Reflectance-Based Cross-Calibration of Landsat Sensors
Or…
MSS Calibration: The Final Word!

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Outline

- Background
- Procedure
- Reflectance-based Cross-Cal Summary from Landsat 8 to Landsat 4
- Issues, Solutions, and Cross-Cal approach of MSS sensors
- Cross-Cal Results (MSS4 to MSS3, MSS3 to MSS2, MSS2 to MSS1
- Final summary chart of Gains and Biases from L8 to L1
- Validation for Reflectance-based Cross-Calibration from Landsat 8 to Landsat 1 using Algodones Dunes
- Conclusion

Background

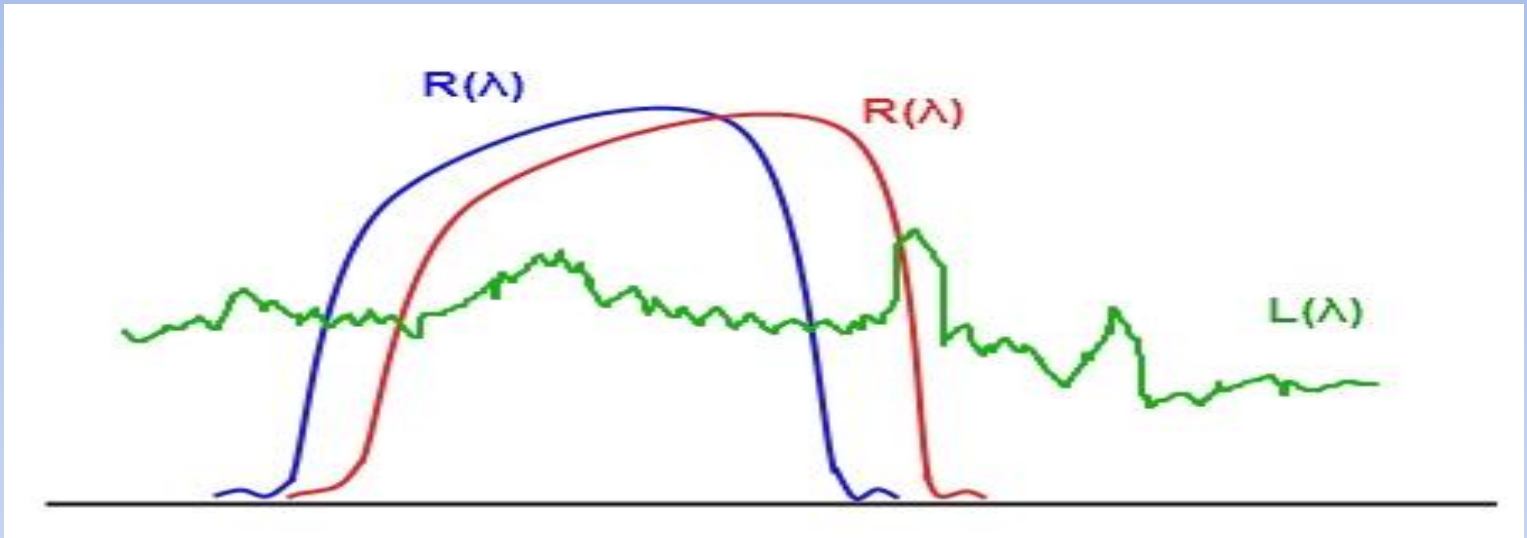
- Goal: Transfer Landsat 8 TOA reflectance calibration back in time to obtain a consistent reflectance-based calibration of the whole Landsat archive

- In general reflectance-based calibration is better than radiance-based calibration.
  - Not dependent upon a solar radiance model
  - OLI reflectance-based calibration has lower uncertainty

Procedure

- Coincident and non-coincident collects from different locations are used as test sites.
  - Two point cross-calibration approach using dark targets and bright targets
  - Begin with L1T product
  - Convert to at-sensor radiance units
  - Remove calibration gain factors (absolute gains, TDF, etc.)
  - Scale by coefficients in the CPF
  - Obtain Artifact Corrected DNs
- Multiple ROIs selected from a given scene
- SBAF derived using Hyperion
- Linear regression is used to determine gain and bias
  - statistical test is performed to check significance
- Validation using other sites

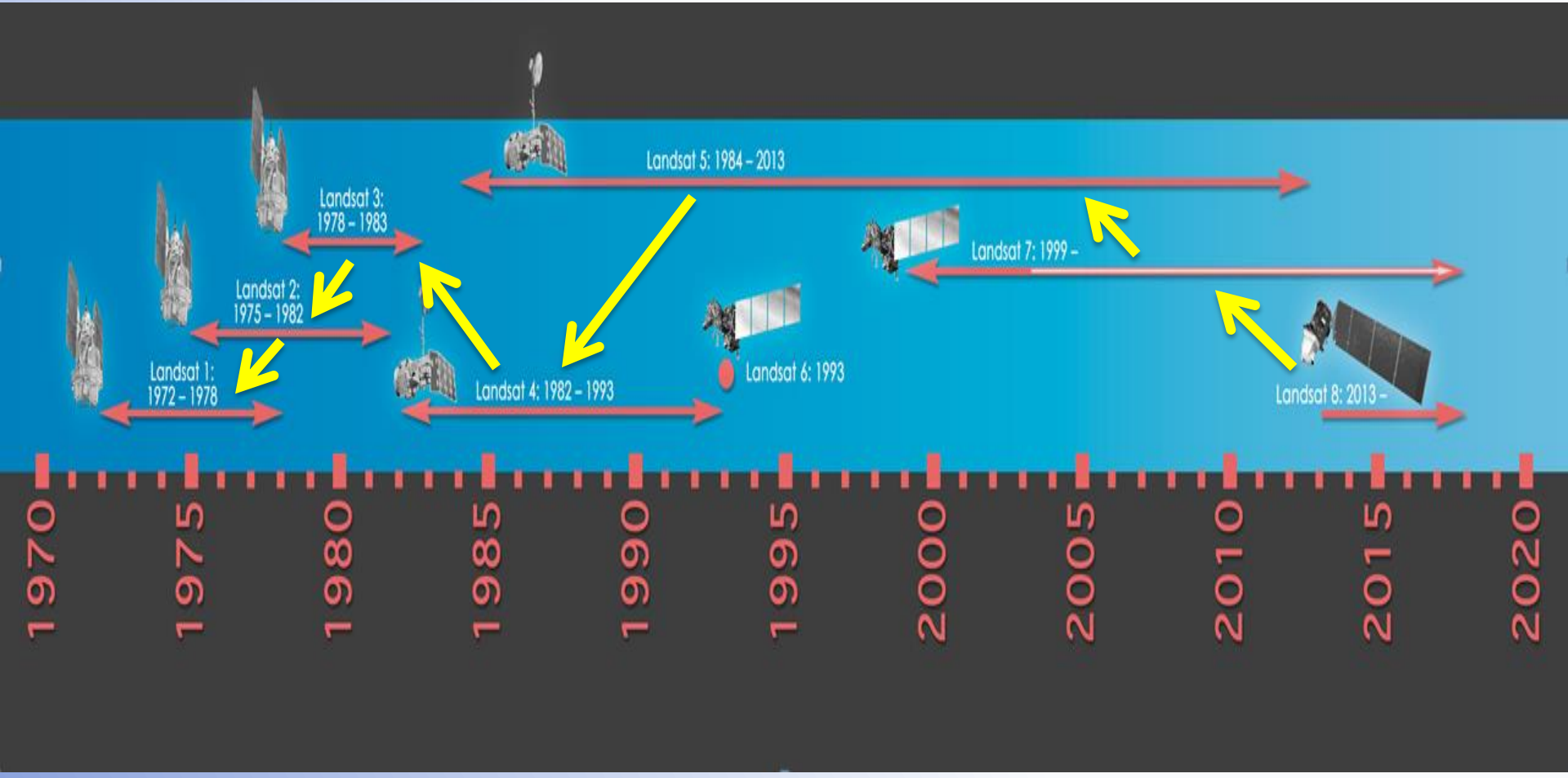
R(λ): Band specific RSR Profile
L(λ): Spectral signature of target



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

- 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.

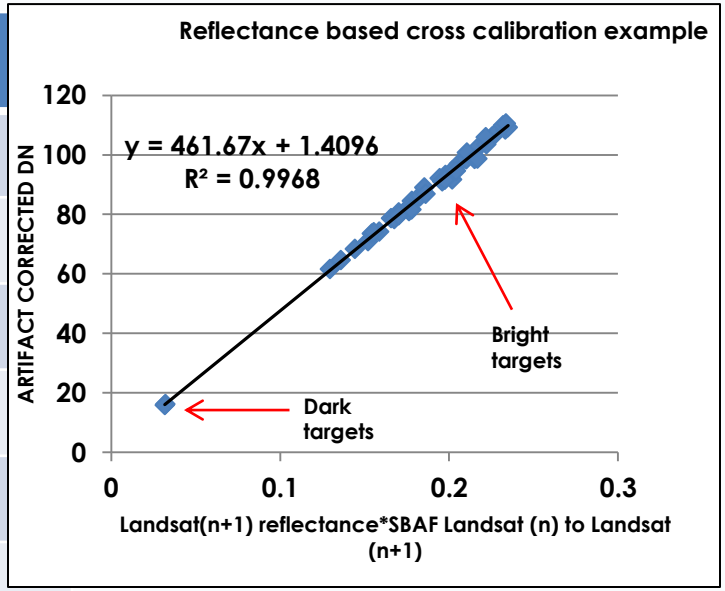
Cross Calibration from Landsat 8 back to Landsat 1



- Cross-Calibration from Landsat 8 to Landsat 4 results were already shown.
- Work now completed for MSS sensors

Reflectance-based Landsat Archive Calibration Process

Sensor Level	Getting DN's
OLI	$DN_{8,\lambda}=g_{8,\lambda}\cdot\rho_{8,\lambda}+b_{8,\lambda}$
OLI to ETM+	$DN_{7,\lambda}=g_{7\lambda}\cdot(SBAF_{7/8,\rho,\lambda,ROI}\cdot\rho_{8,\lambda})+b_{7,\lambda}$
ETM+ to TM5	$DN_{5,\lambda}=g_{5\lambda}\cdot(SBAF_{5/7,\rho,\lambda,ROI}\cdot\rho_{7,\lambda})+b_{5,\lambda}$
TM5 to TM4	$DN_{4,\lambda}=g_{4\lambda}\cdot(SBAF_{4/5,\rho,\lambda,ROI}\cdot\rho_{5,\lambda})+b_{4,\lambda}$
TM5 to MSS5	$DN'_{5M,\lambda}=g_{5M\lambda}\cdot(SBAF_{5M/5,\rho,\lambda,ROI}\cdot\rho_{5,\lambda})+b_{5M,\lambda}$
MSS(n+1) to MSS(n)	$DN'_{nM,\lambda}=g_{nM\lambda}\cdot(SBAF_{nM/(n+1)M,\rho,\lambda,ROI}\cdot\rho_{n+1M,\lambda})+b_{nM,\lambda}$



Now, to get Artifact Corrected DN using coefficients from CPF

$$DN_{7,\lambda} = L_{7,\lambda}\cdot G_{ETM+,Average\ of\ detector\ post\ launch\ gain_{(\lambda)},\ scaled\ from\ 1st\ CPF\ of\ L7}$$

$$DN_{TM5,\lambda} = L_{TM5,\lambda}\cdot\left(\frac{G_{TM5,\lambda,\text{Current CPF avg_band gains}(t)}}{G_{TM5,\lambda,\text{corrected linear drift gains}(t)}}\right)\cdot G_{L7-L5\ \text{cross cal,June1,1999}}$$

$$DN_{TM4,\lambda} = L_{TM4,\lambda}\cdot G_{TM4,CPF\ Day1\ Launch\ average\ band\ gain\ (\lambda)}\ scaled\ from\ 1st\ CPF\ of\ TM4$$

$$DN'_{MSS5,\lambda}=\left(\left(\frac{L_{MSS5,\lambda}}{G_{MSS5,\lambda,\text{cross-cal}}\cdot TDF_{(\lambda)}}\right)/\ G_{MSS5,\lambda,\text{absolute gains}}\right)-\text{bias}_{(n,\lambda,5)}$$

$$DN'_{MSS4,\lambda}=\left(\left(\frac{L_{MSS4,\lambda}}{G_{MSS4,\lambda,\text{cross-cal}}\cdot TDF_{(\lambda)}}\right)/\ G_{MSS4,\lambda,\text{absolute gains}}\right)-\text{bias}_{(n,\lambda,5)}$$

- Summary of number of scene pairs and ROI's used for each pair of sensors

Level	No. of Scene pairs	No. of ROIs
OLI to ETM+	Sonoran Desert : 8 Lake Tahoe: 2 **Total:10**	Sonoran Desert : 5 Lake Tahoe: 1
ETM+ to TM5	Sonoran Desert: 7 Lake Tahoe: 4 **Total: 11**	Sonoran Desert: 5 Lake Tahoe: 1
TM5 to TM4	Sonoran Desert: 1 Ivanpah Playa: 4 Rock Springs: 2 Near to Sonoran: 8 Algodones Dunes: 3 Kelso Dunes: 4 Makhtesh Ramon: 1 Arabian Deserts: 9 **Total: 32**	Sonoran Desert: 11 Ivanpah Playa: 4 Rock Springs: 2 Near to Sonoran: 2 Algodones Dunes: 3 Kelso Dunes: 2 Makhtesh Ramon: 3 Arabian Deserts: 11 (Note :Few ROIS from Arabian and Ivanpah playa are not used for SWIR bands because of saturation)
TM5 to MSS5	Sonoran:7 Lake Tahoe:3 **Total:10**	Sonoran:5 Lake Tahoe:1
MSS5 to MSS4	Sonoran: 1 Lake Tahoe: 2 Ivanpah Playa:2 Crater Lake: 2 White Sands: 1 Alabama: 1 **Total: 9**	Sonoran: 14 Lake Tahoe: 1 Ivanpah Playa:4 Crater Lake: 1 White Sands: 4 Alabama: 5

- Each ROI manually selected after study of spatial and temporal properties

Issues, Solution and Cross-Cal approach for MSS sensors

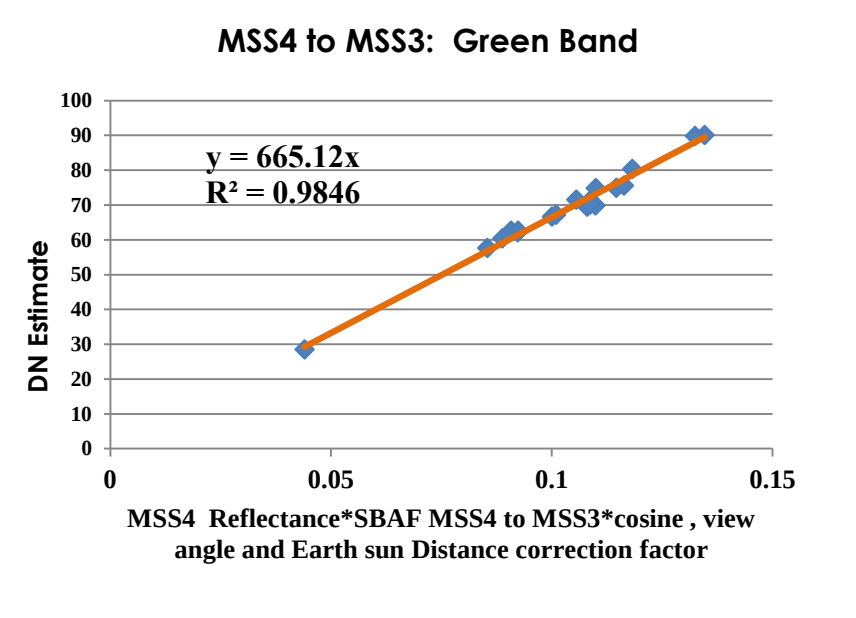
Sensors	Available formats	Comments
MSS3	MSSA, MSSP, MSSR, MSSX (Note MSSX has 3 formats: MSSX_ORF, MSSX_WBVT, MSSX_CCT) Note: Based on availability only MSSA data is used to calibrate MSS3	MSSA and MSSP data is good. Significant bias in MSSR and stripes in MSSX data.
MSS2	MSSA, MSSP, MSSR, MSSX Note: MSSX has 3 formats: MSSX_ORF, MSSX_WBVT, MSSX_CCT Note: MSSA and MSSP used for calibration of MSS2	MSSA, MSSP and MSSX_WBVT are good, Some MSS-R have stripes.
MSS1	MSSX_WBVT, MSSX_ORF Note: Only MSSX_WBVT is used as there is no other data available early in MSS1's lifetime	MSSX_WBVT data is good.

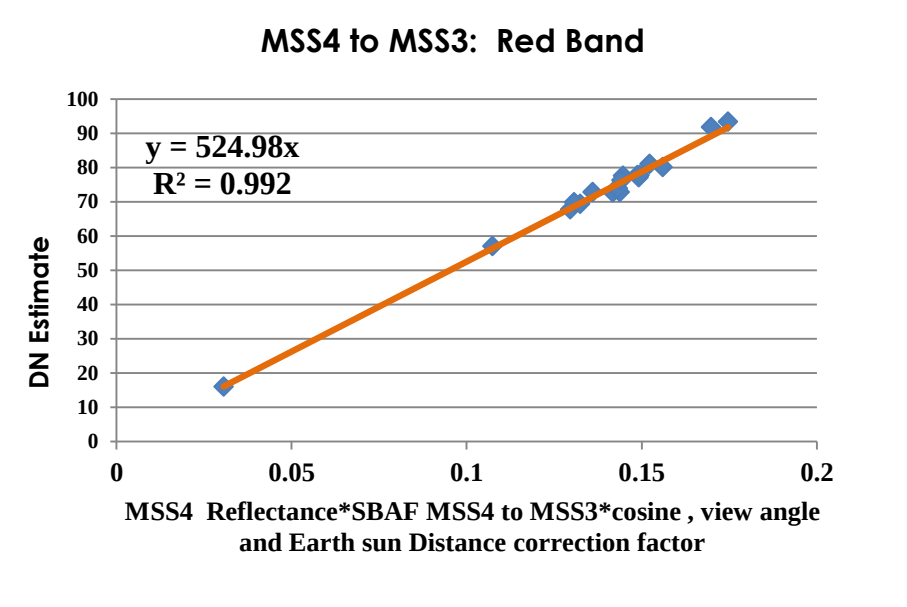
Two key points:

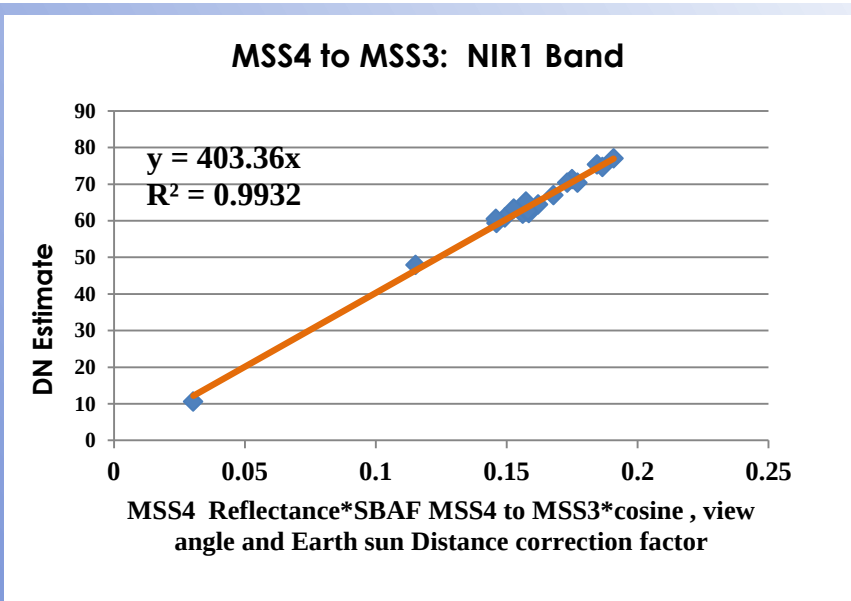
1. MSS data comes in <u>many</u> flavors!
2. Normalization of MSS-R data to the rest of the data formats still in progress…

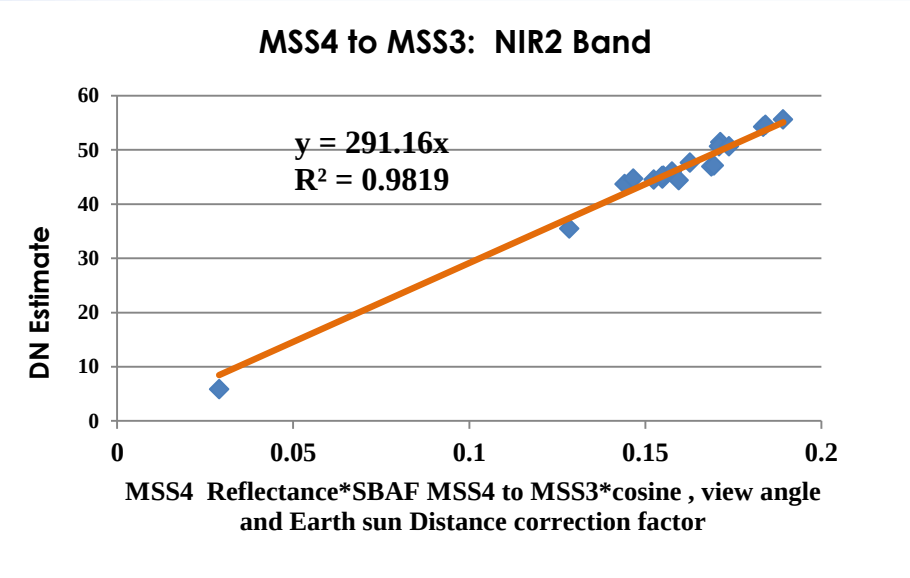
MSS-X (Landsats 1-3)
MSS-X Wide Band Video (WBVT)
No radiometric or geometric correction applied
MSS-X GSFC or CCT-X (some "radiometry")
MSS-X Orphan (no telemetry, acquisition date/time)
MSS-P (Landsats 2-3)
Radiometric + Geometric corrected, similar to current L1G
MSS-A (Landsats 2-5)
Radiometric correction, geometric "grid" not applied

$$DN\ Estimate = \left(\left(\frac{L_{MSS3,\lambda}}{G_{MSS3,\lambda,cross-cal*TDF_{(\lambda)}}}\right) / G_{MSS3,\lambda,absloute\ gains}\right) - bias_{(n,\lambda,5)}$$



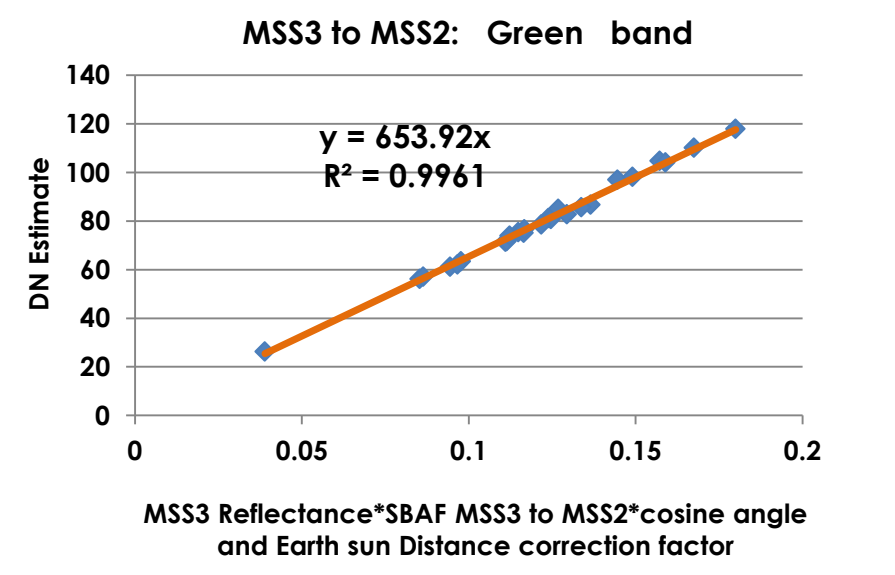


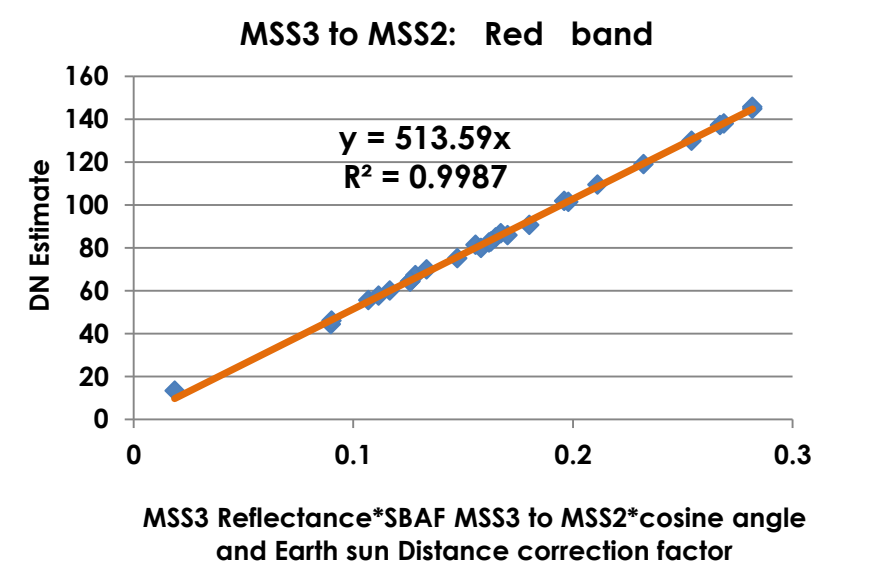


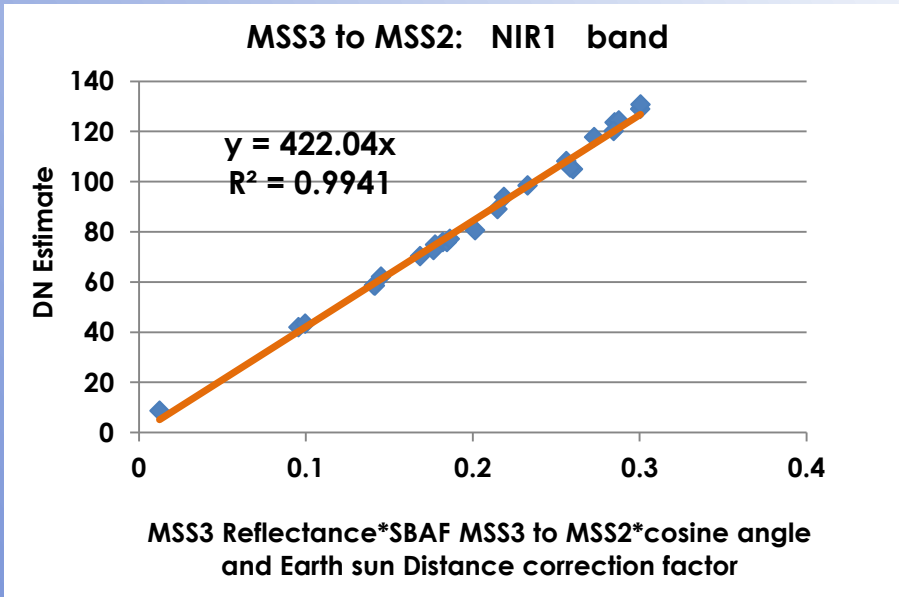


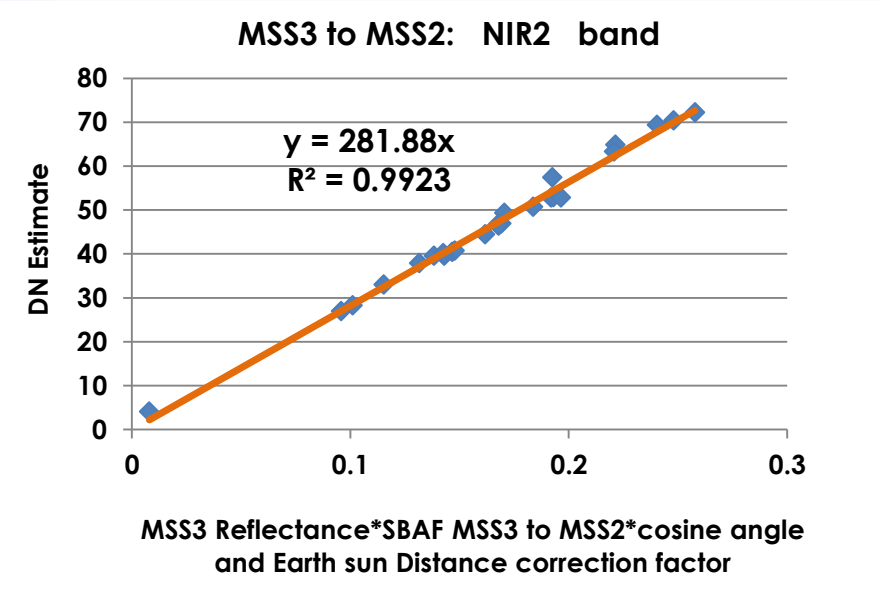
- Statistical test showed there is no significant bias in all bands.
- Bias is passed through zero to find the gain.

$$\text{DN Estimate}=\left(\left(\frac{L_{MSS2,\lambda}}{G_{MSS2,\lambda,cross-cal*TDF_{(\lambda)}}}\right)/\ G_{MSS2,\lambda,absloute\ gains}\right)-bias_{(n,\lambda,5)}$$



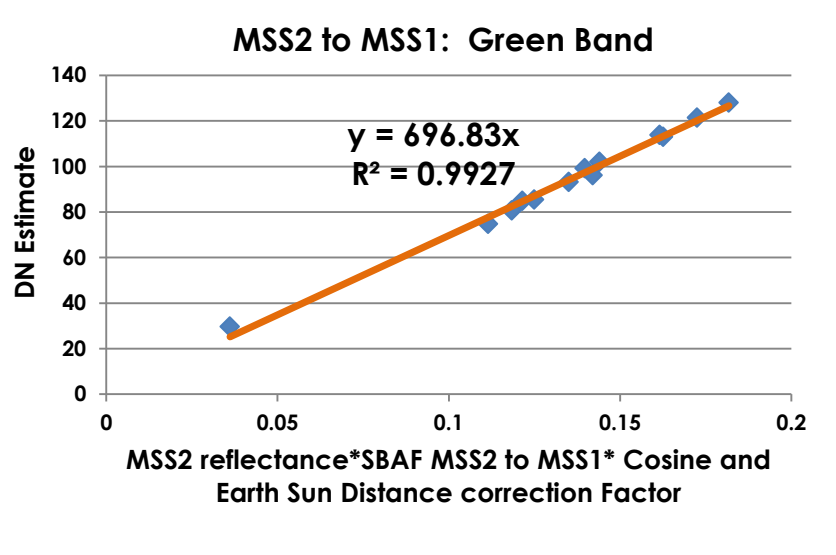


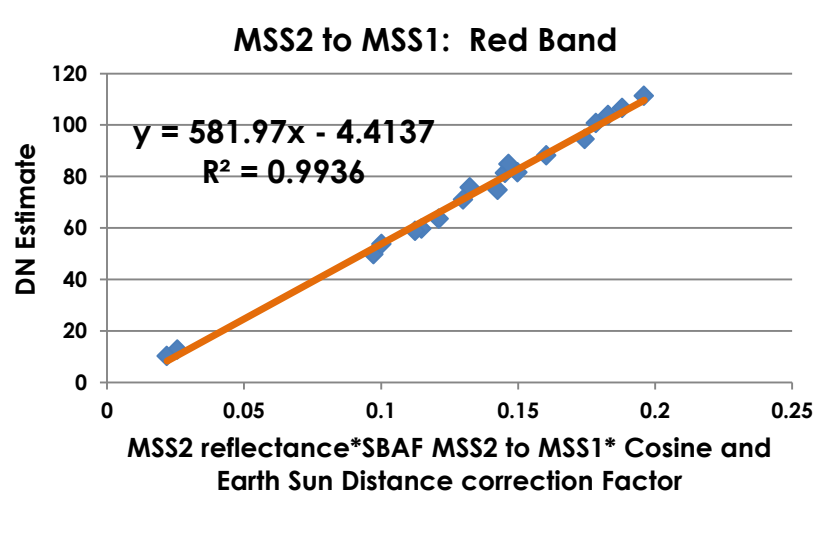


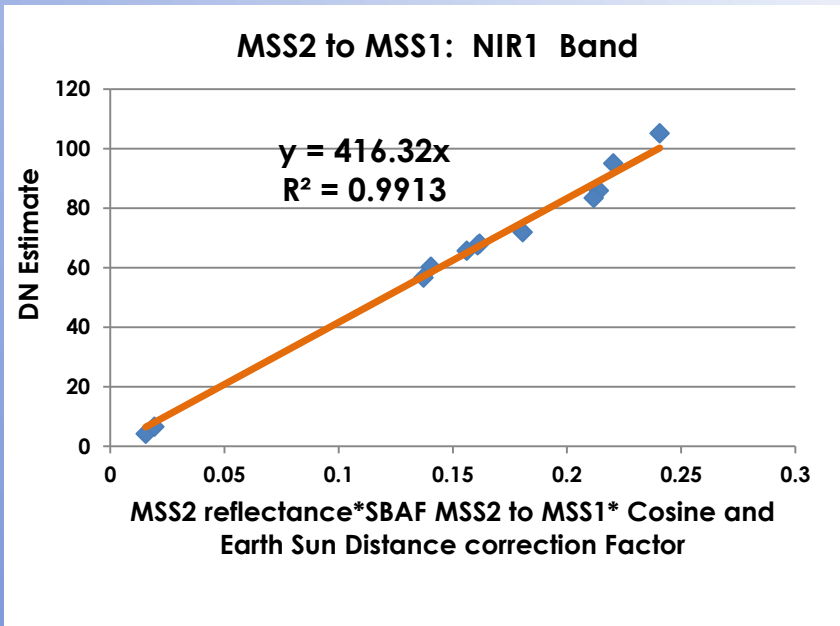


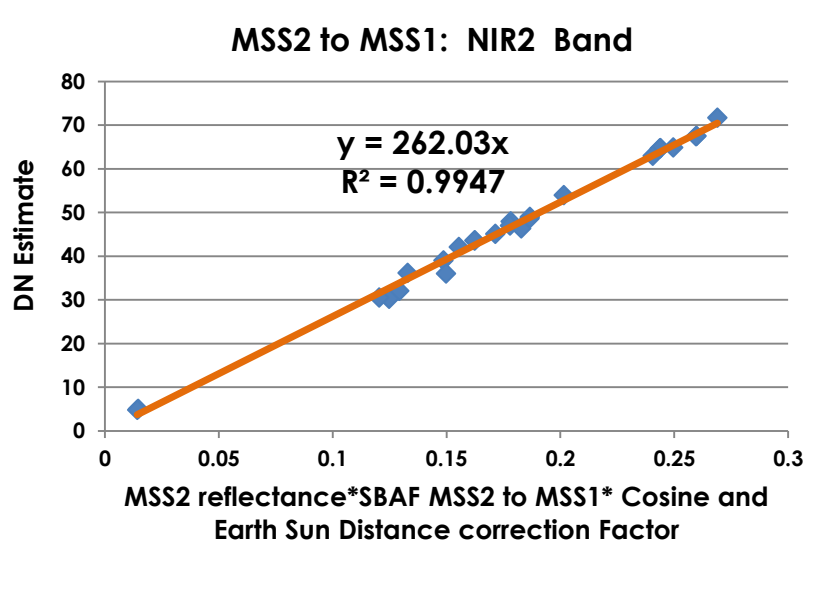
- Statistical test showed there is no significant bias in all bands.
- Bias is passed through zero to find the gain.

$$\text{DN estimate} = \left(\left(\frac{L_{MSS1,\lambda}}{G_{MSS1,\lambda,cross-cal*TDF_{(\lambda)}}}\right) / G_{MSS1,\lambda,absloute\ gains}\right) - bias_{(n,\lambda,5)}$$





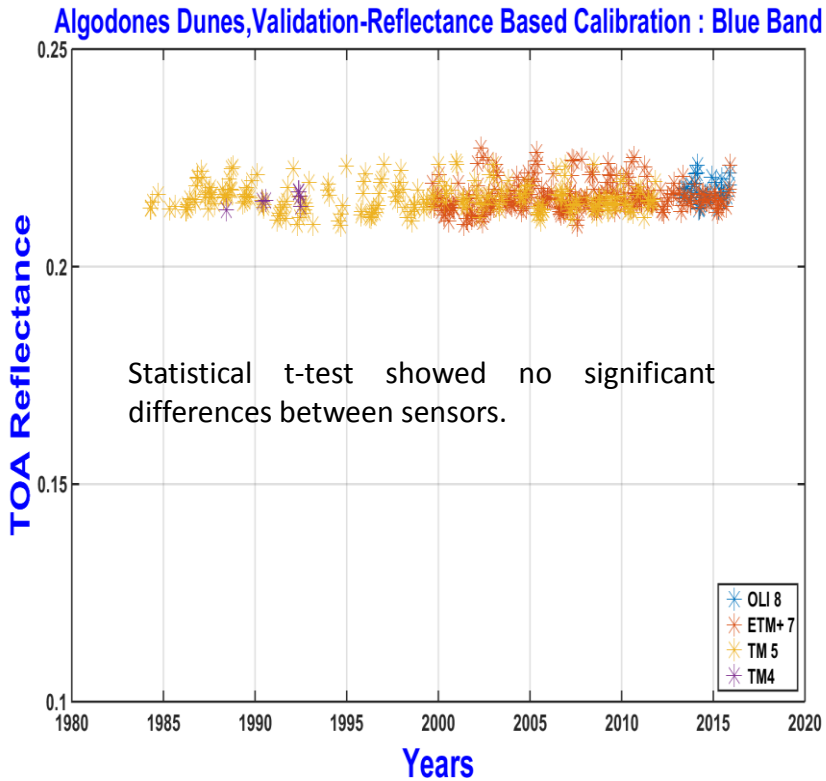


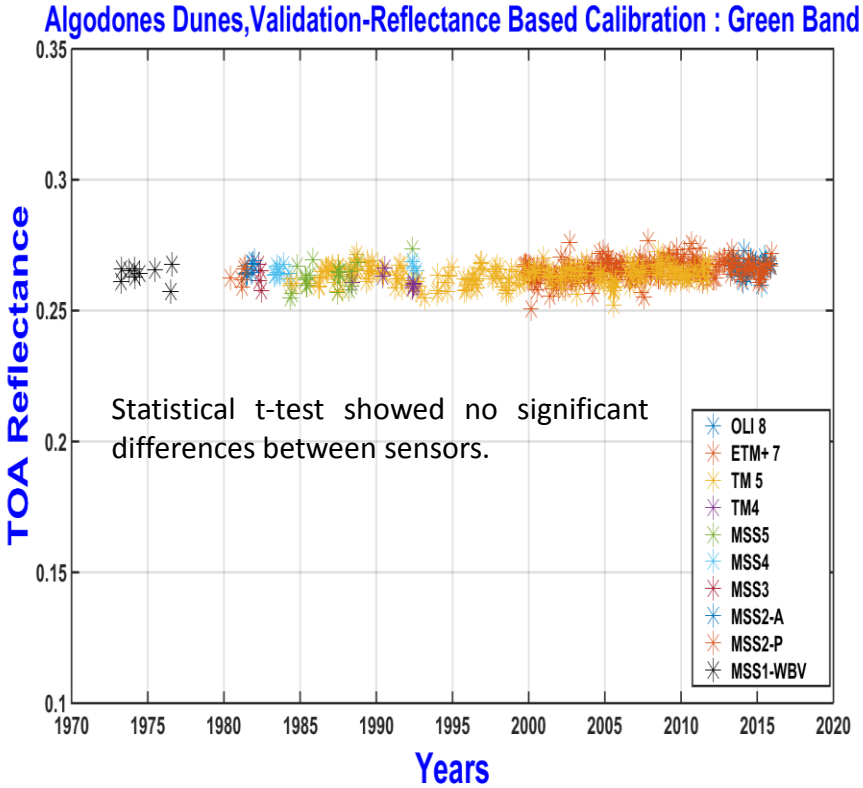


- After statistical test significant bias is seen in only Red band .
- Bias for other bands forced through zero to find the gain

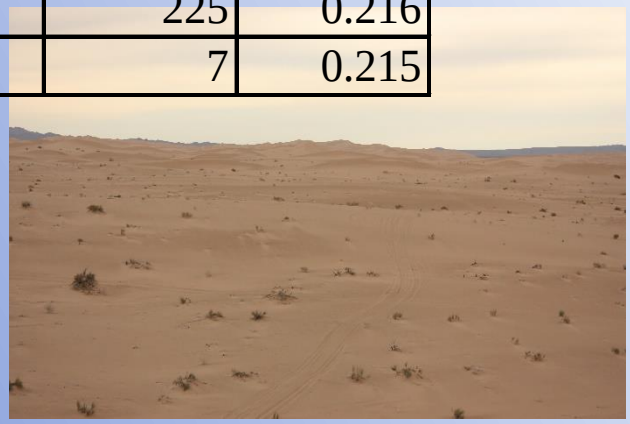
Final Summary of Gains and Biases from Landsat 8 to Landsat 1

Landsat ETM+ 7				Landsat TM5		
Bands	Gain	Bias		Bands	Gain	Bias
BLUE	529.02	0		BLUE	775.30	0
GREEN	468.93	0		GREEN	370.59	0
RED	497.36	0		RED	434.08	0
NIR	339.86	0		NIR	358.43	0
SWIR1	356.88	0		SWIR1	547.57	0
SWIR2	376.37	0		SWIR2	384.66	0
PAN	415.13	0				
Landsat TM4				**Landsat MSS5**		
Bands	Gain	Bias		Bands	Gain	Bias
BLUE	924.32	0		GREEN	689.93	0
GREEN	405.93	0		RED	527.31	0
RED	456.06	0		NIR1	414.05	0
NIR	355.33	0		NIR1	277.73	0
SWIR1	545.07	0				
SWIR2	387.76	0				
Landsat MSS4				**Landsat MSS3**		
Bands	Gain	Bias		Bands	Gain	Bias
GREEN	586.08	0		GREEN	665.12	0
RED	476.03	0		RED	524.98	0
NIR1	377.94	0		NIR1	403.36	0
NIR1	258.77	0		NIR1	291.16	0
Landsat MSS2				**Landsat MSS1**		
Bands	Gain	Bias		Bands	Gain	Bias
GREEN	653.92	0		GREEN	696.83	0
RED	513.59	0		RED	581.97	-4.414
NIR1	422.04	0		NIR1	416.32	0
NIR1	281.88	0		NIR1	262.03	0

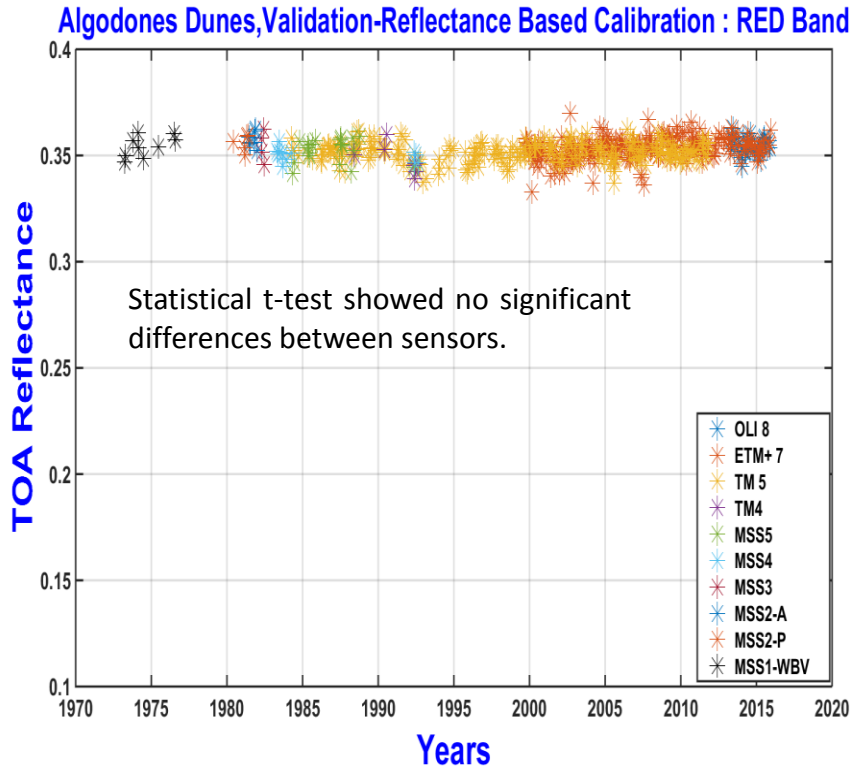


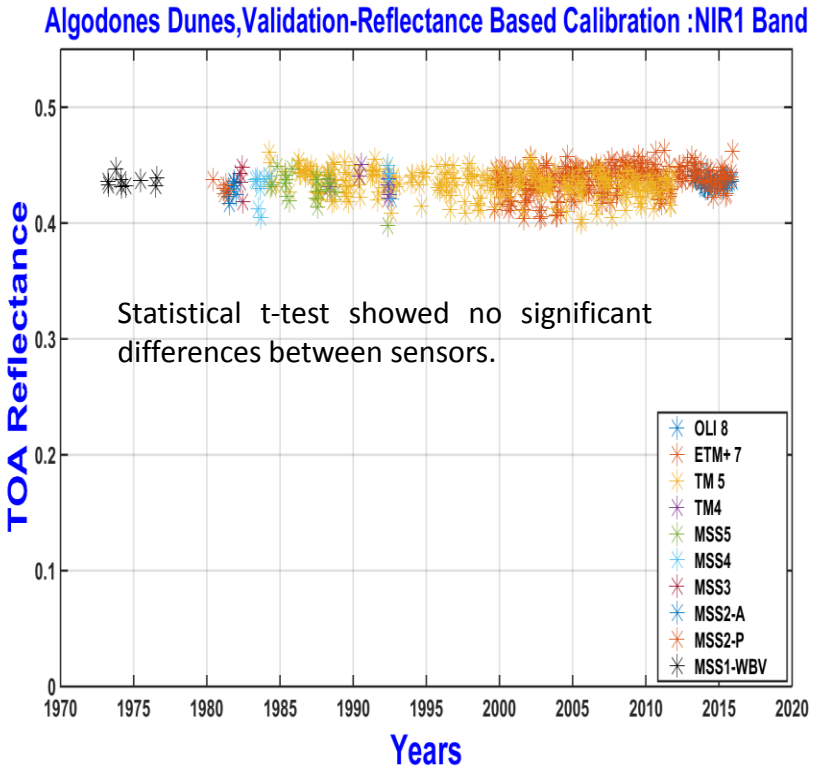


Sensor	Number	Mean
OLI	24	0.217
ETM+	187	0.216
TM5	225	0.216
TM4	7	0.215



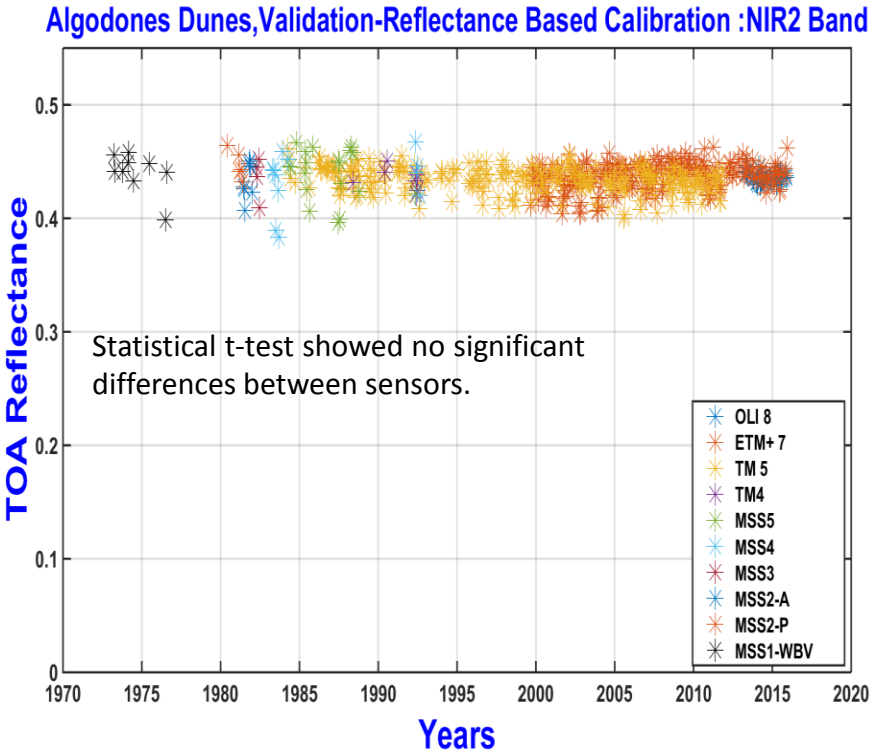
Sensor	Number	Mean
OLI	24	0.266
ETM+	187	0.265
TM5	225	0.263
TM4	7	0.262
MSS5	20	0.268
MSS4	11	0.267
MSS3-A	4	0.262
MSS2-A	7	0.263
MSS2-P	6	0.261
MSS1-WBVT	9	0.263

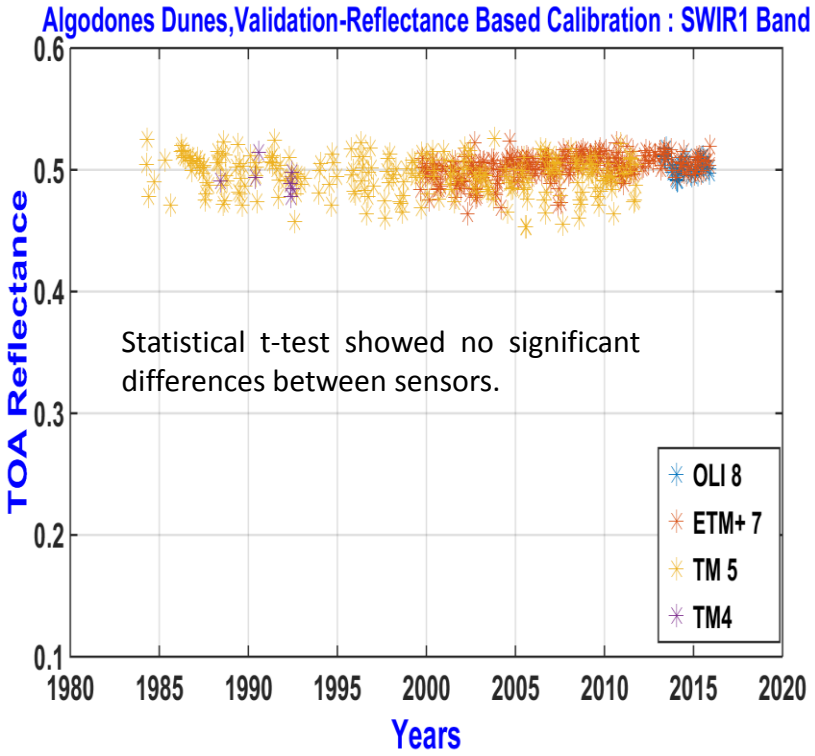




Sensor	Number	Mean
OLI	24	0.354
ETM+	187	0.352
TM5	225	0.351
TM4	7	0.350
MSS5	20	0.352
MSS4	11	0.351
MSS3-A	4	0.354
MSS2-A	7	0.353
MSS2-P	6	0.355
MSS1-WBVT	9	0.351

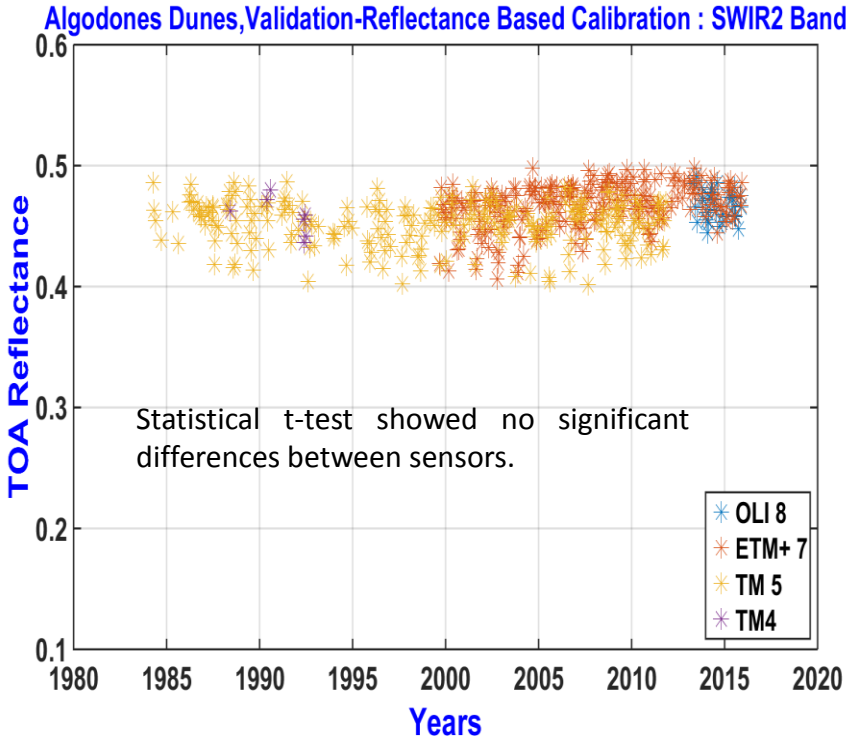
Sensor	Number	Mean
OLI	24	0.435
ETM+	187	0.436
TM5	225	0.434
TM4	7	0.438
MSS5	20	0.433
MSS4	11	0.431
MSS3-A	4	0.436
MSS2-A	7	0.432
MSS2-P	6	0.431
MSS1-WBVT	9	0.436

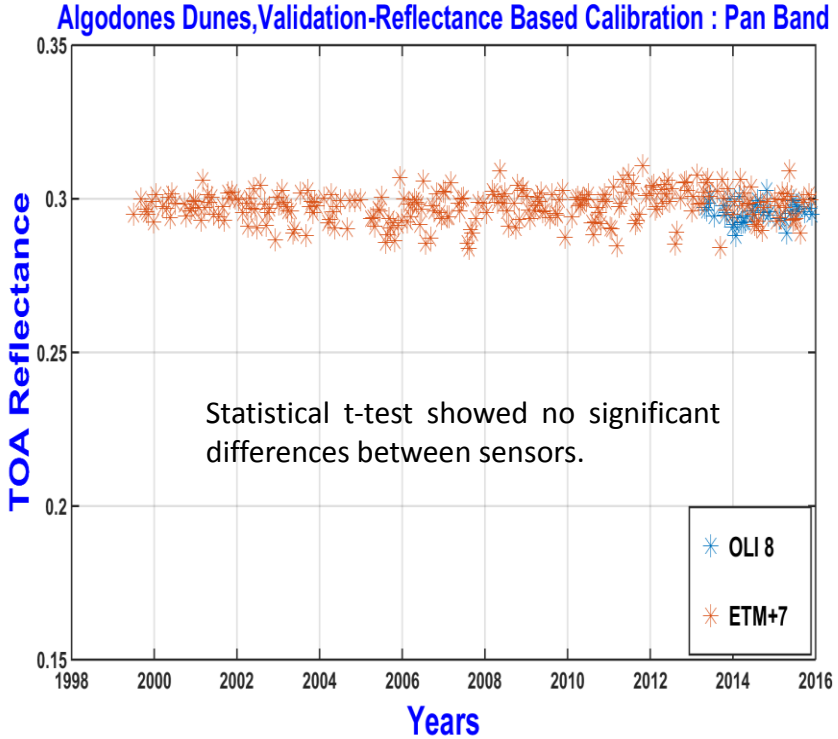




Sensor	Number	Mean
OLI	24	0.435
ETM+	187	0.436
TM5	225	0.434
TM4	7	0.438
MSS5	20	0.437
MSS4	11	0.433
MSS3-A	4	0.435
MSS2-A	7	0.432
MSS2-P	6	0.440
MSS1-WBVT	9	0.439

Sensor	Number	Mean
OLI	24	0.502
ETM+	187	0.501
TM5	225	0.504
TM4	7	0.509





Sensor	Number	Mean
OLI	24	0.469
ETM+	187	0.464
TM5	225	0.461
TM4	7	0.463

Sensor	Number	Mean
OLI	39	0.296
ETM+	295	0.295

Conclusion

- Cross-Calibration from Landsat 8 OLI back to Landsat MSS1 sensors was performed.
- Statistical test was done to check the significance of the gains and biases.
- Validation test using Algodones Dunes showed consistent results from OLI to MSS1.
- One open issue remaining: Normalization of MSS-R data to MSS-A data.

Thank You

Any questions?

Another chapter closed in the MSS book!