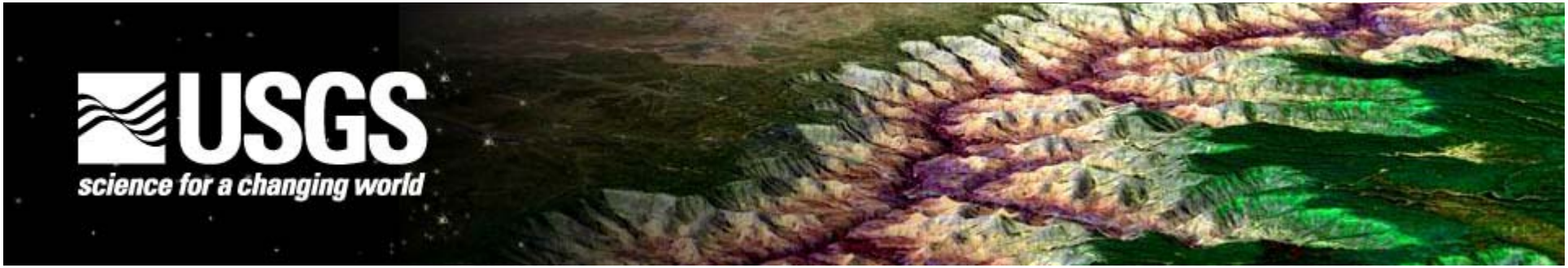


Landsat MSS update to Science Team

19 January 2010

U.S. Department of the Interior

U.S. Geological Survey

MSS migration to LPGS highlights

- **Objective:Create cheaper, better MSS L1T products in a format and with metadata that are compatible with TM and ETM+**
- **Cross-calibration gains, biases, and time dependent variables are used to map the MSS archive data to radiance using the Normalized Radiance method developed at SDSU.**
- **Hierarchical (Gaussian Pyramid) image matching**
- **Geometric verification**

Background – MSS Recap

- **MSS-X (WBVT) Landsat 1, 2, & 3 ~156,000 scenes (7/2010)**
  - Radiometric corrections applied
  - Archived on a scene by scene basis, band sequential format
  - Several thousand “Orphan” scenes exist
- **MSS-X (Goddard “CCT-X”) Landsat 1, 2, & 3 ~43,000 scenes (7/2010)**
  - Radiometric corrections applied
  - Similar physical format as MSS-X (WBVT) but with more information in header data
  - Archived on a scene by scene basis, band sequential format
- **MSS-A (archived source) Landsat 2, 3, 4, & 5 ~261,000 scenes (9/2010)**
  - Radiometric corrections applied
  - Systematic Geometric corrections calculated, not applied (A to P)
  - Archived on a scene-by-scene basis, band sequential format
- **MSS-P (processed source) Landsat 2 & 3 ~61,000 scenes (3/2010)**
  - Radiometric and geometric corrections (is a systematic product)
  - Physical format is similar to MSS-A

MSS Radiometry

- **Archived MSS data were radiometrically-corrected with a 127 saturation value from 6- and 7-bit source data.**
- **Each band of each MSS sensor will have LMin, LMax, and time-dependent parameters stored in the CPF.**
- **LPGS MSS processing will use cross-calibration gains, biases and time dependent variables to map the MSS archive data to radiance using the Normalized Radiance method developed at SDSU.**
- **Radiance values are scaled to a 0-255 range with 0 reserved for fill, 1 (QCalMin) for low saturation value (LMin), and 255 (QCalMax) for high saturation value (LMax).**
- **TOA radiance**
  - LMin, Lmax, QCalMin and QCalMax are reported in the image metadata for use in conversion to TOA radiance.

MSS Geometry

- **Reformatter converts archive formats into standardized HDF format**
- **Ingest HDF formatted data into LPGS**
- **Systematic model uses information available in source data to create systematic grid for conversion of archive data to UTM north-up projection**
- **Hierarchical image matching (Gaussian pyramid) and precision results used to establish a precision grid**
- **Terrain correction and reprojection applied to original source data for a once resampled product**
- **Geometric verification reports and graphics**
  - Quadrant and image RMSE values included in L1T product metadata
  - Verification plots for L1T product
- **Product generation**
- **Collect trending information for use in future refinement.**

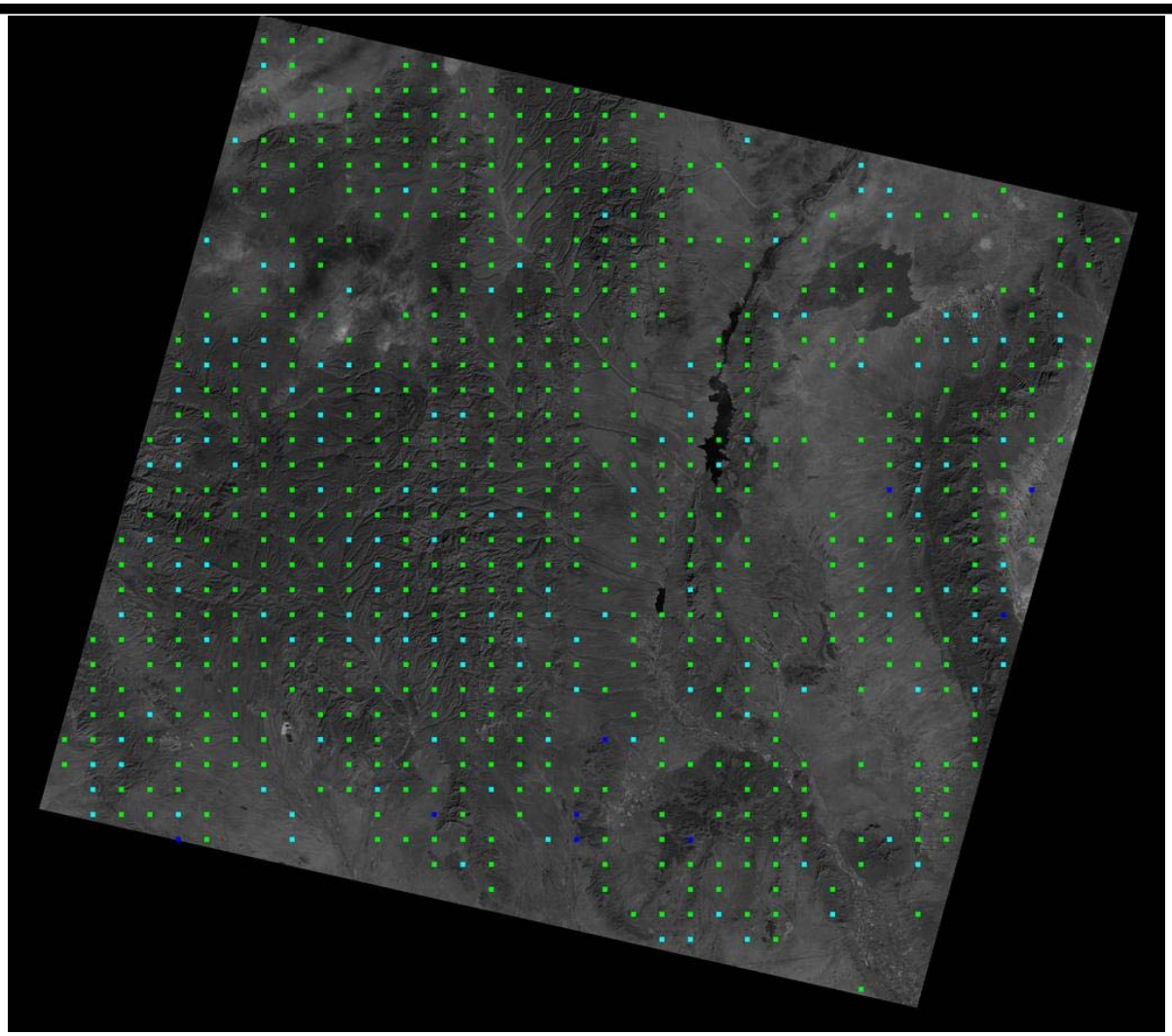
Hierarchical Image Registration Module

- **Gaussian Pyramid based image registration for approximation determination**
- **Refinement using the existing correlation techniques and GLS 2000 GCP chips**
- **Does Hierarchical Image Matching perform as expected?**
  - Yes. We are seeing automated results in cases where NLAPS needed operator assistance with initial control selection.
  - It has matched test scenes that were are far as 10km off (MSS-X)
  - Limitations: Winter scenes (full snow cover) did not perform well at the highest pyramid levels (lowest resolution).
- **System Tests for MSS-P, prior to refinement of parameters, show 24 of 70 images with less than 1-pixel RMSE using independent verification**
- **Should also improve initial location determination for Landsat TM**

Product Verification Module

- **Evaluates and provides a comprehensive accuracy of the L1T products relative to GLS 2000 reference**
- **The product metadata will have RMSE for overall scene and for each quadrant of the scene**
- **A report file with the summary statistics of the verification is provided along with the L1T products**
  - Includes individual point offsets, mean, STD, RMSE
- **A JPEG image showing the offsets measured in the L1T products with respect to GLS 2000 reference**
- **Provides an indication of the expected accuracy in different geographical regions of the scene**
- **Will eventually become available for all Landsat products**

MSS verification example



Path/Row : 36/37 (WRS-1)

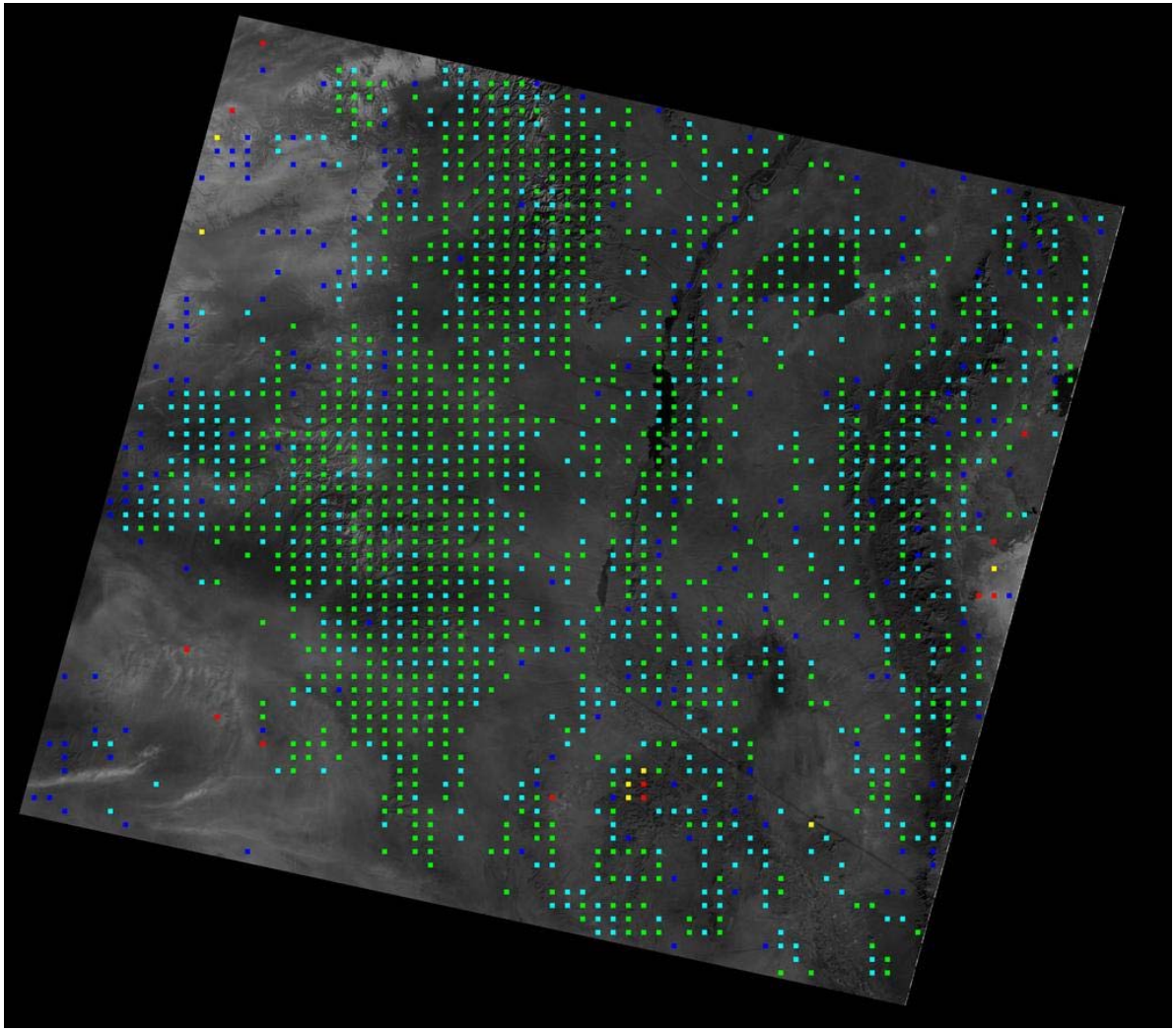
Legend :
Green - RMSE <= 0.5 pixel
Cyan - 0.5 < RMSE <= 1 pixel
Blue - 1 < RMSE <= 2 pixel
Yellow - 2 < RMSE <= 3 pixel
Red - RMSE > 3 pixel

RMSE by quadrant and scene
UL: 0.33 pixel
UR: 0.41pixel
LR: 0.43 pixel
LL: 0.44 pixel
SCENE: 0.41 pixel
stored in metadata file (MTL)

Rules
50 by 50 grid
Strength of correlation
Distance from other points
RMSE

Verification report contains summary statistics and a list of all verification points.

MSS verification example



Path/Row : 36/37 (WRS-1)

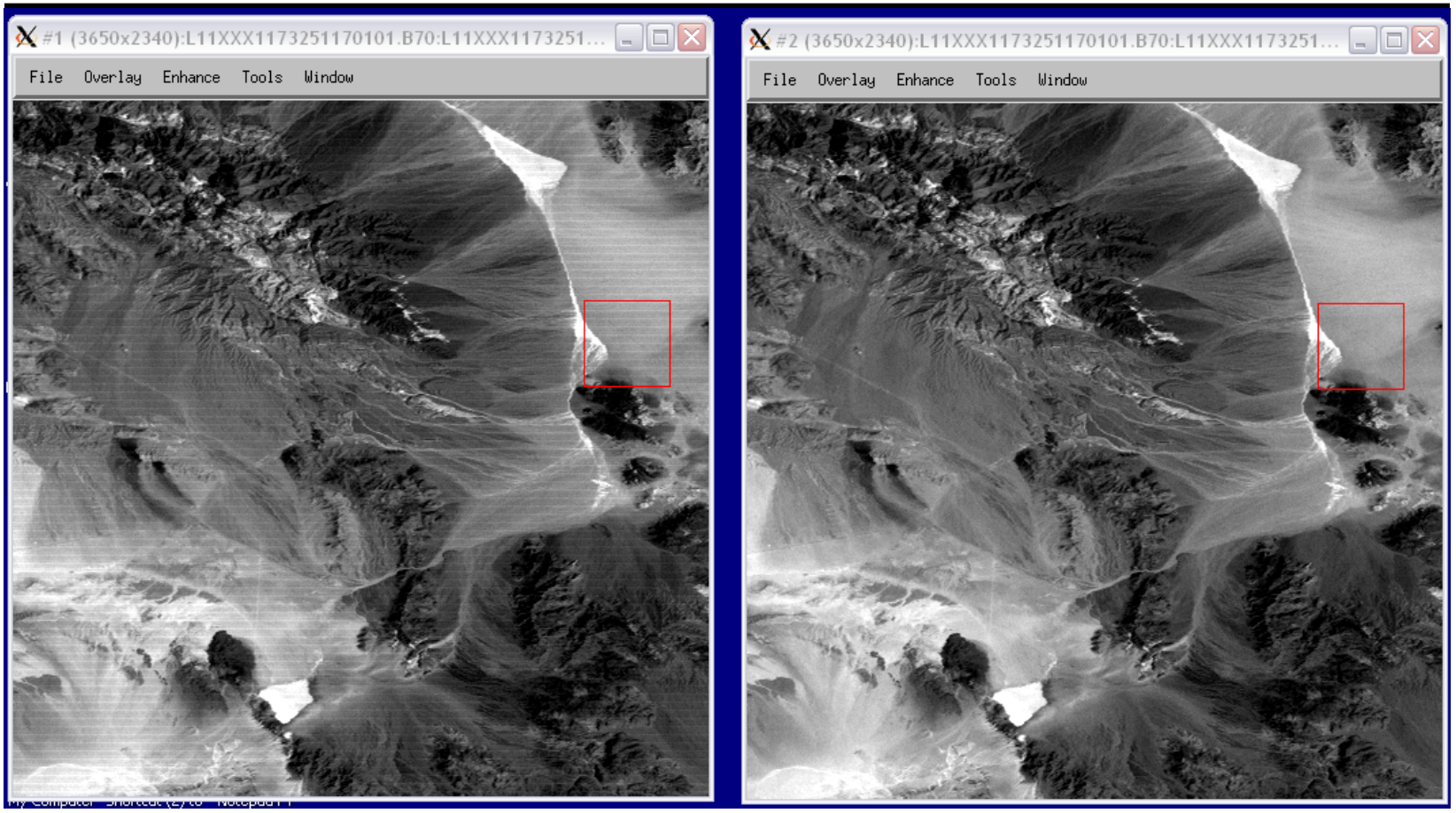
Legend :
Green - RMSE <= 0.5 pixel
Cyan - 0.5 < RMSE <= 1 pixel
Blue - 1 < RMSE <= 2 pixel
Yellow - 2 < RMSE <= 3 pixel
Red - RMSE > 3 pixel

RMSE by quadrant and scene
UL: 0.77 pixel
UR: 1.17 pixel
LR: 0.96 pixel
LL: 0.97 pixel
SCENE: 0.97 pixel
stored in metadata file (MTL)

Rules
75 by 75 grid
Strength of correlation
RMSE
Distance from other points

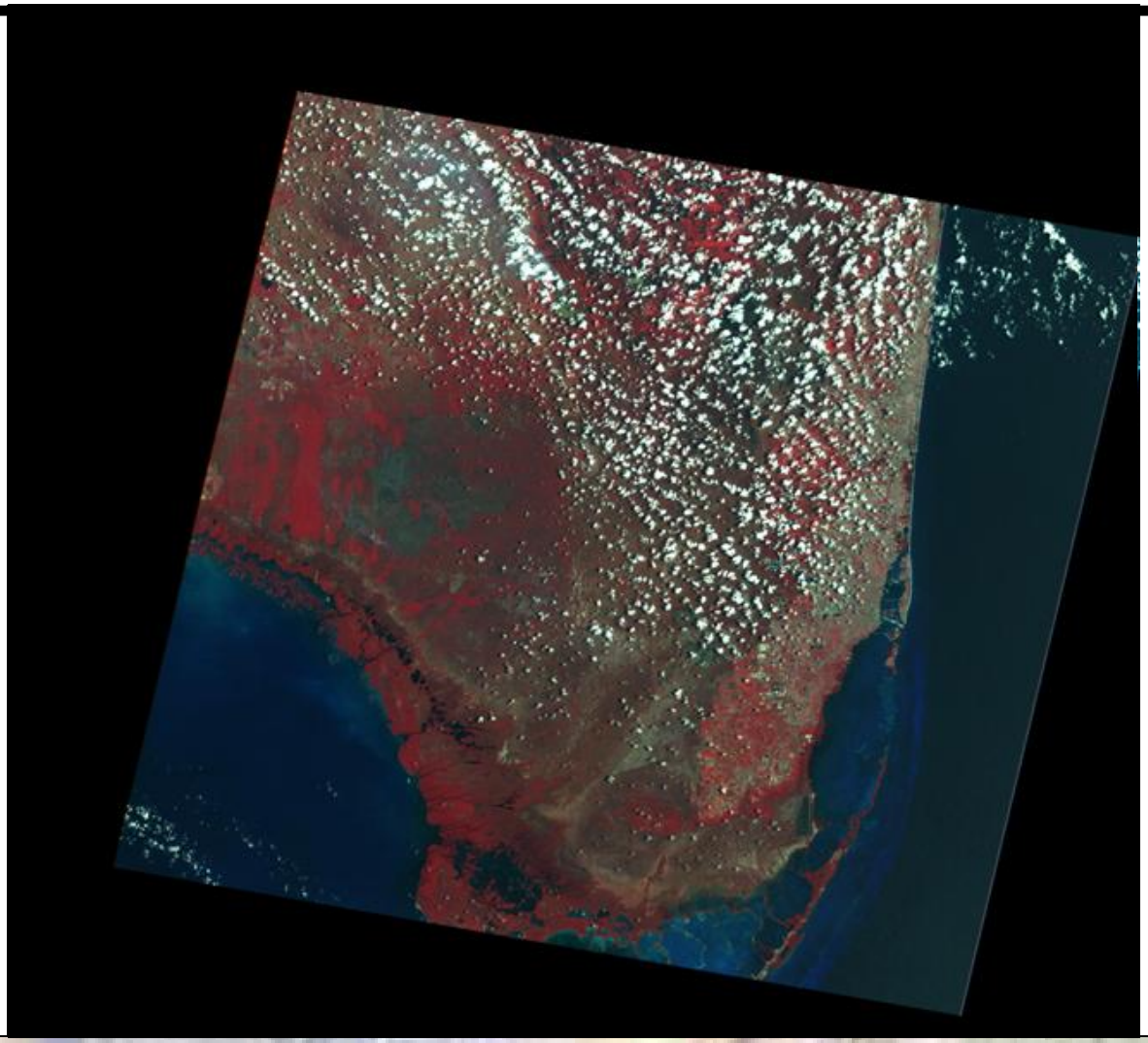
Verification report contains summary statistics and a list of all verification points.

MSS-X/A Destripe



Destriping of MSS data is an acknowledged requirement. Initially the legacy histogram equalization destripe will be implemented. A task for 2010 is to analyze the impact of destripe on radiometric calibration.

MSS registered time series



Landsat MSS “Orphans”

- **What are they?**
  - Wide Band Video images for which imagery exists, but no ephemeris
- **Issue**
  - During the Wide Band Video recovery program about 244,000 images, of which about 150,000 are unique, could not be processed due to a lack of ephemeris
- **Solution**
  - Use orbit dynamics model to generate estimated ephemeris
  - MSS migration to LPGS with it’s more robust registration model should be tolerant of imagery with large initial locational errors.

Landsat MSS OIV and mislocated images

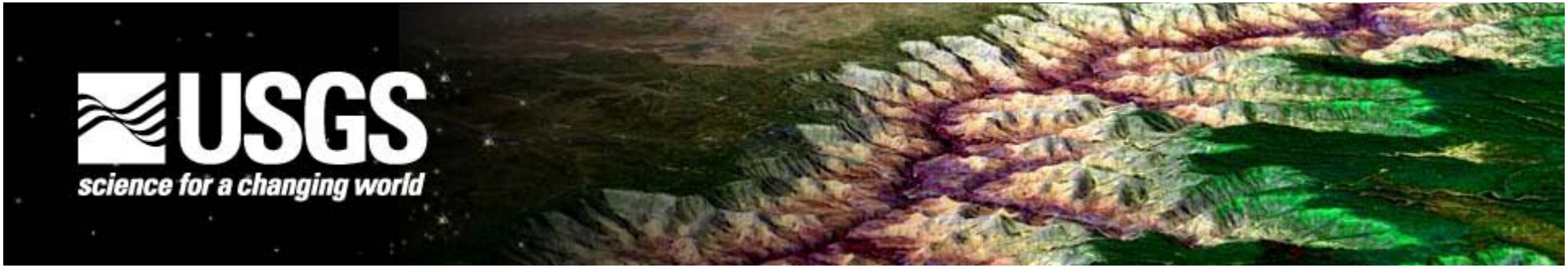
- **What are they?**
  - OIV images are engineering data collected in first few week following launch.
  - Mislocated images are assigned an incorrect path or row, and fail during processing.
- **Issue**
  - OIV images cannot be reliably calibrated and may not be on path. This has increased importance as Landsat data are intercalibrated for time series analysis. Nonetheless, it is desirable that these image remain available to the user community. OIV images need to be appropriately labeled in metadata.
  - Most of the mislocated images are MSS WBVT images. These images may be corrected with new “Orphan” system.

Landsat MSS Products

- **L0R**
  - MSS-X, MSS-A, MSS-P
- **L0Rp**
  - HDF output of reformatter
- **L1G**
  - Registration failed to meet RMSE threshold needed for terrain correction.
    - Fail in hierarchical pyramid correlation or precision control matching
    - Registered, but failed in verification module.
- **L1T**
  - Precision- and Terrain-corrected Product

Landsat MSS release notes

- **A mixed archive (NLAPS & LPGS) will exist through the transition period:**
  - A user will receive either LPGS or an NLAPS MSS format product.
  - Same issue with TM-A, which will follow MSS release.
  - We will flush all MSS-P NLAPS products from the system prior to MSS-P release (3/2010).
  - Likewise for MSS-X (7/2010) and MSS-A (9/2010) releases.
  - Inevitability some LPGS images will fall back to L1G, even though they previously processed to L1T with manual intervention.
- **The new metadata and image format for MSS will be compatible with other LPGS L1T products.**
  - However initially opening the MSS L1T in COTS may fail. For example, ENVI hangs if their Landsat with metadata input function is used – it expects a TM image.
  - All MSS sensors are cross-calibrated to MSS-5, so reflectance calculations need to use MSS-5 parameters for ESUN.
  - Once we get the system tests completed (late February), example products and documentation will be placed on the website for examination so users and vendors can adapt their processing flows.
- **We will ultimately have a consistent, cross-calibrated archive of Landsat data.**
  - We are trending all products and expect to be able to improve the quality. We expect to reprocess MSS products.



Landsat Full-Resolution Browse

19 January 2010

U.S. Department of the Interior

U.S. Geological Survey

LDCM Full-Resolution Browse

- **Browse images will be created for quick and efficient image selection and for visual interpretation. The following three criteria are critical to meet user needs for browse images:**
  - Provide a browse that is geo-registered and GIS-ready
  - Provide full spatial resolution browse for local area evaluation
  - Provide small browse definition for quick delivery, particularly for large areas, over the Internet, and for creation of page-size graphics
- **There may be up to five browse files associated with each scene:**
  - Reflective OLI full resolution JPEG image: 3 band, 8-bits per band
  - Reflective OLI reduced resolution JPEG image: a reduced resolution version of the reflective full resolution browse
  - Thermal TIRS full resolution JPEG image: 1 band, 8-bit grayscale
  - Thermal TIRS reduced resolution JPEG image: a reduced resolution version of the thermal full resolution browse
  - Quality band PNG: a color mapped version of the quality band – future activity for Landsat 1-7

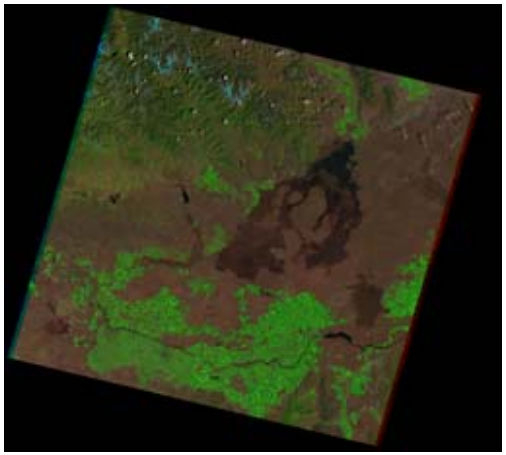
Full-Resolution Reflective Browse

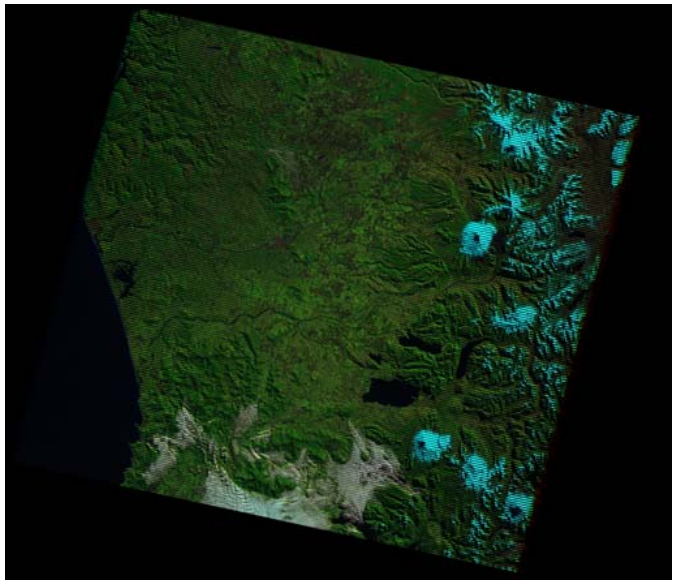
- **Band combinations – “Green”**
  - OLI: 6,5,4
  - ETM+ & TM: 5,4,3
  - MSS: 2,4,1
- **Data values**
  - Top of Atmosphere Reflectance
  - 0 - 0.8 stretched to 0 - 255
- **Image format**
  - 3-band RGB JPEG
  - Georeference information in World & GDAL XML files
  - JPEG and georeference files zipped for download
- **File size is approximately 5 MB**
- **Pixel size is retained**

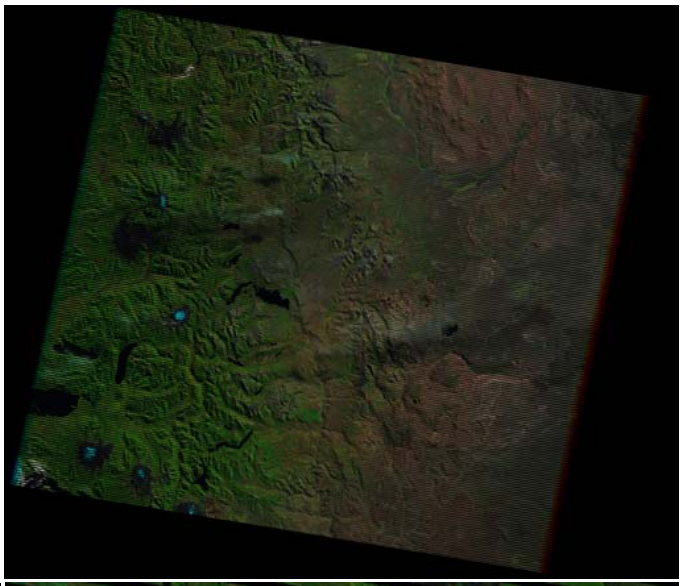
http://picasaweb.google.com/soapnut

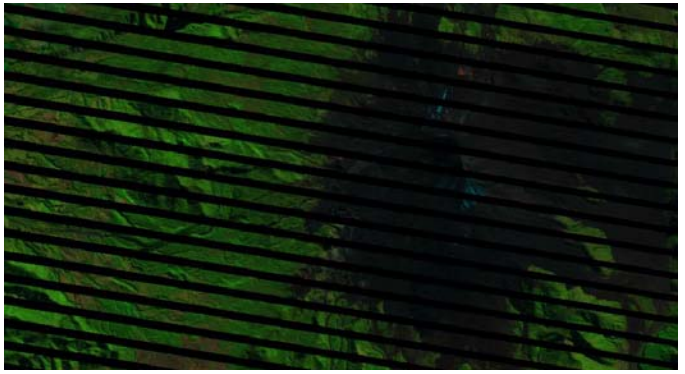
Reflective TM & ETM+ Browse

- **Llaima volcano, Chile**
- **Craters of the Moon, Idaho**
- **Bands 543**
- **TOA reflectance**





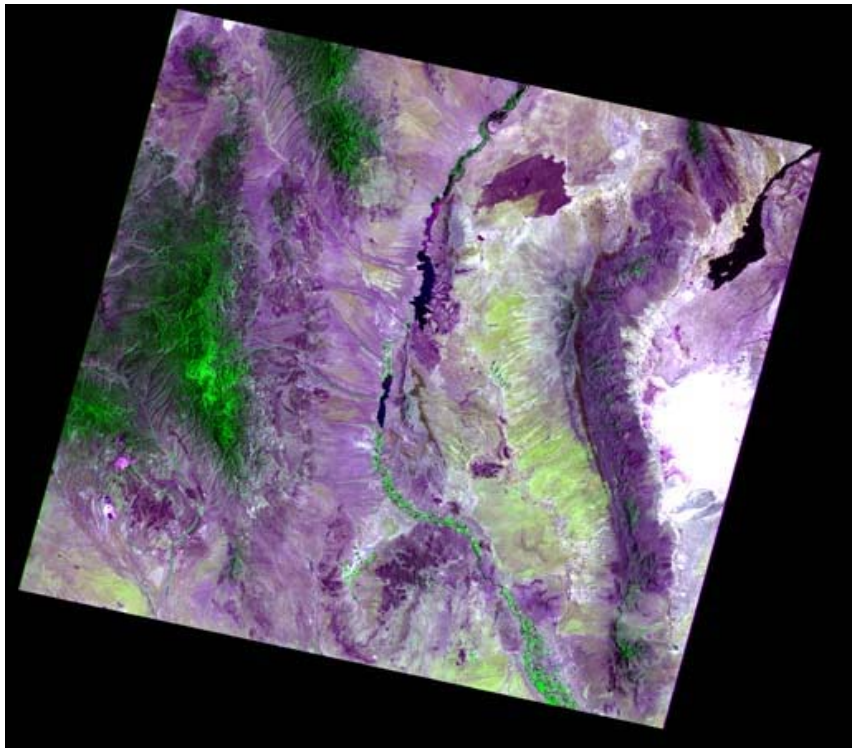




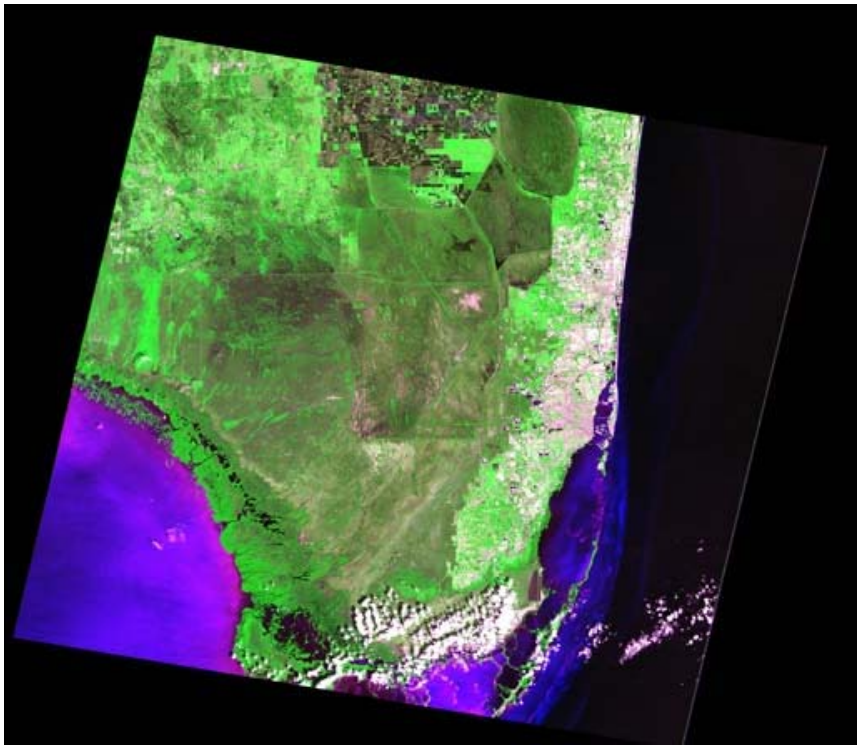
10 July 1996 14 July 2009 18 April 2009

Reflective MSS Browse

- **Desert, Everglades, Miami**
- **Bands 241 (“Green”) - TOA reflectance with 0.8 clip is planned, shown here as TOA radiance with 2% clip**



Landsat 2 MSS
12 June 1980



Landsat 3 MSS
9 March1979

Full-Resolution Thermal Browse

- **Band combinations**
  - TIRS
  - TM: Band 6
  - ETM+: Band 61 (low gain)
  - MSS: None
- **Data values**
  - Top of Atmosphere Brightness Temperature
  - -40 °C to 50 °C stretched to 0 – 255 or 2% clip
- **Image format**
  - Gray-scale JPEG
  - Georeference information in World & GDAL XML file
  - JPEG and georeference files zipped for download
- **File size is approximately 2 MB**
- **Pixel size is retained**

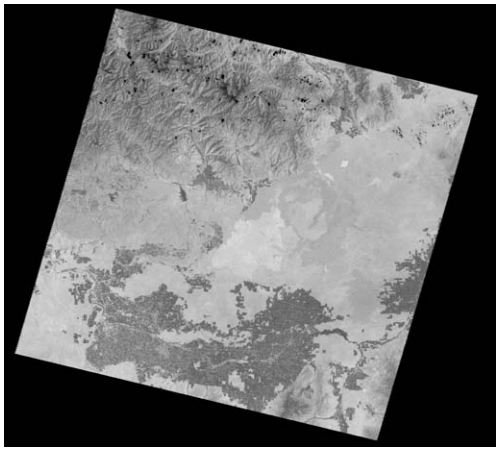
Thermal TM & ETM+ Browse

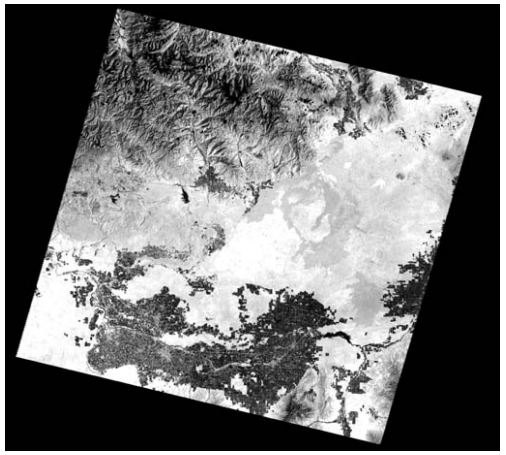
- **Band 6**
- **TOA Brightness Temperature**

-40 °C to 50 °C clip
with linear stretch

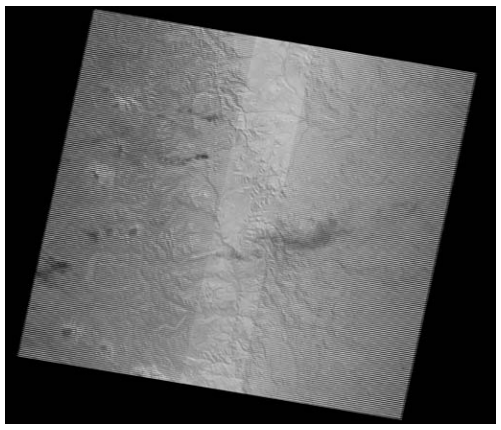
2% clip
with linear stretch

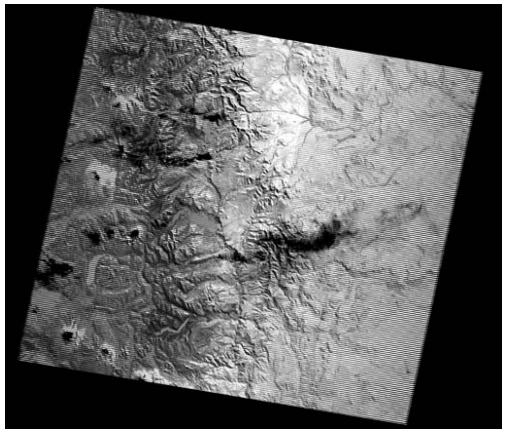
Craters of the Moon, Idaho
Landsat 5 TM
10 July 1996



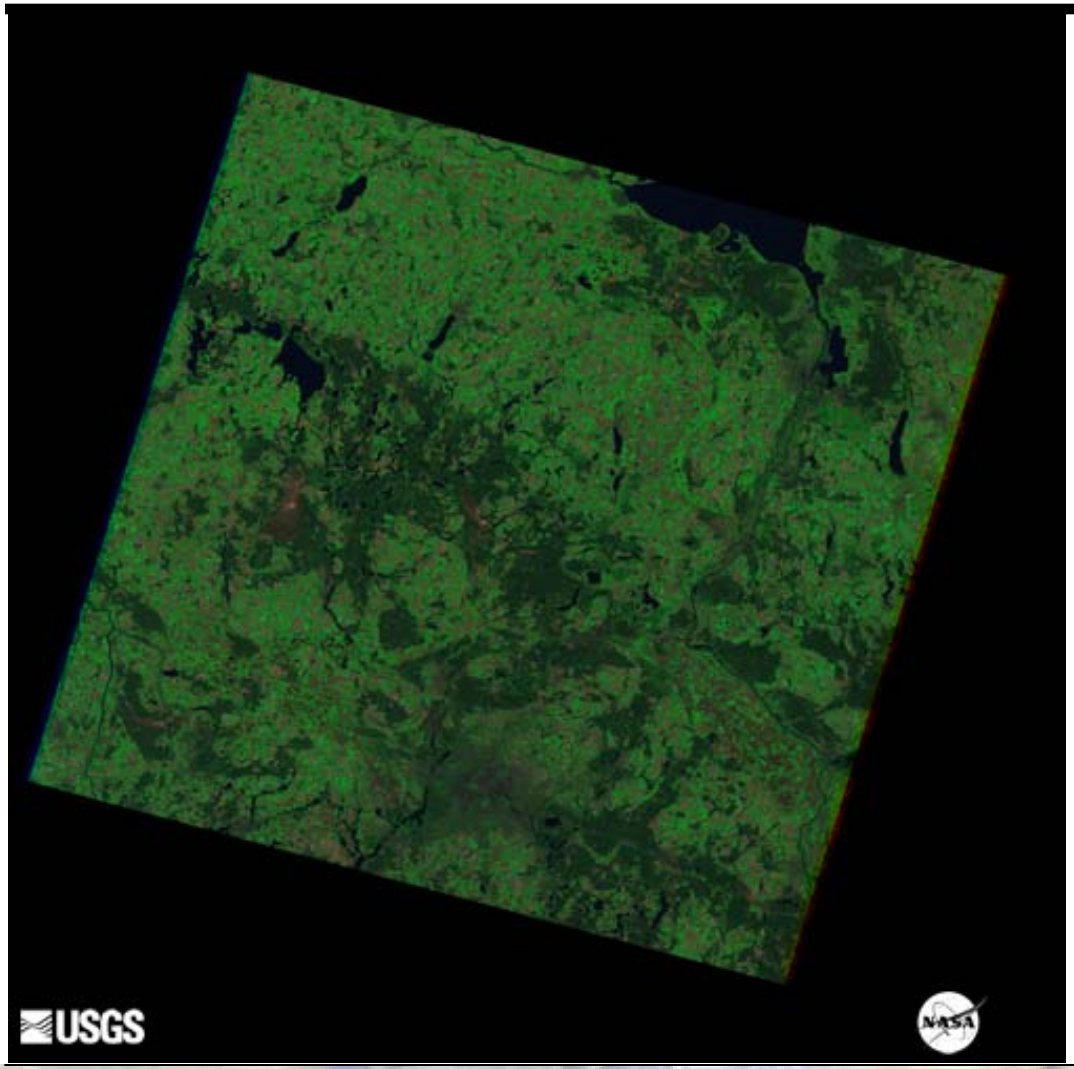


Llaima Volcano, Chile
Landsat 7 ETM+
18 April 2009





Watermarked browse



Production and Distribution

- **Created from L1T data**
- **All files stored online indefinitely**
  - Available for use by web services
  - Available for use by EarthExplorer and Glovis
  - Available for download using Bulk Tool
- **Download individual browse JPEG images and bundled suite of GIS-ready browse images on-demand as Zip file**
  - EarthExplorer
  - Glovis

Rationales

- **Compatibility with LDCM**
- **TOA reflectance with fixed scale**
  - Images more comparable through time and space
- **TOA brightness temperature with 2% or fixed scale TBD**
- **Format**
  - Georeference information distributed as separate files
  - Compressed GeoTIFF and JPEG2000 are not well supported by web or analysis tools

Top of Atmosphere

Landsat TM and ETM+

- **The reflective and thermal TM and ETM+ bands are 8-bit unsigned quantized calibrated digital numbers (QCAL). The conversions from calibrated digital numbers to TOA reflectance and brightness temperature are documented in the Landsat 7 Science Data Users Handbook. Convert digital numbers to radiance (L_λ) by**

$$L_\lambda = ((LMAX_\lambda - LMIN_\lambda) / (QCALMAX - QCALMIN)) * (QCAL - QCALMIN) + LMIN_\lambda$$

- **Bands 5 (1.65ìm), 4 (0.825 ìm), and 3 (0.660 ìm) are used for the Landsat TM & ETM+ reflective browse. These reflective bands are converted to TOA reflectance by**

$$P_p = (\pi * L_\lambda * d^2) / (ESUN_\lambda * \cos\theta_s)$$

Landsat MSS

- **The reflective MSS bands are 8-bit unsigned quantized calibrated digital numbers (QCAL). The conversions from calibrated digital numbers to TOA reflectance and brightness temperature are documented in the Landsat 7 Science Data Users Handbook. Convert digital numbers to radiance (L_λ) by**

$$L_\lambda = ((LMAX_\lambda - LMIN_\lambda) / (QCALMAX - QCALMIN)) * (QCAL - QCALMIN) + LMIN_\lambda$$

- **Bands 2 (0.65 ìm), 4 (0.95 ìm), and 1 (0.55 ìm) are used for the Landsat MSS day-time browse. These reflective bands are converted to TOA reflectance by**

$$P_p = (\pi * L_\lambda * d^2) / (ESUN_\lambda * \cos\theta_s)$$

- **Scaling for reflective bands**

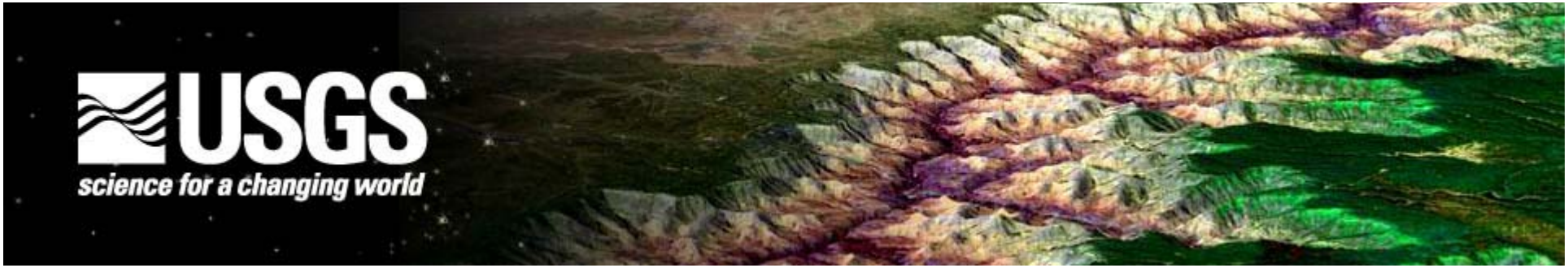
  Browse DN values for a 0.8 clip are:

  If $P_p < 0.8$, then $DN_B = P_p * 255/0.8$

  else $DN_B = 255$

World File

30.0000000000	pixel size in the x-direction in map units
0.00000000000000	rotation about y-axis
0.00000000000000	rotation about x-axis
-30.0000000000	pixel size in the y-direction in map units, almost always negative
415814.9999999999	x-coordinate of the center of the upper left pixel
5048985.0000000000	y-coordinate of the center of the upper left pixel



30-meter Thermal

19 January 2010

U.S. Department of the Interior

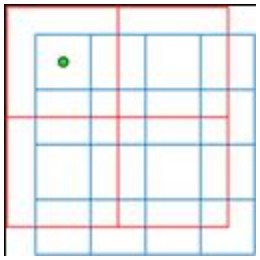
U.S. Geological Survey

Landsat TM & ETM+ Thermal

- **Objectives**
  - Provide “analysis-ready” 30-meter product that does not require resampling to match other Bands
  - Minimize introduction of radiometric artifacts
  - Resist approach that disguises native resolution
  - Minimize time to implementation
  - Provide methodology that can be reused for LDCM TIRS
- **Current approach**
  - CC resampling based on 60-meter (ETM+) or 120-meter (TM) postings in input space
  - Output with 60-meter pixel size
  - Corner point geometry is ambiguously applied in COTS resulting in shifts between thermal and reflective bands

Thermal Band: 30m

- Requested at January 2009 Science Team meeting
  - Help with thermal band offsets from the multispectral
    - COTS package interpretations of resolution mismatch

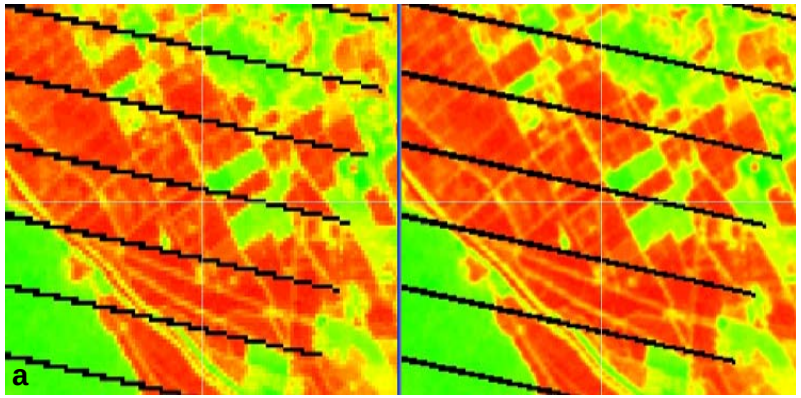


The USGS Landsat processing system references pixel centers to coordinates, which causes an offset in commercial software packages. The blue frame represents 30-meter Landsat 7 multispectral pixels, while the red frame represents the 60-meter Landsat 7 thermal pixels. (R. Allen, 2009)

- June 2009 Science Team at confirmation to proceed @ June meeting

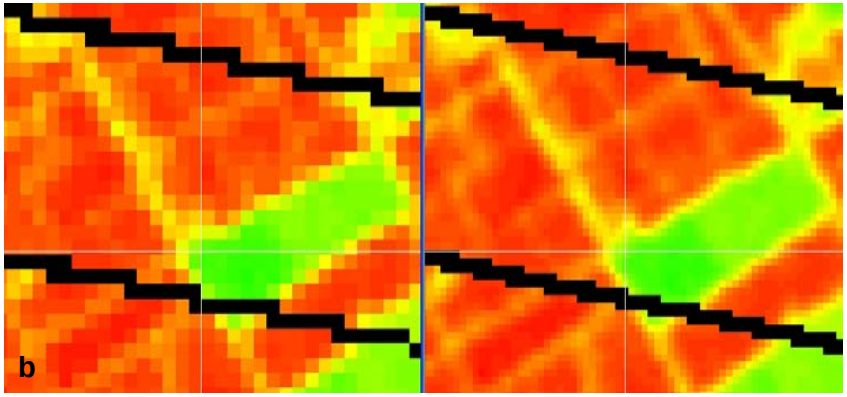
Evaluation

- Landsat developed test products
  - Evaluated by Rick Allen & team



Thermal band resampled to 60 meters (left) and USGS prototype 30 meters (right) as an L1T product for an area south of Las Cruzes, NM.

DN=0 is black; DN 130-150 red through yellow; DN 150-170 yellow through green (R. Allen, 2009)

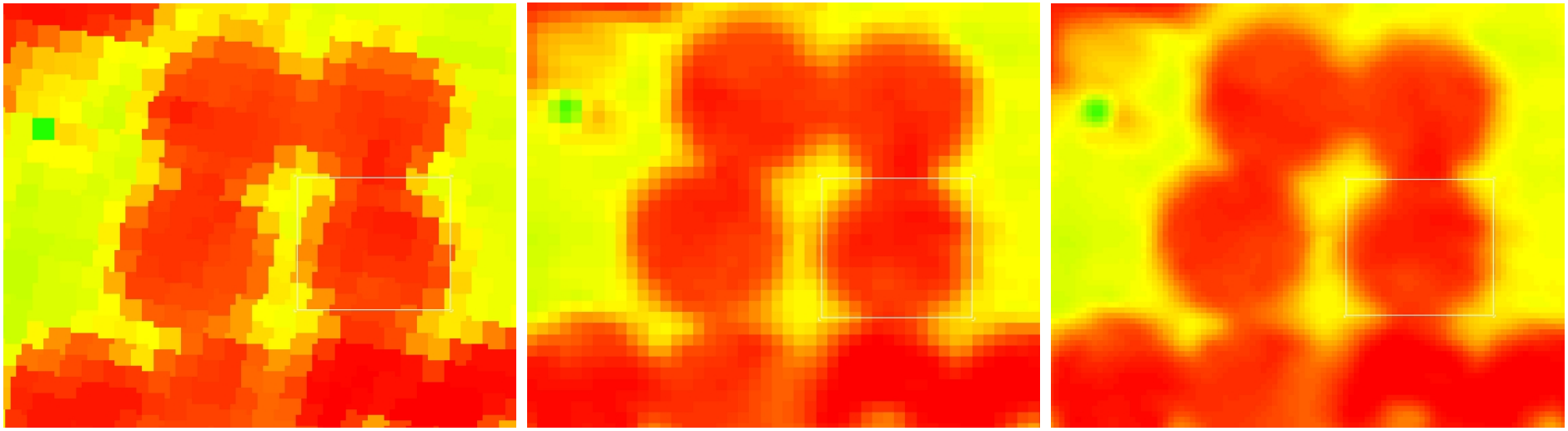


Close-up of the thermal band resampled to 60 meters (left) and prototype 30 meters (right) for an area S of Las Cruzes, NM.

DN=0 is black; DN 130-150 red through yellow; DN 150-170 yellow through green (R. Allen, 2009)

Evaluation

- Landsat developed test products
  - Evaluated by Rick Allen & team



resampled to 30 m using NLAPS
with Nearest Neighbor resampling

resampled to 60 m using LPGS
with cubic convolution resampling

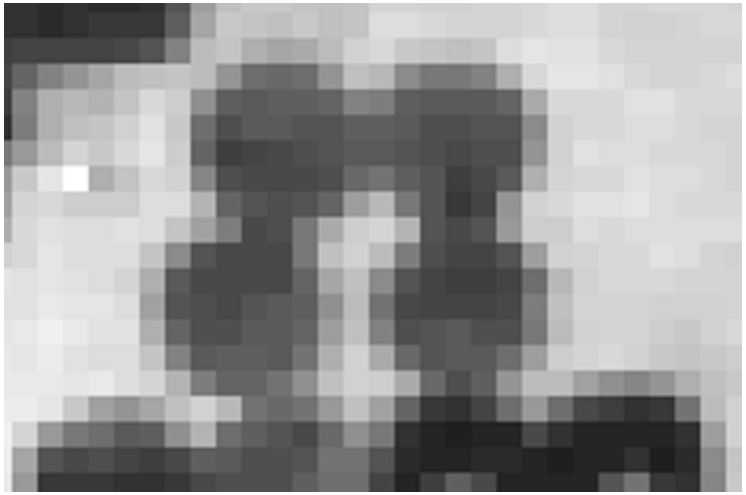
resampled to 30 m using LPGS
with cubic convolution resampling

The thermal band from the path 40 row 30 image from July 10 1996
DN 130-165 red through yellow; DN 165-200 yellow through green. (R. Allen, 2009)

- Resample to 60 meter from 120 meter TM thermal data is existing product
- Resample to 30 meter from either 120-meter TM or 60-meter ETM+ using CC in input space can be implemented with a parameter change

Two other alternatives among many

- **Resampling to native cell size (TM 120- or ETM+ 60-meter) with cubic convolution, then replicate pixels to 30-meter**
  - Estimated to have minimal implementation costs
  - Fewest artifacts, such as ringing
  - Reversible to native resolution



Resampled to 120 m using cubic convolution, then replicated pixels to 30 m

- **Resample to 30-meter pixels with cubic convolution on 30-meter postings in output space**
  - Higher implementation costs
  - Impacts less well understood
  - Similar to replication to 30-meter pixels then resample with cubic convolution

Approaches

- **Approach evaluated by Allen and team**
  - Configuration change: 2 days to execute
- **More complex approach**
  - Research requirement
  - Code changes in Image Assessment System (IAS) & Level-1 Product Generation System (LPGS)
  - Competes with other high priority tasks, such as MSS, for resources
  - Leads toward LDCM solution
- **Revisit GeoTIFF area versus point issues with vendors**
  - Needed for pan