Reflectance-based Calibration of the Landsat Archive: Landsat-8 OLI to Landsat-1MSS

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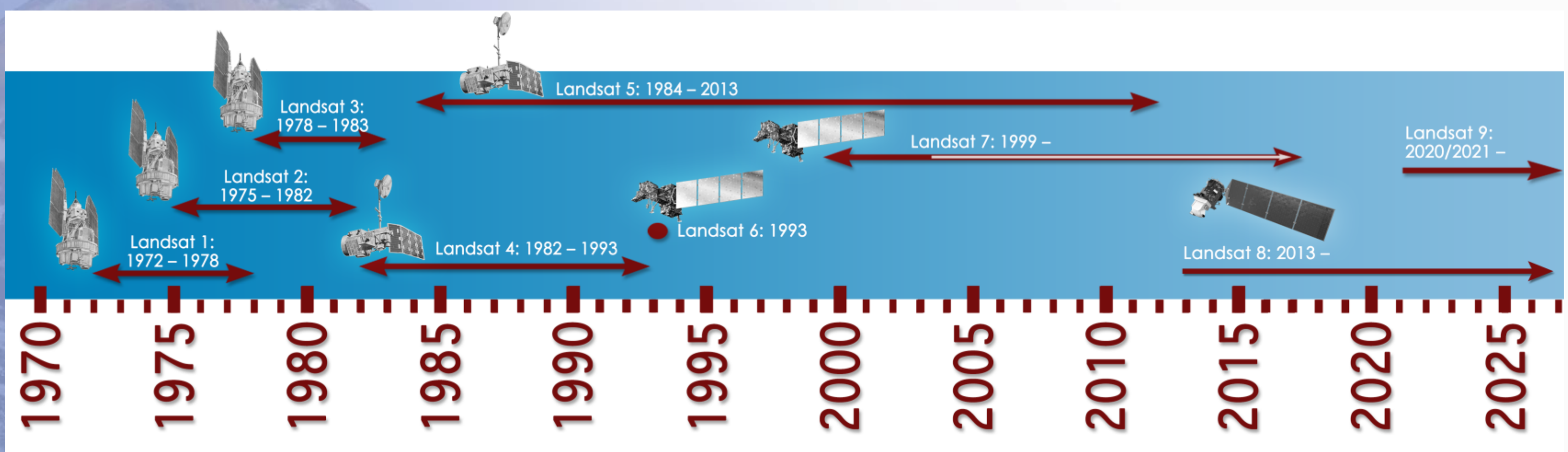
Outline

- Background;
- Cross-calibration based on reflectance;
- Procedure:
- Sequential instrument cross-calibration (OLI to ETM+, ETM+ to TM5, TM5 to TM4, TM5 to MSS5, MSS5 to MSS4, MSS4 to MSS3, MSS3 to MSS2 and MSS 2 to MSS1); …*we are performing satellite archaeology!*
- Result: reflectance-based Gains and Biases from Landsat-8 to Landsat-1;
- Validation of the reflectance-based coefficients from Landsat-8 to Landsat-1 using Algodones Dunes;
- Next Steps (Improvements, Propagation of Uncertainties, Implementation);
- Conclusions and Future Work;

Landsat-1 to -8 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	June 5, 2013	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
Landsat 8	February 11, 2013		OLI, TIRS	16 days/705 km



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

Background

Objective: the primary objective of this project is to consistently calibrate the entire Landsat series to a **common reflectance scale** by performing cross-calibration from OLI Landsat-8 (reference sensor) to MSS Landsat-1.

Cross-calibration based on reflectance:

In general reflectance-based calibration is better than radiance-based calibration:

→ OLI Reflectance-based calibration has lower uncertainty;
→ Not dependent upon a solar radiance model;
→ Most applications use reflectance product;

Cross-Calibration

Equation for cross-calibration based on reflectance:

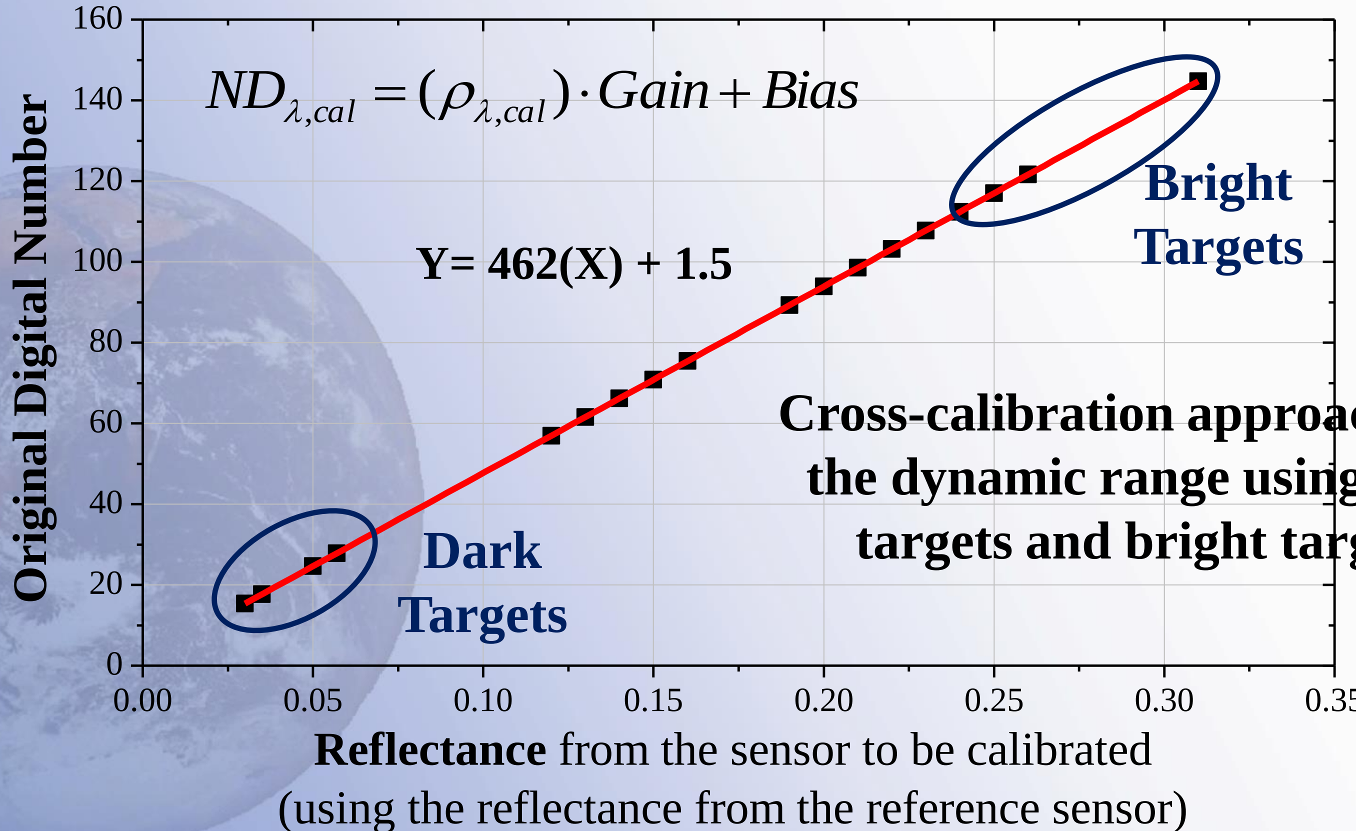
$$\boxed{DN_{\lambda,cal}} = \left[\boxed{\rho_{\lambda,ref}}\right] \cdot \left[\boxed{\frac{\rho_{\lambda,cal}}{\rho_{\lambda,ref}}} \cdot \boxed{\frac{d_{ref}^{\;2}}{d_{cal}^{\;2}}} \cdot \boxed{\frac{\cos\theta_{cal,z}}{\cos\theta_{ref,z}}}\right] \cdot Gain + Bias$$

$$ND_{\lambda,cal} = (\rho_{\lambda,cal}) \cdot Gain + Bias$$

- ✓ Original Digital Number (DN) of the sensor to be calibrated;
- ✓ Reflectance from the reference sensor;
- ✓ Spectral Band Adjustment Factor (SBAF);
- ✓ Earth-Sun distance;
- ✓ θ is the solar zenith angle (illumination);

Cross-Calibration based on Reflectance

$$\overbrace{DN_{\lambda,cal}}^{\text{Y-axis}} = \overbrace{\left[\rho_{\lambda,ref}\right]\cdot\left[\frac{\rho_{\lambda,cal}}{\rho_{\lambda,ref}}\cdot\frac{d_{ref}^{\,2}}{d_{cal}^{\,2}}\cdot\frac{\cos\theta_{cal,z}}{\cos\theta_{ref,z}}\right]}^{\text{X-axis}}\cdot Gain + Bias$$

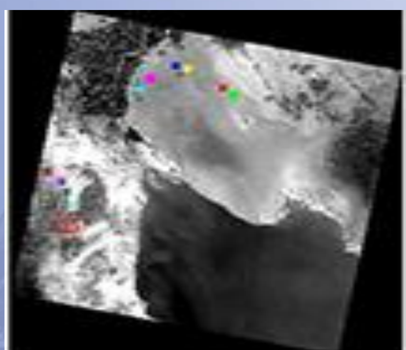


Cross-calibration approach over the dynamic range using dark targets and bright targets

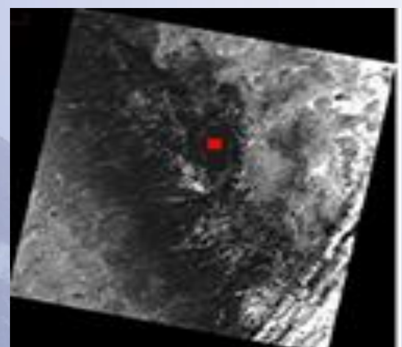
Procedure

1. Sites: Coincident and non-coincident collects from different locations are used as test sites.

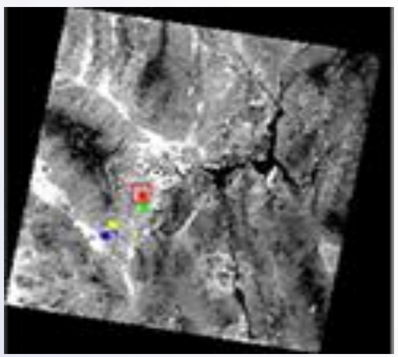
Sonoran Desert
(bright target)



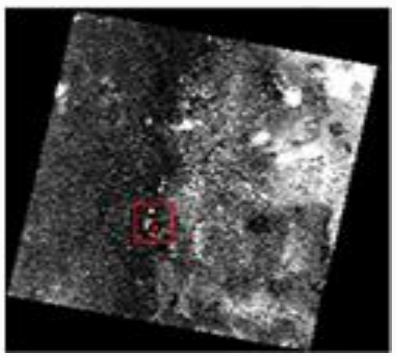
Lake Tahoe
(dark target)



Ivanpah Playa
(bright target)



Crater Lake
(dark target)



→ Each ROI manually selected after study of spatial and temporal properties;
→ Multiple ROIs selected from a given scene;

Procedure

Scene Pairs

OLI to ETM+ → 12 scene pairs
Sonoran Desert → 8
Lake Tahoe →4

ETM+ to TM-5 → 11 scene pairs
Sonoran Desert → 7
Lake Tahoe →4

TM-5 to MSS-5 →10 scene pairs
Sonoran Desert → 7
Lake Tahoe → 3

TM-5 to TM-4 → 31 scene pairs
Sonoran Desert → 1
Near the Sonoran Desert → 8
Makhtesh Ramon → 1
Ivanpah Playa → 4
Arabian Deserts → 8
Algodones Dunes → 1
Near Algodones Dunes → 2
Rocksprings → 2
Kelso Dunes → 4

MSS-5 to MSS-4 →8 scene pairs
Sonoran Desert → 1
Lake Tahoe → 2
Crater Lake → 2
White Sand → 1
Ivanpah Playa → 2

Procedure

Scene Pairs

MSS-3, MSS-2 and MSS-1

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 is used to calibrate MSS2**	MSSA, MSSP and MSSX_WBVT are good, Some MSS-R have stripes.
MSS1	MSSX_WBVT, MSSX_ORF Note: **only MSS_WBVT** is used as there is no other data available early in MSS1's lifetime	MSSX_WBVT data is good.

Procedure

Scene Pairs

MSS-4 to MSS-3 →6 scene pairs
Sonoran Desert → 1
California → 1
Florida → 1
Australia → 3

MSS-2 to MSS-1 → 9 scene pairs
Sonoran Desert → 3
Crater Lake → 2
Algodones Dunes → 3
Lake Tahoe → 1

MSS-3 to MSS-2 →10 scene pairs
Sonoran Desert → 1
Ivanpah Playa → 1
Road valley Desert → 2
Crater Lake → 1
Kelso Desert → 1
Near Sonoran Desert → 2
Algodones Dunes → 1
White Deserts → 1

Procedure

2. Image processing:

- → Begin with L1T product;
- → Convert to at-sensor radiance units;
- → Scale by coefficients in the Calibration Parameter File (CPF) to obtained Artifact Corrected DN’s (**Original DN**);

Procedure

Equations to estimate the Original DN:

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

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

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

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

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

$$DN_{3MSS,\lambda} = \left(\left(\frac{L_{3M,\lambda}}{G_{3M,\lambda,\text{rad\_cross-cal}} \cdot TDF_{\lambda}}\right) / G_{3M,\lambda,\text{absolute gains}}\right) - \text{bias}_{(5M,\lambda)}$$

$$DN_{2MSS,\lambda} = \left(\frac{L_{2M,\lambda}}{G_{2M,\lambda,\text{rad\_cross-cal}} \cdot TDF_{\lambda}}\right) / G_{2M,\lambda,\text{absolute gains}} - \text{bias}_{(5M,\lambda)}$$

$$DN_{1MSS,\lambda} = \left(\frac{L_{1M,\lambda}}{G_{1M,\lambda,\text{rad\_cross-cal}} \cdot TDF_{\lambda}}\right) / G_{1M,\lambda,\text{absolute gains}} - \text{bias}_{(5M,\lambda)}$$

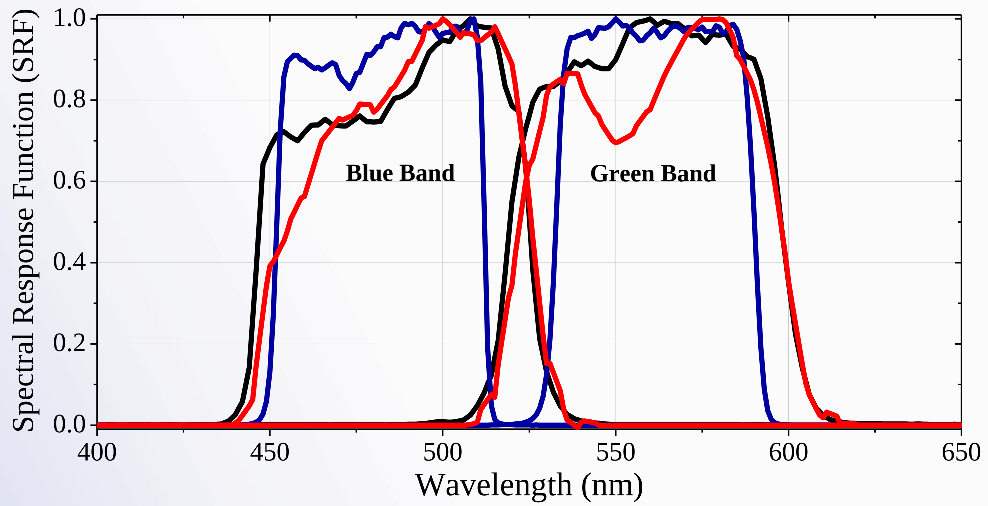
Procedure

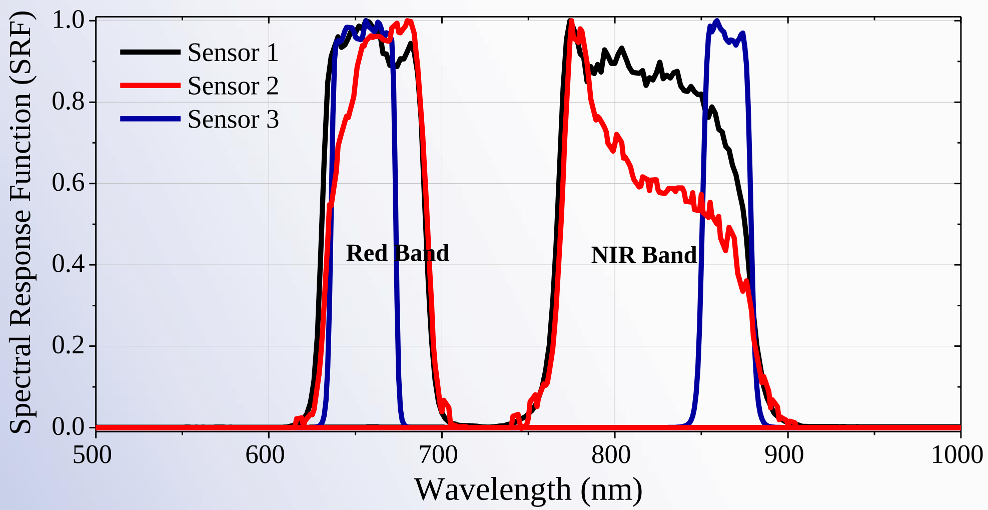
3. Spectral Band Adjustment Factor (SBAF)

$$SBAF = \frac{\rho_{\lambda,A}}{\rho_{\lambda,B}} = \frac{\dfrac{\int_0^\infty \rho_\lambda \times SRF_{\lambda,A} d\lambda}{\int_0^\infty SRF_{\lambda,A} d\lambda}}{\dfrac{\int_0^\infty \rho_\lambda \times SRF_{\lambda,B} d\lambda}{\int_0^\infty SRF_{\lambda,B} d\lambda}}$$

SBAF to compensate the SRF differences between the sensors.

SRF





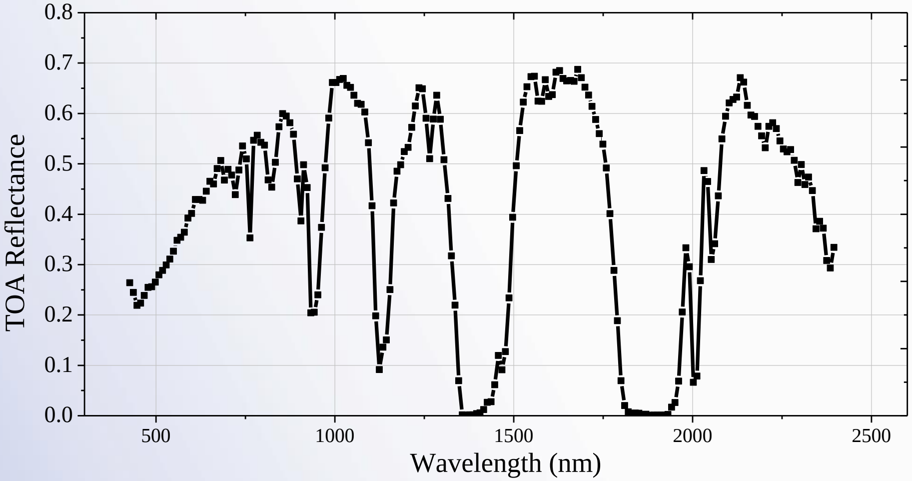
Procedure

3. Spectral Band Adjustment Factor (SBAF)

$$SBAF = \frac{\rho_{\lambda,A}}{\rho_{\lambda,B}} = \frac{\dfrac{\int_0^\infty \rho_\lambda \times SRF_{\lambda,A} d\lambda}{\int_0^\infty SRF_{\lambda,A} d\lambda}}{\dfrac{\int_0^\infty \rho_\lambda \times SRF_{\lambda,B} d\lambda}{\int_0^\infty SRF_{\lambda,B} d\lambda}}$$

SBAF to compensate the SRF differences between the sensors.

ρ_λ → **Hyperion**



The TOA Reflectance profile was used to derive SBAF

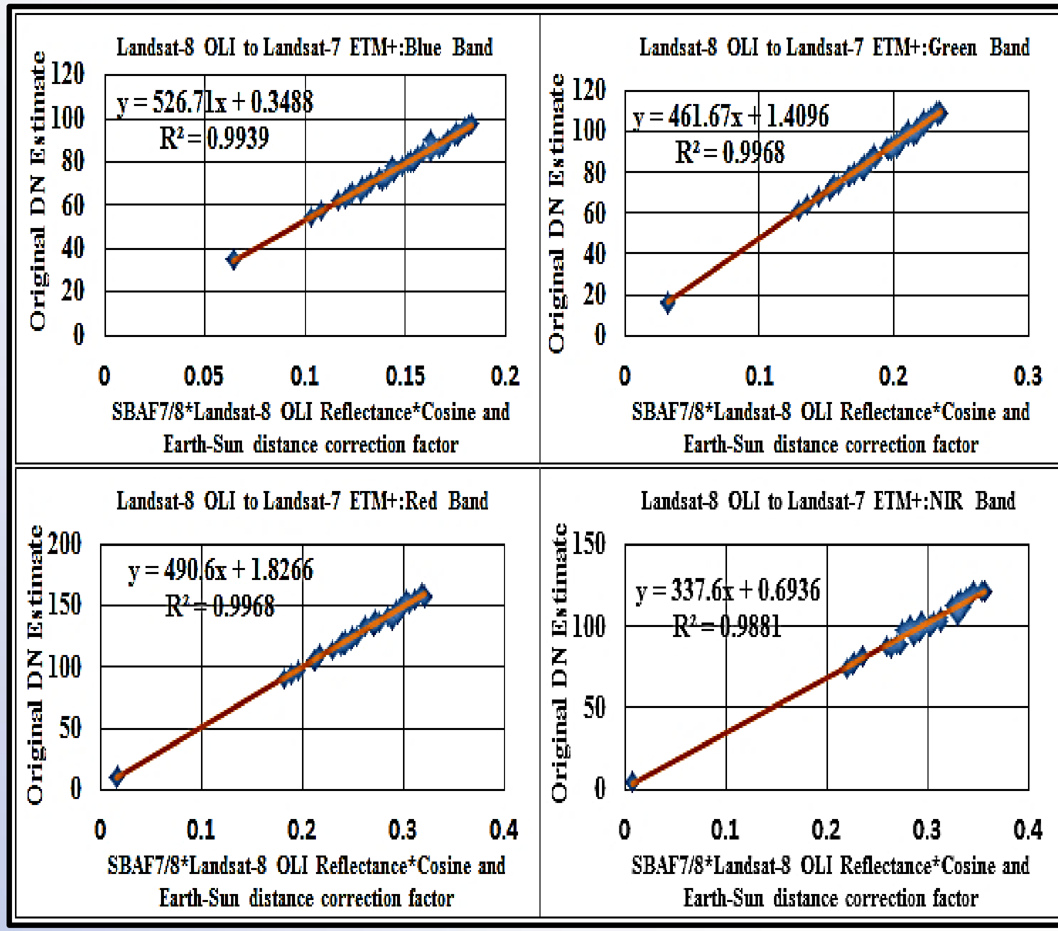
Results

4. Linear Regression

OLI to ETM+

From the statistical test, bias for all the band are found to be insignificant

→ **Forced zero intercept**



$$X - \text{axis} = SBAF_{\frac{7}{8},\rho,\lambda,ROI} \cdot \rho_{8,\lambda} \cdot \frac{1}{d^2_7} \cdot \frac{\cos\alpha_7}{\cos\alpha_8}$$

$$Y - \text{axis} = DN_{7,\lambda} = \left(L_{7,\lambda} \cdot G_{7,\lambda,Avg}\right)$$

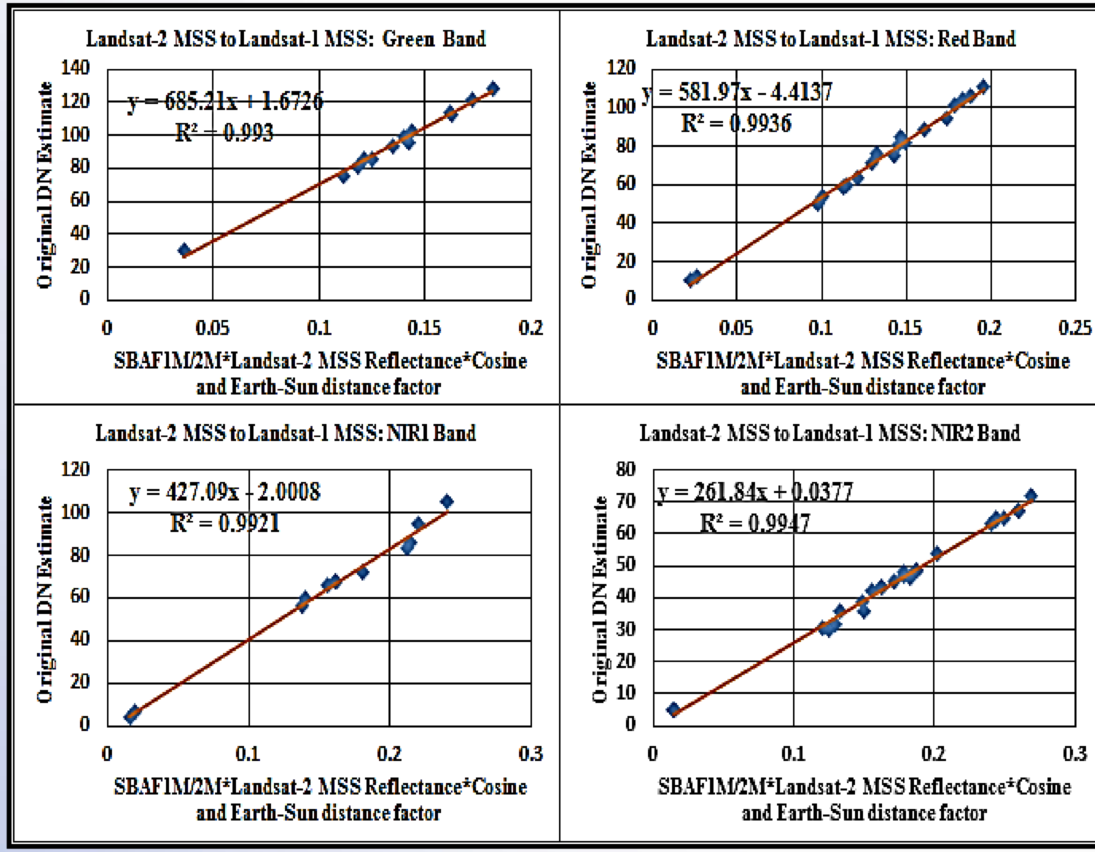
Results

4. Linear Regression

MSS-2 to MSS-1

From the statistical test, except for red band, bias for are found to be insignificant.

→ **Forced zero intercept**
(except for red band)



X-Axis $= SBAF_{\frac{1M}{2M},\rho,\lambda,ROI} \cdot \rho_{2M,\lambda} \cdot \frac{d^2{}_{1M}}{d^2{}_{2M}} \cdot \frac{\cos\alpha_{2M}}{\cos\alpha_{1M}}$

Y-Axis $= DN_{1M,\lambda} = \left(\frac{\left(\frac{L_{1M,\lambda}}{G_{1M,\lambda,rad\_cross\_cal} \,.\, TDF_{\lambda}} \right)}{G_{1M,\lambda,absolute\ gains}} \right) - \mathbf{bias}_{(5,\lambda)}$

Results:
Gains and Bias from Landsat-8 to Landsat-1

Coefficients for Conversion of Original DN to TOA Reflectance:

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

From the statistical test, except for red band in MSS1, bias are found to be insignificant.

Validation

Cross-calibration gains and biases validation:

- ✓ In order to validate cross-calibration gains and biases, systematic validation equations are generated to observe the TOA reflectance that is generated by each sensor (from Landsat-8 OLI to Landsat-1 MSS).
- ✓ Algodones Dunes was used as a test site to validate the cross-calibration gains;
- ✓ The temporal reflectance of all sensors is plotted with respect to Landsat-8 OLI on the same spectral reflectance scale;

Validation

Cross-calibration gains and biases validation:

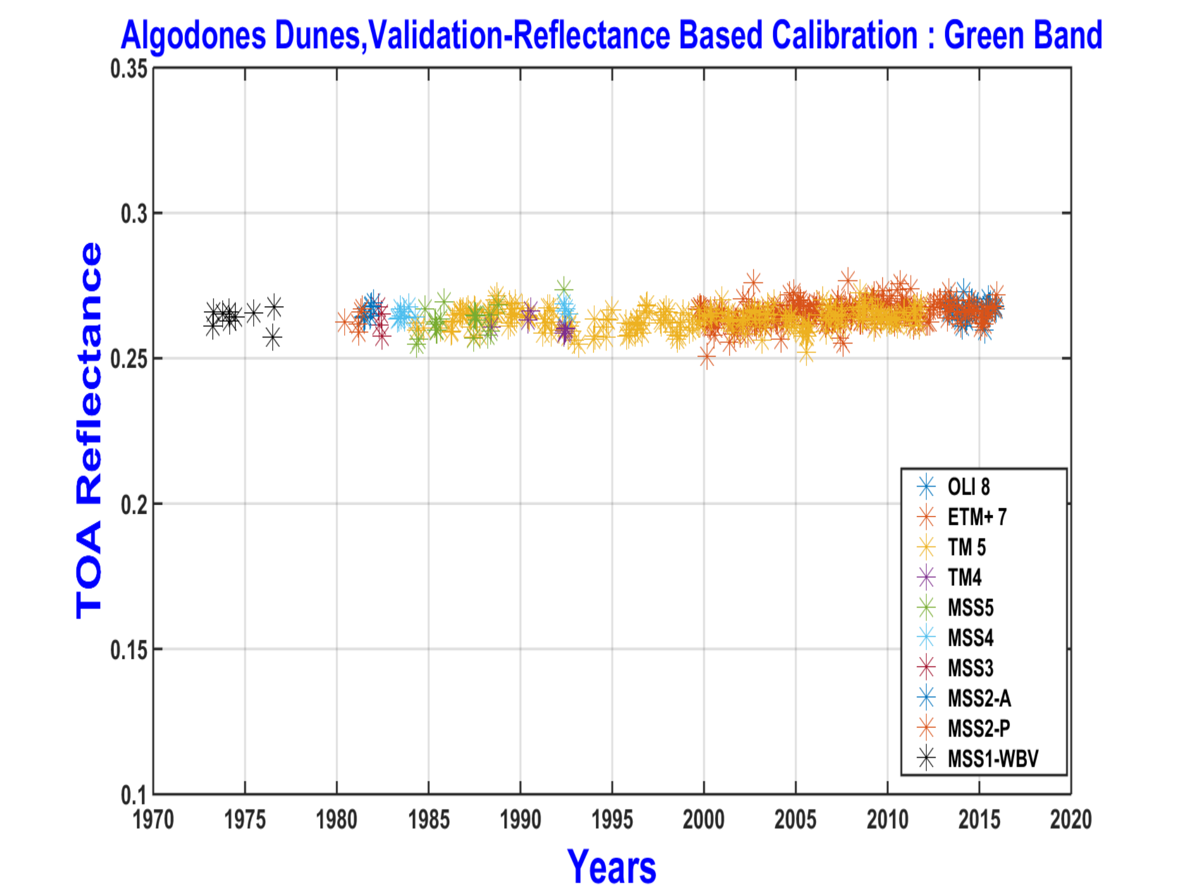
Landsat-8 OLI	$\rho_{8,\lambda} = M_{8,\rho,\lambda} \cdot DN_{8,\lambda} + A_{8,\rho,\lambda}$	(1)
Landsat-7 ETM+	$\rho_{7,\lambda} = \left(\frac{DN_{7,\lambda}}{G_{\frac{8,\lambda}{7,\lambda}}} \cdot \frac{d^2{}_7}{\cos\alpha_7}\right). SBAF_{\frac{8,\lambda}{7,\lambda}}$	(2)
Landsat-5 TM	$\rho_{5,\lambda} = \left(\frac{DN_{5,\lambda}}{G_{\frac{7,\lambda}{5,\lambda}}} \cdot \frac{d^2{}_5}{\cos\alpha_5}\right). SBAF_{\frac{8,\lambda}{5,\lambda}}$	(3)
Landsat-4 TM	$\rho_{4,\lambda} = \left(\frac{DN_{4,\lambda}}{G_{\frac{5,\lambda}{4,\lambda}}} \cdot \frac{d^2{}_4}{\cos\alpha_4}\right). SBAF_{\frac{8,\lambda}{4,\lambda}}$	(4)
Landsat-5 MSS	$\rho_{5M,\lambda} = \left(\frac{DN_{5M,\lambda}}{G_{\frac{5,\lambda}{5M,\lambda}}} \cdot \frac{d^2{}_{5M}}{\cos\alpha_{5M}}\right). SBAF_{\frac{8,\lambda}{5M,\lambda}}$	(5)
Landsat-4 MSS	$\rho_{4M,\lambda} = \left(\frac{DN_{4M,\lambda}}{G_{\frac{5M,\lambda}{4M,\lambda}}} \cdot \frac{d^2{}_{4M}}{\cos\alpha_{4M}}\right). SBAF_{\frac{8,\lambda}{4M,\lambda}}$	(6)
Landsat-3 MSS	$\rho_{3M,\lambda} = \left(\frac{DN_{3M,\lambda}}{G_{\frac{4M,\lambda}{3M,\lambda}}} \cdot \frac{d^2{}_{3M}}{\cos\alpha_{3M}}\right). SBAF_{\frac{8,\lambda}{3M,\lambda}}$	(7)
Landsat-2 MSS	$\rho_{2M,\lambda} = \left(\frac{DN_{2M,\lambda}}{G_{\frac{3M,\lambda}{2M,\lambda}}} \cdot \frac{d^2{}_{2M}}{\cos\alpha_{2M}}\right). SBAF_{\frac{8,\lambda}{2M,\lambda}}$	(8)
Landsat-1 MSS	$\rho_{1M,\lambda} = \left(\frac{DN_{1M,\lambda} + b_{\frac{2M,\lambda}{1M,\lambda}}}{G_{\frac{2M,\lambda}{1M,\lambda}}} \cdot \frac{d^2{}_{1M}}{\cos\alpha_{1M}}\right). SBAF_{\frac{8,\lambda}{1M,\lambda}}$	(9)

In the validation plots, the spectral adjustments are done to place all sensors on the same spectral reflectance OLI scale.

Common reflectance scale (OLI as reference)

Validation

OLI Landsat-8 to MSS Landsat-1 → Green Band

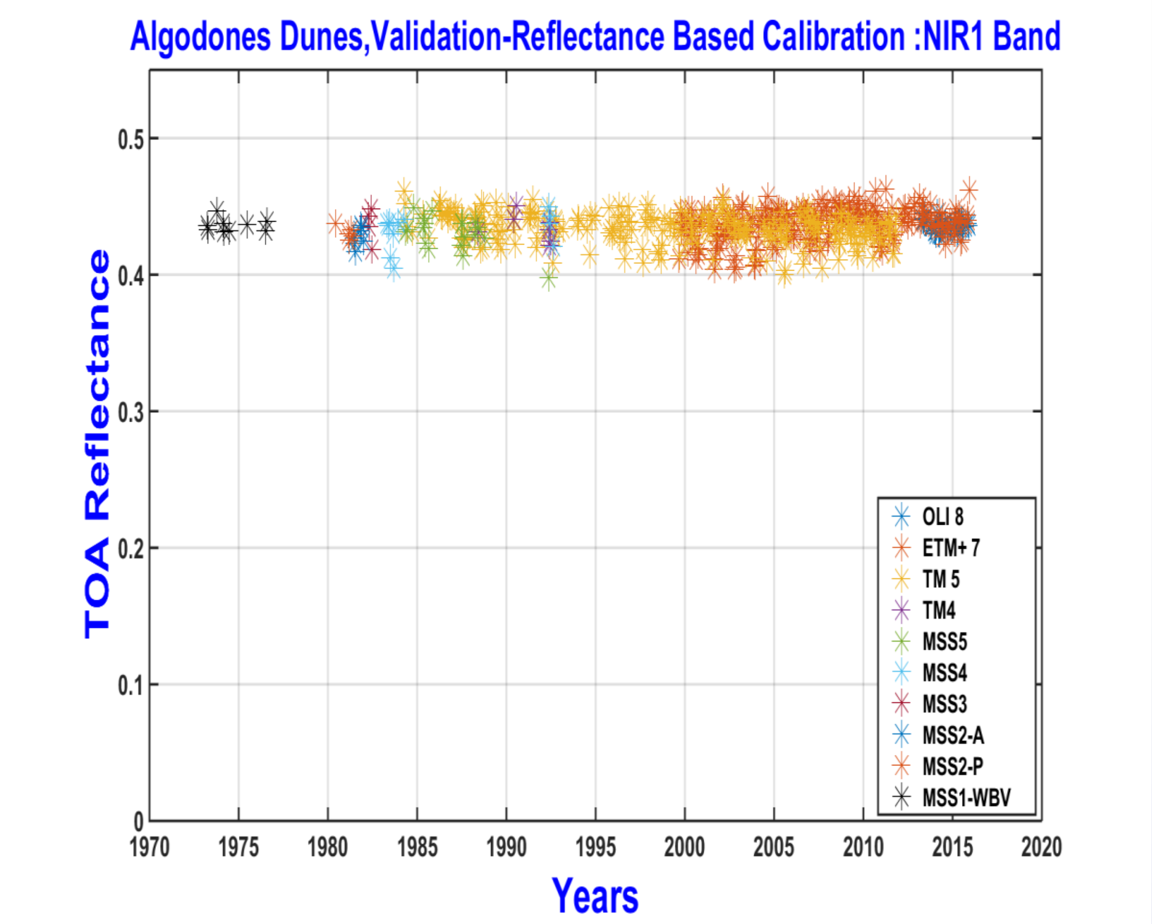


Sensor	Number	Mean
OLI	24	0.266
ETM+	187	0.265
TM5	225	0.263
TM4	7	0.262
MSS5	20	0.268
MSS4	11	0.267
MSS3-A	4	0.262
MSS2-A	7	0.263
MSS2-P	6	0.261
MSS1-WBVT	9	0.263

Statistical t-test showed no significant differences between sensors.

Validation

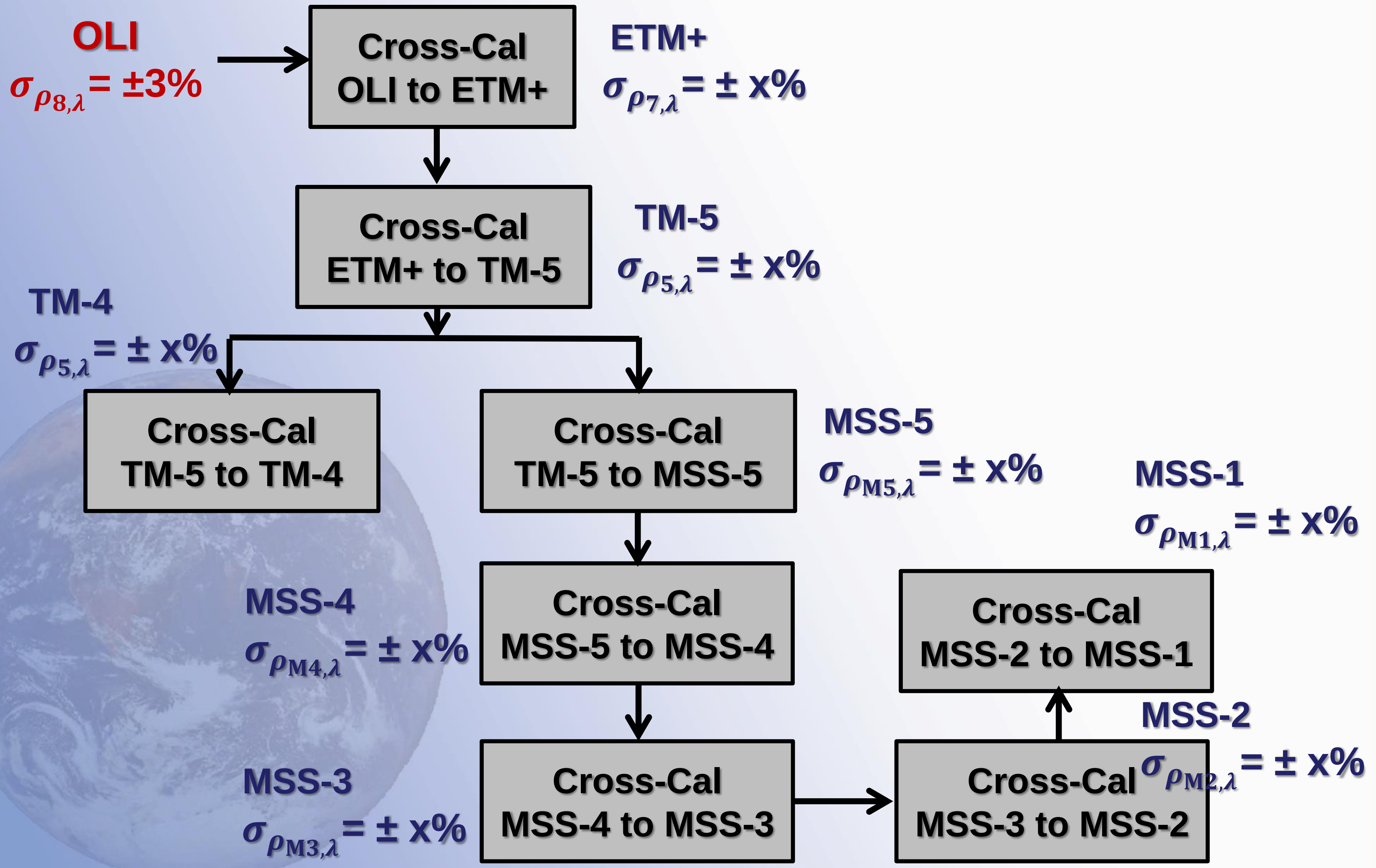
OLI Landsat-8 to MSS Landsat-1 → NIR-1 Band



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

Statistical t-test showed no significant differences between sensors.

Next Steps: Propagation of Uncertainty



Reflectance-based Calibration **Implementation** at USGS EROS

- Landsat 4/5 TM, Landsat 7 ETM+,
  - Collection 1
  - ~April 2017
- Landsat 8
  - Collection 1
  - ~May 2017
- Landsat 1MSS – Landsat 5 MSS, TM NoPCD
  - Collection 1
  - ~end of 2017
- Link for collection processing status: https://landsat.usgs.gov/

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Conclusion and Future Work

- ✓ Cross-Calibration from Landsat-8 OLI back to Landsat-1 MSS 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 Landsat-8 OLI to Landsat-1 MSS;
- ✓ **Next Steps**:
  - → Check the coefficients;
  - → Propagation of Uncertainty;
  - → Validation with other PICs sites.
- ✓ One open issue remaining: Normalization of MSS-R data to MSS-A data.
- ✓ Full implementation at USGS EROS scheduled end of year