Preliminary Assessment of the Value of Landsat 7 ETM+ Data following Scan Line Corrector Malfunction

Including input from Scientists from the USGS, NASA, and the Landsat 7 Science Team
Compiled and summarized by the staff of the U.S. Geological Survey,
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Executive Summary

On May 31, 2003, Landsat 7 experienced an anomaly causing the Scan Line Corrector (SLC) to stop functioning normally. The non-functioning SLC causes individual scan lines to alternately overlap and then leave large gaps at the edges of the image. While it is not possible to correct for this missing data, it is possible to modify the processing algorithms to produce imagery containing roughly 80% 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 requires further research and may not be useful for all science applications.

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. EDC scientists and engineers also performed evaluations of the radiometric and geometric validity of these products.

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, for example developing a mosaic of overlapping scenes or data from subsequent imagery to “fill in” missing pixels, may enable even more scientific use of these data. Even with the anomaly Landsat 7 data is still preferred by some users over more costly alternatives.

Contributors:

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Section I: Introduction

Background of Anomaly

Landsat 7 experienced a Scan Line Corrector (SLC) failure during imaging on May 31, 2003 at approximately 21:44:05 GMT. The SLC is an electromechanical device than compensates for the forward motion of the satellite within the ETM+ image scanning. When operating properly the SLC allows successive forward and reverse scans of the ETM+ scan mirror to image in a series parallel scans. (See Figure A)

With a non-functioning SLC the ETM+ scans the Earth's surface in a pattern similar to that shown in the top illustration of Figure A. Instead of aligning in parallel scans the individual scans alternately overlap then leave large gaps or "underlap" at the edge of the imagery. Only in the center of the image (nadir) do the scans give near-contiguous coverage of the surface scanned below the satellite.

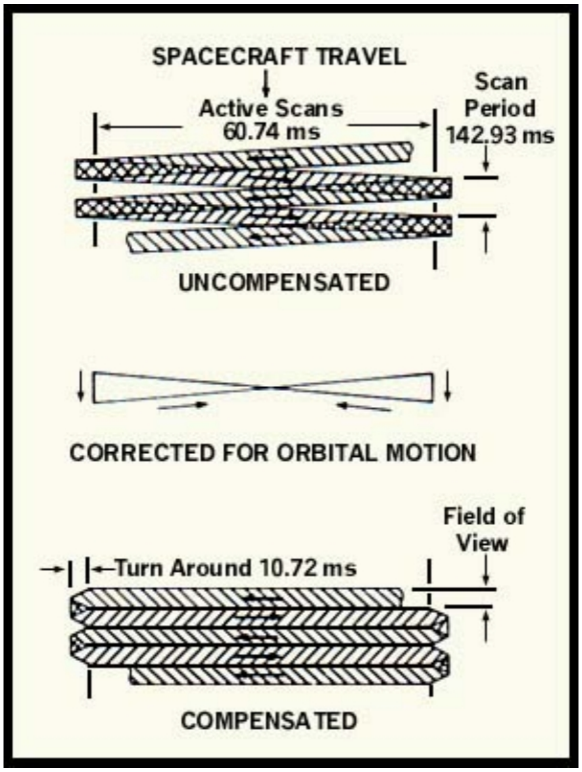

Figure A: Illustrations of SLC functionality

The Potential for Producing Products Containing the Anomaly

The Landsat 7 team modified algorithms to product ETM+ data with the non-functioning SLC. These products display artifacts of the overlap and underlap as shown in the top illustration of Figure A. Optionally, the software can use interpolation to "fill in" some pixels. An initial review of these products looks at the geometric and radiometric accuracy and potential usability of the data in typical Landsat scientific research and applications.

General Findings:

It is possible to generate data products containing the anomaly that retain their geometric and radiometric fidelity although there will be visible data gaps in the imagery. The anomaly does negatively impact the usability of the data although many applications are still possible with these anomalous data. The degree to which this limits their usefulness is dependant on the scientific application. The users and applications of these products fall into one of the two general categories:

1) **Those for whom the anomaly is a Small or Tolerable Impact; the data still retain solid usability with only small consequences or adaptations.** These applications generally are those involved with large area monitoring. These include monitoring tropical deforestation, qualitative assessments of crops, land cover change, and Global Change detection and

monitoring. These large-scale programs have been the primary beneficiaries of the Long-Term Acquisition Plan (LTAP) initiated with Landsat 7. These users also represent the largest portion of Landsat 7 data sales, the bulk customers of hundreds or thousands of scenes over time. Scientists in this category have strongly urged returning to LTAP-like global data collection, ethe anomaly notwithstanding.

2) **Those for whom the anomaly is a Major Impact; the data have little or no remaining usefulness.** Applications that require complete and detailed data over specific areas are the most affected by this anomaly. These include detailed mapping or monitoring small regions that are dependent on complete, reliable coverage of fine details within imagery. This is especially true over areas where infrequent temporal coverage removes the possibility of extracting missing information repeated coverage of the area. The monitoring of coral reefs was cited as one application that will likely be impossible with anomalous data. These are typically users who extract the maximum information from an individual scene. These users will likely look for other datasets or abandon their applications. These users also represent the largest number of individual Landsat 7 customers, those who order a handful of scenes or less over time.

These two groups are not cleanly separated. There are users who will initially fall into the latter category but who may be able to make use of anomalous L7 data with significant effort toward developing new tools or algorithms for analysis. Users who perform extensive digital or automated analyses of data tend to be in this sub-category. It may be possible to develop new tools or data products in the future that would enable these users to again use Landsat 7 data.

Conclusions:

Significant scientific usability remains in anomalous Landsat 7 data. Although some applications are no longer possible numerous other applications still require and can successfully use anomalous Landsat 7 data. Scientists involved with ongoing global and large-scale missions have expressed strong desires for continuing global coverage, calling Landsat 7 a “critical information source” *even in its anomalous state*.

Several scientists expressed strong interest in the possibility of composite data using adjacent or multi-temporal coverage to fill in data gaps. Composite imagery may may improve the usability of these data for some of the applications negatively affected by this anomaly. The majority of scientists participating in this study indicated a strong interest in the potential benefits of this and several methods are explored in the attached scientific analyses.

Section II: Technical Effects of the Scan Line Corrector failure on L7 imagery

Summary of Technical Effects

Products made from Landsat 7 data containing the SLC anomaly will contain regions of missing data visible as gaps beginning at both sides of the image that diminish and then vanish as they approach the center of the scene. However, the more than 75% of the image pixels that remain should retain the radiometric and geometric precision of non-anomalous Landsat 7 data.

Radiometric Implications

During the several seconds immediately before and after the failure of the SLC the ETM+ imagery exhibited strong levels of coherent noise in several detector channels. These were of similar nature, although much larger magnitude, than the low-level coherent noise routinely observed in several detector channels in Landsat 7 imagery. However, within seconds after the apparent failure of the SLC the noise levels dropped in amplitude significantly. Subsequently, when the power to the SLC drive circuitry was turned off the noise signals returned to pre-anomaly levels and, in some cases, vanished altogether. The sudden surge in the level of coherent noise during the anomaly and its subsequent behavior is one of the effects under consideration by the team investigating the anomaly. The low levels of noise remaining in the post-anomaly imagery are at similar levels to the noise found in pre-anomaly Landsat 7 imagery and are not considered to be of any significant detriment to post-anomaly imagery. Future analysis will more fully characterize and quantify any coherent noise in post-anomaly imagery.

The overall radiometric response of Landsat 7 appears unaffected by this anomaly and it is likely that the excellent radiometric performance of Landsat 7 can be maintained with an anomalous SLC. It is anticipated that the ongoing calibration of Landsat 7 radiometric performance will be possible even in imagery without scan line correction. Small adjustments may be made after the instrument is recalibrated in its new mode of operation. The Full Aperture Solar Calibrator (FAC), Partial Aperture Solar Calibrator (PAC) and Internal Calibration shutter (IC) all remain functional in spite of the SLC stoppage and will allow for continued radiometric calibration of the ETM+. Minor modifications to the analysis algorithms and tools may be necessary but are not envisioned to pose significant difficulty.

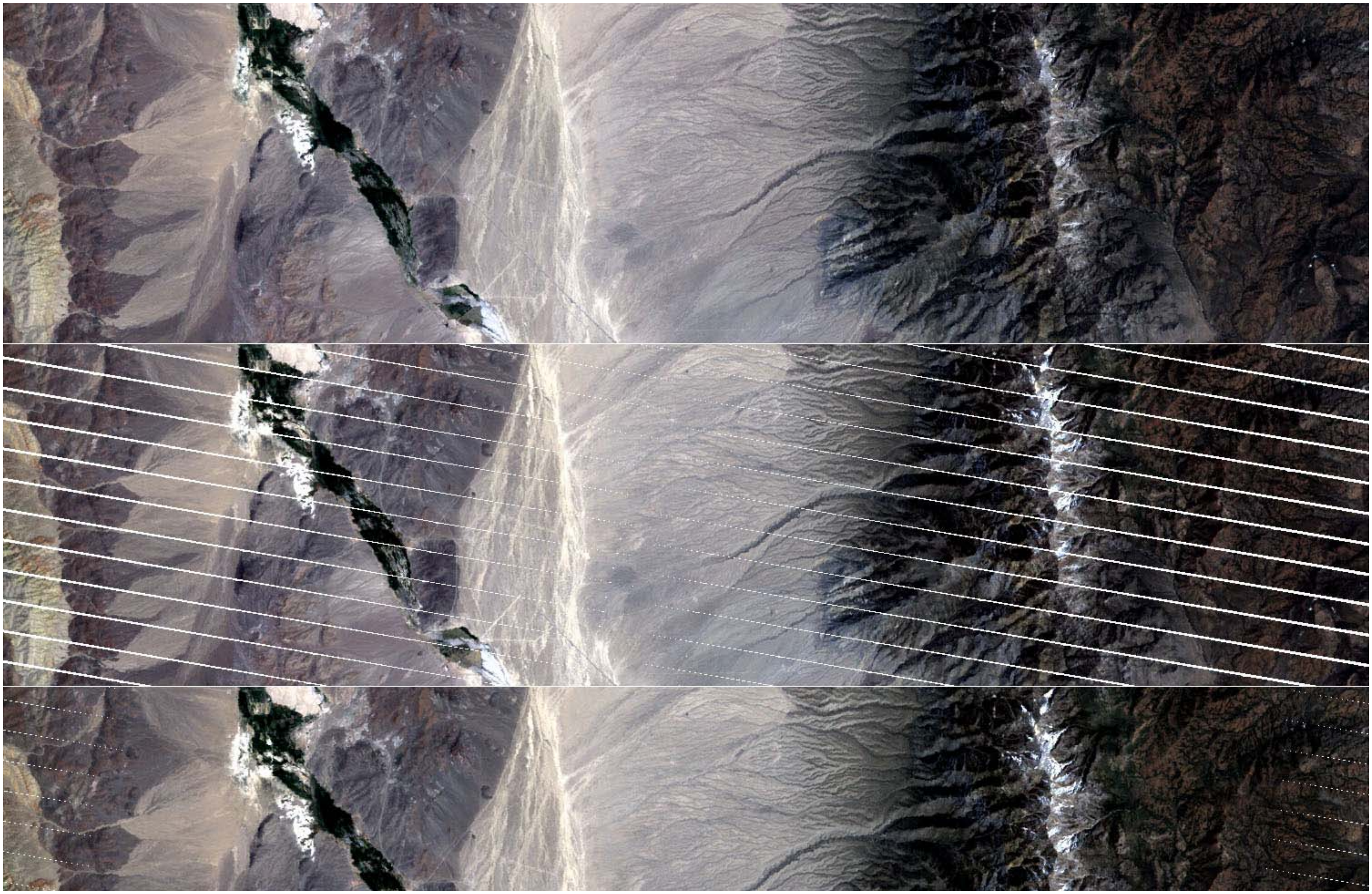

Figure B. Top image: Pre-SLC anomaly scene, middle of image.
Middle image: Scene after SLC anomaly.
Bottom image: Scene after SLC anomaly, with interpolation.

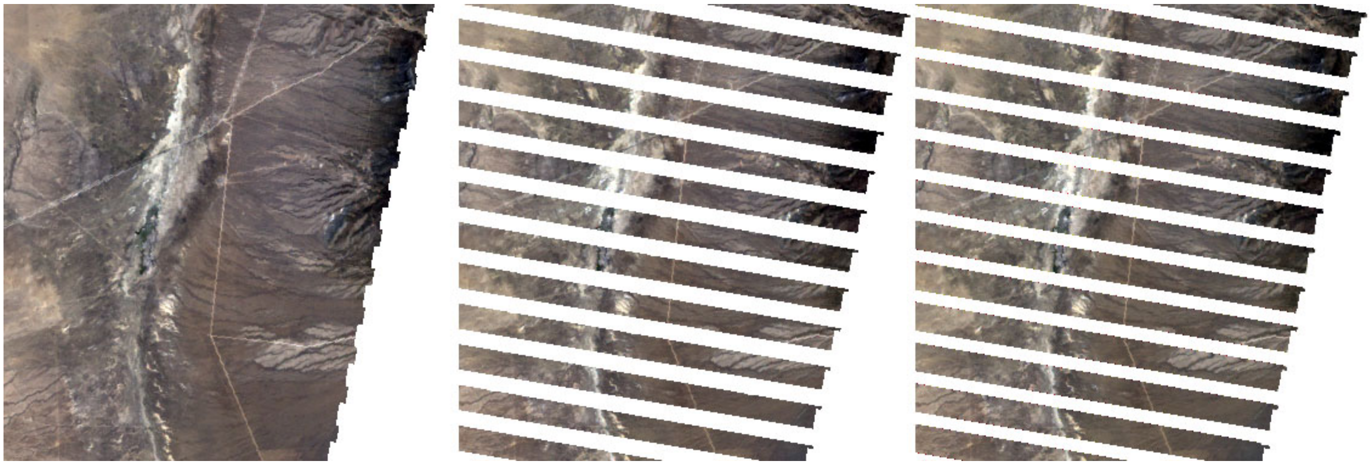

Figure C: Pre-SLC-anomaly scene, edge of image; **Scene after SLC anomaly, edge of scene;** **Scene after SLC Anomaly, edge of image with Interpolation**

The IAS/LPGS processing system can interpolate over short areas of missing data, effectively removing some of the underlap for visual purposes. Processing a scene with interpolation results in a vertical band of approximately 1200 pixels (~36 km) in the center of the image unaffected by missing data. However, this interpolated data may not be desirable for scientific use, as it is calculated by averaging the radiance of the surrounding pixels and is thus not physical data.

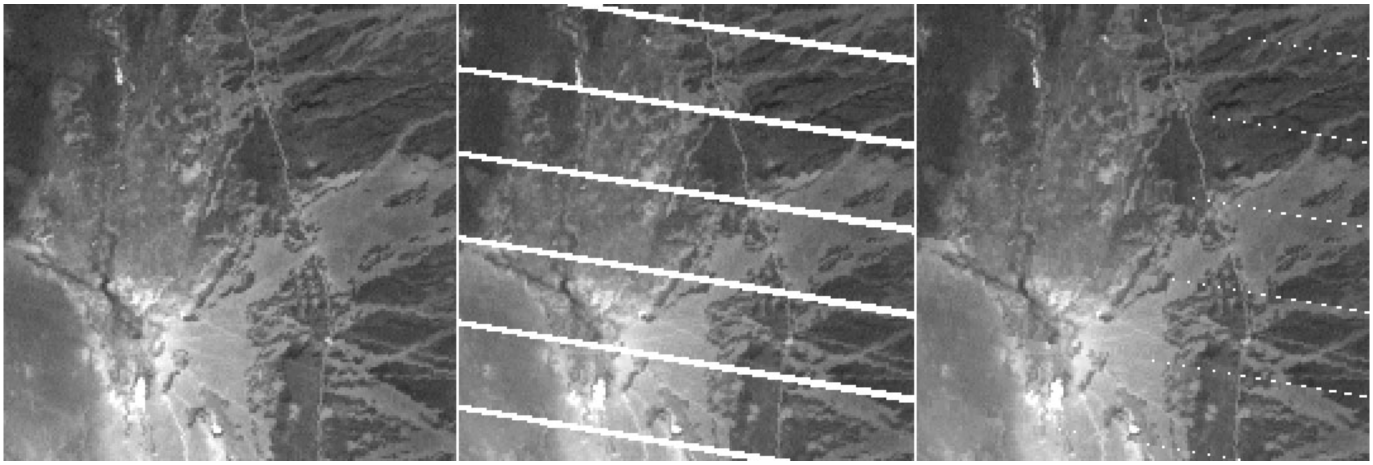

Figure D: Pre-SLC Anomaly scene **Scene after SLC Anomaly** **Scene after SLC anomaly with Interpolation**

As can be seen in the image on the right in Figure D, the interpolated data appears as rows of duplicated pixels. This processing artifact exists in the interpolated image wherever data is missing in the non-interpolated image. In a L1G image this may appear to be striping, but unlike striping it is dependent on local radiance and not correctable.

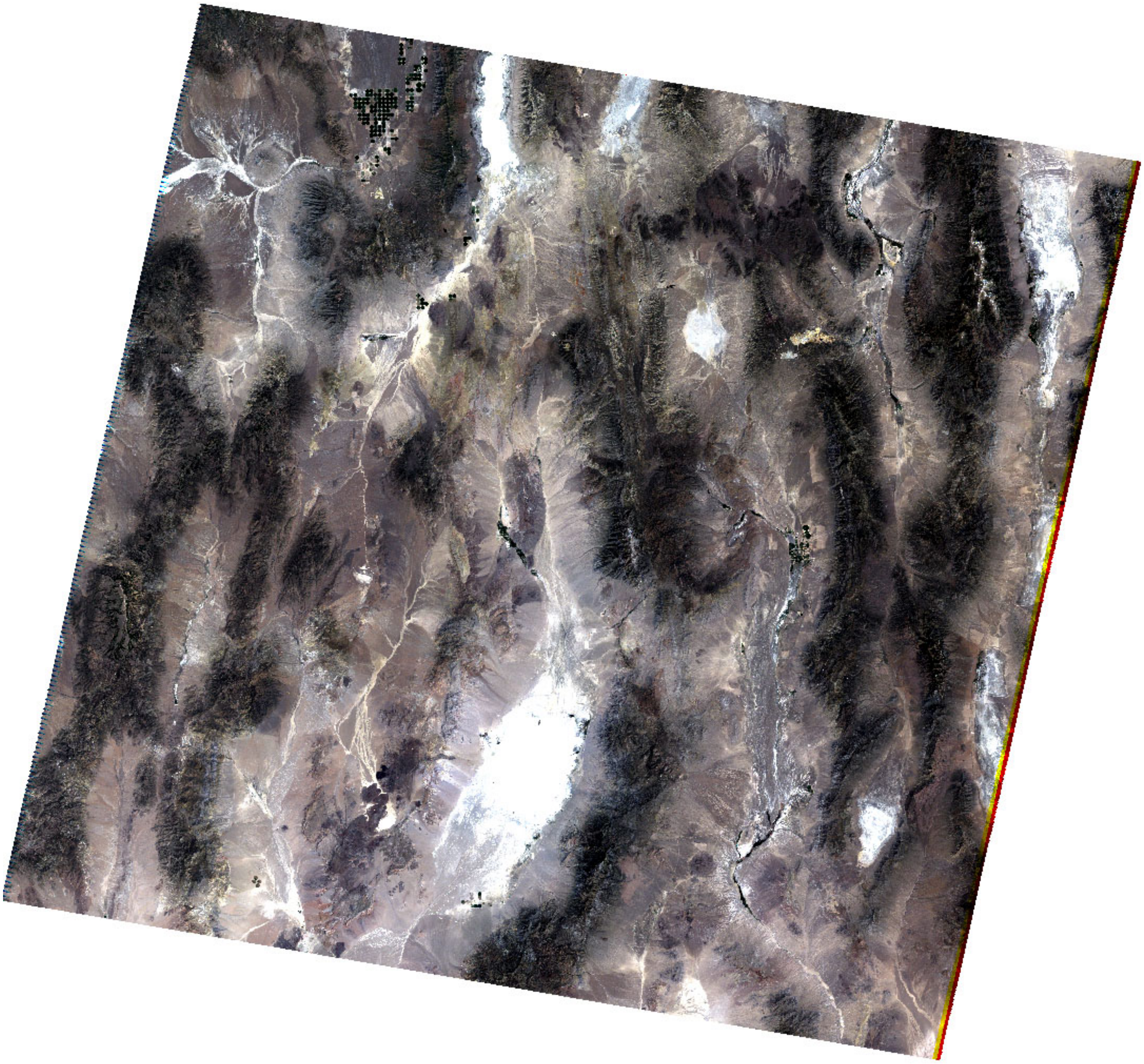

Figure E: Figure E. Path 40, Row 33 acquired 6/17/2002 (pre-SLC failure)

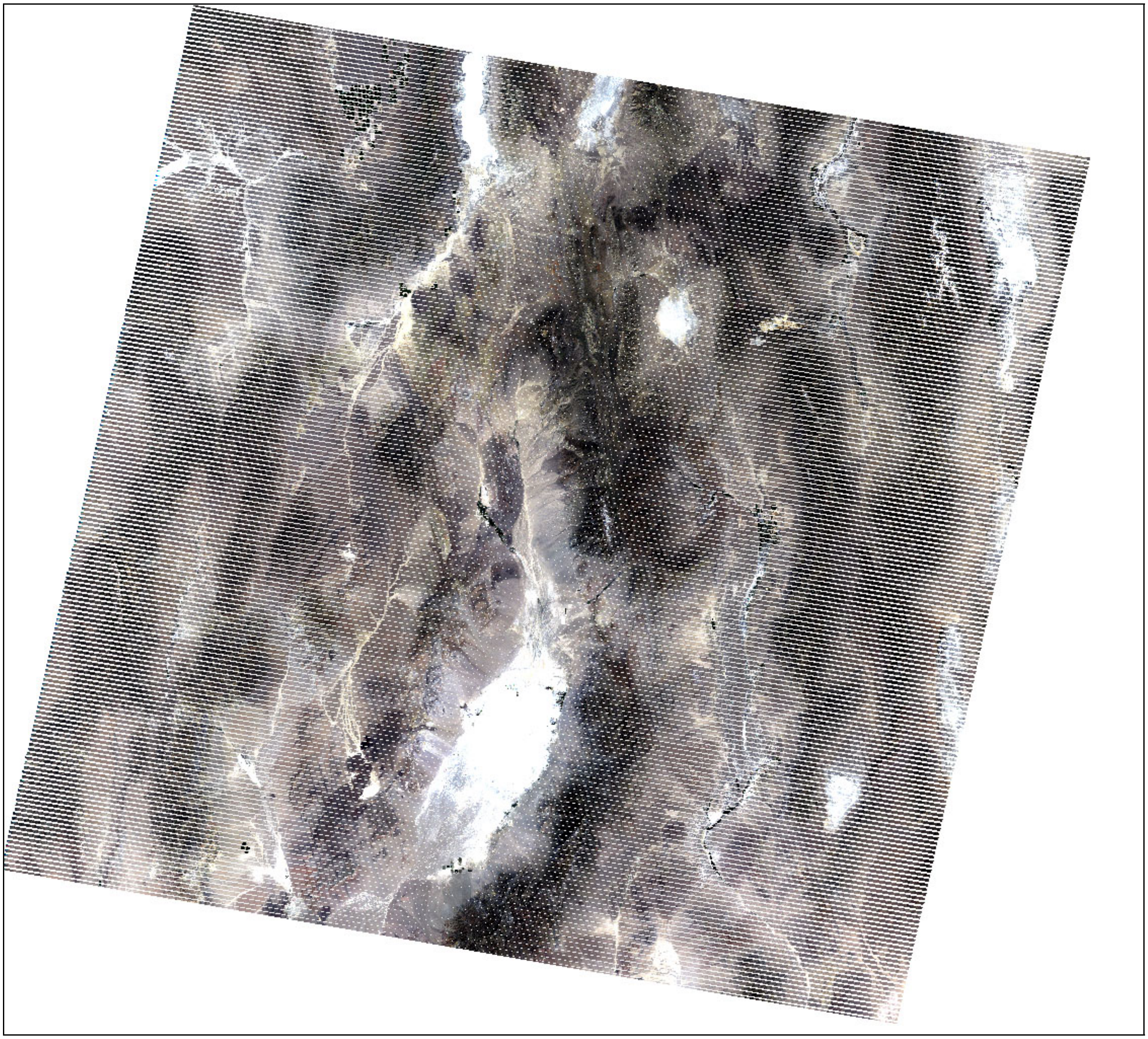

Figure F: Path 40, Row 33 acquired 6/04/2003 (after SLC failure)

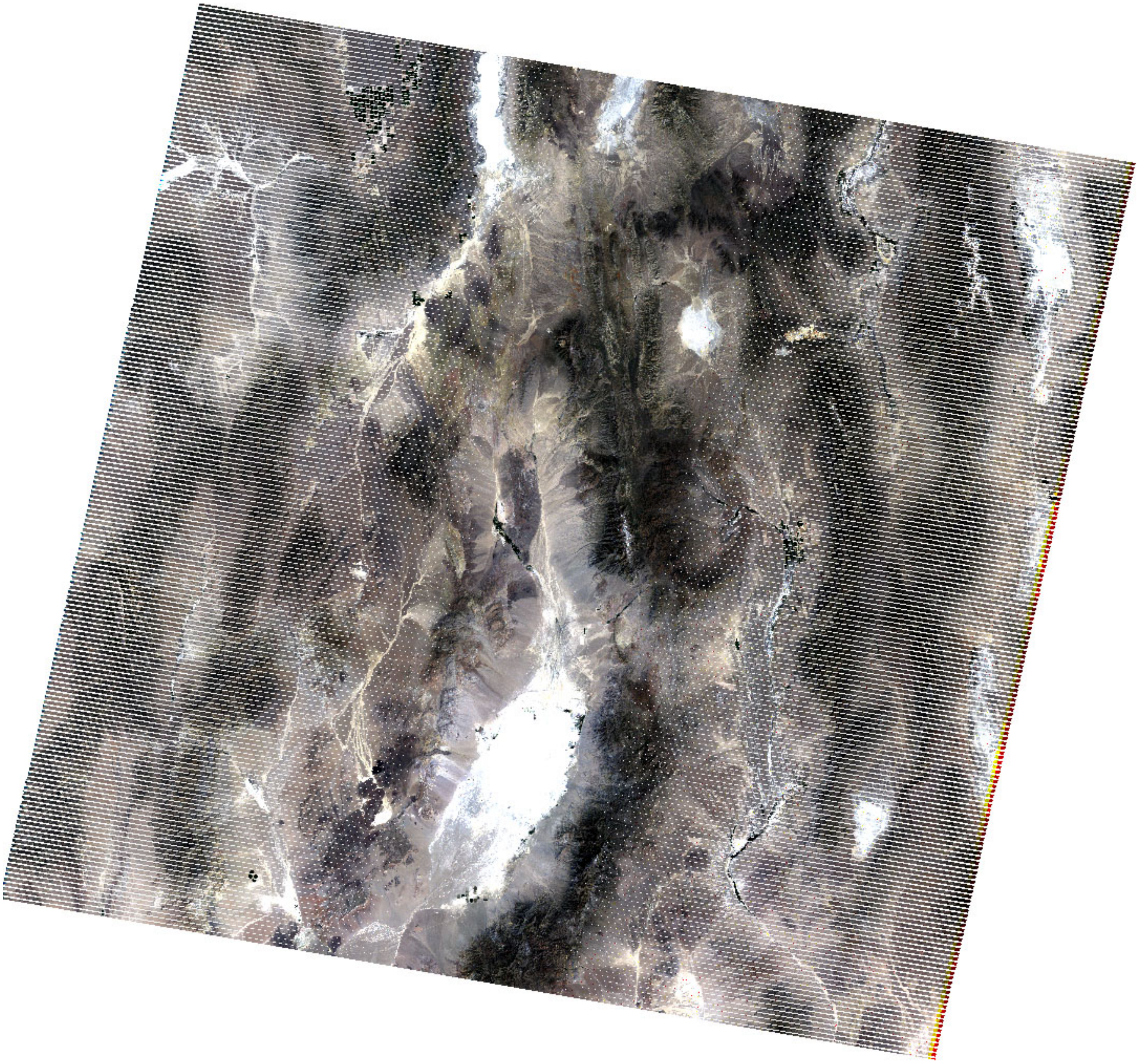

Figure G: Path 40, Row 33 acquired 6/04/2003 (after SLC failure) with interpolated pixels

Geometric Implications

With regard to geometric analysis of the SLC anomaly, efforts have focused on trying to ascertain the position and movement of the SLC before, at, and subsequent to the time of the anomaly. This determining how to create geometrically correct products for comparing pre- and post-anomaly scenes, and running scan mirror calibration procedures. The sections below describe how Level 1G products are being created from post-anomaly scenes in order to analyze the status of the SLC, and the resulting geometric/geodetic fidelity of the processed data, including any residual artifacts present in the output products.

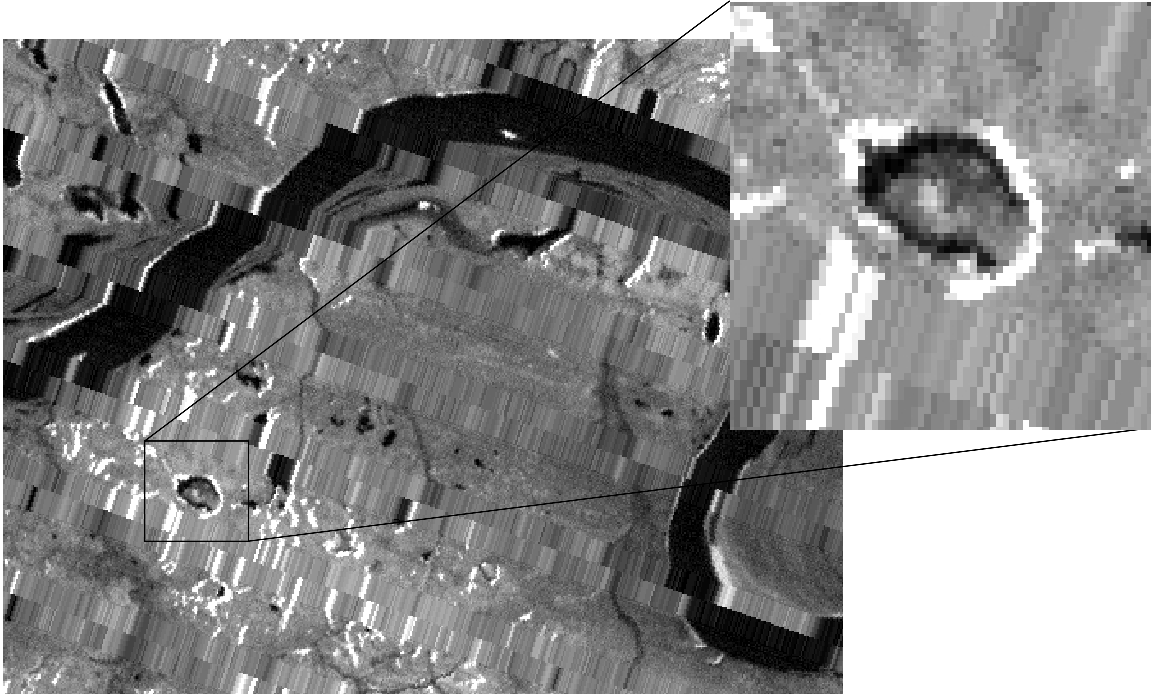

Figure H: Anomaly scene processed using the SLC-off geometric model. The "smeared" effect of some scans is produced by pixel interpolation across the large scan gaps near the edges of the imagery**.**

Figure A shows the zigzag ground coverage pattern resulting from the absence of scan line correction. As stated earlier, data are being lost due to the larger scan gap, as well as from duplication at the edges where forward and reverse scans overlap. In an attempt to confirm initial suspicions that the SLC had halted, post-anomaly imagery was processed to Level 1G with precision and terrain correction by using a geometric model based on a non-moving SLC. Control point matching and precision correction performed normally, as did terrain correction and subsequent scan mirror calibration procedures. Normally, scenes would be resampled using the cubic convolution algorithm. Due to the large scan gaps at the scene edges, however, cubic convolution resampling failed. Therefore, the nearest neighbor algorithm was substituted in order for processing to complete successfully. Post-anomaly scenes processed using the "SLC-off" geometric model had good geometric accuracy, showing that the data were consistent with the SLC being entirely stopped. On the other hand, attempts to process the same data with the production (SLC moving) geometric model led to large numbers of correlation failures during precision correction, probably due to the presence in the resampled product of duplicate imagery from the overlapping scans.

Issues related to resampling are currently being investigated. Under normal circumstances, Landsat 7 viewing geometry may produce a maximum scan gap up to two pixels wide that is filled by interpolating surrounding pixels using the production version of the resampler. With the SLC in its halted state, a large scan gap is present in all imagery. The gap increases from a few pixels near the center of the image to approximately a full scan width at the extreme edges. The production resampler interpolates across this large gap, which results in a "smearing" effect shown in Figure 7. The "Venetian-blind" look seen in earlier figures is the result of modifying the resampler to limit the number of pixels interpolated within the scan gaps. These images are useful in illustrating the data loss resulting from the halted SLC, which is estimated to be 20%. While interpolation may visually improve the imagery somewhat, there is no way to recover the data that would have otherwise been acquired using a properly functioning SLC.

In addition to the large scan gap, the scan line geometry resulting from the halted SLC also produces scan overlaps near the edges, as seen in figure 8. When the image is resampled, it is unclear whether the imagery in the overlap regions will come from the forward scans, reverse scans, or both. Experimental versions of the gridding algorithm have been created to select imagery from either the odd or the even scans in order to avoid this ambiguity, and the software is being tested to measure its effectiveness.

Investigations thus far indicate the SLC stopped in an aft-looking position, but results are inconclusive as to whether there has been any movement following the halt, either prior to or after power to the SLC was removed by the flight operations team on June 6, 2003. Thus, geometric stability of the imagery is still undetermined. Geometric test sites continue to be processed and analyzed as they are acquired in order to determine the position of the SLC, and any possible motion that may have occurred since the time of the anomaly.

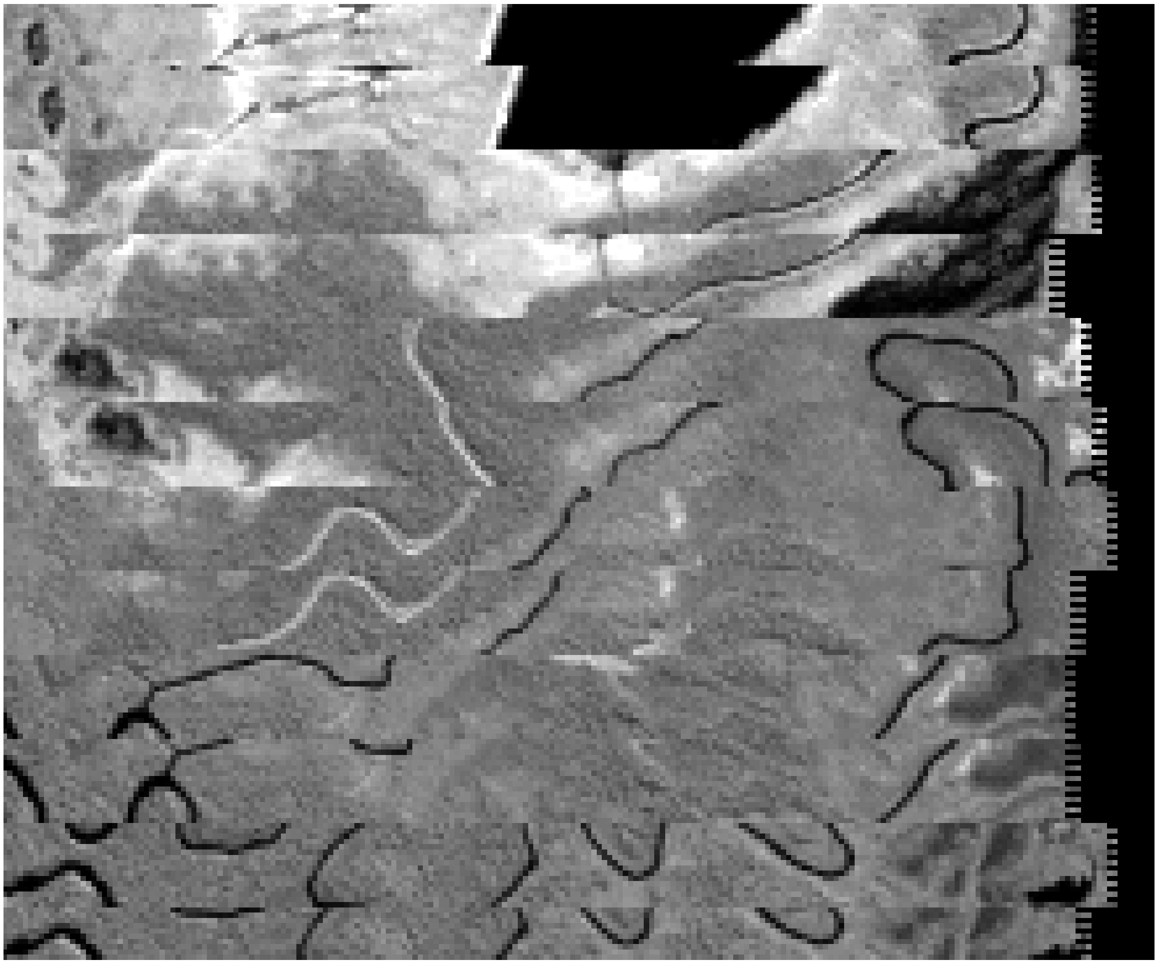

Figure I. Zoomed view of Level 0R imagery showing scan line duplication near edges as a result of halted scan line corrector.

Section III: Reports from the Science Community

The following pages contain reports as written by the various scientists who contributed their analysis and opinions of the scientific usability of anomalous Landsat 7 data. These were volunteer efforts done on short notice, thus the format of these reports varies widely from more detailed written and illustrated analyses to informal e-mails expressing first looks and opinions. Some researchers were able to bring to bear the services of colleagues while others performed the work by themselves.

Report from James Vogelmann

Ph.D., et al, SAIC, USGS/EROS Data Center

Preliminary Assessment of the Value of Landsat 7 ETM+ data following Scan Line Corrector Malfunction: Views from the Sciences

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Introduction

The purpose of this report is to provide first-order assessments of the impact that the Scan Line Corrector (SLC) malfunction has on the scientific usefulness of Landsat 7 ETM+ data. In this report, we provide results from several preliminary applications-oriented investigations in which we use Landsat ETM+ data that were acquired following the SLC malfunction. We also speculate on the utility of the data in their current form to the overall scientific community.

Initial Summary of Results

1. From a user's perspective, the geometric integrity of the "good" pixels in the post-SLC malfunction data sets (based upon visual assessment) remains excellent.
2. Similarly, from a user's perspective, the radiometric properties of the "good" pixels in the post-SLC data sets remains excellent.
3. The "interpolation ON" data sets appears to provide good and useable information, especially appropriate for "filling in the holes" in the center of the scan lines. If one "buys into" the interpolation philosophy, this provides intact imagery for about 1288 contiguous pixels for each scan line, forming a very usable "core" of imagery for each scene.
4. Generation of multi-date image composites is an approach that will help to "fill in the gaps." However, additional work is necessary to determine the overall feasibility of this approach, and how best to composite the data.
5. We believe that, in spite of the current problems, Landsat 7 ETM+ data will be preferred by some users over some of the other more costly alternatives, at least for some applications.

Investigation 1: Change Detection

Landsat data are key for characterizing, quantifying, and mapping the long-term changes that are occurring across the Earth's land surface. The first investigation that we conducted was to evaluate the impacts of the SLC malfunction on standard change detection products. This portion of the investigation was conducted using data sets acquired from the "industrial" forested region to the east of Atlanta, Georgia (WRS 2 path 18 row 37). Forest harvesting (and forest re-growth) typifies the region. The following ETM+ data sets were acquired: June 1, 2000 (pre-SLC malfunction); June 10, 2003 (post-SLC malfunction; interpolation OFF); and June 10, 2003 (post-SLC malfunction; interpolation ON). June 10 data sets were geometrically co-registered to the June 1, 2000 data set. These post-SLC malfunction data sets were then radiometrically normalized to the June 1, 2000 data set using a series of dark and bright pseudoinvariant objects. Individual band difference images were then produced by subtracting the 2003 data sets from the 2000 data set. It should be noted that the geometric referencing of the post-SLC malfunction data sets to the 2000 data set went smoothly, and that visual inspection of the data sets (done by "flickering" between the 2003 and 2000 data sets) indicated that the data sets geometrically overlaid extremely well.

Figures 1-3 show false color composites from the three different data sets for an area located in the north center portion of the scene. Figure 1 represents the "pre-SLC malfunction" scene, whereas Figures 2 and 3 represent the "Interpolation OFF" and "Interpolation ON" post-SLC malfunction scenes, respectively. Because the portion of the scene shown is near the center of the path, the pixel "drop-outs" are minimal in Figure 3 ("Interpolation ON"). The lines of "drop-outs" become much more obvious towards the edges of this scene (and are much more obvious throughout the imagery in the "Interpolation OFF" data set.

We made a quick estimate of the amount of the scenes adversely affected by the SLC malfunction. Of the approximately 39,000,000 pixels in a normal ETM+ scene, approximately 8,000,000 were "blank" in the "Interpolation OFF" data set. Thus, approximately 79.4% of the pixels were considered to be "good" (i.e., useable). Approximately 5,400,000 pixels were "blank" in the "Interpolation ON" data set, implying that, if users are comfortable with the interpolation (i.e., that they are not philosophically opposed to using such interpolation methods), that approximately 86.2% of the pixels can be considered to be useable. With the interpolation on, a 1288 pixel area in the center of each scan line (approximately 38.6 km) is intact (i.e. devoid of SCL drop-outs).

Difference images generated by subtracting the 2003 from the 2000 data sets are shown for bands 3, 4 and 5 in Figures 4-9. In these images, dark areas indicate where reflectance increased between data sets, whereas light areas indicate where reflectance decreased. Large changes generally depict major changes that have taken place in the forests related to harvesting or re-growth.

The primary rationale for generating difference image products for this assessment is that these are image "derivative" products, and many spatial and radiometric problems that might be "hidden" to the eye in a false-color composite become readily apparent in such products. We were especially interested in assessing the quality of the image difference data in areas where interpolation “added” pixel information as compared with the “Interpolation OFF” scenes. In this evaluation, the areas of interpolation are visually satisfactory. While more in-depth statistical analyses might indicate some subtle differences (i.e., errors) as compared with the non-interpolated areas, such differences are likely to be minor and within the normal error limits of variability of such derivative products.

Change Detection Summary

This investigation showed that the quality of the radiometry and geometry of the Landsat 7 ETM+ data sets for the “good pixels” (i.e., the pixels with non-zero digital number values) is still excellent for the purposes of change detection. Approximately 79% of the scene was useable for change detection applications for the “interpolation-off” scene. Change detection products produced using “interpolation-on” scene showed that the interpolated pixels appeared to be reasonable approximations of the “real” ones. No appreciable visual differences were noted between interpolated and non-interpolated pixels in the change products. Approximately 86% of the pixels in “interpolation-on” scenes were found to be usable. Whichever product is used, there is no doubt that enough good data are contained within each scene to provide excellent statistical estimates of regional to global land cover change. However, the “gaps” in the data will hinder generation of “wall-to-wall” spatial change detection products. This will also likely hinder the use of the data for more localized (e.g., community-based or state-based) change assessments.

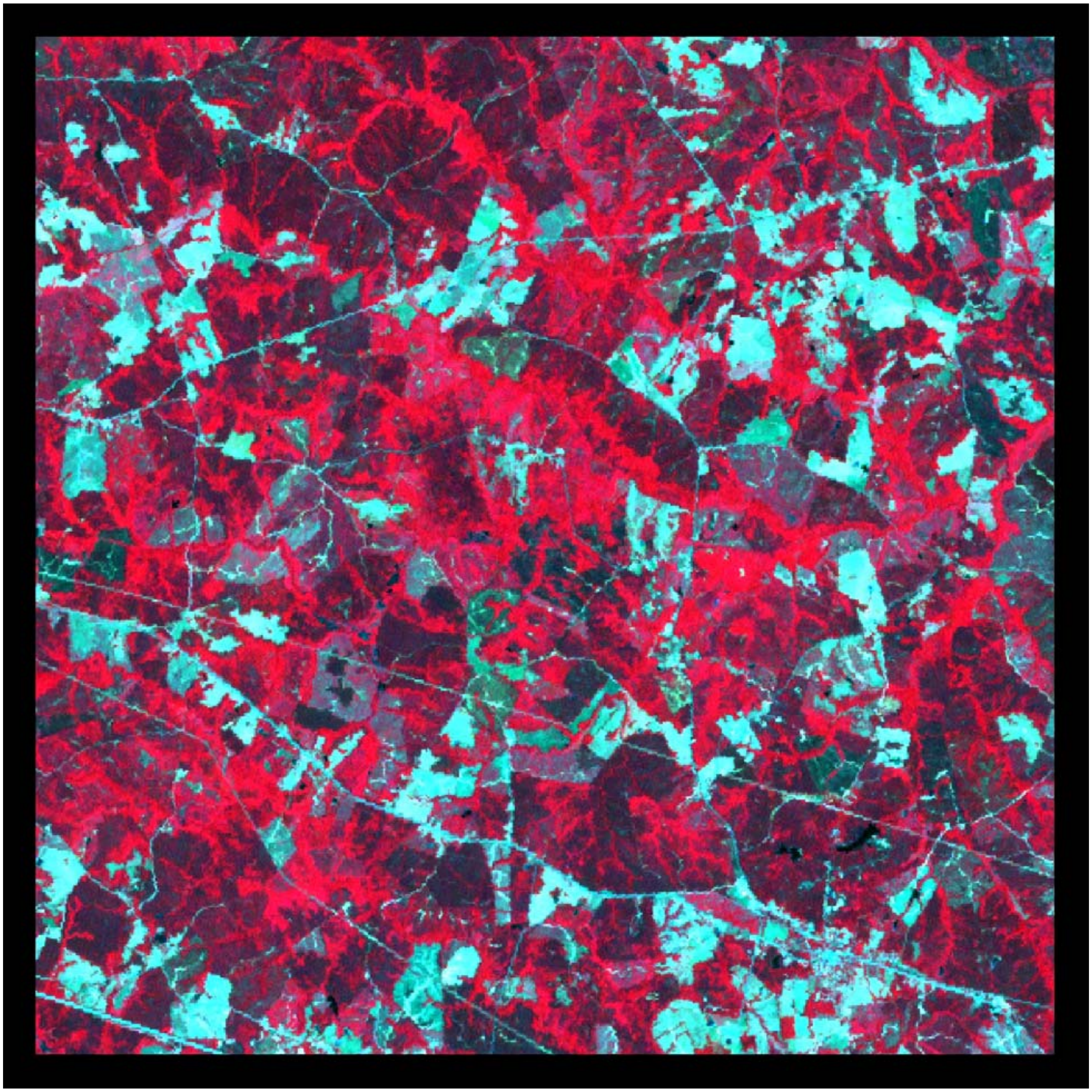


Figure 1: Landsat ETM+ false color composite image showing a portion of WRS 2 Path 18 Row 37. The image was acquired on June 1, 2000, and is located just east of Atlanta, Georgia. Dark areas are mostly conifer forests, bright red is deciduous forest and light areas are cleared areas (mostly from forest harvest operations). The area shown is about 272 sq km (16.5 x 16.5 km) and is located in the north-central portion of the scene.

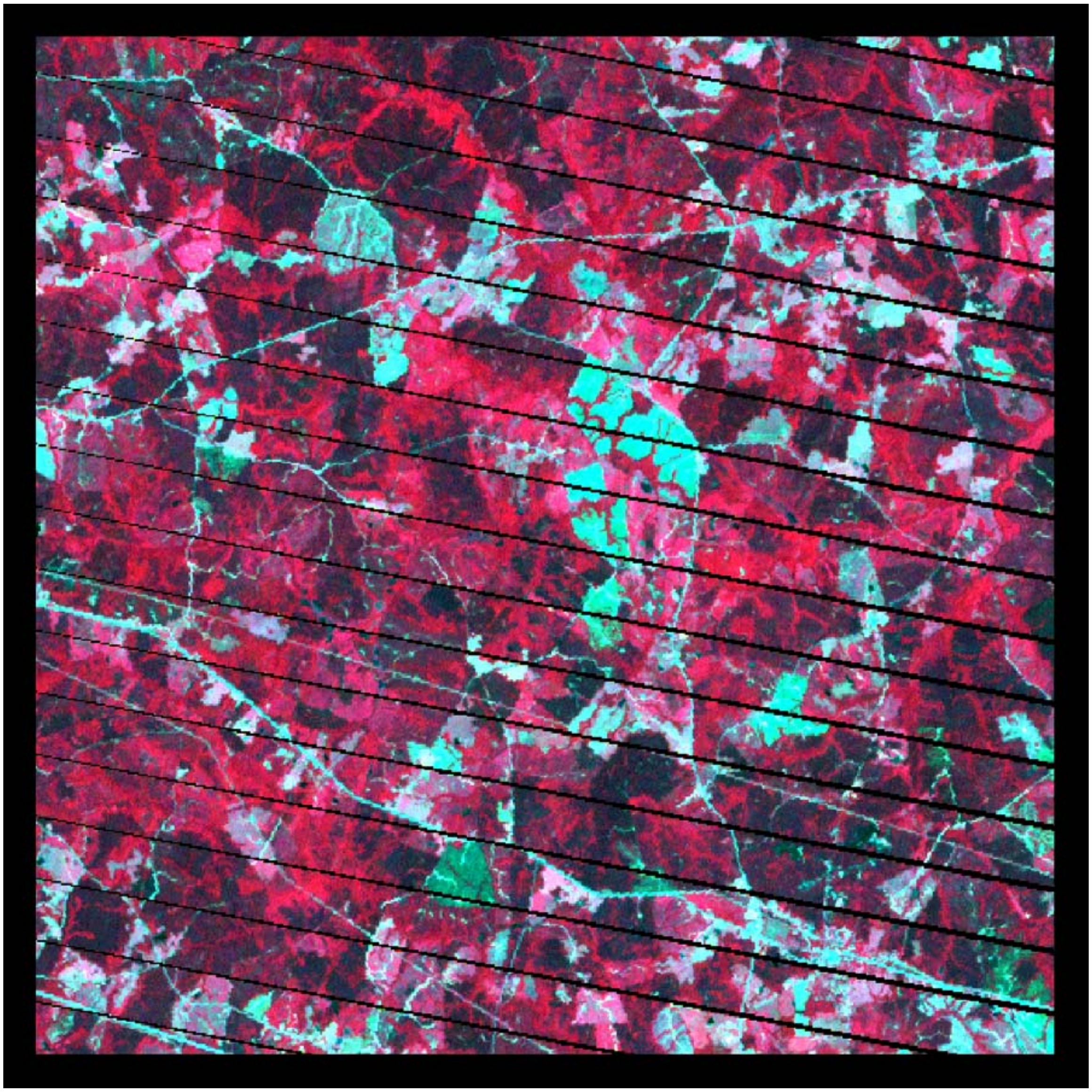


Figure 2. Landsat ETM+ false color composite showing same region as shown in Figure 1. Imagery was acquired on June 10, 2003, after the scan line corrector (SLC) malfunctioned. Interpolation is "OFF" for this product. Because this portion of the image is near the center of the scene, the lines of "drop-out" pixels are somewhat narrower than towards the east or west edges of the data set.

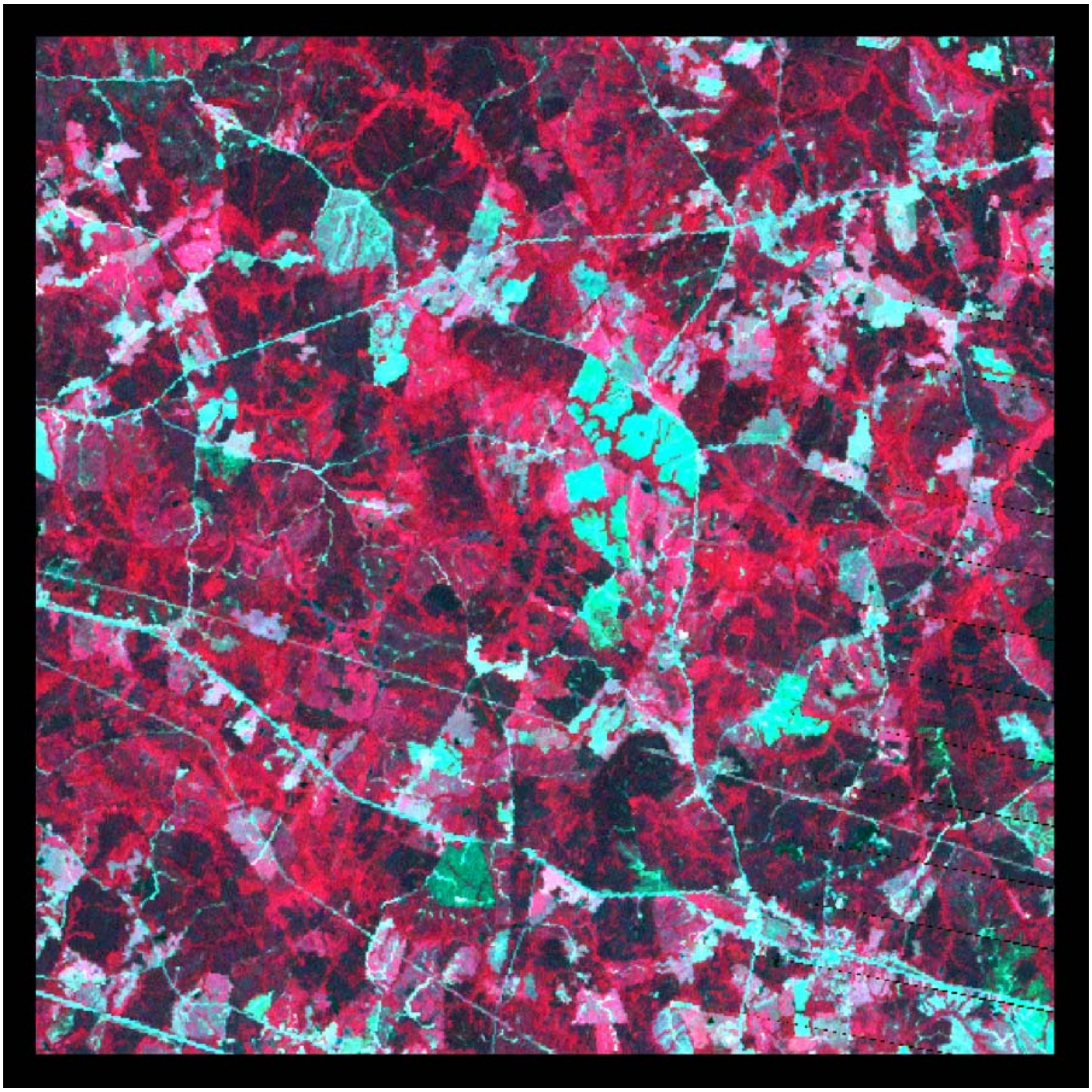


Figure 3. Landsat ETM+ false color composite showing same region as shown in Figure 1. Imagery was acquired on June 10, 2003, after the scan line corrector (SLC) malfunctioned. Interpolation is “ON” for this product. The lines of “drop-out” pixels can bee seen “just starting to form” towards the right of the image. No obvious visually apparent image interpolation-related artifacts are visually apparent throughout most of the area shown.

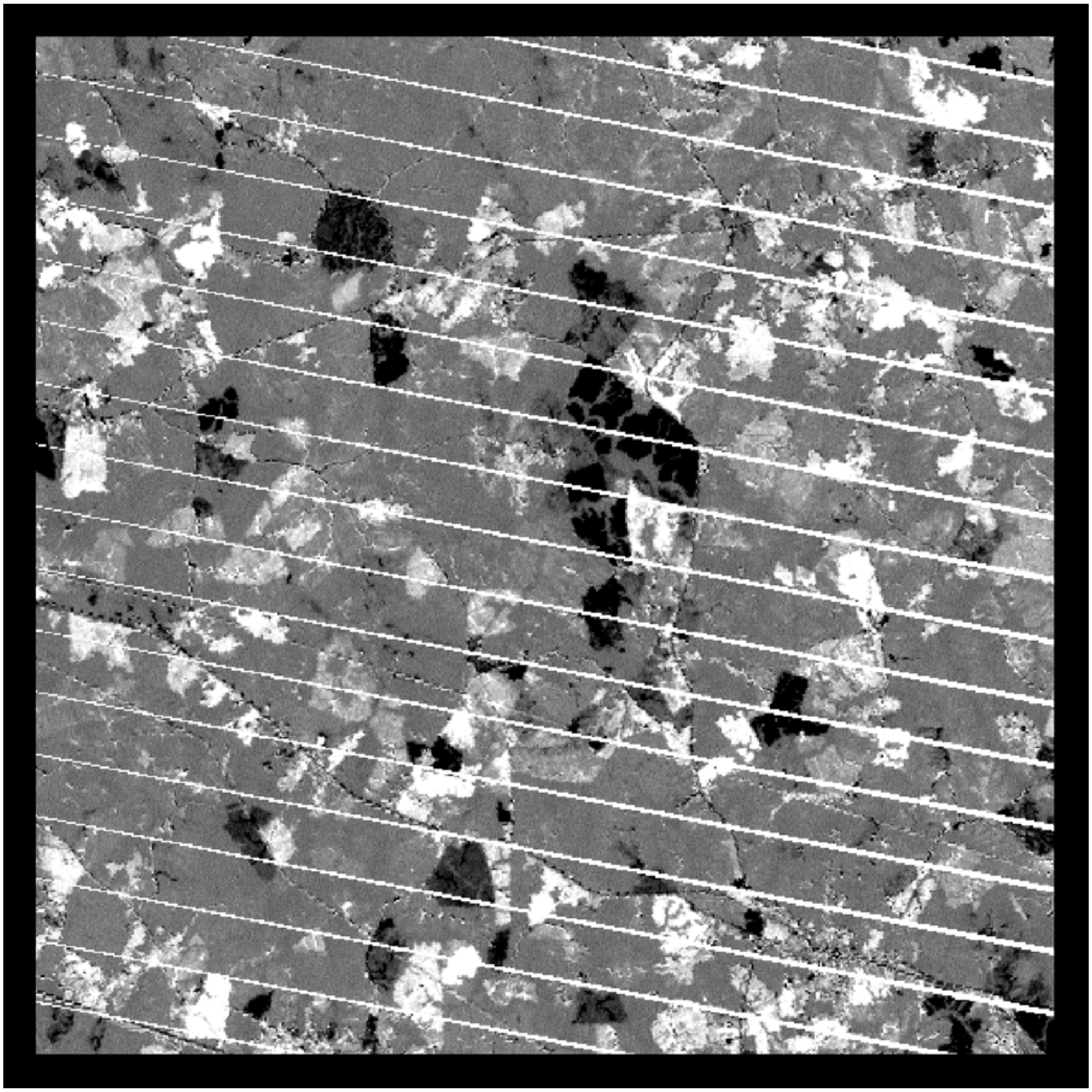


Figure 4. Landsat ETM+ band 3 difference image produced by subtracting 2003 “Interpolation OFF” from 2000 data set. Dark areas depict where reflectance increased over the time period (generally related to where forest harvesting occurred), whereas bright areas show where reflectance decreased (generally related to forest re-growth). SLC dropouts are apparent in these images as bright striping. Areas between the SLC dropouts appear to be “normal” and good data.

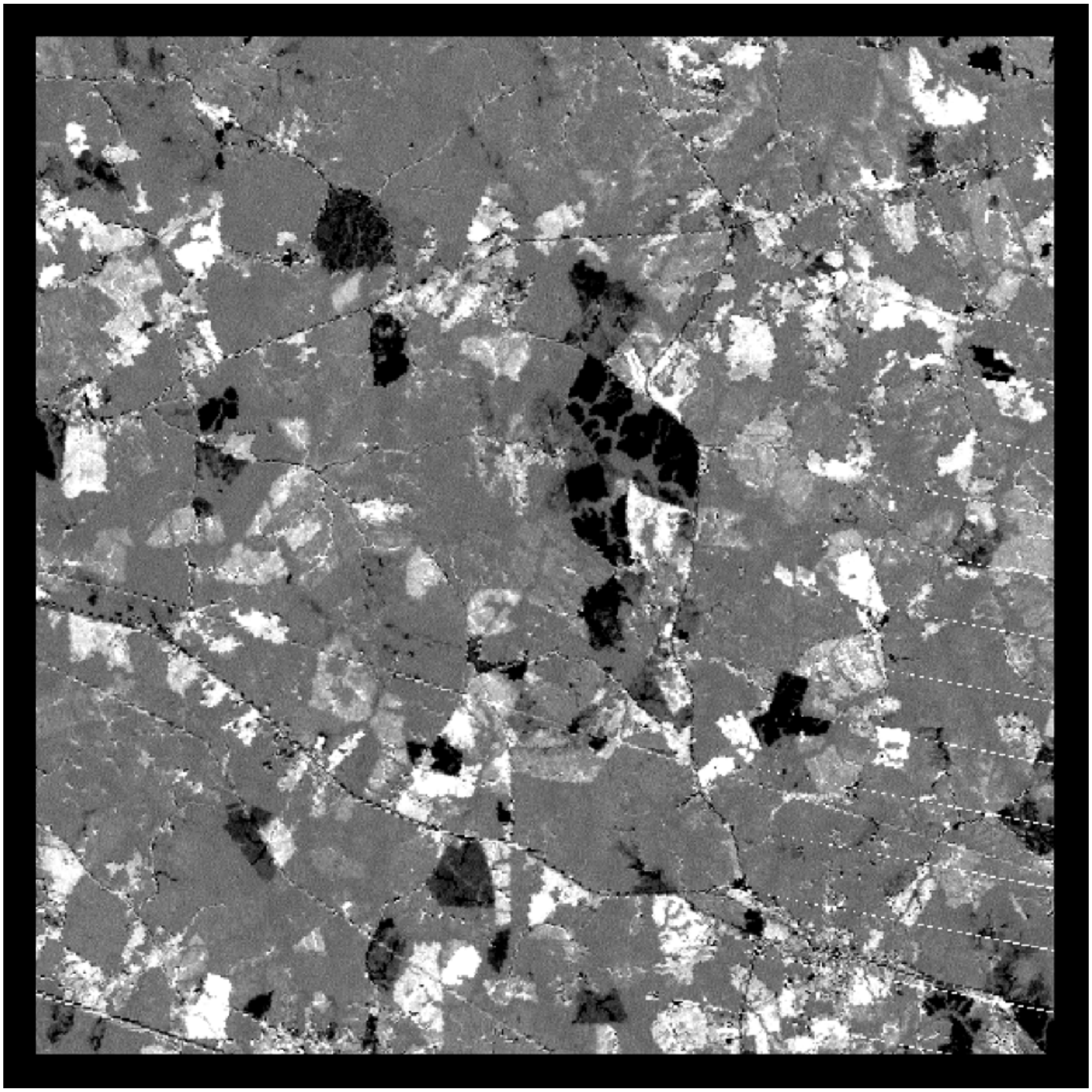


Figure 5. Landsat ETM+ band 3 difference image produced by subtracting 2003 “Interpolation ON” from 2000 data set. Dark areas depict where reflectance increased over the time period (generally related to where forest harvesting occurred), whereas bright areas show where reflectance decreased (generally related to forest re-growth). Some SLC dropouts are apparent in towards the right of these images as bright striping. Areas where the interpolations were done (compare with Figure 4) appear to be good and useable data.

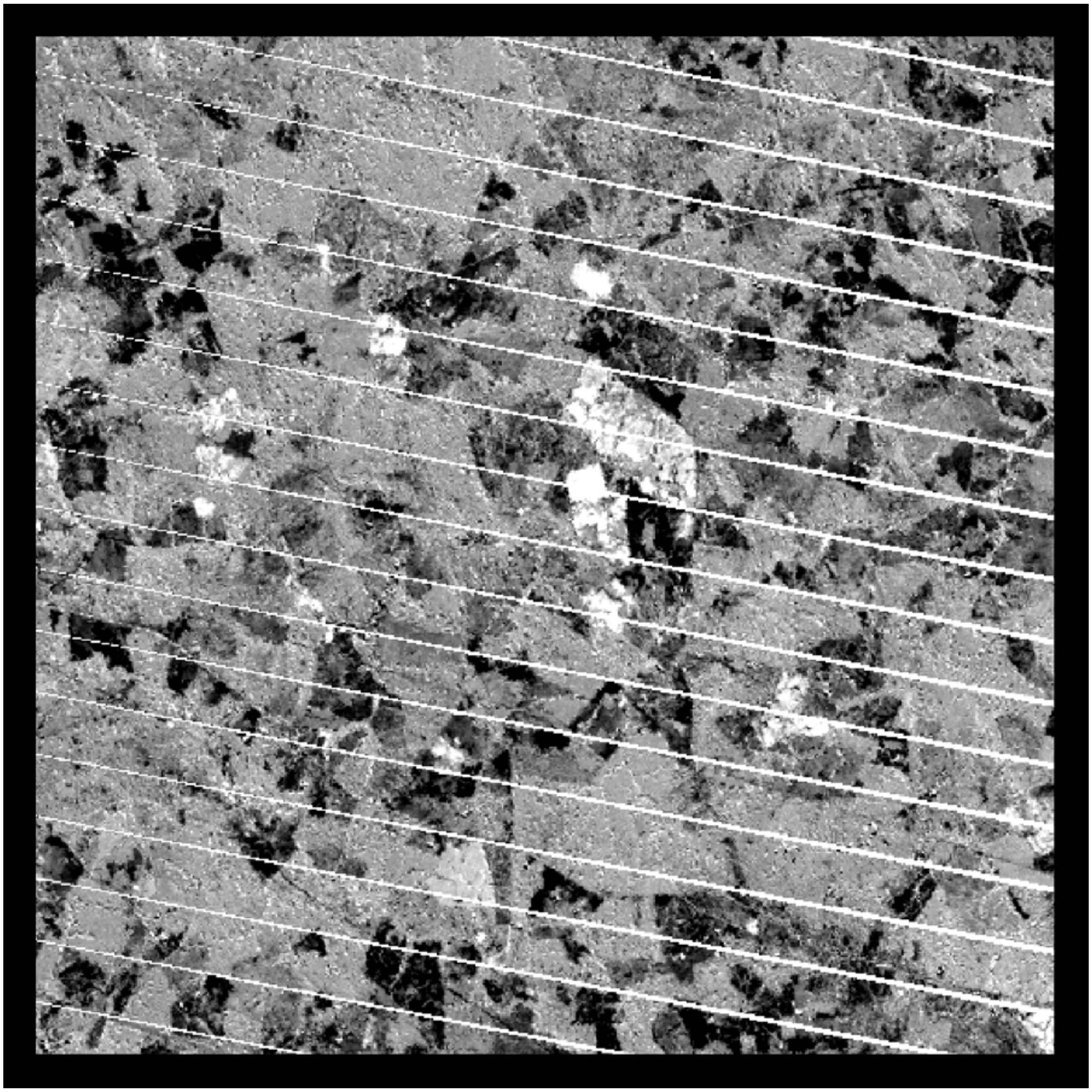


Figure 6. Landsat ETM+ band 4 difference image produced by subtracting 2003 “Interpolation OFF” from 2000 data set. Dark areas depict where reflectance increased over the time period (generally related to where forest re-growth occurred), whereas bright areas show where reflectance decreased (generally related to forest harvesting). SLC dropouts are apparent in these images as bright striping. Areas between the SLC dropouts appear to be “normal” and good data.

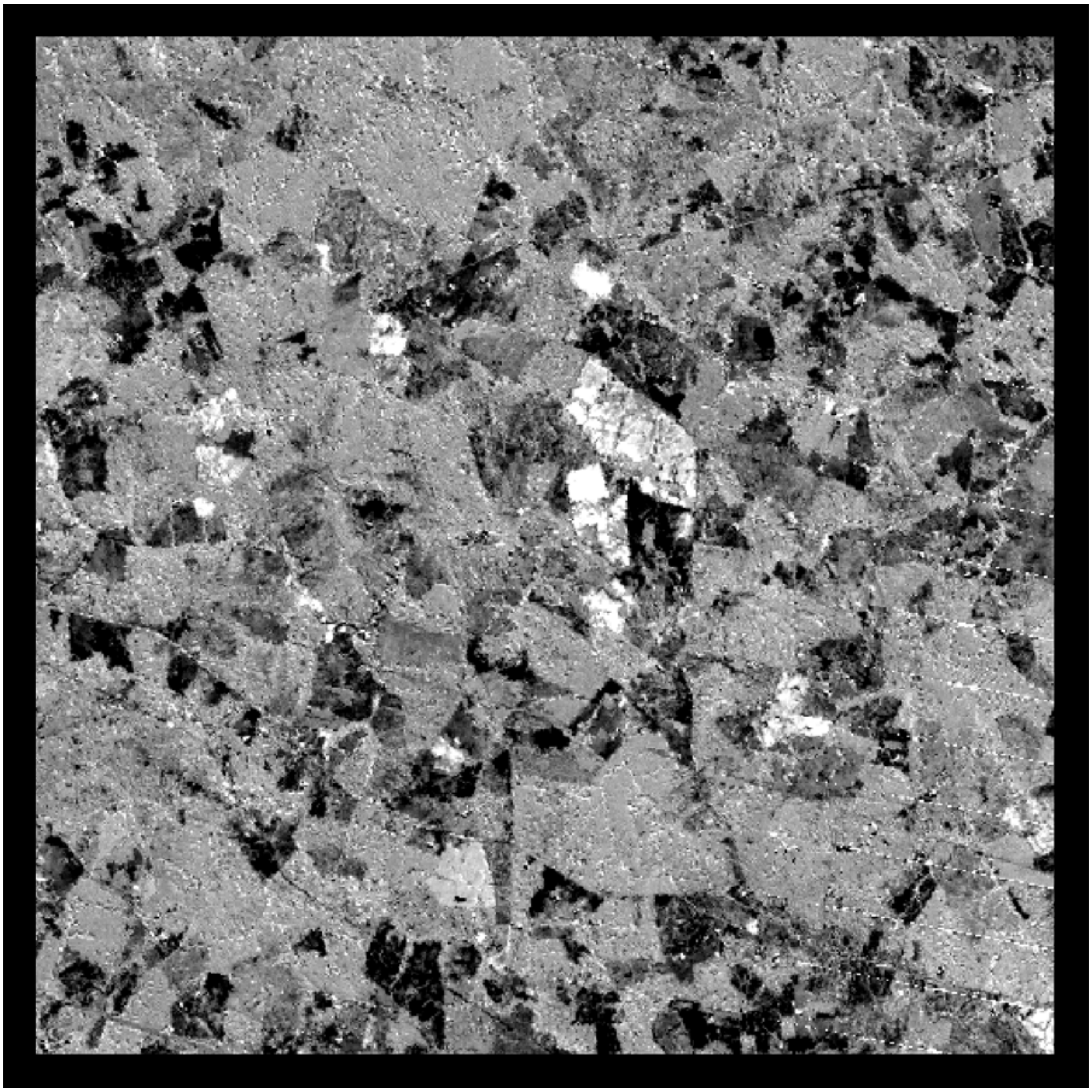


Figure 7. Landsat ETM+ band 5 difference image produced by subtracting 2003 "Interpolation ON" from 2000 data set. Dark areas depict where reflectance increased over the time period (generally related to where forest re-growth occurred), whereas bright areas show where reflectance decreased (generally related to forest harvesting). Some SLC dropouts are apparent in towards the right of these images as bright striping. Areas where the interpolations were done (compare with Figure 6) appear to be good and useable data.

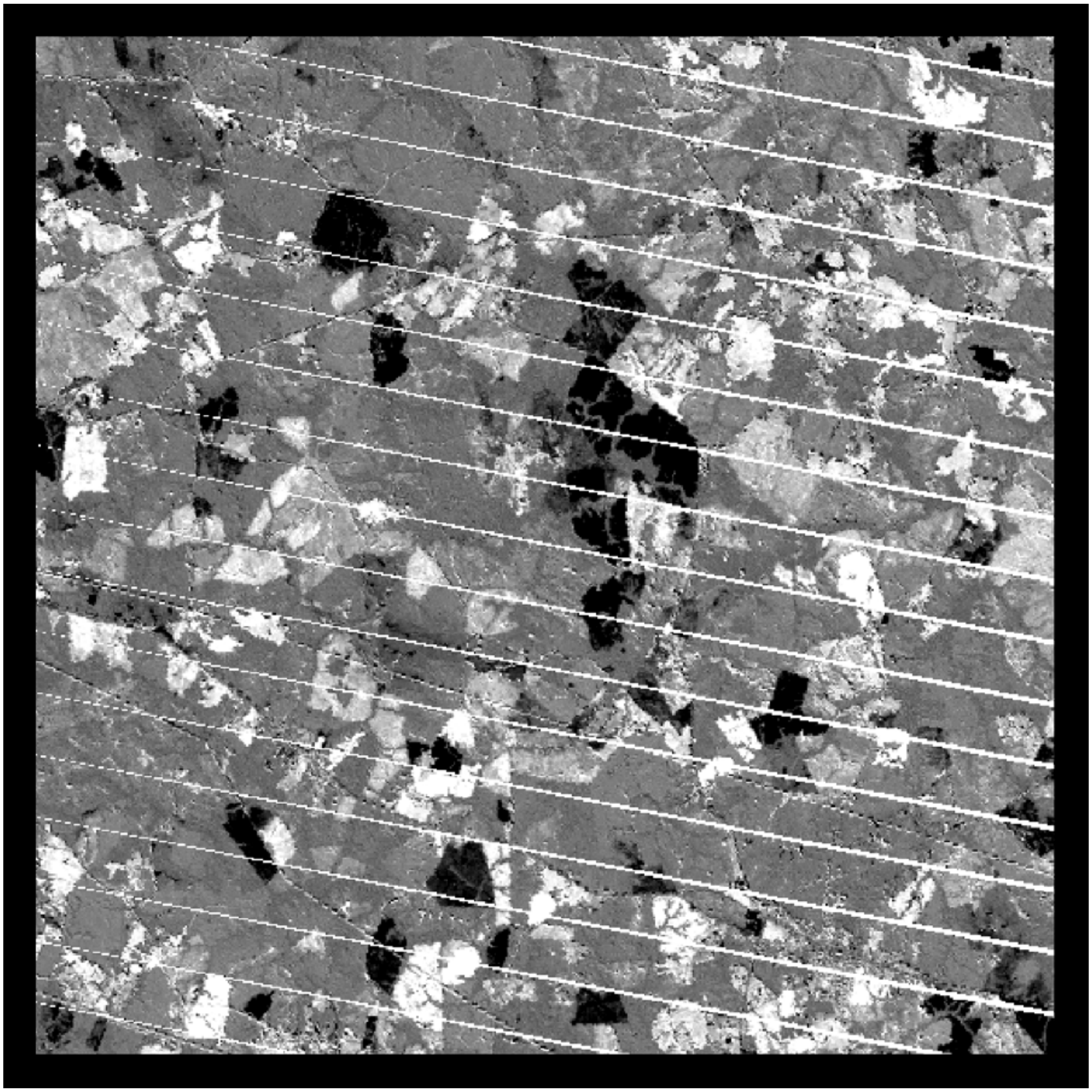


Figure 8. Landsat ETM+ band 5 difference image produced by subtracting 2003 “Interpolation OFF” from 2000 data set. Dark areas depict where reflectance increased over the time period (generally related to where forest harvesting occurred), whereas bright areas show where reflectance decreased (generally related to forest re-growth). SLC dropouts are apparent in these images as bright striping. Areas between the SLC dropouts appear to be “normal” and good data.

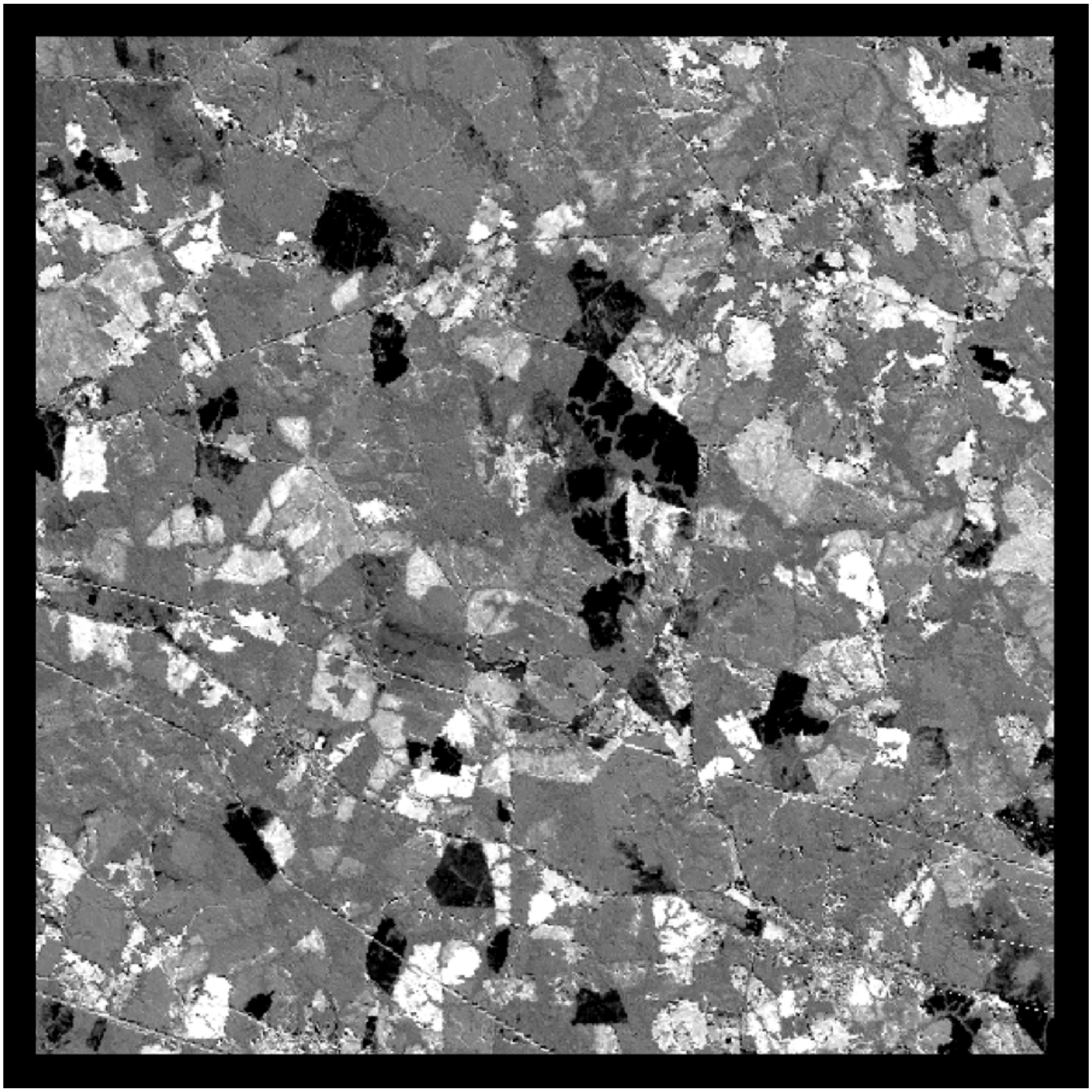


Figure 9. Landsat ETM+ band 5 difference image produced by subtracting 2003 "Interpolation ON" from 2000 data set. Dark areas depict where reflectance increased over the time period (generally related to where forest harvesting occurred), whereas bright areas show where reflectance decreased (generally related to forest re-growth). Some SLC dropouts are apparent in towards the right of these images as bright striping. Areas where the interpolations were done (compare with Figure 8) appear to be good and useable data.

Investigation 2: Burn Mapping Applications

Mapping the spatial heterogeneity of wildland burns for the purpose of understanding how fire interacts with vegetation and topography is valued information. The information measured and mapped is “burn severity” – a scaled index gauging the magnitude of ecological change caused by fire. Landsat 7 ETM+ data have been used in this process to derive a radiometric value that we call the Normalized Burn Ratio (NBR). The NBR is differenced between pre- and post-fire datasets to determine the extent and degree of detected change from burning,

The NBR is a transformation similar to the Normalized Difference Vegetation Index (NDVI). The difference is that NBR integrates the two bands that respond most but in opposite ways to burning characteristics. The two bands used by the NBR are TM/ETM+ band 4 and band 7. The NBR is calculated as:

$$\mathbf{NBR = (RB4-RB7)/(RB4+RB7)};$$

where RB values are the calculated per-pixel “at satellite “ reflectance quantities per band. These bands provide the optimum signal for information about variation of burn severity found within the boundary of the burn. The (R4-R7) difference is scaled by the sum of the two bands to normalize fro overall brightness tat is consistent across all bands. This helps minimize the within-scene topographic effects and between-scene solar illumination effects. To isolate burned from unburned areas, and to provide a quantitative measure of absolute change, the NBR dataset derived after burning is subtracted from the NBR dataset obtained from before the burning. This measured change in NBR is hypothesized to be correlative in magnitude to the environmental change caused by fire as it relates to fire effects on previously existing vegetative communities. Burned areas assume strongly positive or negative values, depending on whether the fire distresses or actually enhances productivity on the burn. Strongly positive differenced NBR is more typical, where fire generally creates longer-lasting conversions of biomass to less productive, or earlier successional, states.
(source: Key, Carl H. and Benson, Nate C., Landscape Assessment. FIREMON Webpage: http://fire.org/firemon/default.htm.)

The Rodeo–Chediski fire in Arizona during the 2002 fire season will be the test site for this analysis. Data sets include the following:

Path/Row 36/36
June 02, 2002 ID: L71036036_03620020605 Pre-fire scene
May 07, 2003 ID: L71036036_03620030507 Post-fire scene before the SLC anomaly
June 08, 2003 - Post-fire scene following SLC anomaly (Data provide with both Interpolation on and Interpolation off)

Burn Mapping Applications Summary

Until recently, an automated approach has been used to map the perimeters of forest fires using Landsat 7 data. The automated procedure no longer works using the post-SLC anomaly data. However, the burn mapping delineations can still be accomplished using the post-SLC anomaly data through manual interpretations. While the missing data may make it difficult to obtain a complete spatial burn mapping summary, the images still have value for providing estimates of forest fire impacts. In the future, there may be more emphasis of using Landsat 5 data for burn mapping applications, but the Lansat 7 data will be used when the Landsat 5 data are not available. Meanwhile, rapid assessment of forest fire impacts can still be accomplished using post-SLC anomaly Landsat data. For rapid assessment work, the ability to obtain Landsat data close to when the forest fire is occurring is very critical, and post-SLC anomaly Landsat data still have value in this regard.

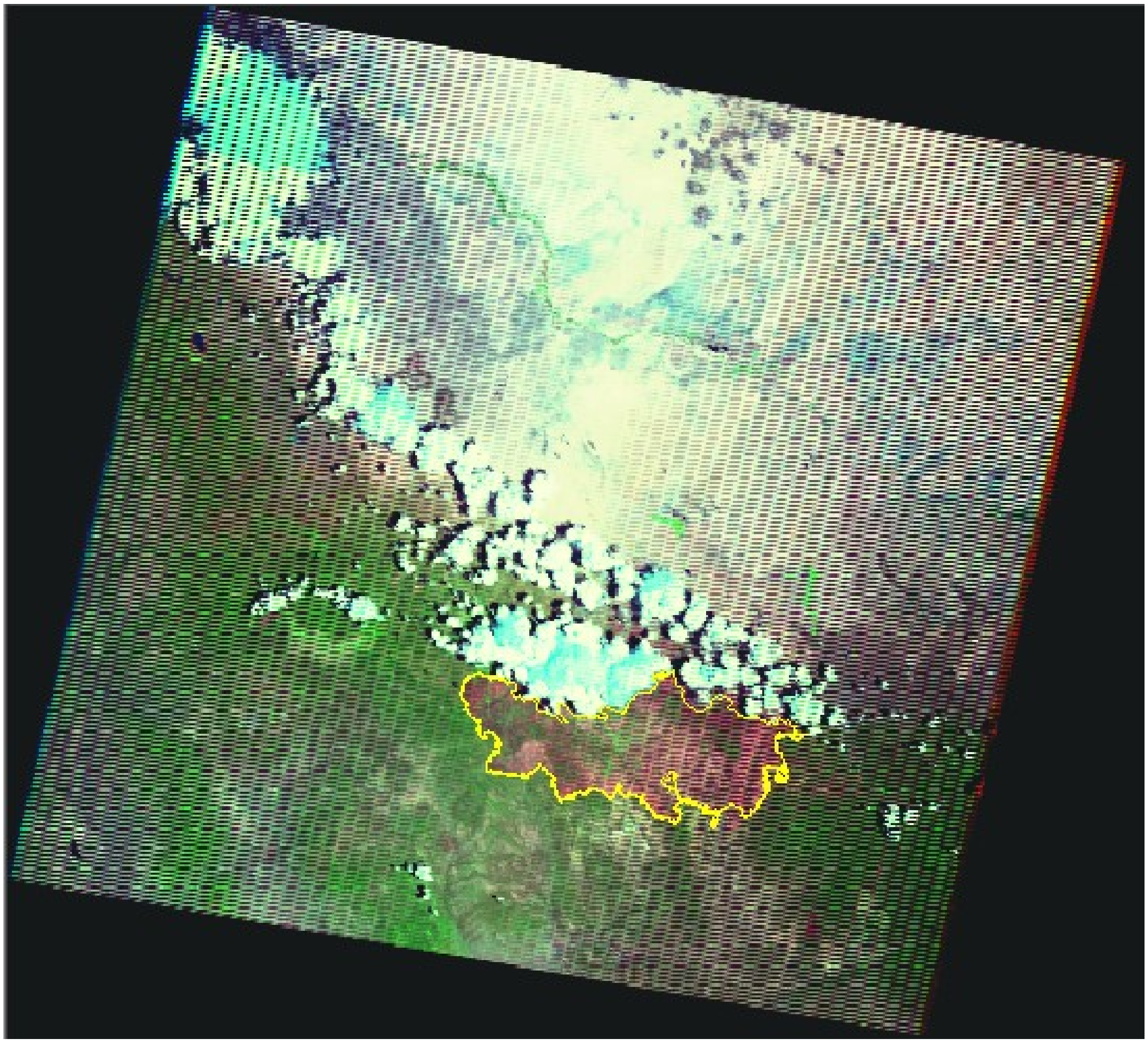


Figure 10. Landsat 7 ETM+ June 8, 2003 data with scan line corrector anomaly. The Rodeo_Chediski fire perimeter is highlighted in yellow. The fire perimeter is derived from differenced NBR images using a hybrid of automated and on-screen digitizing methods. Landsat data with the scan line corrector anomaly will not provide an opportunity to use the automated interpolation of the fire perimeter.

Figure 11. This figure is a subset of Landsat 7 ETM+ data representing the pre-fire data set. The acquisition date for this scene is June 2, 2002.

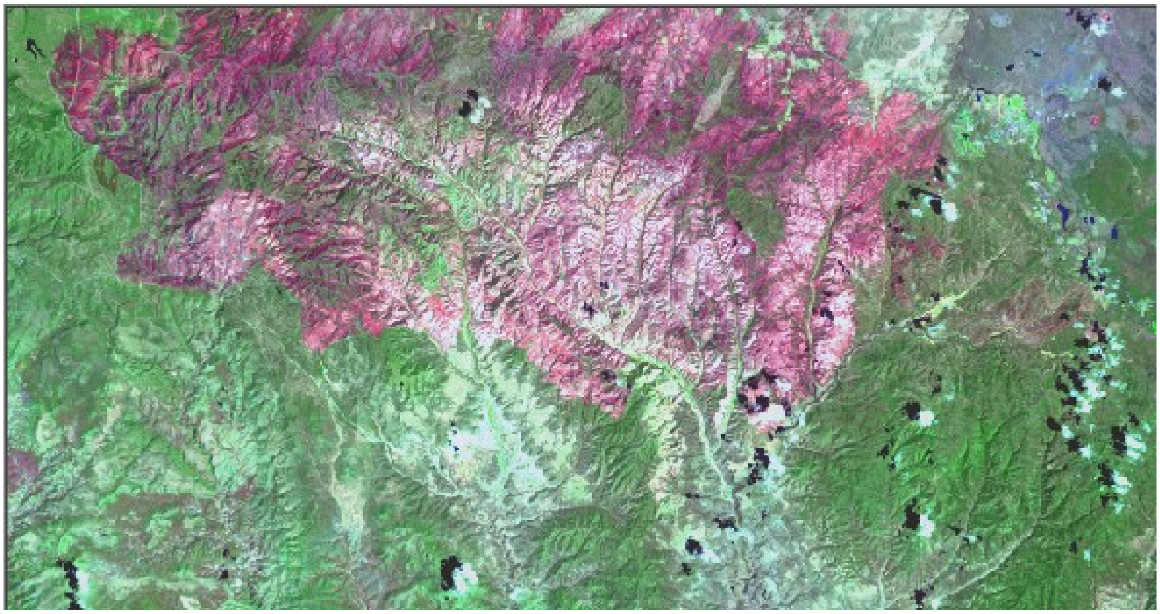


Figure 12. This data represents the control post-fire data. This is Landsat 7 ETM+ data acquired on May 7, 2003.

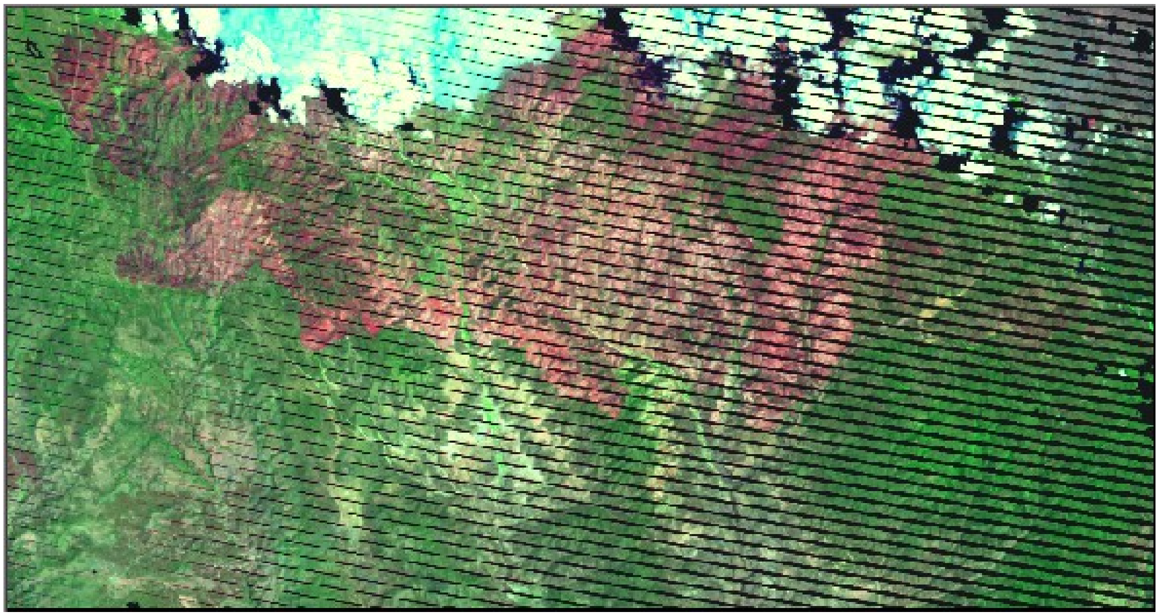


Figure 13. This is a subset of the Landsat 7 ETM+ June 8, 2003 data with the scan line corrector anomaly and with the interpolation option turned off. In viewing these data, it is obvious that data are lost but yet the majority of the scene is intact and spatial patterns are detectable.

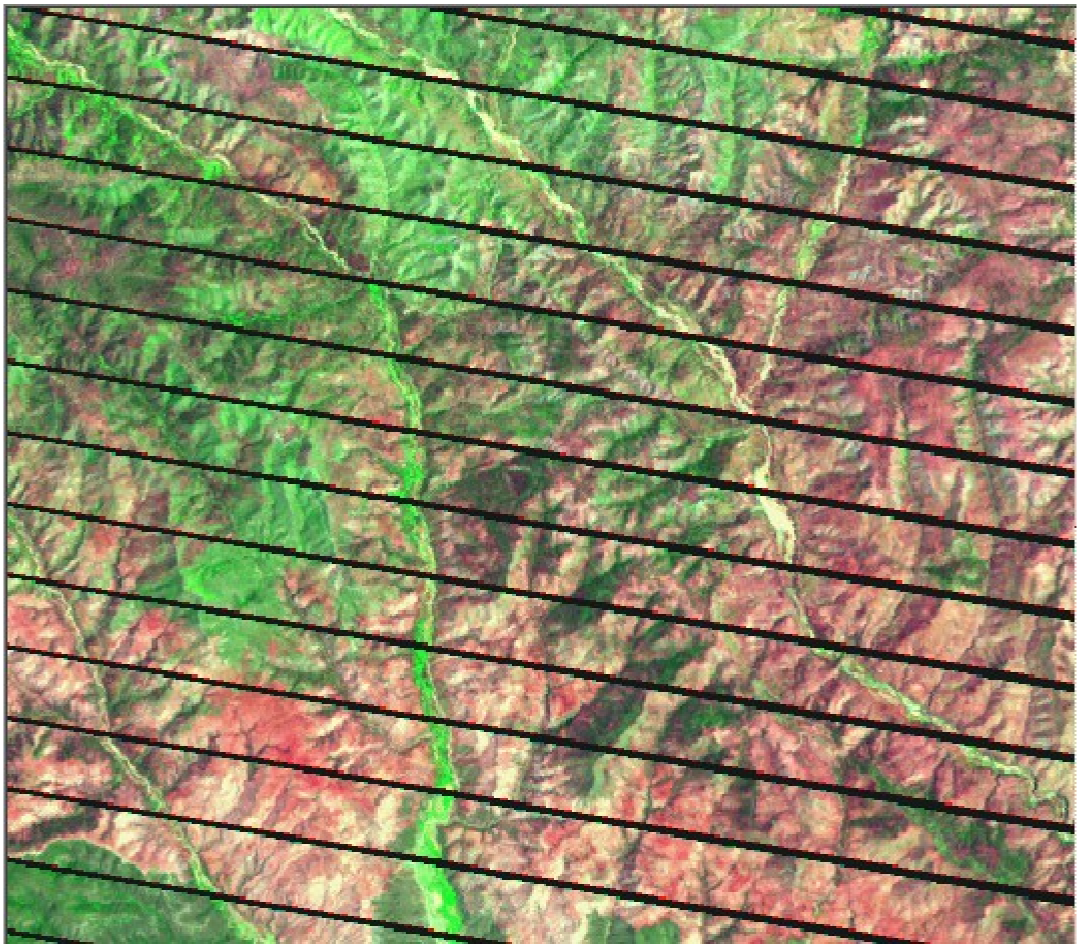


Figure 14. This figure is an enlargement illustrating more detail of the Landsat 7 ETM+ June 8, 2003 data with the scan line corrector anomaly and with the interpolation option turned off.

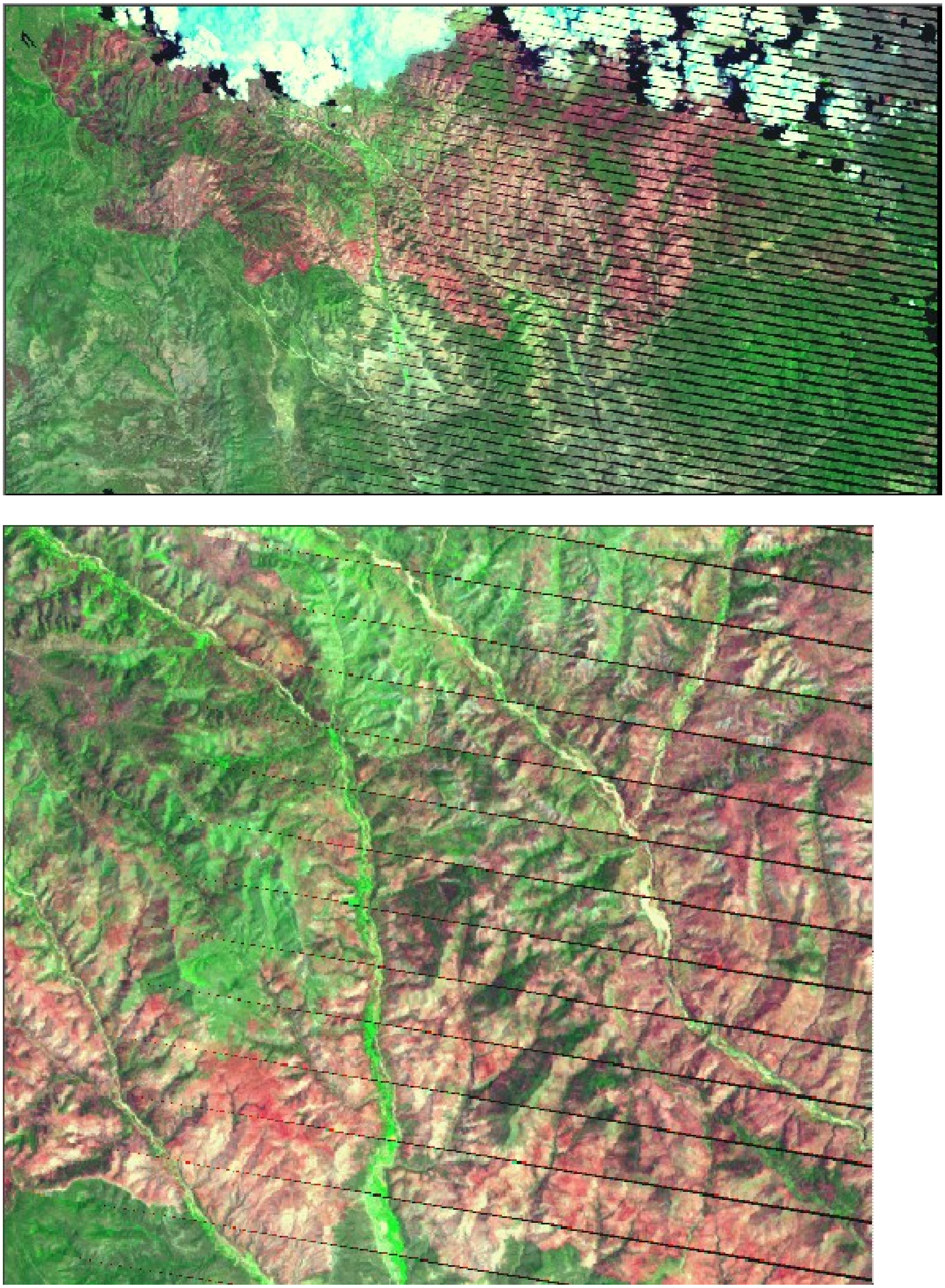


Figure 15 a and b. These two figures are subset of the Landsat 7 ETM+ June 8, 2003 data with the scan line corrector anomaly and with the interpolation option turned on. The amount of useable data has improved.

The NBR differenced data are used to measure magnitude of environmental change caused by the fire. Below are these data. The pre-fire data are constant for each of these differenced data sets (June 05, 2003).

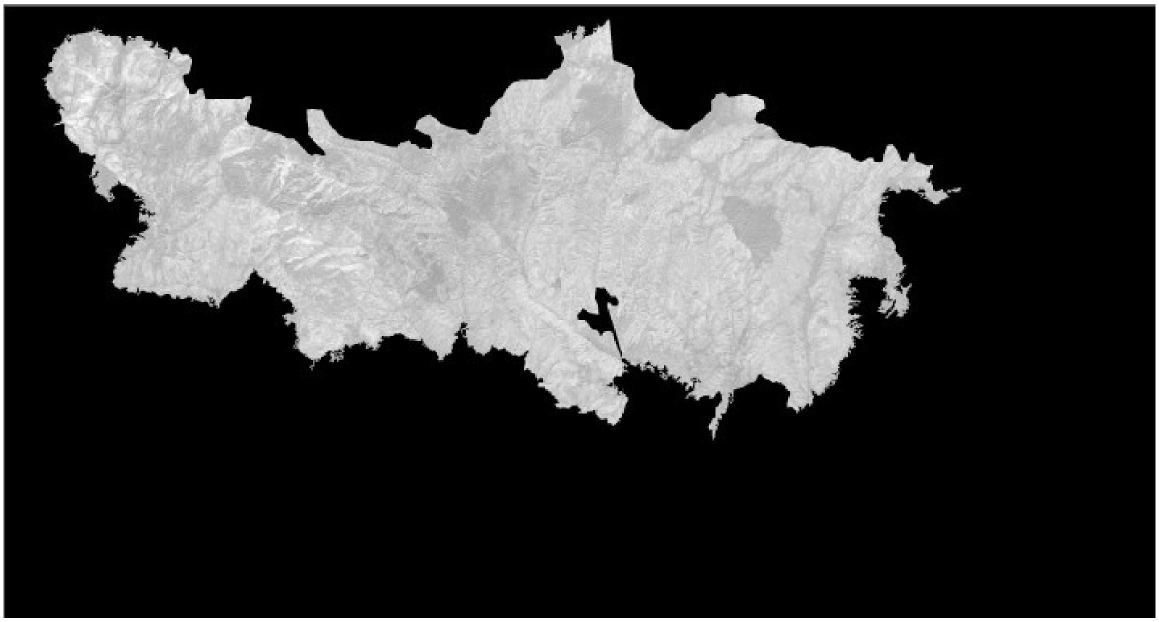
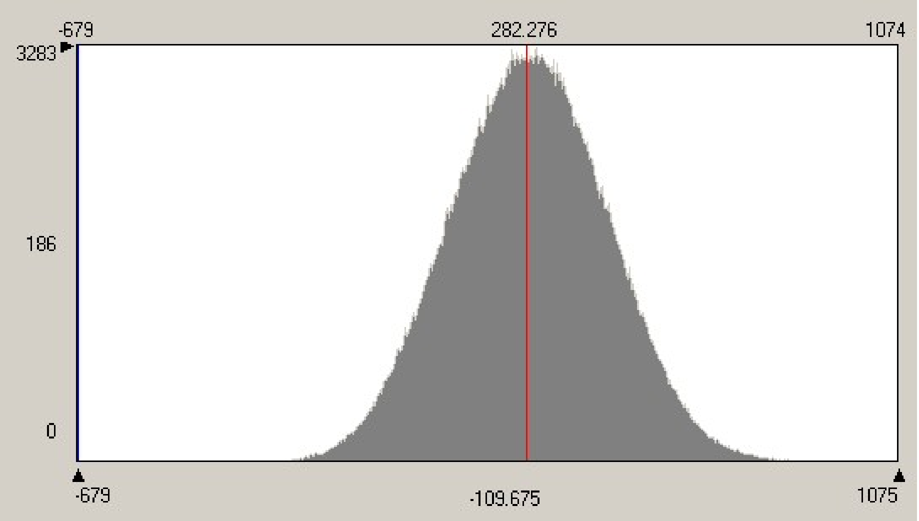


Figure 16. This figure is the control data set of differenced NBR data within the fire perimeter and with post-fire data from the May 07, 2003 Landsat 7 scene. Cloud contamination has been excluded from these differenced data sets.

Data characteristics are:



Min Val: -679 Max Val: 1074
Mean: 282.276 Std Dev: 166.373
Median: 283 Mode: 297
Figure 17.

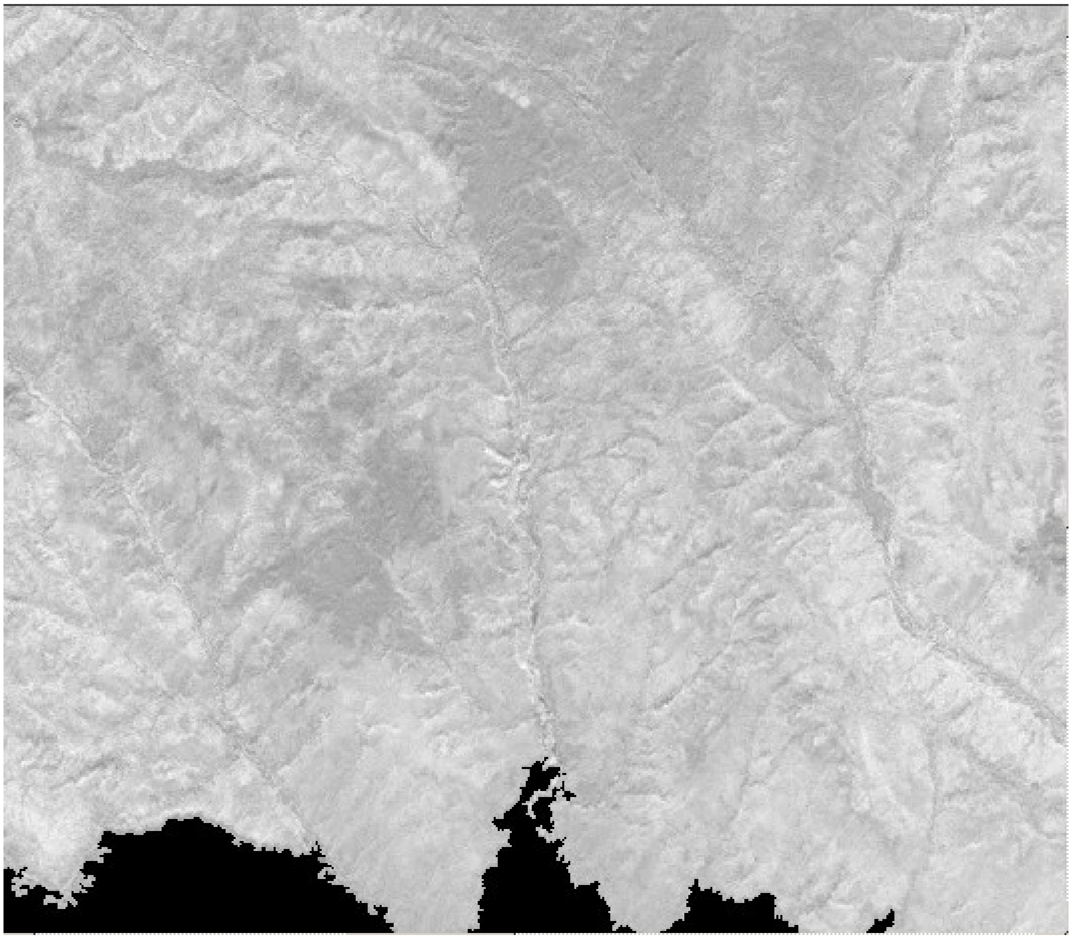


Figure 18. The lighter toned areas represent regions that have experienced more change due to fire activity.

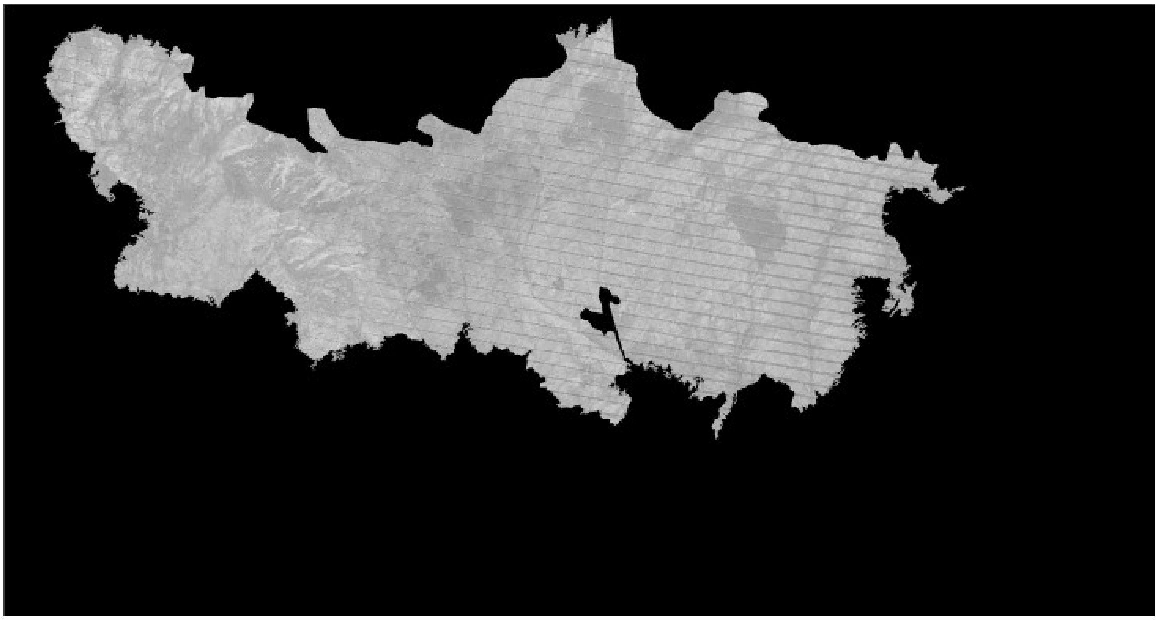
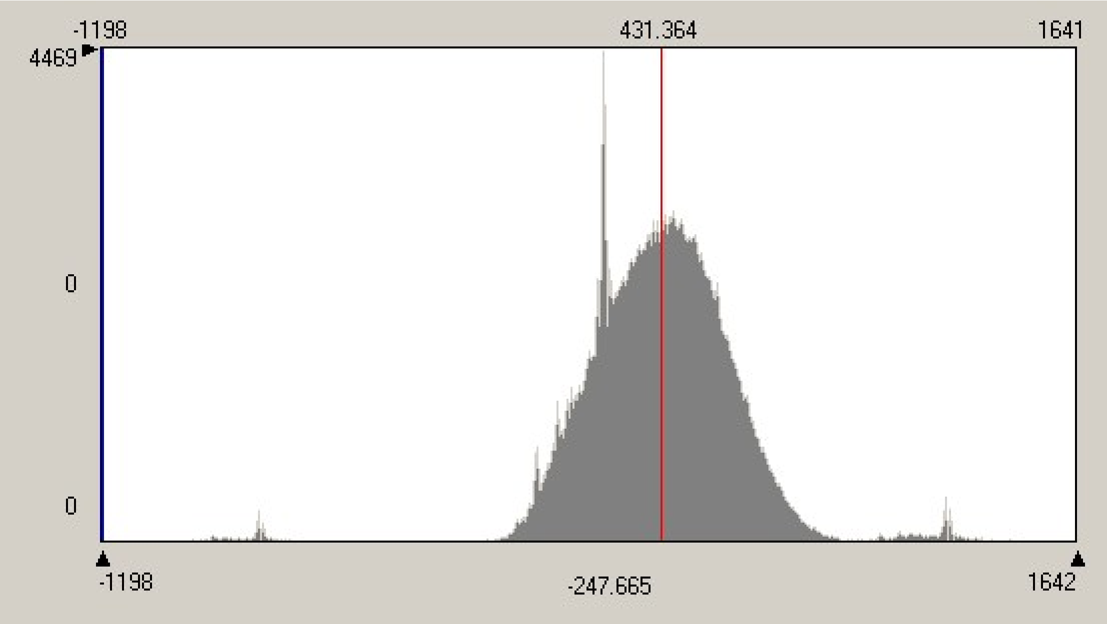


Figure 19. This image is the differenced NBR with the post-fire data being the June 08, 2003 Landsat 7 scene with interpolation off.

Data characteristics are:



Min Val: -1198 Max Val: 1641
Mean: 431.364 Std Dev: 232.032
Median: 436 Mode: 256
Figure 20.

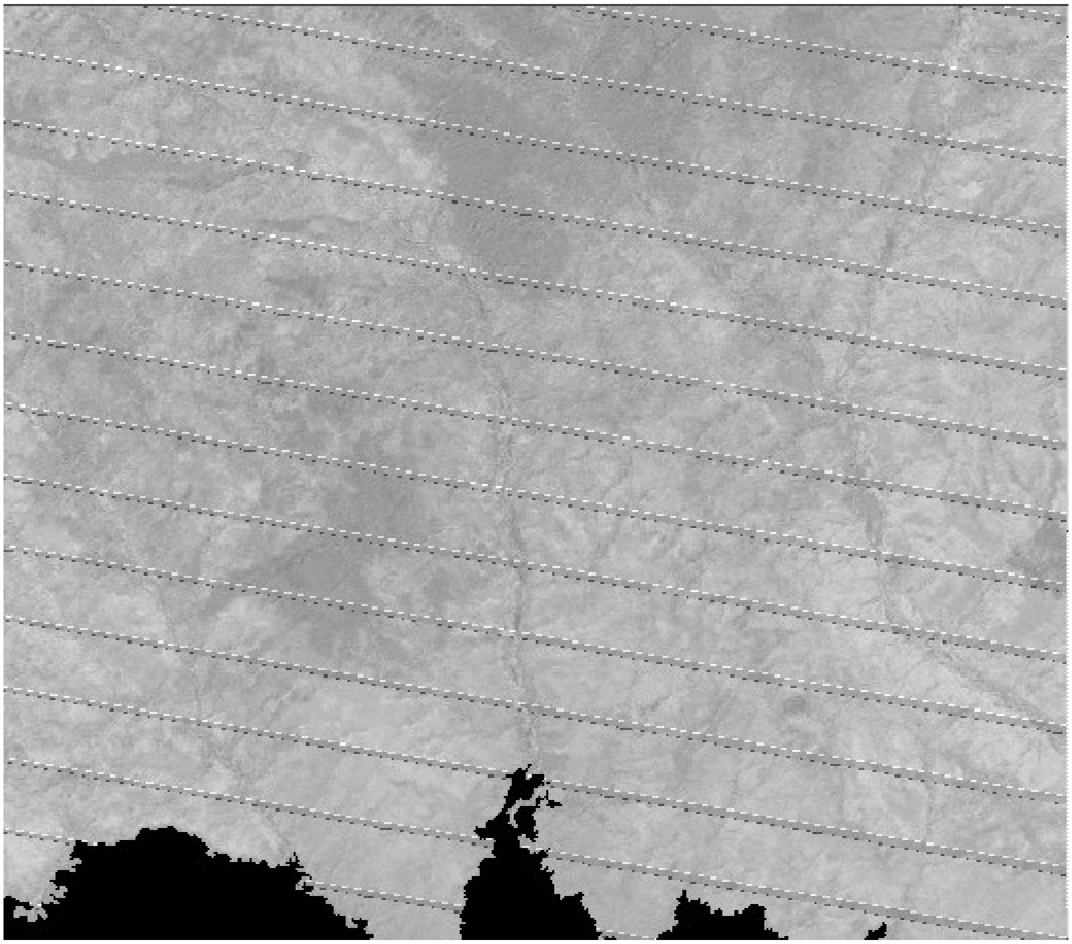


Figure 21. Remember that the data within the anomaly scan lines are the result of the differenced June 5, 2002 and the June 08, 2003 data with interpolation off. The data within the anomaly reflect the pre-fire data values.

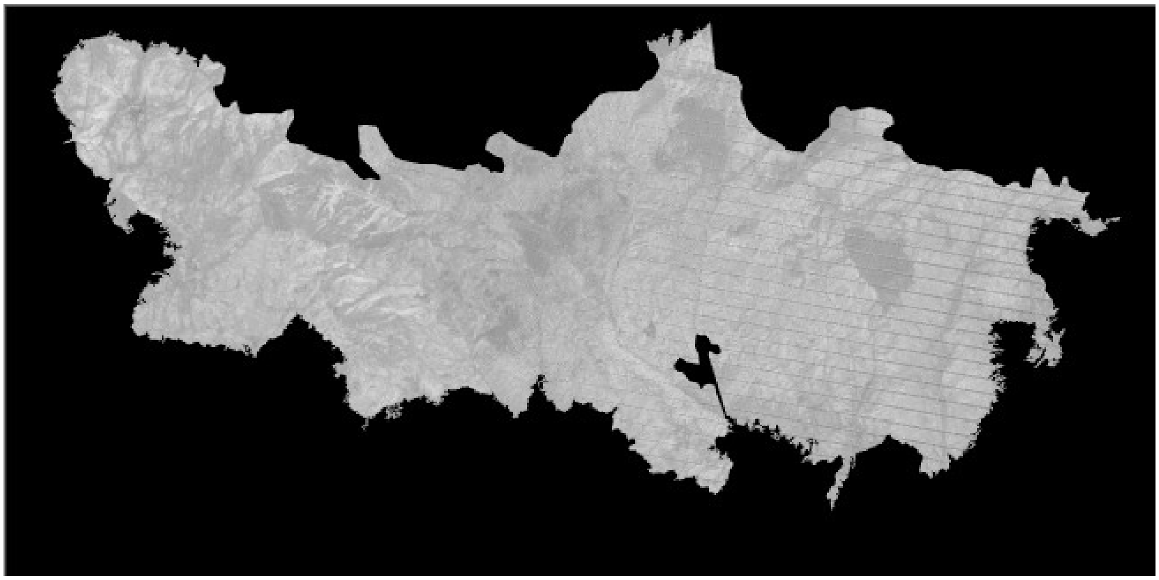
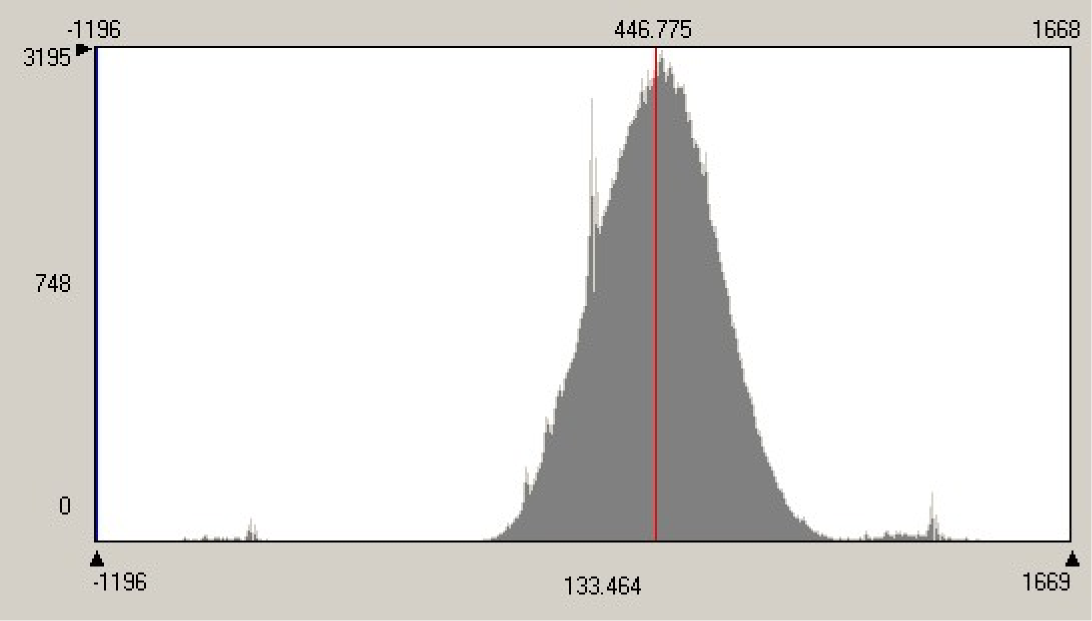


Figure 22. This image is the differenced NBR with the post-fire data being the June 08, 2003 Landsat 7 scene with interpolation on.

Data characteristics are:



Min Val: -1196 Max Val: 1668
Mean: 446.775 Std Dev: 208.693
Median: 450 Mode: 459
Figure 23.

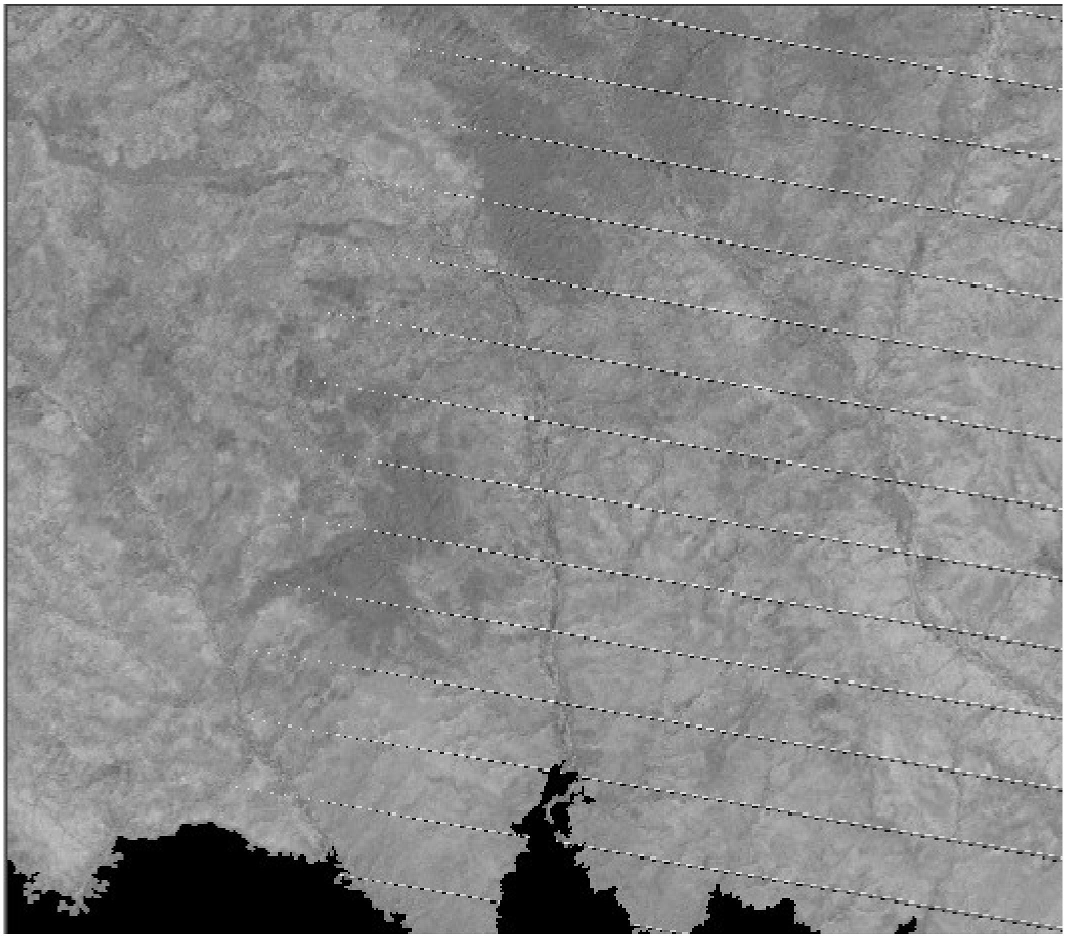


Figure 24. Visually this differenced data set appears to be improved, however the data characteristics do not note a significant difference between the interpolation on and the interpolation off data sets.

Investigation 3: Image Compositing Using Adjacent Overlapping Images

One possibility for recovering some of the lost Landsat 7 data is to assemble composite data sets composed of mosaics of adjacent scenes. The idea is that the missing data caused by the SLC anomaly may be replaced by good data in the overlap portion of adjacent scenes or by subsequent passes over the same scene.

For this analysis, we examined the extent of data gap removal by compositing adjacent scenes. As repeat observations during the anomaly are only becoming available at present, this question is not addressed in this short report. The scenes used in this analysis are the following:

Path 35 Row 36	17 June 2003
Path 36 Row 36	8 June 2003
Path 37 Row 36	15 June 2003

Since Path 36 Row 36 is the center scene, subsequent analysis will be based on the statistics from this scene. The analysis was performed using ENVI image processing software. The three scenes (using Interpolation-On option Landsat scenes as input) were first composited using the mosaic function with zero values ignored, meaning that the gaps would be filled by non-zero values. The total area of zero values in the central scene was then examined before and after the compositing.

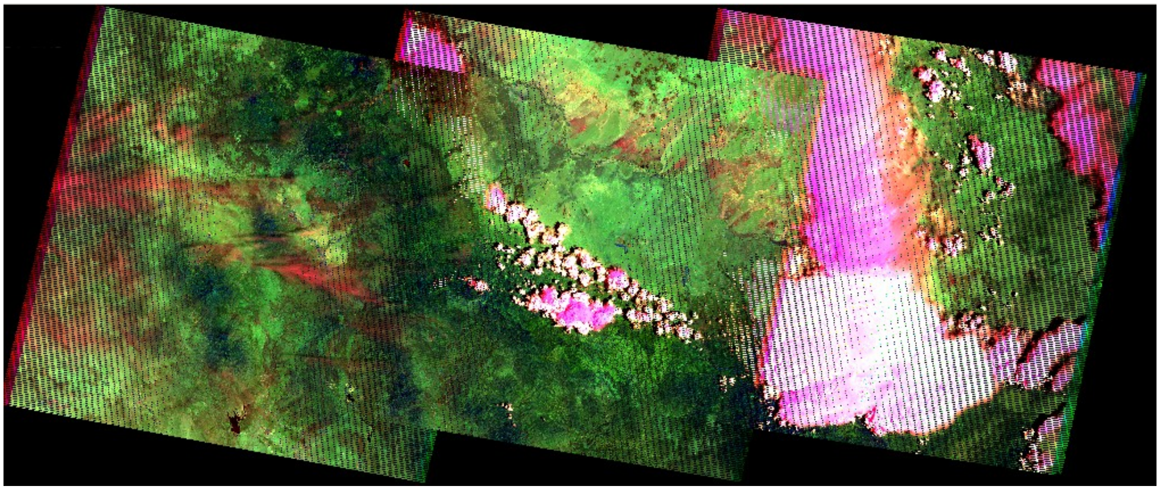


Figure 25. Mosaic of three adjacent Landsat 7 scenes.

The image mosaic (Fig. 25) shows some of the inherent possibilities, as well as inherent problems with this approach. The left two images mosaic well together with similar radiometry and little obvious problems in the merging. The far right image has significant cloud cover and thus does not merge well with the others.

Before the images were merged, the center image (P36R36) had 9.49% pixels with zero value, meaning nearly 10% of the pixels were affected by the SLC anomaly. After the mosaic was created, the region occupied by the center scene was 5.39% pixels with zero value. The resulting overlap region still has significant artifacts from the mosaic process and the data gaps of the two input images, namely radiometric differences and small georeferencing errors (Fig. 26).

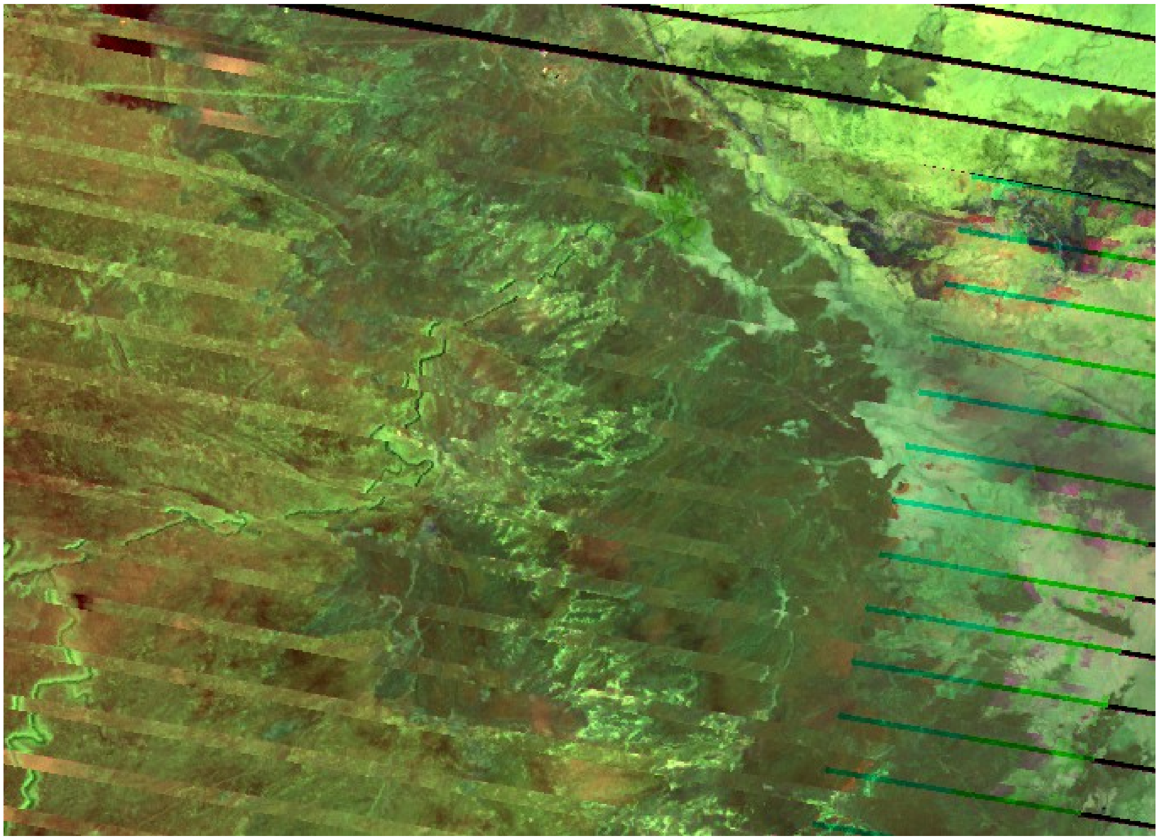


Figure 26. Zoom image of overlap region of adjacent images.

Other regions were not as successful in the filling of data gaps as the overlap regions was simply not as fortuitously placed. In other words, the gaps from both images were coincident (as in the right side of Fig. 27).

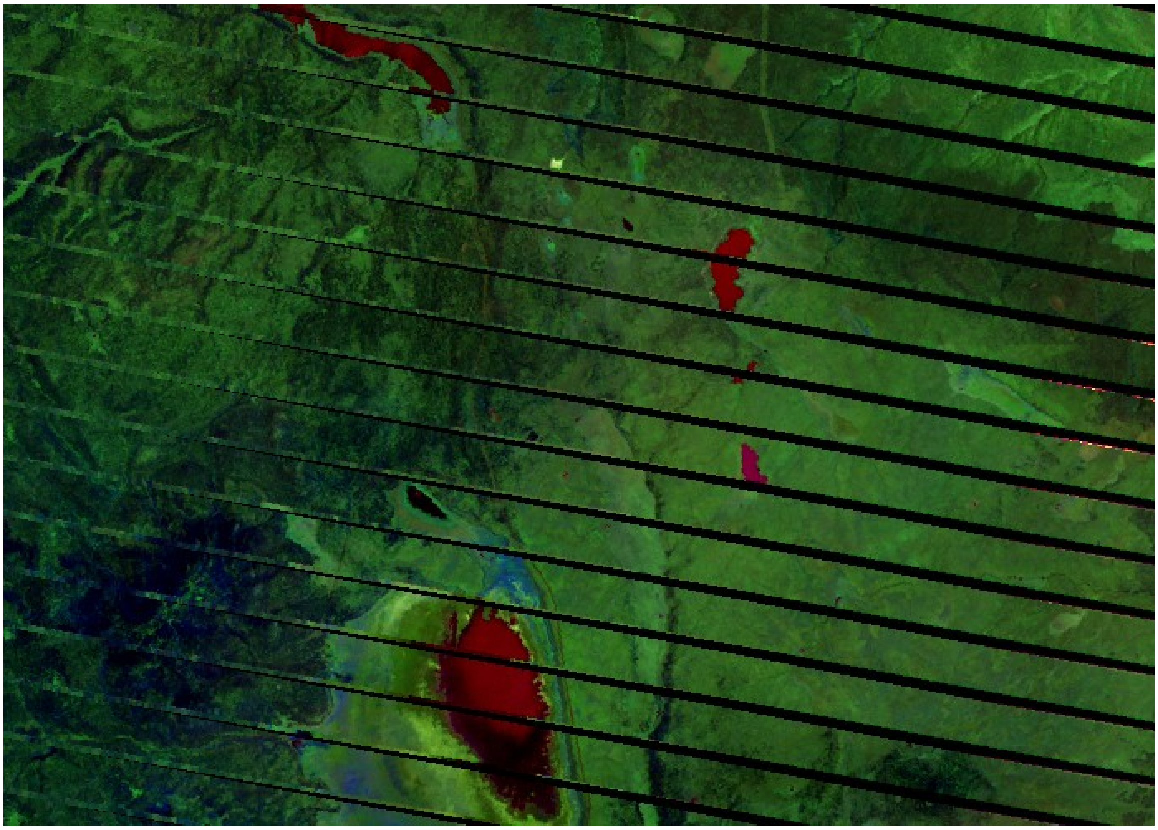


Figure 27. Region where SLC anomaly from adjacent images overlap.

Adjacent Overlapping Image Compositing Summary

In conclusion, it appears that a significant reduction in the zero value areas caused by the SLC anomaly may be filled by data from adjacent scenes, but a significant region of zero values (in this case 5%) might remain. Issues in using this approach include a need for more precise georeferencing, radiometric matching of scenes, illumination and land surface changes caused by the several day difference between the scenes, and processing time. Problems were encountered related to inter-scene georegistration issues and radiometric normalization, but it is felt that these issues could be resolved via additional image processing using standard techniques.

Investigation 4: Composite Imagery Using Regression Tree Analysis

The premise of this test is that the "gaps" in the post-SLC anomaly data sets can be effectively estimated and filled using the digital number predictions derived between digital number values of the data set with the gaps, and values from one (or more) Landsat scene(s) acquired close in time to the scene in question. The idea for this test was developed by B. Wylie and C. Huang, and processing of the data was done by B. Wylie.

The methods used in the current analysis are outlined as follows:

1) Acquire post-SLC scene (path 36, row 36; June 8, 2003). A subset of this data set is shown in Figure 1.
2) Acquire pre-SLC scene (path 36, row 36; May 7, 2003). This data set is a high quality ETM+ data set.
3) Select approximately 7,000 pixels (done mostly randomly) common to both data sets, all with "good" DN values (i.e. no blank pixels). "Good' as defined here also implies that the pixels are not unduly influenced by clouds in either data set.
4) Use regression tree analysis to derive relationships between suites of pixel values of both data sets. In this investigation, ETM+ bands 3, 4 and 5 were used to derive the relationships.
5) Use cross-validation to determine the error in the relationship. In essence, a subset of pixels was "held out" of the regression tree analysis for each "run" as a check on probable accuracy of the results. R^2 values were generated to evaluate the error between actual post-SLC anomaly scene values and the estimated values. In this test, r^2 values were .921, .865 and .846 for bands 3, 4 and 5, respectively.
6) Using the regression tree relationships, estimate the digital values for areas that are blank in the post-SLC data set (based on extrapolation from the May 7, 2003 pre-SLC anomaly data set digital values), and use these values to "fill in the gaps".

Results of the above procedure to fill in post-SLC gaps are shown in Figures 2-5. Figure 2 is a false-color composite (bands 5,4,3), whereas Figures 3-5 depict the individual bands (3, 4 and 5, respectively). While some evidence of "banding" is still evident where the gaps were previously located (see Figure 1), it is apparent that the approach has great promise for "filling in the image blanks".

It should be noted that there are a number of variables that are important for maximizing the effectiveness of the above procedure. Dates of scene acquisition are especially important, and the predictive capabilities of using multiple scenes to "fill in the gaps" of one scene will be the best when phenological change between scenes is gradual. As an example, the technique will work less well in times of rapid green-up than in mid-summer. It is noteworthy that the scenes used in this investigation were acquired in late spring when green-up is still expected to be a factor, yet the data show that the approach still worked reasonably well. Another factor important to consider is that the scenes used need to match up geometrically very well. BRDF factors could also play a role.

It should also be noted that this was just one of many tests that could have been run using regression tree analysis. There are many things that could be done that could improve results, all requiring additional research and development. Increasing the number of scenes used, exploration of the technique in other types of environments and during other times of the year, increasing the number of sample pixels used, and increasing the number of bands used to generate the digital value estimates are all topics worthwhile pursuing.

Composite Imagery Using Regression Tree Summary

This study used regression tree analysis to help “fill in the gaps” in the post-SLC anomaly data sets. For this approach to work, one needs a scene acquired before and/or after the scene that has the gaps that need to be filled. If all are post-SLC anomaly data sets, there must be valid digital number values in the “before” and/or “after” scenes spatially located where the gaps exist in the scene that is being “filled”. Regression tree analysis is used to develop predictive digital number relationships among the scenes for each band. These relationships are then used to infer the digital number values for the pixels located in the gaps in the scene being “filled”. In this study, the approach was very effective in filling in the gaps, although more research and development is recommended to determine the robustness of the method. It is expected that the approach will work especially well when scenes being used are acquired close in time to each other. However, the method will work less well when substantial seasonal differences exist among the scenes. It is not expected that atmospheric differences will create much of an image artifact problem using this approach, although bi-directional reflectance may create artifacts in some cases. This approach will be very appropriate for some types of investigations (e.g., deforestation assessments, regional land cover mapping), but not for others (e.g., assessments and mapping in areas where rapid intra-seasonal changes take place, such as in agricultural landscapes).

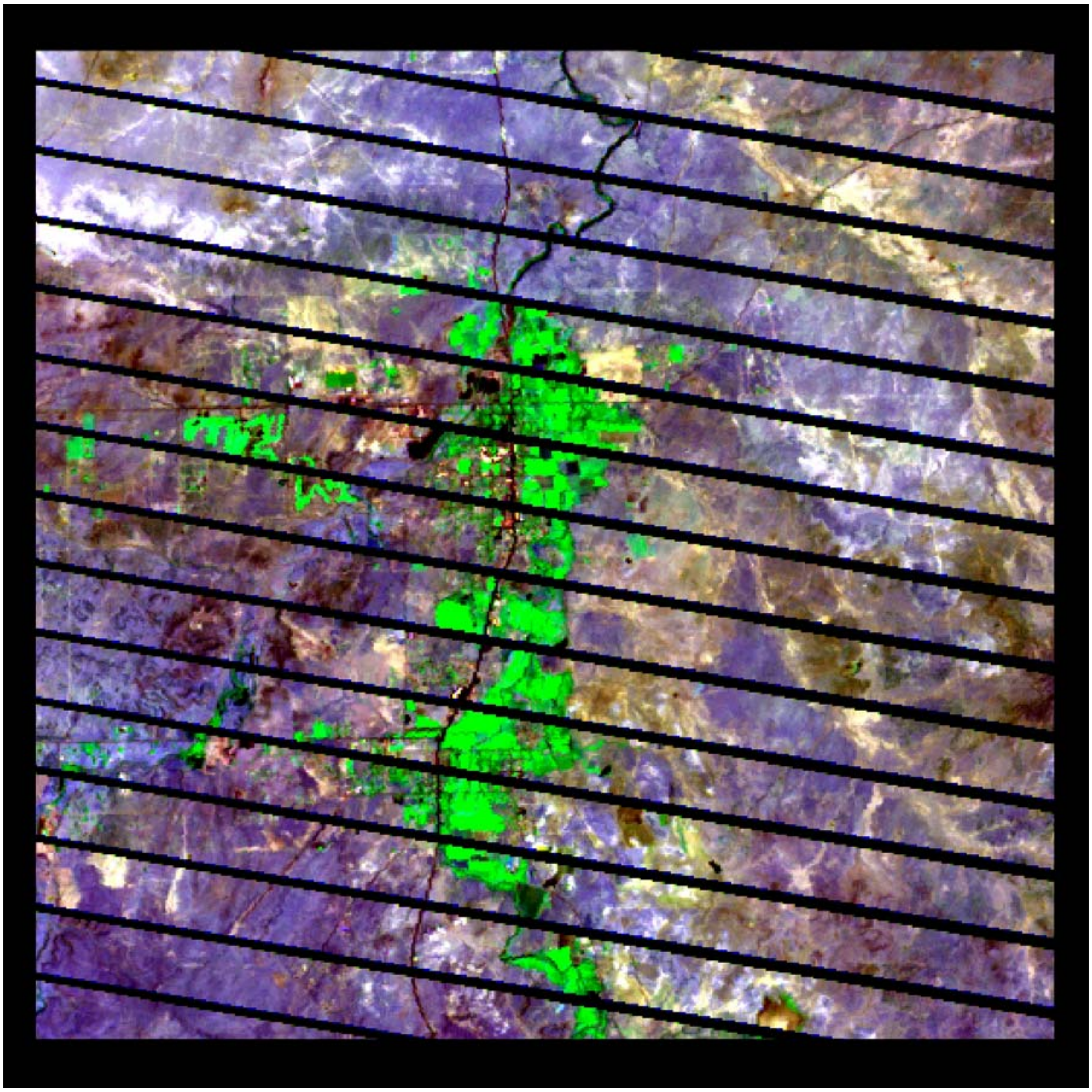


Figure 28. Subset of post-SCL anomaly data set for WRS 2 path/row 36/36 acquired on June 8, 2003. Bands shown are 5, 4 and 3 (RGB).

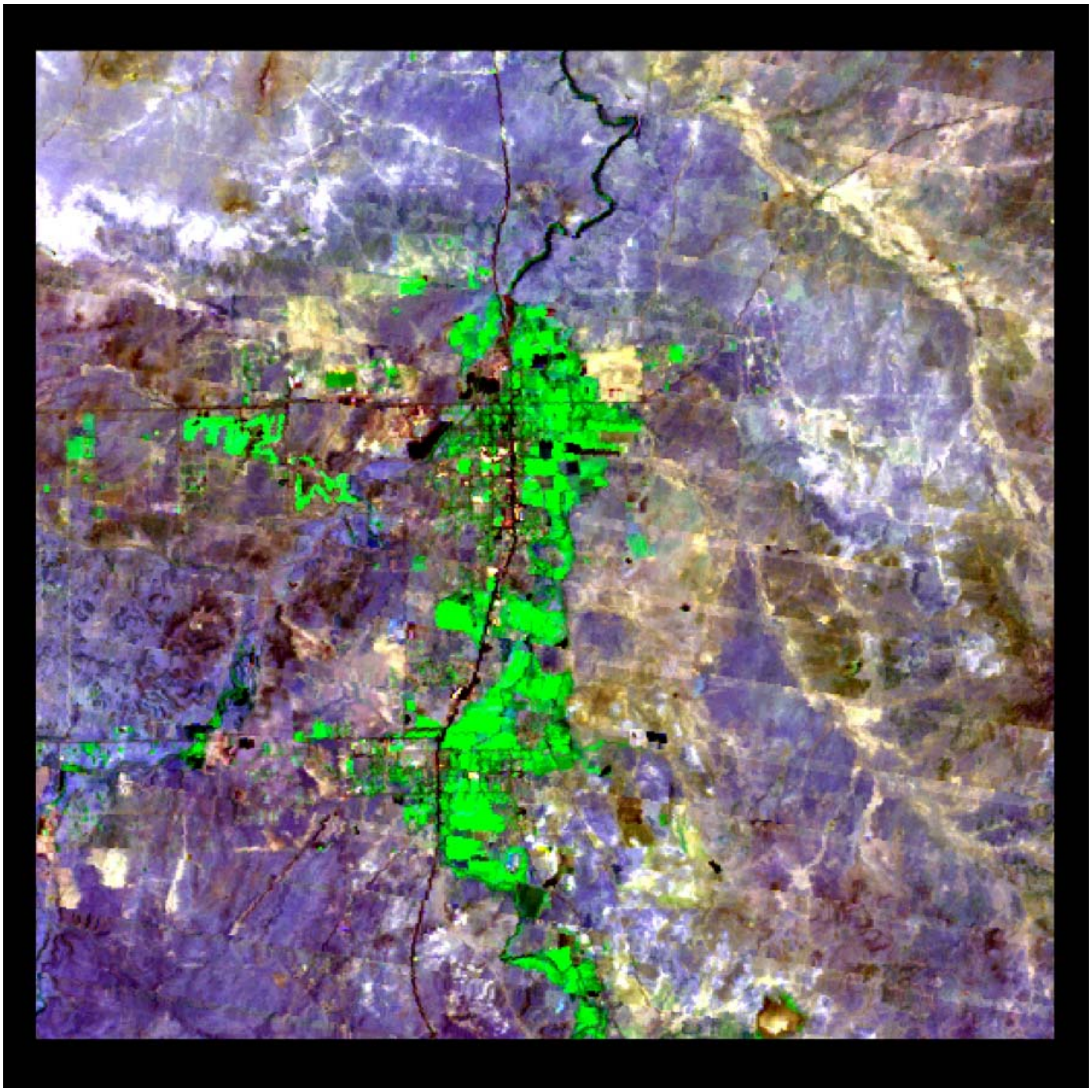


Figure 29. Subset of scene shown in Figure 1 after filling in the blanks with digital numbers derived from regression tree analysis. Approximately 7,000 pixels from May 7, 2003 scene (pre-SCL anomaly) and the June 8, 3003 post-SLC anomaly data set were used to estimate digital values.

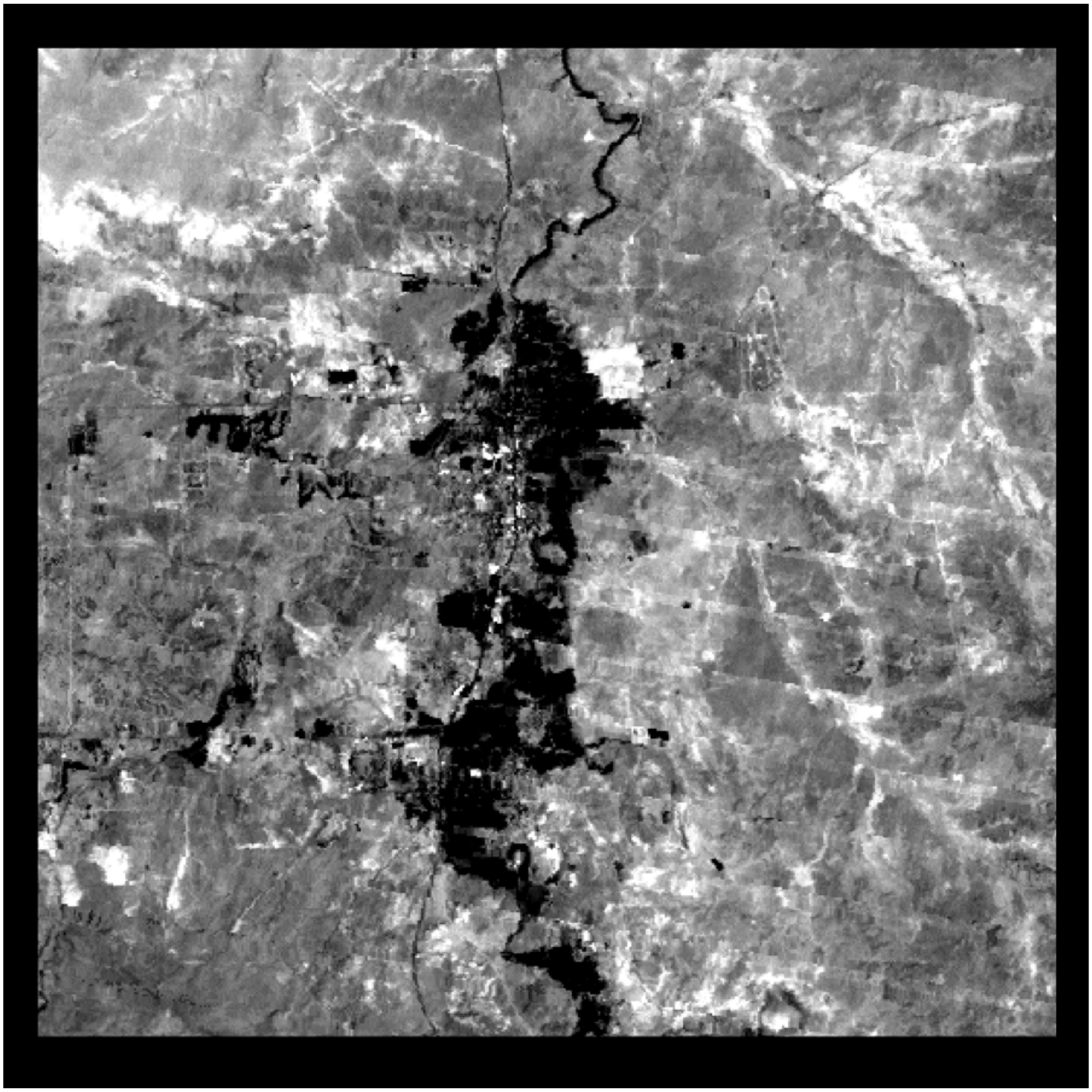


Figure 30. ETM+ Band 3 subset of scene shown in Figure 1 after filling in the blanks with digital numbers derived from regression tree analysis.

Figure 31. ETM+ Band 4 subset of scene shown in Figure 1 after filling in the blanks with digital numbers derived from regression tree analysis.

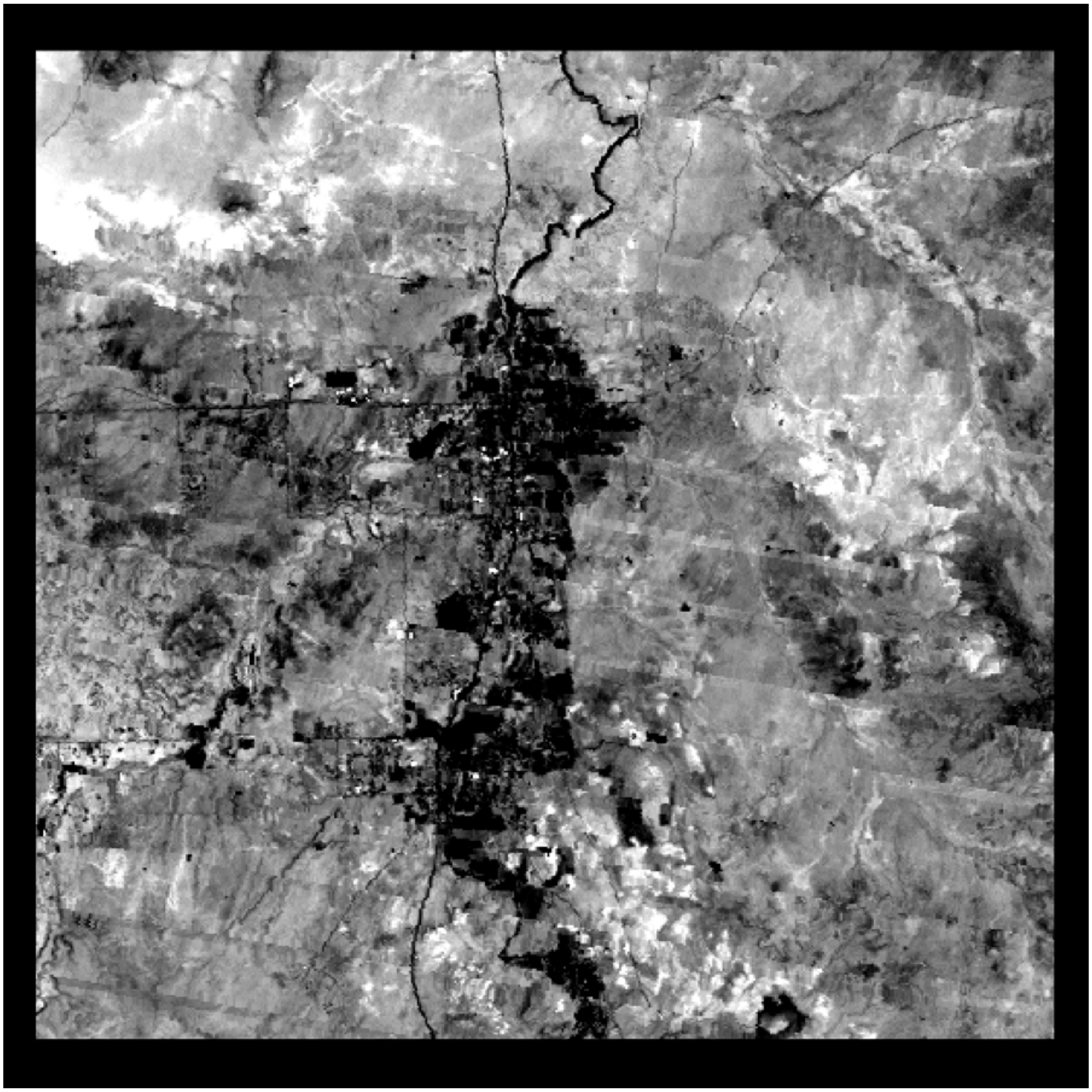


Figure 32. ETM+ Band 5 subset of scene shown in Figure 1 after filling in the blanks with digital numbers derived from regression tree analysis

Report from Bradley Doorn, PhD

Remote Sensing/Technical Coordinator
US Dept. of Agriculture, Foreign Agricultural Service

Landsat 7 test images provided by USGS were evaluated by four USDA/Foreign Agricultural Service crop analysts and two technical support personnel from 27 June 2003 to 2 July 2003. The following is a list of the test images:

Path	Row
177*	27
28	34
28	31
91	80
222	76
174	37
228	67
29	40
28	29

* SLC Powered

80% of the use of Landsat imagery for the global crop analysts is for qualitative assessments of crop type, crop conditions, and crop stage. For this purpose the foreign crop analysts were emphatic that the imagery was still of use and very much needed. Geometric accuracy was excellent and the radiometry “appears” to be consistent with L7 images before the anomaly. The banding does have a detrimental effect on coverage and use in published reports. However, we have limited crop intelligence in many areas of the world making Landsat 7 a critical information source.

Note that one of the test images is providing critical evidence during this month’s production briefings. Even with a disclaimer on the quality of the image, the Landsat 7 image provides obvious and validating observations.

The other 20% of the use of Landsat imagery is severely degraded. NDVI extraction processes may have some use with modifications to our programs and selective use of the indices. Ad-hoc projects in Brazil, Argentina, Europe, Cuba, the Middle East depend on the full extent of the imagery. In fact, the Rapid Area Assessment project in Argentina uses the side lap areas to get higher temporal resolution coverage for ground truth sampling. Each of these projects are multi-year projects and Landsat 7 has been the base layer for classification efforts. All image processing efforts for these projects are suspended until alternatives are determined.

The USDA Satellite Imagery Library customers (other USDA agencies focused primarily on domestic issues) are severely impacted. NASS, Forest Service, and NRCS efforts often require cloudless scenes and consistent radiometry. Fortunately, Landsat 5 has been consistently available for domestic operations. We have 180 subscribers to our imagery library. I am discussing with them the effect of the Landsat 7 anomaly. I will try to forward you my findings.

In summary, USDA/FAS strongly requests that the LTAP be restored on Landsat 7 as soon as possible. While we are currently scrambling to get observations during critical crop stages in the Northern Hemisphere, we still have time to catch the Southern Hemisphere growing season.

The best alternative available is Landsat 5. Landsat 5 is now downloaded in Argentina (pending), Brazil, Australia, and China. We are still waiting on an ESA decision.

Here are specific answers to your questions:

Can you use the ETM+ data acquired without an operational SLC, as provided, for your investigations or applications?
For qualitative and select vegetative index assessments – Yes
For projects that automatically extract information or segment the imagery – No
For projects that require consistent area coverage – No

What is the impact of the problems on your investigations or applications?
Currently the problem is significant since we have lost observations during critical portions of the crop calendar in the Northern Hemisphere. This problem will become more severe the longer Landsat 7 is not acquiring imagery. Operational global crop production estimates will have lost coverage which may impact the level of interpretation and/or validation of the crop estimates. Ad-hoc studies and programs have suspended image processing activities.

If the scan line corrector cannot be repaired, will you substitute data from other sources for you investigations or applications?
If available we will use the "banded" Landsat 7 data to the maximum extent possible. There is no substitute for Landsat 7 data, even Landsat 5. We will have to use other sources of imagery to minimize the observation gap.

If you are likely to use other sources of data, which sources best meet your requirements?
Landsat 5, MODIS combined with a sparser set of observations from Landsat 5, ALI, ASTER, or similar sensor.

If the scan line corrector cannot be repaired, will you be left with no viable data sources for your investigations or applications?
Yes, Landsat 7 fills a unique role in our operations and is a critical requirement to our ability to perform global crop assessments. The multi-year, systematic global coverage using IGS and LTAP is a key factor in our ability to assess global crop conditions. The cost/acre of other products is very prohibitive.

Can you suggest any steps that might be taken to make the ETM+ data acquired without an operational SLC more useful? For example, would you prefer to receive data where the pixels in the data gaps were filled by interpolation
Interpolation may be helpful for visual interpretation. I would like to see some examples before I would commit to that type of processing even for qualitative assessments.

USDA/FAS would like more acquisitions over agriculture regions to help compensate for the loss of area coverage, if the LTAP can accommodate.

Report from Jeffrey G. Masek, Ph.D.

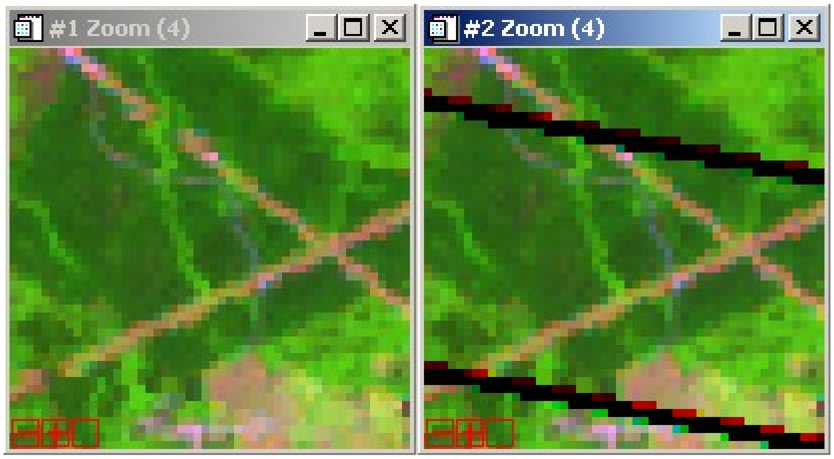
NASA GSFC Code 923

Landsat Anomaly Investigation **Jeff Masek (GSFC)**

1) What is the effect of interpolation on image quality?

Visual inspection of p18r37 with and without interpolation suggests that image interpolation does have a few noticeable impacts on image quality, although they are not severe. Linear features are particularly affected, as in the image below, where the roads “disappear” into the forest (Fig. 1). For most scientific analyses this wouldn’t be a problem. For some applications uses (transportation planning, trafficability analysis) it might be.

Also note that in the “interpolation off” version of Fig. 1, some “gap” pixels are non-zero (reddish color). It appears that the gap shifts position slightly with spectral band, resulting in valid data in some bands and no data in others. This could present a problem in trying to identify and mask the data gap.



2) What is the effect of interpolation on change detection?

I downloaded the June, 1987 GeoCover version of p18r37 and co-registered it to the post-anomaly acquisition (both on/off interpolation). The scene pairs were converted to TOA reflectance (no atmospheric correction) and then to NDVI. Arbitrary ΔNDVI (NDVI_2003-NDVI_1987) thresholds were selected to portray vegetation increase (ΔNDVI > 0.20) and vegetation loss (ΔNDVI < 0.20). Table 1 summarizes the results for both the interpolation-on and interpolation-off versions. As expected there was little difference (~0.1%) between the two analyses. This suggests that using interpolated data for change detection applications should not severely impact science results.

	Off	**On**	**Difference**
Null pixels	2562141	1821148	
Valid pixels	9687859	10428852	
Veg loss pixels	258508	272230	
Veg gain pixels	1082392	1178307	
%veg loss	2.668371	2.610354	0.058016
%veg gain	11.17266	11.29853	-0.12587

Table 1: Vegetation change with/without interpolation

Report from David Skole, PhD, et al
Michigan State University

Analysis of the Scan Line Corrector Anomaly onboard Landsat 7 with respect to Measurement and Mapping of Land Cover Change

Success with SLC Anomalous Data

David L. Skole
Landsat 7 Science Team PI

Jiagou Qi
Analysis of the Fourier Transformation Interpolation Image Restoration

Walter Chomentowski
Analysis of Post-Classification Methods and End-Product Accuracy

Jay Samek
Analysis of Compositing Image Restoration

1 July 2003

Introduction

We evaluated several anomalous scenes from the ETM+ to assess whether the SCL problem presented issues for measurement of deforestation, regeneration, fragmentation, and selective logging in tropical forests. The measurement of tropical forest change is an important element of global change research since these changes are important forcing functions for carbon flux estimates, changes in ecosystem structure and function, and various aspects of natural resource inventory and management. Our effort focused on two questions, 1) how does the current image quality affect our ability to measure and map these land cover changes, and 2) how can we implement algorithms to make improvements if needed. We used the EDC-corrected, or “ON” images for this assessment.

Data

We acquired four anomalous images. One scene was from SE Asia, and three scenes were from the Brazilian Amazon. The Amazon scenes were contiguous, in an “L” shape, with overlap along and across track. The dates and location of the scenes used were listed in previous emails with the Landsat program office. We used all bands for our analysis including the panchromatic bands. Initial image quality was performed. All scenes were cloud free except one from the Amazon.

To perform this test we also used several scenes from the archive of the Tropical Rain Forest Information Center. These scenes were acquired close in time to the images being assessed. We also used the processed derived product from these “good” images to make a comparison of the SLC problem. This head-to-head comparison allowed us to put the anomalous images through our processing stream and compare the end-product of an anomalous derived product with one which was derived from a “good” image.

Tests Performed

We analyzed the problem using three approaches.

1) ***Processing and Post Processing Techniques.*** We processed one anomalous Amazon image through our method for standard land cover change products, and compared this derived product with one which had been derived from a good image of a recent date. As part of this analysis we also simulated the effect of the SLC problem on recent good images from several locations in the Amazon to ascertain the effect of the SLC anomaly in several locations with varying degrees and spatial configurations of deforestation. The anomalous derived product was compared “as is” to a good derived product, and we also used two additional post-classification corrections. These were a) using a post-classification majority filter on the anomalous derived product, b) using a composite of a good derived product with an anomalous derived product. We then compared the “good” derived products with the anomalous derived products for a) the total area of deforestation and b) the map of deforestation.

2) ***Transformation and Interpolation Techniques.*** We used a Fourier transformation of the anomalous image from the Amazon to interpolate the areas of scan line drop out. This was done in two ways. First we performed a basic transformation of the image “as-is”. Second we rotated the image, clipped the missing scan lines evenly (to reduce the low frequency noise caused by an uneven “wedge” deformation of the image in the missing scan lines” and then transformed the image. In both cases we re-composited the transformed and original anomalous images.

3) ***Compositing of adjacent and Previous Images.*** We used both side-lap and along-track compositing of several anomalous images to remove the scan line drops. We also took an image from the last good date and composited it with an anomalous image. These composited images were both classified (1 above) and transformed/interpolated (2 above).

Conclusions

The utility of ETM+ with its SLC problem is still extremely high for measurement of deforestation and its associated land cover changes. In tests comparing operational data with data containing SLC artifacts, we recover 90% of the deforestation. That means our estimates of the total area deforested and its rate of change using SLC anomalous data are within 10% of the value with completely good data. This uncertainty of the estimate is consistent over many scenes and patterns and intensities of deforestation. The uncertainty is well within the normal range of uncertainty for our current methods, which have classification and measurement error terms usually larger than this.

A particular post classification technique in which we pass a simple majority filter over the derived product produces an estimate which is within 1% of the true estimate, indicating that measurements using the SLC anomalous data is essentially identical to that without the anomaly. Moreover, other post-classification techniques can be employed which almost certainly create an end product essentially identical to one we could get without the error. For instance using a pervious-date base map to “fill” gaps creates an extremely good product. This is because the actual rate of change from one year to the next is usually less that 1 percent of the total area of forest/image, and because areas of new change do not spread very far from previous areas. Thus, mapping using the SLC anomalous data can be assured.

This latter point is particularly important. It would be extremely useful to populate a publicly available global archive with wall-to-wall data for the best and last image date in the year 2002 or 2003. This base map would be used to gap-fill post classification products for several years, and probably to beyond the normal life of the instrument or until the Continuation Mission is achieved.

Having a global last-best archive would also help in pre-processing correction of the anomalous image data. Our tests of interpolation were extremely successful, although obviously interpolation for gap filling cannot perfectly restore the image. A technique in which we rotate the image, remove equally-sized rows surrounding the scan line drop out portions, then subjecting the image to a Fourier transform to remove this regular high frequency noise and interpolate works extremely well. The technique can be further improved by compositing the FFT derived fill-space into the original image. Classification of such imagery gives results identical to non-problem data.

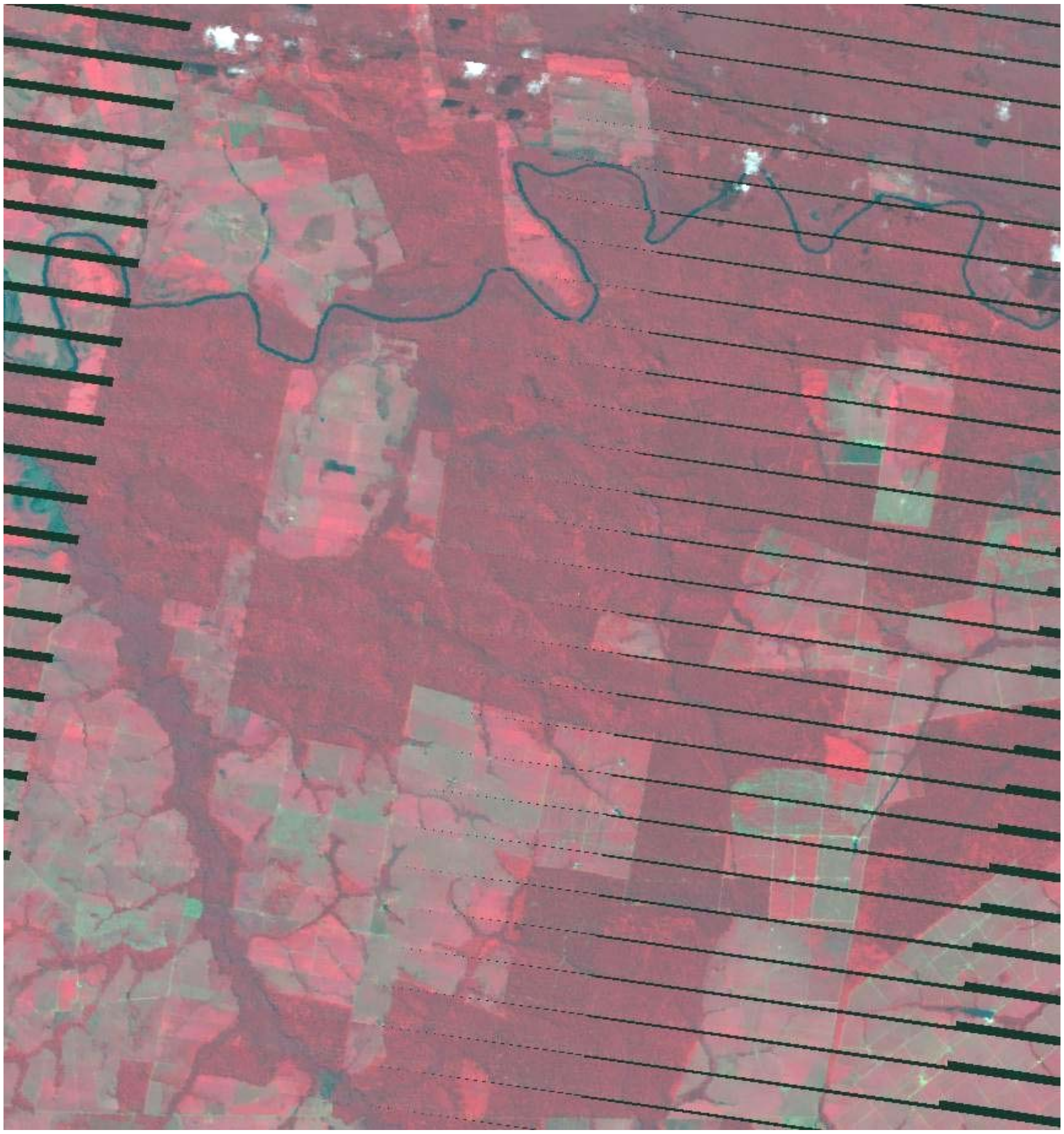
In addition we have found extremely good results through compositing. Since our methods for large-area mapping requires mosaicing large-area contiguous areas, the side lap, even in the equatorial regions, replaces a significant number of missing pixels. This technique would almost certainly be far better, if not completely restorative, in high latitudes where scene-to-scene overlap is high.

Further success with compositing also is achieved for our type of land cover change analysis when we use prior passes for a given path/row location. It is possible to produce a quarterly or annually composited image product with very high level of filled pixels. And, it is important to note, that either side-lap or repeat-pass compositing vastly improves the FFT interpolation as well. We believe that a very good product can be obtained with some sacrifice of date using simple compositing, or less so but with some sacrifice of radiometric integrity when you use a combination of compositing (first with side-lap, then with most recent date) and the FFT interpolation.

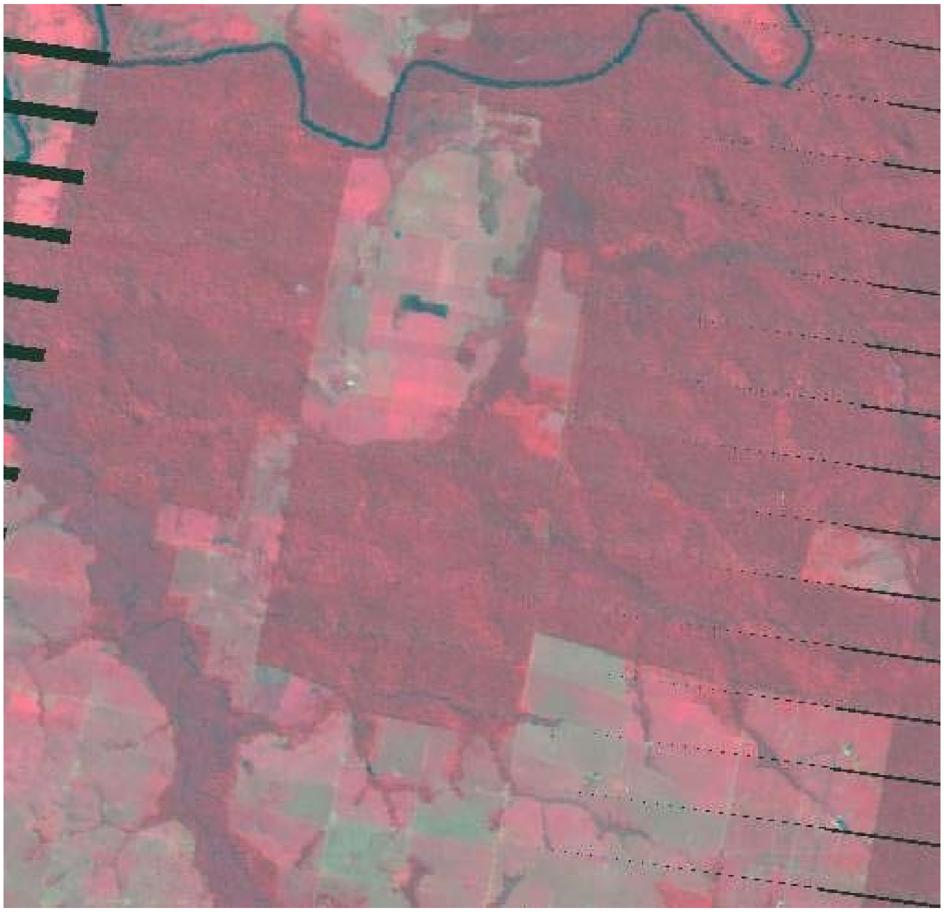
The use of the archive for image restoration using an interpolation scheme can be extremely valuable in image restoration. A previous scene, almost regardless of date can be used to “guide” the interpolation. Moreover, use of MOIDS 250 m data can also be used to guide the interpolation.

Although none of the techniques completely restore the image, the effect of the SLC anomaly on achieving continuity and accuracy of our measurements of tropical land cover change is unaffected – or more precisely within 1-5% of our current levels.

The impact on the science we do will be minimal, but we will need to acquire significantly more data and there will be added burdens on pre- or post-processing. We recommend considering: 1) acquisition of a last-best date global archive, 2) pricing or bundling schemes which take advantage of the LTAP seasonal global refresh approach to build composite image sets for restorative work and/or for analyses of the type we developed.

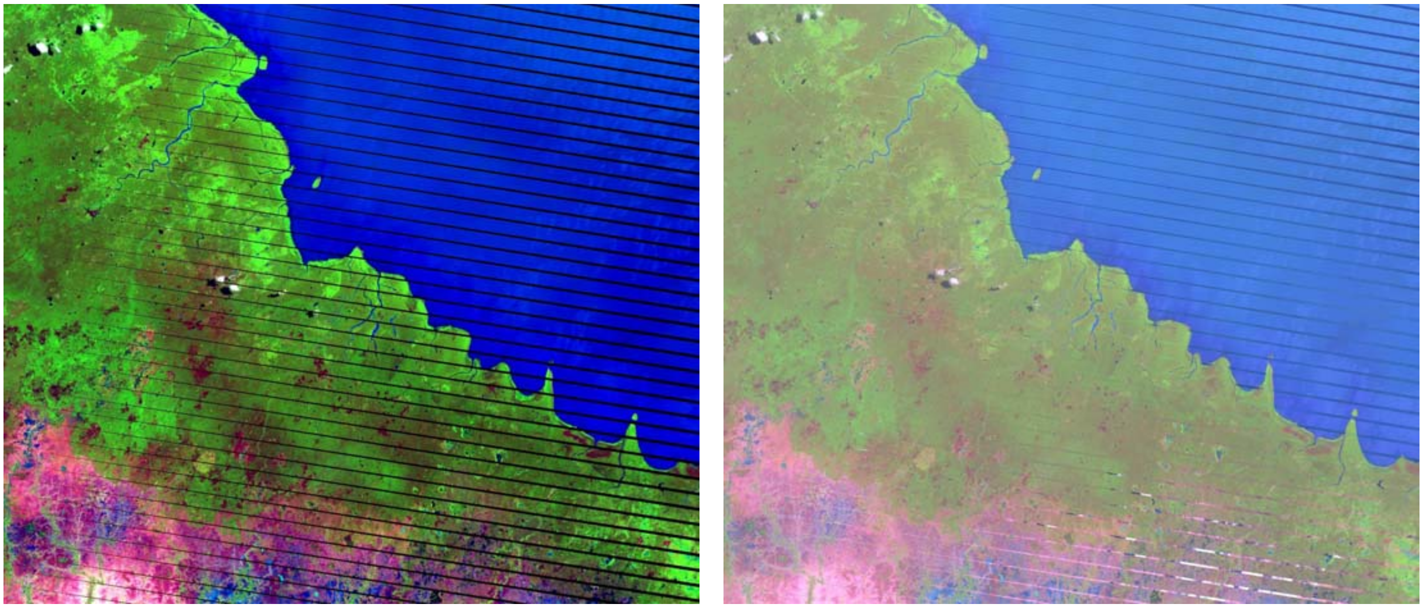


Side-Lap Composting, no interpolation



Side-Lap Composting, no interpolation

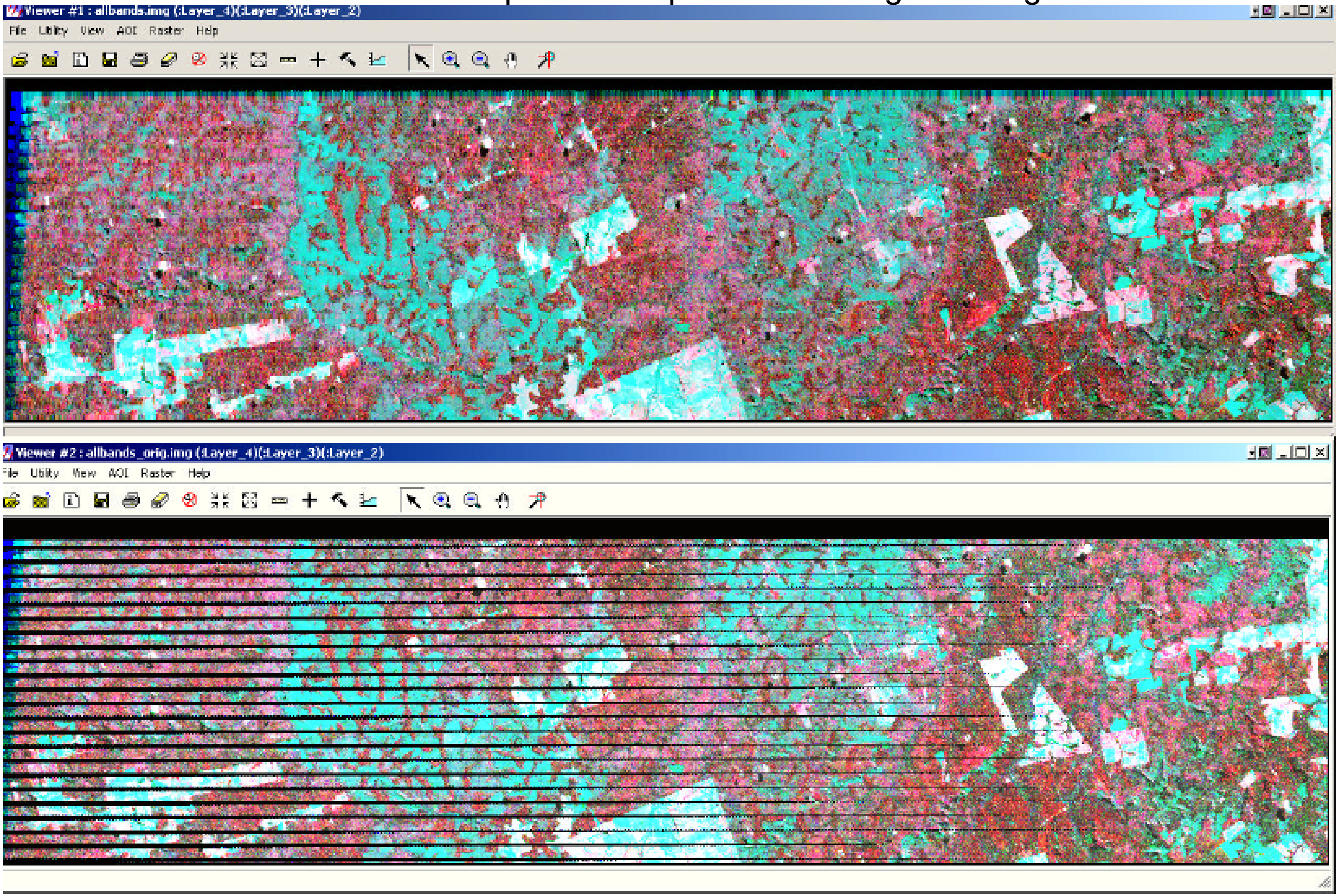
Multi-pass compositing, no Interpolation



Before

After

Example of Interpolated vs. original image



Report from Frank Mueller-Karger, Ph.D., et al
University of South Florida

Landsat 7 ETM+ SLC Anomaly Report

By David Palandro, Damaris Torres-Pulliza, Christine Kranenburg, Serge Andrefouet, Frank Muller-Karger

IMPACTED COMMUNITY:
Coral Reef, islands, and coastal research and monitoring

This report is in response to NASA's request for information on how the inoperable SLC may affect the applications for which Landsat data are used.

Images acquired:

Path	*Row*	*Date*	*Location*	*Interpolation*
15	43	5 June 2003	Florida Keys	On
16	42	12 June 2003	Florida coast	On
104	62	5 June 2003	Borneo coast	On

These images were chosen for their coverage of coral reef areas, diversity in reef type, and to assess geographic disparity of reefs between two separate locations. Unfortunately, one image (p-16, r-42) contained heavy cloud cover over the reef area and was not useful to generate any insight.

Currently, we are conducting two major NASA-funded coral reef remote sensing projects. One uses Landsat data to generate the first-ever map of all coral reefs worldwide. The second project looks at long-term change of reef habitats in the Florida Keys.

Individual live coral reef structures in a coral reef environment are generally on the order of two to three pixels in size. Because of this, an inoperable SLC renders it impossible to conduct high-resolution, local scale research. Interpolated data smoothens real spatial variability, which our studies, and coral reef ecosystem managers, seek to detect and monitor.

The image acquired of the Borneo coast contained 50,585 pixels of reef habitat coverage, of which 22.4% was void of data (DN=0) over target areas due to the inoperable SLC. This means that any geomorphological map produced from these data would be highly suspect, inaccurate due to interpolation, and unfortunately of limited use to both researchers and ecosystem resource managers.

With the need for coverage of specific coral reefs in the Florida Keys, which are designated as Sanctuary Preservation Areas by NOAA, the Landsat data contained 15.2% absent data over these areas. Interpolated data over these area leads to further loss of viable data, on the order of

20%. Because of the inoperable SLC, our long-term monitoring project cannot be continued. The ETM+ data would provide false results over such small and heterogeneous areas without an SLC.

The following satellites/sensors can provide some very limited relief to coral reef research and management: ALI, ASTER, Hyperion, IKONOS, IRS-LSIII and SPOT. Of these, only ALI, Hyperion and IKONOS have spectral coverage in the blue range, which is critical to coral reef and aquatic research. Unfortunately, ALI and Hyperion (onboard EO-1) with a 37km swath width and IKONOS (privately operated by Space Imaging, LLC.) would both require several images to provide the same coverage as Landsat. Therefore, these are costly options. Landsat 5 TM may be the only viable alternative, but the quality of the TM data needs to be assessed to understand possible degradation with time.

The inoperable SLC has dealt a significant blow to coral reef remote sensing as Landsat 7 ETM+ to date had provided the only long-term, relatively inexpensive satellite data for submerged aquatic ecosystems at the correct spatial and spectral resolution.

I hope NASA can find a solution to the SLC problem or replace this important space-based capability in short order.

Report from John Price, Ph.D.,

(retired) Landsat 7 Investigator

Subject: Anomaly in ETM+ scan mirror and implications
From: John C. Price, Landsat 7 Investigator

My background relating to this topic is 1) My investigation comparing ETM+ and MODIS for large area and global studies, particularly for climate monitoring, and 2) my experience in the Agricultural Research Service, during which I became familiar with procedures used by the National Agriculture Statistics Service (NASS) and the Foreign Agriculture Service (FAS).

The ETM+ and earlier Landsat instruments serve two overlapping purposes: 1) For high resolution relatively frequent observations of the whole earth, and 2) For intensive study, including mapping and classification, of local areas of interest to commercial, government and environmental groups.

Regional/whole earth applications

First I examined condensed imagery (4 scenes, 18/37, 25/36, etc.) made available through the EROS Data Center. The imagery of the arid southwest of the US is not definitive for my purposes. Therefore I downloaded 18/37 – South Carolina, for close examination. Taking the Landsat project's statement that geographic fidelity has been maintained, I would say that the imagery is the same as it has always been, namely outstanding. The issue is the missing data for narrow triangles that pass from either side almost to the center of the imagery. What is the significance of these?

Instead of viewing each area on the earth every 16 days (more frequently as one approaches the poles), the ETM+ now views a narrow strip along the nadir at this frequency, while wide strips between adjacent nadir paths are observed at a lower frequency than previously. If the intent of an ETM+ user is to supply aggregated results concerning surface parameters over very large areas, then the implication of the scan mirror problem is simply to alter the statistical weighting to ETM+ data pixels. An area weighting must be applied in order to obtain a spatially uniform distribution of inferences over a region of interest. For example, if high resolution data @30 meters from ETM+ is to be analyzed with the result reported on a 10 km grid, then the central strip of an ETM+ image is fully represented, while the border strips are represented at something more than 50% area coverage. Adjusting weighting functions for the scan mirror anomaly is straightforward. This assumes, as I recommend, that the data used have not been subjected to interpolation. If the data have been interpolated then the borders of the blank regions must be extended by the amount (distance ~ 2 pixels) filled in by the interpolation.

The above statements do not imply that the implications of the scan mirror anomaly are trivial, but that the ETM+ will may still be used for derivation of large area aggregate results. The question whether users wish to modify analysis procedures to take advantage of the data under these circumstances is up to them, but in principle the data are still useful virtually as before, with minor degradation due to loss of statistical significance.

Intensive studies

For local area mapping (up to a few contiguous scenes) the scan mirror problem is essentially fatal. A map with missing areas, particularly at small spatial intervals, of order ½ kilometer, is not a map. One cannot reliably use consecutive observations at 16 or somewhat fewer days to fill in missing areas because the along track phasing of the missing areas is essentially random, so that a number of observations may be required to fill in the blanks. Clouds and changes in atmospheric transmittance will affect scenes differently, making scene-to-scene compositing of results difficult, depending on the level of accuracy sought.

Finally, for local areas, uncorrupted imagery from IRS, SPOT, or the commercial satellites (Space Imaging, Digital Globe) would be preferable in any case, unless relative cost is too unfavorable to them as compared to Landsat.

Possible implications for the U.S. Department of Agriculture

I could manage only an extremely brief discussion of this issue with George Hanushak of the National Agricultural Statistics Service (NASS), in which he referred to the problem as a “major impact”. I also discussed it at some length with Brad Doorn of the Foreign Agriculture Service (FAS). In both cases the analysis of the issue lies in the future, so I give my opinion based on my knowledge of the procedures used some years ago. I also believe that these procedures have not changed much in the last 5-10 years. It should be noted that the USDA is one of the larger users of Landsat data.

NASS

The Landsat data have been used in a two-step procedure for estimates of crop conditions in the United States:

1. Development of spectral training signatures from selected areas, “segments”, having known ground truth. These areas are small – they used to be 5 by 7 miles. Such areas come under the “intensive study” category mentioned above, since they are large enough to be affected badly by the strips of missing data, and the regions of ground truth are small enough and scattered enough so that some type of aggregation is not feasible. Thus the derivation of spectral training signatures is severely impacted.
2. Use of these spectral signatures to classify entire Landsat scenes. If the signatures were available this step would be feasible, but with some considerable loss of statistical significance, because agricultural fields are characterized by small size, considerable variability in crop type, in physiological maturity, in soil color, etc.

Given the two limitations it appears that use of another data source is preferable to developing alternative procedures for analysis using ETM+.

FAS

The Foreign Agriculture Service also uses Landsat data in two ways. The first is to obtain vegetation index values over full scenes, aggregated to a grid whose dimensions I do not recall. The calculation of the vegetation index within each box is not straightforward (like aggregation of individual index values for each pixel), but it is fully automated. Since the FAS is concerned with a significant fraction of all agricultural land over the globe the processing demands are heavy, and sampling is used (or at least used to be) in order to reduce computation. The modification of the ETM+ scan pattern should be addressable by a rather straightforward weighting procedure, as described above in the section on Regional/whole earth applications. I have no idea of the cost implications to the FAS.

The second use of Landsat data is by analyst interpreters (AI's), who examine whole frame imagery at workstations for a semiquantitive assessment of vegetation conditions. Although this is subjective the AI's develop considerable skill over time and with the accumulation of a personal memory of their region of interest from year to year. I would judge that the pattern of data/blanks will be very distracting to the AI's, but this is just a guess.

Summary

The anomaly in the scan mirror performance should not be a major impediment for estimation of statistical information over very large/global areas. It is quite damaging for local mapping applications. The overall effect within the Department of Agriculture is to be determined, but surely will have a serious effect in the NASS, and potentially a substantial effect within the FAS.

Report from Dr. M. Susan Moran

Research Leader, USDA.-ARS, Southwest Watershed Research Center, Tucson, AZ

(Assessment from Dr. M. Susan Moran, Research Leader, USDA-ARS Southwest Watershed Research Center, Tucson, Arizona. Contents of PowerPoint presentation follow the text below.)

Conclusion 1: The extent of the image covered by striping or missing data increases as image resolution improves.

Conclusion 2: In the multispectral bands, the areas that have missing pixels are not identical. The green and blue pixels indicate places where one or more bands are missing pixels. The black area indicates the places were all the bands are missing pixels.

Conclusion 3 (radiometry): Based on a comparison of histograms of the same site (under similar atmospheric conditions) in June 2001 and June 2003, it appears that the dn of the same target in ETM+ bands 1-5 and 7 are not discernibly different; from this data set, there can be no conclusion about the effect of the SLC failure on the radiometry of the thermal band, and there is a large discrepancy in the histograms of the panchromatic bands of the June 1 2001 and June 17 2003. For an unknown reason, it appeared that the pan data in the June 1 scene was compromised.

Here are the answers to your L7 SLC questions. ***Our main concern is the damage done to the thermal data, and the lack of replacement data.***

1. *Can you use the ETM+ data acquired without an operational SLC, as provided, for your investigations or applications?*

Yes, but only because our field site is centrally located in the scene.

2. What is the impact of the problems on your investigations or applications?

Basically, if the striping was on our field site we could not use the imagery.

3. If the scan line corrector cannot be repaired, will you substitute data from other sources for your investigations or applications?

Some of our work only needs reflective bands, so we would substitute data in those cases. We could possibly use SPOT HRV images or some of the commercial products (IKONOS, etc.). However, ***there is no viable replacement for the thermal data. We are currently using some MTI imagery, but is not optimal for our application. We need the reliable, repetitive coverage of the Landsat sensor.***

4. If you are likely to use other sources of data, which sources best meet your requirements?

We would likely try using Landsat-5 TM, SPOT, and/or MTI.

5. If the scan line corrector cannot be repaired, will you be left with no viable data sources for your investigations or applications?

Yes, we would be left without TIR data. For the reflectance data, there may be other viable sources, but they are not ideal.

6. Can you suggest any steps that might be taken to make the ETM+ data acquired without an operational SLC more useful? For example, would you prefer to receive data where the pixels in the data gaps were filled by interpolation?

Yes, we would prefer images with gaps filled by interpolation. However, in the test images we received, pixels are still missing.

(adapted from original PowerPoint slides)

Images:

Path35, Row38, 1 June 2003 and 17 June 2003

Compared with an archived scene: Path35, Row 38, 27 June 2001

All images were obtained with very clear, dry sky conditions and surface conditions were similar (I.e., sparse vegetation, dry soil)

Methods:

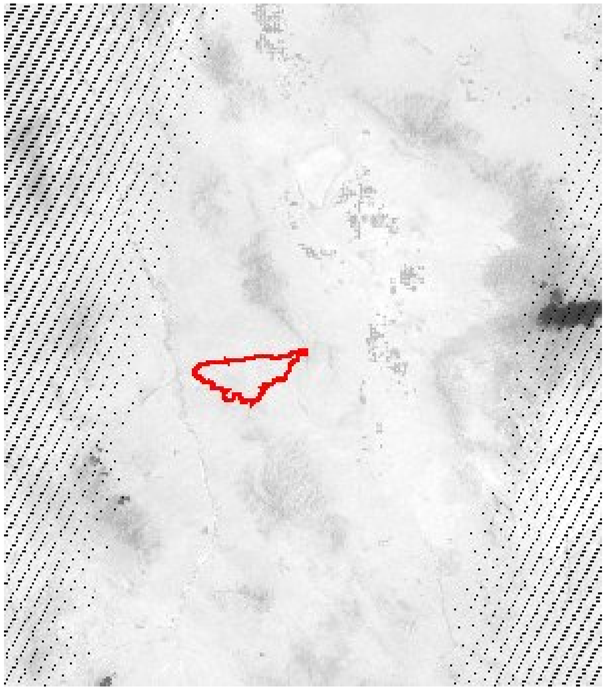
Geometric:

1. Visually assess June 2003 images to determine trends in striping

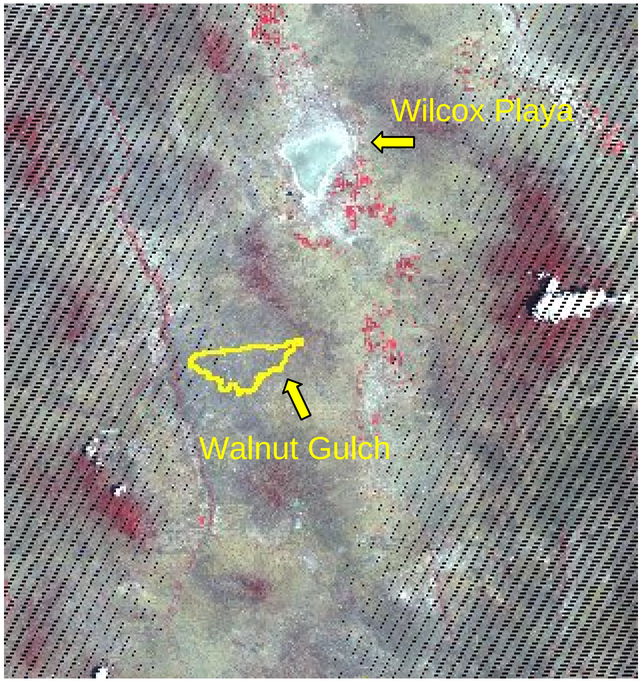
Radiometric:

1. Compare histograms of 2001 and 2003 scenes at same sites:
  - **a) Wilcox Playa (bright, sandy dry playa), and**
  - **b) Walnut Gulch (grassland, dry soils),**

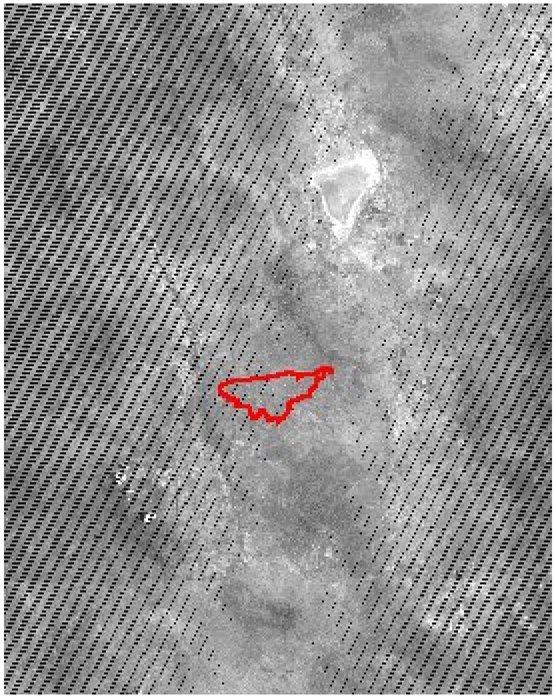
where both sites were NOT in the striped parts of the 2003 scenes.



6/17/03 Band 6 (60m res.)
60% of the image is good



6/17/03 Band 1-5,7 (30m res.)
40% of the image is good



6/17/03 Band 8 (15m res.)
20% of the image is good

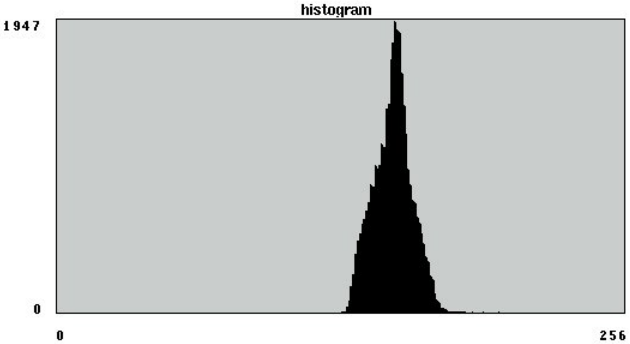
Conclusion 1:

The extent of the image covered by striping or missing data increases as image resolution improves.

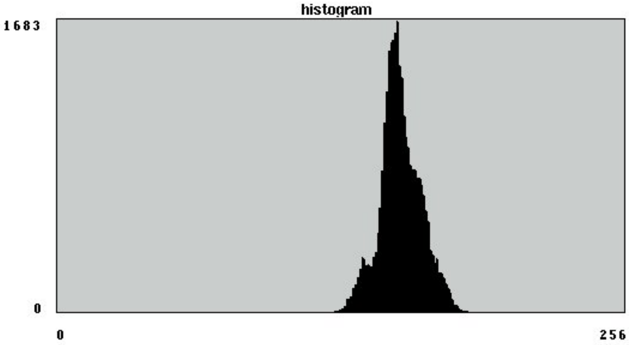
Conclusion 2:

In the multispectral bands, the areas that have missing pixels are not identical. The green and blue pixels indicate places where one or more bands are missing pixels. The black area indicates the places were all the bands are missing pixels.

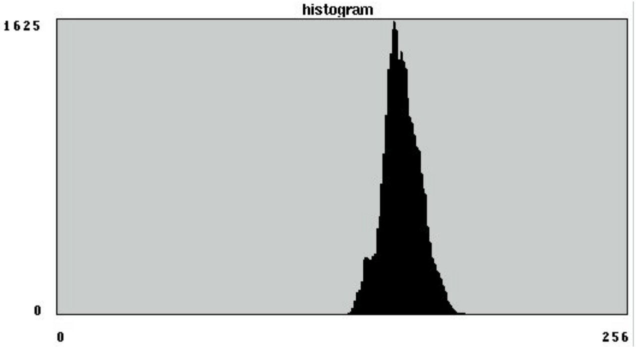
Radiometric comparison of June 2001 scene with June 2003 scenes : Wilcox Playa



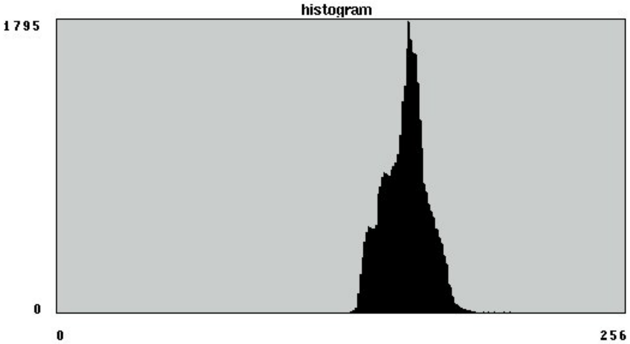
6/27/01 band 1



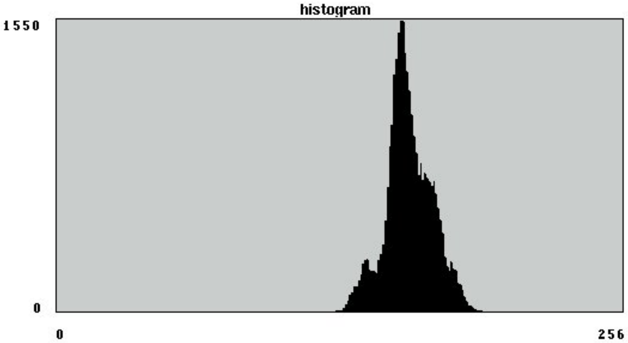
6/1/03 band 1



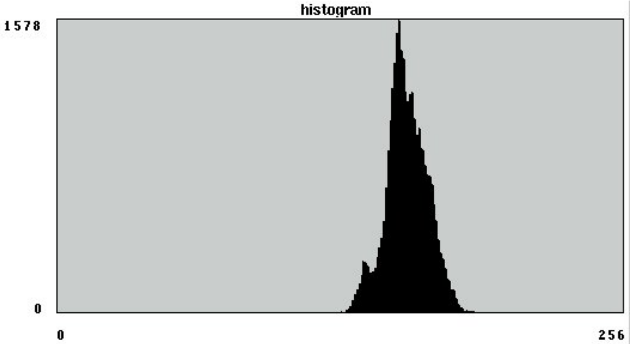
6/17/03 band 1



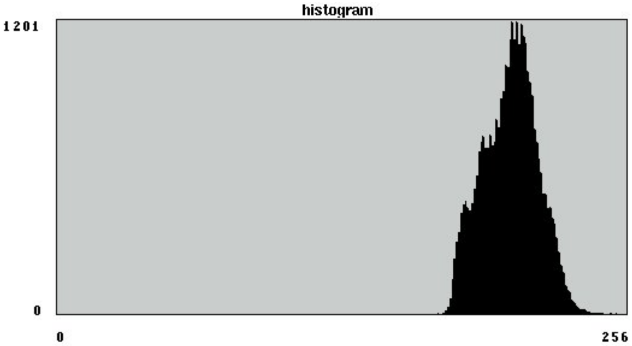
6/27/01 band 2



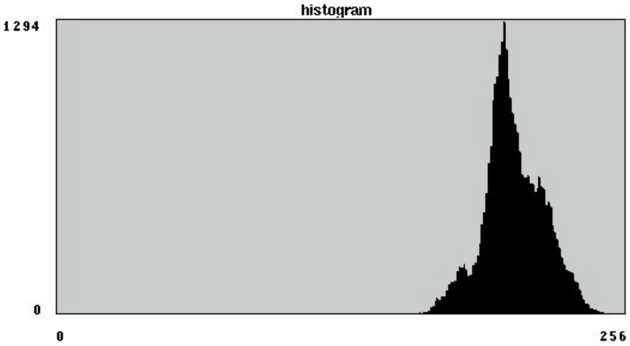
6/1/03 band 2



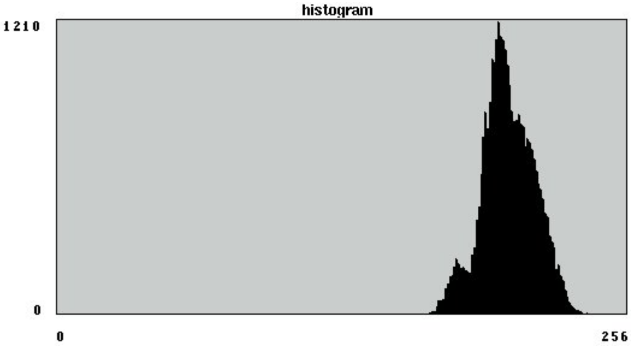
6/17/03 band 2



6/27/01 band 3



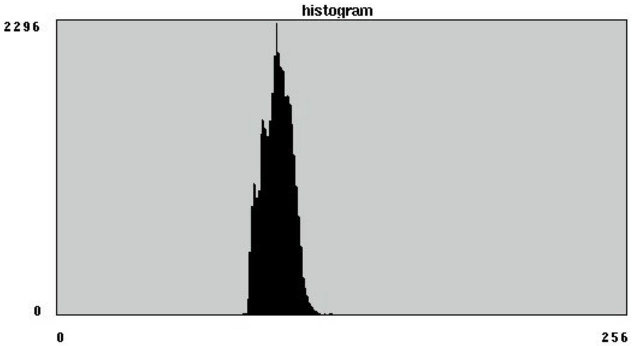
6/1/03 band 3



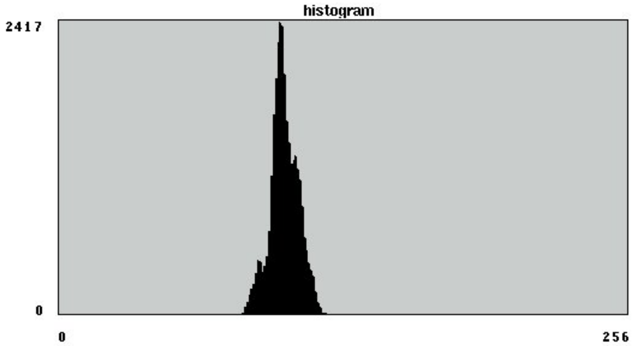
6/17/03 band 3

Note: Y axis is frequency and X axis is dn, ranging from 0 to 256.

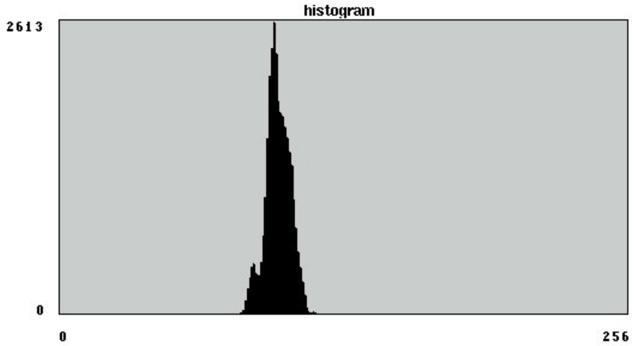
Radiometric comparison of June 2001 scene with June 2003 scenes : Wilcox Playa



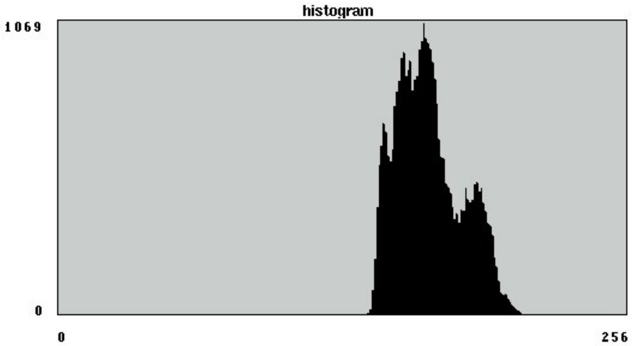
6/27/01 band 4



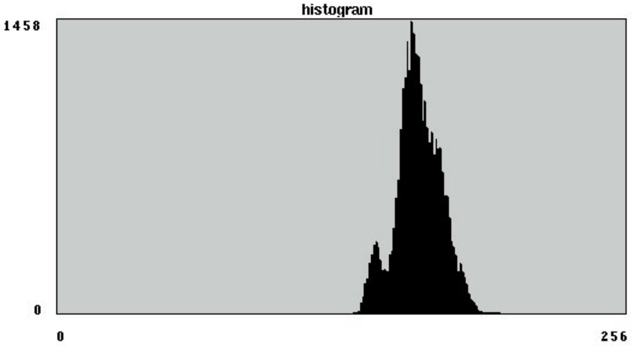
6/1/03 band 4



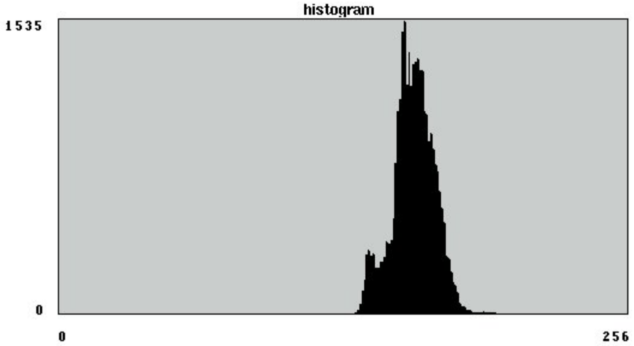
6/17/03 band 4



6/27/01 band 5

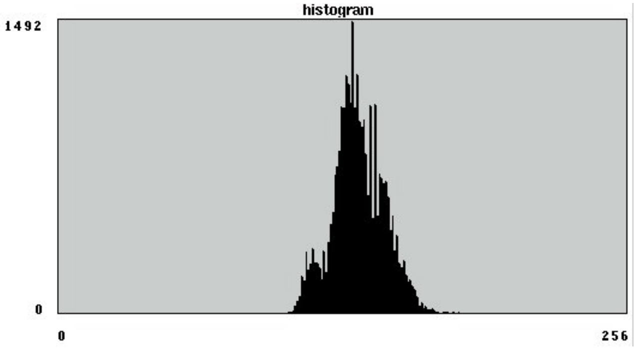


6/1/03 band 5

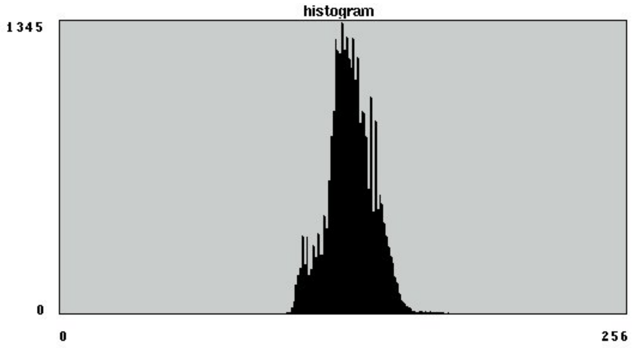


6/17/03 band 5

Note: The differences found between band 5 histograms in the 2001 image and 2003 images are most likely due to changes in site placement (possibly soil moisture) within the playa.

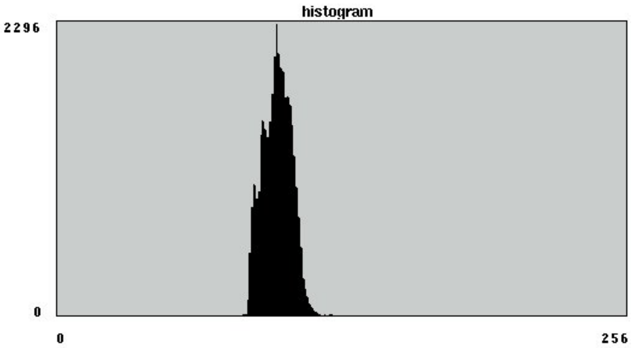


6/1/03 band 7

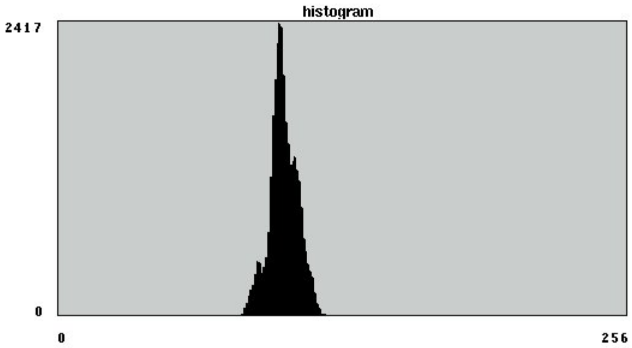


6/17/03 band 7

Radiometric comparison of June 2001 scene with June 2003 scenes : Wilcox Playa



6/27/01 band 4



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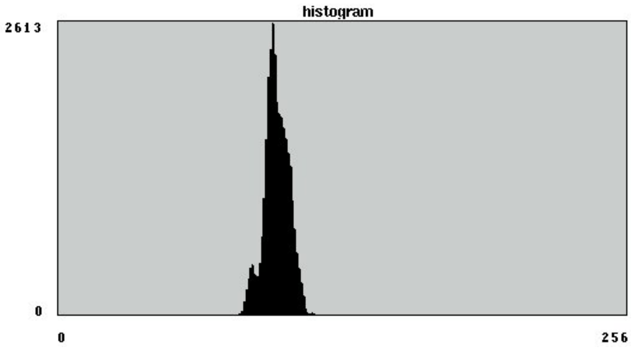

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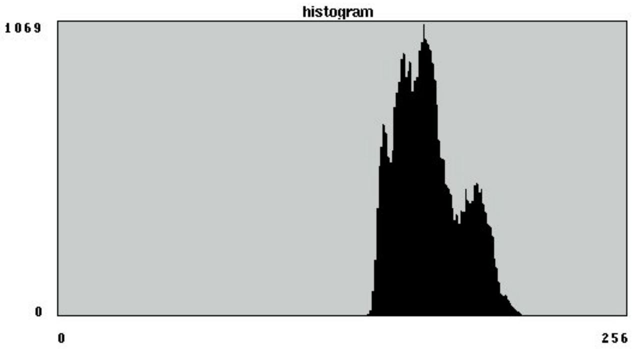

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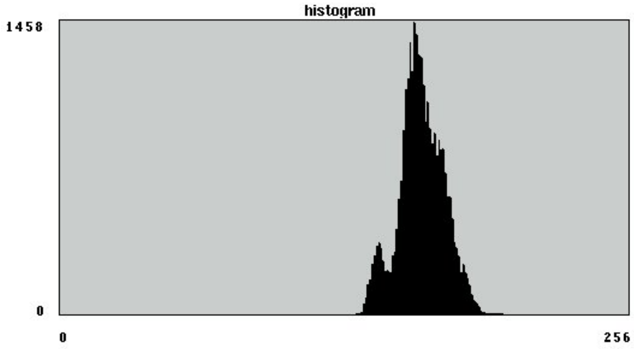

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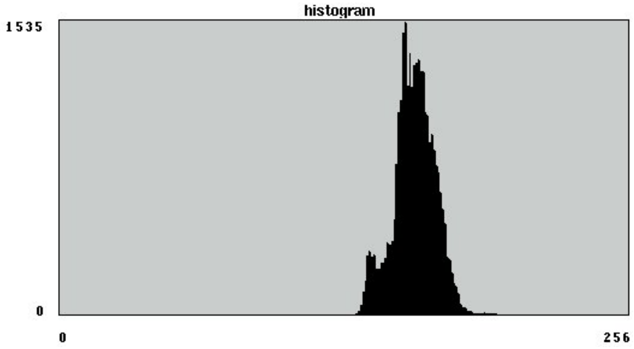
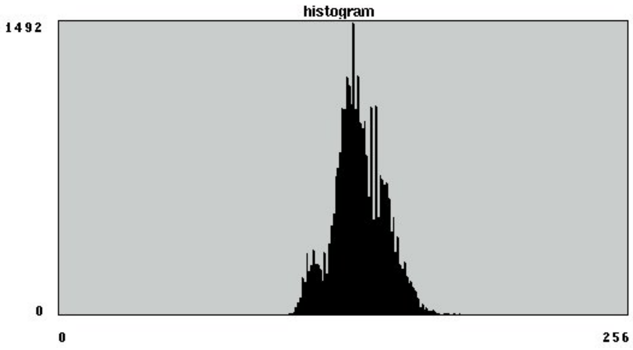
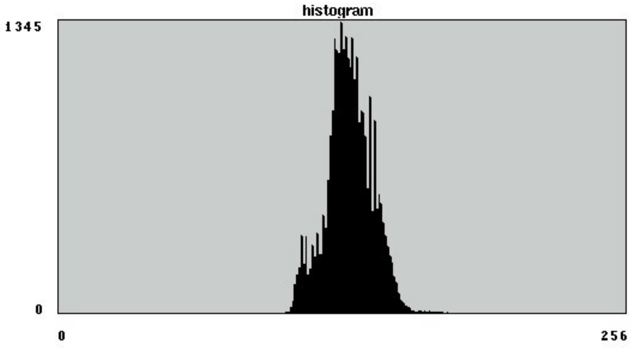


6/17/03 band 5

Note: The differences found between band 5 histograms in the 2001 image and 2003 images are most likely due to changes in site placement (possibly soil moisture) within the playa.



6/1/03 band 7



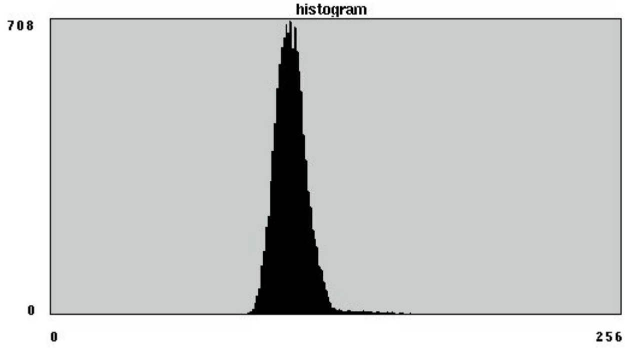
6/17/03 band 7

Radiometric comparison of June 2001 scene with June 2003 scenes : Wilcox Playa Tabular Summary

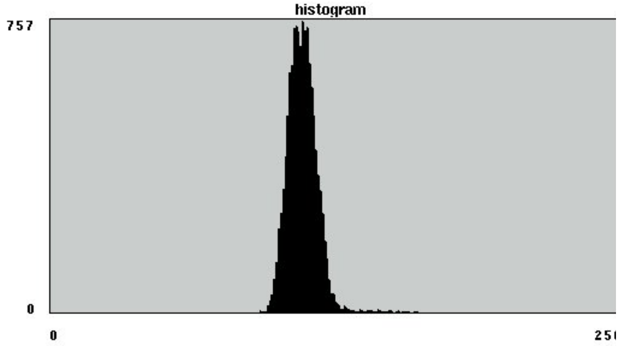
Image 6/27/01 Wilcox Playa				**Image 6/1/03 Wilcox Playa**				**Image 6/17/03 Wilcox Playa**			
Band	**Min**	**Max**	**Mean**	**Band**	**Min**	**Max**	**Mean**	**Band**	**Min**	**Max**	**Mean**
1	128	199	150.8	1	125	185	154.2	1	130	183	154
2	132	204	156.5	2	126	192	158.5	2	128	188	157.4
3	171	255	203	3	163	246	205.1	3	167	238	202.2
4	83	123	98.1	4	82	120	100.8	4	81	115	97.6
5	139	208	166.3	5	133	199	161.9	5	133	196	159
				6 low	178	197	188.5	6 low	175	188	181.7
				6 high	235	255	251.5	6 high	229	253	240.7
				7	103	180	134.5	7	102	177	130.6
				8	161	255	248.6	8	0	136	111.9

Min, Max, and Mean DN values for images 6/27/01, 6/1/03, and 6/17/03.

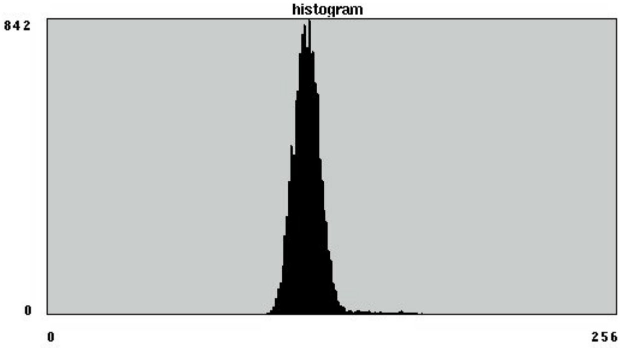
Radiometric comparison of June 2001 scene with June 2003 scenes : Walnut Gulch



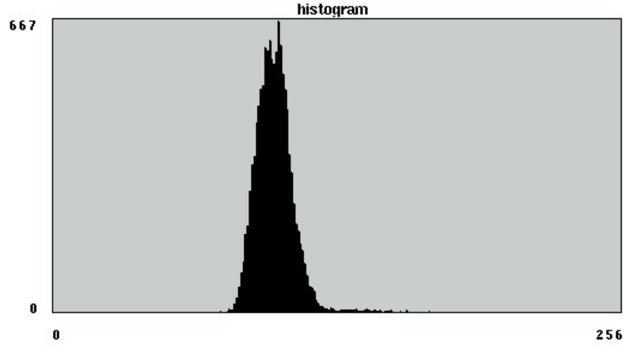
6/27/01 band 1



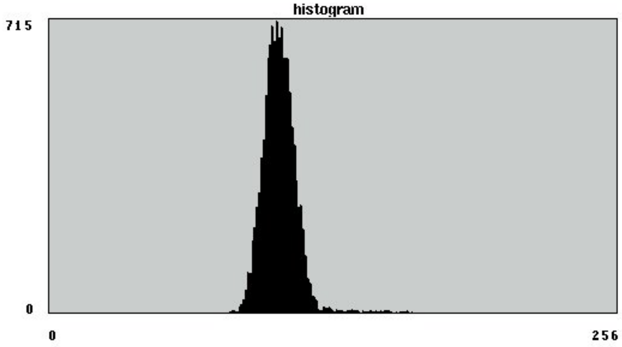
6/1/03 band 1



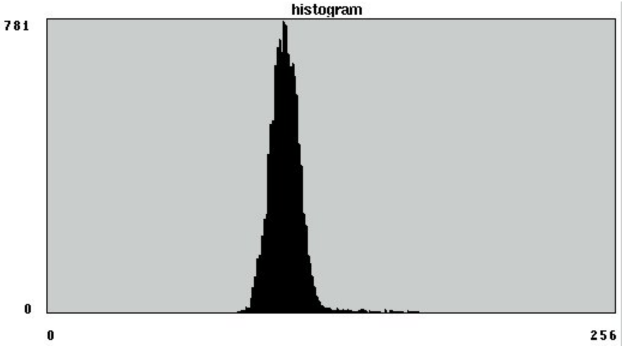
6/17/03 band 1



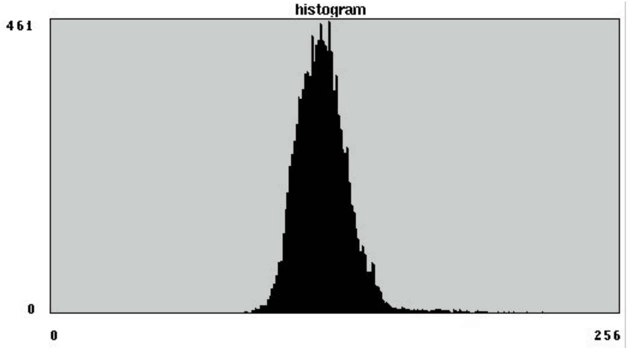
6/27/01 band 2



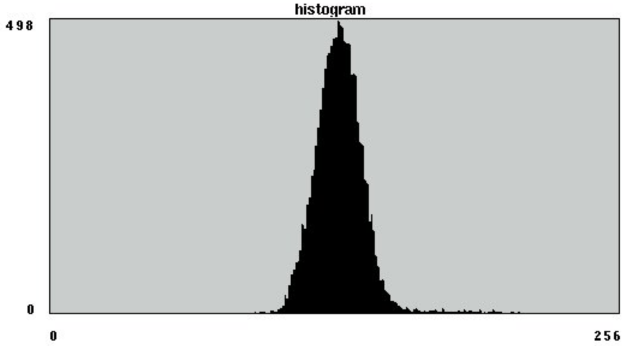
6/1/03 band 2



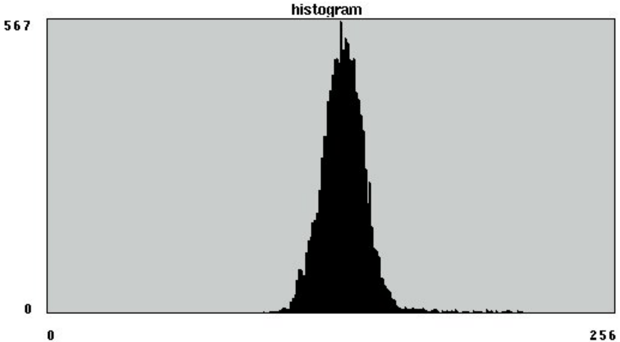
6/17/03 band 2



6/27/01 band 3



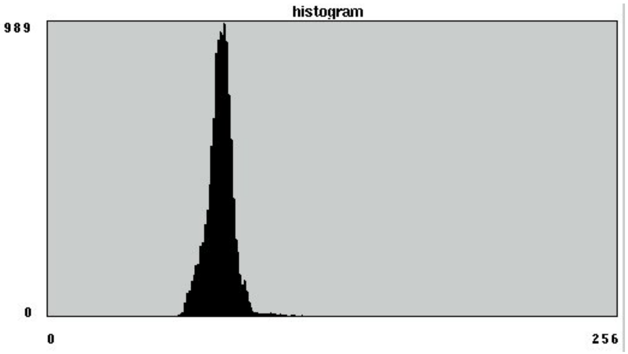
6/1/03 band 3



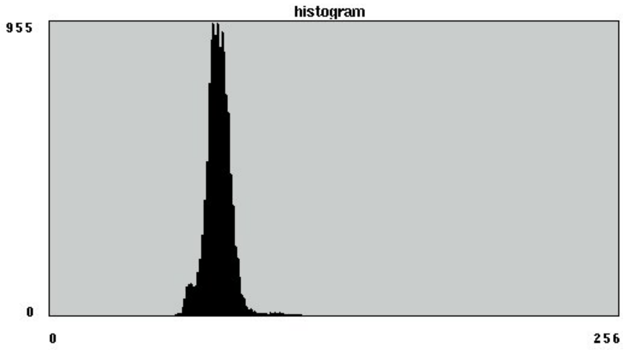
6/17/03 band 3

Note: Y axis is frequency and X axis is dn, ranging from 0 to 256.

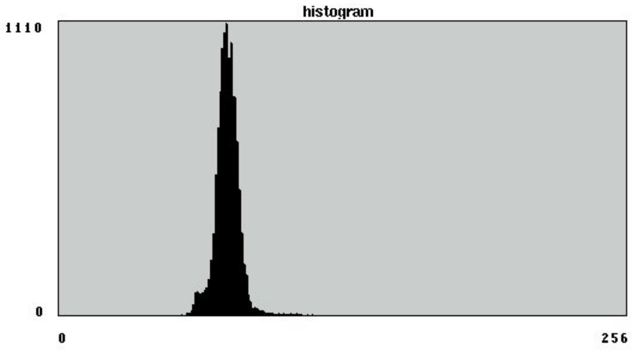
Radiometric comparison of June 2001 scene with June 2003 scenes : Walnut Gulch



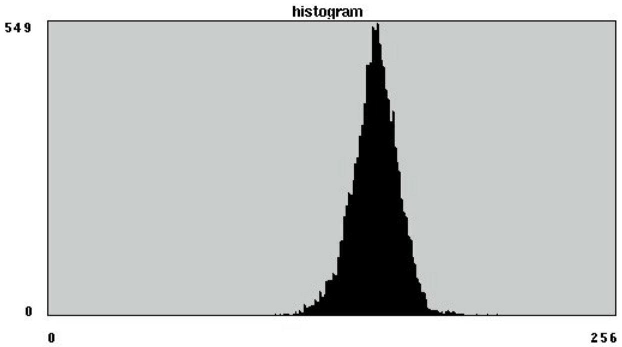
6/27/01 band 4



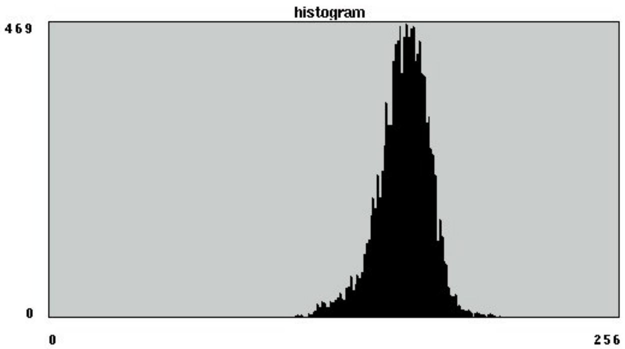
6/1/03 band 4



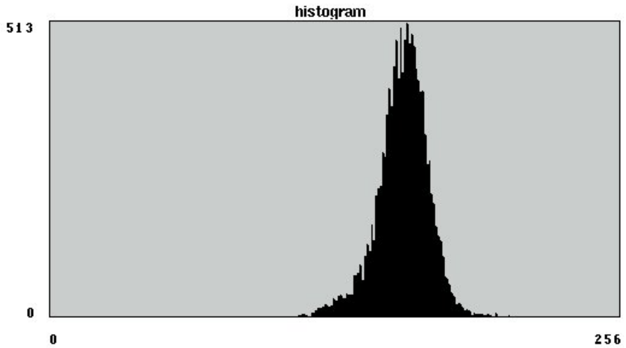
6/17/03 band 4



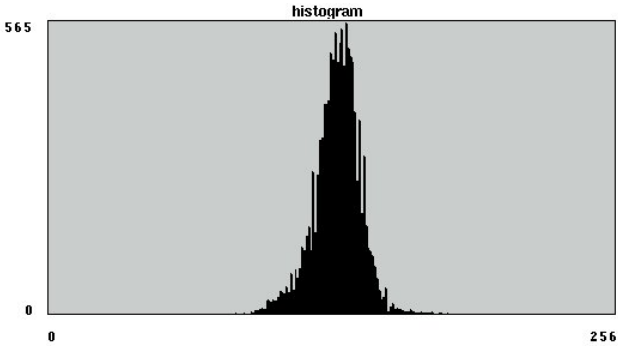
6/27/01 band 5



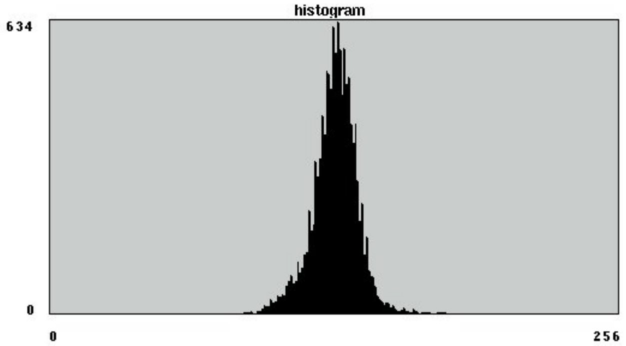
6/1/03 band 5



6/17/03 band 5



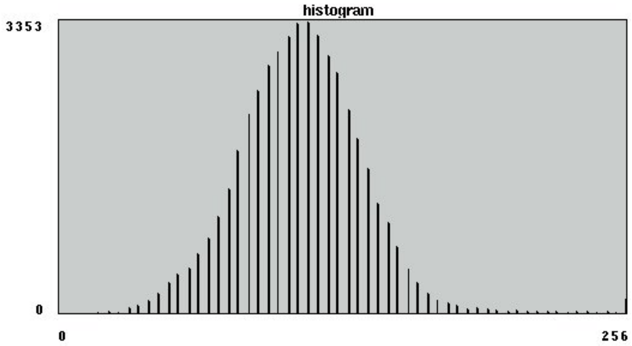
6/1/03 band 7



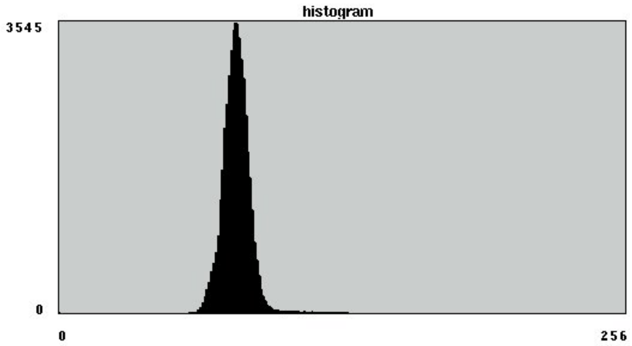
6/17/03 band 7

Radiometric comparison of June 2001 scene with June 2003 scenes : Walnut Gulch

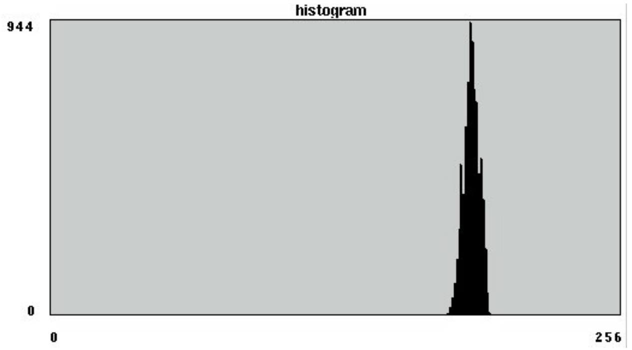
Note: Saturation of pixels occurred throughout various portions of band 8 in the 6/1/03 image.



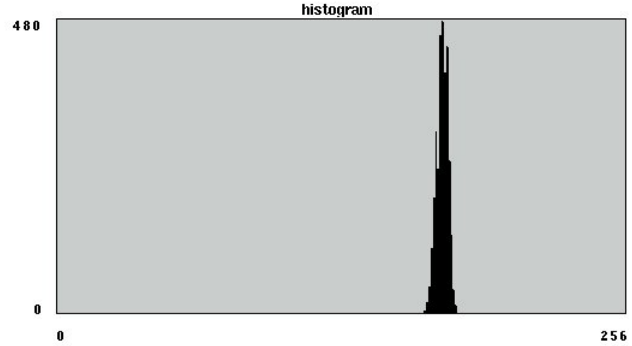
6/1/03 band 8



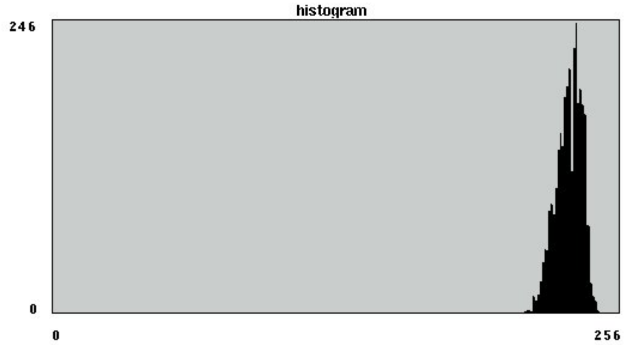
6/17/03 band 8



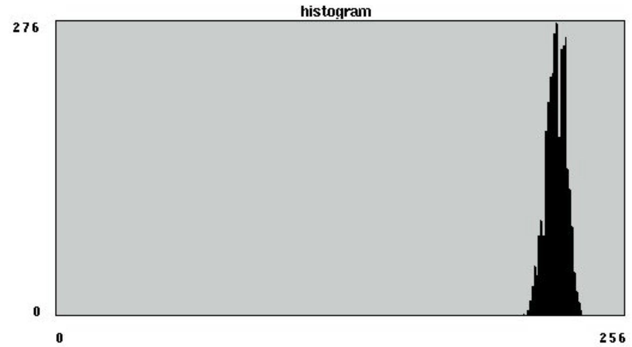
6/1/03 band 6_1 low



6/17/03 band 6_1 low



6/1/03 band 6_2 high



6/17/03 band 6_2 high

Radiometric comparison of June 2001 scene with June 2003 scenes : Walnut Gulch Tabular Summary

Image 6/27/01 Walnut Gulch				Image 6/1/03 Walnut Gulch				Image 6/17/03 Walnut Gulch			
Band	**Min**	**Max**	**Mean**	**Band**	**Min**	**Max**	**Mean**	**Band**	**Min**	**Max**	**Mean**
1	88	164	107.3	1	94	165	112.7	1	98	170	116.3
2	75	169	99	2	81	163	103.2	2	85	167	106.7
3	87	221	121.9	3	92	211	129.6	3	97	214	133.3
4	58	114	76.8	4	56	113	75.1	4	55	114	75.2
5	102	202	146.8	5	110	202	158.5	5	111	206	158
				6 low	166	185	177.2	6 low	165	179	172.8
				6 high	213	246	232.8	6 high	210	236	224.7
				7	84	180	129.8	7	87	178	127.8
				8	13	255	108.9	8	0	130	79.4

Min, Max, and Mean DN values for images 6/27/01, 6/1/03, and 6/17/03.

Conclusion 3 (radiometry) :

Based on a comparison of histograms of the same site (under similar atmospheric conditions) in June 2001 and June 2003, it appears that

- **the dn of the same target in ETM+ bands 1-5 and 7 are not discernibly different,**
- **from this data set, there can be no conclusion about the effect of the SLC failure on the radiometry of the thermal band, and**
- **there is a large discrepancy in the histograms of of the panchromatic bands of the June 1 2003 and June 17 2003. For unknown reason, it appeared that the pan data in the June 1 scene was compromised.**

Followup :

All scenes (2001 and 2003) are available for anyone to conduct further testing.

Darrell: If you have any further requests for analysis, please let us know

Acknowledgement :

Chandra Holifield expended a great deal of effort and creativity to conduct this timely analysis.

Report from Dorothy K. Hall, Ph.D.

Hydrological Sciences Branch, NASA GSFC Code 974

I looked at five different "damaged" ETM+ scenes, and I think that there is a lot of usable information there. In spite of the very serious image-quality problem, since there isn't anything else that adequately serves the user community other than the Landsat-7, my opinion is that the damaged scenes should be saved with a possibility of using the images at some time in the future. I imagine that people are working on ways to improve the images, and if that works, at least to some degree, it would be good to have the data available to retrospectively improve the damaged scenes. I think we are missing out on some good data if the scenes are not retained.

E-mail report from Robert Bindschadler, Ph.D.

Senior Fellow, NASA GSFC Code 971

I've done a quick look at the scenes you staged. Here's my feedback. I was not part of Friday's telecon, so I might not be aware of many thoughts/plans within the L7 control/operations structure.

You are to be complimented for catching this SLC anomaly and getting some sample data out to an ad-hoc advisory group. I was not aware of the problem. Seeing it for the first time, it strikes me as a big problem.

One polar-based question is whether the data gaps are a function of latitude with smaller gaps at higher latitudes. I would expect this might be the case if what the SLC does is compensate for the differences between spacecraft motion and earth rotation. At higher latitudes, the "ground speed" of the earth's surface is lower and as the max latitude is reached, the satellite velocity and earth surface velocity line up. I don't have any polar image to check, but you probably know the answer to this.

In your sample Florida images, the data gaps are serious. I don't see that there is much gained by setting the resampler to ON (differencing two images shows this clearly). The data gaps are still large. For the pan band, the resampler is even less effective because it only corrects two pixels into the gap. The reverse is true for the thermal band, but still there are significant gaps.

Speaking from what my community uses Landsat for, there is still some utility in using imagery as proxy maps. Many of the features we study would span across the gaps. In addition, we high-latitude guys have the benefit of significant path overlap, which, with patience, would allow us to use just the central portion of images as a work-around.

However, we also use Landsat in very "digital" ways and here the data gaps are a severe impediment. Image correlation for velocity determination is an obvious application that would be severely disrupted by the data gaps or any attempt to fill in the data gaps by any resampling scheme.

I have one other suggestion to toss out. If the case can be made that the LTAP is of fundamental national interest and importance (I firmly believe this is true), then could ASTER data become a substitute or augmentative data source to continue the LTAP monitoring mission? Stitching together 9 scenes for every Landsat scene, though cumbersome, is far preferable from my scientific viewpoint, than trying to fill large data gaps in L7 data.

E-mail report from Kurt Thome, Ph.D.

Univ. of Arizona

I can say with extreme confidence that the radiometric quality of the data with the SLC problem is at the same level as prior to the malfunction. This conclusion was reached using the Railroad Valley (RRV) Playa and Ivanpah Playa scenes obtained from EDC. Unfortunately, the 10% of clouds in the White Sands scene was directly over our site. The method used was the following:

1) Ivanpah data were collected on May 28 and June 29 of this year and surface reflectance of the playa varied by less than 2% as measured on the ground. Comparison of the June 13 ETM+ imagery showed agreement with the data from May 28 to better than 2% when accounting for the different sun angles on the two dates. This was an at-sensor comparison, so no correction for atmospheric changes was attempted but the surface reflectance dominates the problem so much that I am very confident in reporting no discernible change in the calibration.

2) RRV data were collected on May 27 and July 6 of this year. Unfortunately, the surface reflectance of the playa changed pretty significantly between the dates and the measurements of July 6 were about 16% higher than from a June 17, 2002 collection date. Thus, these data are not as conclusive, but I was able to predict the band 1-3 ETM+ radiances to better than 2% (don't think this was coincidence) and better than 8% in the other bands. The SWIR bands have rather large uncertainties due to a spectral effect in the surface reflectance that I can see in the ground data.

3) ETM+ will still be extremely useful in the cross-calibration of sensors since RRV playa is in the center of the scene and suffers little from the SLC dropouts. In other scenes, it will still be useful simply because it is the best radiometric sensor in orbit at this time, bar none. Several other sensors are gaining (MODIS, ALI, for example, but only through comparison to ETM+). In the case of cross-comparisons, nearest-neighbor interpolation towards the center of the scene would not impact the radiometric comparisons too badly. The interpolation scheme would need further evaluation towards the edge of the scene, but this problem is tractable.

Report from Curtis Woodcock, Ph.D.

Geography Dept., Boston Univ.

Let me just comment on a few points.

1. Landsat data is still the only high quality high-resolution data available and as such is essential to ESE and its many endeavors.

2. For large area mapping applications it is going to be necessary to start compositing data -- which is something new for the high esolution community, but not for the remote sensing community in general. There is the opportunity to use the overlap on the sides as well as multiple dates for the same image.
I think with some careful work and thought you could produce some nice composites that it will be hard to tell from the real thing. I haven't had the chance to really work on this yet, but it is not something that will be solved for all time in a few days work anyway.

3. One of the main uses of Landsat data is for land cover and land use change. I think we all know now that it takes high-resolution data to track human changes in landscapes. Landsat data has been and will continue to be the workhorse in this domain. From that perspective, having a sensor with problems like Landsat 7 is much better than no sensor at all. Almost all the work done on land cover and land use change uses what I call the "endpoints" paradigm, where change is assessed between two endpoints in time -- most frequently years to decades apart. If we now have a problem with dropped areas for a few years, this "endpoints" analysis of land cover and land use change will be affected to be sure, but it won't be crippled. The first thing to remember is that one of the "endpoints" (for the time being, the initial time) will still have beautiful, complete coverage imagery. To use the current images (with their problems), it will simply be a matter of accumulating a few images for comparison with the initial date instead of a single image to fill the role of the second "endpoint." So the argument should be made that it will be more important than ever to collect as many images as possible, as it may take 2 or 3 (or maybe even 4 or 5) to fill the role previously filled by a single image. Is that great? No, it isn't. Is it the end of the world? No, it isn't. Not having any Landsat imagery is the "end of the world" scenario from the land cover and land use change perspective.

I hope this perspective helps. Once LDCM is up again, we may be in the situation where L7 data is needed for the "initial endpoint" in land cover and land use change analysis -- so let's do what we can to make sure that whatever we can collect gets collected. Please let me know if I can help further.

Report from Dr. Eric Brown de Colstoun
NASA GSFC

(Assessment by Dr. Eric Brown de Colstoun at NASA GSFC from a land use / land cover change perspective.)

I have looked at a couple of scenes from the EDC SLC archive and tried some unsupervised classifications and simple land cover change detection but nothing terribly in depth. Here are a couple of comments in response to your list of questions:

Can you use the ETM+ data acquired without an operational SLC, as provided, for your investigations or applications?

The data are still quite useable in my opinion for both classifications and land cover change analyses. While localized studies of pixel level changes may be impacted the data still allow these issues to be examined on a regional basis (i.e., how much of x type has changed over a region).

What is the impact of the problems on your investigations or applications?

I am trying to come up with some statistics to better understand what percentage of a scene is still useable with both interpolation and no interpolation. Seems like there may be workarounds to limit the impact.

If the scan line corrector cannot be repaired, will you substitute data from other sources for you investigations or applications?

Data substitution would be a last resort.

I think Jeff Masek's suggestion of using data 16-days apart to fill gaps would be an acceptable solution, better than using MODIS 250m data certainly. However, Jim Storey says that this may not necessarily work all the time and for the entire scene. It would be good for EDC to produce an additional "interpolation off" scene with an acquisition date 16-days after the other so this could be examined.

Can you suggest any steps that might be taken to make the ETM+ data acquired without an operational SLC more useful? For example, would you prefer to receive data where the pixels in the data gaps were filled by interpolation?

I would rather have interpolation off for research activities. The interpolated data look ok but I would be very cautious about detecting change in these areas. I am not quite sure what you do for folks who want "pretty pictures" of their areas of interest. Maybe the user should have an option to order interp on or off scenes? I think an approach that uses multiple scenes to fill gaps should be looked into. I also think all images will need to have a "gap mask" as is provided with these current EDC data. I was not sure whether this mask would be exactly the same for all scenes or whether it would have to be generated for each individual scene.

Report from Dr. John Schott

Rochester Institute of Technology

(Assessment by Dr. John Schott, Rochester Institute of Technology with regard to remote sensing of the Great Lakes water quality which is largely driven by seasonal thermal rollover.)

“I believe we could continue to do our large area studies of Great Lakes hydrodynamics and water quality with the system as is and with a little more effort (patience) the local phenomena would be observable as well. I can't yet tell you if the (thermal) calibration is steady in the current mode. We are just getting into some recent collections. However, I am confident that we could recalibrate the thermal to account for any operational changes in the instrument in necessary.”