Sentinel 3 Mission Performance Centre

Comparison of Vicarious Calibration Results for SLSTR Visible and SWIR Channels

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1. RAL Space, Science and Technologies Facilities Council, United Kingdom
2. CNES
3. Rayference
4. University of Arizona

Science and Technology Facilities Council

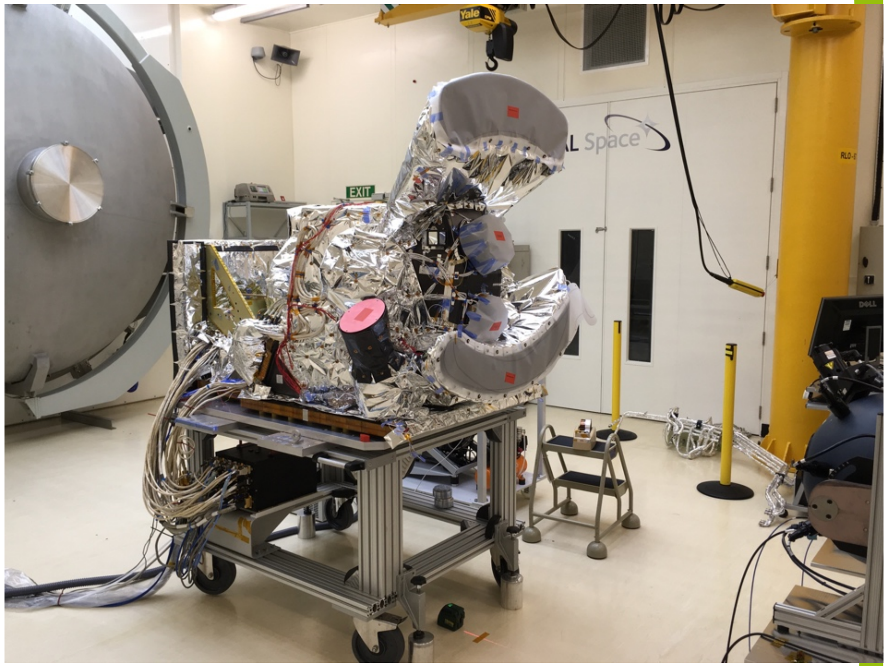
ACRI ST

esa

EUMETSAT

Sea and Land Surface Temperature Radiometer

Nadir swath	>74°	(1400km swath)
Dual view swath	49°	(750 km)
Two telescopes	Φ110 mm / 800mm focal length	
Spectral bands	TIR : 3.74µm, 10.85µm, 12µm SWIR : 1.38µm, 1.61µm, 2.25 µm VIS: 555nm, 659nm, 859nm	
Spatial Resolution	1km at nadir for TIR, 0.5km for VIS/SWIR	
Radiometric quality	NEΔT 30 mK (LWIR) – 50mK (MWIR) SNR 20 for VIS - SWIR	
Radiometric accuracy	0.2K for IR channels 2% for Solar channels relative to Sun	



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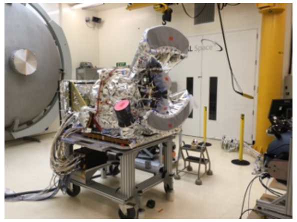
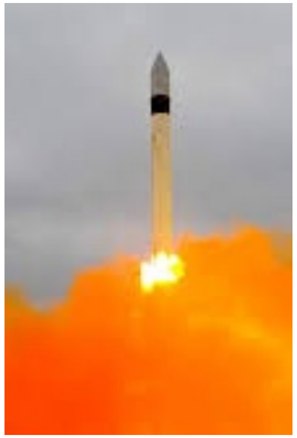
Sentinel-3 Series

2016 – Sentinel 3A

Launched 16-Feb-2016 ☺

2018 – Sentinel 3B





Launched 25-Apr-2018 ☺

2021 – Sentinel 3C

- Instrument Calibration
  Nov 2019 - ?

2023 – Sentinel-3D

- Instrument Calibration
  Q1 2021

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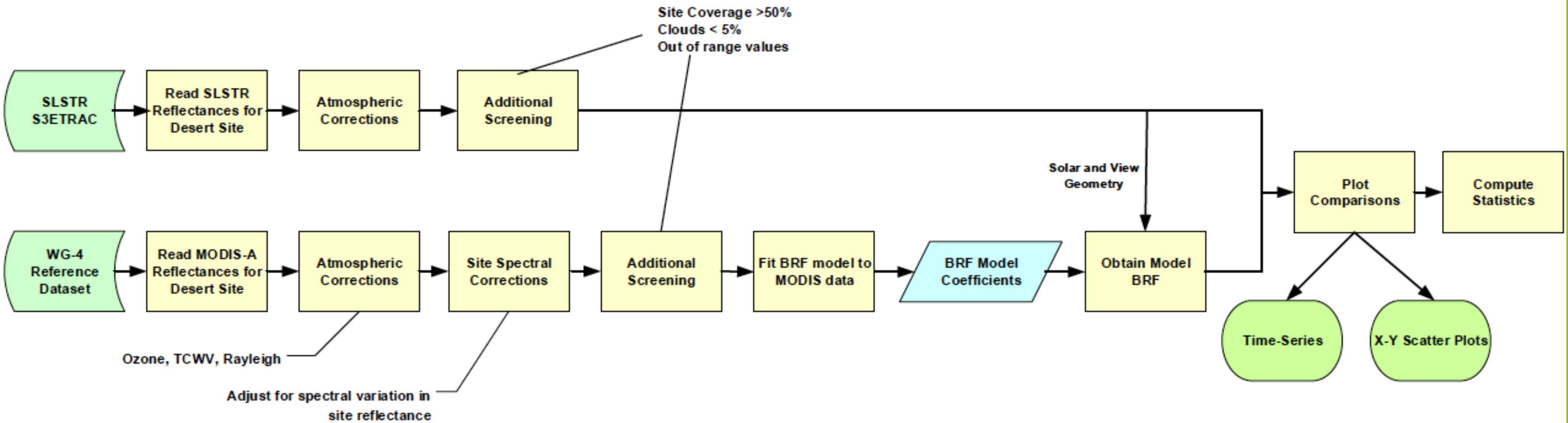
Vicarious Calibration Analyses

- **Independent analyses have been performed to assess the radiometric calibration of the SLSTR VIS and SWIR channels.**
  - RAL Space for the MPC comparisons with AATSR and MODIS-A over desert sites
  - CNES assessment using the SADE/MUSCLE vicarious calibration system
  - Radiative Transfer Modelling of the Libya-4 desert site by Rayference.
  - University of Arizona comparisons against in-situ field measurements of the Railroad Valley Playa RadCalNet site.

- **The goal is to determine the offsets of SLSTR to a common reference that can be traced to a primary standard.**

- **Comparison and combination of the results is presented in detail in S3MPC.RAL.TN.005.**
  - This was to be presented at the S3VT in March.

Inter-comparison Method - RAL



Geometric corrections are needed to account for different overpass times

Corrections for spectral variations, atmosphere + site spectral profile are needed

Calibration Sites Extracted using S3ETRAC

Site name	North Latitude	South Latitude	East Longitude	West Longitude	Latitude size	Longitude size
CEOS_ALGERIA-3	30.82	29.82	8.16	7.16	1	1
CEOS_ALGERIA-5	31.52	30.52	2.73	1.73	1	1
CEOS_LIBYA-1	24.92	23.92	13.85	12.85	1	1
CEOS_LIBYA-4	29.05	28.05	23.89	22.89	1	1
CEOS_MAURITANIA-1	19.9	18.9	-8.8	-9.8	1	1
CEOS_MAURITANIA-2	21.35	20.35	-8.28	-9.28	1	1
Algeria 1	24.25	23.35	0.05	-0.85	0.9	0.9
Algeria 2	26.54	25.64	-0.93	-1.83	0.9	0.9
Algeria 3	30.77	29.87	8.11	7.21	0.9	0.9
Algeria 4	30.49	29.59	6.04	5.14	0.9	0.9
Algeria 5	31.47	30.57	2.68	1.78	0.9	0.9
Arabia 1	19.33	18.43	47.21	46.31	0.9	0.9
Arabia 2	20.58	19.68	51.41	50.51	0.9	0.9
Arabia 3	29.37	28.47	44.18	43.28	0.9	0.9
Egypt 1	27.57	26.67	26.55	25.65	0.9	0.9
Libya 1	24.87	23.97	13.8	12.9	0.9	0.9
Libya 2	25.5	24.6	20.93	20.03	0.9	0.9
Libya 3	23.6	22.7	23.55	22.65	0.9	0.9
Libya 4	29	28.1	23.84	22.94	0.9	0.9
Mali 1	19.57	18.67	-4.4	-5.3	0.9	0.9
Mauritania 1	19.85	18.95	-8.85	-9.75	0.9	0.9
Mauritania 2	21.3	20.4	-8.33	-9.23	0.9	0.9
Niger 1	20.12	19.22	10.26	9.36	0.9	0.9
Niger 2	21.82	20.92	11.04	10.14	0.9	0.9
Niger 3	22.02	21.12	8.41	7.51	0.9	0.9
Sudan 1	22.19	21.29	28.67	27.77	0.9	0.9

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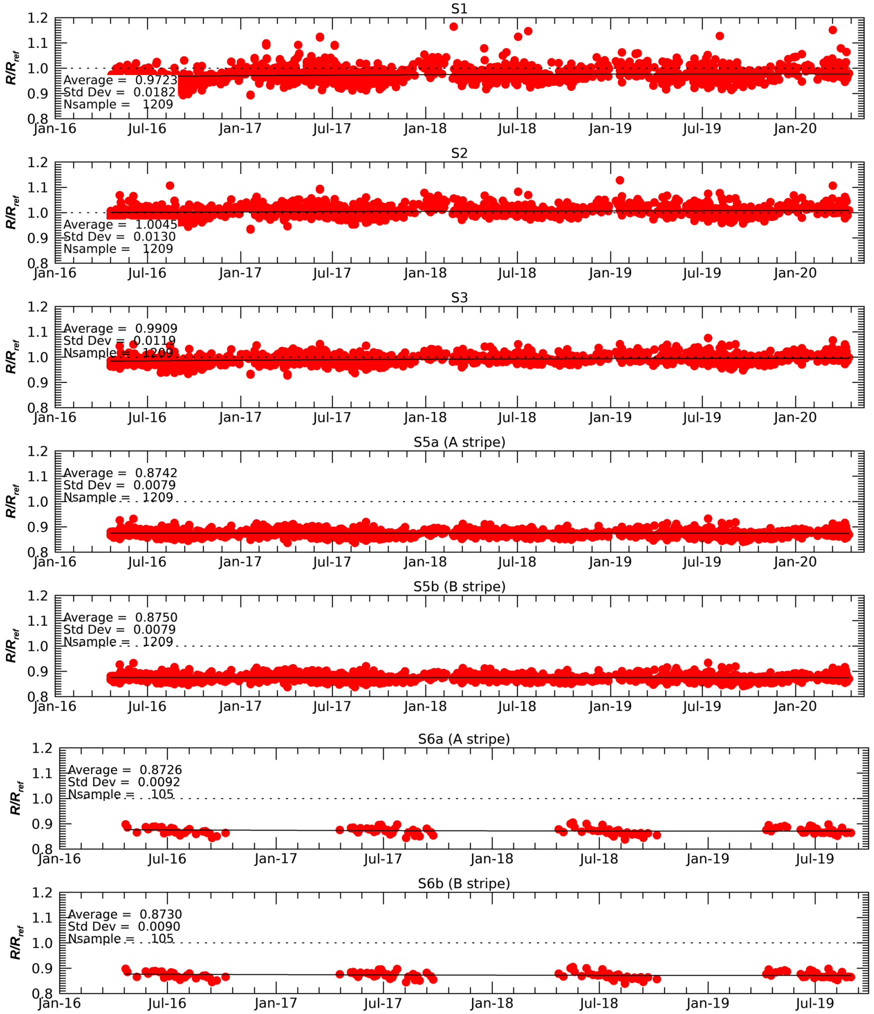
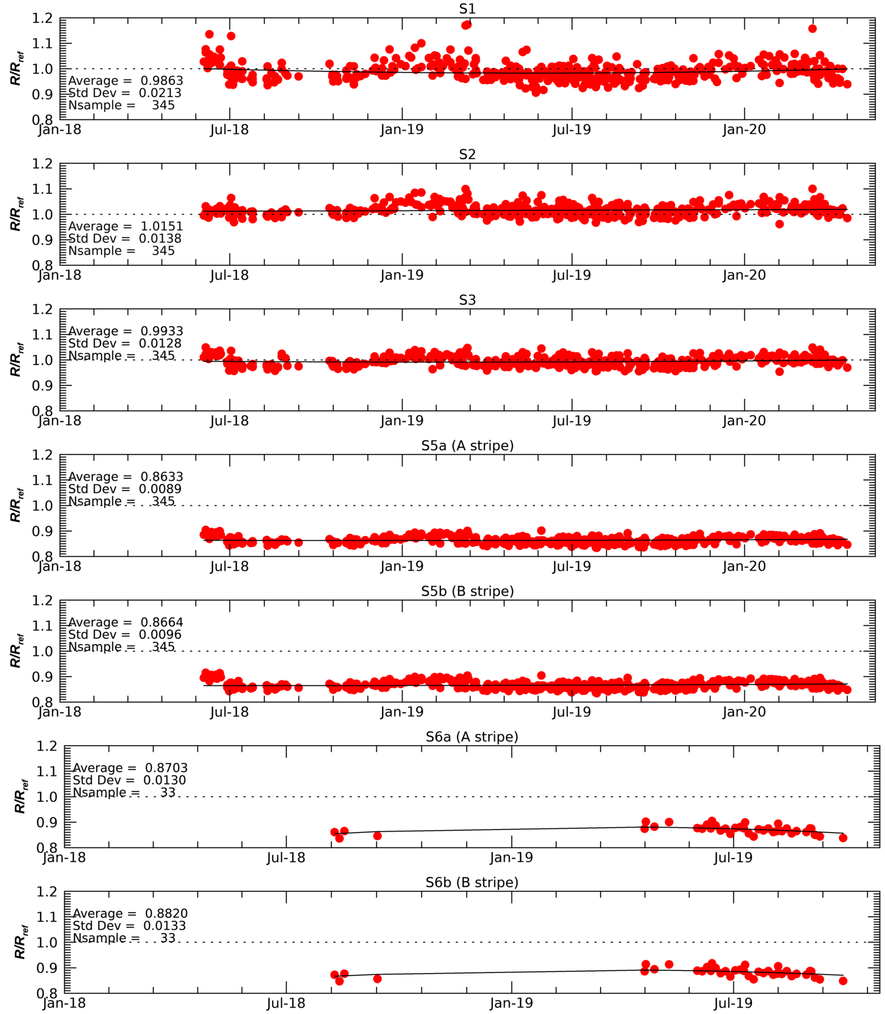
SLSTR Trends

SLSTR-A



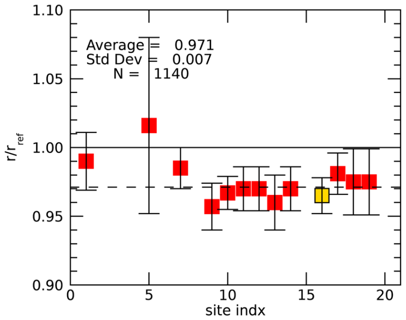
SLSTR-B



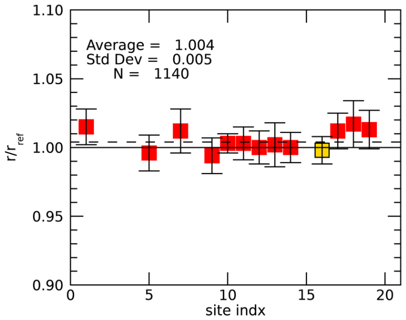
S1-S5 ref = AATSR, S6 ref = MODIS (Libya-4 only)

S3A Comparisons over Deserts (RAL)

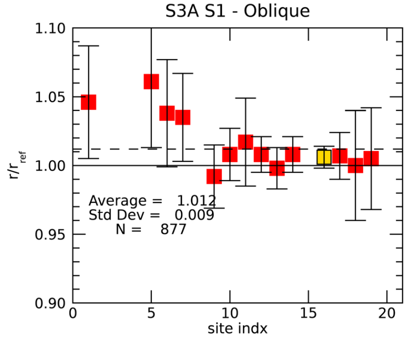
S3A S1 - Nadir



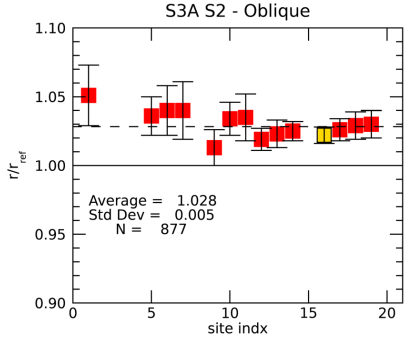
S3A S2 - Nadir



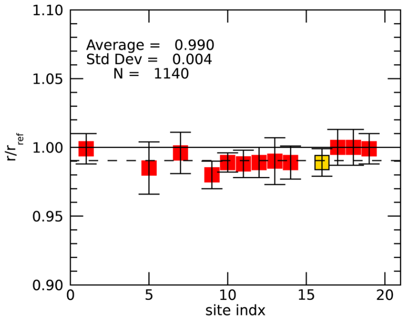
S3A S1 - Oblique



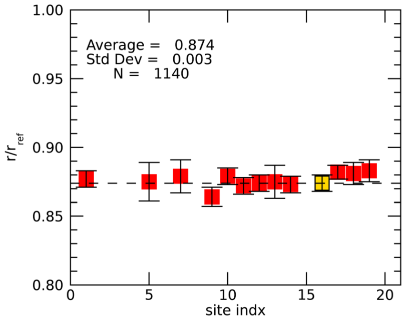
S3A S2 - Oblique



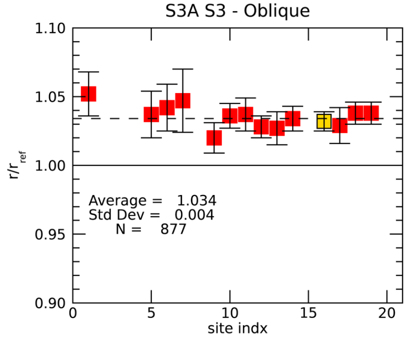
S3A S3 - Nadir



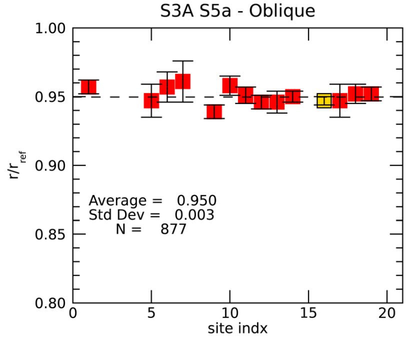
S3A S5a - Nadir



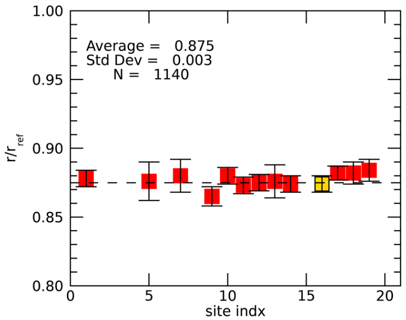
S3A S3 - Oblique



S3A S5a - Oblique

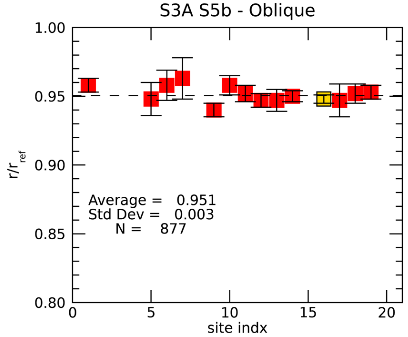


S3A S5b - Nadir



Site Index
1 : Algeria1
2 : Algeria2
3 : Algeria3
4 : Algeria4
5 : Algeria5
6 : Arabia1
7 : Arabia2
8 : Arabia3
9 : Sudan1
10 : Niger1
11 : Niger2
12 : Egypt1
13 : Libya1
14 : Libya2
15 : Libya3
16 : Libya4
17 : Mali1
18 : Mauritania1
19 : Mauritania2

S3A S5b - Oblique



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15 : Libya3
16 : Libya4
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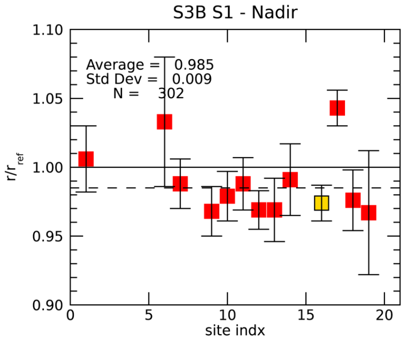
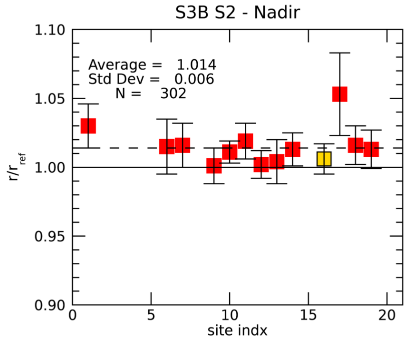
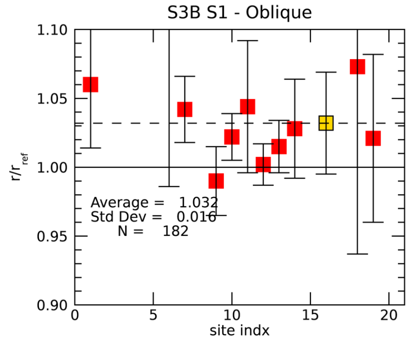
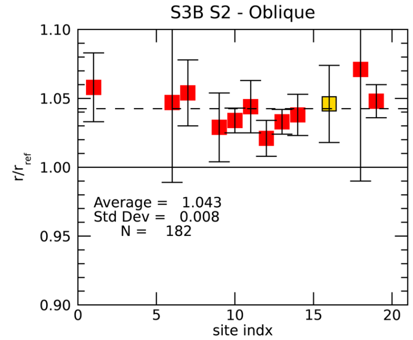
18 : Mauritania1
19 : Mauritania2

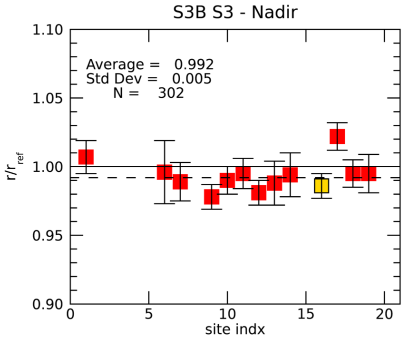
S3B Comparisons over Deserts (RAL)

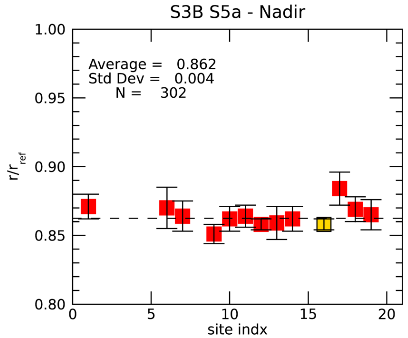


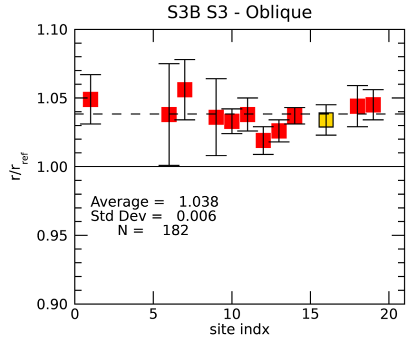


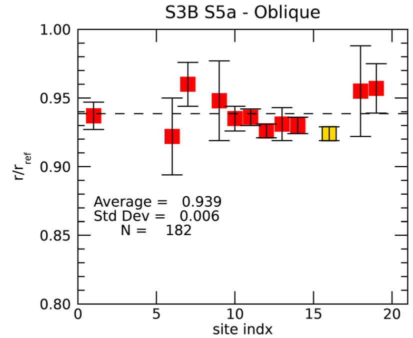


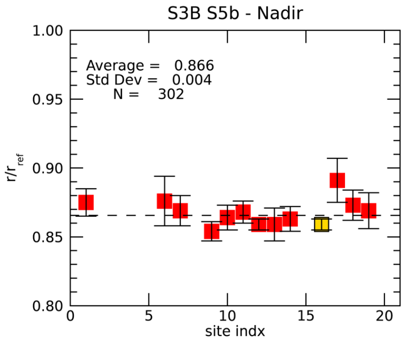












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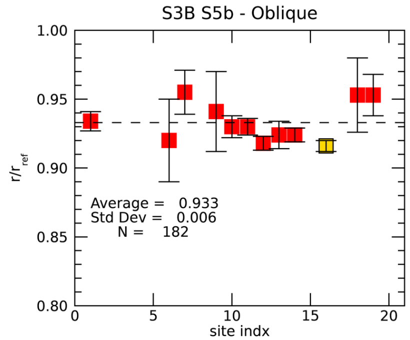

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CNES Results

Nadir View

Method	S1		S2		S3		S5		S6	
	Rmeas/ Rref	StdDev	Rmeas/ Rref	StdDev	Rmeas/ Rref	StdDev	Rmeas/ Rref	StdDev	Rmeas/ Rref	StdDev
Desert MODIS	1.050	0.033	1.028	0.030	1.030	0.025	0.892	0.017	0.894	0.029
Libya-4 MODIS	1.044	0.020	1.037	0.069	1.035	0.020	0.896	0.011	0.837	0.022
Desert MERIS	1.023	0.036	1.020	0.025	1.010	0.023	-	-	-	-
Libya-4 MERIS	1.021	0.018	1.021	0.015	1.012	0.014	-	-	-	-
Desert PARASOL	1.040	0.037	1.050	0.028	1.040	0.027	-	-	-	-
Libya-4 PARASOL	1.041	0.020	1.049	0.020	1.045	0.021	-	-	-	-
S2A	1.010	0.025	1.008	0.025	0.996	0.024	0.899	0.016	0.882	0.031
Libya-4 S2A	1.012	0.018	1.002	0.014	0.994	0.014	0.897	0.011	0.890	0.020
Desert L8	1.001	0.022	1.002	0.017	0.996	0.018	0.898	0.012	0.872	0.018
Libya-4 L8	1.003	0.015	1.002	0.013	0.995	0.013	0.899	0.009	0.872	0.017

Oblique View

Method	S1		S2		S3		S5		S6	
	Rmeas/ Rref	StdDev	Rmeas/ Rref	StdDev	Rmeas/ Rref	StdDev	Rmeas/ Rref	StdDev	Rmeas/ Rref	StdDev
Desert MODIS	1.070	0.053	1.070	0.030	1.070	0.031	0.950	0.023	0.890	0.076
Desert PARASOL	1.040	0.037	1.050	0.028	1.040	0.027	-	-	-	-

Reported uncertainties are standard deviations

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Rayference (Yves Goaverts)

Nadir View

RTM	S1		S2		S3		S5		S6	
	Rmeas/Rref	StdDev	Rmeas/Rref	StdDev	Rmeas/Rref	StdDev	Rmeas/Rref	StdDev	Rmeas/Rref	StdDev
6SV	1.037	0.013	1.022	0.009	1.016	0.010	0.892	0.007	0.887	0.011
LibRadtran	1.054	0.014	1.031	0.009	1.024	0.011	0.898	0.007	0.900	0.010
RTMOM	1.055	0.015	1.039	0.011	1.024	0.011	0.916	0.008	0.908	0.012
ARTDECO	1.054	0.014	1.035	0.009	1.024	0.009	0.908	0.007	0.909	0.009
Average	**1.050**	**0.016**	**1.032**	**0.012**	**1.022**	**0.011**	**0.903**	**0.013**	**0.901**	**0.014**
Combined Uncertainty	**0.026**		**0.024**		**0.024**		**0.025**		**0.025**	

Oblique View

RTM	S1		S2		S3		S5		S6	
	Rmeas/Rref	StdDev	Rmeas/Rref	StdDev	Rmeas/Rref	StdDev	Rmeas/Rref	StdDev	Rmeas/Rref	StdDev
6SV	1.079	0.015	1.060	0.012	1.070	0.012	0.971	0.008	0.940	0.015
LibRadtran	1.094	0.018	1.072	0.013	1.074	0.013	0.978	0.008	0.961	0.013
RTMOM	1.097	0.017	1.080	0.012	1.077	0.012	1.003	0.007	0.971	0.011
ARTDECO	1.088	0.016	1.070	0.012	1.074	0.013	0.988	0.008	0.964	0.014
Average	**1.089**	**0.018**	**1.070**	**0.015**	**1.074**	**0.012**	**0.985**	**0.016**	**0.959**	**0.018**
Combined Uncertainty	**0.028**		**0.026**		**0.024**		**0.026**		**0.028**	

Libya-4 Radiometric Calibration Reference (LRCR) simulates the TOA BRF using a model of the surface BRF and 4 different Radiative Transfer Models (RTMs)

Reported uncertainties are standard deviations

University of Arizona

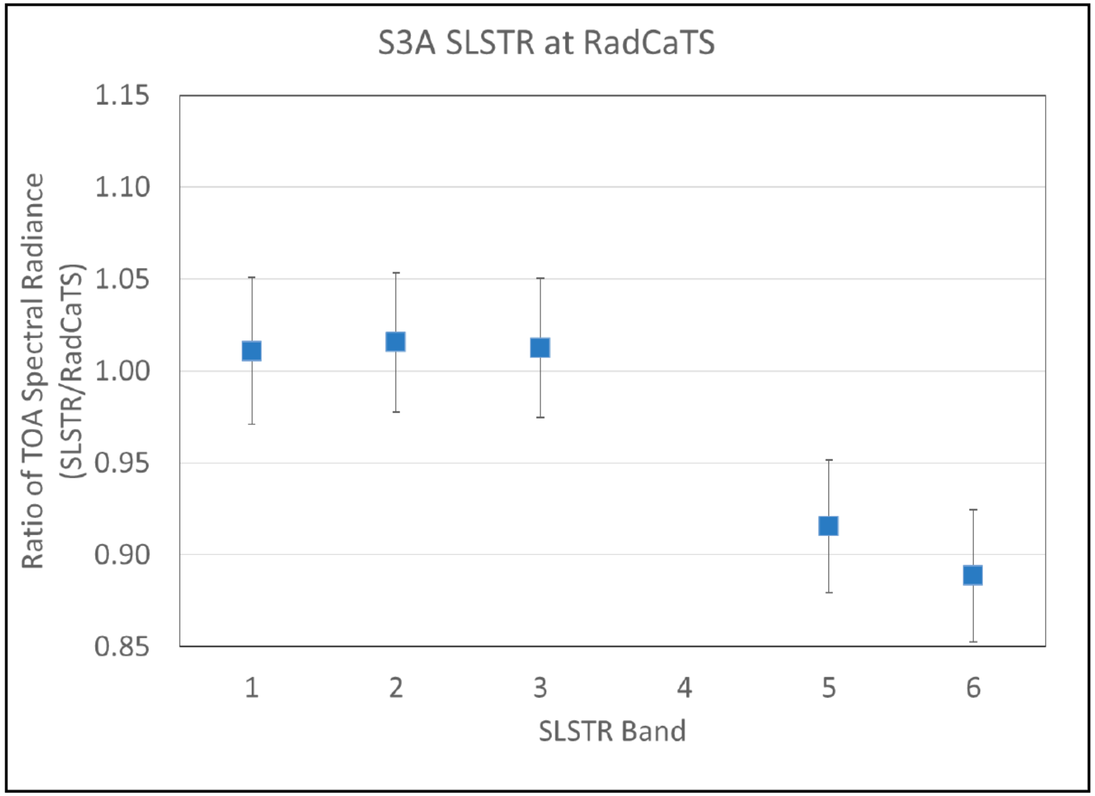
Sentinel-3A data over Railroad Valley Playa RadCalNet site.

11 Match-ups from 51 overpasses,

Analyses are constrained to 6.5° view zenith angle and 2x2 pixel region of interest (~1km x 1km)

Data for larger view angles were not included because the BRDF for the site does not currently extend beyond 6.5°.

Uncertainties are 4% based on the RadCalNet uncertainty statement



Results courtesy Jeff Czapla-Meyers, University of Arizona

Jeff Czapla-Myers and Emma Woolliams “Uncertainty Analysis Statement – Railroad Valley USA”, RadCalNet project document QA4EO-WGCV-IVO-CSP002, 2018

Alignment to Common Reference

- **Results of comparisons depend on the reference sensor being used**
- E.g. AATSR

- **To combine the results we need to align to a common reference.**
- For S1-S3 MERIS is proposed as the common reference
- For S5, S6 MODIS-Aqua is used
- We chose these because their calibration has been verified through with other independent methods (such as RadCalNet)

- **We need to account for relative differences between the reference and common reference so that.**

$$\text{rel\_diff'} = \frac{R_{SLSTR}}{R_{ref}} \frac{R_{ref}}{R_{ref\_new}}$$

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Adjustment Factors

Factors for AATSR for RAL comparisons

Method	S1		S2		S3		S5	
	Rmeas/Rref	StdDev	Rmeas/Rref	StdDev	Rmeas/Rref	StdDev	Rmeas/Rref	StdDev
MERIS	1.015	0.032	1.012	0.030	1.023	0.025	-	-
MODIS	-	-	1.034	0.013	1.031	0.011	1.002	0.009

Dave Smith and Caroline Cox, "(A)ATSR Solar Channel Calibration", IEEE Transactions on Geoscience and Remote Sensing, 51 (3), 1370-1382, 2013, 10.1109/TGRS.2012.2230333

Factors for MODIS, PARASOL to MERIS for CNES comparisons

Method	S1		S2		S3	
	Rmeas/Rref	StdDev	Rmeas/Rref	StdDev	Rmeas/Rref	StdDev
MODIS	0.974	0.027	0.986	0.018	0.988	0.017
PARASOL	0.972	0.032	0.968	0.023	0.974	0.020

Sophie Lacherade, Bertrand Fougnie, Patrice Henry and Phillipe Gamet, "Cross Calibration Over Desert Sites: Description, Methodology and Operational Implementation", IEEE Transactions on Geoscience and Remote Sensing, 51 (3), 1098-1113, 2013, 10.1109/TGRS.2012.2237061

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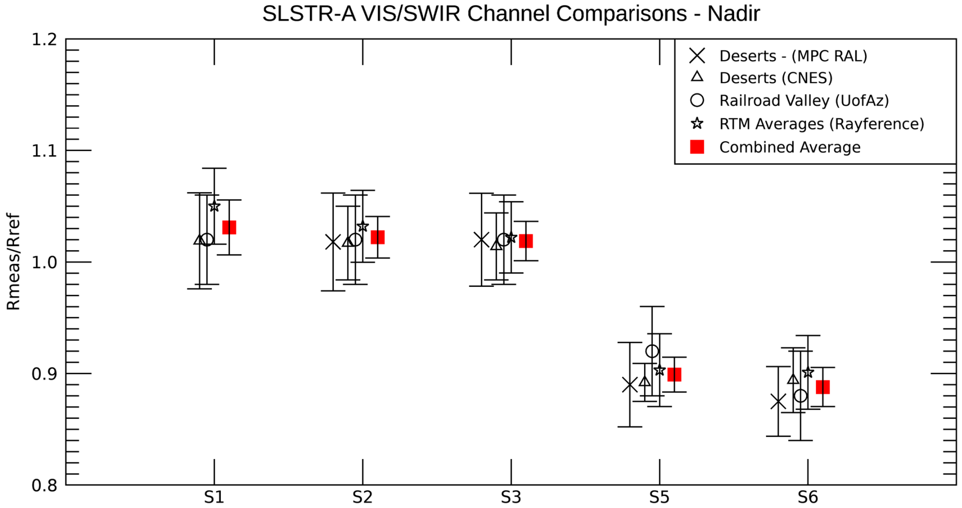
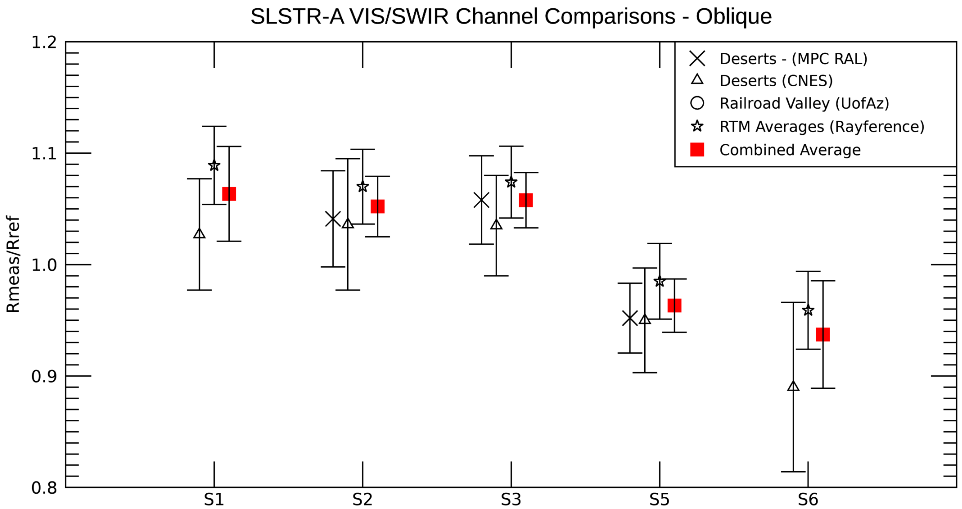
Combined Results after Adjustment to Common Reference





Averages are weighted by uncertainty

$$\overline{\mathrm{rel\_diff}} = \sum_{i=1}^{N} \mathrm{w}_i \, \mathrm{rel\_diff}_i$$

$$w_i = 1/\sigma_i \Big/ \sum_{i=1}^{N} 1/\sigma_i$$

$$\sigma^2 = \sum_{i=1}^{N} w_i \left(\mathrm{rel\_diff}_i - \overline{\mathrm{rel\_diff}}\right)^2 \Big/ (\mathrm{N}-1) + \sum_{i=1}^{N} (w_i \sigma_i)^2$$

Assume methods are uncorrelated.

Combined uncertainties include 3% estimate for systematic effects for RAL, CNES and RTM methods.

Combined Results

Nadir View

Method	S1		S2		S3		S5		S6	
	Rmeas/Rref	Uncert	Rmeas/Rref	Uncert	Rmeas/Rref	Uncert	Rmeas/Rref	Uncert	Rmeas/Rref	Uncert
MPC (RAL)	-	-	1.02	0.04	1.02	0.04	0.89	0.04	0.88	0.03
CNES	1.02	0.05	1.02	0.05	1.01	0.04	0.89	0.03	0.89	0.04
RTM (Rayference)	1.05	0.03	1.03	0.03	1.02	0.03	0.90	0.03	0.90	0.03
RailRoad Valley	1.02	0.04	1.02	0.04	1.02	0.04	0.92	0.04	0.88	0.04
Median	**1.02**		**1.02**		**1.02**		**0.90**		**0.89**	
Average	**1.03**	**0.03**	**1.02**	**0.02**	**1.02**	**0.02**	**0.90**	**0.02**	**0.89**	**0.02**
Weighted Average	**1.03**	**0.03**	**1.02**	**0.02**	**1.02**	**0.02**	**0.90**	**0.02**	**0.89**	**0.02**

Oblique View

Method	S1		S2		S3		S5		S6	
	Rmeas/Rref	Uncert	Rmeas/Rref	Uncert	Rmeas/Rref	Uncert	Rmeas/Rref	Uncert	Rmeas/Rref	Uncert
MPC (RAL)	-	-	1.04	0.04	1.06	0.04	0.95	0.04	-	-
CNES	1.03	0.06	1.04	0.07	1.04	0.05	0.95	0.06	0.89	0.08
RTM (Rayference)	1.09	0.03	1.07	0.03	1.07	0.03	0.99	0.03	0.96	0.03
RailRoad Valley	-	-	-	-	-	-	--	-	-	-
Median	**1.09**		**1.04**		**1.06**		**0.95**		**0.96**	
Average	**1.06**	**0.06**	**1.05**	**0.04**	**1.06**	**0.03**	**0.96**	**0.03**	**0.92**	**0.07**
Weighted Average	**1.07**	**0.05**	**1.05**	**0.03**	**1.06**	**0.03**	**0.97**	**0.03**	**0.94**	**0.05**

Proposed Correction Factors

- **Proposal is to adopt the following correction factors for the radiometric calibration based on the combined averages of the vicarious calibration results**

Nadir View

	S1	S2	S3	S5	S6
Correction	0.97	0.98	0.98	1.11	1.13
Uncertainty	0.03	0.02	0.02	0.02	0.02
Input Analysis	UoAz Rayference CNES	UoAz MPC (RAL) Rayference CNES	UoAz MPC (RAL) Rayference CNES	UoAz MPC (RAL) Rayference CNES	UoAz MPC (RAL) Rayference CNES

Oblique View

	S1	S2	S3	S5	S6
Correction	0.94	0.95	0.95	1.04	1.07
Uncertainty	0.05	0.03	0.03	0.03	0.05
Input Analysis	Rayference CNES	MPC (RAL) Rayference CNES	MPC (RAL) Rayference CNES	MPC (RAL) Rayference CNES	Rayference CNES

Note: Uncertainty estimates are at k=1.

Conclusions

- **We have compared the results of 4 different analysis of SLSTR top-of-atmosphere radiances over stable reference sites.**
  - The analyses show good agreement within the reported uncertainties.
  - We do not attempt to state which method is closest to the true value since all methods are relative to a different reference.

- **Using the combined weighted averages, we are able to provide vicarious adjustment factors to align SLSTR reflectances to MERIS and MODIS Aqua L1 calibrations.**
  - This is on the basis that MERIS and MODIS calibrations have been assessed over many years and are considered as reference sensors in the VIS/SWIR and relative differences with other sensors are reported.
  - Alignment to a different reference sensor, e.g. Sentinel-2 would be possible provided that relative differences and uncertainty estimates are provided.

- **Uncertainties in the calibration factors are based on those reported by the different teams and are the best estimate at the time of writing.**