Absolute Calibration of Landsat 1 through Landsat 5 MSS Sensors: Extending the Data Record Back Through Time

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Outline

- MSS **Consistent** Calibration – circa JACIE 2009
- MSS **Absolute** Calibration
  - Methodology
  - Results
  - Verification
- A look at all the Landsat sensors
  - Are they really all on the same scale?

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

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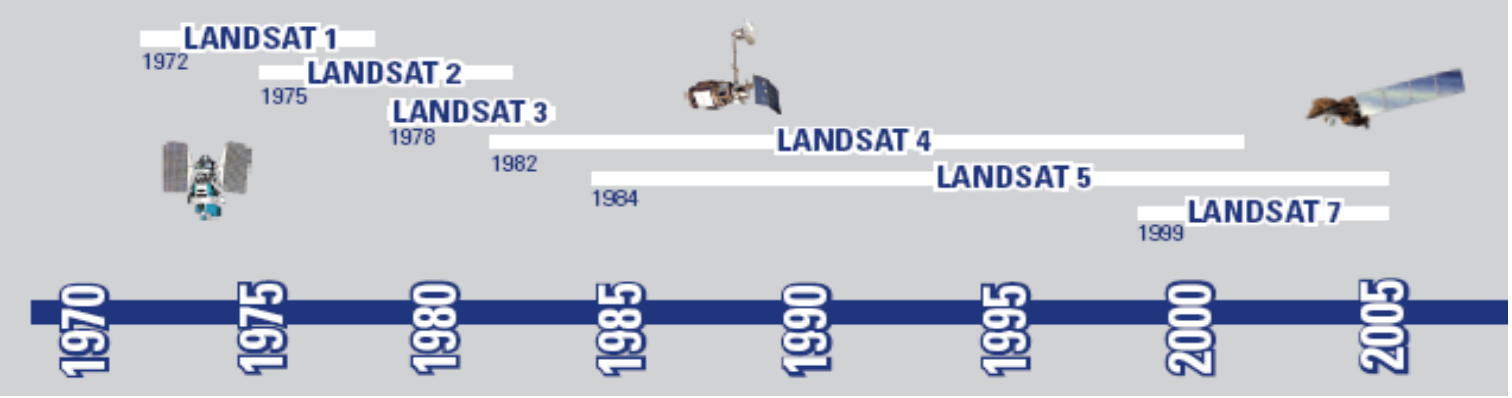
Landsat-1 to -7 Characteristics

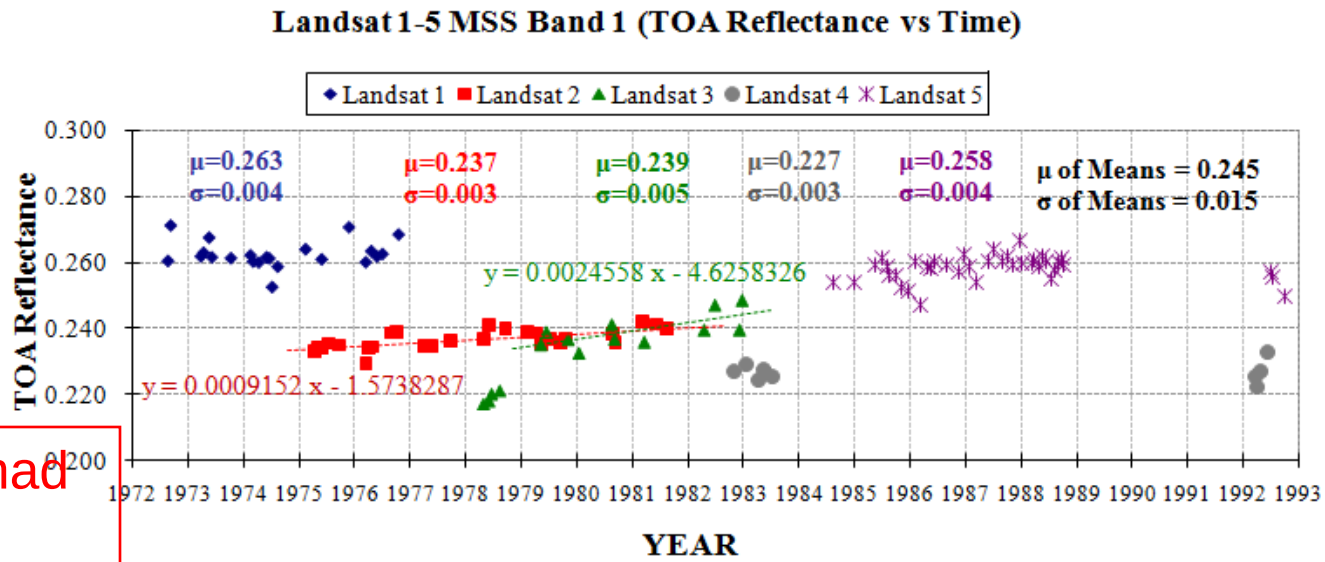
Satellite	Launched	Decommissioned	Sensors	Orbit
Landsat-1	July 23, 1972	January 6, 1978	RBV*, **MSS**	18 days/900 km
Landsat-2	January 22, 1975	February 25, 1982	RBV, **MSS**	18 days/900 km
Landsat-3	March 5, 1978	March 31, 1983	RBV, **MSS**	18 days/900 km
Landsat-4	July 16, 1982	June 15, 2001	**MSS**, TM	16 days/705 km
Landsat-5	March 1, 1984	**Still Alive after more than 25 years**	**MSS**, TM	16 days/705 km
Landsat-6	October 5, 1993	Failure upon launch	ETM	16 days/705 km
Landsat-7	April 15, 1999		ETM+	16 days/705 km



*The RBV (Return Beam Vidicon) cameras did not achieve the popularity of the MSS sensor

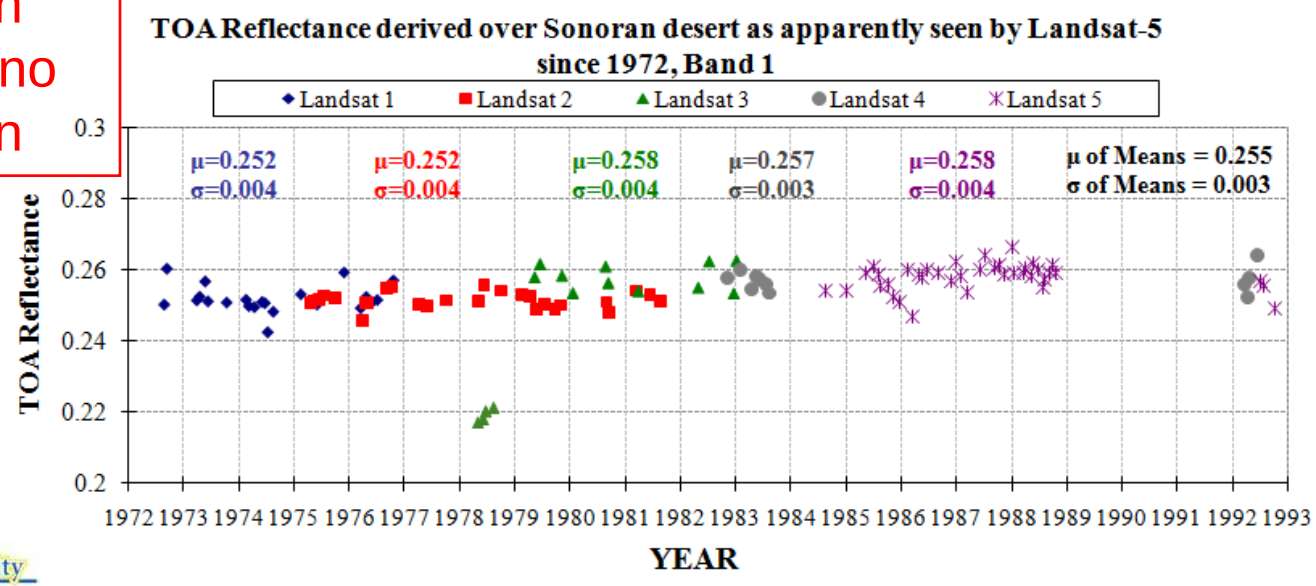
Results: Band 1 **MSS Calibration – circa JACIE 2009**

Before Cross-calibration applied



Note: In 2009 we had a consistent calibration between MSS sensors, but no absolute calibration

After Cross-calibration applied



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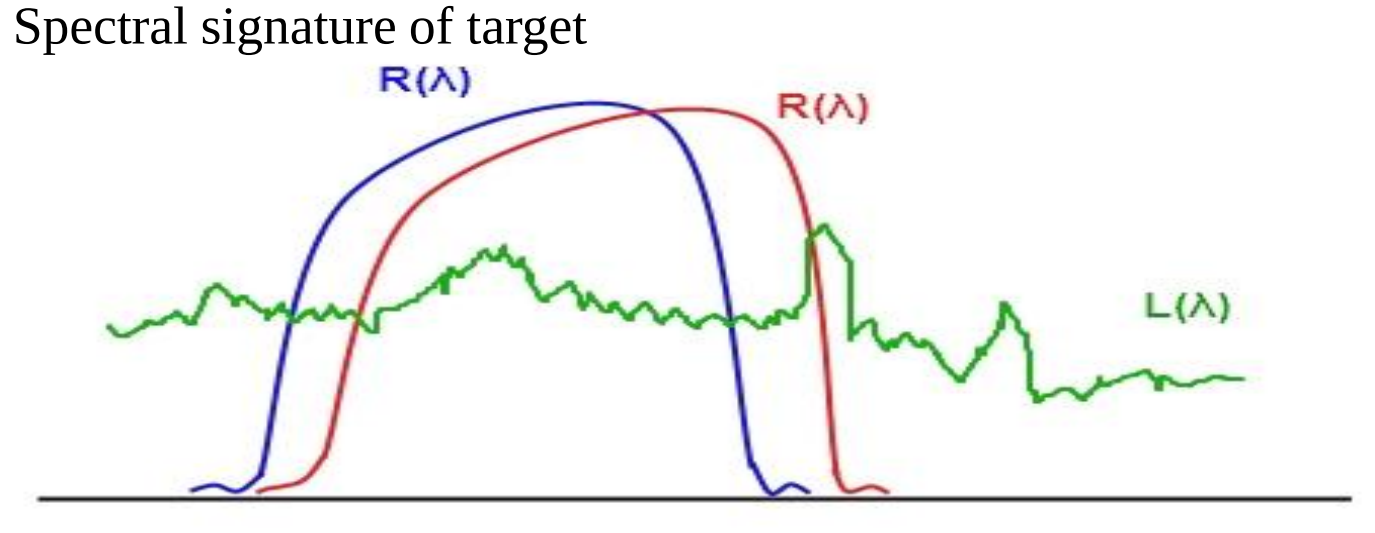
MSS Absolute Cal: Methodology

- MSS-5 and TM-5 collected hundreds (thousands!) of simultaneous images
  - TM-5 calibrated based on simultaneous overpass with Landsat 7 ETM+
  - TM-5 lifetime trend based on ‘Libya 4’ pseudo-invariant calibration site (PICS)
- 25 MSS-5/TM-5 image pairs were selected from the well-known Sonora PICS
- No corrections needed for atmosphere or BRDF
- Spectral band adjustment factors (SBAFs) calculated for TM to MSS differences
  - Hyperion hyperspectral data used for target spectra
- Uncertainties estimated
- MSS:TM radiance ratio provides absolute calibration for MSS

Accounting for Sensor Spectral Differences: SBAF

R(λ): Sensor specific RSR Profile

L(λ): Spectral signature of target



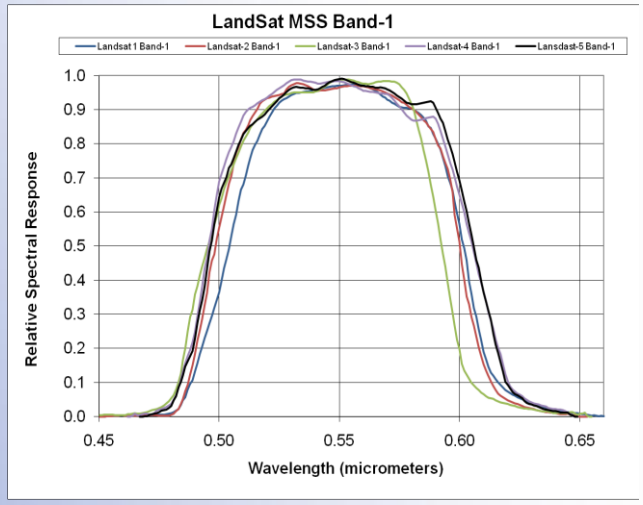
$$SBAF = \frac{(\int R(\lambda).L(\lambda)\, d\lambda / \int R(\lambda).d\lambda)}{(\int R(\lambda).L(\lambda) d\lambda / \int R(\lambda)\, .d\lambda)}$$

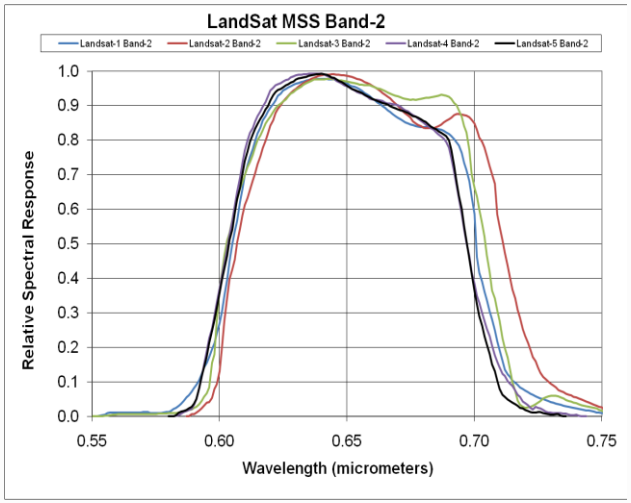
- This phenomena is accounted for using a Spectral Band Adjustment Factor (SBAF).
- The SBAF uses a known Spectral Signature of a ground target to adjust for these differences of two different sensor bands by calculating the reflectance seen by each sensor of a specific ground target's spectral signature. **Therefore, SBAFs are specific to each ground target.**

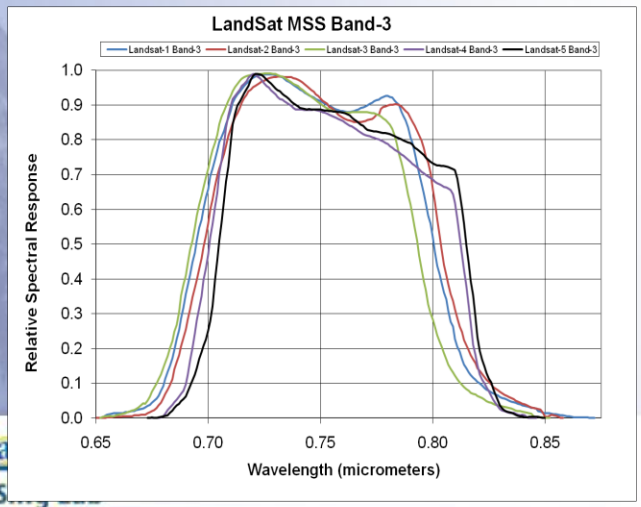
MSS 1-5 Average Spectral Filter Responses

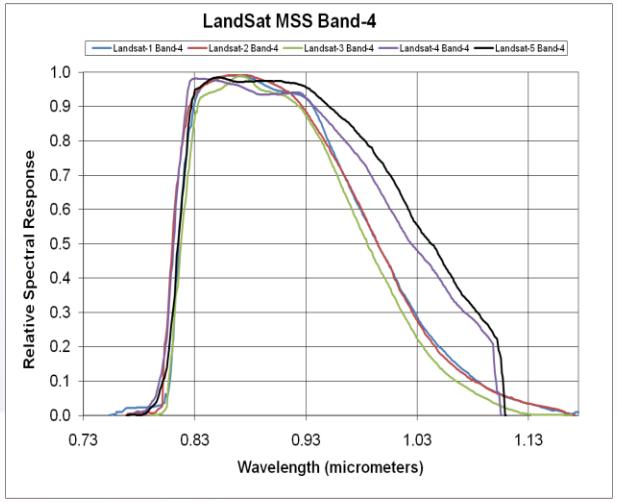
Note substantial differences exist among the spectral responses of the five MSS sensors!

Just spectral differences between MSS filters alone can change SBAF by 1.5%!









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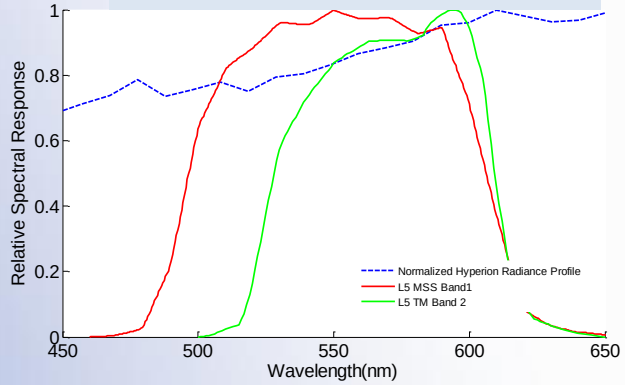
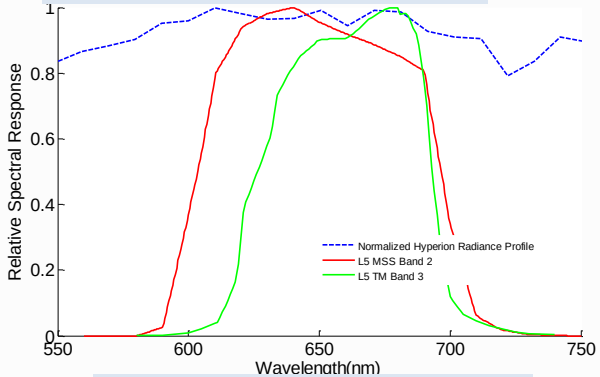
Relative Spectral Response for MSS & TM

Note the pronounced differences between the MSS and TM RSRs requiring accurate knowledge of target spectral signature for calibration

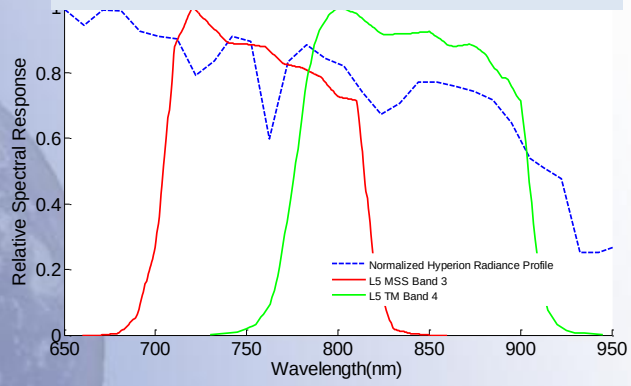
MSS Band 1 (Green)



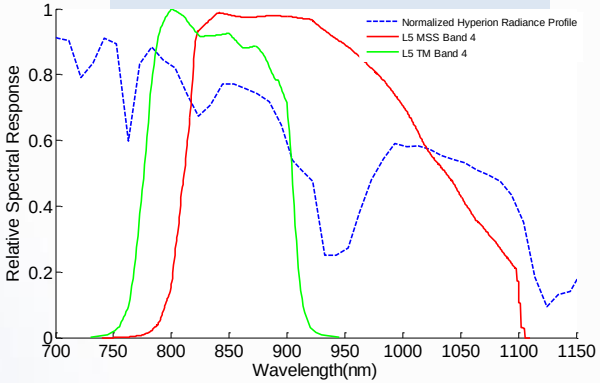
MSS Band 2 (Red)



MSS Band 3 (Red Edge)



MSS Band 4 (NIR)



MSS
TM
Target

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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

Sensor-to-Sensor Uncertainty Estimates for Landsat (MSS) Cross Calibration

Uncertainty contributions:

- 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-to-TM
Simultaneous Imaging

MSS Band 1 Results

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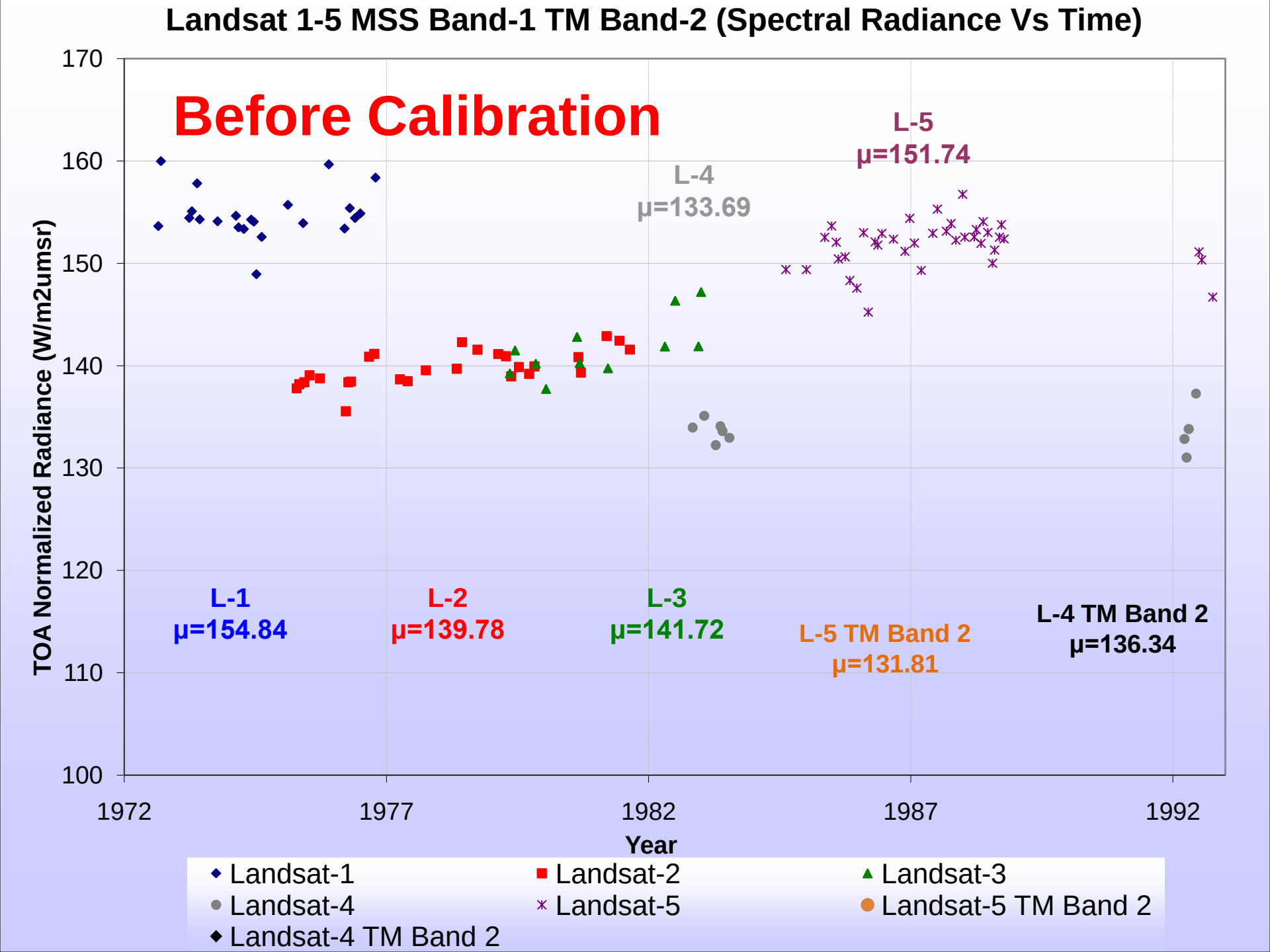
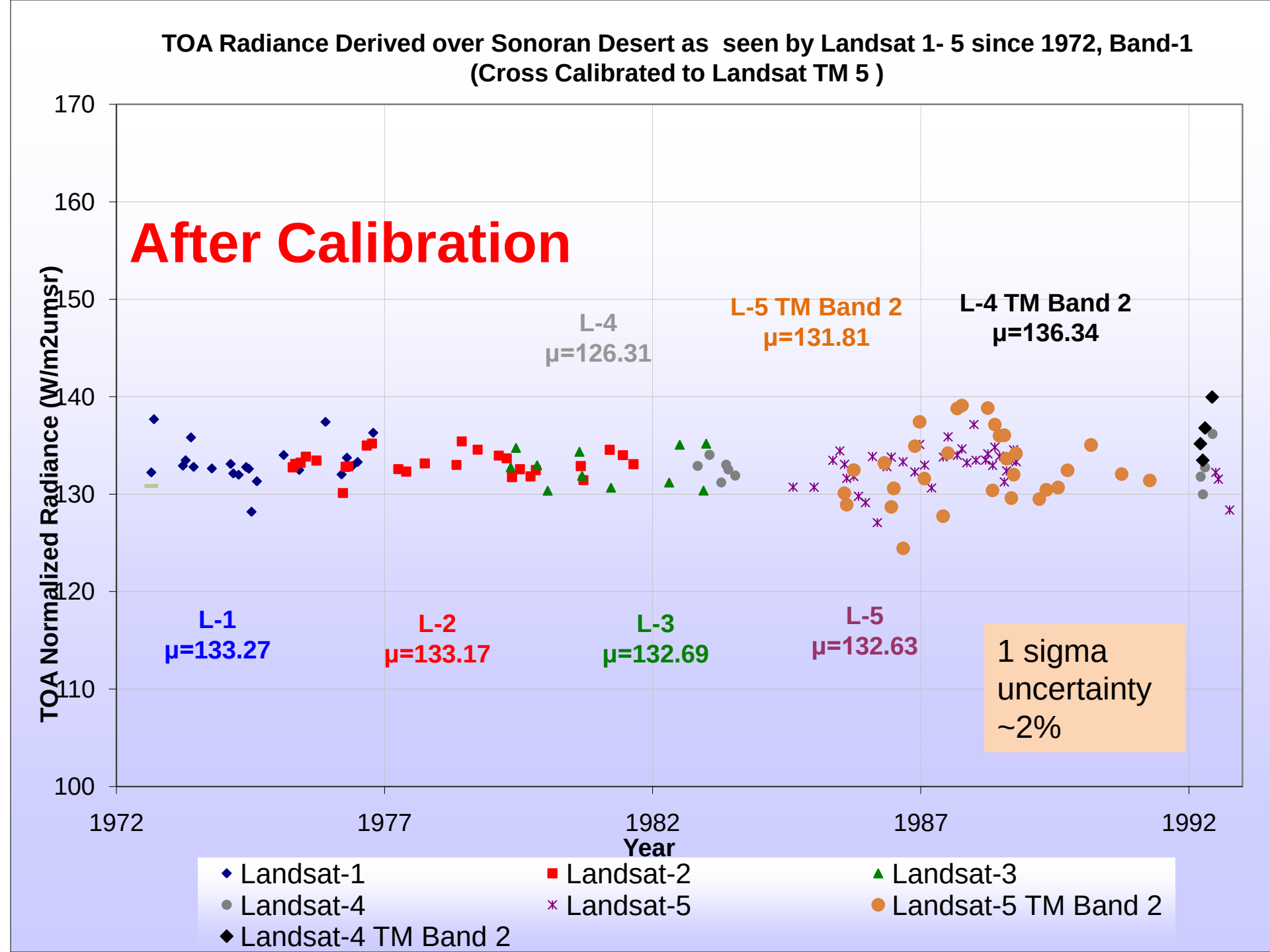

Landsat 1-5 MSS Band-1 TM Band-2 (Spectral Radiance Vs Time)
Before Calibration
L-5
μ=151.74
L-4
μ=133.69
L-1
μ=154.84
L-2
μ=139.78
L-3
μ=141.72
L-5 TM Band 2
μ=131.81
L-4 TM Band 2
μ=136.34
TOA Normalized Radiance (W/m2umsr)
170
160
150
140
130
120
110
100
1972
1977
1982
1987
1992
Year
Landsat-1
Landsat-2
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)
After Calibration
TOA Normalized Radiance (W/m2umsr)
170
160
150
140
130
120
110
100
1972
1977
1982
1987
1992
Year
L-1
μ=133.27
L-2
μ=133.17
L-4
μ=126.31
L-3
μ=132.69
L-5 TM Band 2
μ=131.81
L-5
μ=132.63
L-4 TM Band 2
μ=136.34
1 sigma
uncertainty
~2%
Landsat-1
Landsat-2
Landsat-3
Landsat-4
Landsat-5
Landsat-5 TM Band 2
Landsat-4 TM Band 2

MSS Band 2 Results

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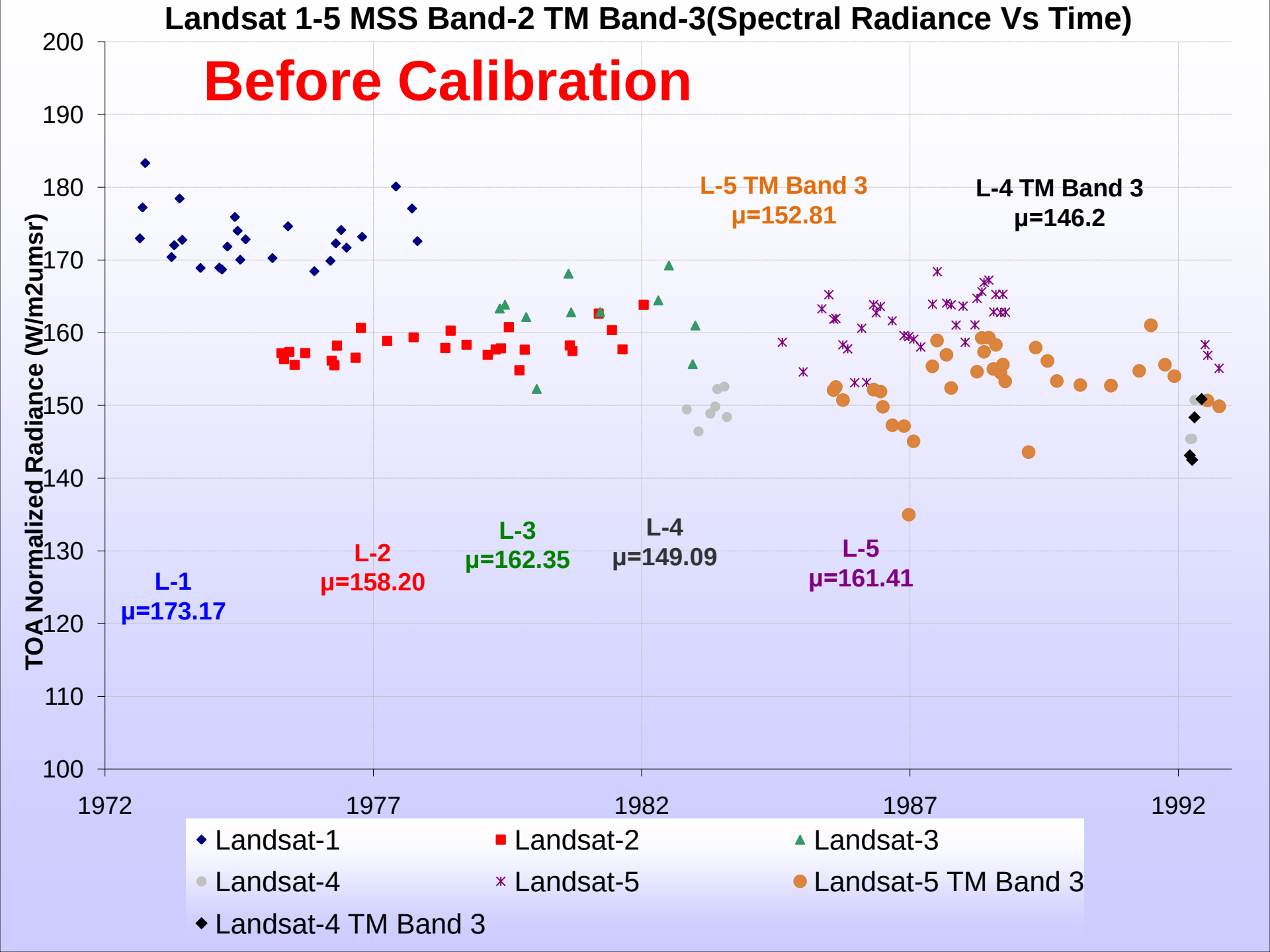
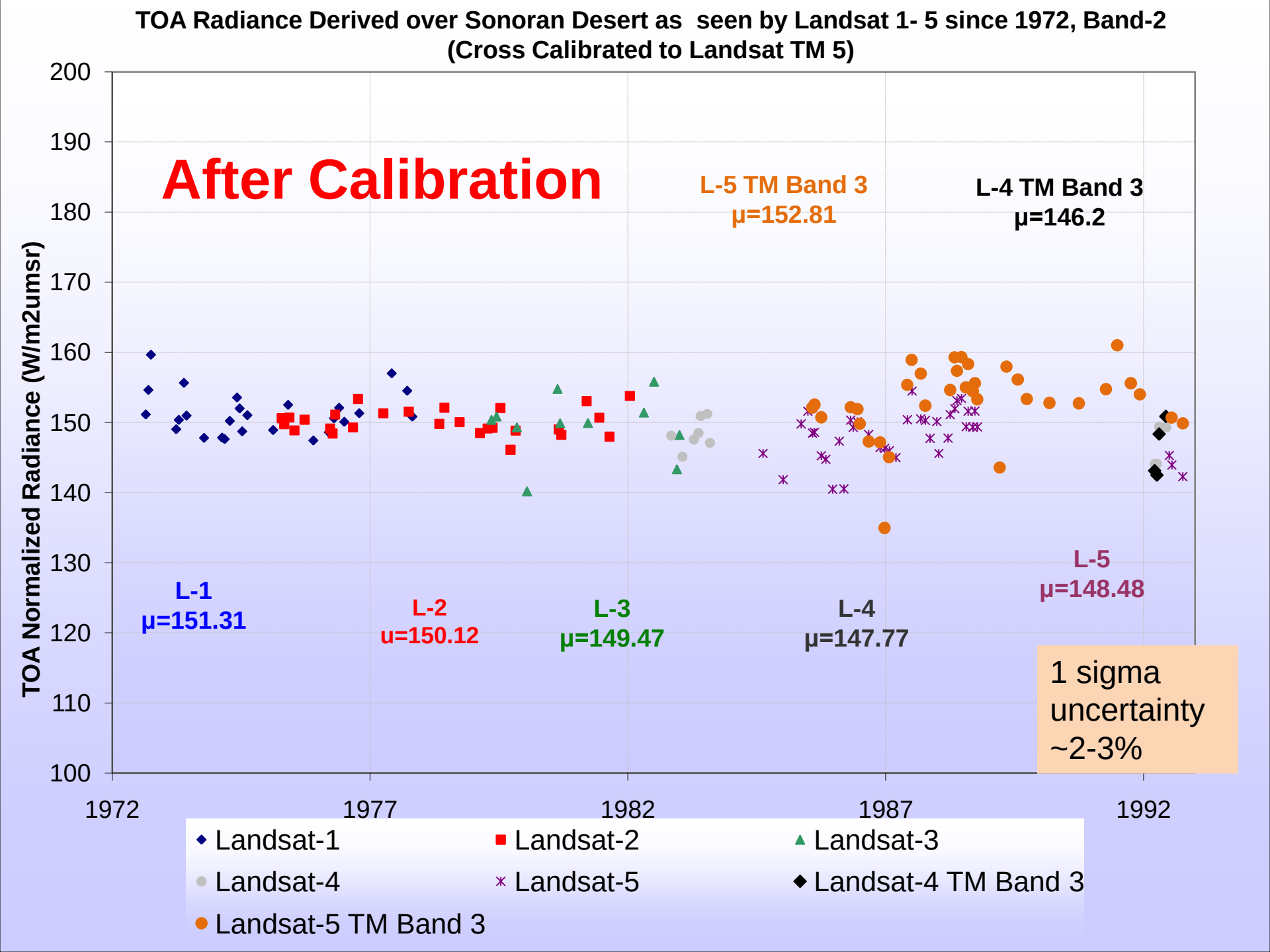

Landsat 1-5 MSS Band-2 TM Band-3(Spectral Radiance Vs Time)
Before Calibration
TOA Normalized Radiance (W/m2umsr)
200
190
180
170
160
150
140
130
120
110
100
1972
1977
1982
1987
1992
L-1
μ=173.17
L-2
μ=158.20
L-3
μ=162.35
L-4
μ=149.09
L-5
μ=161.41
L-5 TM Band 3
μ=152.81
L-4 TM Band 3
μ=146.2
Landsat-1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


TOA Radiance Derived over Sonoran Desert as seen by Landsat 1- 5 since 1972, Band-2
(Cross Calibrated to Landsat TM 5)
After Calibration
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%
TOA Normalized Radiance (W/m2umsr)
200
190
180
170
160
150
140
130
120
110
100
1972
1977
1982
1987
1992
Landsat-1
Landsat-2
Landsat-3
Landsat-4
Landsat-5
Landsat-4 TM Band 3
Landsat-5 TM Band 3

MSS Band 3 Results

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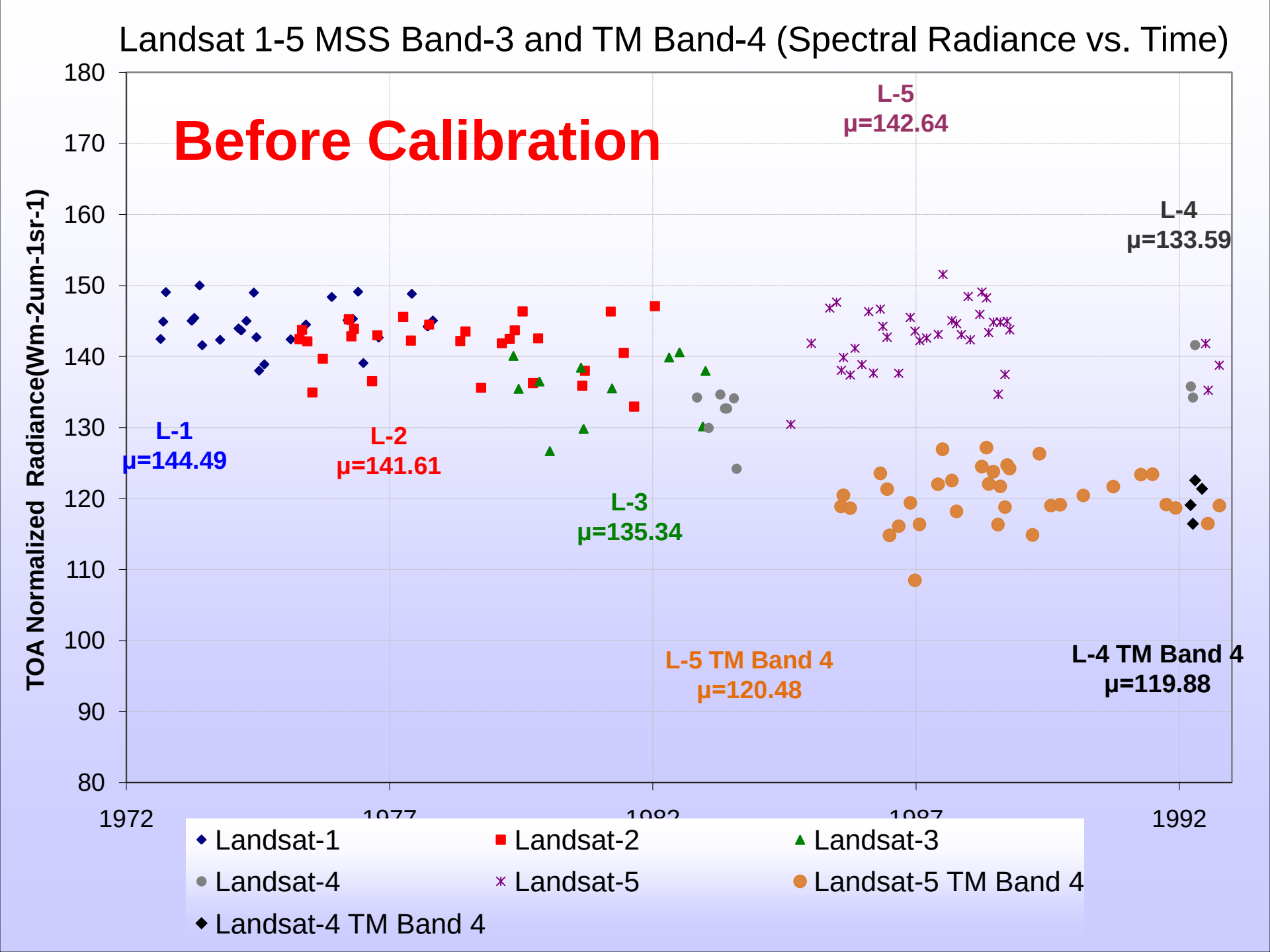
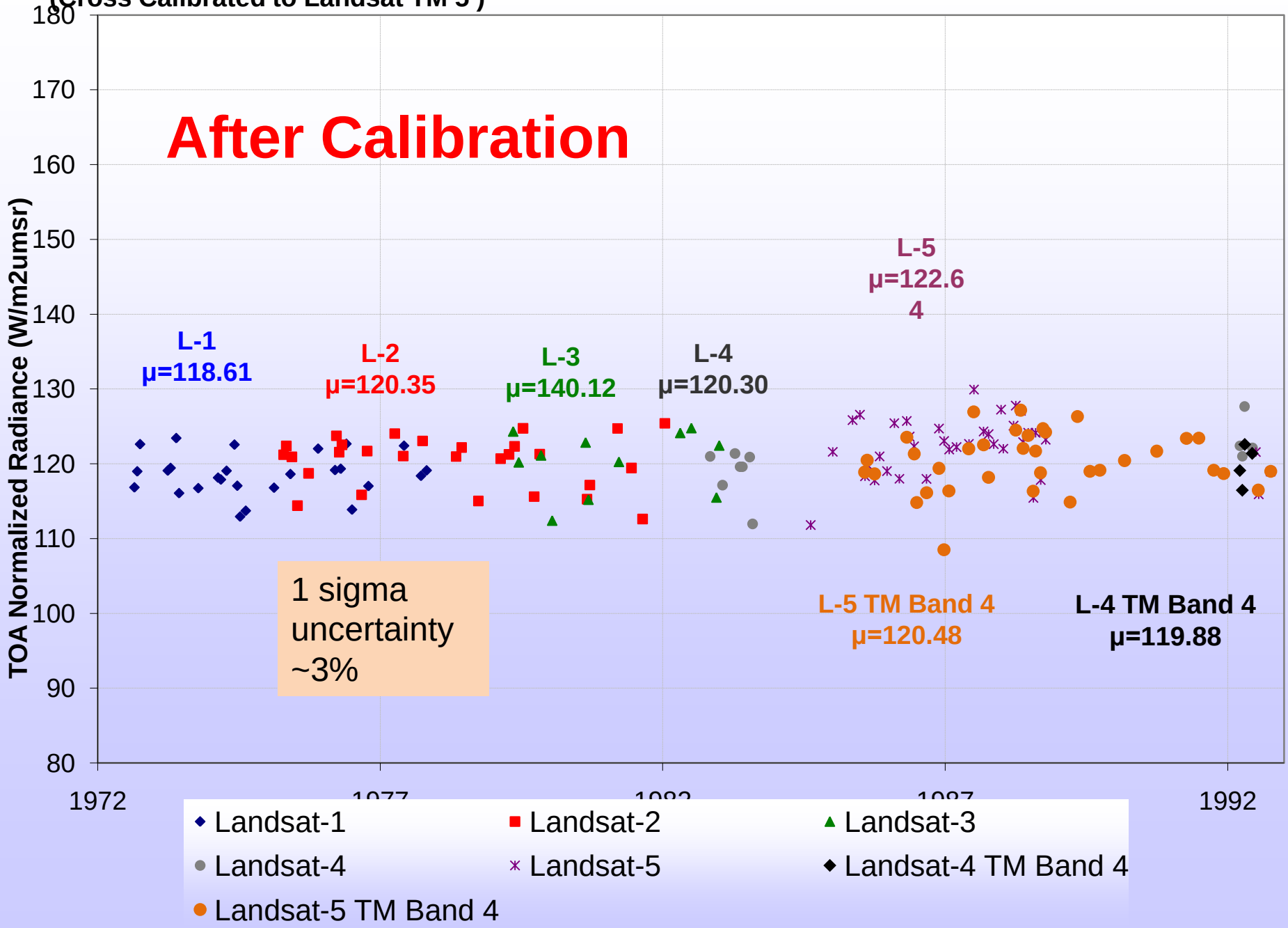

Landsat 1-5 MSS Band-3 and TM Band-4 (Spectral Radiance vs. Time)
Before Calibration
TOA Normalized Radiance(Wm-2um-1sr-1)
180
170
160
150
140
130
120
110
100
90
80
1972
1977
1982
1987
1992
L-1
μ=144.49
L-2
μ=141.61
L-3
μ=135.34
L-5
μ=142.64
L-4
μ=133.59
L-5 TM Band 4
μ=120.48
L-4 TM Band 4
μ=119.88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

TOA Radiance Derived over Sonoran Desert as seen by Landsat 1- 5 since 1972, Band-4 (Cross Calibrated to Landsat TM 5)



MSS Band 4 Results

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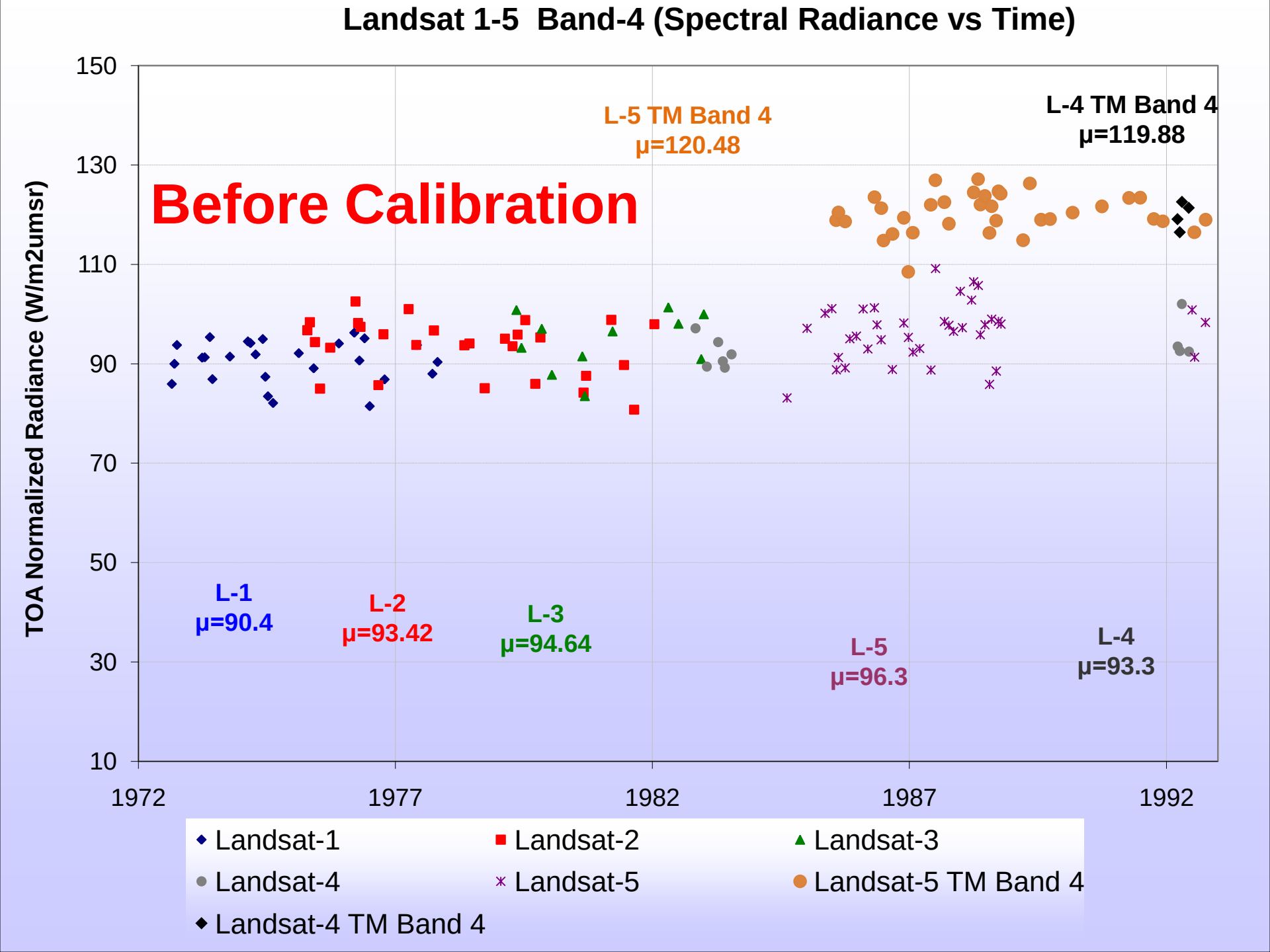
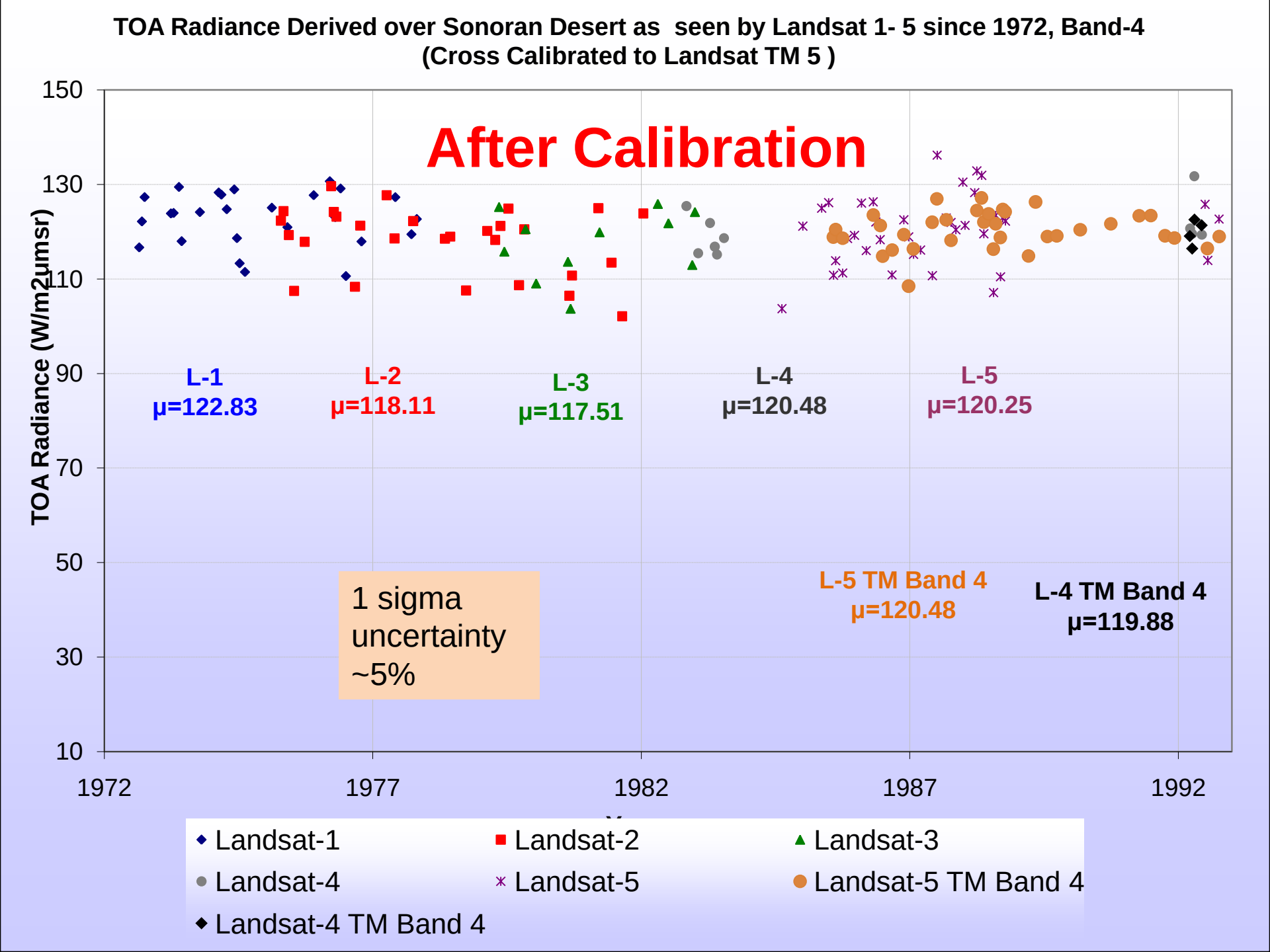

Landsat 1-5 Band-4 (Spectral Radiance vs Time)
TOA Normalized Radiance (W/m2umsr)
150
130
110
90
70
50
30
10
1972
1977
1982
1987
1992
Before Calibration
L-5 TM Band 4
μ=120.48
L-4 TM Band 4
μ=119.88
L-1
μ=90.4
L-2
μ=93.42
L-3
μ=94.64
L-5
μ=96.3
L-4
μ=93.3
Landsat-1
Landsat-2
Landsat-3
Landsat-4
Landsat-5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


TOA Radiance Derived over Sonoran Desert as seen by Landsat 1- 5 since 1972, Band-4
(Cross Calibrated to Landsat TM 5)
After Calibration
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
L-5 TM Band 4
µ=120.48
L-4 TM Band 4
µ=119.88
1 sigma
uncertainty
~5%
Landsat-1
Landsat-2
Landsat-3
Landsat-4
Landsat-5
Landsat-5 TM Band 4
Landsat-4 TM Band 4

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

Landsat 1 MSS			Landsat 2 MSS			Landsat 3 MSS		
	G (W/m²srμm) / DN	**Bias** (W/m²srμm)		**G** (W/m²srμm) / DN	**Bias** (W/m²srμm)		**G** (W/m²srμm) / DN	**Bias** (W/m²srμm)
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 (W/m²srμm) / DN	**Bias** (W/m²srμm)		**G** (W/m²srμm) / DN	**Bias** (W/m²srμm)		**G** (W/m²srμm) / DN	**Bias** (W/m²srμm)
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

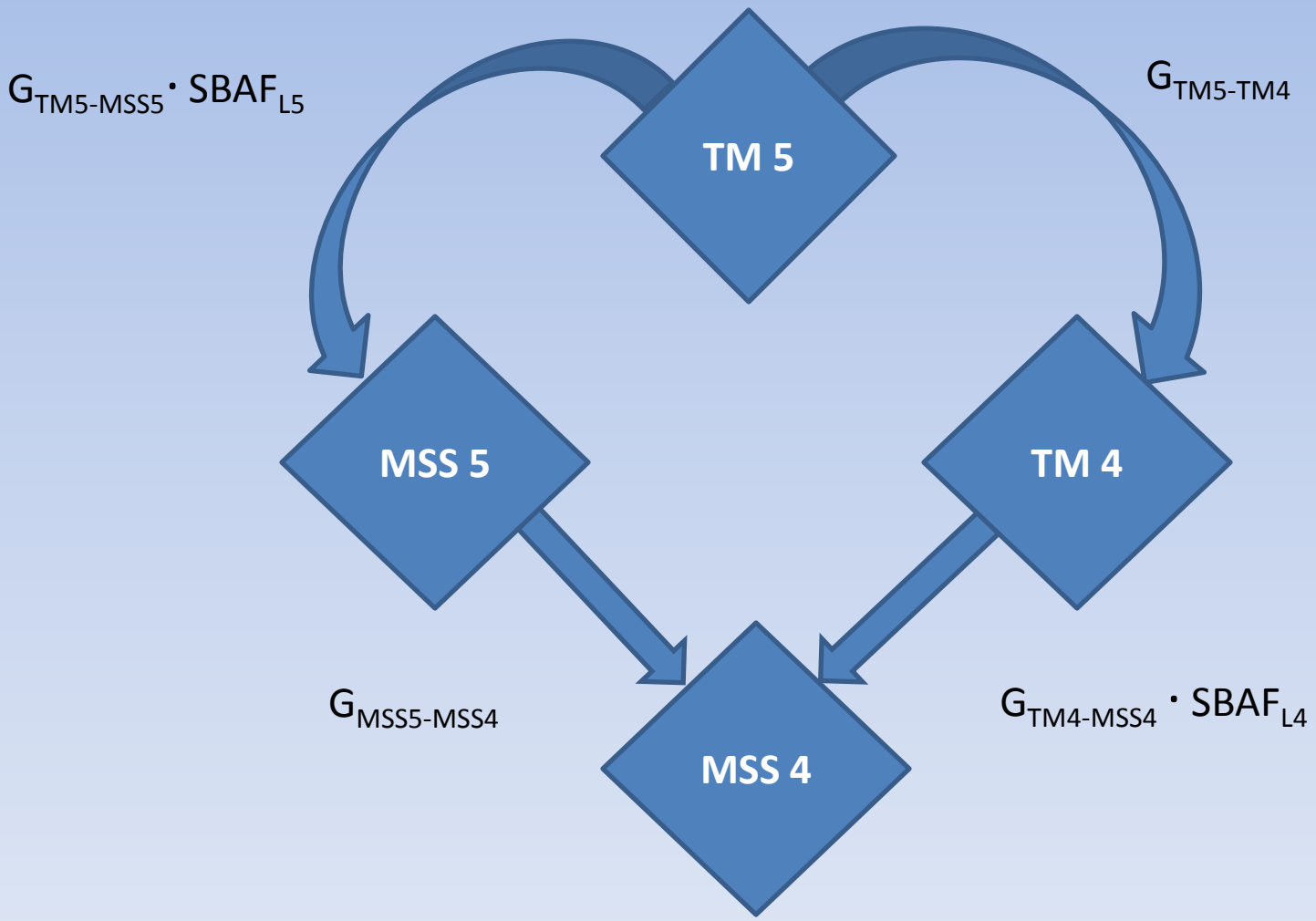
Values marked with * have an additional time dependent factor

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

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



Results 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

Multispectral Scanner

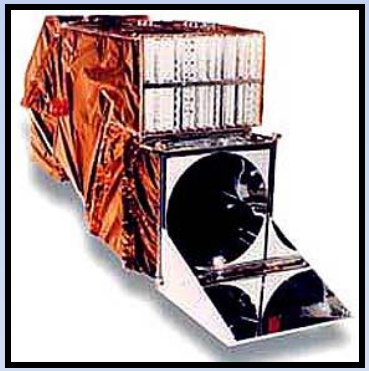
MSS 5 ↔ TM 5 ↔ ETM+

MSS 4 ↔ TM 4

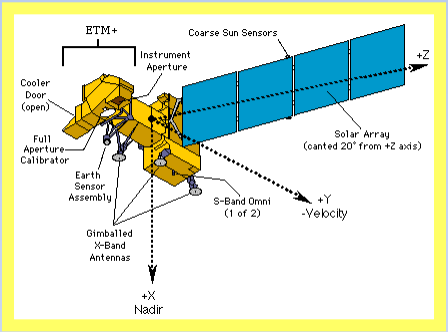
MSS 3

MSS 2

MSS 1



Thematic Mapper



Landsat 7 ETM+

A look at all the Landsat sensors

Are they really all on the same scale?

Pseudo-Invariant Calibration Site (PICS) Sonoran Desert

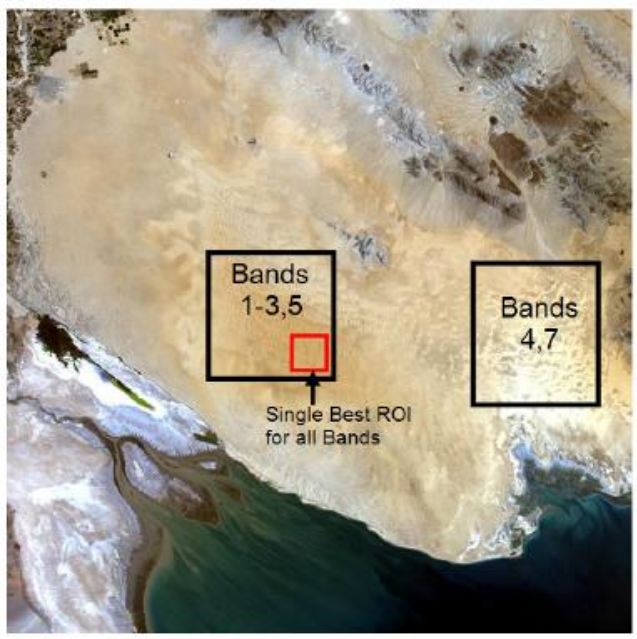
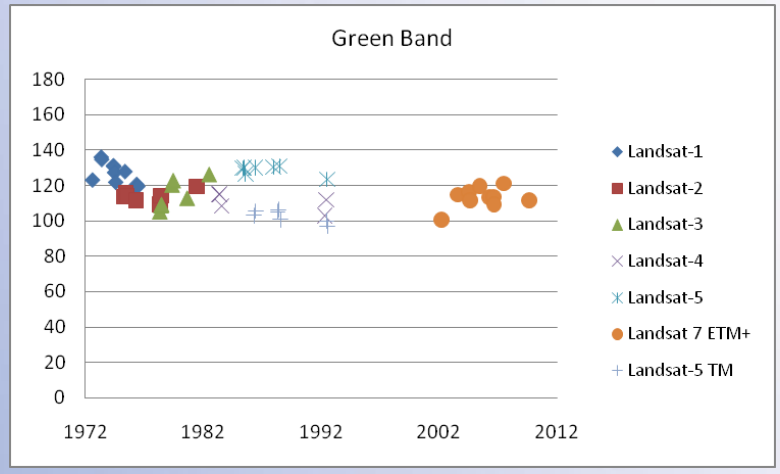


Figure: Sonoran desert (on the Mexican American border)

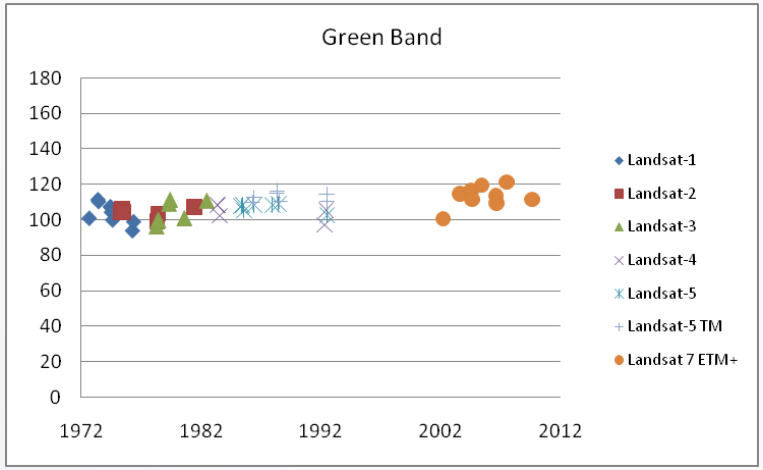
Green Band

Un-calibrated Imagery



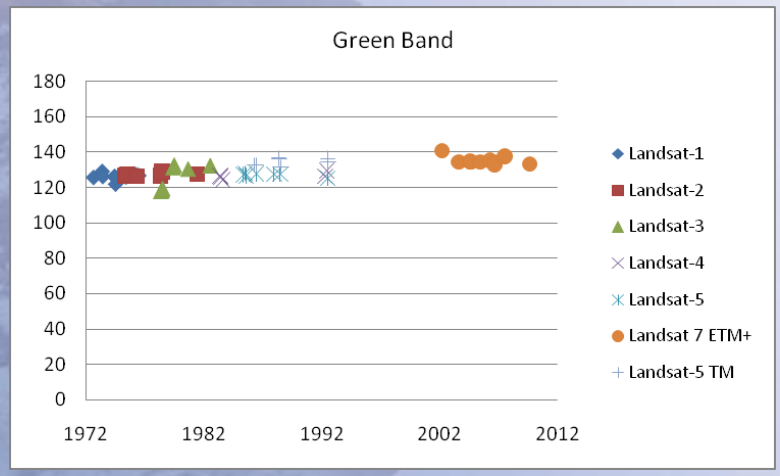
Original Radiance Values Vs Digital Year

Calibrated Imagery-Abs. Radiometric Cal. Applied



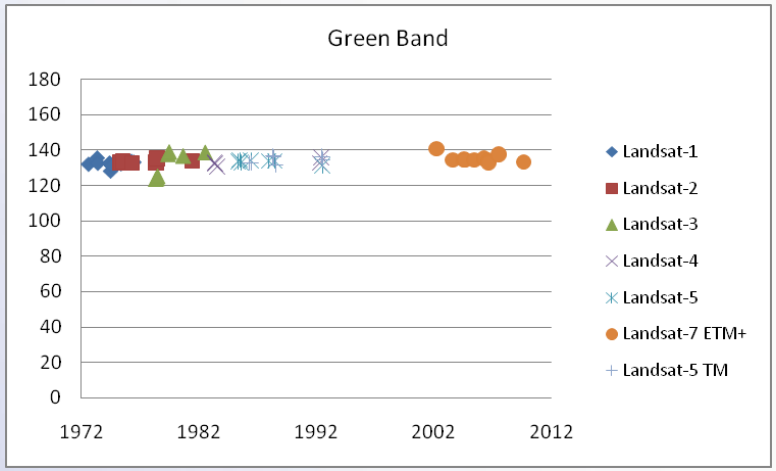
Calibrated Radiance Values Vs Digital Year

$d^2/\cos(\theta)$ Applied



Calibrated TOA Radiance Values Vs Digital Year

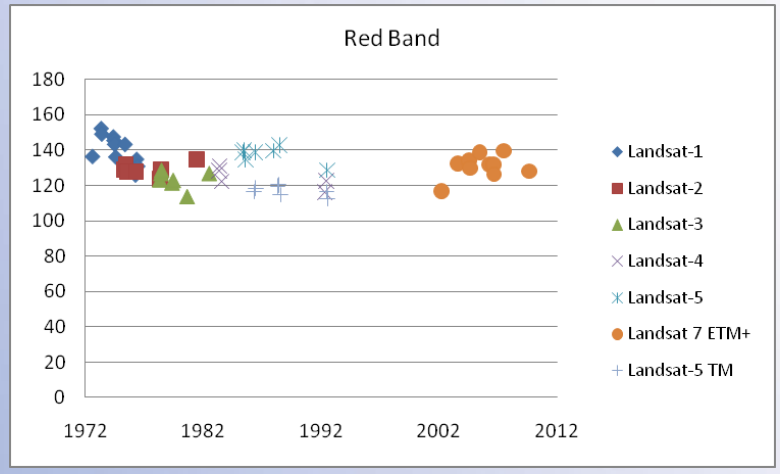
SBAF Applied



SBAF applied on Calibrated TOA Radiance Values Vs Digital Year

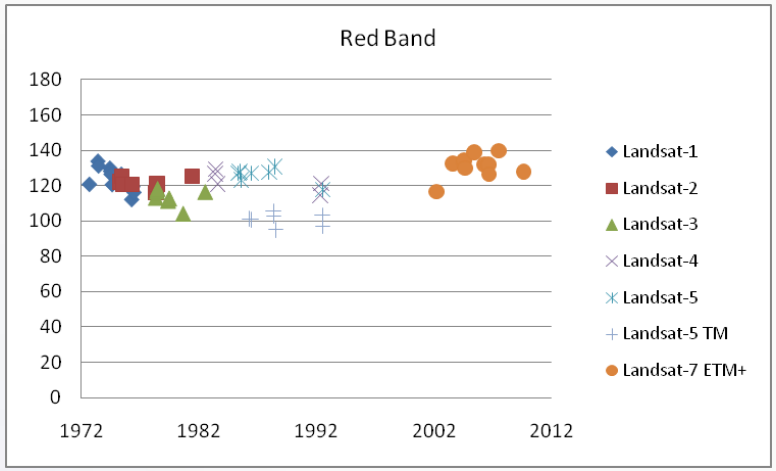
Red Band

Un-calibrated Imagery



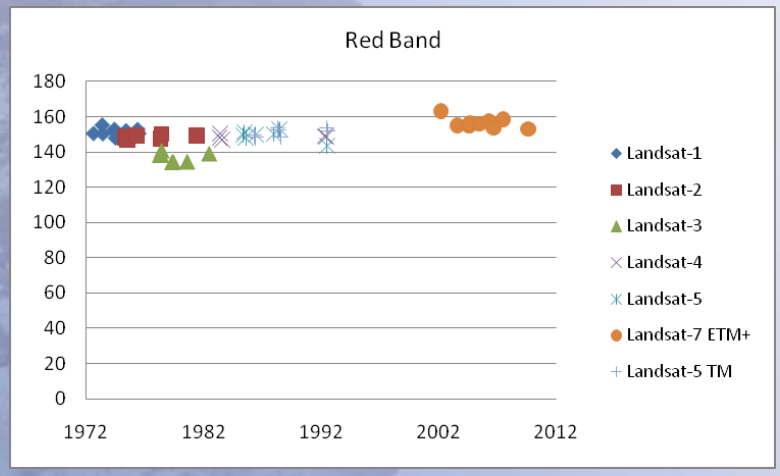
Original Radiance Values Vs Digital Year

Calibrated Imagery-Abs. Radiometric Cal. Applied



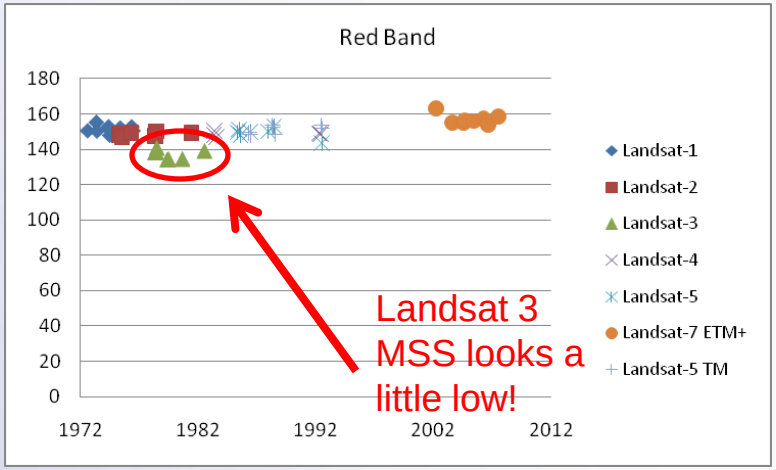
Calibrated Radiance Values Vs Digital Year

$d^2/\cos(\theta)$ Applied



Calibrated TOA Radiance Values Vs Digital Year

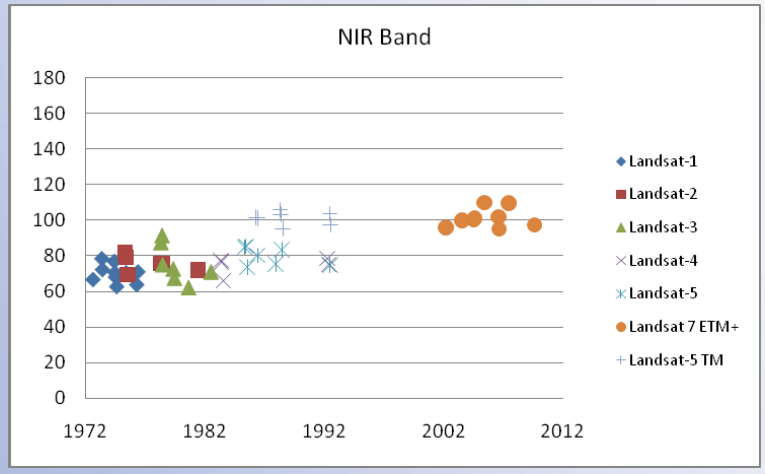
SBAF Applied



SBAF applied on Calibrated TOA Radiance Values Vs Digital Year

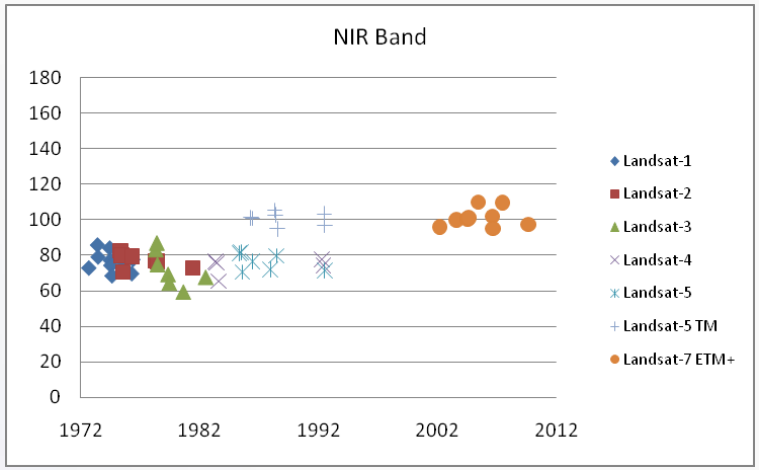
NIR Band

Un-calibrated Imagery



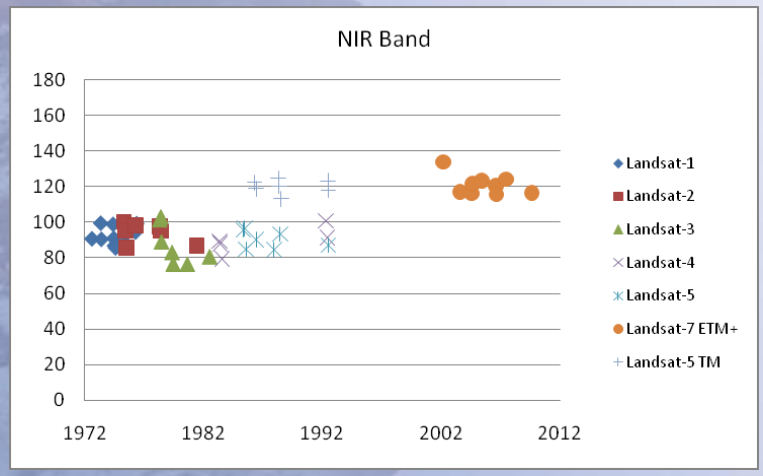
Original Radiance Values Vs Digital Year

Calibrated Imagery-Abs. Radiometric Cal. Applied



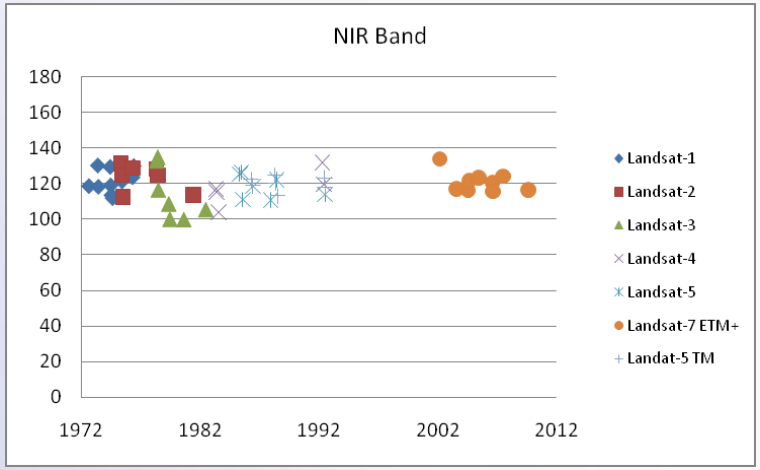
Calibrated Radiance Values Vs Digital Year

$d^2/\cos(\theta)$ Applied



Calibrated TOA Radiance Values Vs Digital Year

SBAF Applied

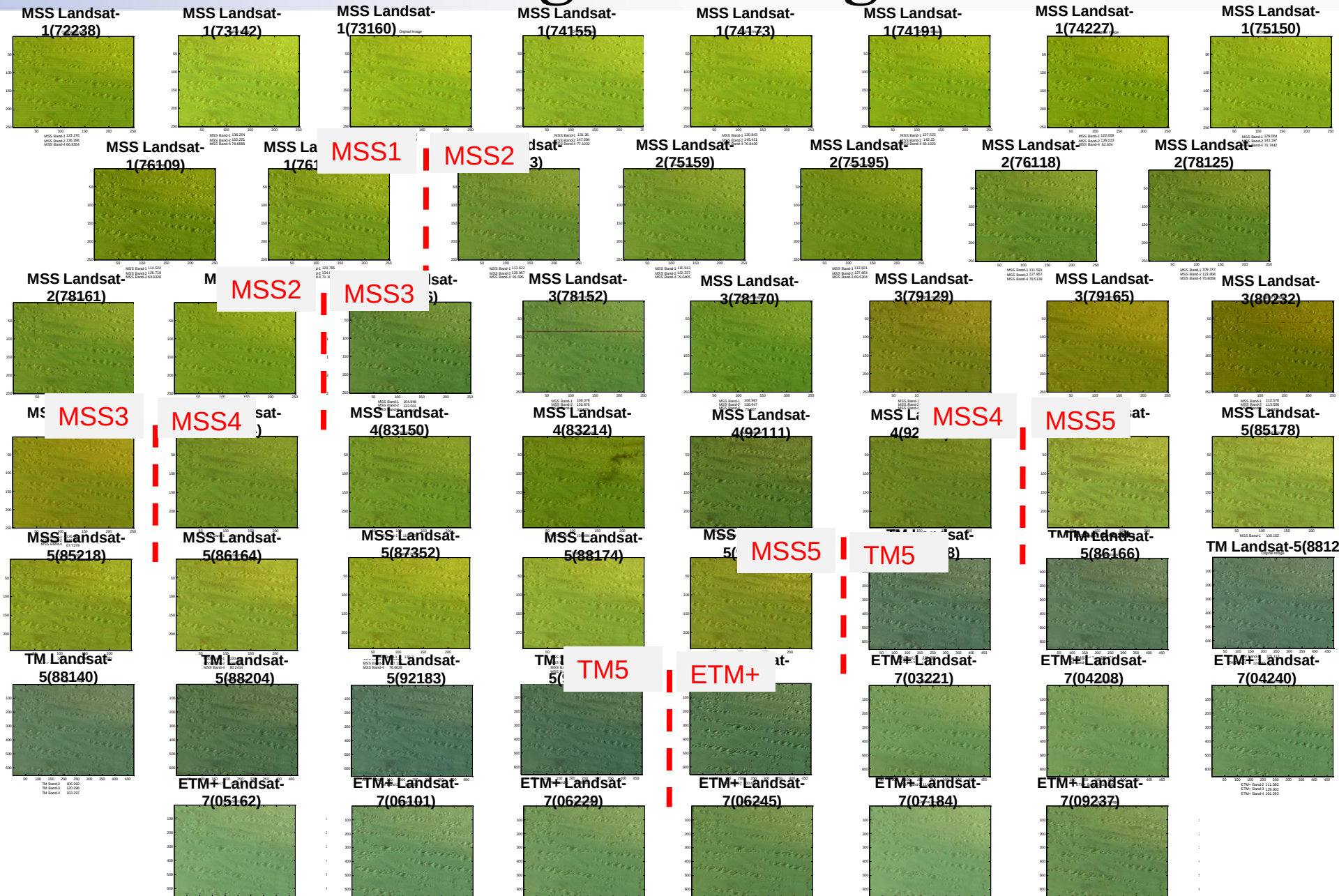


SBAF applied on Calibrated TOA Radiance Values Vs Digital Year

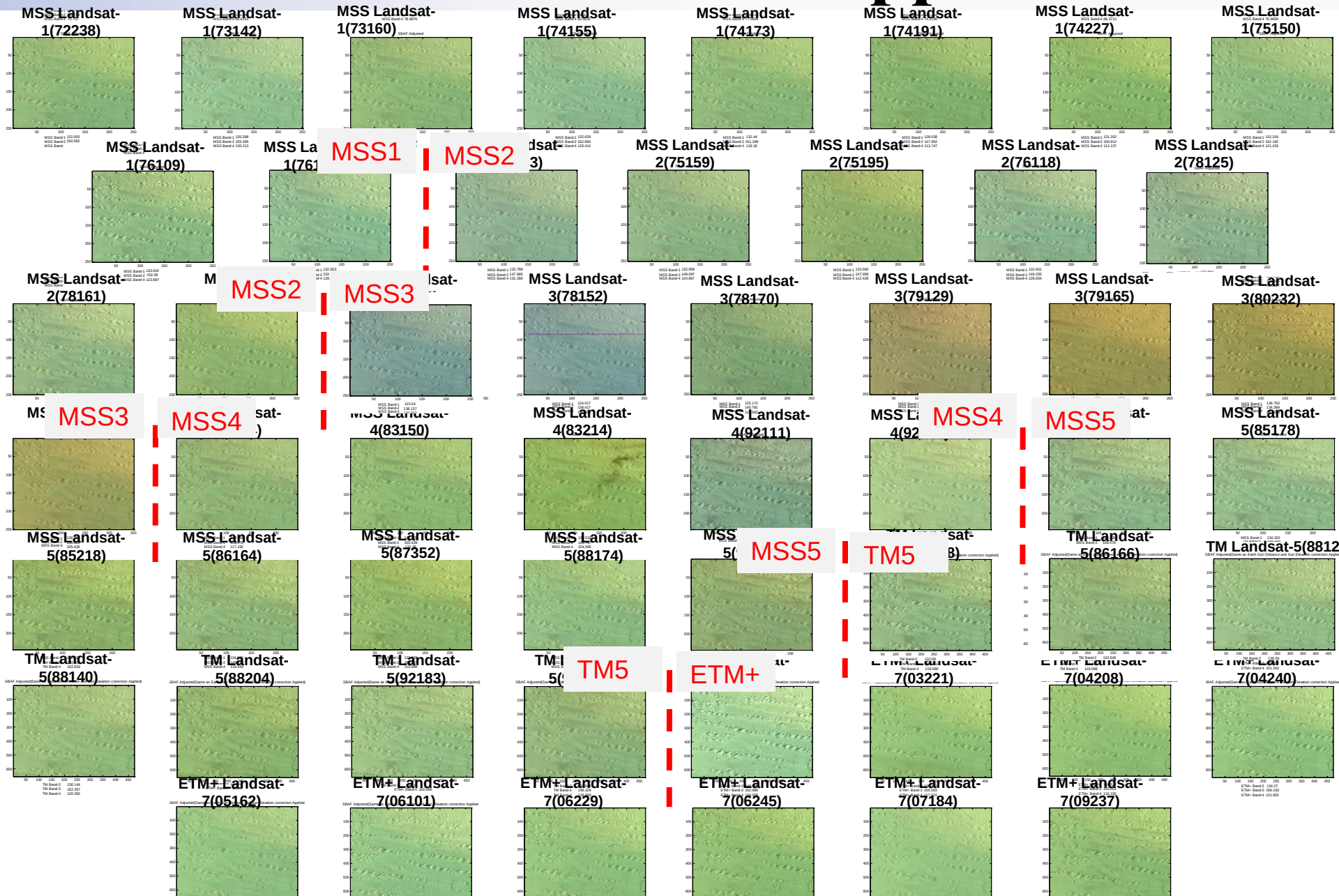
Landsat Images of Sonoran PICS from 1972 through 2009

- Landsat 1-5 MSS, TM, and ETM+ false color (NIR, Red, Green) images of the ROI are displayed left to right, top to bottom in roughly chronological order
- A contrast enhancement has been applied $f(L_\lambda) = 2*[L_\lambda — 58]$ to emphasize differences between images
  - These image tiles in no way represent true color images!
- Essentially uncalibrated imagery will be displayed first followed by 'fully calibrated' imagery

Original Image

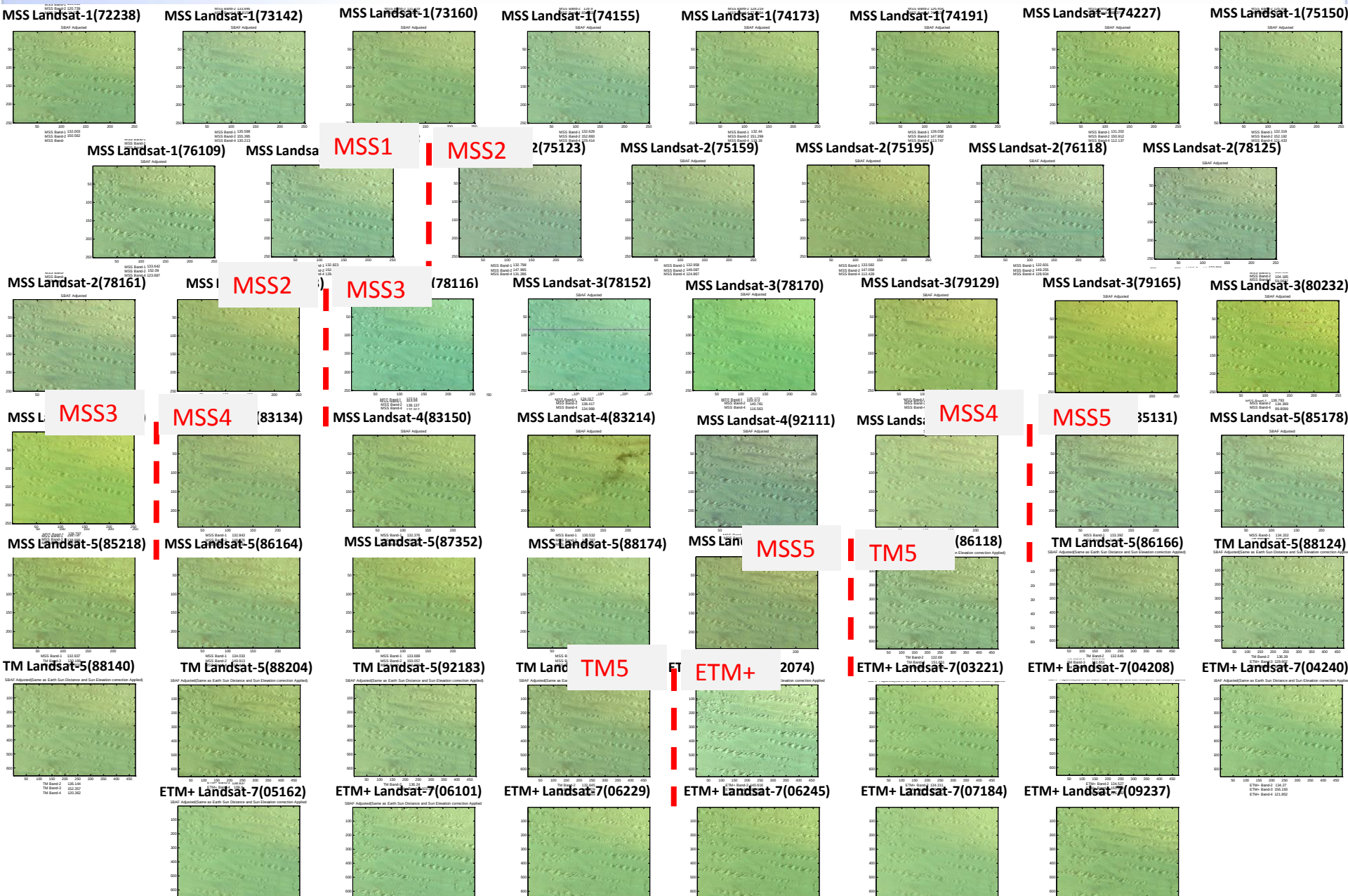


Final Correction Applied



Final Correction Applied

Adding 15 radiance units to band-2 of Landsat-3



SUMMARY

- A consistent absolute radiometric calibration of Landsat sensors has been accomplished
  - MSS, TM, and ETM+ have been placed on a consistent radiometric scale spanning 1972 through the present
  - Sensor-to-sensor uncertainties appear to be within 5%
- Calibration/validation based on spectral profiles of invariant desert sites
  - Consistent results demonstrated across sensors by taking spectral responses into account
  - Other types of targets would require the same approach
- Implementation of MSS absolute calibration is scheduled to occur at USGS EROS in April 2011
  - **And the data is all free!**