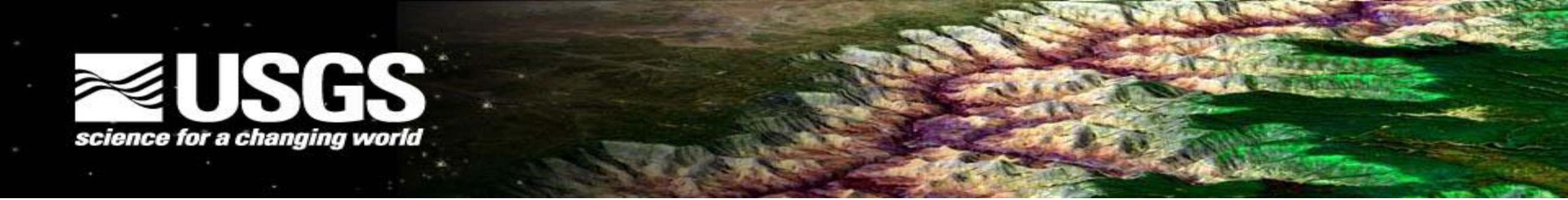

USGS MSS Development Activities

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Work Performed by
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SDSU: Dennis Helder, and Ashish Shrestha
Others: Dan Steinwand and Raj Rengarajan

Overview

- **Current State of EROS MSS Archive**
  - MSS data in archive
  - MSS source data types
  - Radiometry
  - Geometry
- **MSS Activities**
- **Summary**

MSS Data in Archive

- **Several flavors of MSS data at EROS (**1,306,597 total scenes**)**

Data Type	Number of Scenes	%L1G	%L1G_FB	%L1T_<30m	%L1T_>30m
MSS-R	706385	17.1%	47.8%	14.6%	20.5%
MSS-X	34077	13.3%	22.2%	34.1%	30.3%
MSS-X (WBV)	145181	17.4%	54.3%	13.5%	14.7%
MSS-X (orphan)	158706	14.1%	52.6%	15.9%	17.5%
MSS-A	244581	5.1%	52.3%	23.0%	19.7%
MSS-P	17667	5.4%	56.8%	17.8%	20.0%

- **MSS archive has increased under Landsat Global Archive Consolidation (LGAC) effort**
  - This has increased the complexity and challenges of processing
  - As more MSS data delivered, further complications may arise

MSS-R

- **Raw format with no radiometric or geometric processing**
- **Contains calibration wedges for proper radiometric correction**
- **Treated geometrically like MSS-X orphan data**
  - No original attitude or ephemeris data available
  - Ephemeris derived from Two-Line Element (TLE) like X-Orphan data
  - Attitude data not available like X-Orphan, but polynomial fit corrects some of the problems with missing attitude data

MSS-X

- **Neither radiometrically nor geometrically corrected**
- **Radiometric calibration information included**
  - Either the full calibration wedges or calibration words
- **Information to create systematic grid are included**
  - Geometric grid generated similarly to TM, ETM+ and OLI/TIRS
  - Ephemeris and attitude information are stored in header files (auxillary files with the image data)

MSS-X (CCT)

- **Goddard Space Flight Center (GSFC) format**
- **Some Radiometric processing**
  - Bands 1-3 radiometric corrected
  - Band 4 was never radiometrically corrected post-launch
    - Original calibration wedge discarded
  - Separate calibration data record stored with image data
    - Associated with all four bands
- **No Geometric calibration applied**
  - Same as plain MSS-X

MSS-X (WBV)

- **Wideband Video Tape format**
- **No Radiometric or Geometric corrections applied**
- **Full calibration wedge retained**
  - Allows for characterization of cal wedge and cal words
  - Refined calibration word extraction methods
  - Provides more accurate radiometric correction

MSS-X (Orphan)

- **Subset of MSS-X WBV**
- **Original attitude and ephemeris data missing**
  - Ephemeris data is simulated using Two-Line Element (TLE) records
  - Unable to simulate attitude data – zeroed out
  - Polynomial fit corrects some of the issues with having no attitude data available
  - Results in lower geometric quality

MSS-A

- **Radiometrically corrected but not resampled**
  - Includes some radiometric calibration information
    - Calibration words/processed calibration wedges
  - Includes geometric grid information for simple resampling
  - Projected in path oriented projection
    - HOM projection for L2 and L3 scenes
    - SOM projection for L4 and L5 scenes

MSS-P

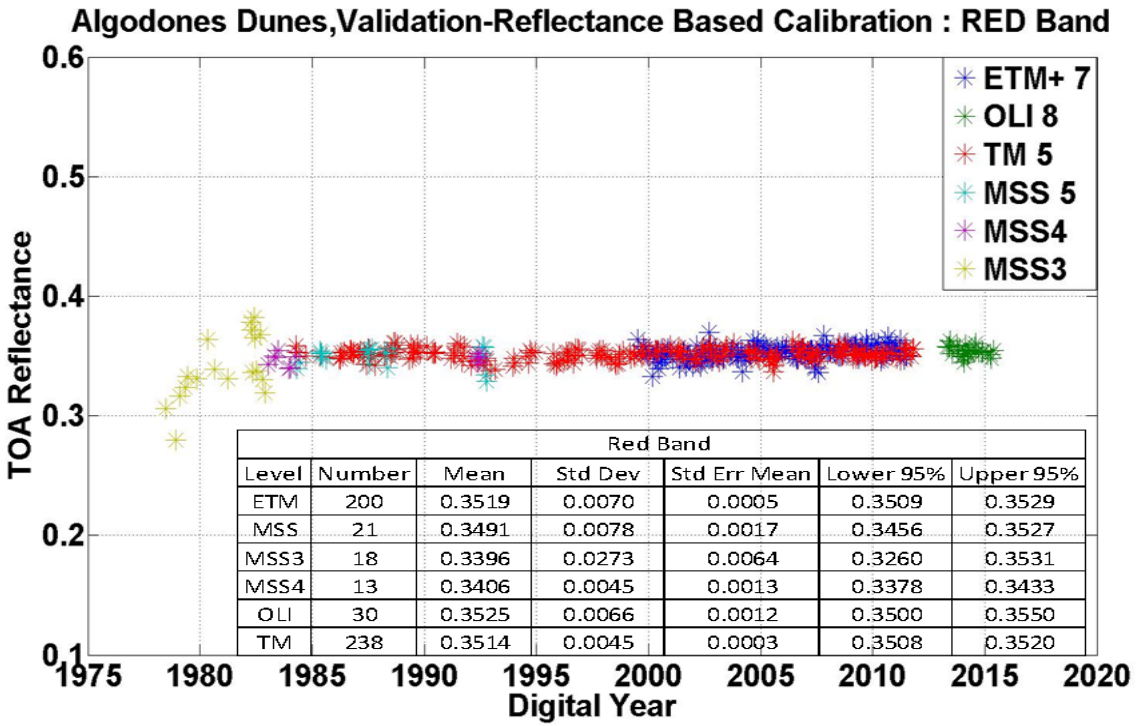
- **Radiometrically and geometrically corrected products**
  - Does not contain any radiometric calibration information
    - Unknown what was applied to do radiometric corrections
  - Control points may have been used in creating the systematic product for certain scenes
  - Projected in path oriented projection
    - Majority of scenes are HOM projection
  - Images are double resampled
    - Once to systematic product and once more for precision correction

Radiometry

- **Quality depends upon**
  - Source of MSS data (MSS-R, MSS-P, …)
  - Quality of source data (missing PCD, dropped frames, …)
- **Current products based on radiance using Pseudo-Invariant Calibration Site (PICS) cross-calibration from Landsat-5**
  - Spectral Band Adjustment Factor (SBAF) derived from Hyperion for desert PICS sites
  - Some issues with specific scenes and source of MSS data
- **Quality issues**
  - Significant striping for some products
  - Some saturation introduced in processing for some products

Radiometry Continued

- **Attempt to transfer Landsat 8 reflectance calibration back through archive**
  - Landsat 3 MSS showed large variation
  - Appears to be due to inconsistent calibration across different types of MSS
    - Requires software modification
    - May expose additional issues for some source data



Red Band

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
ETM	200	0.3519	0.0070	0.0005	0.3509	0.3529
MSS	21	0.3491	0.0078	0.0017	0.3456	0.3527
MSS3	18	0.3396	0.0273	0.0064	0.3260	0.3531
MSS4	13	0.3406	0.0045	0.0013	0.3378	0.3433
OLI	30	0.3525	0.0066	0.0012	0.3500	0.3550
TM	238	0.3514	0.0045	0.0003	0.3508	0.3520

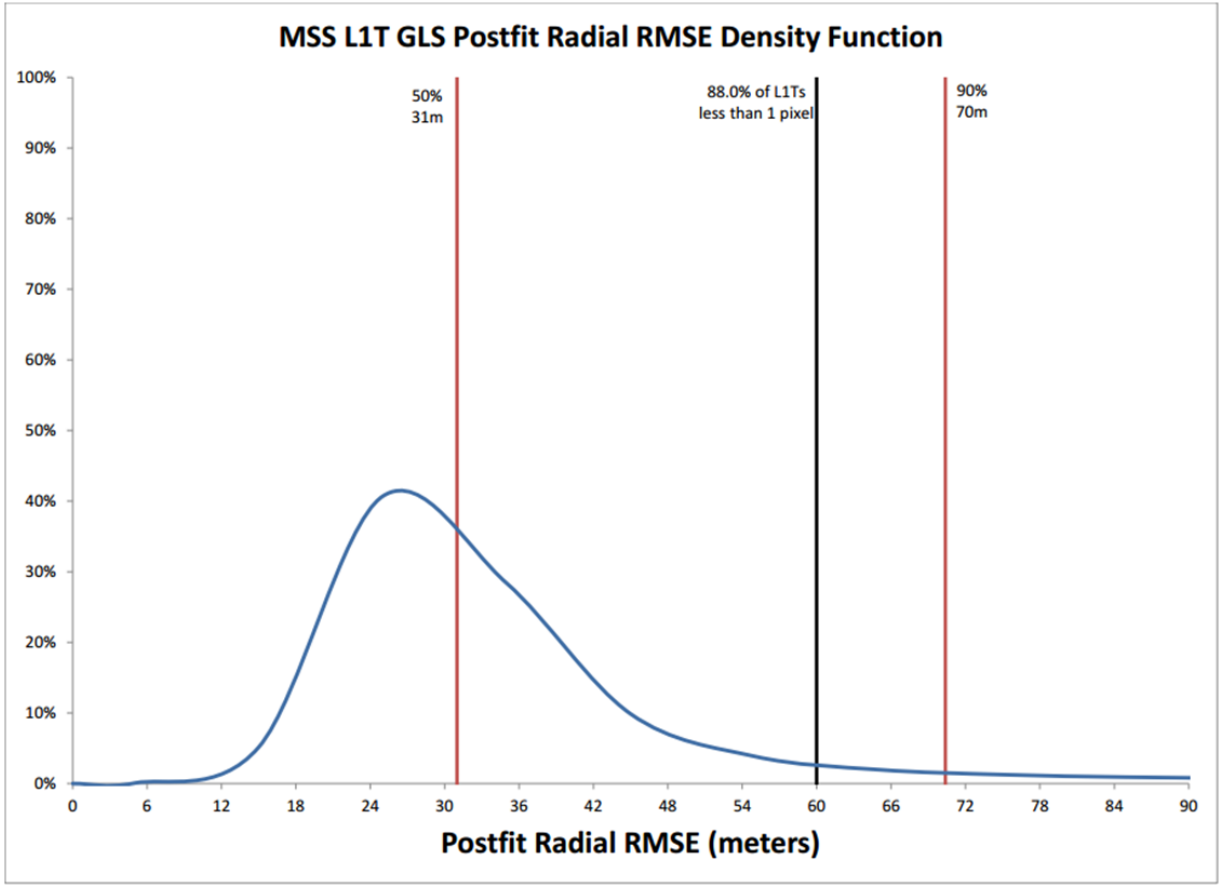
Courtesy of Ashish Shrestha (SDSU)

Geometry

- **Quality depends upon**
  - Source of MSS data (MSS-R, MSS-P, …)
  - Quality of source data (missing PCD, dropped frames, …)
- **Improvements developed to improve quality**
  - GPYRAMID (Gaussian Pyramid)
    - Hierarchical image registration intended to improve scenes significantly (~15 km) offset from GLS reference
  - MSSREFINE (Precision correction)
    - Precision grid to account for terrain and GPYRAMID results
    - Second or first order polynomial (rubber sheeting)
  - GVERIFY (Verification)
    - Independent verification of accuracy relative to GLS reference
    - Provides RMSE of scene and scene quadrants

Geometry Continued

- **Most L1T products from MSS-R**
  - 36% of MSS products are L1T
    - 480,000 products
  - 88% of MSS L1T products are within 1 pixel (60m)
    - 420,000 products
- **Very few less than 11.9m RMSEr**



Current MSS Processing

- **Default MSS source is MSS-R**
  - Provides most accurate product radiometrically and geometrically
  - Also provides the most known pedigree
  - Source precedence after R determined on quality and low level information
    - In general, P lowest quality
- **Radiometry**
  - Lowest level of radiometric calibration used
    - Calibration wedges, then calibration words, then processed data untouched (for now)
- **Geometry**
  - Reproject to UTM (process depends on source)
  - GPYRAMID, MSSREFINE and GVERIFY used to correct and report on geometric quality

Current Activities

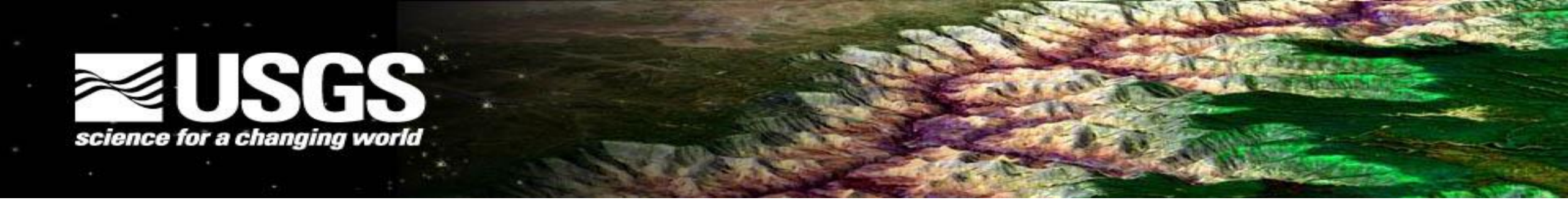
- **Transfer reflectance calibration from Landsat 8 to MSS**
  - Requires modification to current MSS processing to complete
    - To fix issues currently seen with Landsat 3
  - Requires further investigation into other MSS sensor data
    - Similar issues could exist for Landsat 2 and Landsat 1
    - Additional issue may exist
  - Convert all data types to MSS-R equivalent reflectance

Potential Activities

- **Radiometry**
  - Correct (or reduce) striping in some MSS products
  - Reexamine radiance calibration transfer
    - LGAC in infancy when radiance calibration transfer completed
    - Possible issues due to same issue as reflectance calibration transfer
  - Further investigations on historical processing
- **Geometry**
  - Improve precision outlier process to improve geometric accuracy
  - Improve geometric support data (e.g., TLEs and attitude parameters)
  - Create GCPs that correlate to MSS products better (temporal)
- **In general**
  - Interrogate MSS archive for further issues

Summary

- **Potential for some improvement to MSS archive**
  - Requires significant work, especially from geometry team
    - May be significant work for radiometry team
  - Some MSS products will not be improved
    - Impossible to predict which scenes and how many until attempted
- **LGAC effort will continue to increase EROS MSS archive**
  - As MSS volume increases, further issues may arise
- **Other major activities using same expertise**
  - Landsat 9 development
  - Landsat operations
  - TIRS encoder issues



Backup

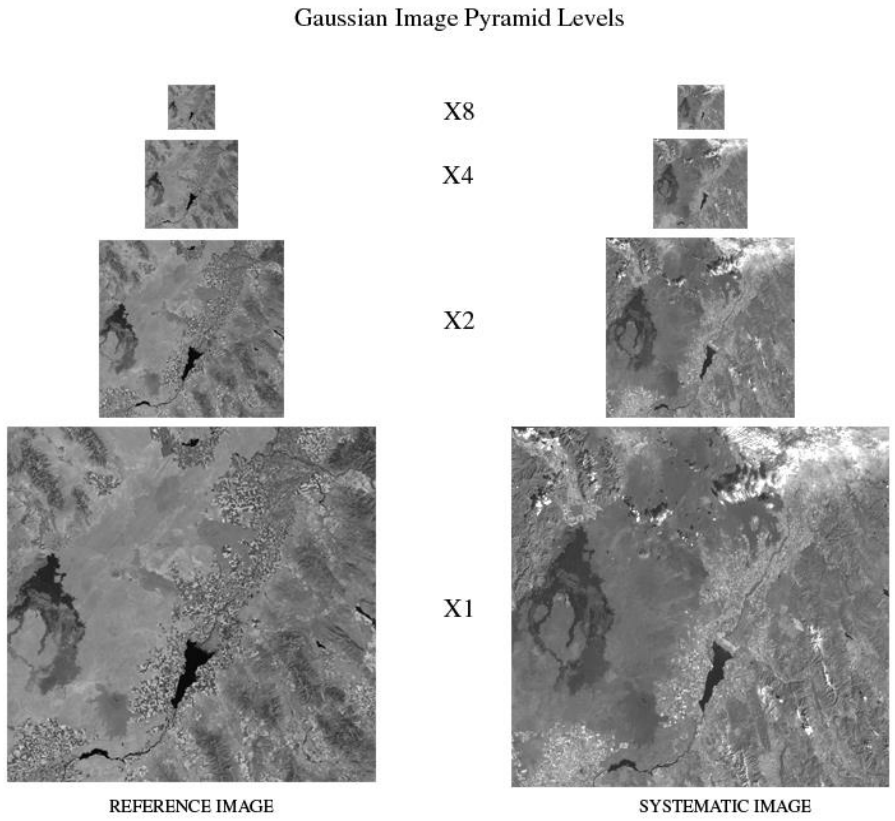
GPYRAMID, MSSREFINE and GVERIFY Details

GPYRAMID – Gaussian Pyramid

- **The GPYRAMID / hierarchical image registration module is used to register images that have significant relative offsets**
- **The GPYRAMID registers the two images at multiple resolution levels, and uses the results from each higher level image pyramid to correct for the subsequent pyramid levels**
- **Gpyramid has capability to register accurately in certain cases for MSS scenes with offsets as high as15 km from GLS reference**
- **The hierarchial image registration module is generic to handle TM and MSS data**

GPYRAMID – Gaussian Pyramid

- **The GLS(1975,1990,2000) and MSS data are resampled to X8 to create the systematic image at 480m pixel size (60m nominal pixel size)**



GPYRAMID – Gaussian Pyramid

- Even spaced points from both images are correlated by grey-scale correlation using a 64x64 chip size
- More ground area for correlation ensures reduced false matches due to temporal changes
- Low resolution or High pixel size indicates wider search area to register two corresponding image points
- Outlier rejection is used to remove false matches or bad correlated points
- The results from the X8 gpyramid level is used as initial approximation for next pyramid level

GPYRAMID – Gaussian Pyramid

- For X4, 120 m pixel size, the registered points are used and the search space is limited as the previous pyramid level has corrected for gross errors
- Outlier rejection is used to remove false matches or bad correlation and the good points are reiterated to X2 and X1 similarly
- The final offsets are averaged and used as initial approximation to conventional grey scale correlation with GLS2000 GCP chips (derived based on MMIO algorithm)
- The final GCP residuals are used for precision solution

MSSREFINE – Precision Correction

- Creates a precision grid by applying the registration information from GPYRAMID to systematic grid using a second order polynomial
- GCPS correlated from GPYRAMID are adjusted for relief displacement
- Location of GCPS from systematic image and relief adjusted locations are used to create a second or first order polynomial. Default is second order polynomial using least squares fit
- Outliers in the polynomial fits are removed

MSSREFINE – Precision Correction

- **The polynomial coefficients are used to test for skew or scene warping due to second order polynomial fit.**
- **If scene curvature is determined, then first order polynomial fit is used for precision correction.**
- **The polynomial coefficients are convolved with systematic grid to generate precision grid**

GVERIFY – Verification

- Since the scenes are corrected by second order polynomial function, it is necesaary to validate the products.

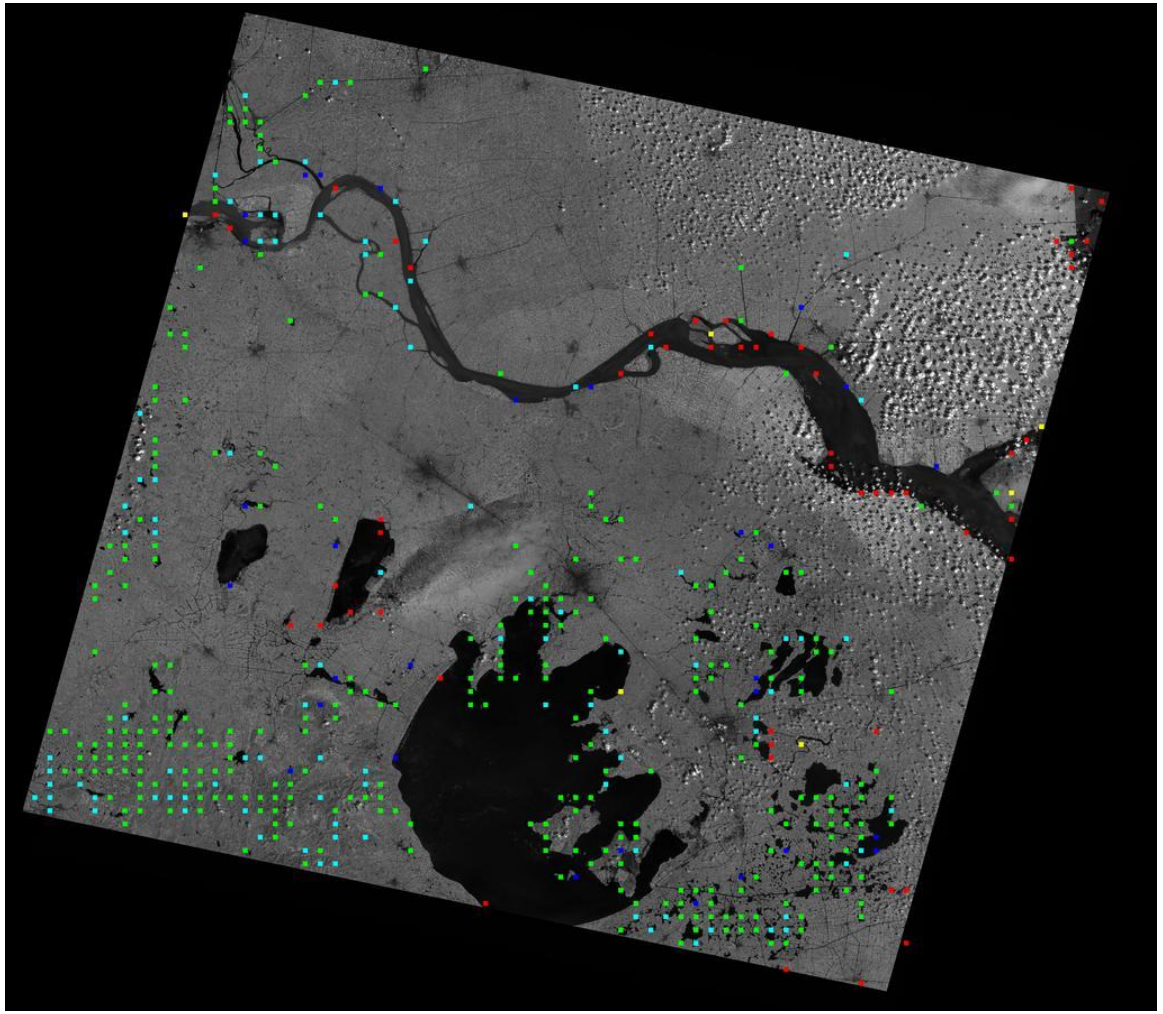
- Gverify's purpose is to independent veirfication of relative accuracy of GLS2000 and the MSS / TM scenes
- Uses Image to Image registration method to register the resampled GLS2000 in WRS1 to MSS scnees

- Conservative outlier rejection is employed to identify potential problem areas in the scene
- Provides RMSE of scene and scene quadrants, and a browse jpeg image showing correlation points color coded based on their residuals.

GVERIFY – Verification - Limitations

- GLS2000 Band 5 is correlated with MSS Band 7, (non-overlapping spectral bands are registered)
- Temporal variations between GLS2000 (aquired between 1999-2001) and MSS scenes.
- Spatial resolution of GLS2000 is 30m for B5, where as the MSS scene has a spatial resolution of about 80m
- Sensor's radiometric resolution of GLS2000 is 8 bit while that of MSS is 6 bit.
- Improvements to GVERIFY are planned in the future

MSS GVERIFY examples



P/R: 128 / 38

Date : 9/8/1981

Systematic Offsets measured

(# 165 points)

Line : 9.7 Km

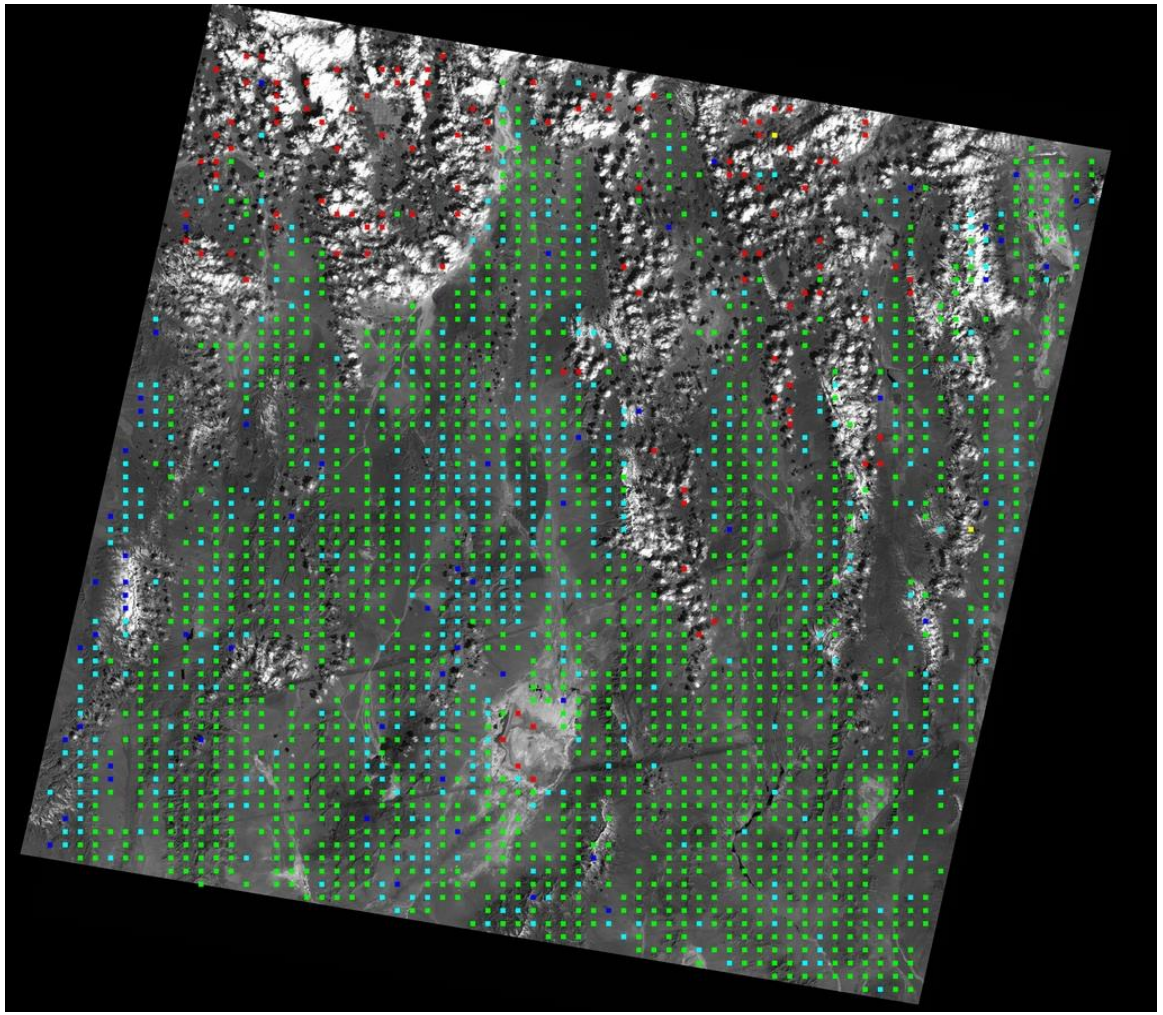
Sample : 3.8 Km

GVERIFY RMSE 4.4 pixel

(# 468 points)

Fit Order = 2

MSS GVERIFY examples



P/R: 40 / 33

Date : 3/25/1986

Systematic Offsets measured

(# 355 points)

Line : 0.25 Km

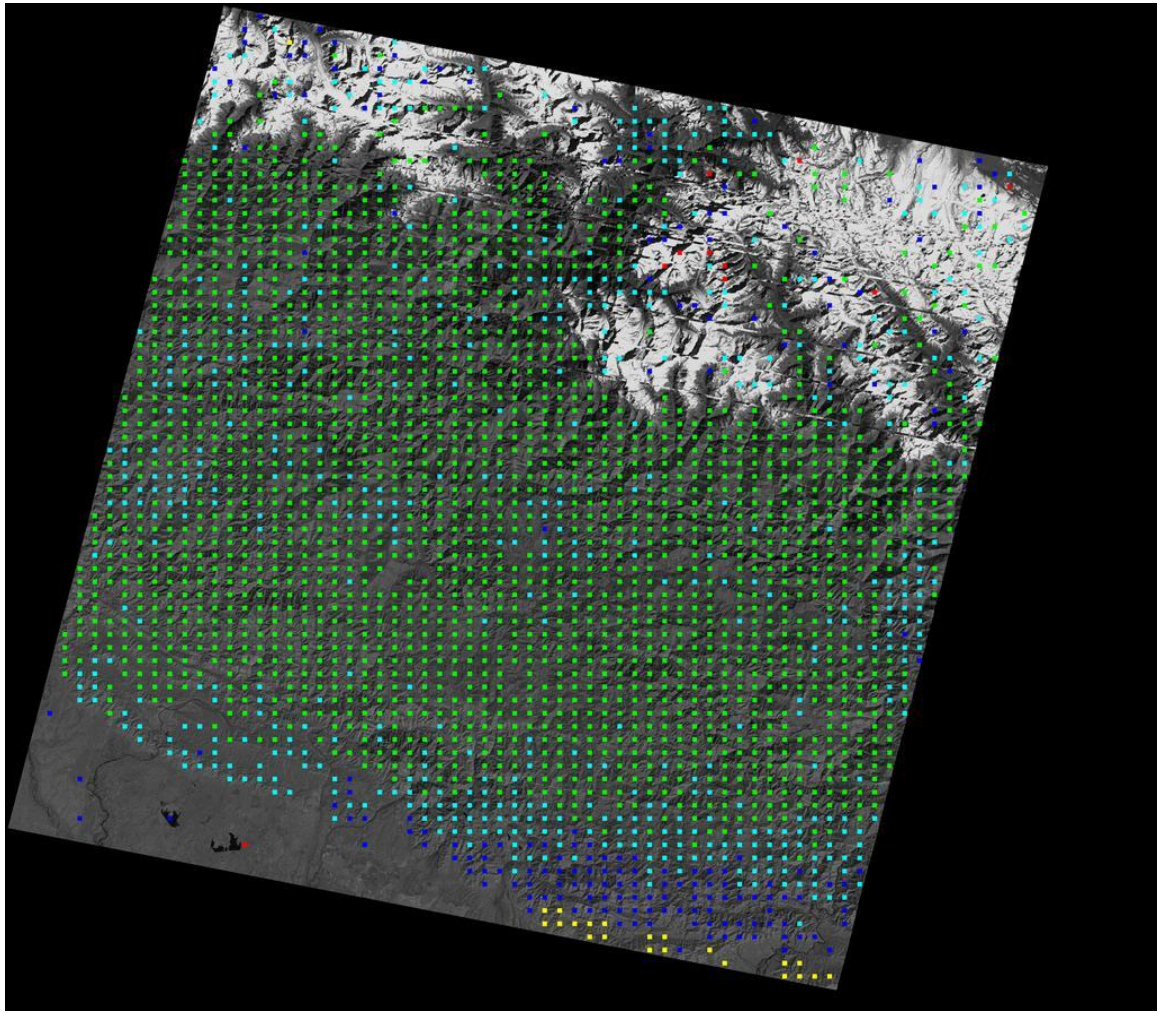
Sample : 0.5 Km

GVERIFY RMSE 2.7 pixel

(# 2099 points)

Fit Order = 2

MSS GVERIFY examples



P/R: 156 / 39

Date : 10/26/1972

Systematic Offsets measured

(# 480 points)

Line : 16.7 Km

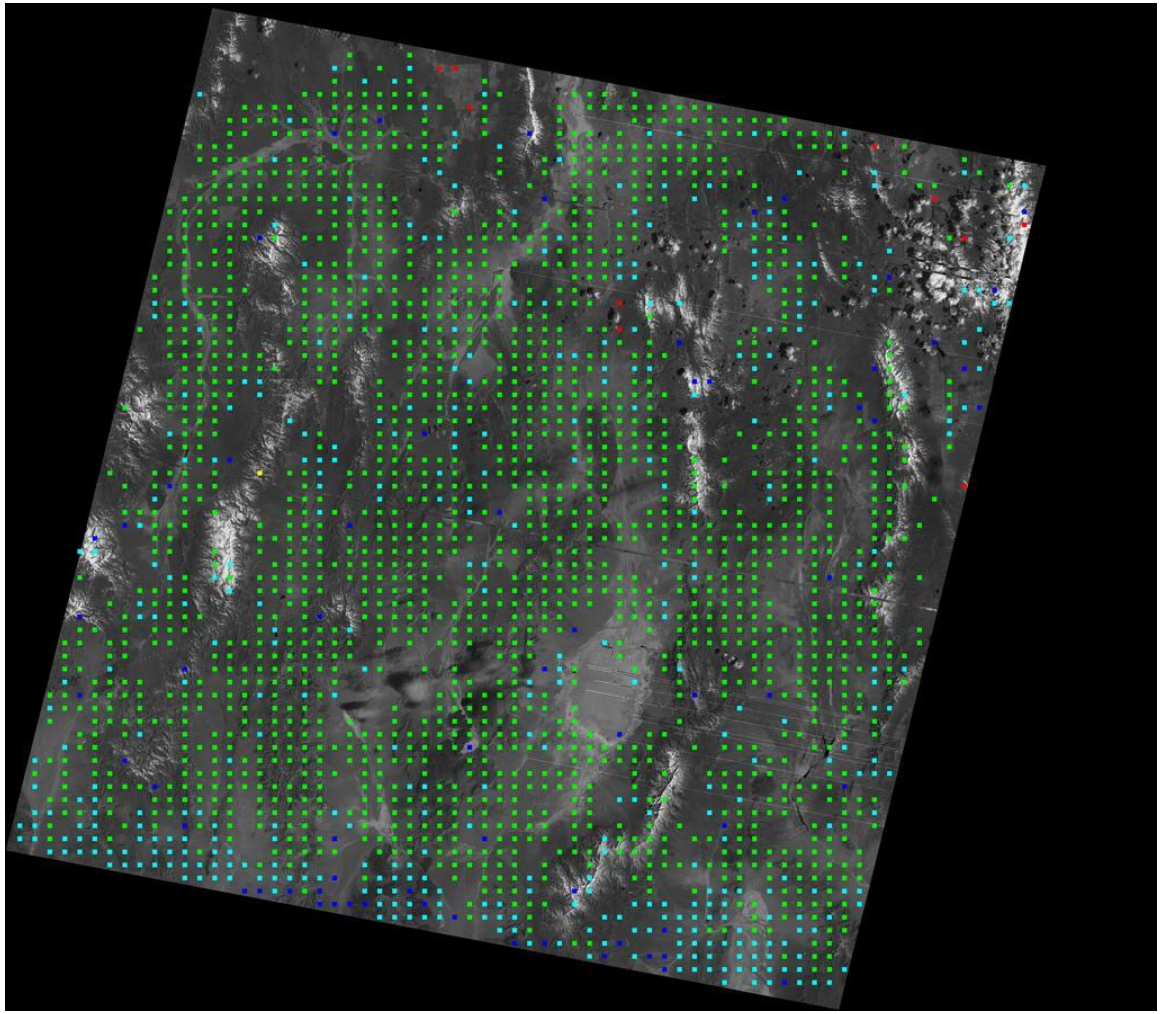
Sample : 3.8 Km

GVERIFY RMSE 0.6 pixel

(# 2607 points)

Fit Order = 2

MSS GVERIFY examples



P/R: 43 / 33

Date : 04/20/1976

Systematic Offsets measured

(# 211 points)

Line : 15.2 Km

Sample : 2.3 Km

GVERIFY RMSE 0.7 pixel

(# 2173 points)

Fit Order = 2