. The cost of initial SLC-off products is the same as for Landsat 7 data collected prior to the SLC anomaly. As required by public law, the USGS must charge for data products according to the cost of fulfilling user requests. The data are accessible via the Earth Observing System (EOS) Data Gateway (EDG) at: <http://edcimswww.cr.usgs.gov/pub/imswelcome>.

The SLC aboard Landsat 7 malfunctioned on May 31, 2003. The SLC compensates for the forward motion of the satellite during data acquisition. Subsequent efforts to recover the SLC were not successful and the problem appears to be permanent.

In mid-July 2003, Landsat 7 returned to its normal scene acquisition schedule with the SLC turned off. Since that time, Landsat 7 has collected approximately 250 scenes per day for the USGS archive in the SLC-off mode. An SLC-off image will contain alternating bands of missing data along the scene edge, which gradually diminish in width toward the middle of the scene. The middle portion of an SLC-off L1G image contains no scan gaps. The radiometric and

geometric quality of all of the SLC-off data is the same as previous Landsat 7 image data. For further information on SLC-off data products, please visit: <http://landsat7.usgs.gov>.

Landsat Product Meeting

The USGS Landsat Project and National Aeronautics and Space Administration (NASA) Landsat Project Science Office jointly held a Landsat 7 SLC-off product enhancement workshop in Maryland on October 28-29, 2003. The workshop was intended to identify methods to enhance the use of SLC-off data and new potential SLC-off data products. Scientists from the former Landsat 7 Science Team and technical representatives from USGS and NASA participated and generated many improvements the USGS is pursuing for near-term implementation.

Release schedules for the suggested near term SLC-off improvements are in work and will be announced in an upcoming issue of the monthly update. These improvements include:

1. Enhancements to the current Landsat 7 browse displayed on the various data ordering web interfaces to help users assess the impact of the SLC-off scan gaps on their area of interest.
2. Provide users the option to choose the number of interpolation pixels used during L1G processing. Current EROS Data Center (EDC) systems use two pixels of interpolation during processing.
3. A pixel mask file to be included with all Level 1 data products to assist users in identifying the location of the scan gaps in SLC-off L1G products.
4. Release of any new Landsat 7 data product that is the result of compositing a Landsat 7 SLC-off image with a Landsat 7 SLC-on image. This would provide users with a complete Landsat 7 image.
5. Enhancements to the current interpolation methods used by the operational EDC Level 1 processing systems.

Beyond these initial improvements, the USGS and NASA are also pursuing new composite data products that combine two or more SLC-off images to produce a current Landsat 7 scene that may eliminate the scan gaps present in a single SLC-off scene. As the USGS has stated in previous communications, the Landsat 7 SLC-off data are of the same radiometric and geometric quality as those collected prior to the SLC failure. The release of these product improvements will enable users to more effectively utilize the L7 SLC-off data into the future.

NLAPS Enhancements

On November 20, 2003, the USGS released enhancements to the National Land Archive Processing System (NLAPS). These enhancements include the addition of a work order report file with Landsat 5 GeoTIFF products that contains the radiometric gains and biases used during processing. Additionally, a significant improvement was made to remove striping in Landsat 5 products using the NASA Look Up Table (LUT) processing method. A late-January NLAPS release is expected to provide the initial Landsat 7 SLC-off products.

Landsat Ground Station Operators Working Group (LGSOWG-32) Meeting

Fifty participants from fifteen different countries gathered in Hiroshima, Japan during the week of October 12, 2003, to attend the 32nd Landsat Ground Station Operators Working Group (LGSOWG-32) meeting. The four Japanese organizations (JAXA, RESTEC, HIT and HEEIC) were extremely gracious hosts to the record number of attendees, and provided an excellent venue for both the meeting and after-hour discussions. Topics such as the Landsat 7 SLC anomaly, the Landsat 5 mission status and recent announcements regarding the Landsat Data Continuity Mission (LDCM) made this LGSOWG an important and productive meeting.

Of primary interest to all participants was the status of the Landsat 7 mission and news as to when the USGS would resume operational downlinks to the International Cooperator (IC) network. The USGS provided a series of presentations on the nature of the SLC failure and its impacts to the data and ground processing. Tracy Zeiler, the USGS Landsat Project Chief, announced several programs for re-introducing the Enhanced Thematic Mapper Plus (ETM+) data to the ICs. Of primary interest were that the USGS would immediately resume downlinks to all ICs at no charge through the end of 2003 and that each IC would be permitted to order up to 10 SLC-off data products from the USGS archive to use in evaluating the utility of the impaired products for their local applications. The USGS will provide additional information to all ICs regarding the cost share fees in early December.

The next LGSOWG meeting for participating International Cooperators will be held in October 2004 in Chiang Mai, Thailand.