Recent Landsat Calibration Updates

Dennis Helder

Landsat Science Team Meeting

Boise, Idaho

June 16, 2010

South Dakota State University
Image Processing Lab

Topics

- Landsat 5 TM Relative Gain Update
  - An example of the value of the Landsat Image Assessment System
- Landsat 4 TM MTF Corrrection
  - Restoring data never seen by mortals
- MSS Absolute Calibration
  - The final(?) word

Acknowledgements
  - Landsat Project Science Office, GSFC
  - USGS EROS
  - SDSU Image Processing Lab

L5TM Relative Gains

J.Dewald

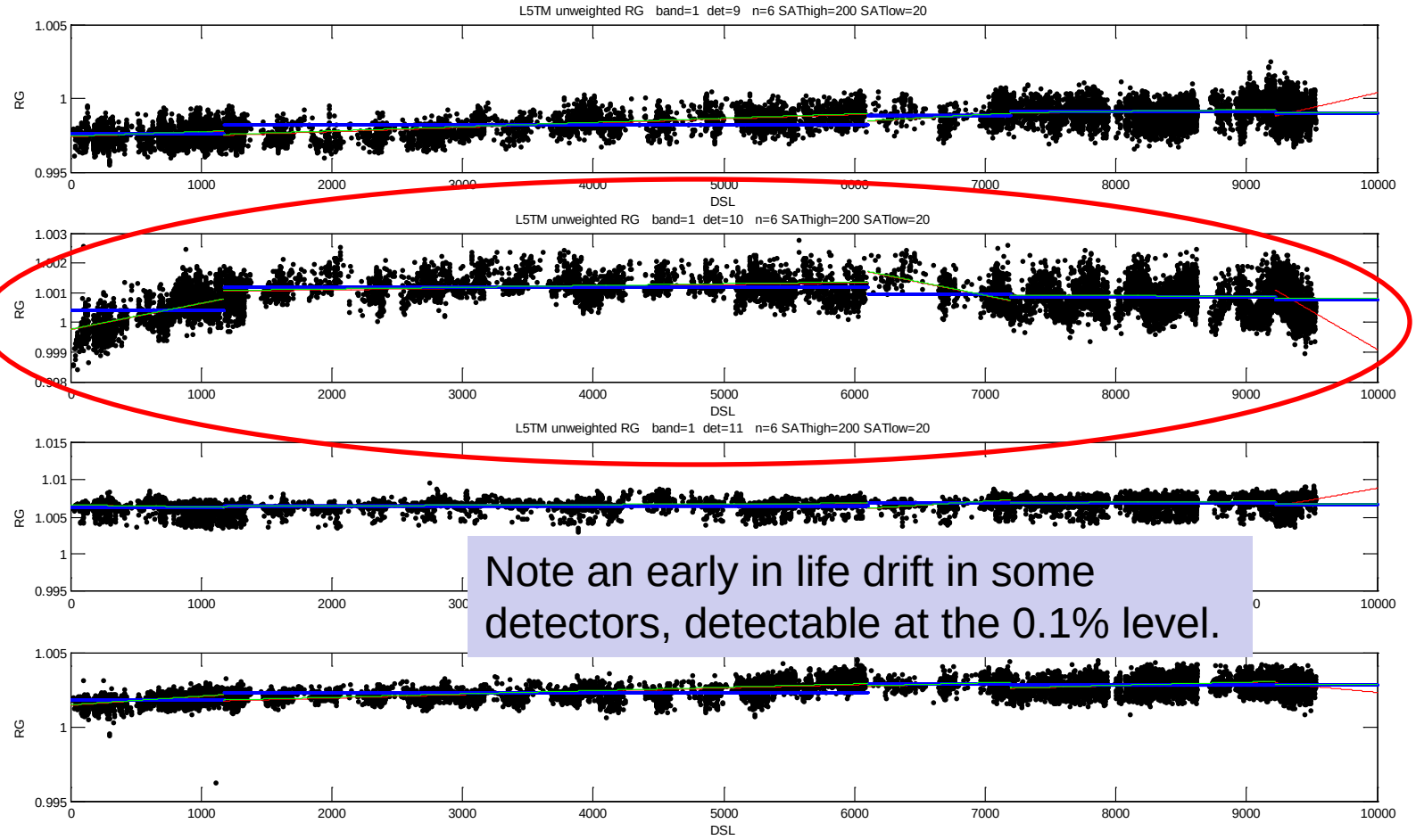
South Dakota State University
Image Processing Lab

The IAS and Relative Gains

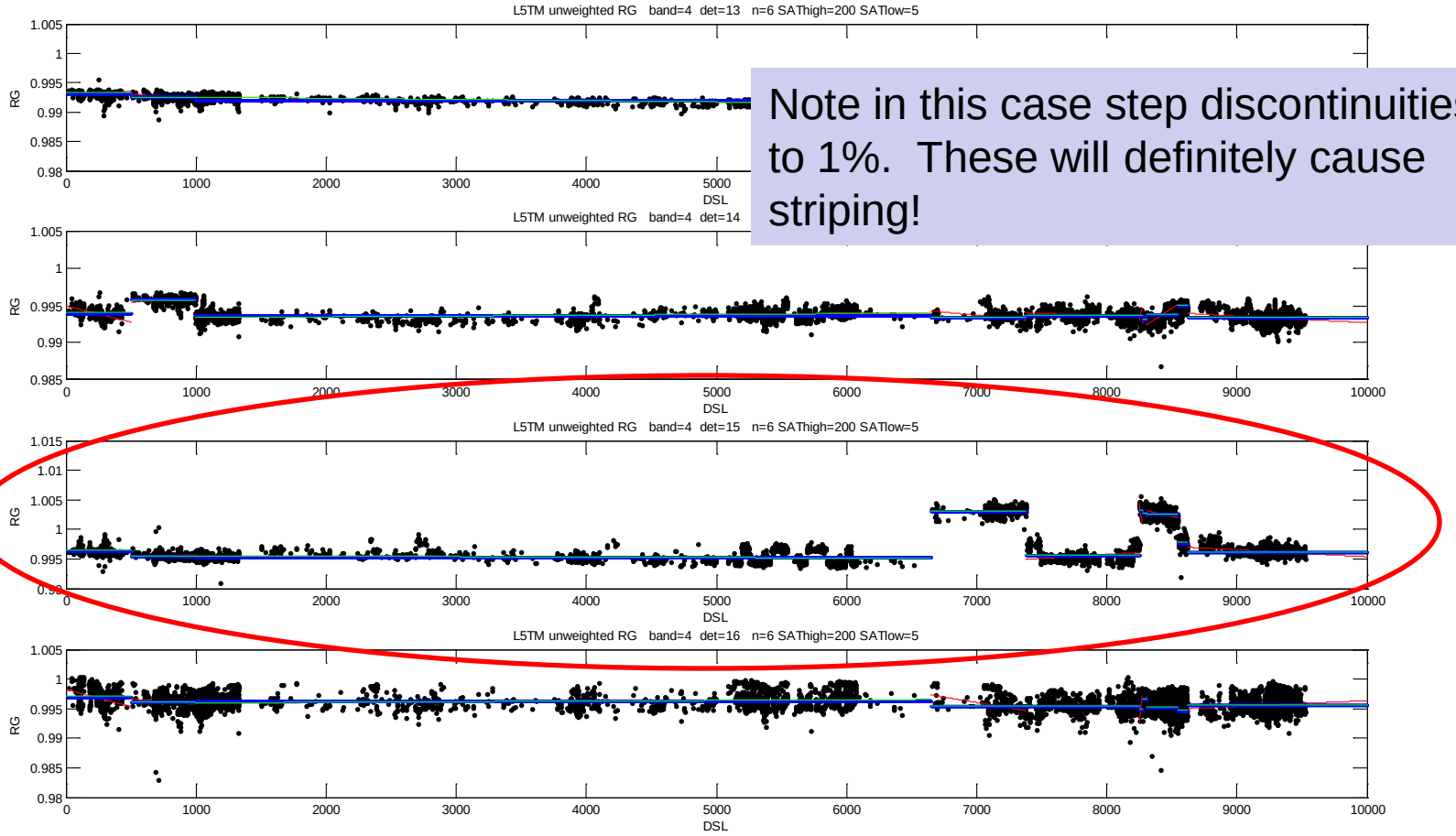
- The Landsat Image Assessment System provides a quality check on every image processed at USGS EROS
  - Pertinent calibration information is extracted from each scene, cal file, and metadata
  - This information provides long and short term trending information that is invaluable for calibration updates
  - Literally 10’s of 1000’s of data points can be obtained for any cal parameter
- Detector Relative Gains are a primary source of striping in Landsat Imagery
  - Various methods of calculating these values have been used including on-board cal lamps, scene-based equalization, and lifetime trending
  - The IAS collects data on the relative response of each detector for each scene
  - Very dense data sets, properly filtered, have allowed accurate model development over the lifetime of Landsat TM instruments.

Band 1 RG Trend (det 9-12)

Blue: Simple Average Red: 1st order Green: Selected Model

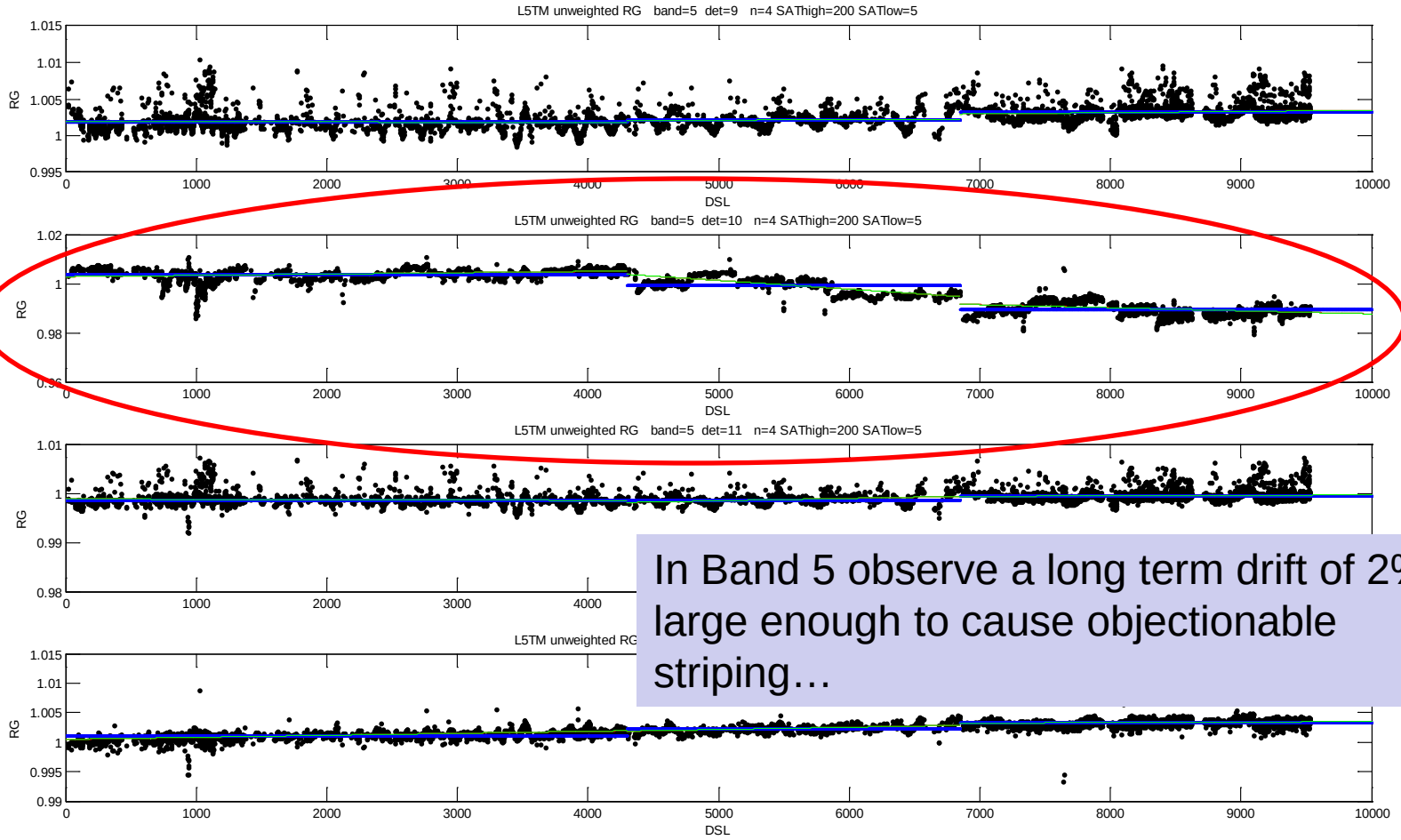


Band 4 RG Trend (det 13-16)



Note in this case step discontinuities up to 1%. These will definitely cause striping!

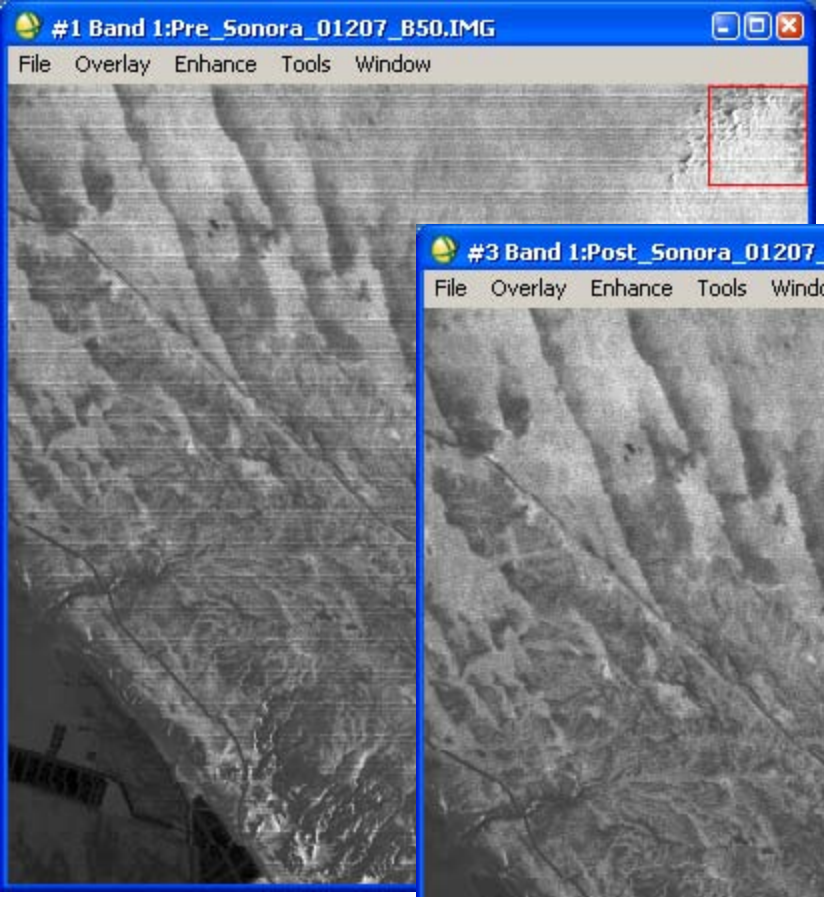
Band 5 RG Trend (det 9-12)



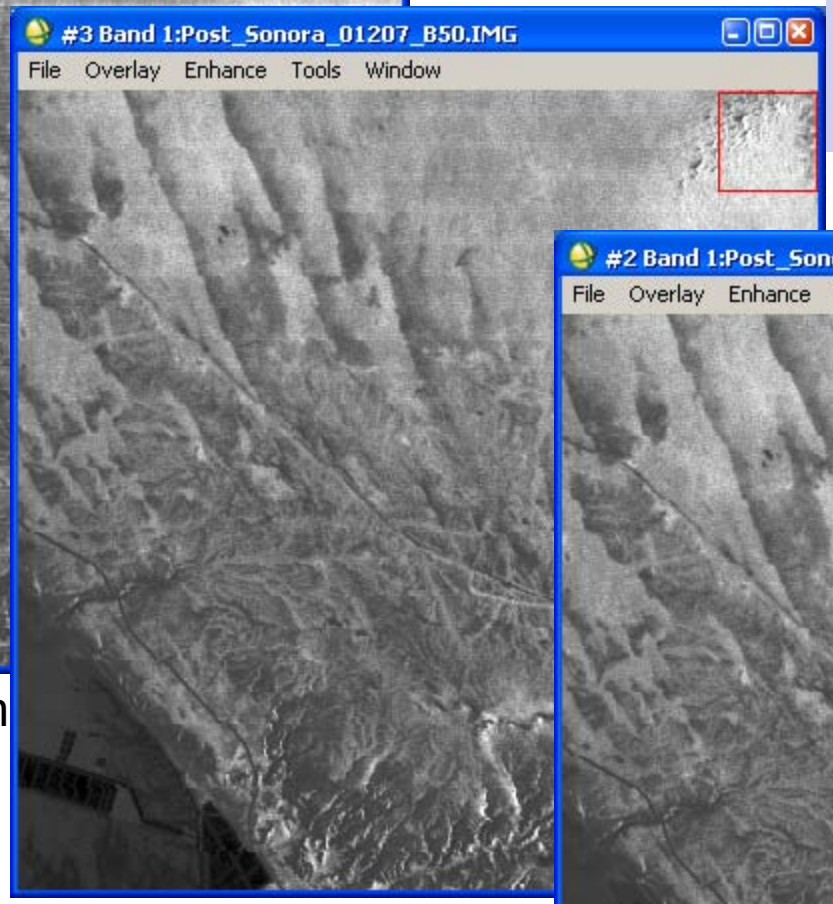
In Band 5 observe a long term drift of 2%--large enough to cause objectionable striping…

2001 Day-207 Band-5

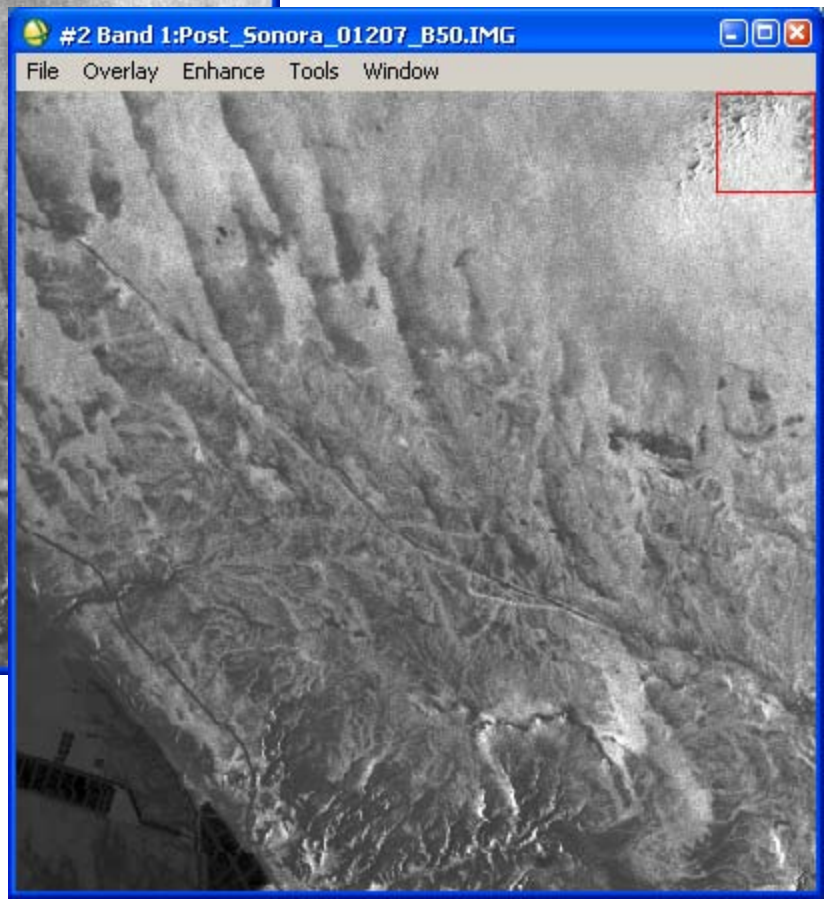
An example of removing the long term drift in relative gain occurring in Band 5.



w/o RG correction



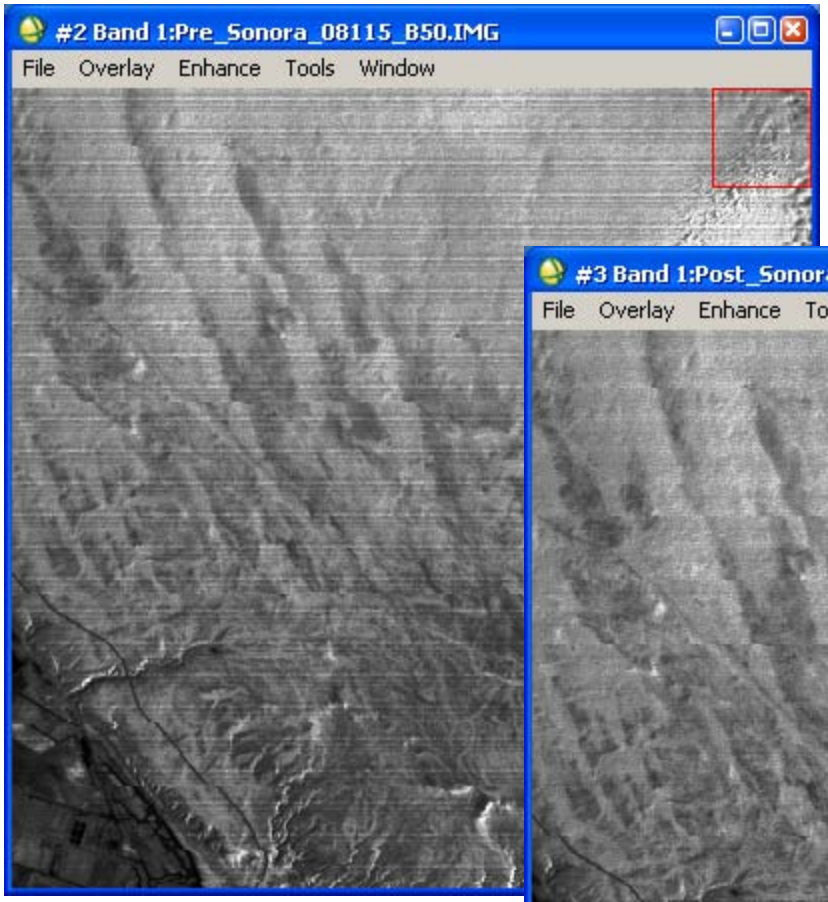
current RG correction



new RG correction

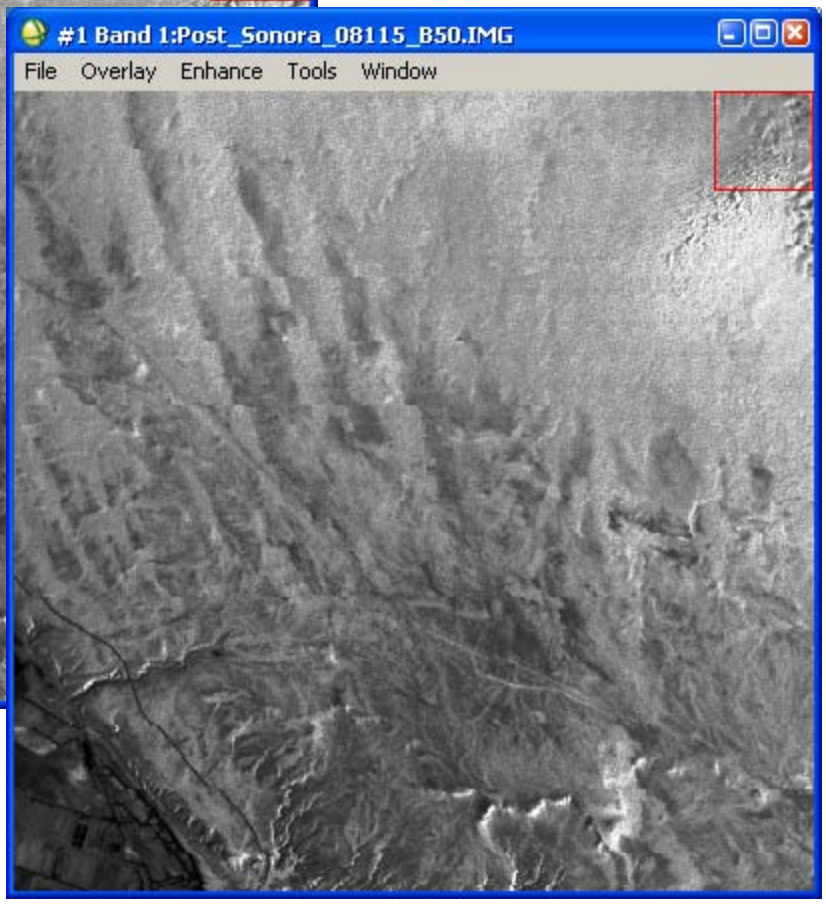
2008 Day-115 Band-5

A second example from Band 5 showing how the detector drift had become appreciable worse later in life.



w/o RG correction

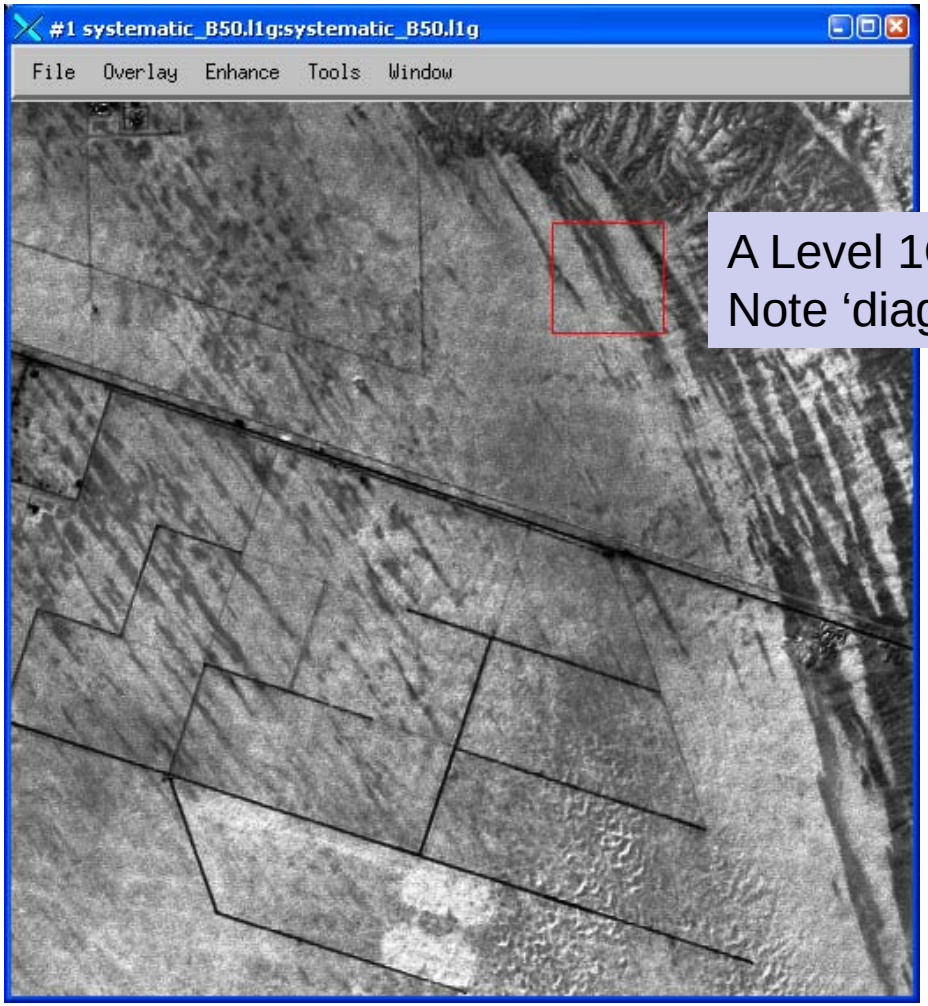
current RG correction



new RG correction

2/25/2010 Band 5 L1G

Old RG: S12605
New RG: S12606

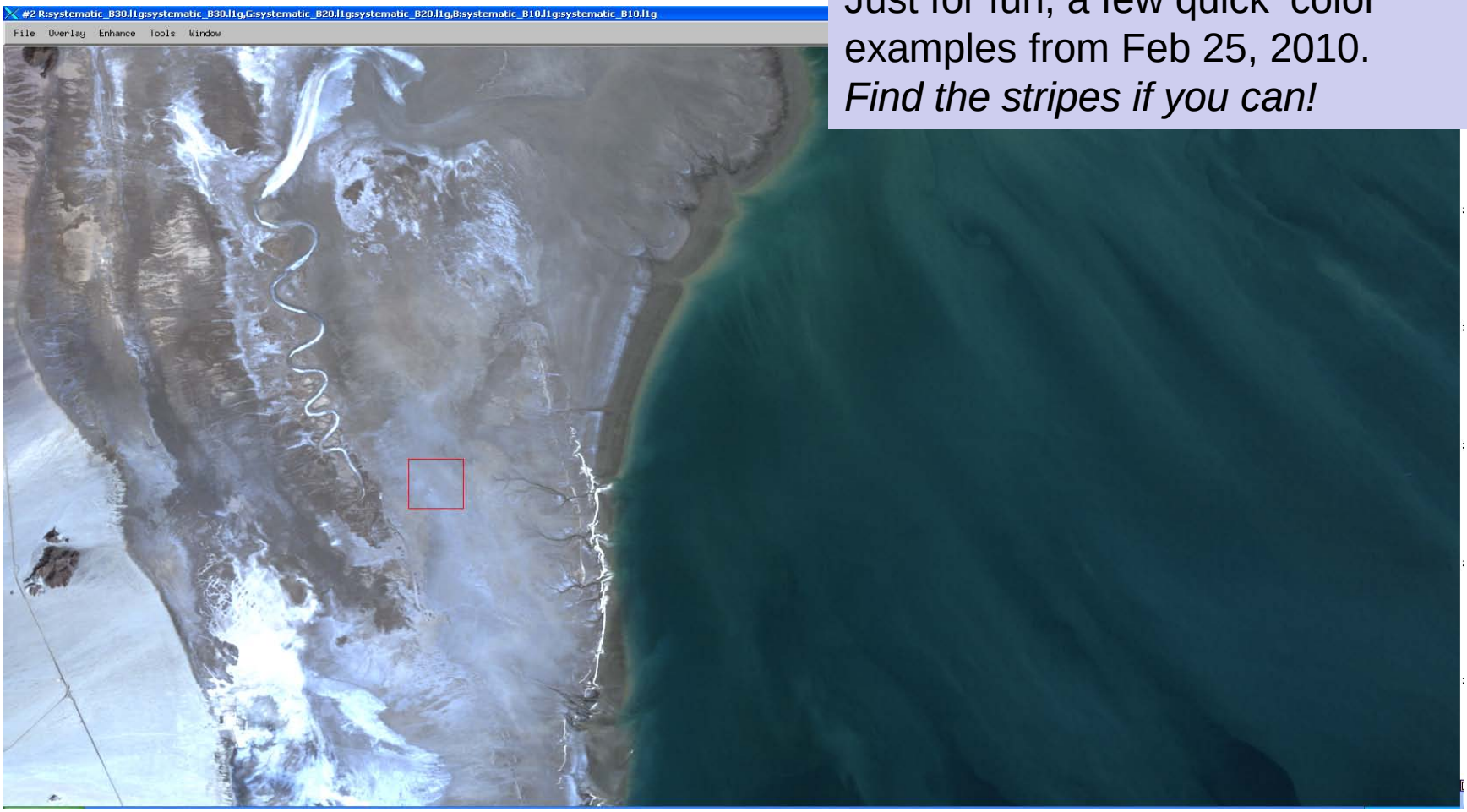


A Level 1G band 5 example from 2010.
Note ‘diagonal striping pattern is removed.

Current Models

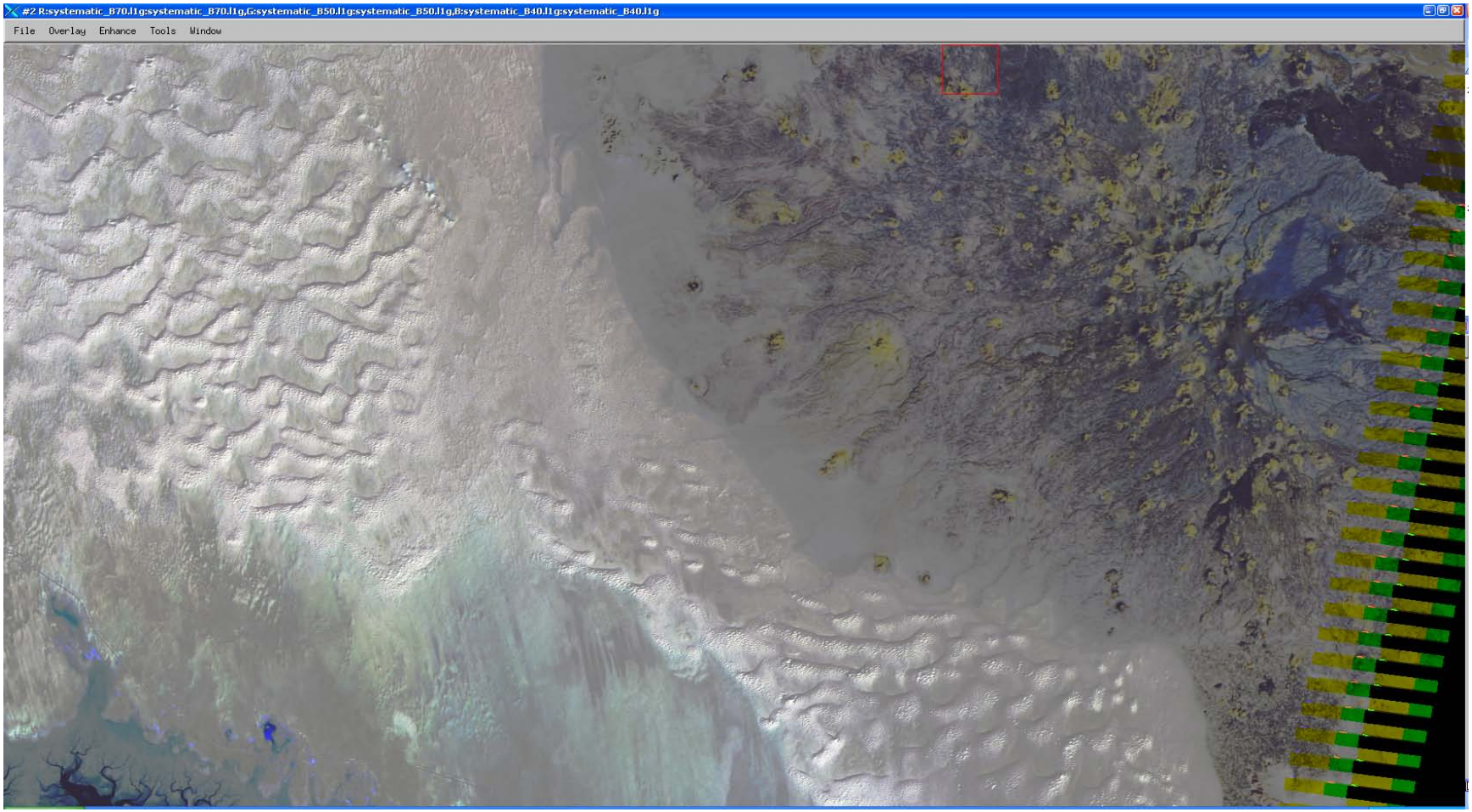
New Models

2/25/2010 321RGB

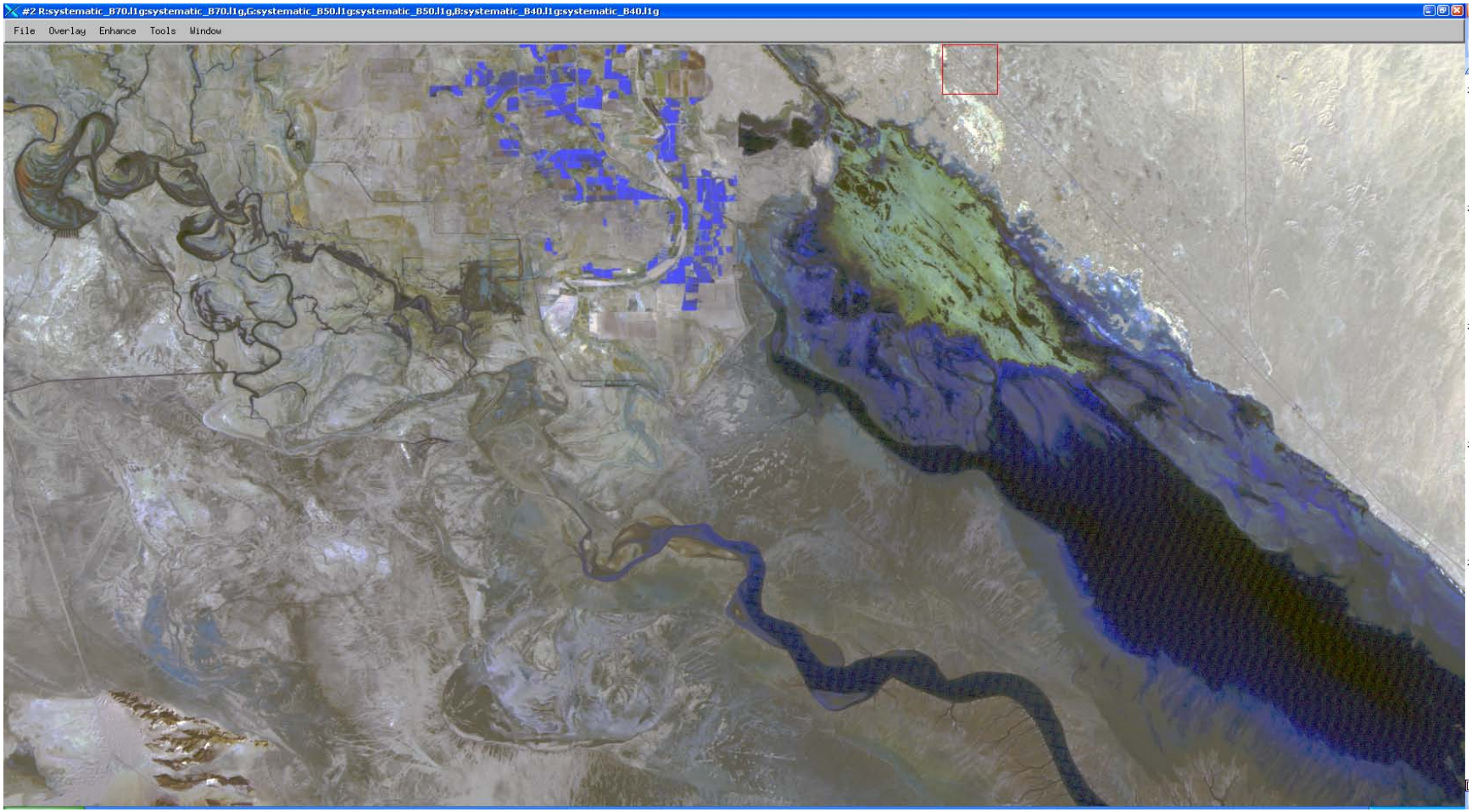


Just for fun, a few quick ‘color’ examples from Feb 25, 2010.
Find the stripes if you can!

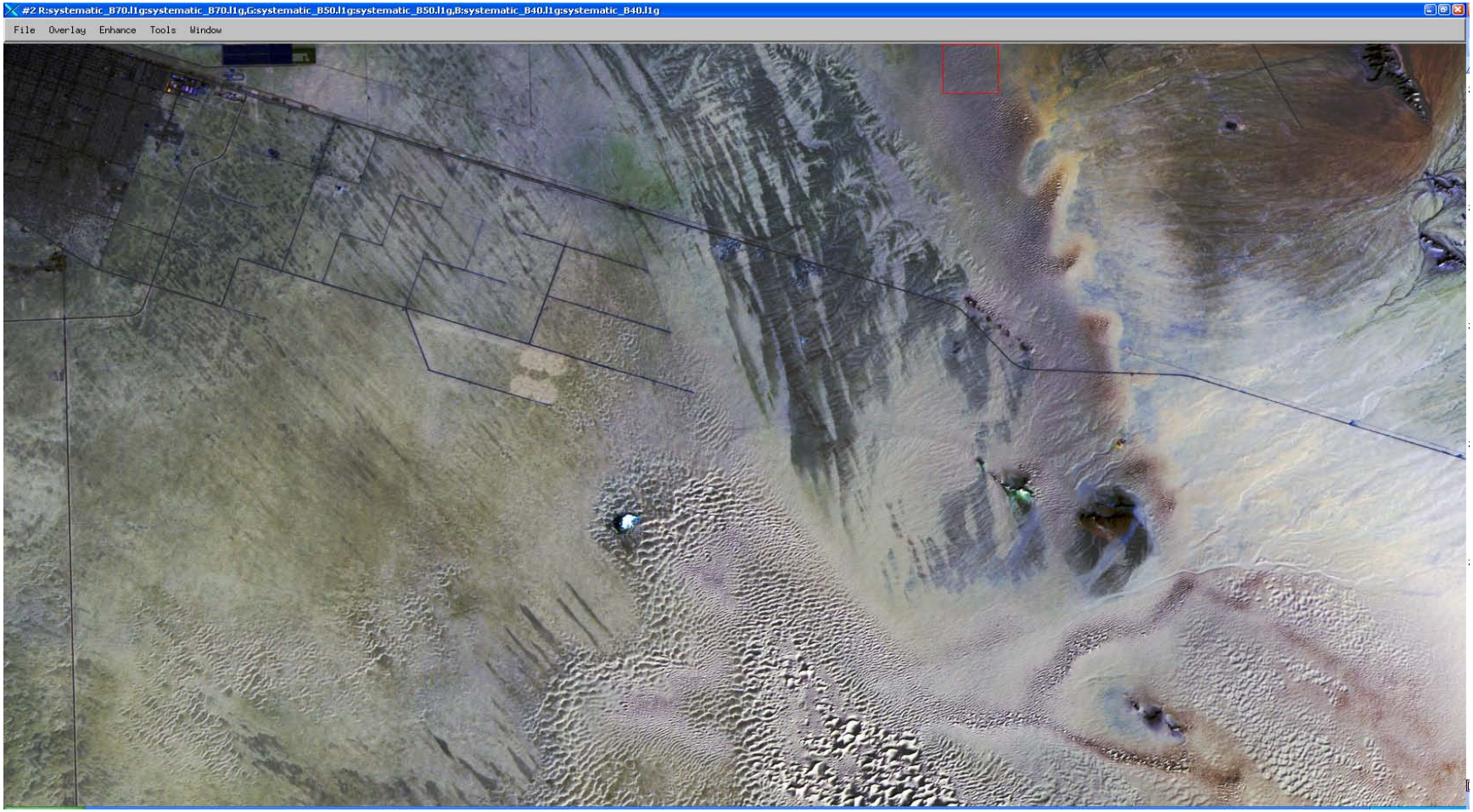
2/25/2010 754RGB



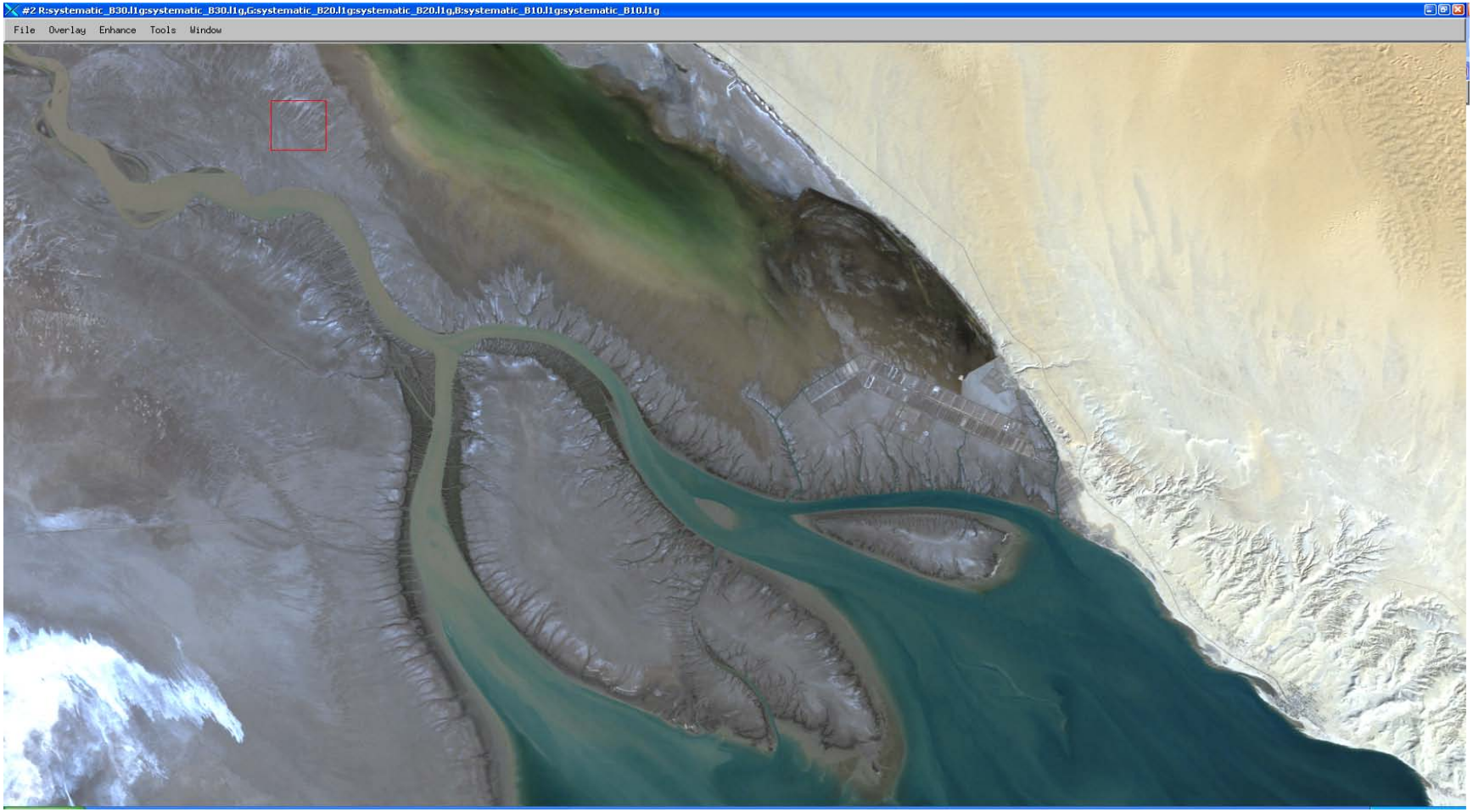
2/25/2010 754RGB



2/25/2010 754RGB



2/25/2010 321RGB

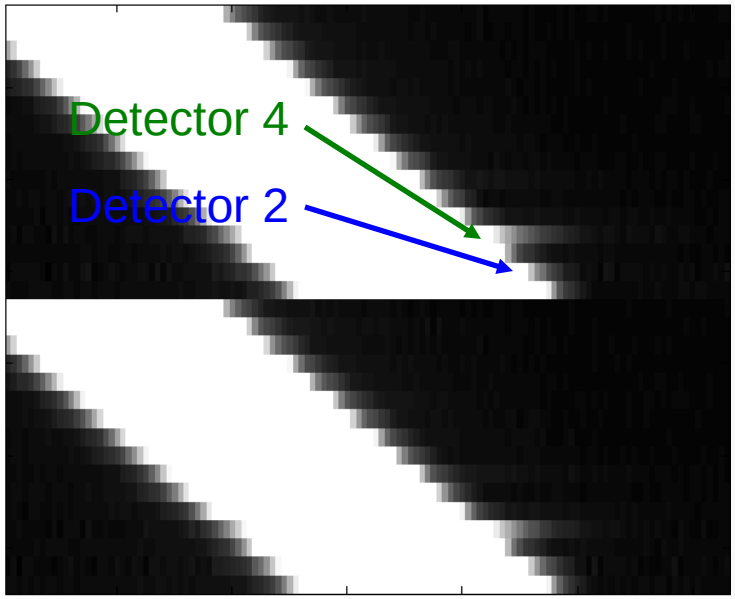


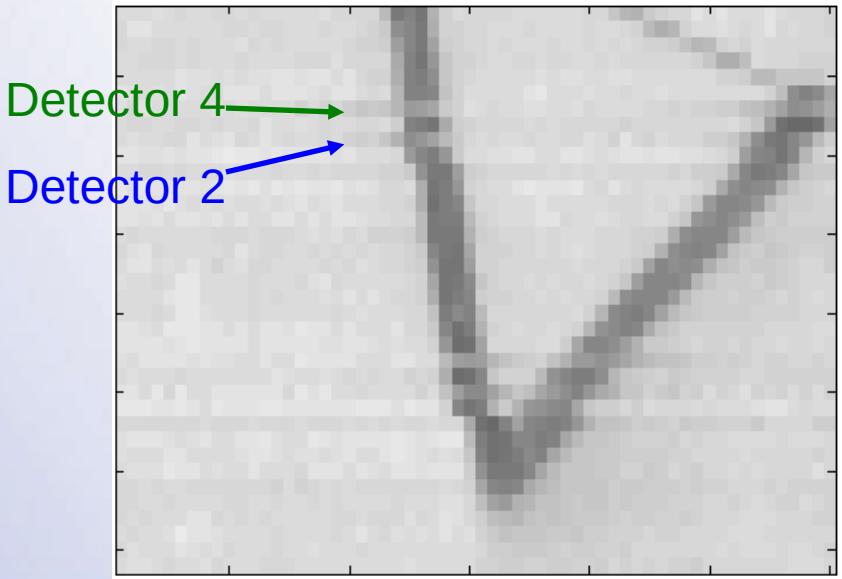
Landsat 4 Relative MTF Characterization/Correction

Dennis Helder
Dinesh Shilpakar
Cody Anderson
Image Processing Laboratory
EECS Department
South Dakota State University

Background

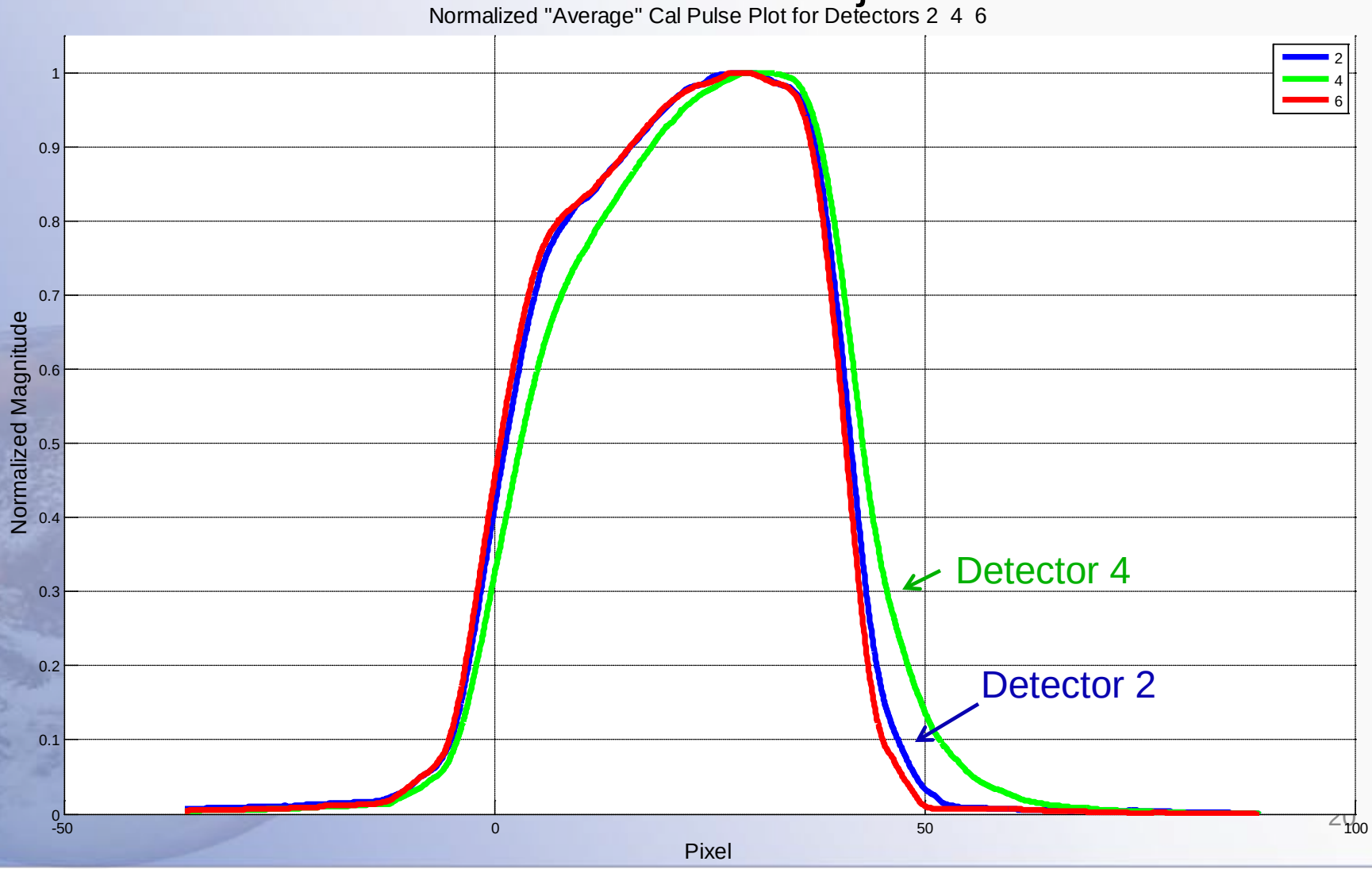
- In Landsat 4 TM Band 2 (Green), two detectors (2 and 4) exhibit poor MTF performance (they exhibit more blur than the other 14 detectors).
- Historically, data from these detectors were replaced with data from neighboring detectors
- Characterization/Correction of these detectors will allow 12.5% more information in band 2.
- The approach is to compare detectors 2 and 4 to another well behaved detector, and calculate a “relative MTF“ that will be used to correct detectors 2 and 4.



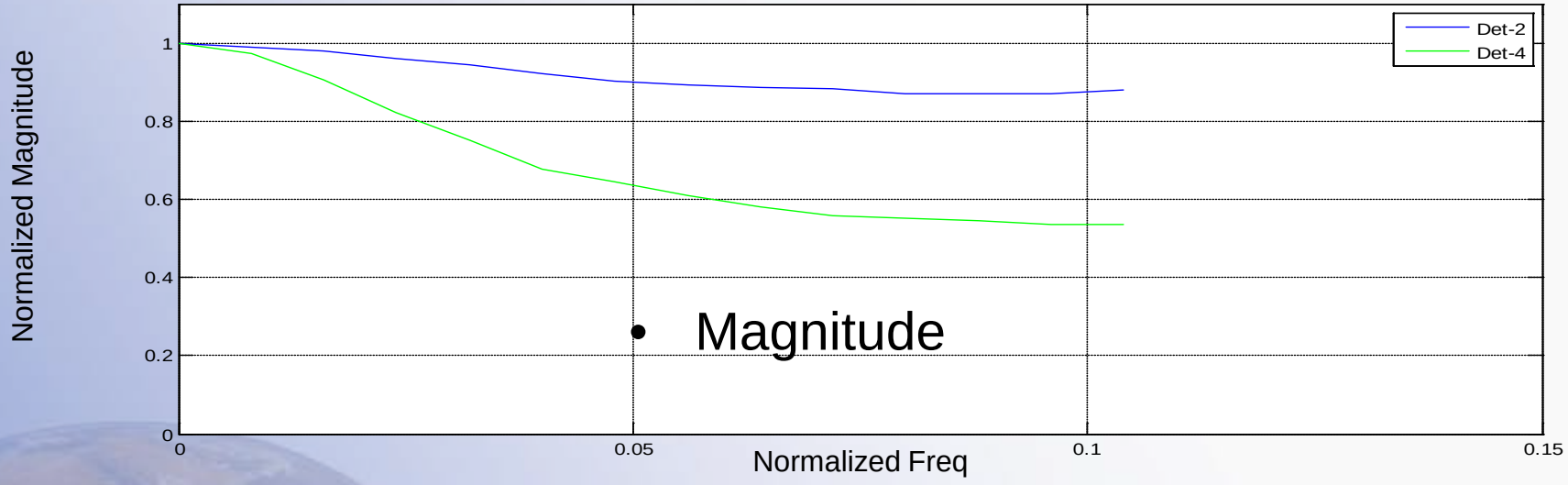


Calibration Pulse Response used for Relative MTF Characterization

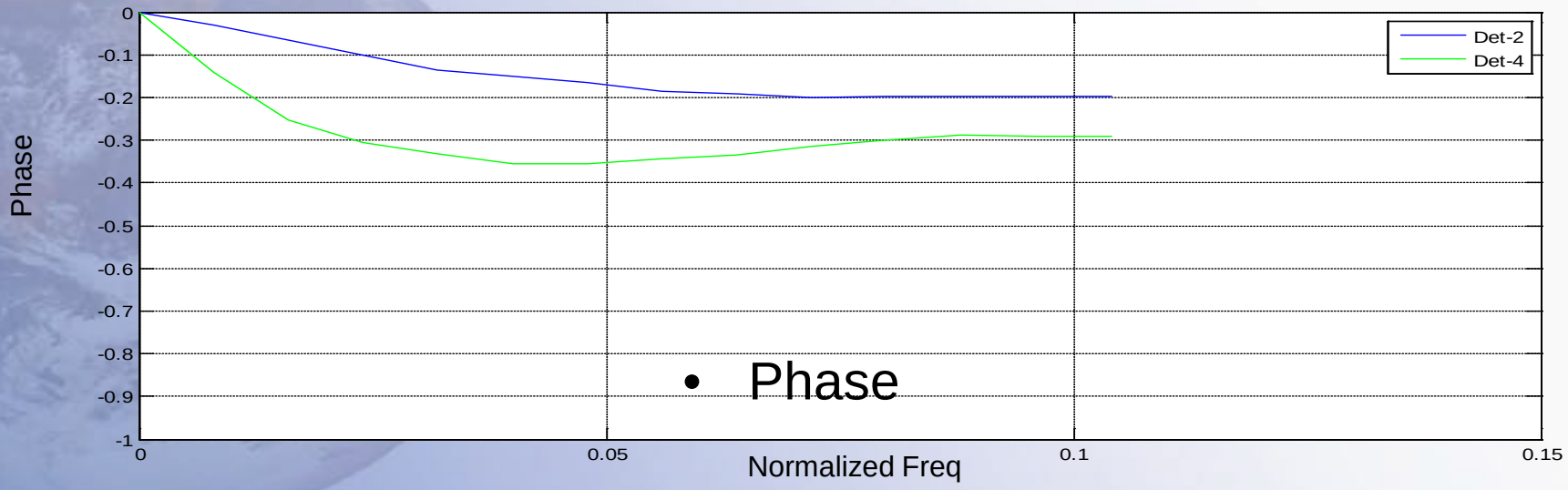
Detectors 2 and 4 are the “bad” detectors. Detector 6 is the reference detector that will be used to adjust detectors 2 and 4.



Final Relative MTF Estimate of Detectors 2 and 4

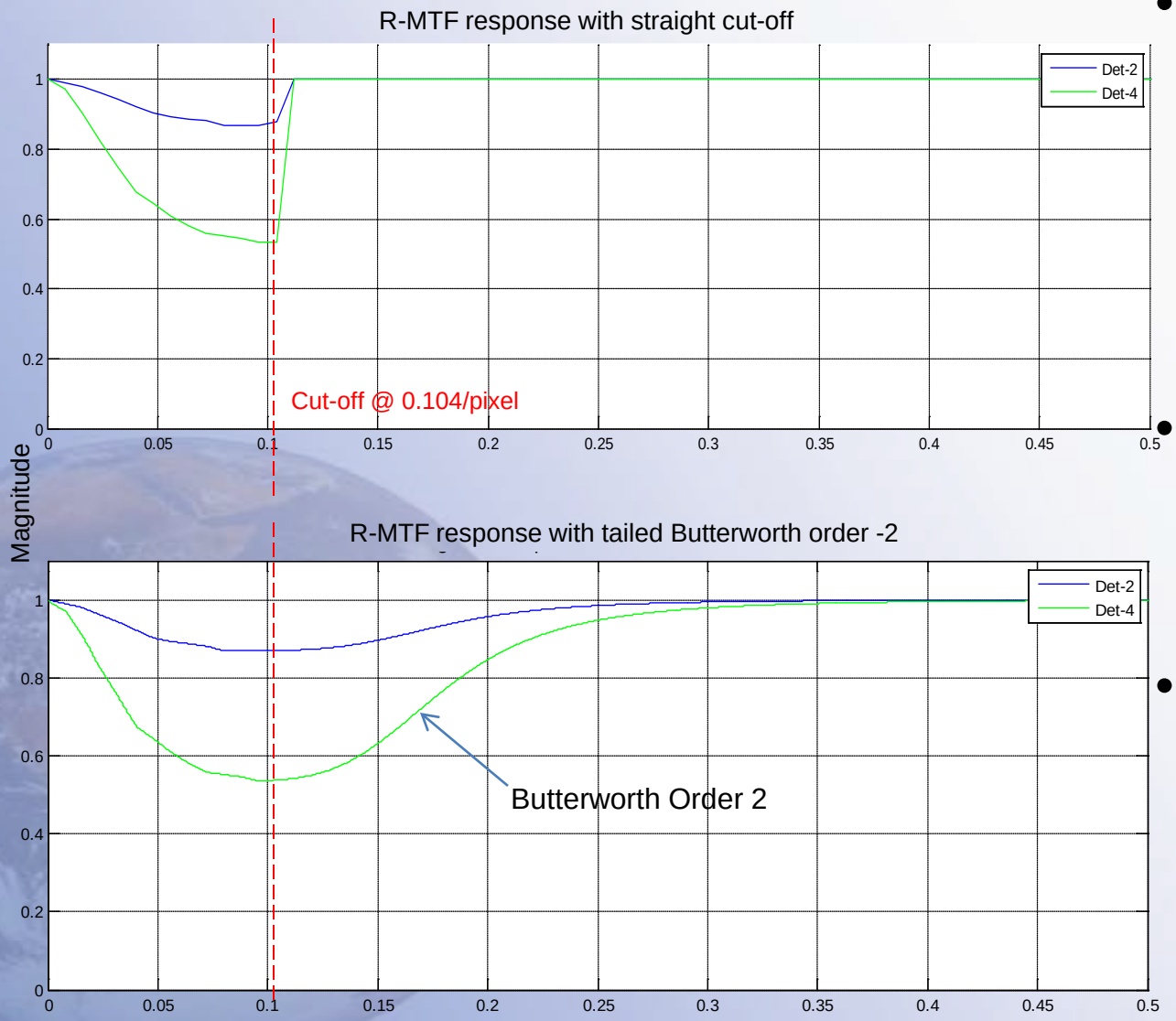


- Magnitude



- Phase

Butterworth Tailed Relative MTF



- Butterworth Filter:

$$B(u) = \frac{1}{1 + (D_0 / D_u)^{2n}}$$

D_0 = cut-off freq
D_u = freq from center
n = order of filter

- Helps reduce the ringing effect in the corrected image.
- Correction is best for order 2. Higher orders provide significantly less correction.

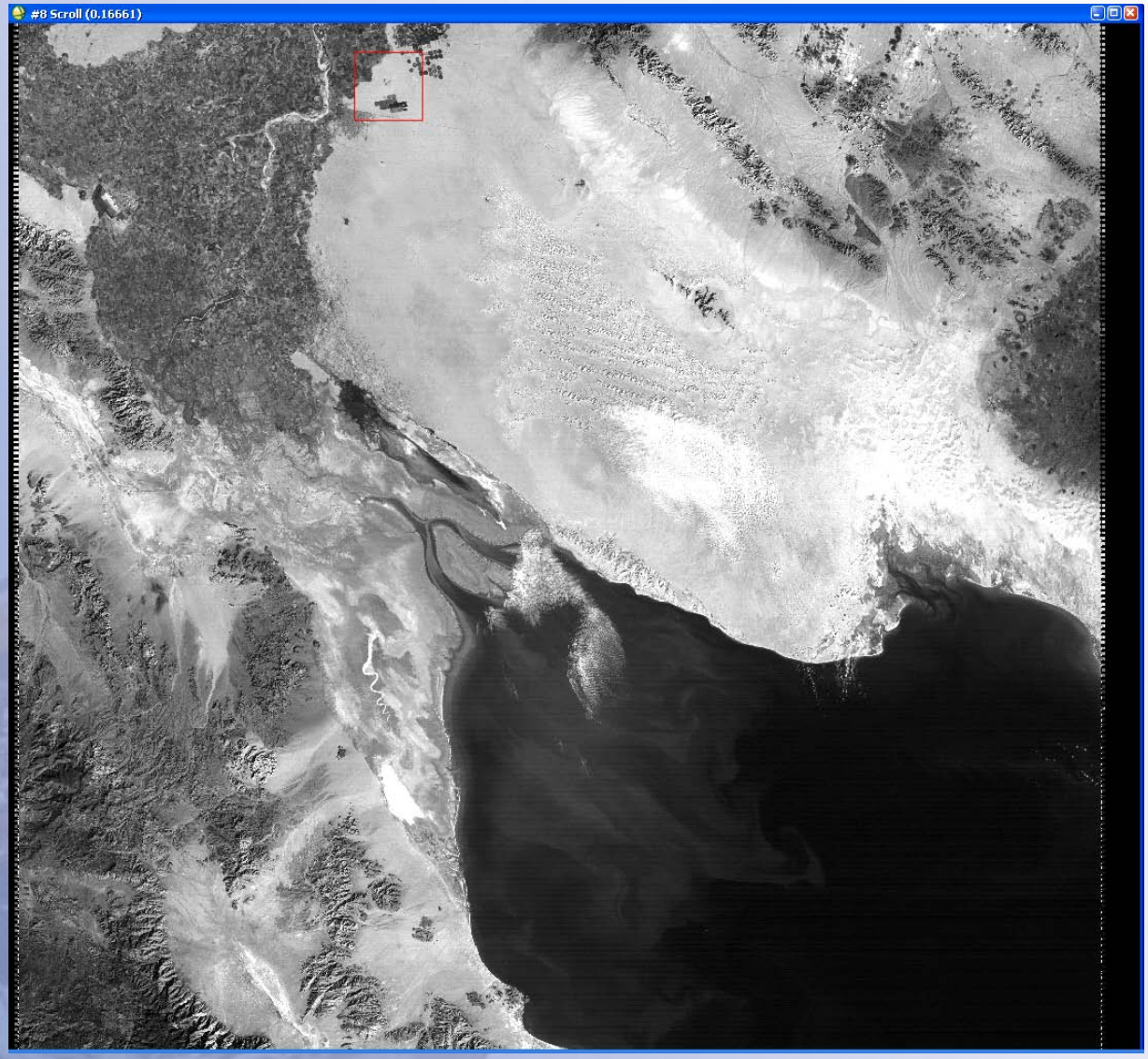
Correction Process

- For each scan line, the FFT of detectors 2 and 4 must be found.
- The FFTs of detectors 2 and 4 are divided by their estimated relative MTF.
- The IFFT is then taken and the corrected data is inserted back into the image.
- There are 374 scan lines in a scene, so 748, 6357 point FFTs and inverse FFTs are calculated for every scene.
- 6357 is the fixed length of MTF response model. This was derived from the maximum length of a valid scan line plus an extra buffer.
- Entire process takes ~1.5 seconds on a 3 GHz desktop machine!!

Results

- Some Visual Treats

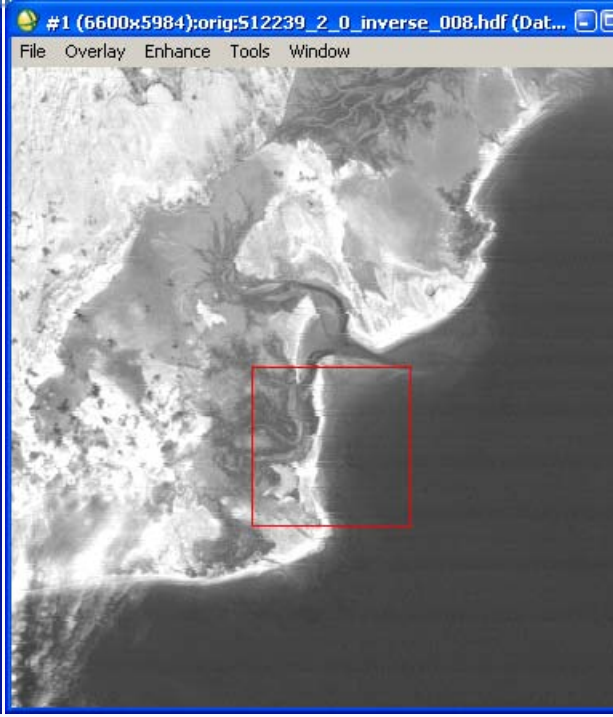
Sonoran Desert, Baja California

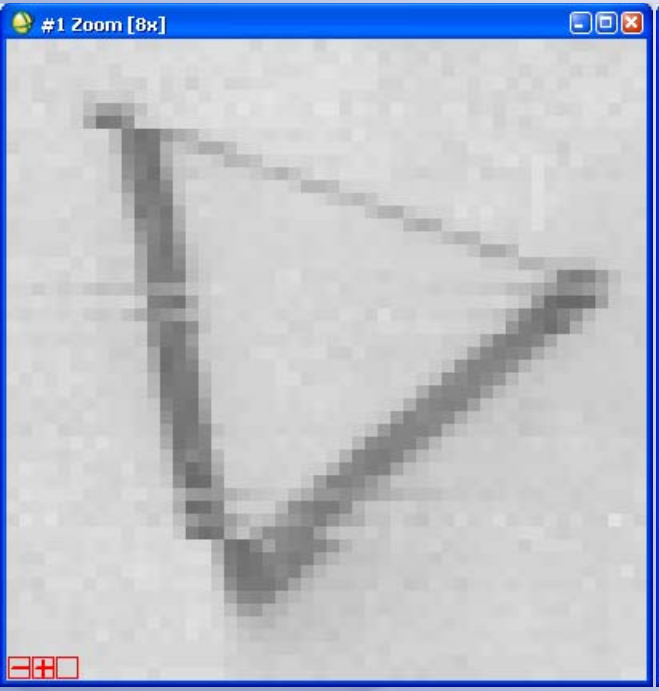


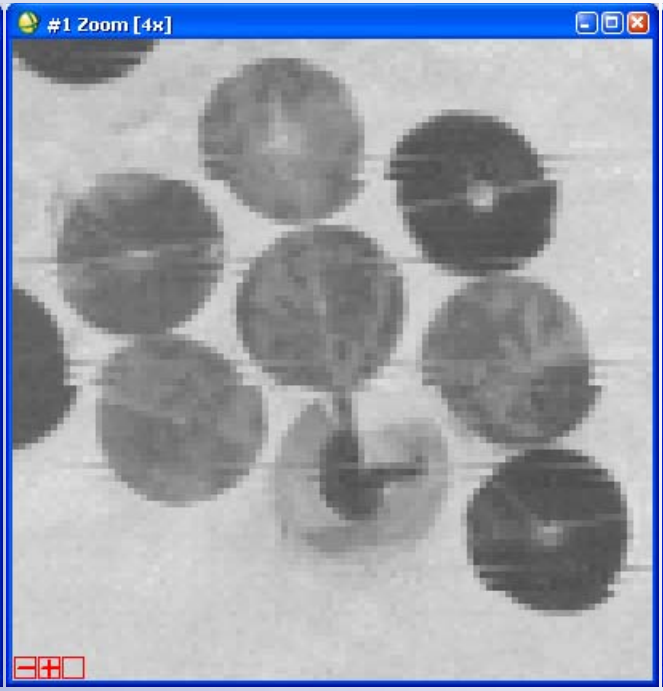
- Acquired on 11/25/1990
- Homogenous desert site often used for satellite calibration.

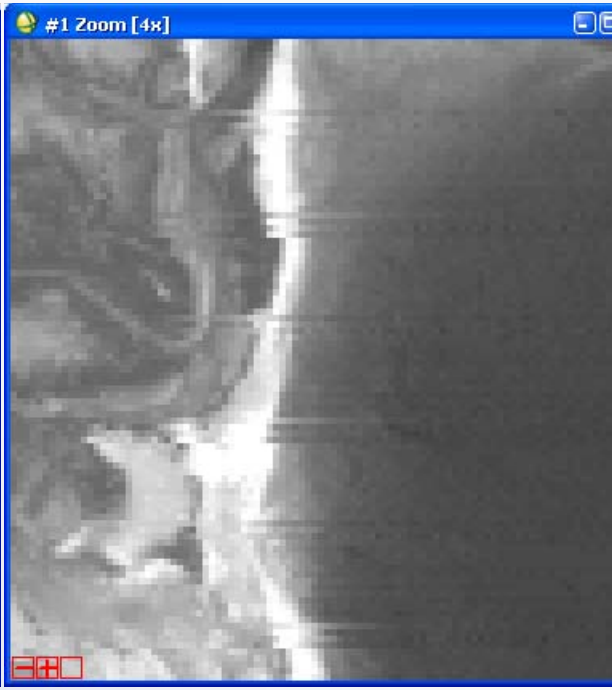

#1 (6600x5984):orig:512239_2_0_inverse_008.hdf (Dat...
File Overlay Enhance Tools Window


#1 (6600x5984):orig:512239_2_0_inverse_008.hdf (Dat...
File Overlay Enhance Tools Window

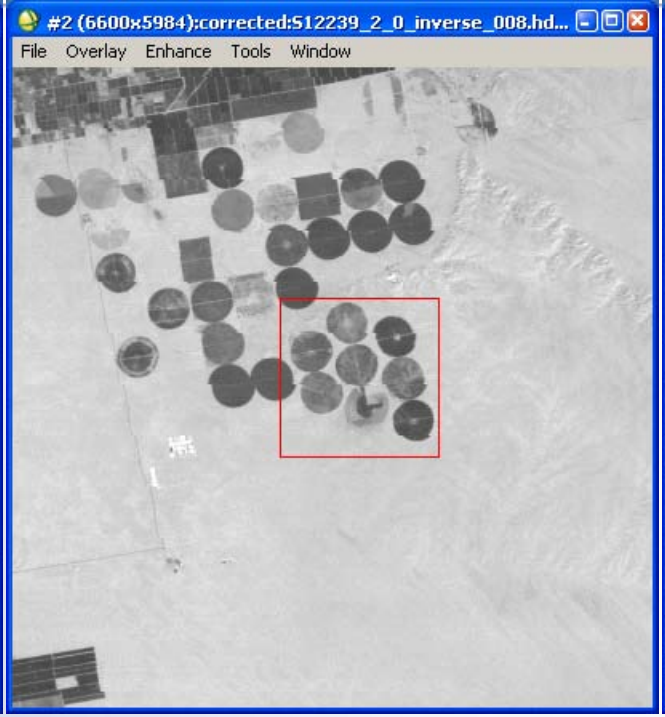

#1 (6600x5984):orig:512239_2_0_inverse_008.hdf (Dat...
File Overlay Enhance Tools Window

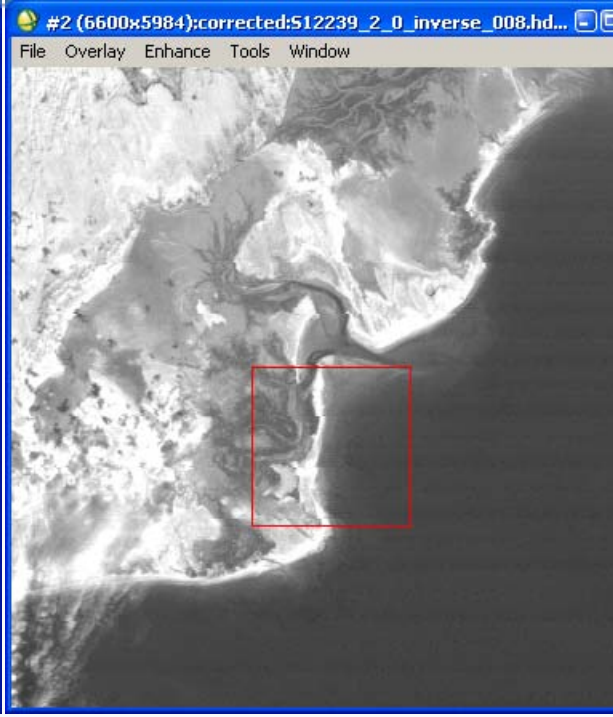

#1 Zoom [8x]

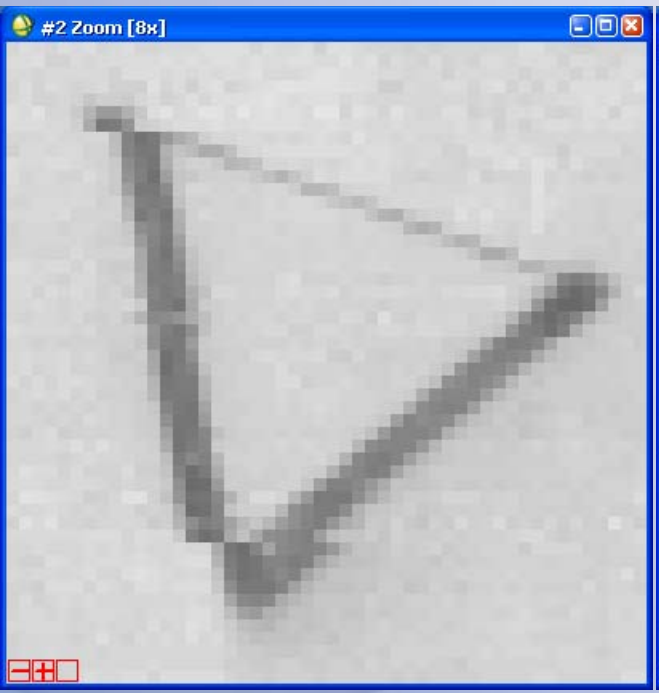

#1 Zoom [4x]

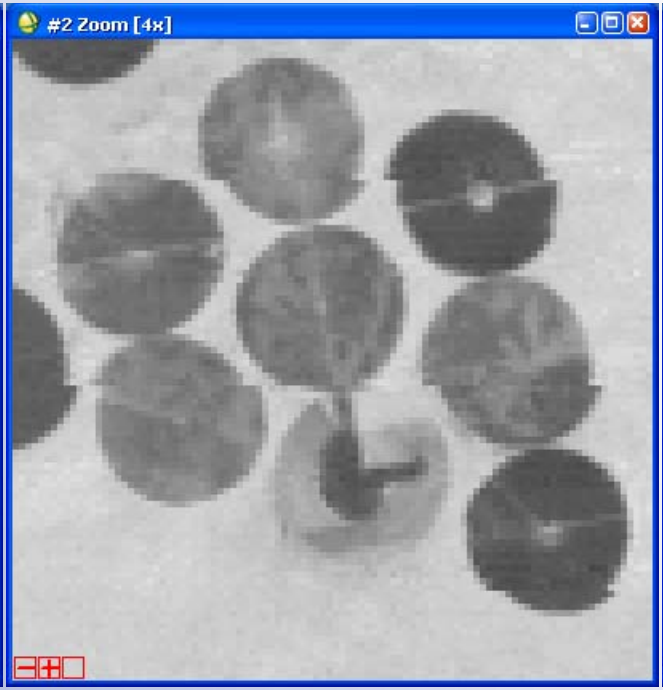

#1 Zoom [4x]

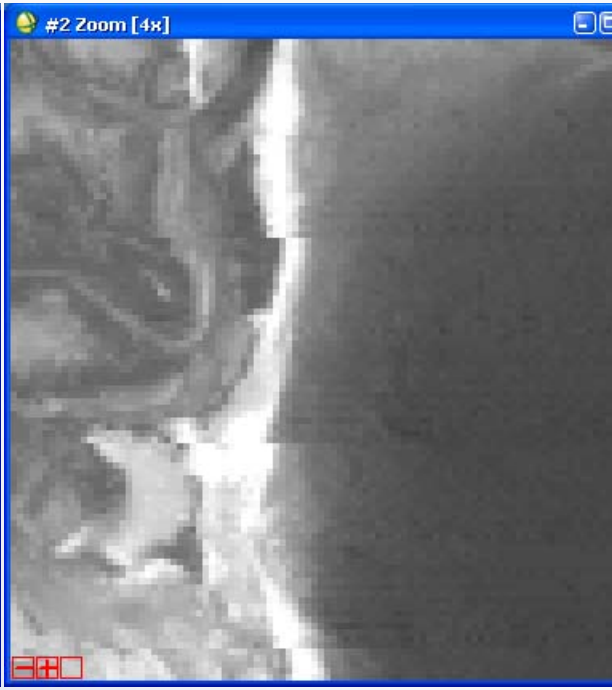

#2 (6600x5984):corrected:512239_2_0_inverse_008.hd...
File Overlay Enhance Tools Window


#2 (6600x5984):corrected:512239_2_0_inverse_008.hd...
File Overlay Enhance Tools Window

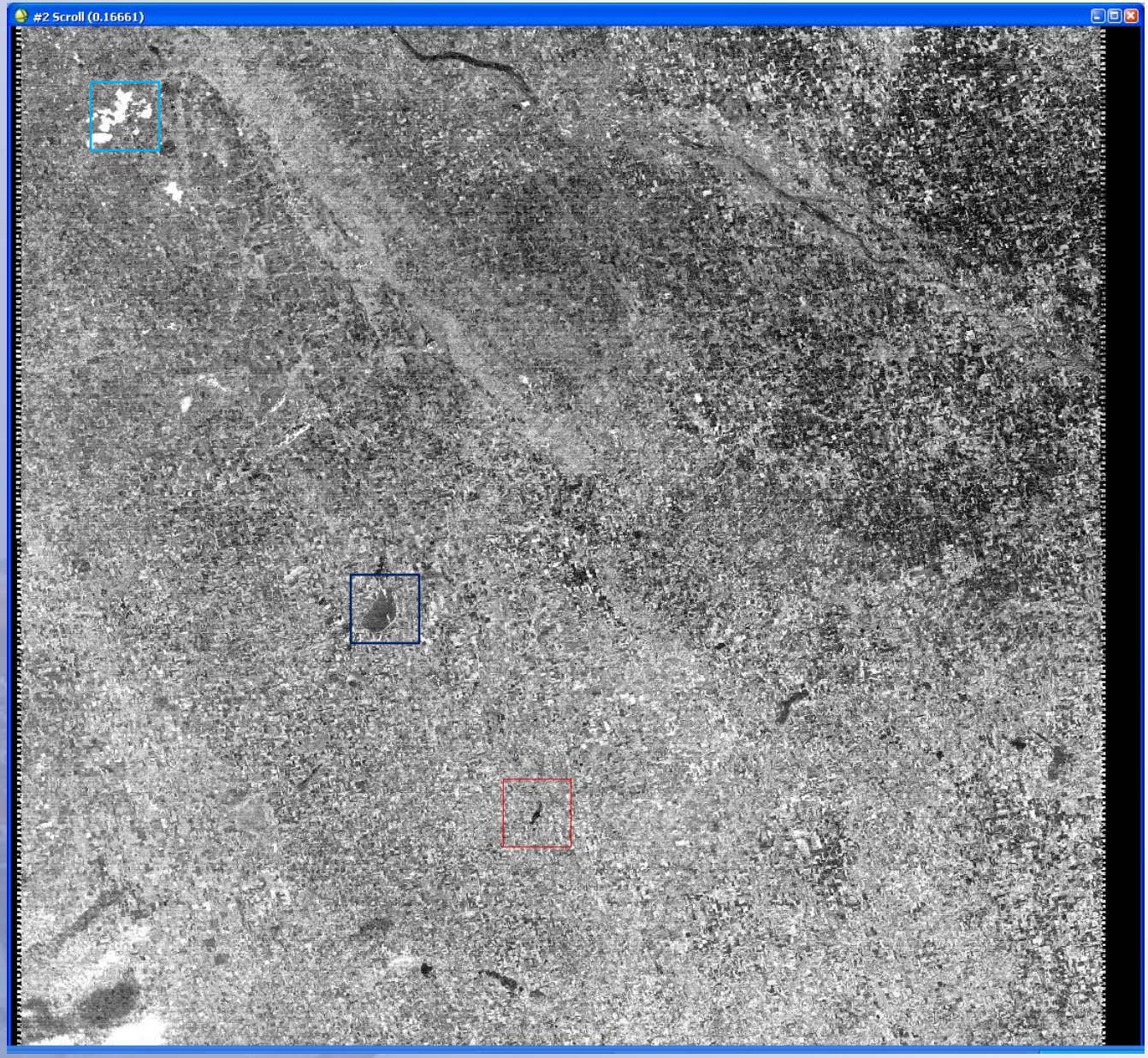

#2 (6600x5984):corrected:512239_2_0_inverse_008.hd...
File Overlay Enhance Tools Window


#2 Zoom [8x]


#2 Zoom [4x]


#2 Zoom [4x]

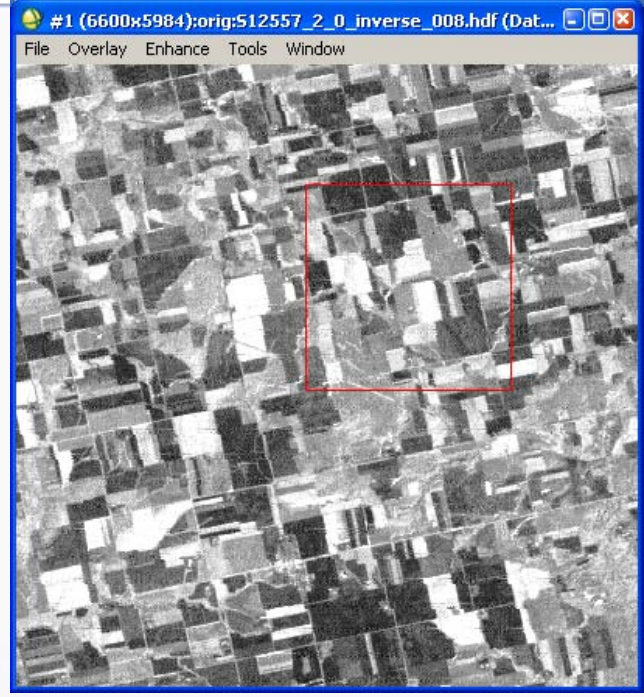
Brookings, South Dakota



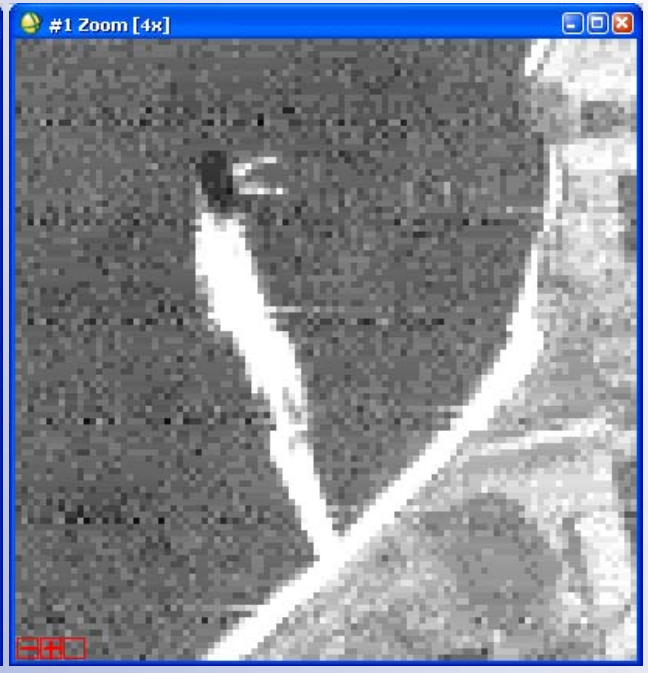
- Acquired on 12/6/1982


#1 (6600x5984):orig:S12557_2_0_inverse_008.hdf (Dat...
File Overlay Enhance Tools Window


#1 (6600x5984):orig:S12557_2_0_inverse_008.hdf (Dat...
File Overlay Enhance Tools Window


#1 (6600x5984):orig:S12557_2_0_inverse_008.hdf (Dat...
File Overlay Enhance Tools Window


#1 Zoom [4x]

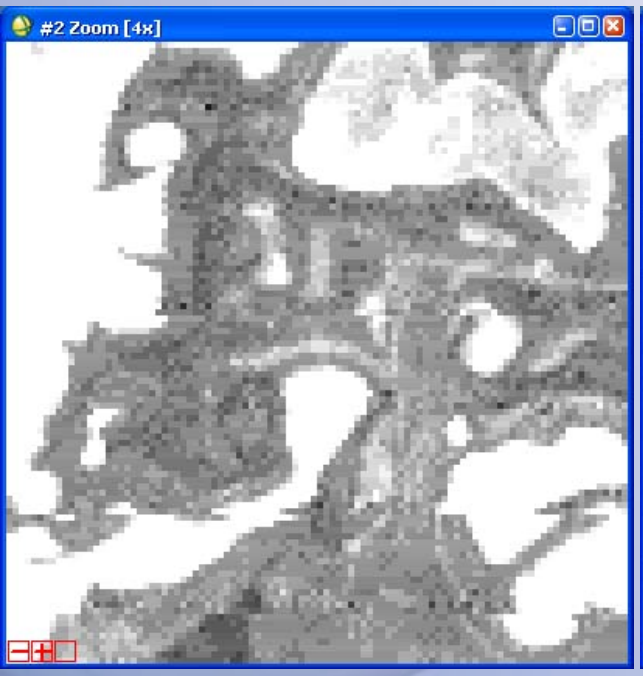

#1 Zoom [4x]


#1 Zoom [3x]


#2 (6600x5984):corrected:512557_2_0_inverse_008.hd...
File Overlay Enhance Tools Window


#2 (6600x5984):corrected:512557_2_0_inverse_008.hd...
File Overlay Enhance Tools Window

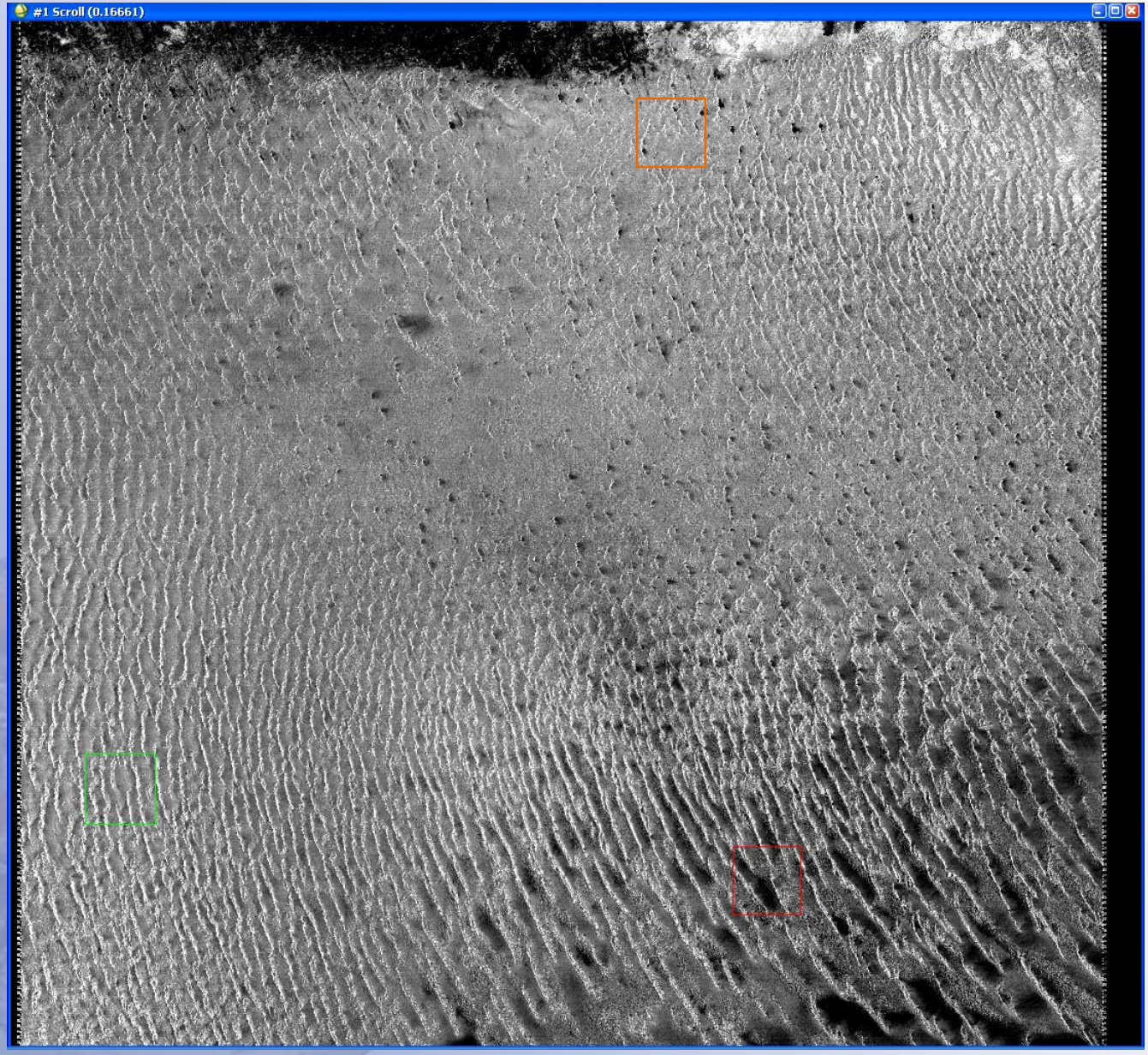

#2 (6600x5984):corrected:512557_2_0_inverse_008.hd...
File Overlay Enhance Tools Window


#2 Zoom [4x]

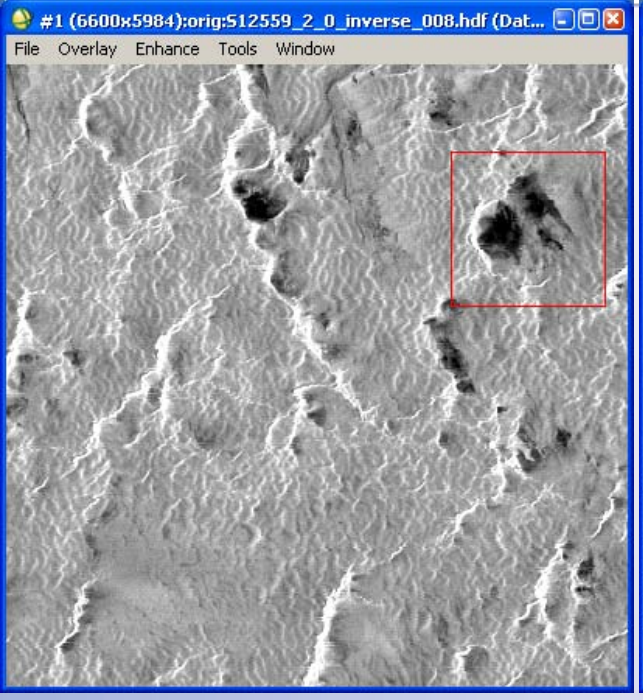

#2 Zoom [4x]

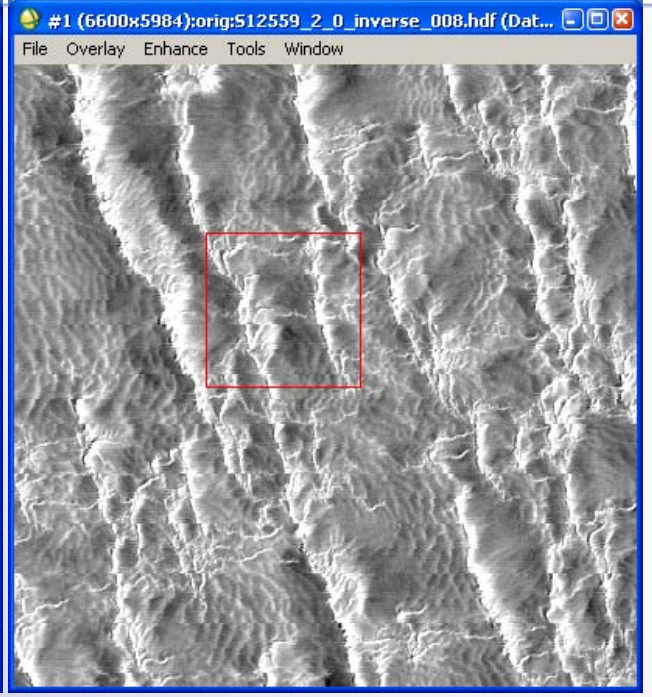

#2 Zoom [3x]

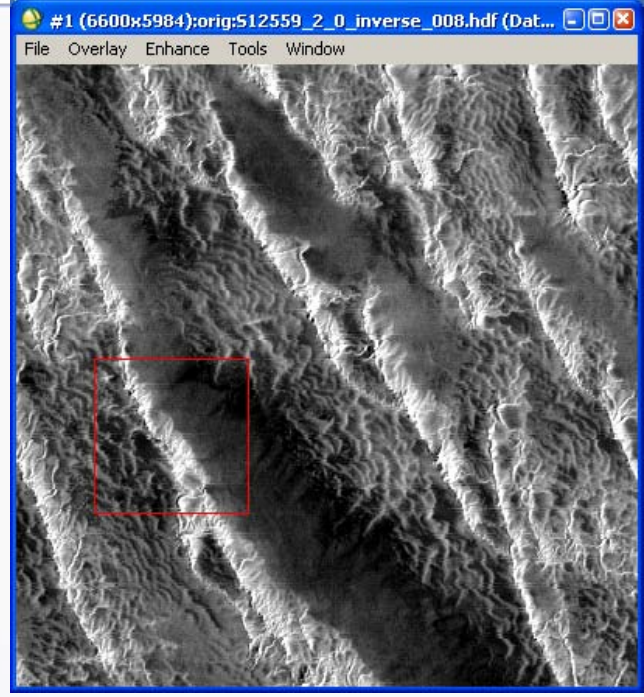
Libya-4, Africa

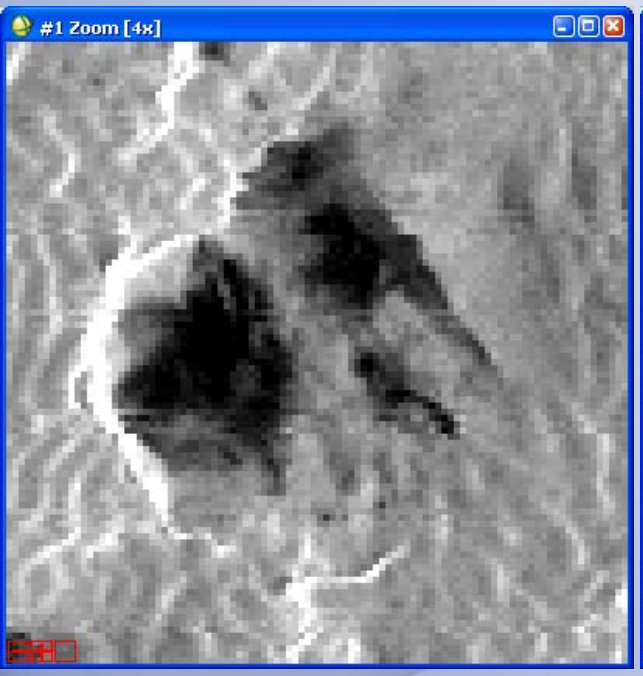


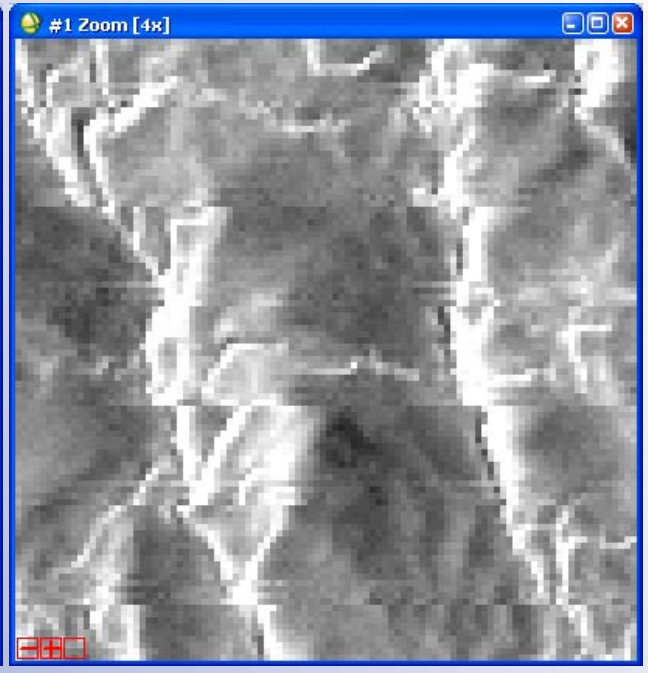
- Acquired on 3/18/1988
- Homogeneous Regions.

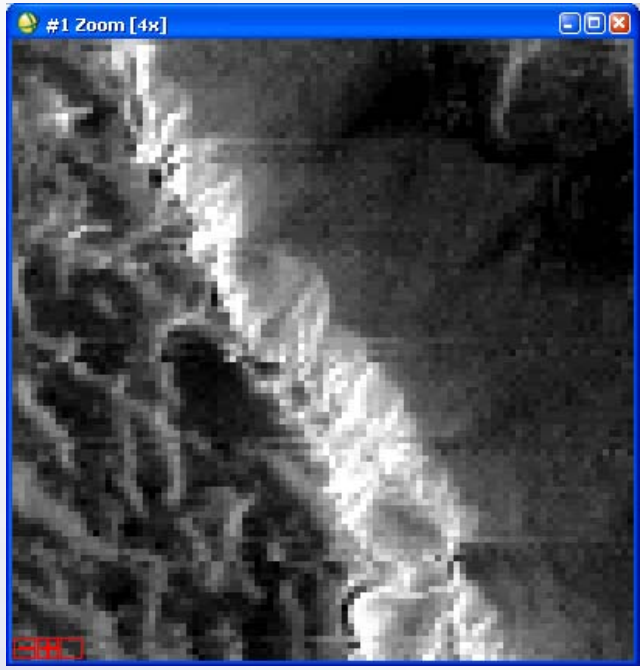

#1 (6600x5984):orig:S12559_2_0_inverse_008.hdf (Dat...
File Overlay Enhance Tools Window

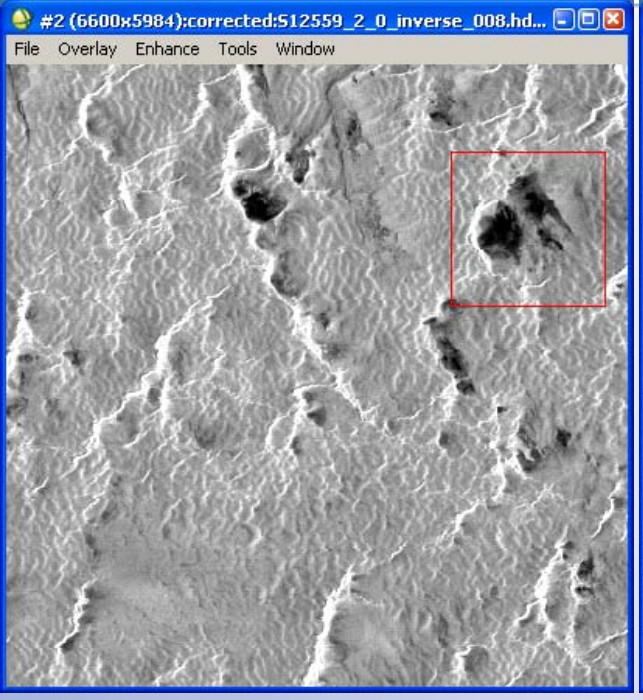

#1 (6600x5984):orig:S12559_2_0_inverse_008.hdf (Dat...
File Overlay Enhance Tools Window

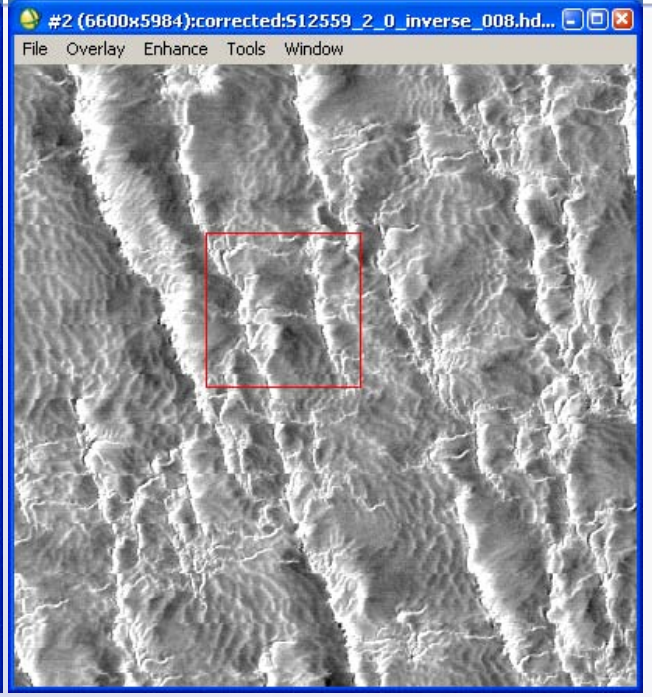

#1 (6600x5984):orig:S12559_2_0_inverse_008.hdf (Dat...
File Overlay Enhance Tools Window

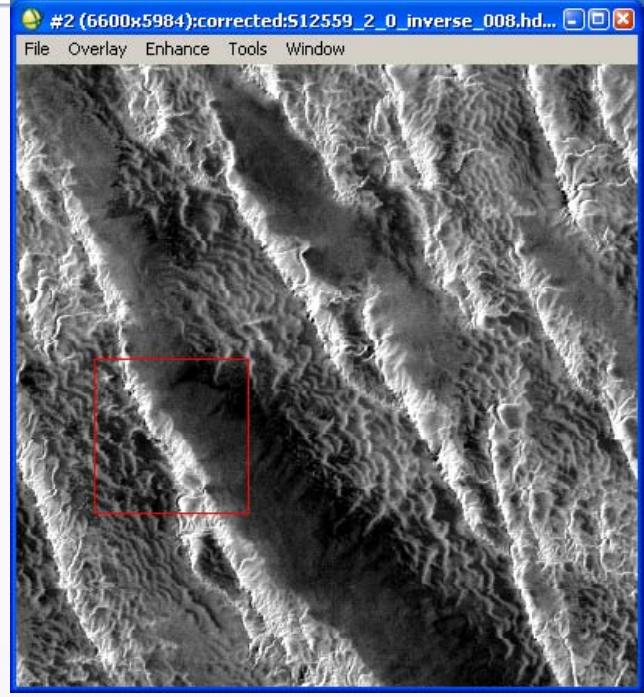

#1 Zoom [4x]

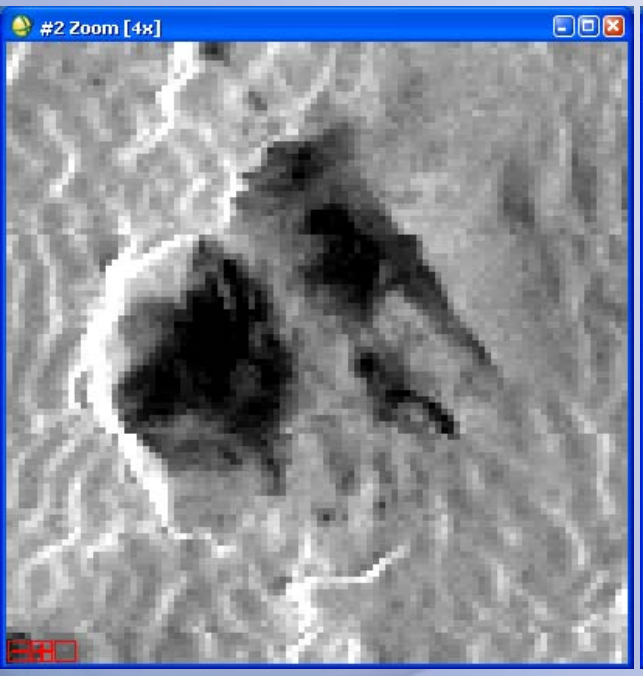

#1 Zoom [4x]

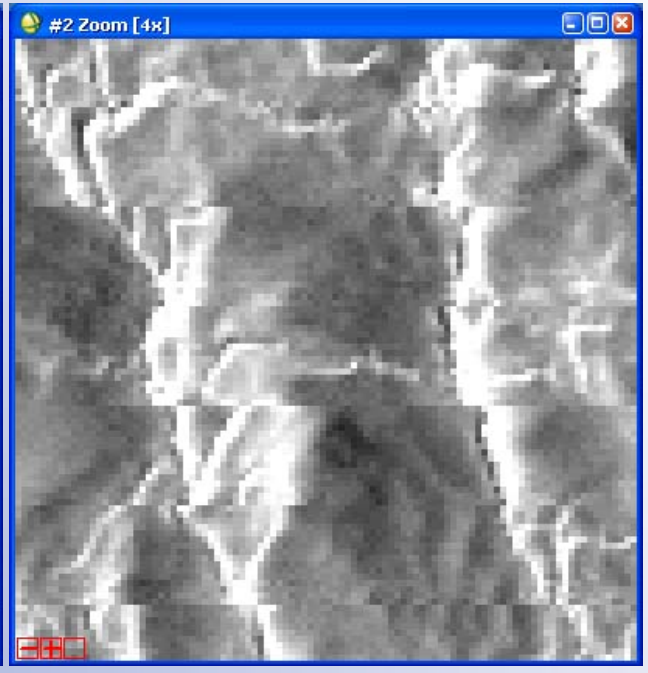

#1 Zoom [4x]

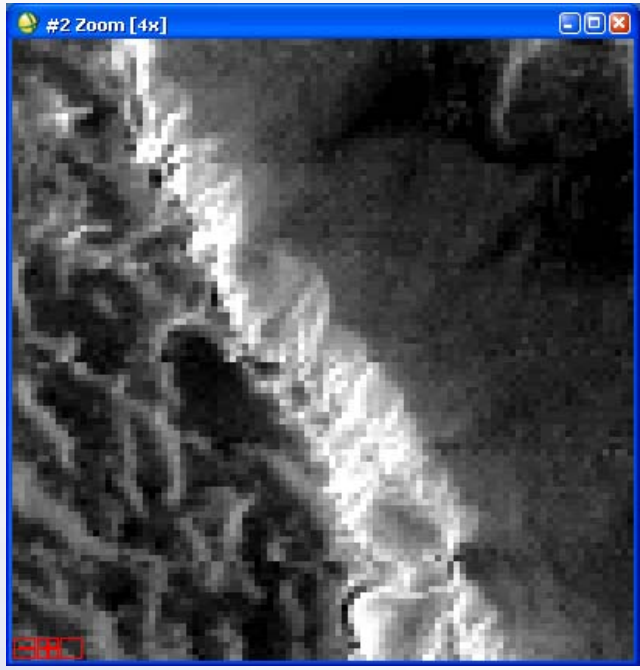

#2 (6600x5984):corrected:512559_2_0_inverse_008.hd...
File Overlay Enhance Tools Window


#2 (6600x5984):corrected:512559_2_0_inverse_008.hd...
File Overlay Enhance Tools Window

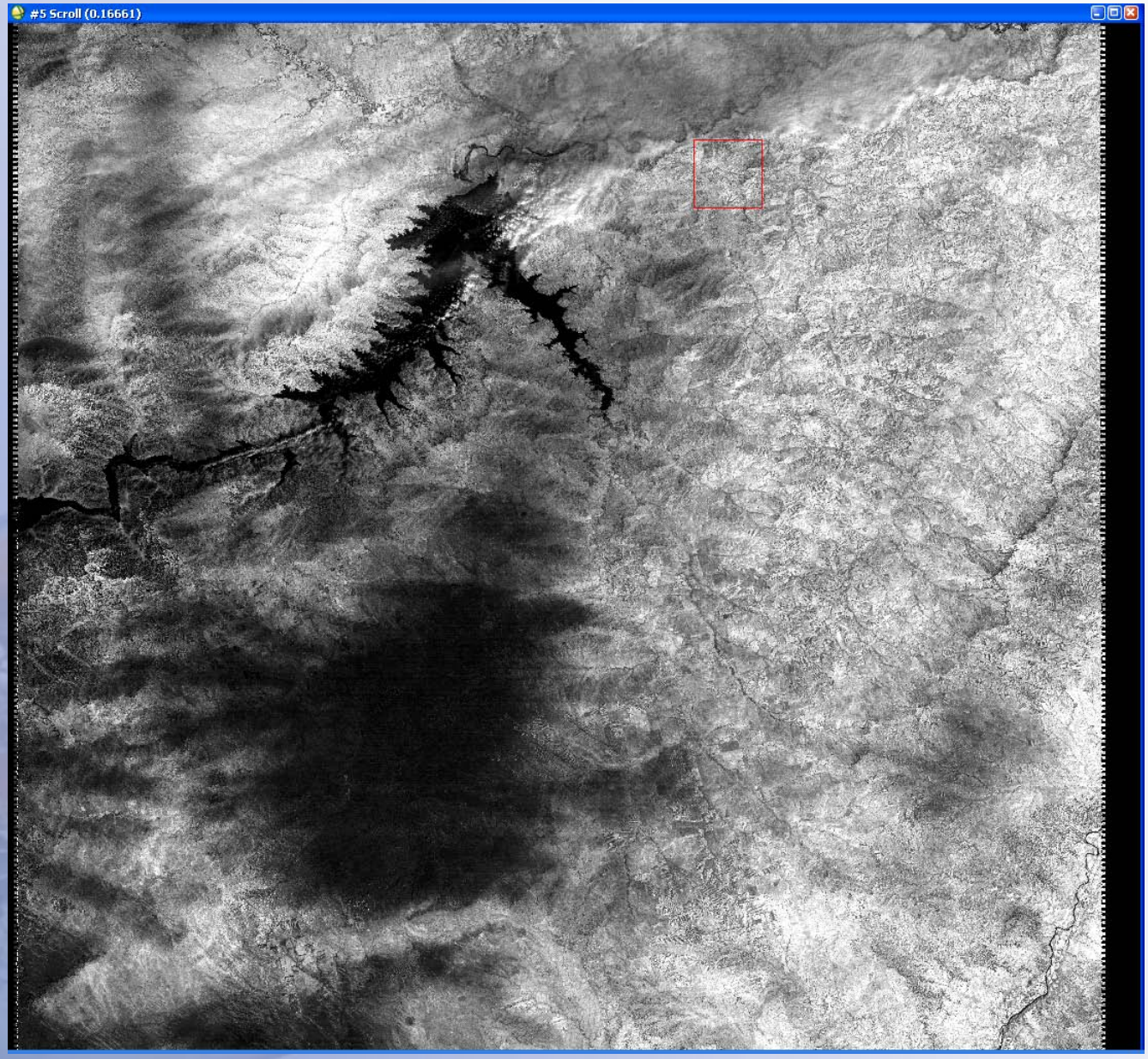

#2 (6600x5984):corrected:512559_2_0_inverse_008.hd...
File Overlay Enhance Tools Window


#2 Zoom [4x]

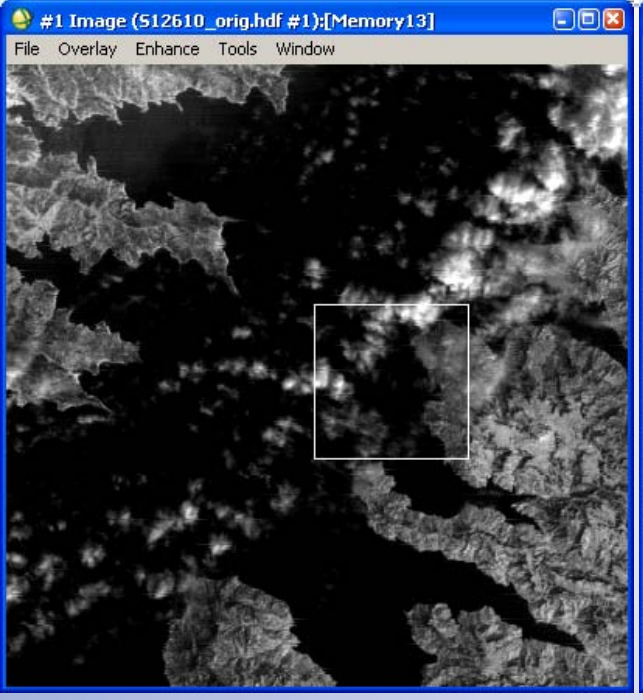

#2 Zoom [4x]

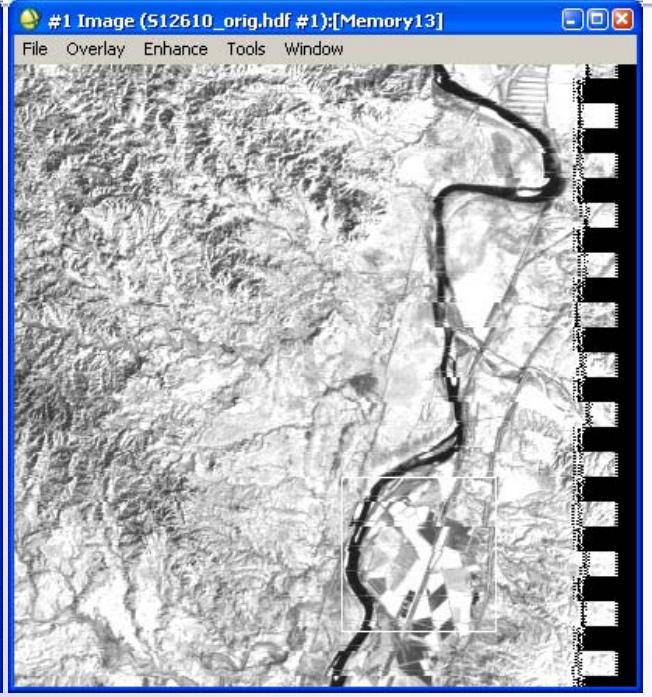

#2 Zoom [4x]

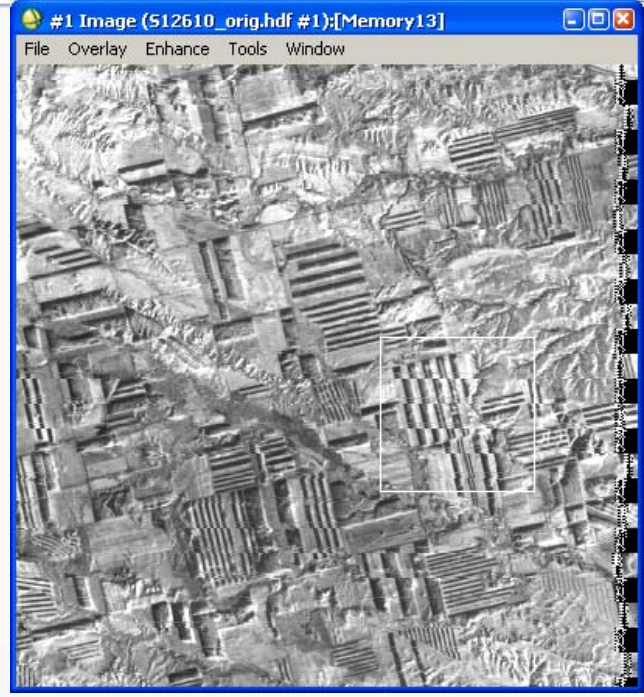
Montana

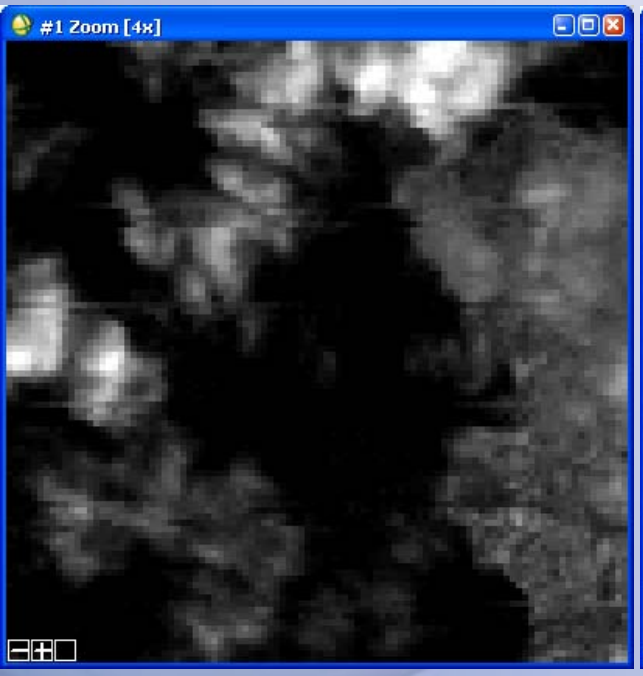


- Acquired on 12/07/1982
- Periodic Crop Lands.
- High frequency structures.


#1 Image (512610_orig.hdf #1):[Memory13]
File Overlay Enhance Tools Window

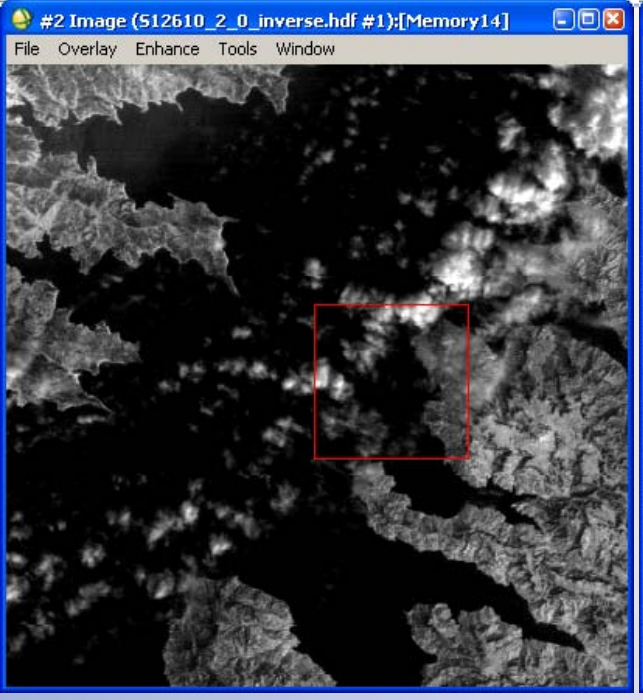

#1 Image (512610_orig.hdf #1):[Memory13]
File Overlay Enhance Tools Window

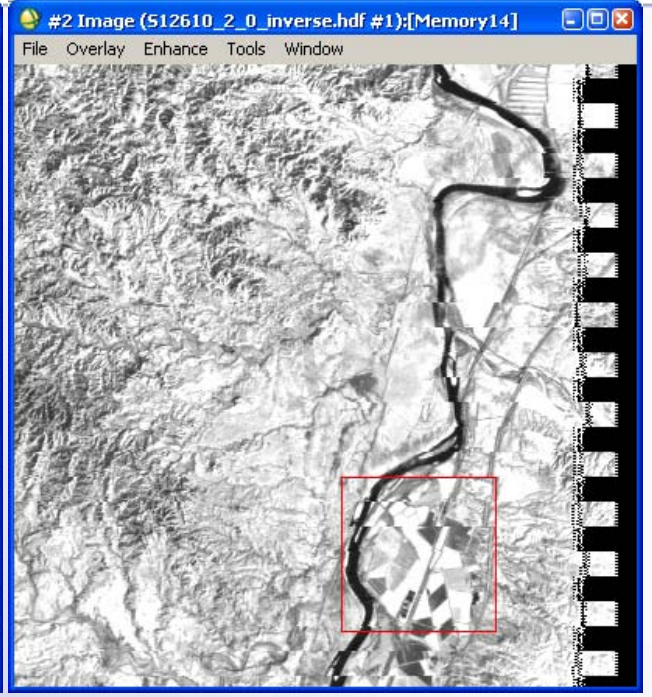

#1 Image (512610_orig.hdf #1):[Memory13]
File Overlay Enhance Tools Window

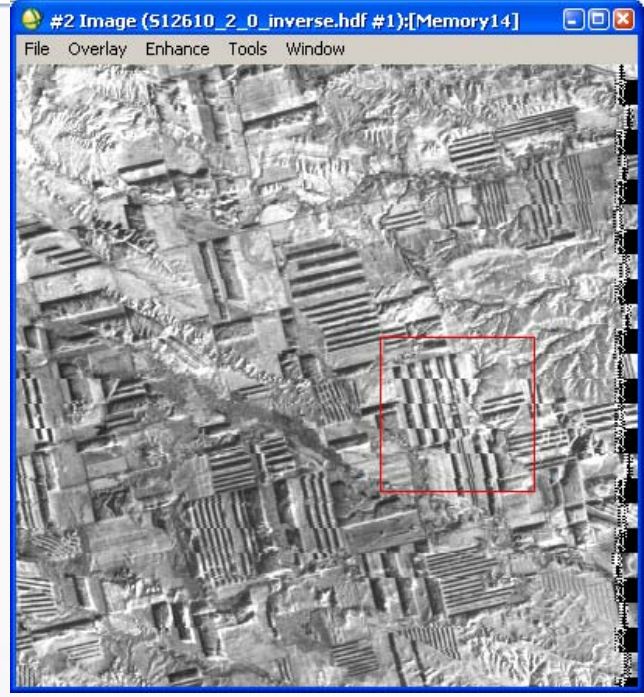

#1 Zoom [4x]

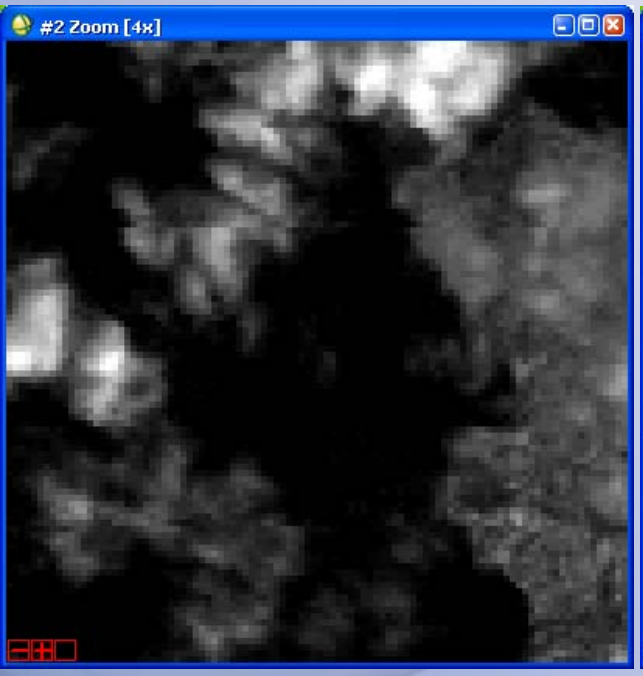

#1 Zoom [4x]


#1 Zoom [4x]

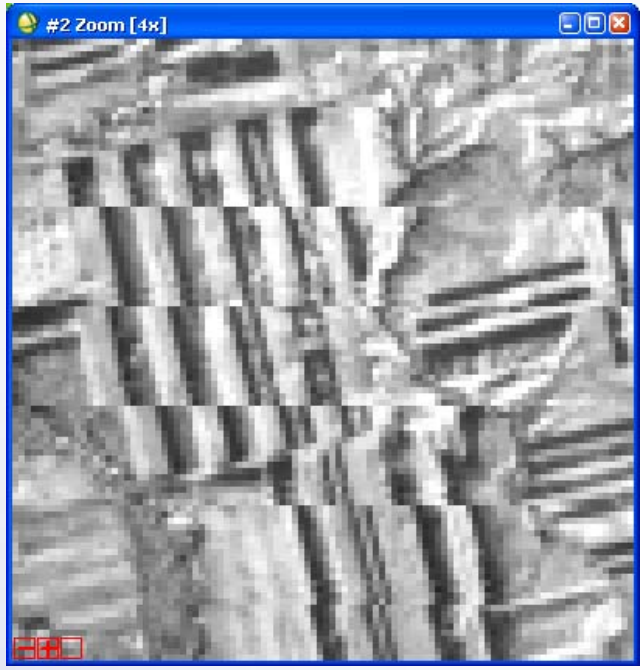

#2 Image (512610_2_0_inverse.hdf #1):[Memory14]
File Overlay Enhance Tools Window


#2 Image (512610_2_0_inverse.hdf #1):[Memory14]
File Overlay Enhance Tools Window


#2 Image (512610_2_0_inverse.hdf #1):[Memory14]
File Overlay Enhance Tools Window


#2 Zoom [4x]


#2 Zoom [4x]


#2 Zoom [4x]

“The Whole Ball of Wax”
A Complete Landsat Calibration

- Dave Aaron
- Ben Jasinski
- Sadhana Karki

Recall from previous meetings…

- Landsat 5 TM cross-calibrated to Landsat 7 ETM+
- Landsat 4 TM cross-calibrated to Landsat 5 TM
- Landsat 1-5 MSS instruments cross-calibrated sequentially to Landsat 5 MSS
- Missing Piece: Absolute Calibration of MSS series. Approach…
  - Use simultaneous collects of Landsat 5 TM and MSS data over stable calibration site—Sonora Desert
  - Use Hyperion to account for spectral differences

Sonora Desert SBAF Results

Sonora Desert ROI	MSS1:TM2		MSS2:TM3		MSS3:TM4		MSS4:TM4	
	Reflectance	Radiance	Reflectance	Radiance	Reflectance	Radiance	Reflectance	Radiance
ROI #1	1.06	1.05	1.02	1.00	1.08	0.90	1.04	1.31
ROI #2	1.06	1.05	1.02	1.00	1.08	0.90	1.04	1.30
ROI #3	1.06	1.04	1.02	1.00	1.08	0.90	1.05	1.32

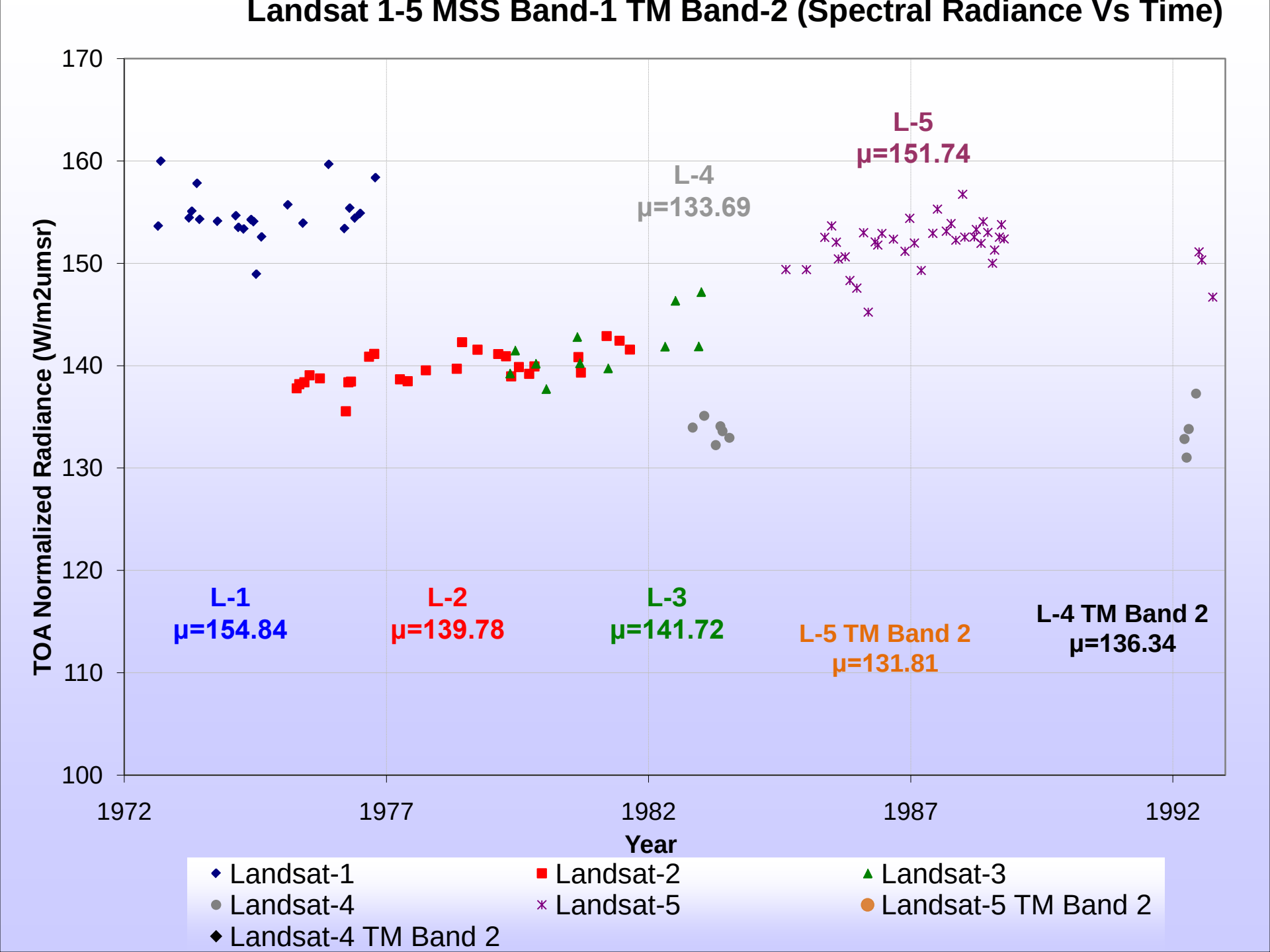
Uncertainty Estimates for Landsat Cross Calibration

Taking into consideration:

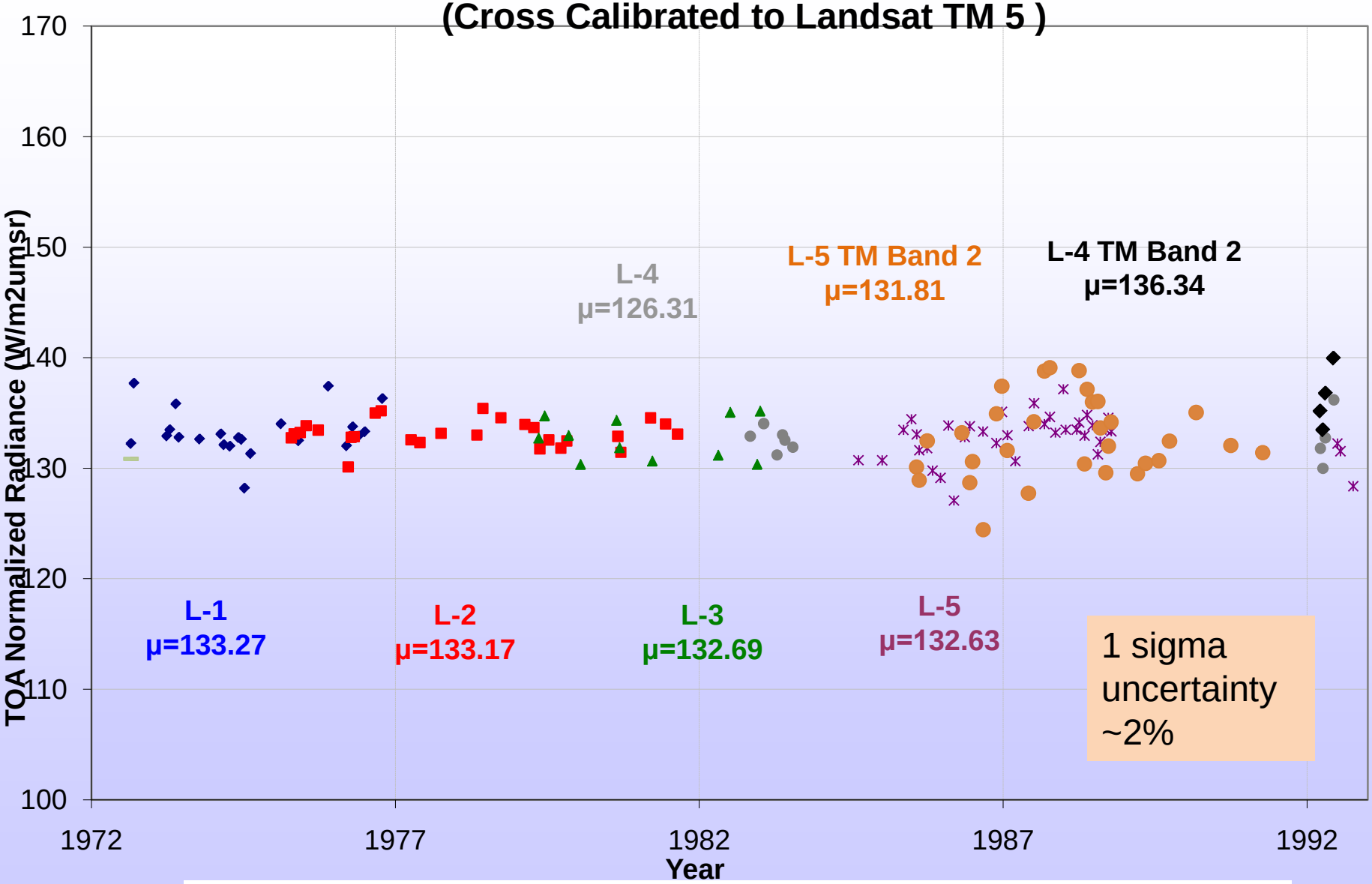
- Atmospheric Differences between Scenes
- Spectral Differences between Scenes
- Target Geometry
- ROI Misregistration Sensitivity

	Atmospheric Effect	SBAF	BRDF	ROI Jitter	Total Uncertainty estimates
Band-1	4.3%	1.1%	0.3%	0.3%	~4.5%
Band-2	3.4%	0.8%	0.4%	0.6%	~4.0%
Band-3	4.4%	1.4%	0.7%	0.8%	~5.0%
Band-4	11.4%	3.0%	0.7%	0.3%	~12.0%

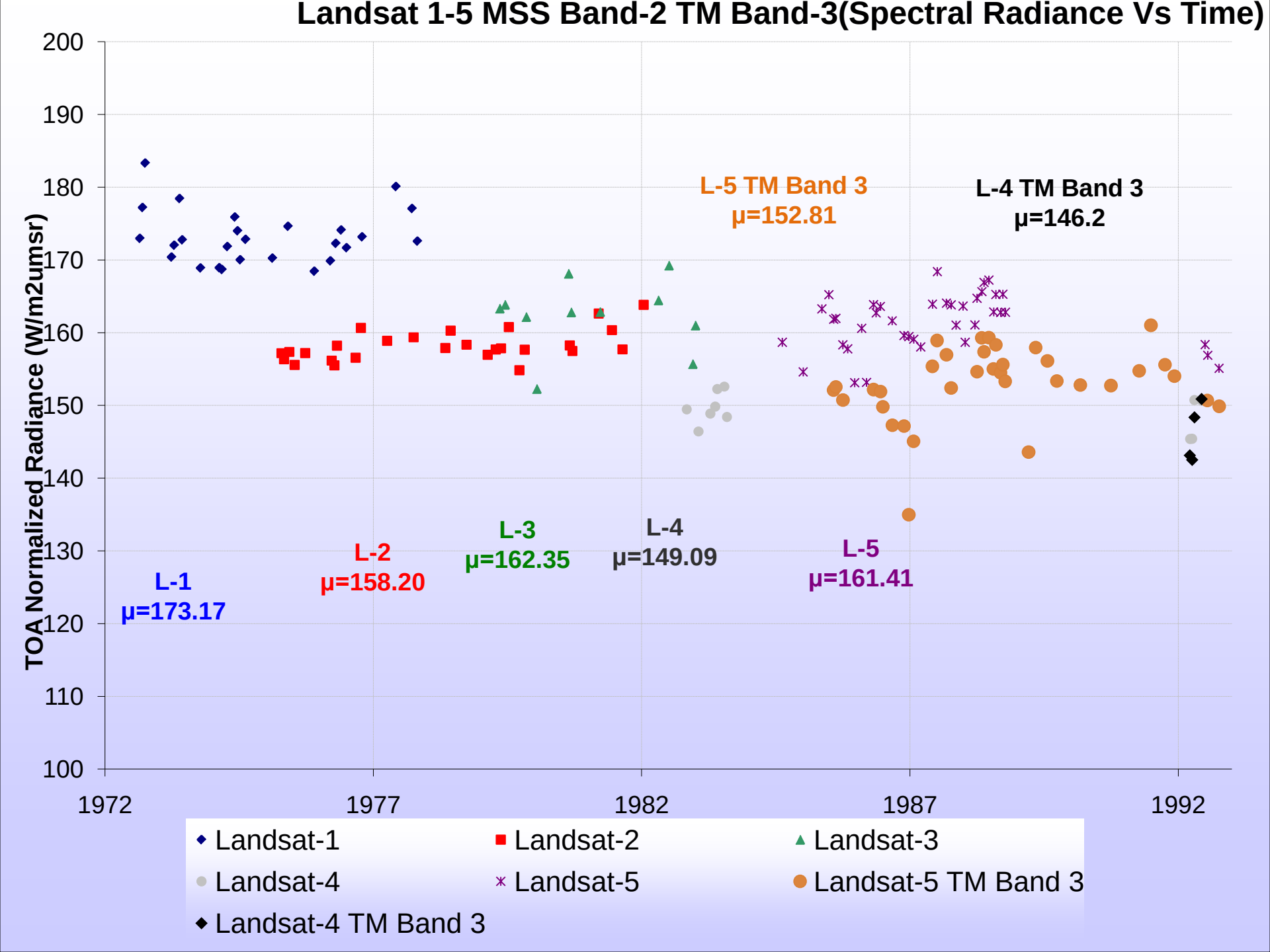
MSS Band 1 Results

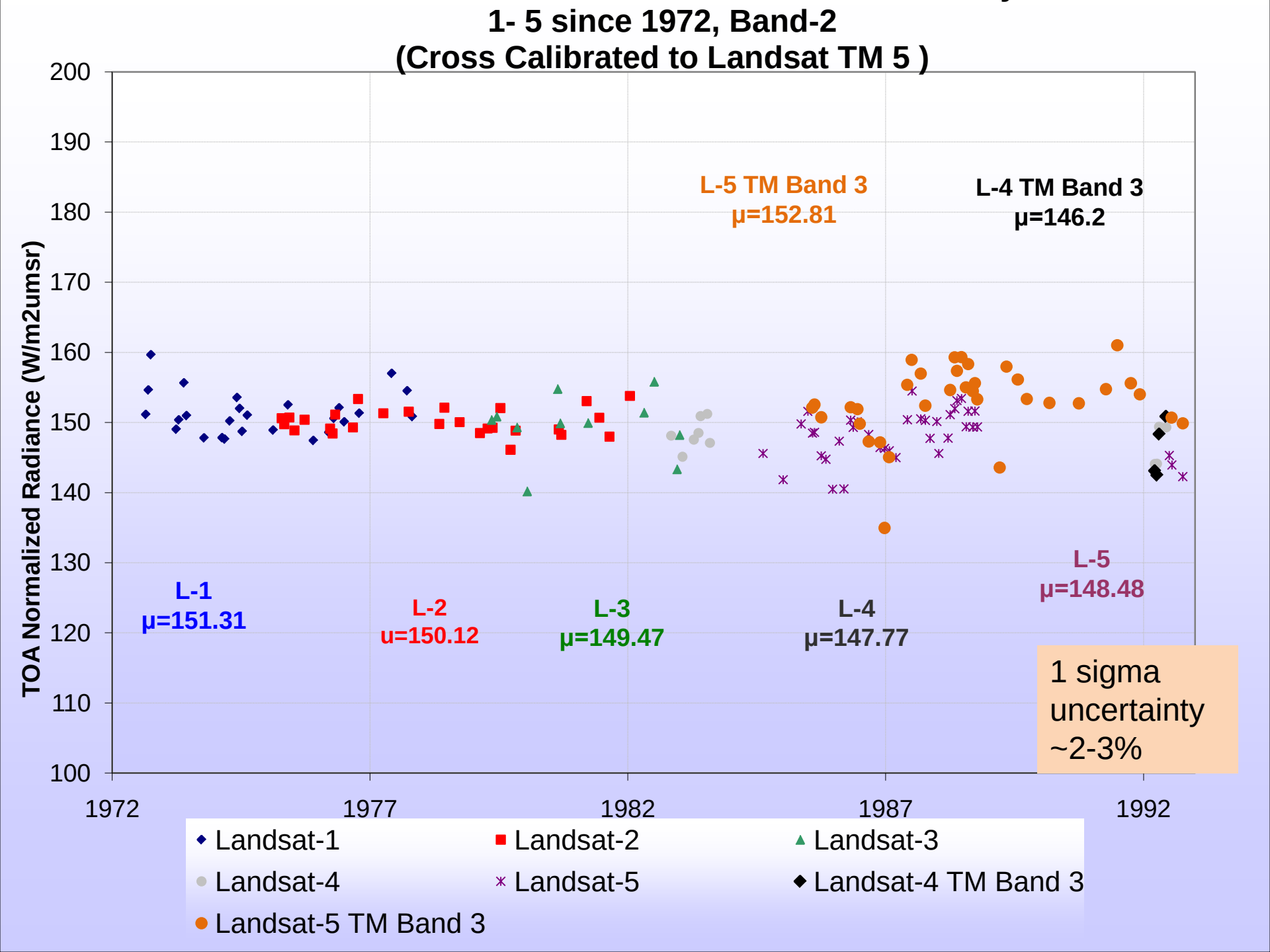

Landsat 1-5 MSS Band-1 TM Band-2 (Spectral Radiance Vs Time)
TOA Normalized Radiance (W/m2umsr)
170
160
150
140
130
120
110
100
1972
1977
1982
1987
1992
Year
L-1
μ=154.84
L-2
μ=139.78
L-3
μ=141.72
L-4
μ=133.69
L-5
μ=151.74
L-5 TM Band 2
μ=131.81
L-4 TM Band 2
μ=136.34
Landsat-1
Landsat-2
Landsat-3
Landsat-4
Landsat-5
Landsat-5 TM Band 2
Landsat-4 TM Band 2

TOA Radiance Derived over Sonoran Desert as seen by Landsat 1- 5 since 1972, Band-1 (Cross Calibrated to Landsat TM 5)

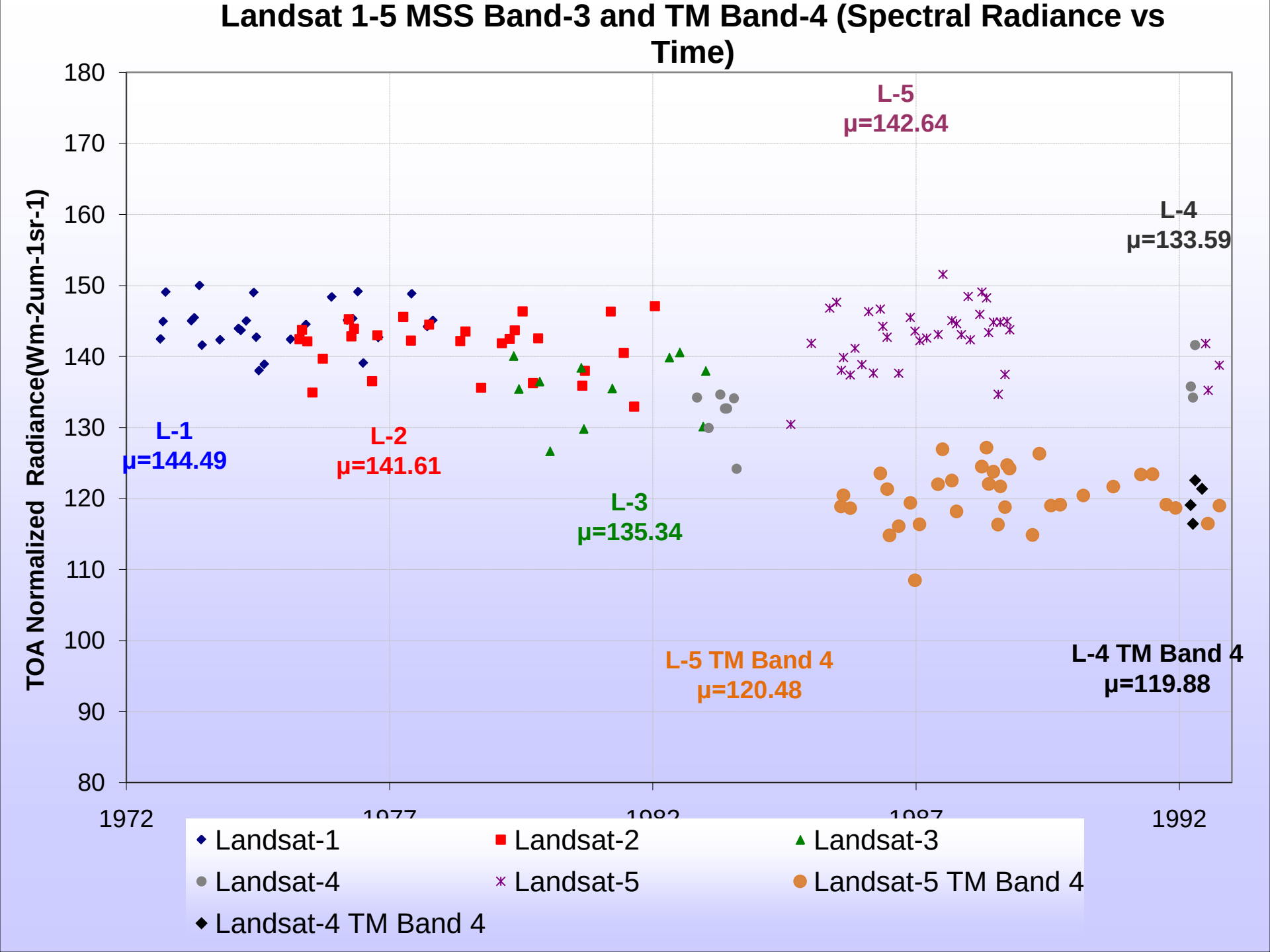


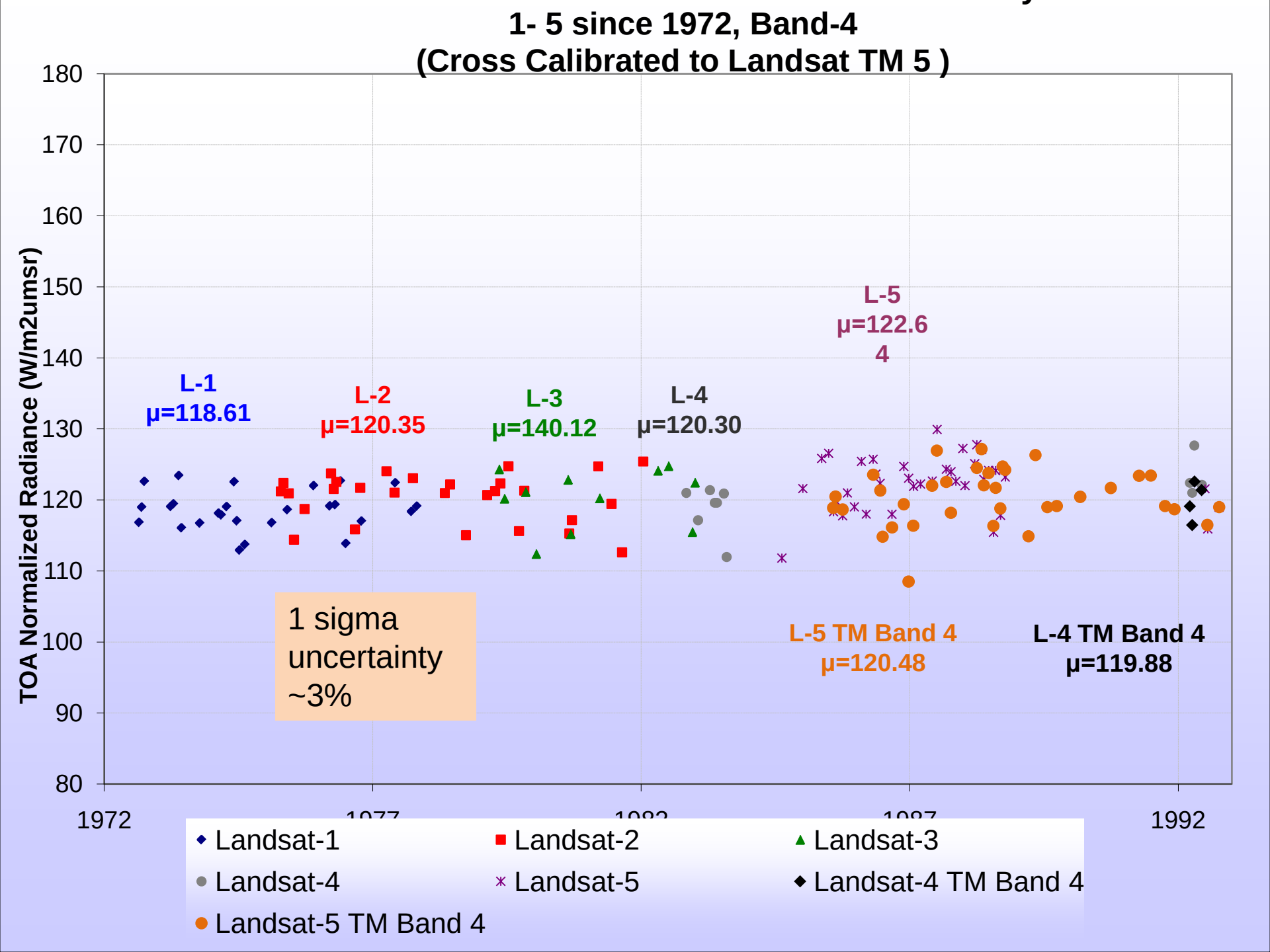
MSS Band 2 Results


Landsat 1-5 MSS Band-2 TM Band-3(Spectral Radiance Vs Time)
TOA Normalized Radiance (W/m2umsr)
200
190
180
170
160
150
140
130
120
110
100
1972
1977
1982
1987
1992
L-1
μ=173.17
L-2
μ=158.20
L-3
μ=162.35
L-4
μ=149.09
L-5
μ=161.41
L-5 TM Band 3
μ=152.81
L-4 TM Band 3
μ=146.2
Landsat-1
Landsat-2
Landsat-3
Landsat-4
Landsat-5
Landsat-5 TM Band 3
Landsat-4 TM Band 3

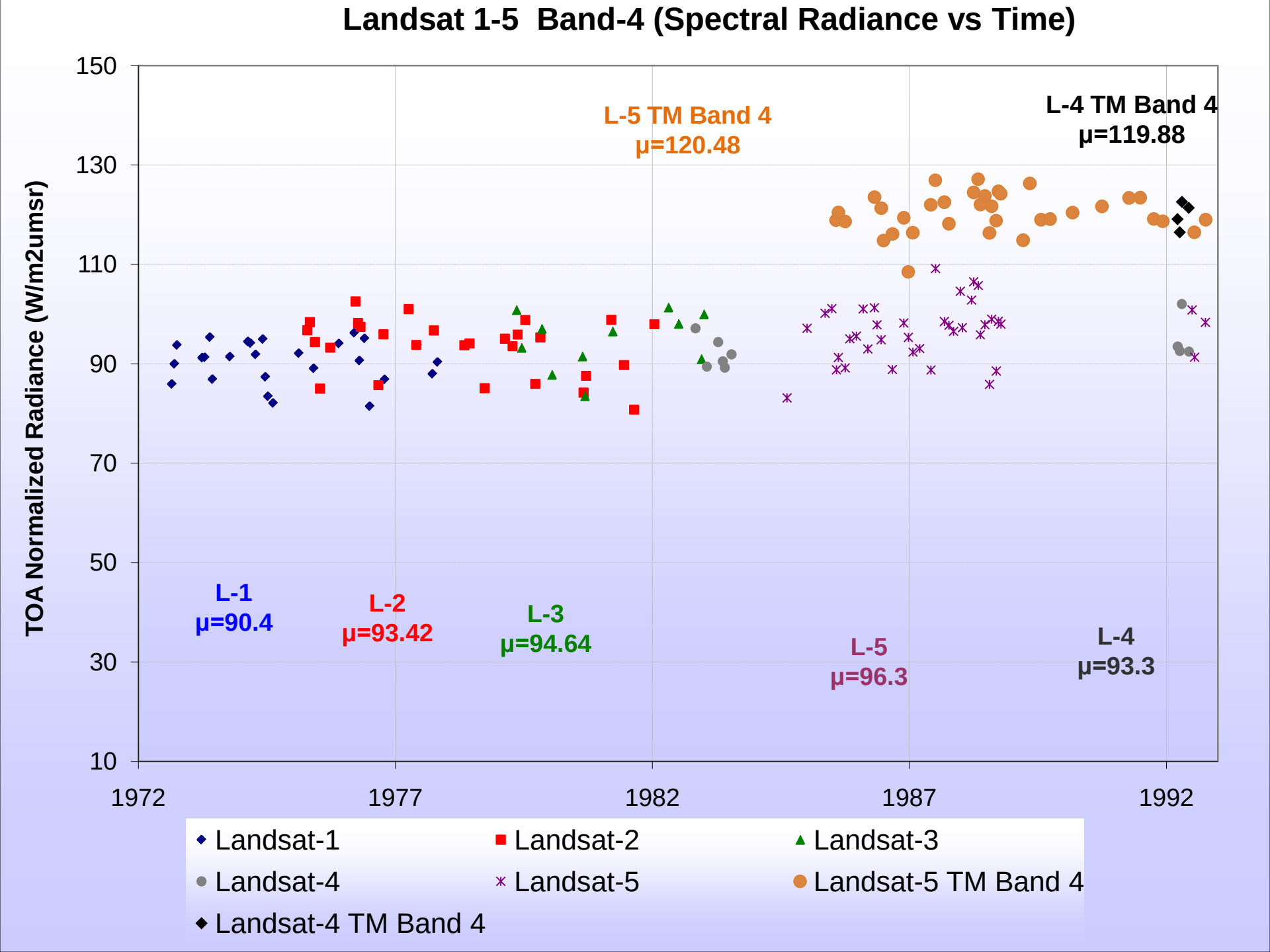

1- 5 since 1972, Band-2
(Cross Calibrated to Landsat TM 5)
TOA Normalized Radiance (W/m2umsr)
200
190
180
170
160
150
140
130
120
110
100
1972
1977
1982
1987
1992
L-5 TM Band 3
μ=152.81
L-4 TM Band 3
μ=146.2
L-1
μ=151.31
L-2
u=150.12
L-3
μ=149.47
L-4
μ=147.77
L-5
μ=148.48
1 sigma
uncertainty
~2-3%
Landsat-1
Landsat-2
Landsat-3
Landsat-4
Landsat-5
Landsat-4 TM Band 3
Landsat-5 TM Band 3

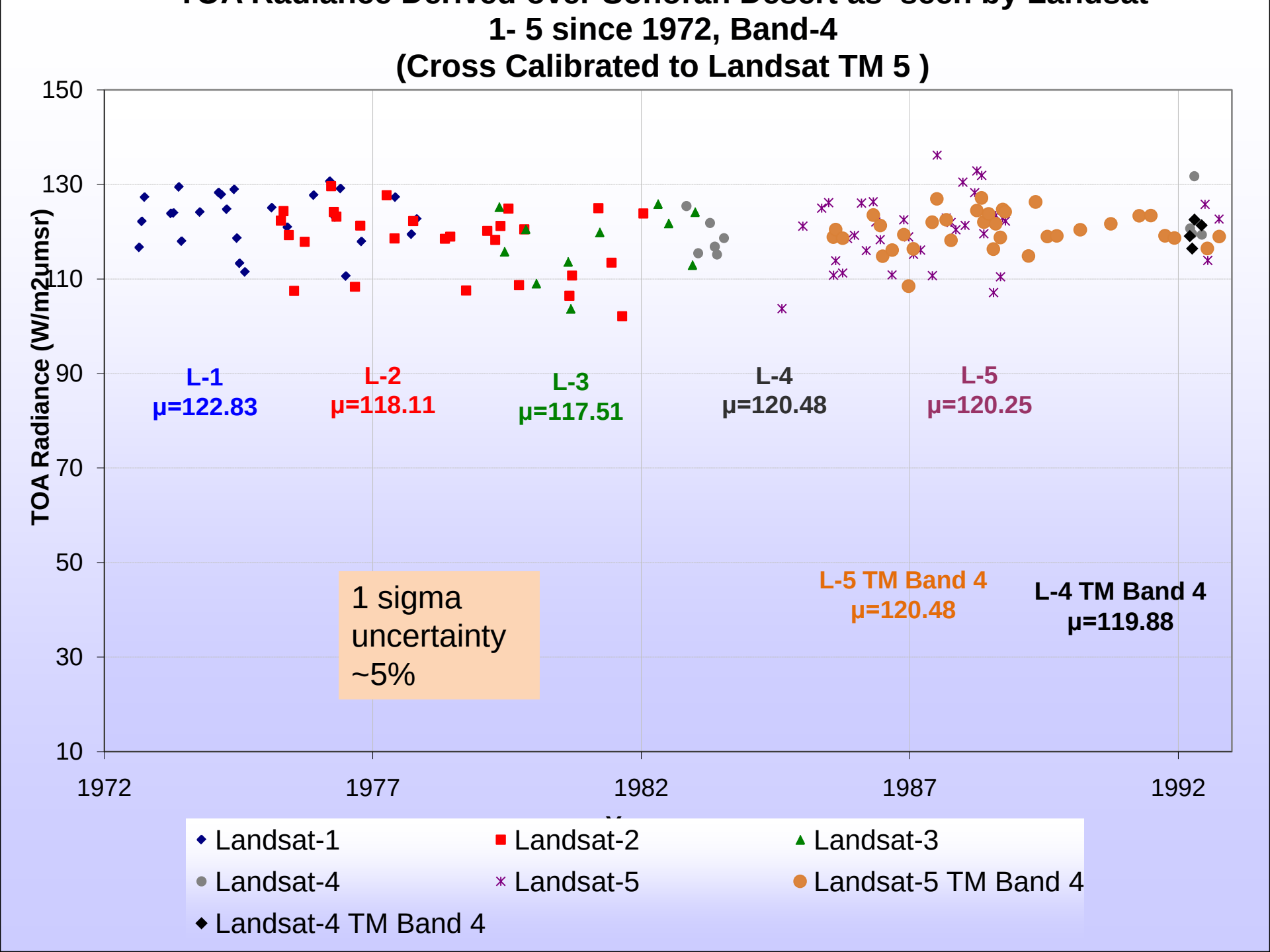
MSS Band 3 Results


Landsat 1-5 MSS Band-3 and TM Band-4 (Spectral Radiance vs Time)
TOA Normalized Radiance(Wm-2um-1sr-1)
180
170
160
150
140
130
120
110
100
90
80
1972
1977
1982
1987
1992
L-5
μ=142.64
L-4
μ=133.59
L-1
μ=144.49
L-2
μ=141.61
L-3
μ=135.34
L-5 TM Band 4
μ=120.48
L-4 TM Band 4
μ=119.88
Landsat-1
Landsat-2
Landsat-3
Landsat-4
Landsat-5
Landsat-5 TM Band 4
Landsat-4 TM Band 4

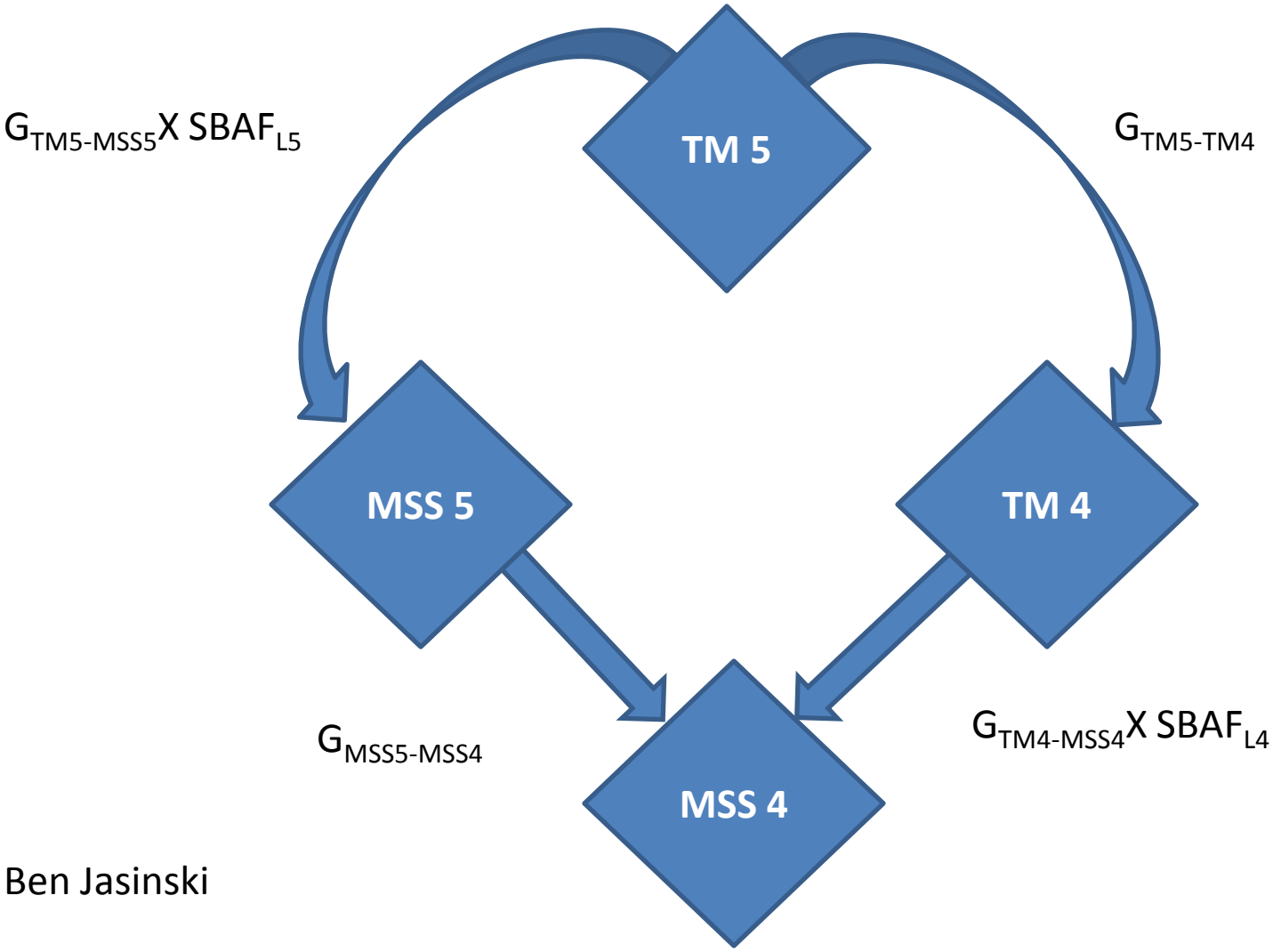

1- 5 since 1972, Band-4
(Cross Calibrated to Landsat TM 5)
TOA Normalized Radiance (W/m2umsr)
180
170
160
150
140
130
120
110
100
90
80
1972
1992
L-1
μ=118.61
L-2
μ=120.35
L-3
μ=140.12
L-4
μ=120.30
L-5
μ=122.6
4
1 sigma
uncertainty
~3%
L-5 TM Band 4
μ=120.48
L-4 TM Band 4
μ=119.88
Landsat-1
Landsat-2
Landsat-3
Landsat-4
Landsat-5
Landsat-4 TM Band 4
Landsat-5 TM Band 4

MSS Band 4 Results


Landsat 1-5 Band-4 (Spectral Radiance vs Time)
TOA Normalized Radiance (W/m2umsr)
150
130
110
90
70
50
30
10
1972
1977
1982
1987
1992
L-5 TM Band 4
μ=120.48
L-4 TM Band 4
μ=119.88
L-1
μ=90.4
L-2
μ=93.42
L-3
μ=94.64
L-5
μ=96.3
L-4
μ=93.3
Landsat-1
Landsat-2
Landsat-3
Landsat-4
Landsat-5
Landsat-5 TM Band 4
Landsat-4 TM Band 4


1- 5 since 1972, Band-4
(Cross Calibrated to Landsat TM 5)
TOA Radiance (W/m2µmsr)
150
130
110
90
70
50
30
10
1972
1977
1982
1987
1992
L-1
µ=122.83
L-2
µ=118.11
L-3
µ=117.51
L-4
µ=120.48
L-5
µ=120.25
1 sigma
uncertainty
~5%
L-5 TM Band 4
µ=120.48
L-4 TM Band 4
µ=119.88
Landsat-1
Landsat-2
Landsat-3
Landsat-4
Landsat-5
Landsat-5 TM Band 4
Landsat-4 TM Band 4

Validation By Completing the TM-MSS Love Loop
(Converting TM 5 Radiance data to MSS 4 Radiance data)



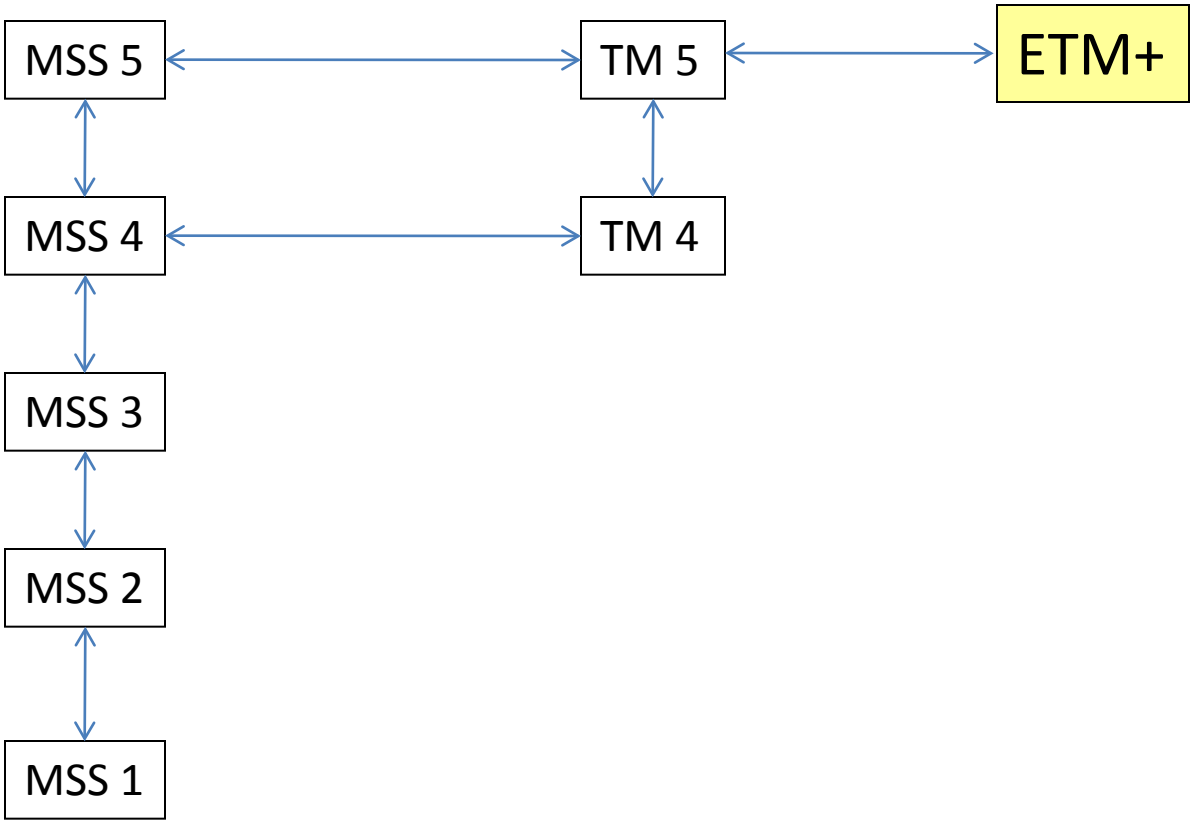
Ben Jasinski

Results from Equation (1) for all Bands For MSS 4

MSS 4 Bands	Left Side Gain	Right Side Gain	% Difference
Band 1	1.009	1.010	0.1%
Band 2	1.010	1.012	0.2%
Band 3	1.081	1.112	2.9%
Band 4	0.783	0.772	1.4%

The percent difference between the two different routes taken to obtain gains from TM 5 to MSS 4 agree within 3%. Well within the estimated uncertainties, predicted before cross calibration.

Absolute Gain and Bias for placing all Landsat Sensors on a consistent absolute radiance scale



Equivalent Landsat 5 TM Radiance Conversion Factors For All Landsat Sensors (From Qcal to At-Sensor Radiance) (SBAF Specific)

Landsat 1 MSS			Landsat 2 MSS			Landsat 3 MSS		
	G $\frac{(W/m^2srμm)}{DN}$	**Bias** ($W/m^2srμm$)		**G** $\frac{(W/m^2srμm)}{DN}$	**Bias** ($W/m^2srμm$)		**G** $\frac{(W/m^2srμm)}{DN}$	**Bias** ($W/m^2srμm$)
Band 1	1.5968	0	**Band 1**	*1.8036	*7.1860	**Band 1**	*1.7507	*3.4876
Band 2	1.2897	9.1157	**Band 2**	*1.3150	*0.7062	**Band 2**	1.2724	2.7543
Band 3	1.3415	-8.4567	**Band 3**	1.1520	-2.4442	**Band 3**	1.0517	2.9496
Band 4	1.2522	0	**Band 4**	0.9654	3.5493	**Band 4**	1.0349	0.9505
Landsat 4 MSS			**Landsat 5 MSS**			**Landsat 4 TM**		
	G $\frac{(W/m^2srμm)}{DN}$	**Bias** ($W/m^2srμm$)		**G** $\frac{(W/m^2srμm)}{DN}$	**Bias** ($W/m^2srμm$)		**G** $\frac{(W/m^2srμm)}{DN}$	**Bias** ($W/m^2srμm$)
Band 1	1.7365	3.7699	**Band 1**	1.7345	2.4937	**Band 1**	0.6792	-2.2
Band 2	1.2452	3.9535	**Band 2**	1.2679	2.7447	**Band 2**	1.3340	-4.17
Band 3	1.0774	4.9938	**Band 3**	1.0693	4.7483	**Band 3**	1.0046	-2.17
Band 4	0.8717	3.9538	**Band 4**	0.9025	2.8653	**Band 4**	0.8760	-2.39

Values marked with * have an additional time dependent factor

Time Dependent Factor

Landsat 2 MSS	
	Time Dependent Factor
Band 1	$\frac{147.72}{(0.56709*(T-T_{Launch})+144.85)}$
Band 2	$\frac{170.85}{(0.53916*(T-T_{Launch})+168.11)}$
Landsat 3 MSS	
Band 1	$\frac{151.55}{(1.5251*(T-T_{Launch})+144.10)}$

Multiply the Gain and the Bias by the Time Dependent Factor

SUMMARY

- Landsat Image Assessment System (IAS) invaluable for continuous improvement of sensor calibration
  - Landsat 5 TM Relative Gains is a good example
- MTF Compensation is now a Landsat reality
  - Success with L4 TM Band 2 detectors may suggest additional opportunities for improvements
- A consistent absolute radiometric calibration of Landsat sensors has been accomplished
  - At least in the desert…