Long Term Radiometric Calibration: Can We Extend Consistent Calibration Parameters From Landsats 7 & 5 Back Through Landsats 1-4 MSS?

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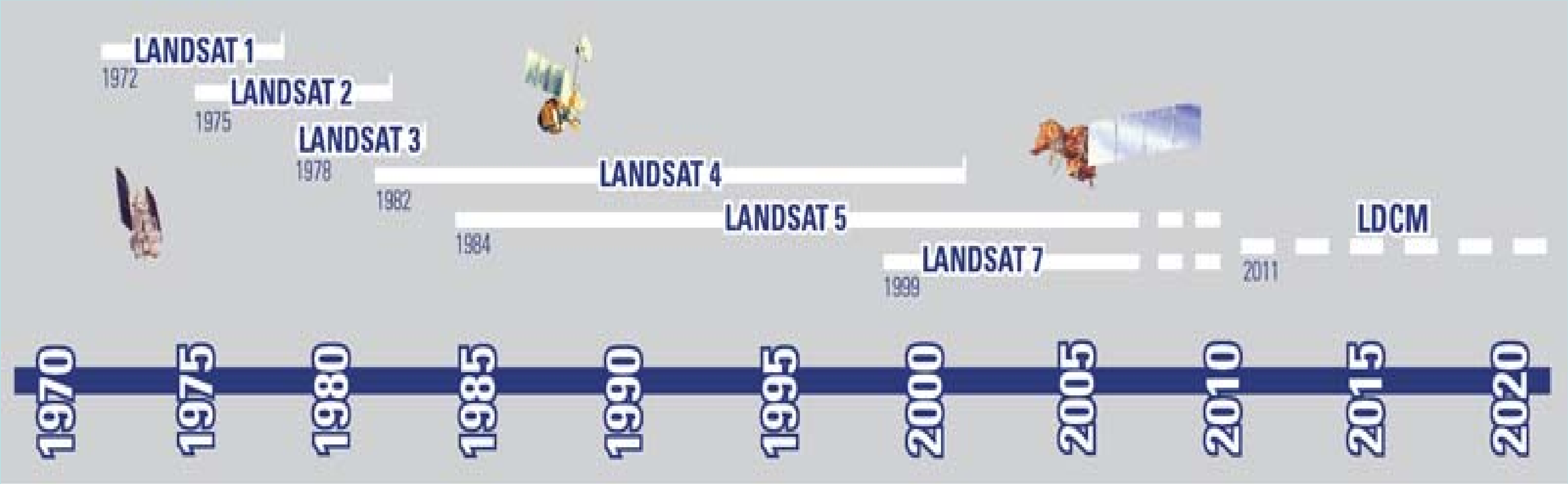
Motivation:
Over 35 years of data

Landsat Missions Timeline



Graphic from: **landsat.usgs.gov/about_mission_history.php**

Data from Landsat 7(ETM+) and Landsat 5(TM) are trended and processed using a consistent system (IAS projects).

An archive exists from 6 Landsat sensor systems:

- Landsats 1-3
  - RBV
  - MSS
- Landsats 4-5
  - MSS
  - TM
- Landsat 7
  - ETM+

With the launch of OLI the long term data base will extend into the future.

As we extend earth observation into the future, can archived Landsat data be reprocessed to provide a better data continuum?

SDSU is taking its experience base in radiometric calibration to:

- Evaluate the viability of extending the Landsat 5 and 7 calibration base back through the predecessor Landsat sensor systems.
- Establish a basis for an IAS system to trend these predecessor systems.
- Sadly we can’t use our vicarious calibration technique
  - Time machine?

MSS Calibration Plan Outline

- **L5 MSS Calibration**
  - Calibrate to L5 TM through coincident scenes
  - Develop trend through use of invariant sites
  - Develop trend through use of internal cal wedge data
- **L4 MSS Calibration**
  - Calibrate to L4 TM through coincident scenes
  - Calibrate to L5 MSS through coincident or near-coincident scenes
  - Develop trend through use of invariant sites
  - Develop trend through use of cal wedge data
- **L3 MSS Calibration**
  - Calibrate to L4 MSS through coincident or near coincident scenes
    - Note: this is likely the highest risk point in the process!
  - Potential cross-calibration to L4 TM through coincident or near coincident scenes
  - Develop trend through use of invariant sites
  - Develop trend through use of cal wedge data
- **Landsat 2 MSS Calibration**
  - Calibrate to L3 MSS through coincident or near coincident scenes
  - Develop trend through use of invariant sites
  - Develop trend through use of cal wedge data
- **Landsat 1 MSS Calibration**
  - Calibrate to L2 MSS through coincident or near coincident scenes
  - Develop trend through use of invariant sites
  - Develop trend through use of cal wedge data

‘Back-calibrate’ via:

L5 TM ⇨L5 MSS

L5 MSS ⇨L4 MSS

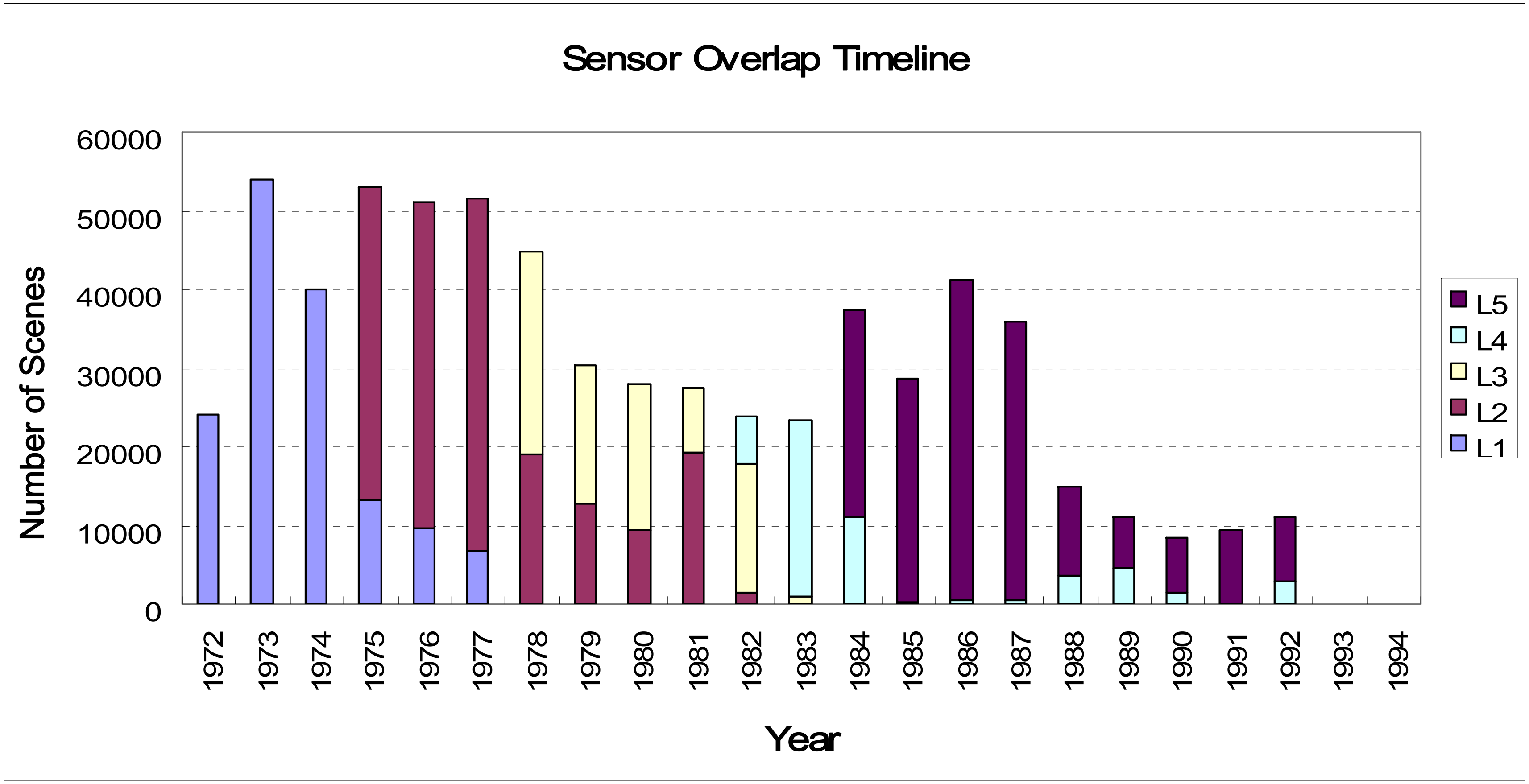
L4 MSS ⇨L3 MSS

L3 MSS ⇨L2 MSS

L2 MSS ⇨L1 MSS

Question: Is there sufficient data to follow this data chain?

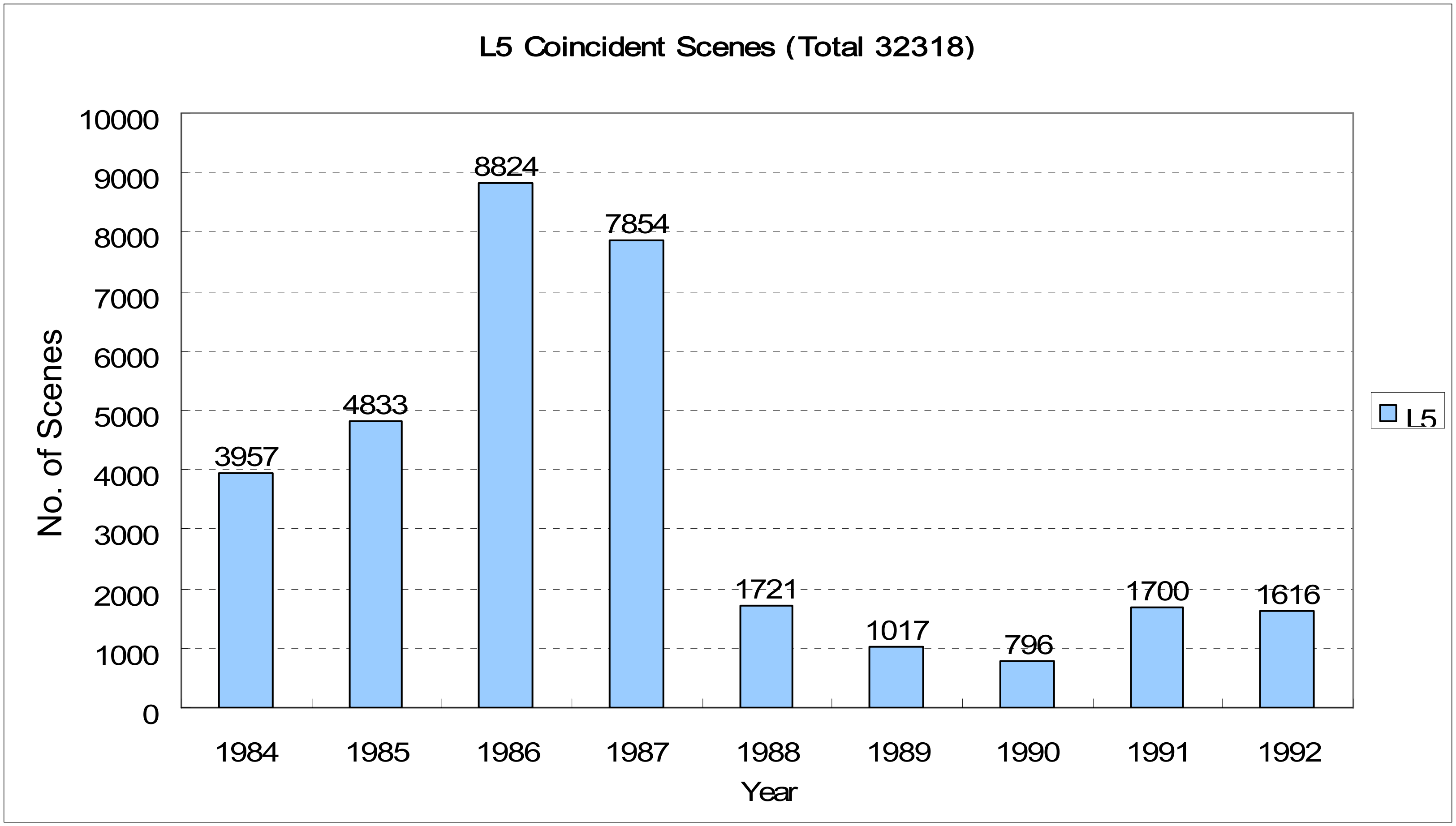
Archive Data Overlap Timeline



Overlap Timeline

Year	L1	L2	L3	L4	L5
1972	24100				
1973	53884				
1974	40047				
1975	13138	39784			
1976	9633	41424			
1977	6824	44774			
1978	101	18868	25858		
1979		12801	17572		
1980		9280	18724		
1981		19257	8142		
1982		1481	16348	6058	
1983			872	22460	
1984				11141	26204
1985				348	28447
1986				423	40780
1987				464	35469
1988				3612	11217
1989				4687	6506
1990				1377	7059
1991				116	9174
1992				2932	8043
1993					0
1994					1
Total Scenes	**147727**	**187669**	**87516**	**53619**	**172900**

Timeframe of L5 TM/MSS Coincident Scenes



L5/L4 Near Coincident MSS Scenes

- The shortest period between any two near-coincident scenes of L4 and L5 MSS is 8 days.
- Several good quality near-coincident scenes from White Sands, Sonoran Desert, Railroad Valley, Ivanpah Playa, and Rogers Dry lake exists for Cross-Calibrating L5 MSS to L4 MSS.

White Sands (P33R37)

L4 Scene ID	L5 Scene ID
LM40330371984310AAA03	LM50330371984302AAA03
LM40330371985056AAA03	LM50330371985048AAA03
LM40330371992188AAA03	LM50330371992180AAA03

L5/L4 Near Coincident MSS Scenes (contd.)

Sonoran Desert (P38R38)

L4 Scene ID	L5 Scene ID
LM40380381992159AAA03	LM50380381992183AAA03

Railroad Valley(P40R33)

L4 Scene ID	L5 Scene ID
LM40400331992205AAA03	LM50400331992213AAA03

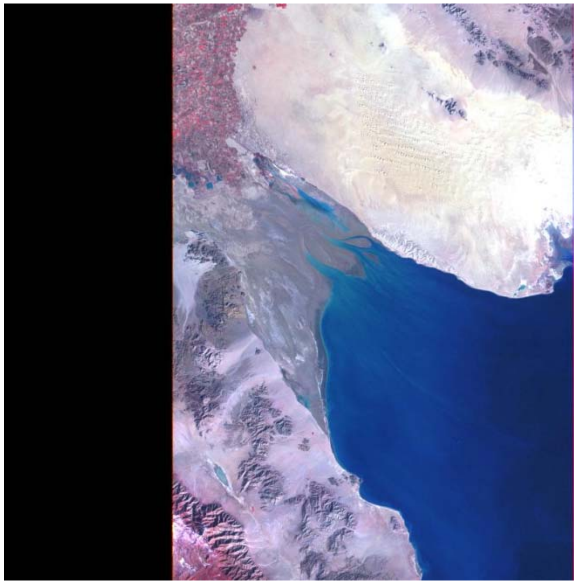
Ivanpah Playa (P39R35)

L4 Scene ID	L5 Scene ID
LM40390351986277AAA03	LM50390351986285AAA03
LM40390351986309AAA03	LM50390351986317AAA03

Example: Sonoran Desert L3/L4 MSS Cross Cal images

L3 MSS

- **ID: LM30410381982365AAA03**
- **Cloud Cover: 90%** Qlty: 9
- Date: 1982/12/31
- Sun Elevation: 27
- Sun Azimuth: 147



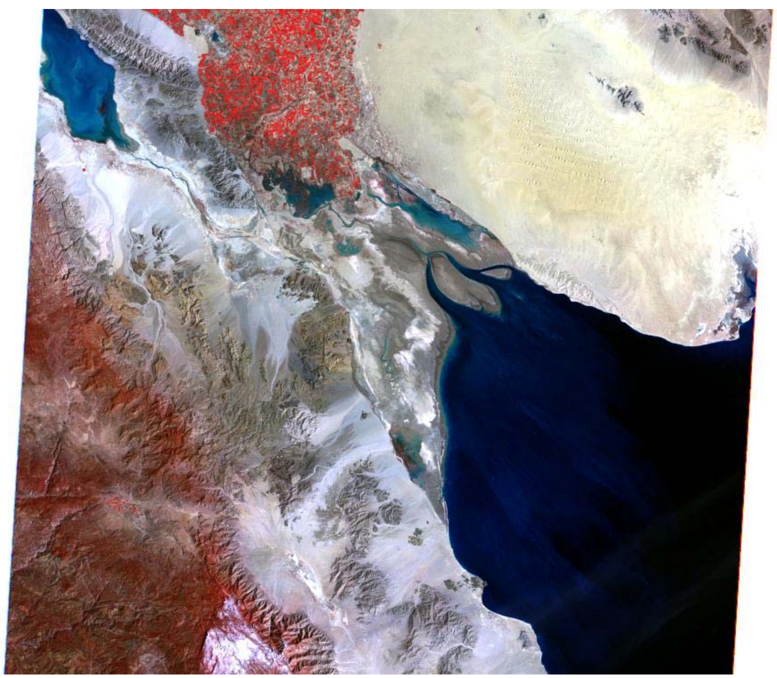
L4 MSS

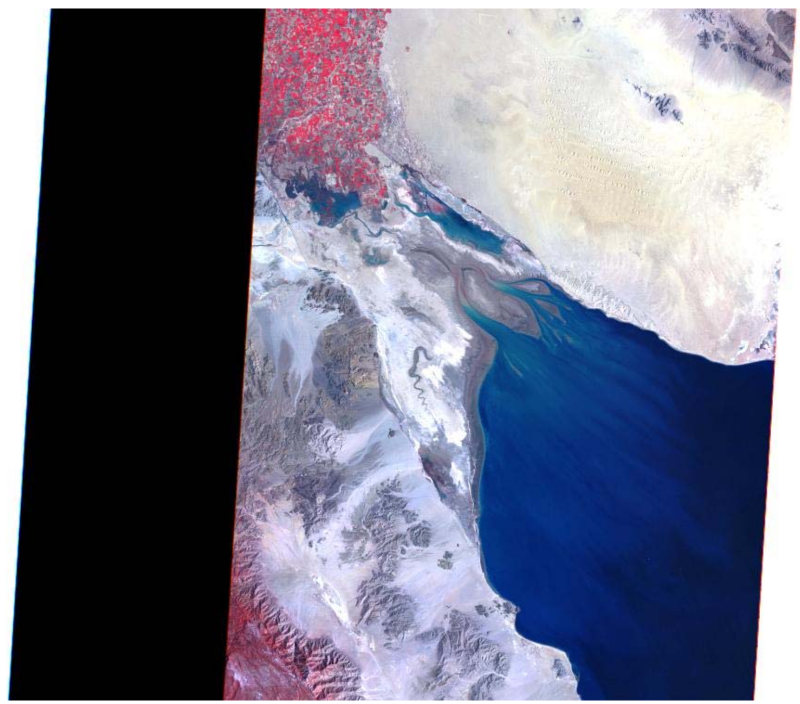
- **ID: LM40380381983022AAA03**
- Cloud Cover: 10% Qlty: 9
- Date: 1983/1/22
- Sun Elevation: 29
- Sun Azimuth: 144

Example: Sonoran Desert L2/L3 MSS Cross Cal images

- **ID: LM20410381981073AAA03**
- **Cloud Cover: 10% Qlty: 9**
- **Date: 1981/3/14**
- **Sun Elevation: 42**
- **Sun Azimuth: 129**

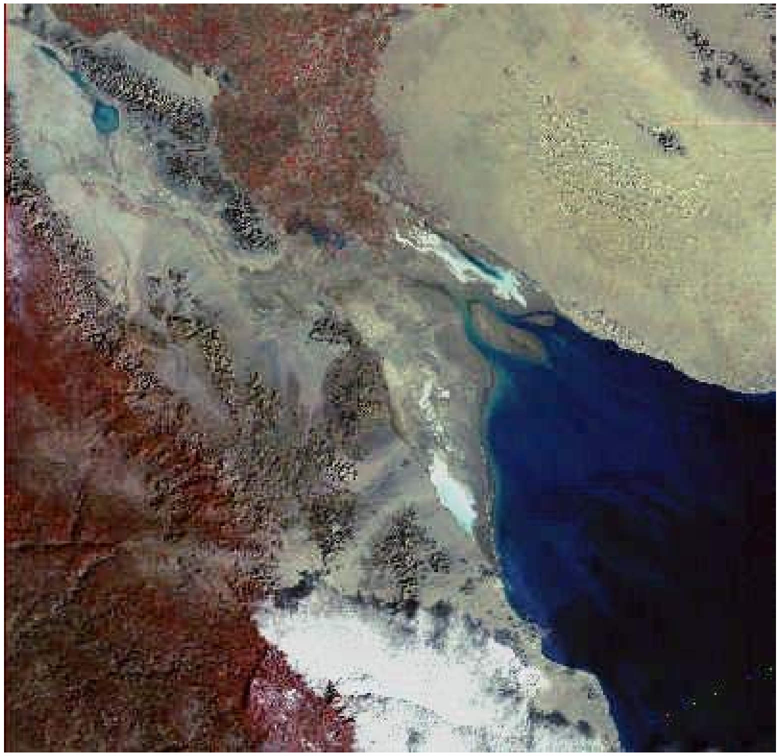
- **ID: LM30410381981082AAA04**
- **Cloud Cover: 0% Qlty: 7**
- **Date: 1981/3/23**
- **Sun Elevation: 45**
- **Sun Azimuth: 125**





Example: Sonoran Desert L1/L2 MSS Cross Cal images

- **ID: LM10410381975348AAA01**
- **Cloud Cover: 10% Qlty: 4**
- **Date: 1975/12/14**
- **Sun Elevation: 25**
- **Sun Azimuth: 143**



- **ID: LM20410381975357AAA01**
- **Cloud Cover: 10% Qlty: 4**
- **Date: 1975/12/23**
- **Sun Elevation: 26**
- **Sun Azimuth: 147**

Scene availability summary

- Significant number of TM/MSS coincident scenes from various calibration sites exists (particularly for L5).
- Sufficient near-coincident scenes are available for cross-calibration of L5 to L4 MSS, L3 to L2 MSS, and L2 to L1 MSS.
- Cross-calibration of L4 MSS to L3 MSS is somewhat critical (very few near-coincident scenes are available *in the EROS archive*)

Our partners at ESA

Libya 4 scenes at ESA

- Some additional Libya 4 scenes of Landsat 1-7 are available at ESA that are not in USGS archive.
- As per information in ESA’s website, they have L0R data available for MSS sensors.
- Landsat 2
  - 14 Libya 4 scenes available for Landsat 2 from 1976 to 1981 (at least one scene every year).
  - The L0R data of these could be the potential source to investigate the lifetime trend of this sensor.
- Some scenes exist for other sensors too which along with the scenes available in USGS archive could be useful for cross-cal of MSS sensors.
- Received an initial set of scenes which are in the process of being analyzed.

Notes on applying the Pseudo-Invariant Calibration Site (PICS) technique

L5 TM ⇨L5 MSS

- There are many instances where L5 imaged our known invariant test sites with TM and MSS instruments simultaneously; thus, opening the opportunity of Cross-calibrating L5 MSS against L5 TM using a simultaneous scene-pair based approach

L5 MSS ⇨L4 MSS

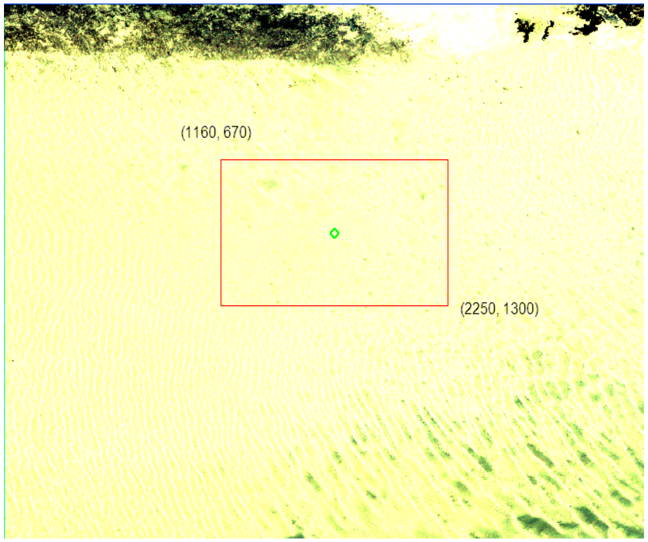
- The shortest period between any two near-coincident scenes of L4 and L5 MSS is 8 days

- The MSS-A data available is in calibrated DNs (Q_{cal})

Region of Interest

L5 TM ⇨L5 MSS

- Twelve good quality, cloud free coincident TM and MSS scenes (1984 to 1987) from Libya 4 test site were used for this study
- ROI : 1090*630 pixels rectangle on Libya 4 MSS scene



- The sensitivity to possible misregistration was checked by shifting the ROI up and down; left and right (up to 5 MSS pixels, one at a time) and mean DN was calculated for the specified ROI in every shift of the ROI
- Very low standard deviation (less than 1%) of the Mean DNs indicates misregistration should not pose a significant problem for Libya 4 scenes

Spectral Considerations

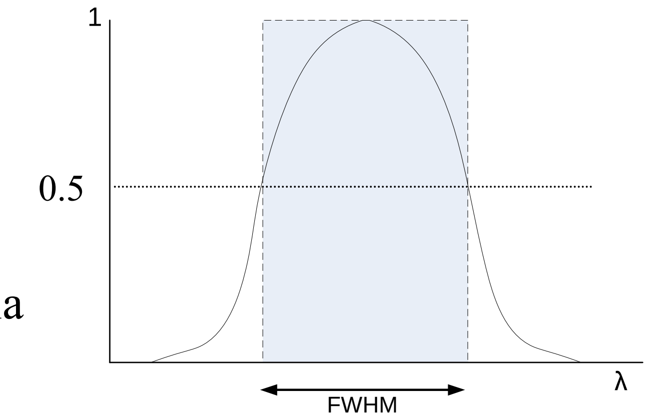
In band radiance is a function of:

- specified bandwidth (BW)
- system relative spectral response (RSR)

In-band Radiance to Spectral Radiance Conversion: Bandwidth considerations

Different specifications of bandwidth

- Nominal BW
- FWHM (Markham and Barker, 1983)
- Equivalent Rectangular Bandwidth (ERBW)
- Quadratic moment BWs (Palmer, 1984; Malila and Anderson, 1986)



Possible specifiers for effective BWs for L5 MSS bands (in micrometers)

Band	Nominal BW	FWHM BW	ERBW	QMBW
1	0.100	0.109	0.106	0.1162
2	0.100	0.0937	0.089	0.0988
3	0.100	0.1099	0.099	0.1163
4	0.300	0.2263	0.221	0.2752

Dissimilar RSR Profiles: A key concern

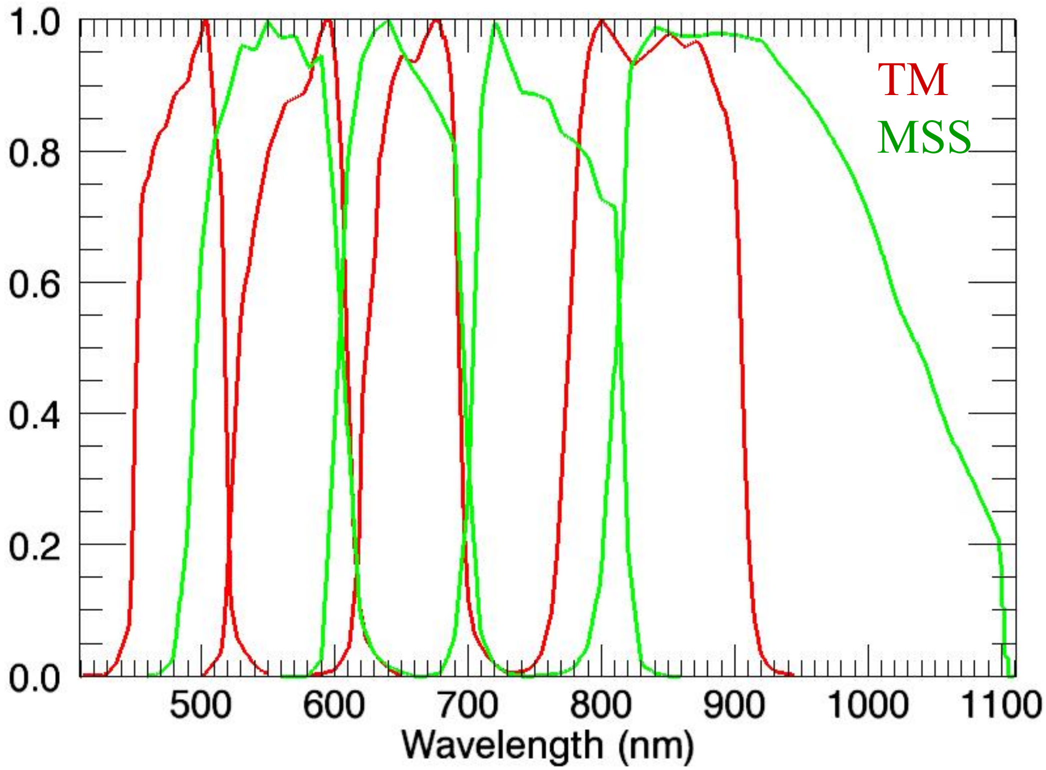
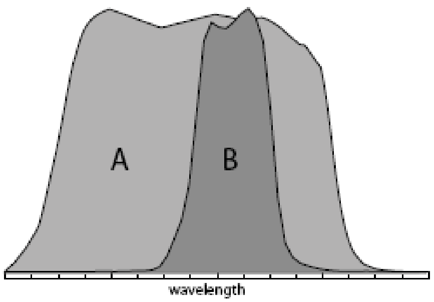


Figure of Merit (FOM)

$$\alpha = \frac{A \cap B}{A \cup B}$$



This indicates which bands of two different sensing instruments should respond more similarly to ground targets as compared to others

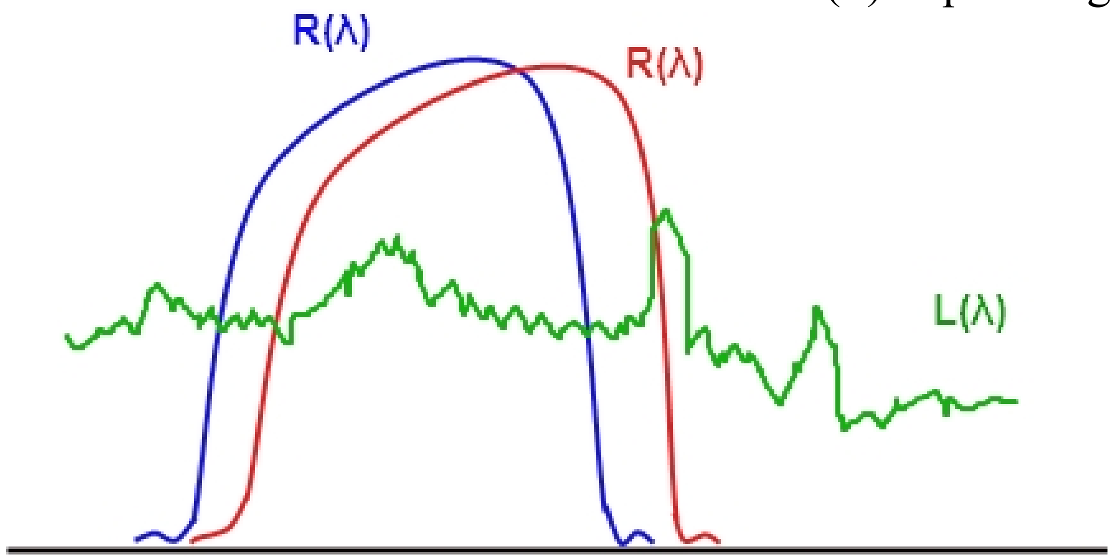
- **None of the four bands match closely in their RSR profiles**, indicating that the two sensors may produce different results while looking at the same ground target
- Effect of Spectral Band Difference is scene specific, and we need to know the spectral signature of target as well to find the Spectral Band Adjustment Factors (SBAFs)

Spectrally best matching pairs

MSS	TM	FOM
B1	B2	0.635
B2	B3	0.708
B3	B4	0.182
B4	B4	0.328

Spectral Band Adjustment Factors (SBAFs)

R(λ): Band specific RSR Profile
L(λ): Upwelling Radiance of Target



$$SBAF = \frac{(\int R_{\lambda,MSS} L_{\lambda} d\lambda) / BW_{MSS}}{(\int R_{\lambda,TM} L_{\lambda} d\lambda) / BW_{TM}}$$

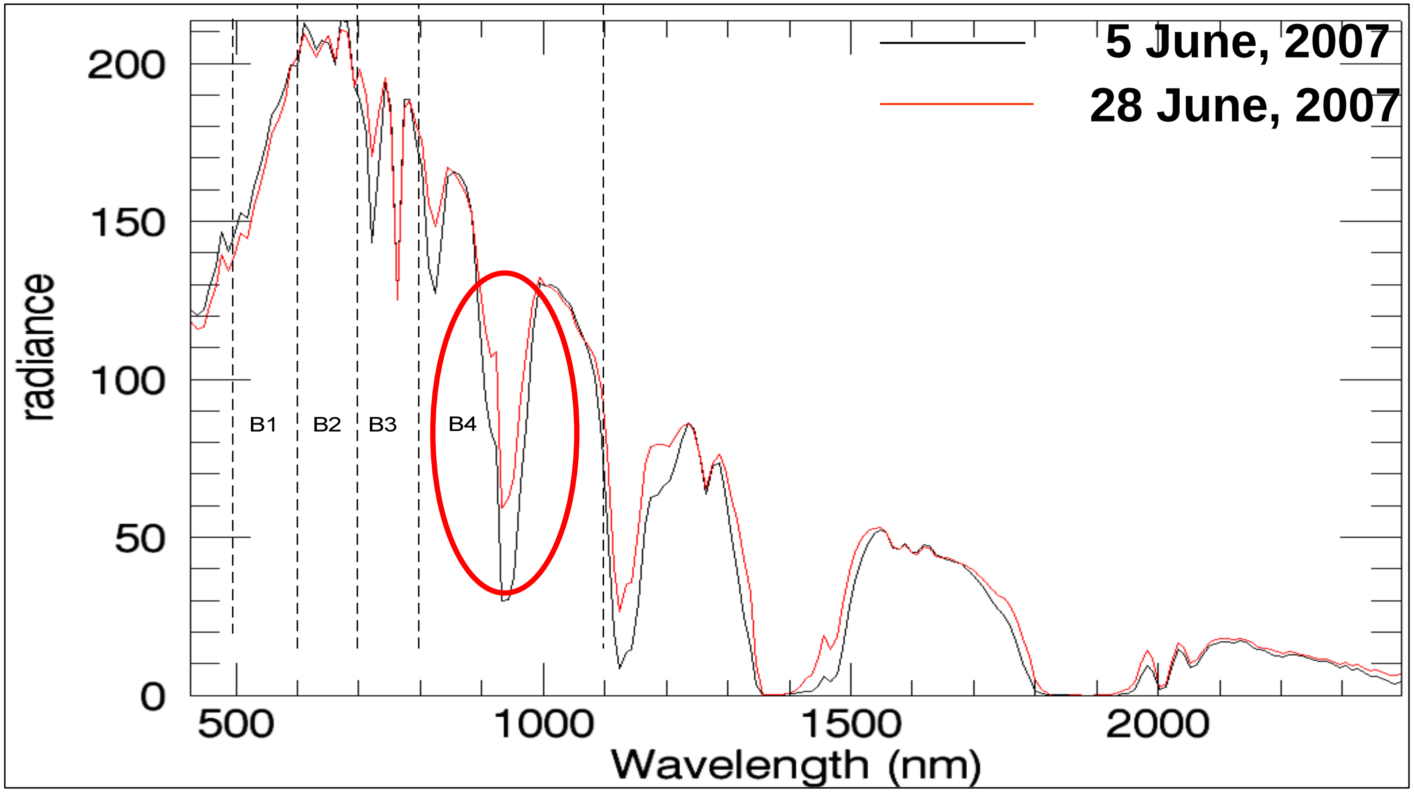
Need RSR's and Appropriate Surface Spectral Signature (SSS).

RSR's

- TM
- MSS
  - L5 and L4 easy
  - L3, L2, L1 analog only
    - MSS Radiometric Calibration Handbook (RCH) 1993
    - FindGraph

SSS for desert site

Spectral Signature of Libya 4
Hyperion to the rescue
(MSS Bands indicated)

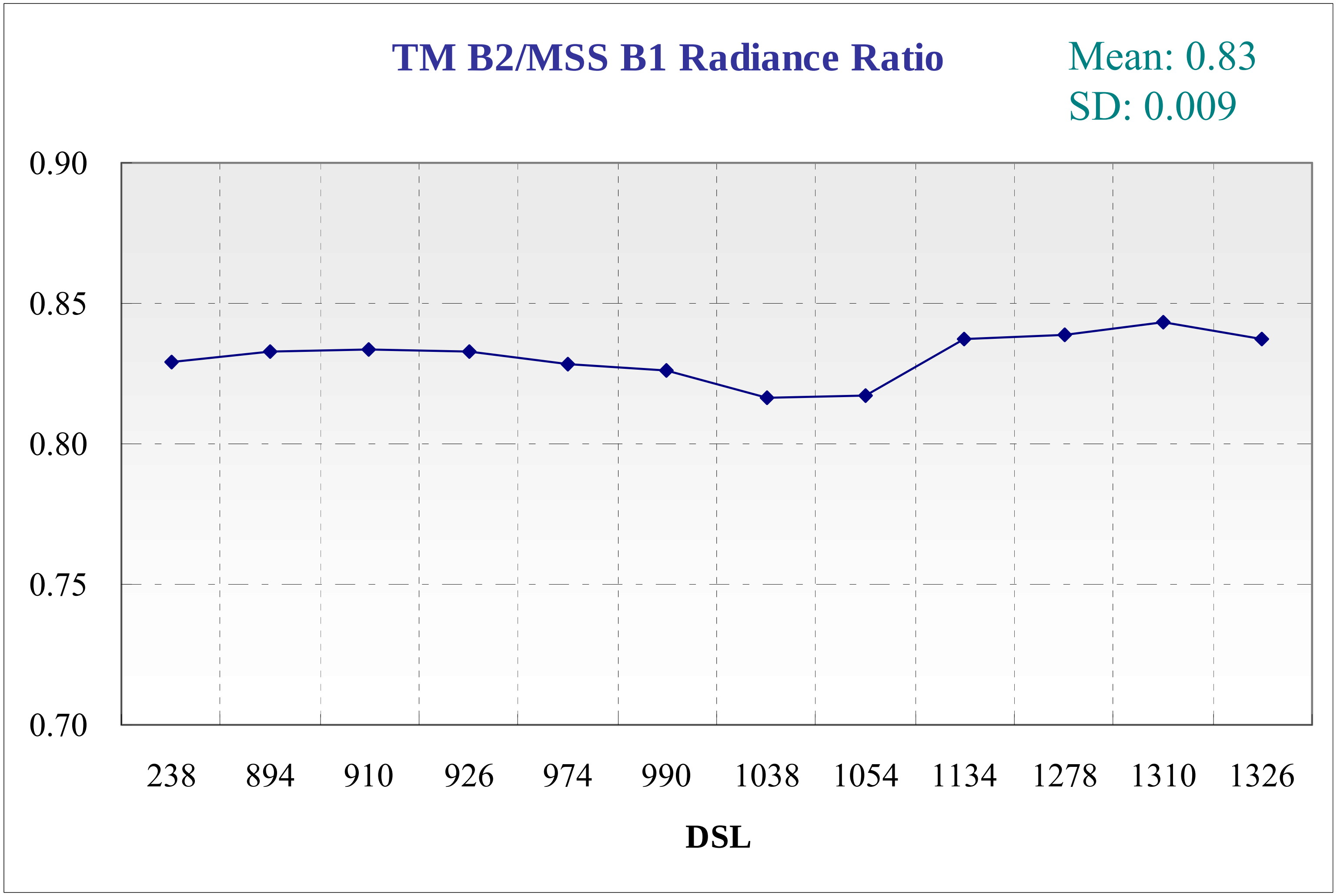


L5 MSS Band 4 is susceptible to water vapor content in the atmosphere, whereas the corresponding band in L5 TM is not.

Cross-calibration procedure

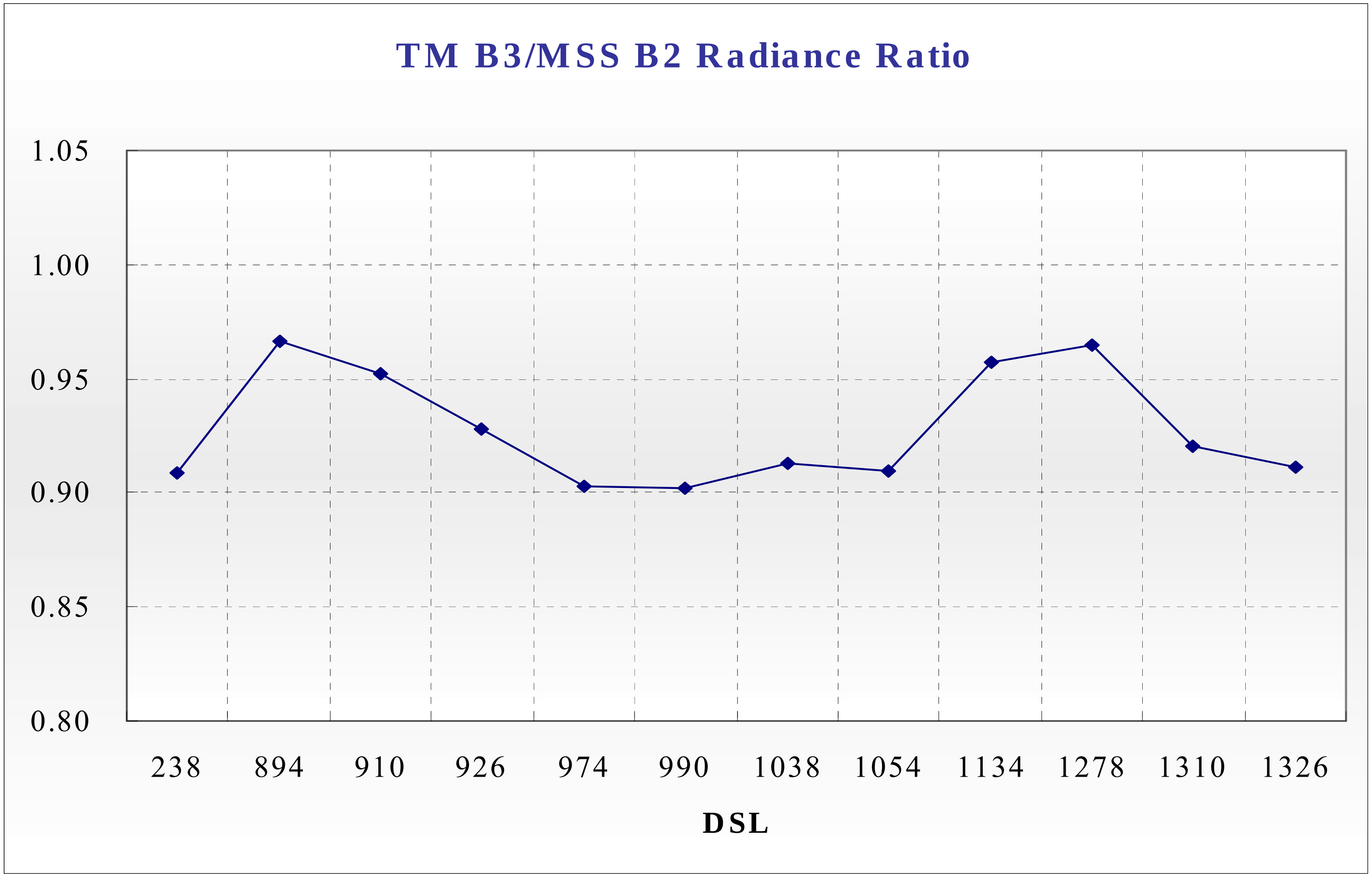
- Mean of all pixels (calibrated DNs, Q_{cal}) within specified region of interest was calculated from MSS data for each band
- LMIN and LMAX values (W/m^2 sr um) for L5 MSS were calculated from historical RMIN and RMAX values (W/m^2 sr) found in MSS RCH by multiplying with a factor of 10 and dividing by the **Nominal BW** (*private communication with* ***Brian Markham)*** of respective bands.
- These LMIN and LMAX values were used as scaling factors to convert Q_{cal} (for MSS) to band average spectral radiance values.
- Corresponding TM scenes were processed on TMIAS 8.0.2, and mean spectral radiance values for the ROI were found directly using L1R product data.
- The ratio of TM and MSS radiance values for best matching bands were multiplied by corresponding Spectral Band Adjustment Factors (SBAFs), and plotted against DSL.

L5 TM ⇨L5 MSS : Trended Radiometric Cal Results



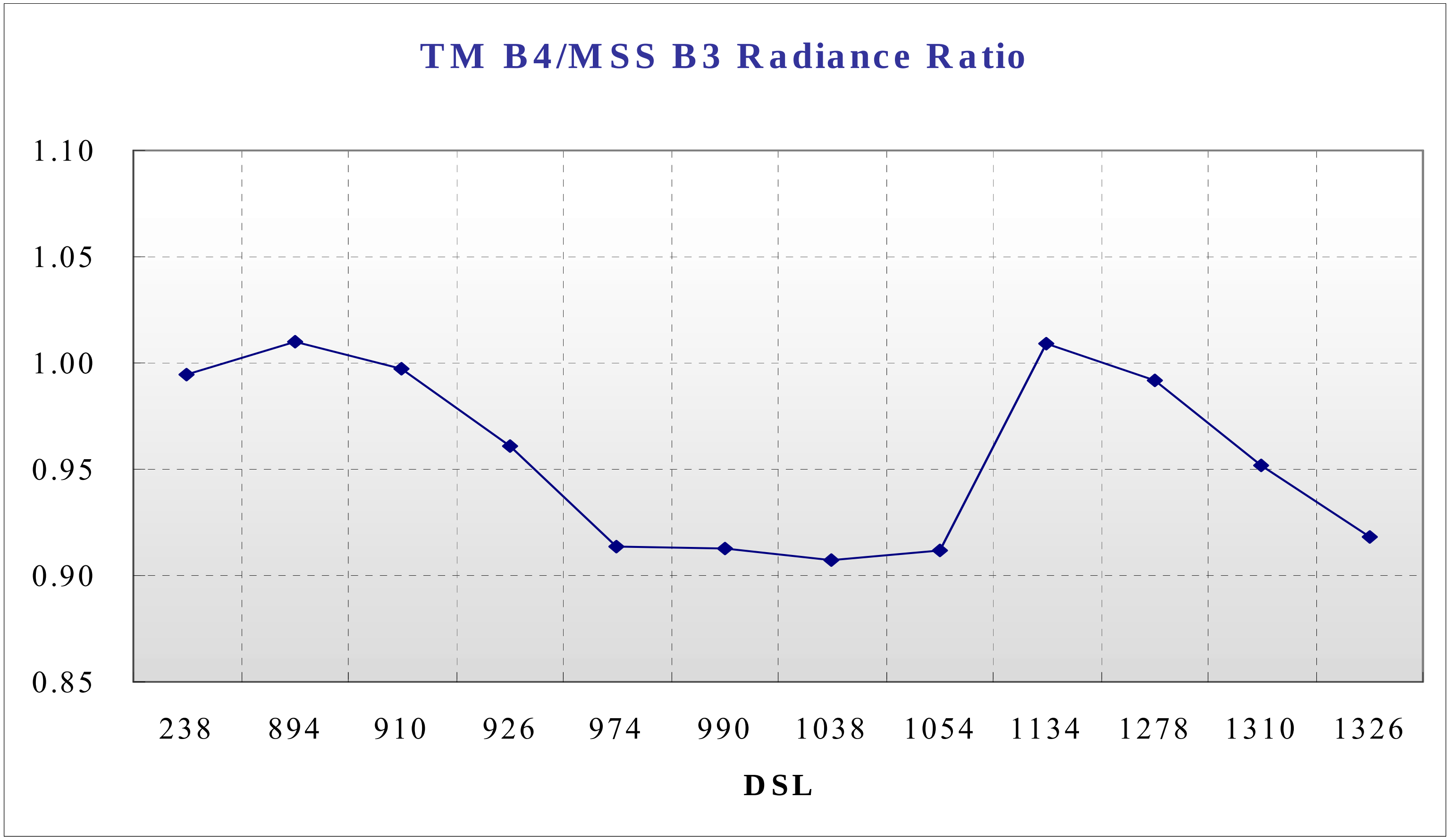
L5 TM ➪L5 MSS : Trended Radiometric Cal Results

Mean: 0.93
SD: 0.025



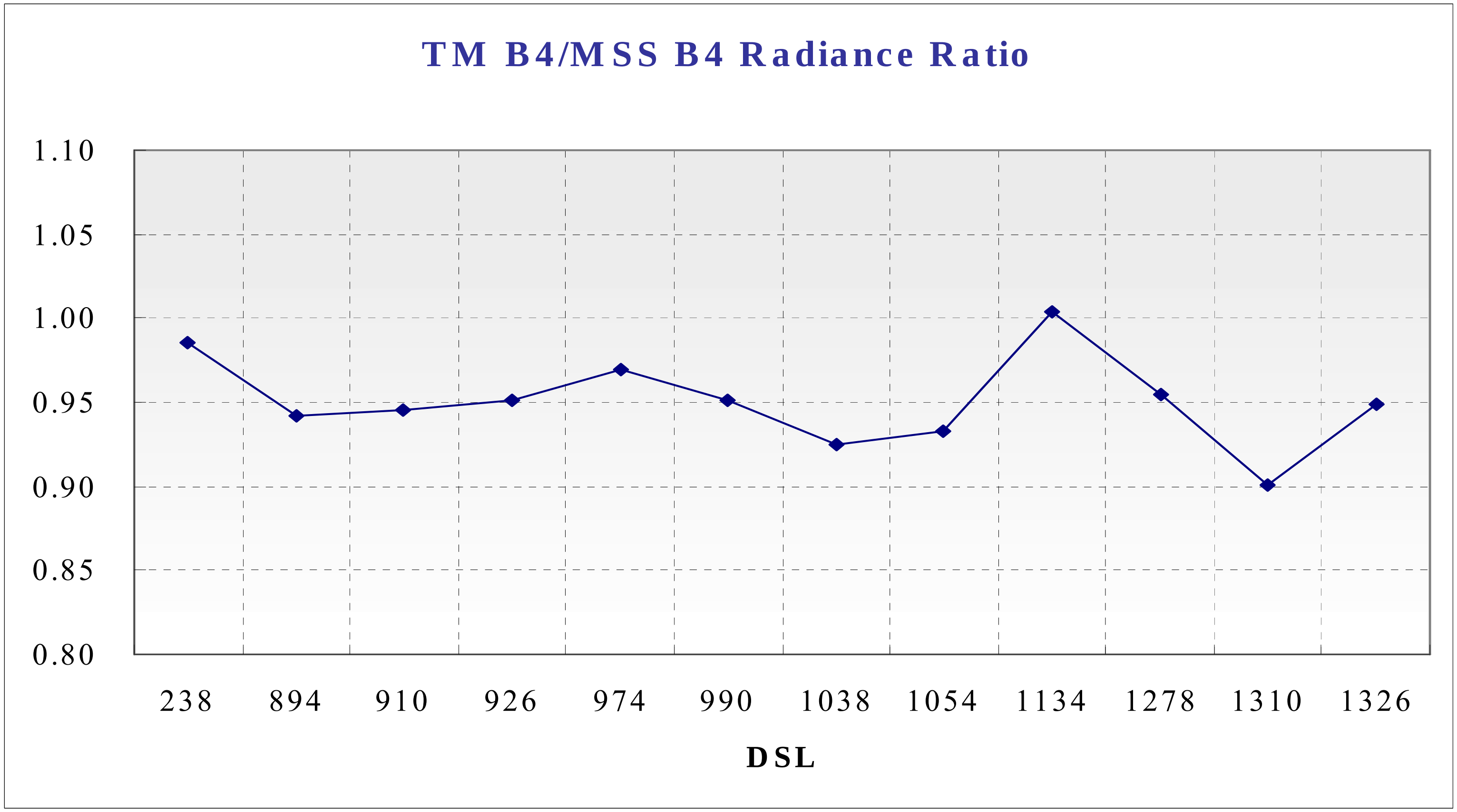
L5 TM ⇨L5 MSS : Trended Radiometric Cal Results

Mean: 0.95
SD: 0.042



L5 TM ⇨L5 MSS : Trended Radiometric Cal Results

Mean: 0.95
SD: 0.026



Summary: Cross-calibration results normalized to L5 TM

Initial round of test results (using FWHM BWs)

Sensor	MSS B1 /TM B2	MSS B2 /TM B3	MSS B3 /TM B4	MSS B4 /TM B4
L5 TM	1.00	1.00	1.00	1.00
L5 MSS	1.08	1.14	0.99	1.33

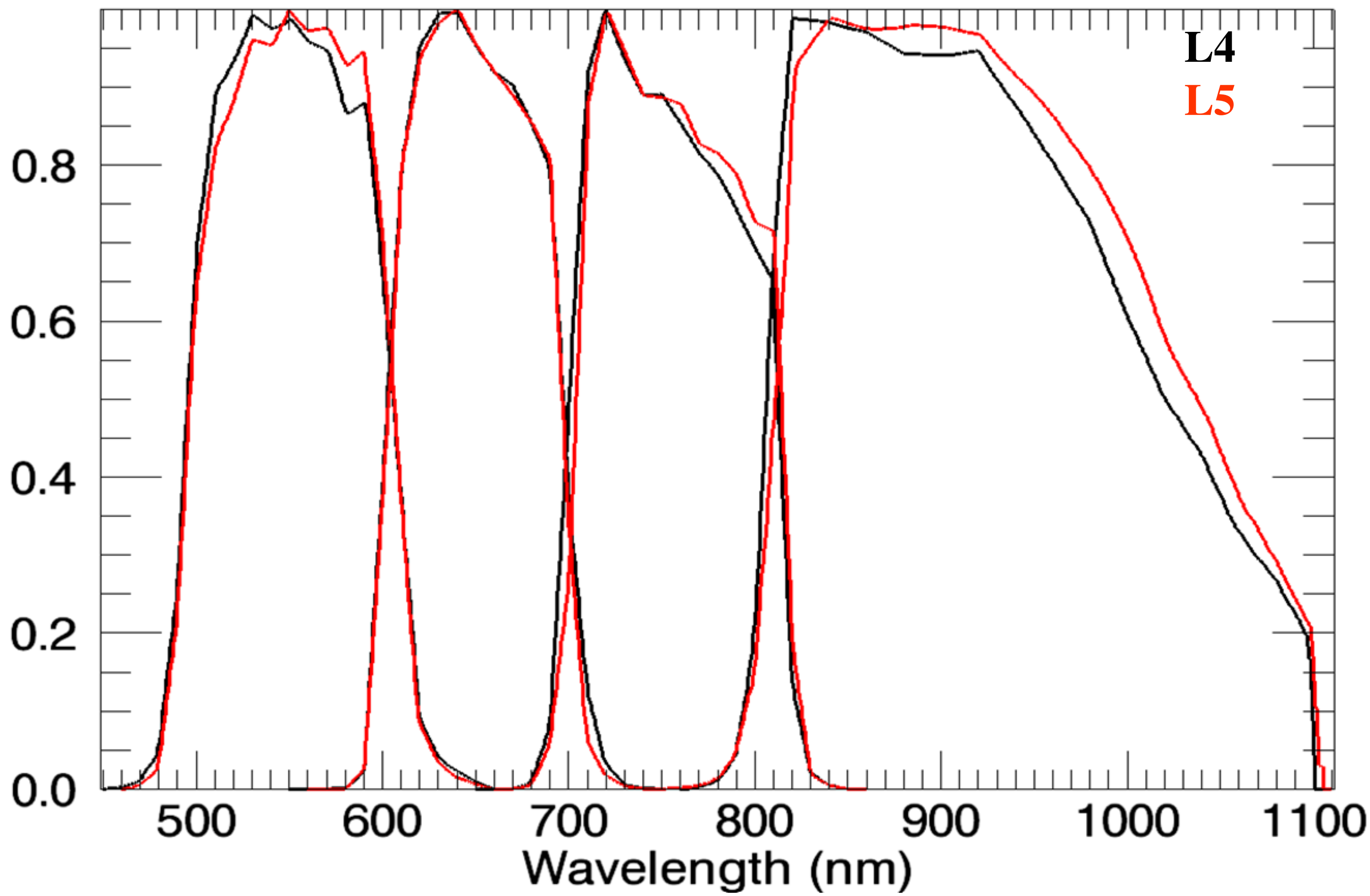
New Results (using Nominal BWs)

Sensor	MSS B1 /TM B2	MSS B2 /TM B3	MSS B3 /TM B4	MSS B4 /TM B4
L5 TM	1.00	1.00	1.00	1.00
L5 MSS	1.20	1.08	1.05	1.05

L5 MSS ⇨ L4 MSS Pilot radiometric cross cal

- Near-coincident scene pairs from White Sands, Ivanpah Playa, RRV, and Sonoran Desert used for this study
- Nominal passbands were used to convert In-Band radiance to Spectral radiance units
- What about RSR's?

RSR profiles of L4 and L5 MSS bands



- Life is good: Very similar RSR profiles (SBDE consequently neglected)

What about geolocation?

- A particular object on the ground may not have the same pixel coordinates in the near coincident scenes taken by different satellites
- The following steps were followed to ensure the best possible co-location:
  - Find coordinates of three geographical reference points (Highway intersection, runway edges, buildings, etc) on each of the scene pairs and determined their offset values.
  - Offset values were not the same for different reference points, indicating
    - Translation
    - Rotation
    - Shear/Skew
  - Used standard transforms (Affine) to obtain best co-location

Radiometric Evaluation Formulation

- Convert calibrated DNs to TOA radiance using appropriate rescaling gains (standard Lmin, Lmax, Qcal conversion)

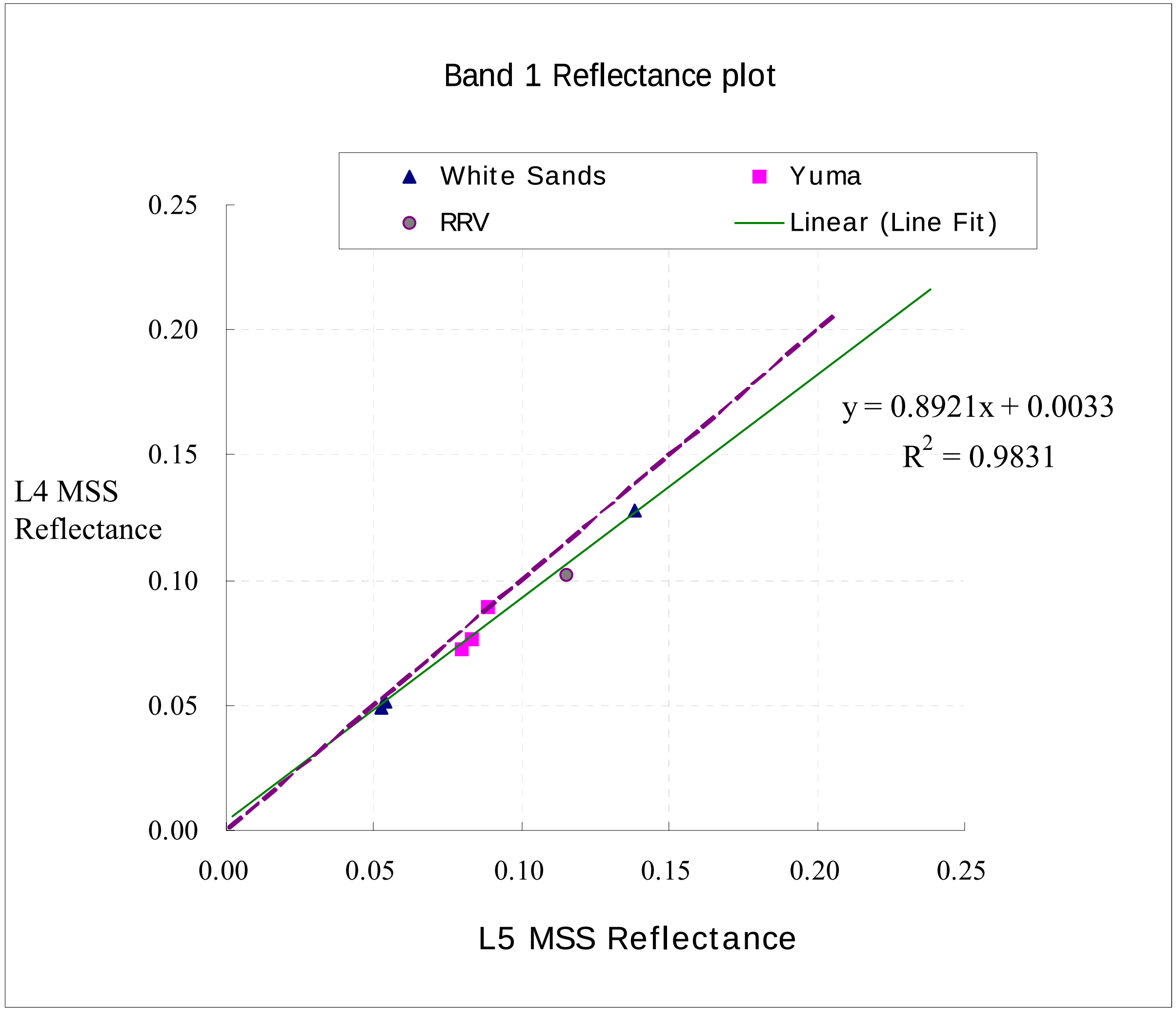
- Convert TOA radiance to TOA reflectance to remove the cosine effect of different solar zenith angles and compensate for different values of exo-atmospheric solar irradiance

  $$\rho_i^* = \pi L_{\lambda i}^* d_s^2 / (E_{oi} \cos\theta)$$

  where, E_{oi}: Exo-atmospheric solar irradiance

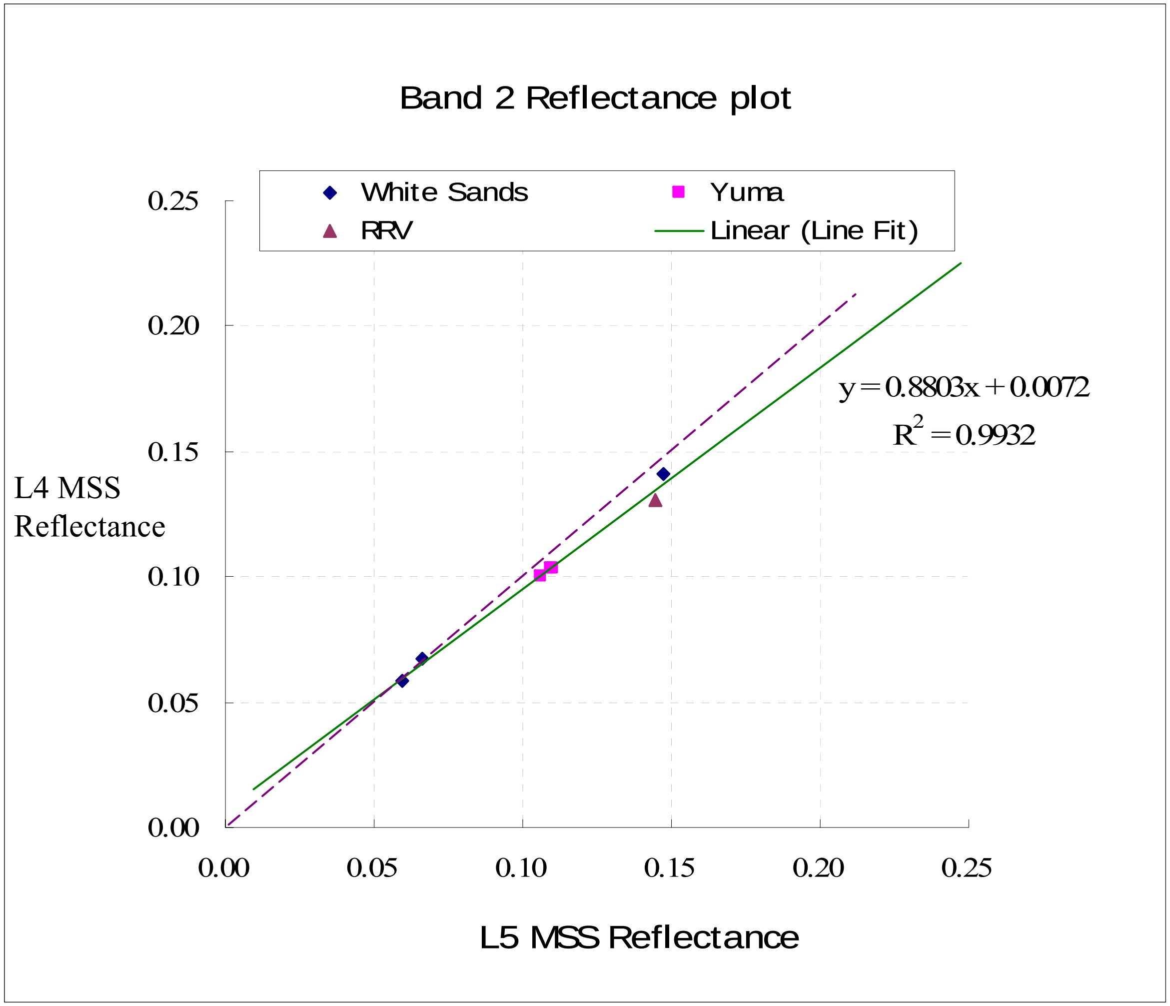
- Plot L4 MSS reflectance against L5 MSS reflectance for different ROIs

- Least square fit the data in each band and find cross cal Gain and biases as the coefficients of the linear fit.



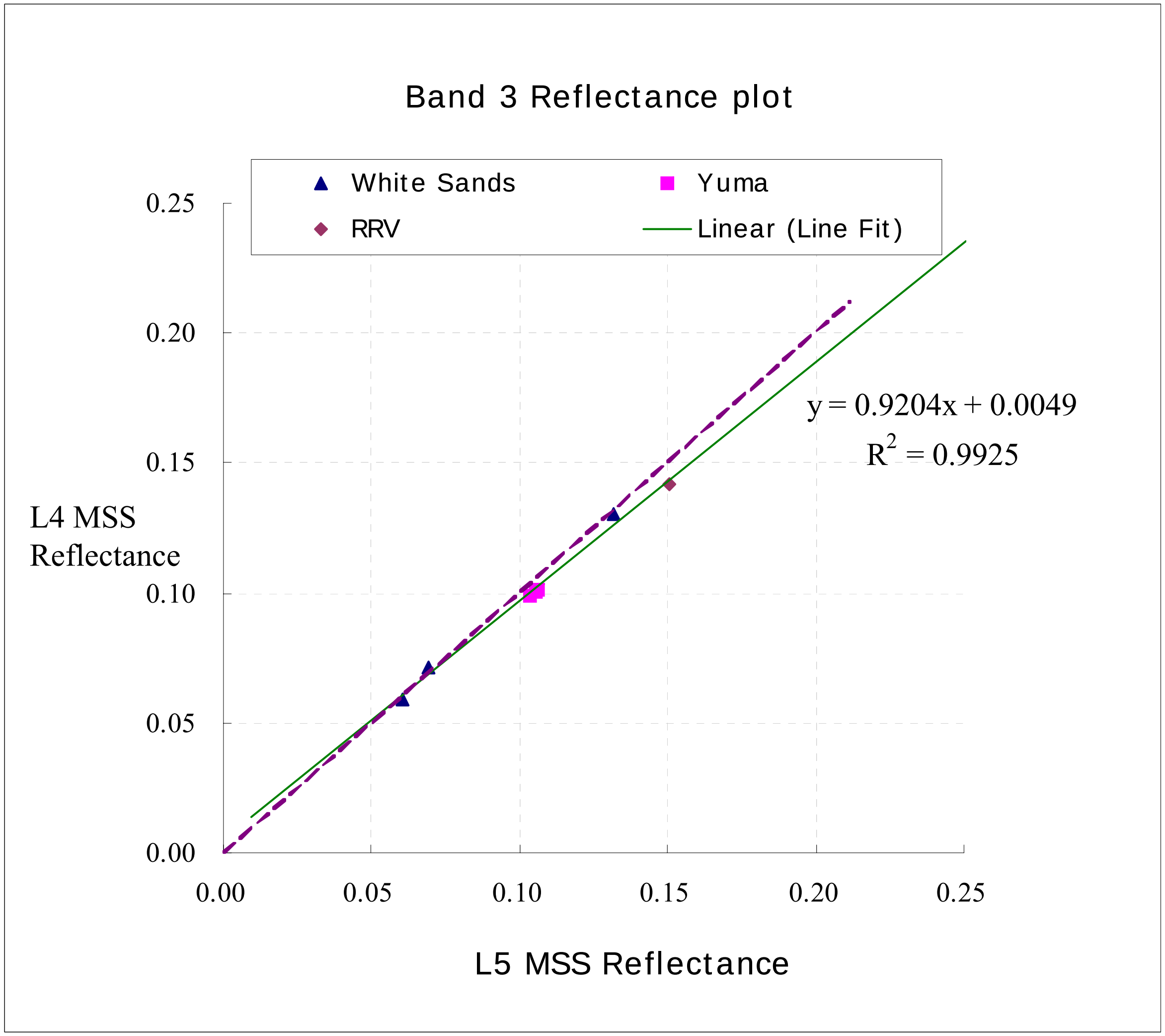
Band 1 Summary

	L4 to L5 MSS TOA Reflectance Ratio			% Difference in Reflectance Estimates		
ROI	**White Sands**	**Sonoran Desert**	**RRV**	**White Sands**	**Sonoran Desert**	**RRV**
1	0.954	0.913	0.885	4.47	8.71	11.55
2	0.923	1.014		8.95	1.37	
3	0.933	0.914		1.99	8.56	
				Average:	**6.51**	



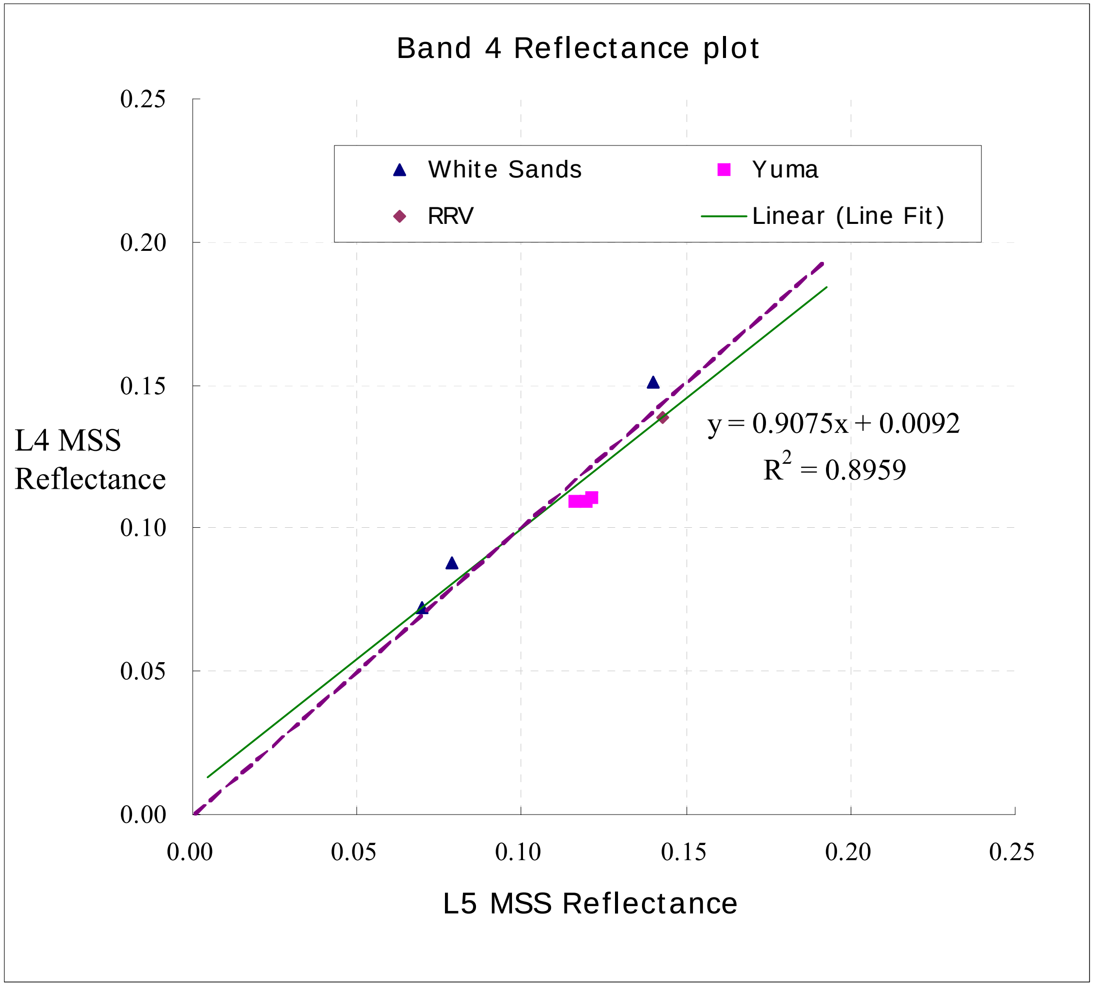
Band 2 Summary

	L4 to L5 MSS TOA Reflectance Ratio			% Difference in Reflectance Estimates		
ROI	**White Sands**	**Sonoran Desert**	**RRV**	**White Sands**	**Sonoran Desert**	**RRV**
1	1.017	0.949	0.904	1.74	5.13	9.56
2	0.958	0.936		4.25	6.39	
3	0.983	0.943		1.73	5.72	
				Average:	**4.93**	



Band 3 Summary

	L4 to L5 MSS TOA Reflectance Ratio			% Difference in Reflectance Estimates		
ROI	**White Sands**	**Sonoran Desert**	**RRV**	**White Sands**	**Sonoran Desert**	**RRV**
1	1.036	0.961	0.942	3.64	3.94	5.78
2	0.989	0.952		1.07	4.78	
3	0.974	0.949		2.63	5.14	
				Average	**3.85**	



Band 4 Summary

	L4 to L5 MSS TOA Reflectance Ratio			**% Difference in Reflectance Estimates**		
ROI	**White Sands**	**Sonoran Desert**	**RRV**	**White Sands**	**Sonoran Desert**	**RRV**
1	1.118	0.941	0.971	11.82	5.88	2.91
2	1.082	0.915		8.22	8.47	
3	1.041	0.911		4.14	8.91	

Average: **7.19**

Conclusions: L5 TM to L5 MSS
L5 MSS to L4 MSS

- The average radiance estimates for L5 MSS bands 2, 3, and 4 agree within 8% to the best matching L5 TM bands after accounting for spectral band difference effects.
- Cross-calibration result for L5 MSS band 1 (using Nominal BW for MSS to convert In-band Radiance to Spectral units) is not good (agrees within 20%).

- The reflectance estimates of L4 MSS agree with those of L5 MSS to within 7% for Band 1, 5% for Band 2, 4% for Band 3,and 8% (*was 9% with FWHM BW*) for Band 4.
- L4 and L5 MSS calibration approaches seems to be consistent within 8%.
- More scenes and BRDF considerations may help in analysis.

What about L1-L3?

- Need to understand the scene data
  - Format
  - Level of product
    - Calibration applied?
  - PM and silicon diode
- Calibration lamp (‘wedge data’)
- Instrument stability as measured by wedge
  - ‘short term’ stability

Systems background for Landsat 1 MSS

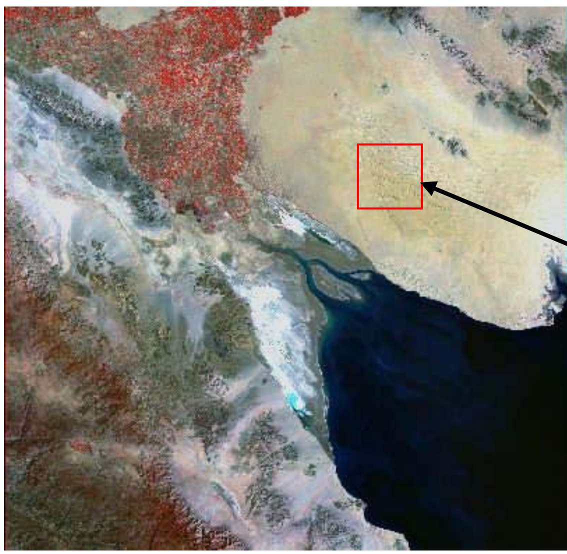
- Landsat 1 MSS bands 1, 2, and 3 were already calibrated, whereas band 4 was left uncalibrated.
- Looking only at the calwedge lifetime trends, it is hard to rigidly distinguish the detector vs. lamp stability over lifetime as there is no common lifetime trends among the detectors.
  - Trends reflect the performance of either detector or lamp, or both.
- One possible way to distinguish the detector vs. lamp stability is to get the lifetime detector response from two different sources:
  - Lamp (calwedge lifetime trends) and
  - Invariant site Approach
- For L1, there exists the potential to implement the two approaches since band 4 was left uncalibrated postlaunch.
- Two sources of MSSX data: WBVT and GSFC
  - WBVT/MSSX band 4 data decompressed to 0-127 when it should not have been.
  - Band 4 data from WBVT/MSSX had calibration applied to it by WBVT/APGS software.
  - Band 4 data from GSFC/MSSX has dynamic range of 0-63.

Landsat 1 MSS Stability and Calibration

- Study Landsat 1 MSS instrument stability and trend.
- Investigate the calibration consistency of Landsat 1 MSS bands 1, 2 , and 3.
- Evaluate Post Launch Band 4 Calibration based on Gains and Offsets from cal-wedge data

Pilot Study Using Sonoran PICS

- Cal-wedge data extraction was done with 28 scenes (from SN 1-28)
- Scenes 29-30 have corrupted data for band 1



ROI (250*250)

1. **10410380072238904**
2. **10410380072256904**
3. **10410380072274904**
4. **10410380072310904**
5. **10410380072364904**
6. **10410380073088904**
7. **10410380073106904**
8. **10410380073142904**
9. **10410380073160904**
10. **10410380073196904**
11. **10410380073286904**
12. **10410380074047904**
13. **10410380074065904**
14. **10410380074101904**
15. **10410380074155904**
16. **10410380074173904**
17. **10410380074191904**
18. **10410380074227904**
19. **10410380075042904**
20. **10410380075150904**
21. **10410380075294904**
22. **10410380075330904**
23. **10410380076073904**
24. **10410380076109904**
25. **10410380076145904**
26. **10410380076181904**
27. **10410380076235904**
28. **10410380076289904**
29. **10410381977154904**
30. **10410381977262904**
31. **10410381977298904**

* Not appropriate for Invariant Site Approach due to Cloud over ROI

* WBVT Scenes

- The ROI taken is the best invariant region in Sonoran site as per the Small Invariant Site study done at SDSU
- Affine transformation method used to geolocate the ROI in every scene.

Can We Extend Consistent Calibration Parameters From Landsats 7 & 5 Back Through Landsats 1-4 MSS?

- Yes
  - L5 MSS
  - L4 MSS
  - L1-L3
    - PICS imagery available
    - Cal wedge data understandable
    - SBDE methodology to normalize bands

What next?

- Complete data format validation for L1-L3 MSS
- Complete cal lamp based stability validation
- Complete PICS stability validation
- Work back from L4 MSS to
  - L3 MSS
    - -L2 MSS
      - -L1 MSS
- Continue work with EROS Data Center to develop MSIAS

ISSUES:

•Per detector calibration

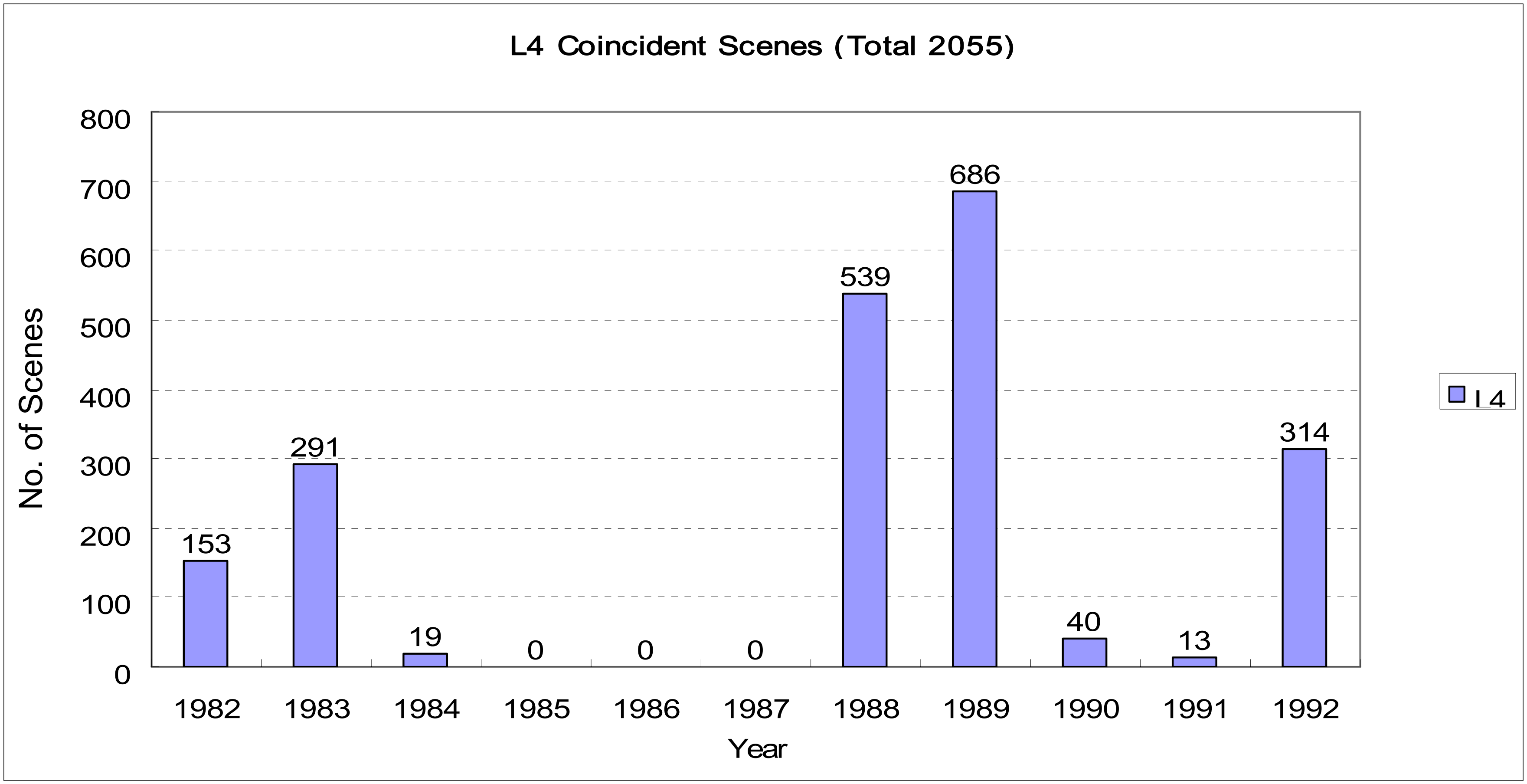
    •Different RSR's due to filter variations

    •Images available have been resampled so detector info lost

•Band difference interpretation/education

BACKUP SLIDES

Timeframe of L4 TM/MSS Coincident Scenes



Atmospheric Transmittance