SENTINEL 3 Mission Performance Centre

S3 SLSTR Post Launch Vicarious Calibration

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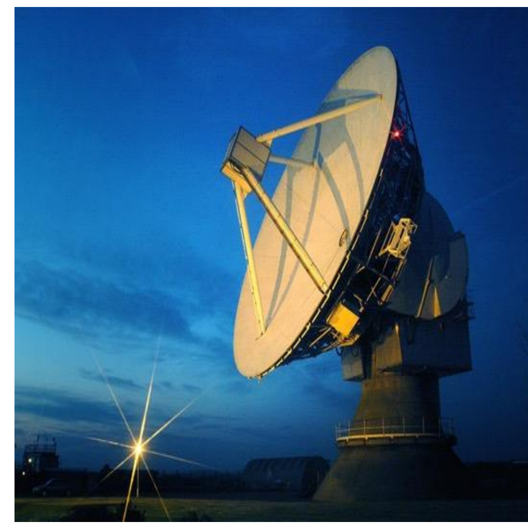
RAL Space, Science and Technologies Facilities Council, United Kingdom



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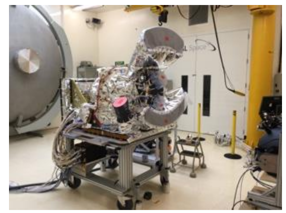
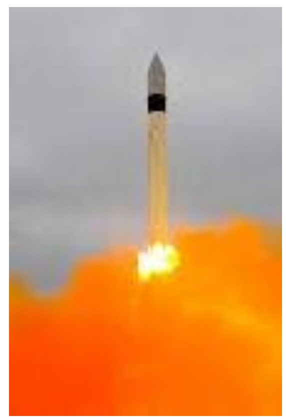
Sentinel-3 Series

2016 – Sentinel 3A

2018 – Sentinel 3B





Launched 16-Feb-2016 ☺ Launched 25-Apr-2018 ☺

2021 – Sentinel 3C

- Spectral Calibration in progress
- Instrument Calibration Spring 2019

2023 – Sentinel-3D

…

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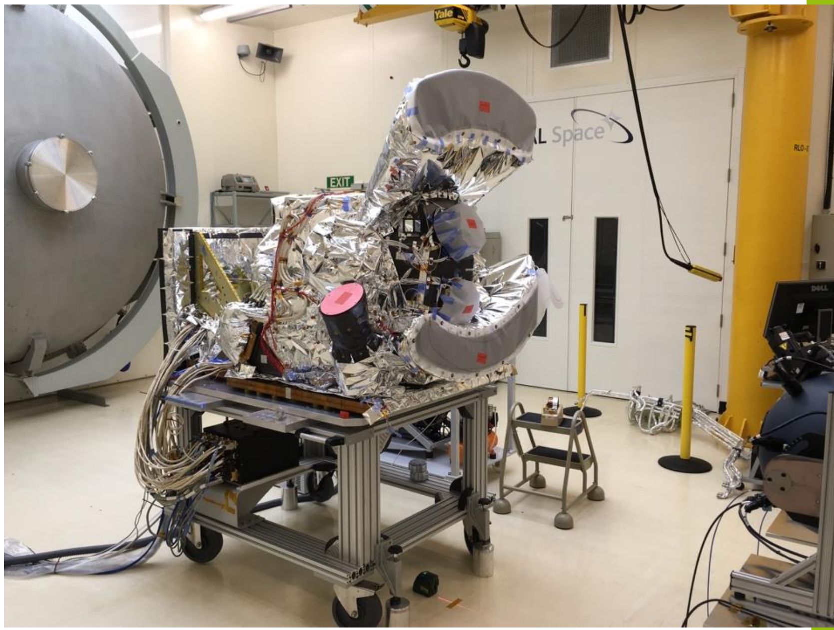
Sea and Land Surface Temperature Radiometer

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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SLSTR-B Known Issues

The following issues are under formal investigation by ESA supported by Industrial team and RAL

- **VIS/SWIR Calibration** – significant differences in some bands between pre/post launch and SLSTR-A/B - **NC-ESA-COM-00037**

- **S1(555nm)/S2(669nm) noise in VISCAL signals** leading to 2-3% apparent gain variation. **NC-ESA-COM-00038**

- **S7/S8 Co-Registration** – apparent (130m shift) - **NC-ESA-COM-00039**
  - ✓ Similar to effect seen on S3A (250m shift)
  - ✓ Thought to be related to timing within detection chain

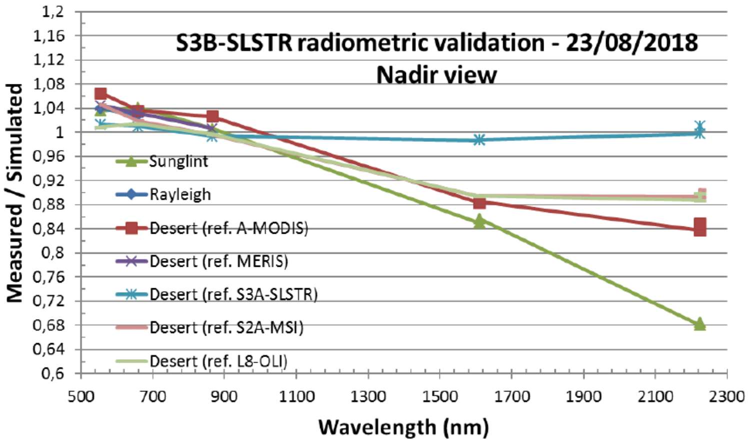
SLSTR-B Summary of CNES Vicarious Calibration Results

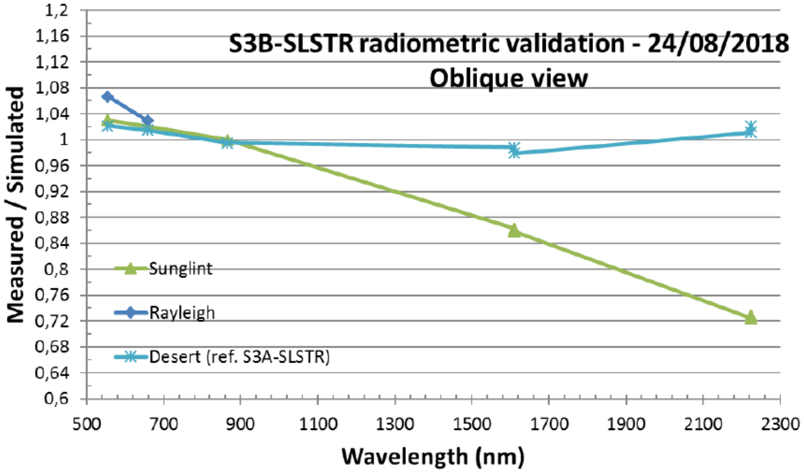
Results from Desert Sites

NC-ESA-COM-00037

- S1-S3 Nadir Are consistent with S2A-MSI, S3A-OLCI, S3A-SLSTR MERIS, AATSR
- S5 and S6 Consistency with SLSTR-A but not AATSR, MODIS-A, L8-OLI or S2

Discrepancies in S6 between desert and sunglint methods.





Results from Yves Govaerts

- **Radiative transfer modelling of the Libya-4 site performed by Yves Govaerts has produced a different result for S6 which is more in line with S5.**

MEAN RELATIVE DIFF.						
BAND	0.44μm	0.55μm	0.66μm	0.84μm	1.62μm	2.20μm
MODISA	-0.76%	-0.24%	-0.89%	-0.92%	-1.05%	-0.59%
MERIS	+ 0.07%	+ 1.13%	+ 0.04%	-0.06%		
S2A_MSI	+ 0.67%	+ 0.66%	+ 0.83%	+ 0.16%	-1.84%	-2.87%
L8_OLI	-1.91%	+ 0.49%	+ 0.11%	+ 0.29%	-2.56%	-2.67%
S3A_SLSTR		+ 4.17%	+ 2.21%	+ 1.29%	-11.14%	$\boxed{\text{-11.12\%}}$
STANDARD DEVIATION OF RELATIVE DIFF.						
MODISA	+ 2.60%	+ 1.43%	+ 1.23%	+ 1.25%	+ 1.06%	+ 1.89%
MERIS	+ 2.65%	+ 1.66%	+ 1.40%	+ 1.26%		
S2A_MSI	+ 2.49%	+ 1.42%	+ 1.29%	+ 2.19%	+ 1.29%	+ 2.11%
L8_OLI	+ 2.38%	+ 1.29%	+ 1.20%	+ 1.37%	+ 1.43%	+ 1.97%
S3A_SLSTR		+ 1.83%	+ 1.44%	+ 1.44%	+ 1.17%	+ 1.57%

SLSTR VIS/SWIR Calibration – March 2018

	Comparisons over Deserts				Sunglint	
Channel	SLSTR-A/OLCI-A (Nadir Only)	SLSTR-A/MODIS-A (Nadir Only)	SLSTR-A/AATSR (Nadir)	SLSTR-A/AATSR (Oblique)	SLSTR (Nadir)	SLSTR (Oblique)
S1	1.003 (0.005)	1.024 (0.009)	0.969 (0.019)	0.9926 (0.023)		
S2	1.000 (0.004)	1.034 (0.007)	0.998 (0.012)	1.024 (0.010)		
S3	0.990 (0.005)	1.036 (0.008)	0.989 (0.010)	1.031 (0.009)		
S5a	---	0.887 (0.006)	0.880 (0.007)	0.952 (0.006)	0.879 (0.027)	0.845 (0.027)
S5b	---	0.887 (0.006)	0.880 (0.007)	0.953 (0.006)		
S6a	---	0.808 (0.010)	---	---	0.762 (0.030)	0.738 (0.030)
S6b	---	0.808 (0.010)	---	---		

* Numbers in brackets are standard deviations – not full combined uncertainty

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Vicarious Calibration Approach

- **Analysis using PICS sites**

- **L1 images over desert, ice, sunglint are processed using S3ETRAC tool and TOA reflectances + ancillary information are saved to Netcdf files.**
  - Avoids the need for downloading large volumes of data,
  - Approach was developed and used successfully for AATSR
  - Tool developed by ACRI-ST based on specifications from CNES and RAL

- **Extractions allow comparisons with other sensors**
- Directly as in the case of SLSTR and OLCI/AATSR and MERIS
- Indirectly where satellites are not time coincident using matching geometry
  - E.g. AATSR/MERIS vs MODIS
  - E.g. AATSR vs ATSR-2 vs ATSR-1

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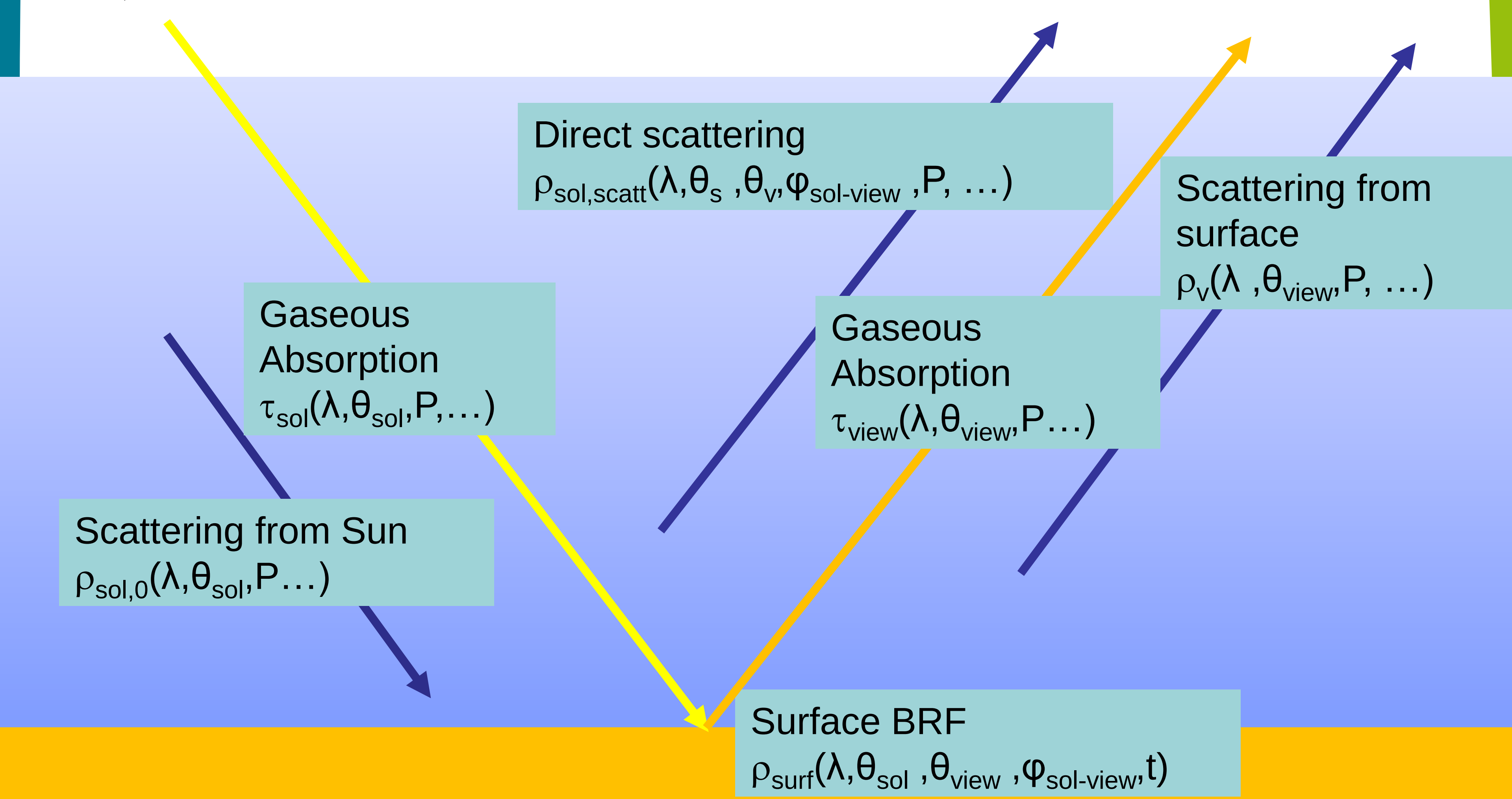
Vicarious calibration model over sites

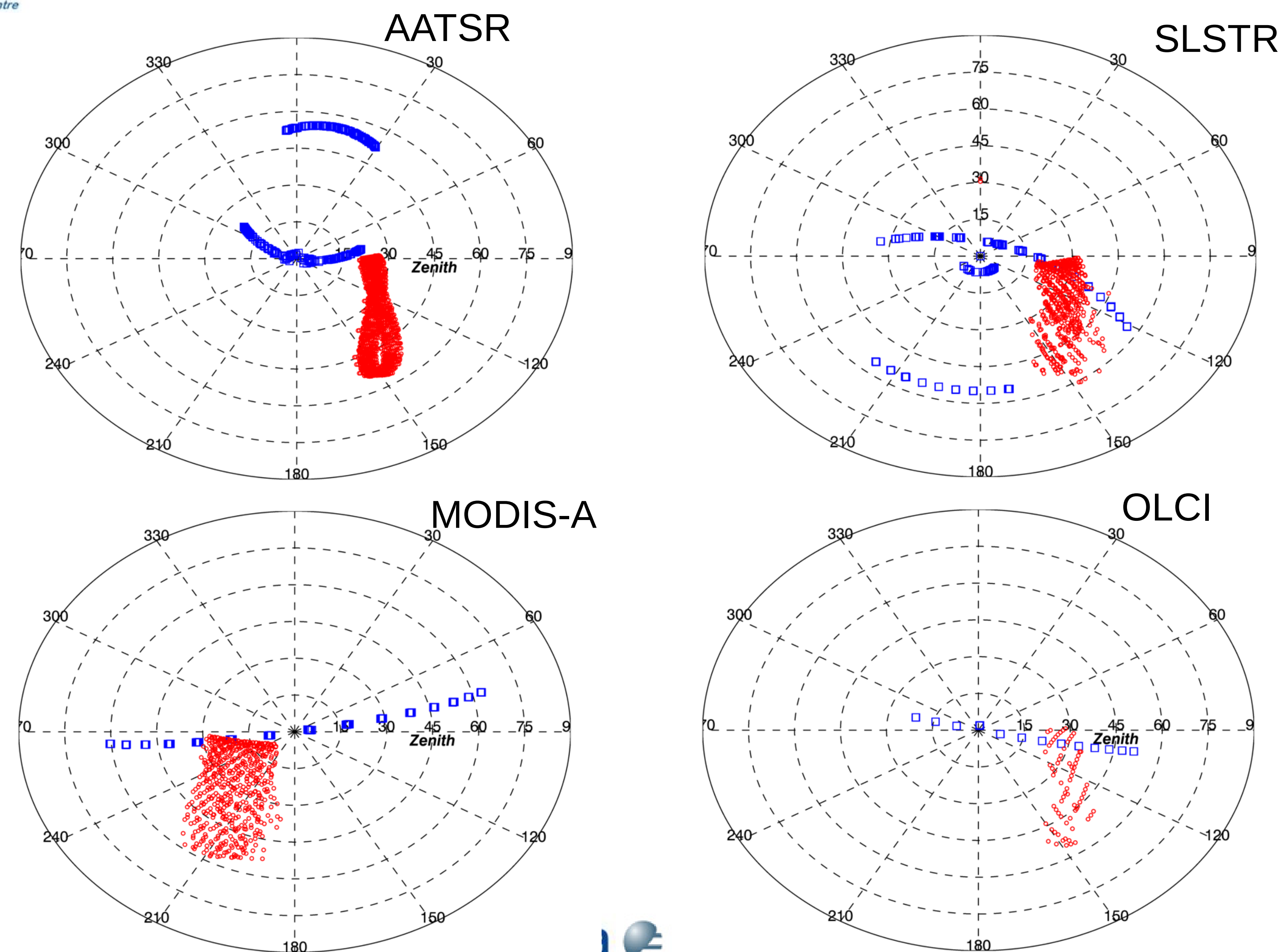
$$\rho_{scene} = L_{scene}/(I_{sun}\cos(\theta_s)/\pi)$$

$$\rho_{scene} = (\rho_{surf}(\rho_{sol,0}+\tau_{sol})(\rho_{view,0}+\tau_{view,0}) + \rho_{sol,scatt})\,\tau_{gas,sol}\tau_{gas,view}$$

Sensor

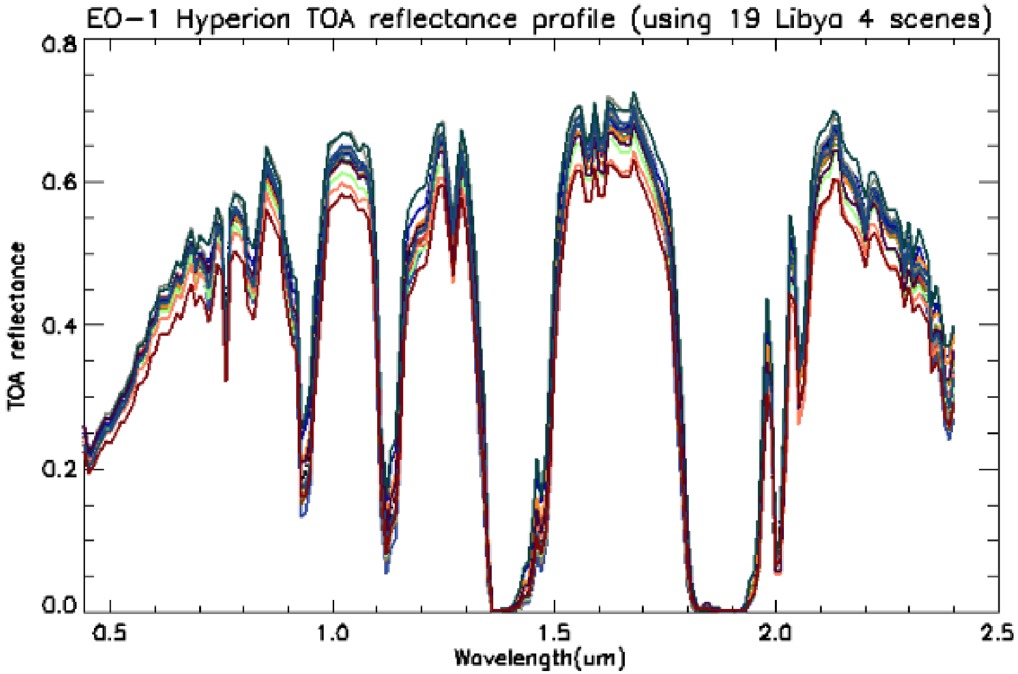


Geometric Comparisons



Spectral Comparisons

- ~~Desert sites are~~ The earth is not spectrally flat!
    - Affects band-band comparisons and inter-satellite comparisons
    - Spectral differences are due to surface BRDF + atmospheric conditions



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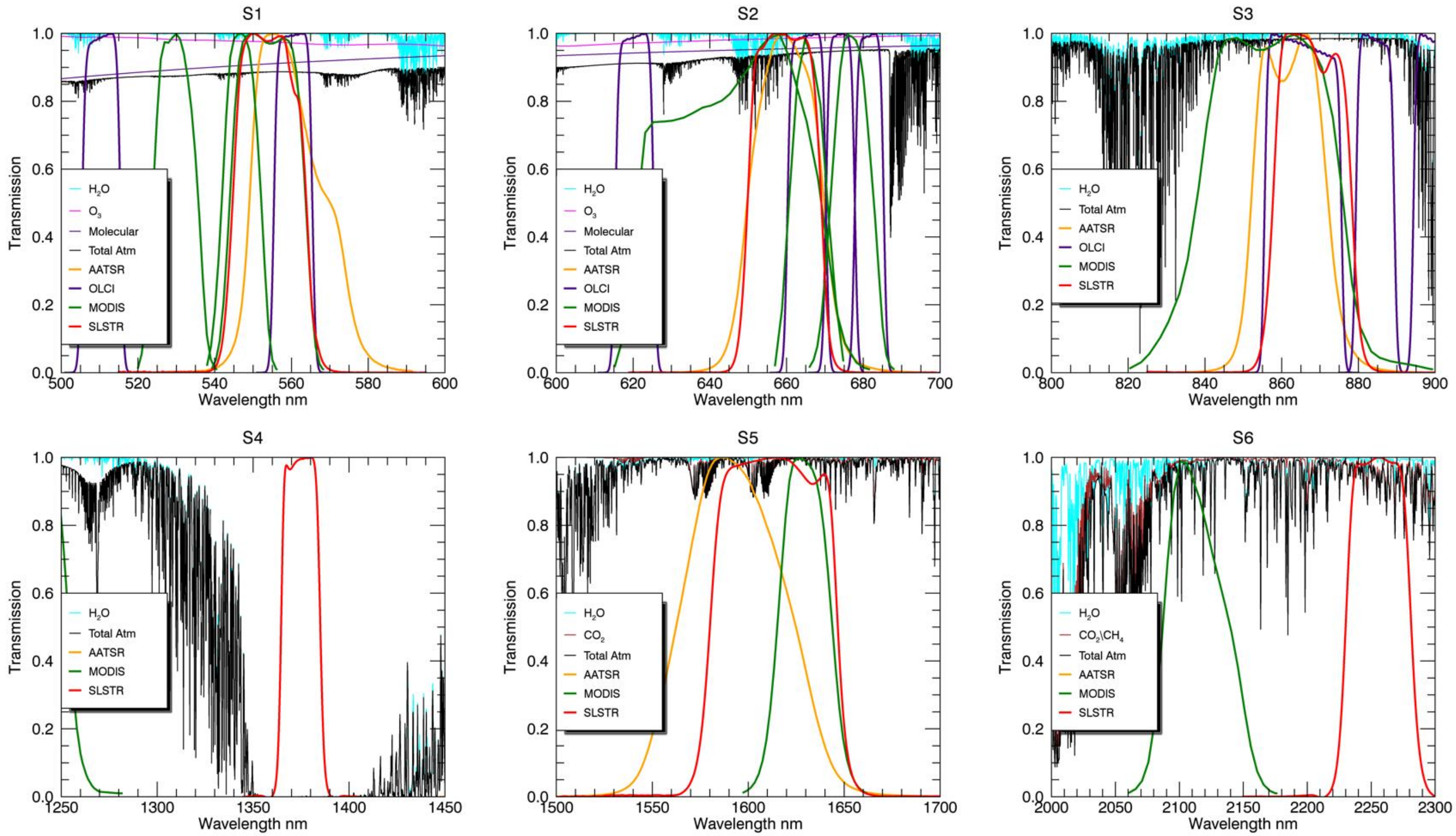
Spectral Band Comparisons



At 2.25um Methane is a significant absorber!

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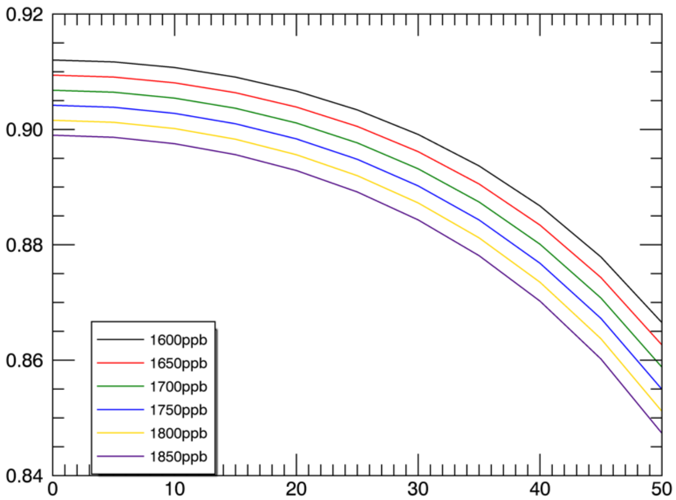
Impact of Methane on S6



SLSTR 2.25um comparisons vs. MODIS 2.13 comparisons

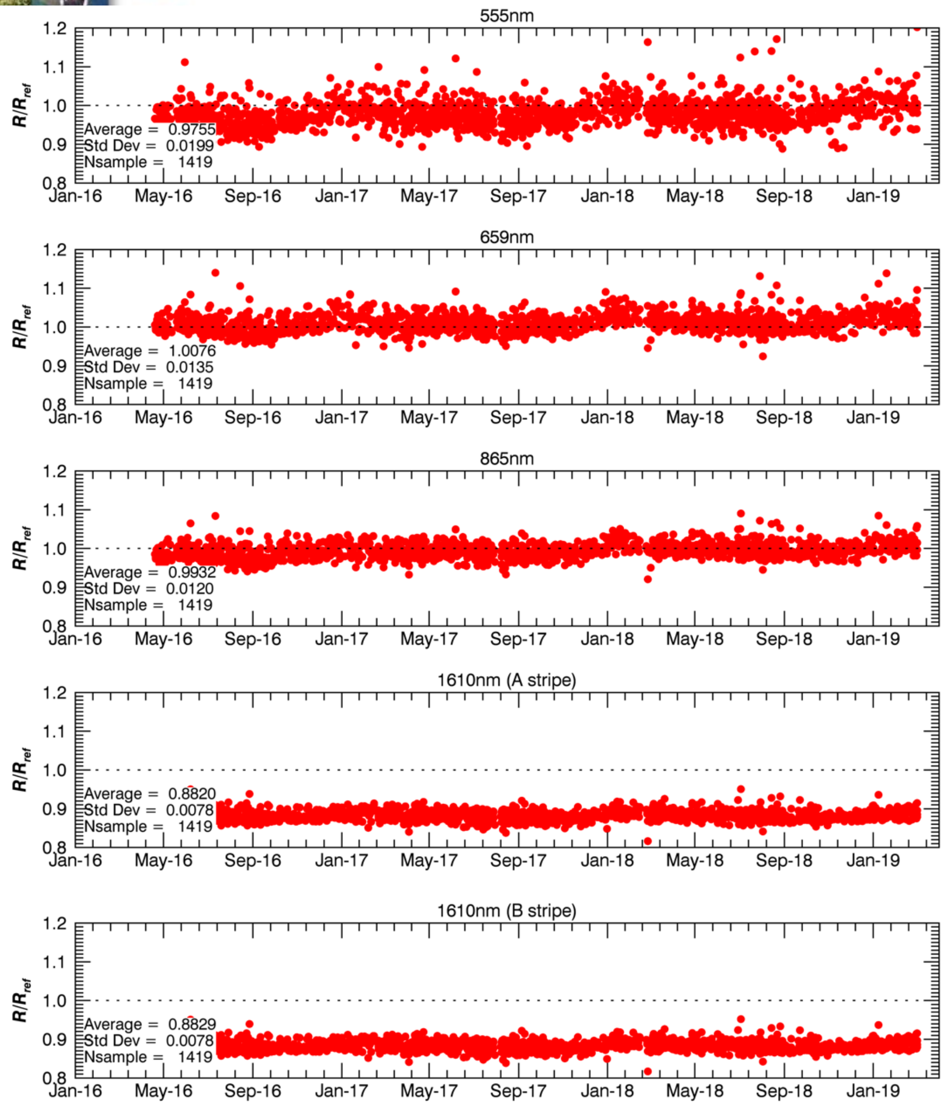
No CH4
SLSTR/MODIS = 0.78

With CH4 – Defualt values
SLSTR/MODIS = 0.86

With CH4 – 2018 values
SLSTR/MODIS ~ 0.88

RTM code – such as MODTRAN and 6S use hard coded values of CH4
MODTRAN = 1600ppb
Current values = 1860ppb and increasing

SLSTR-A vs AATSR (Nadir View)



Geometric matching is used to despite different overpass times. Assume same spectral profile

Combined results for all desert sites processed to date

Match-ups constrained to VZA <25 degrees (AATSR < 22degrees)

SWIR A and B stripes show excellent agreement – mean difference < 0.1%

	Average R/R_{ref}	Stddev
S1	0.974	0.019
S2	1.006	0.013
S3	0.992	0.012
S5a	0.882	0.008
S5b	0.882	0.008

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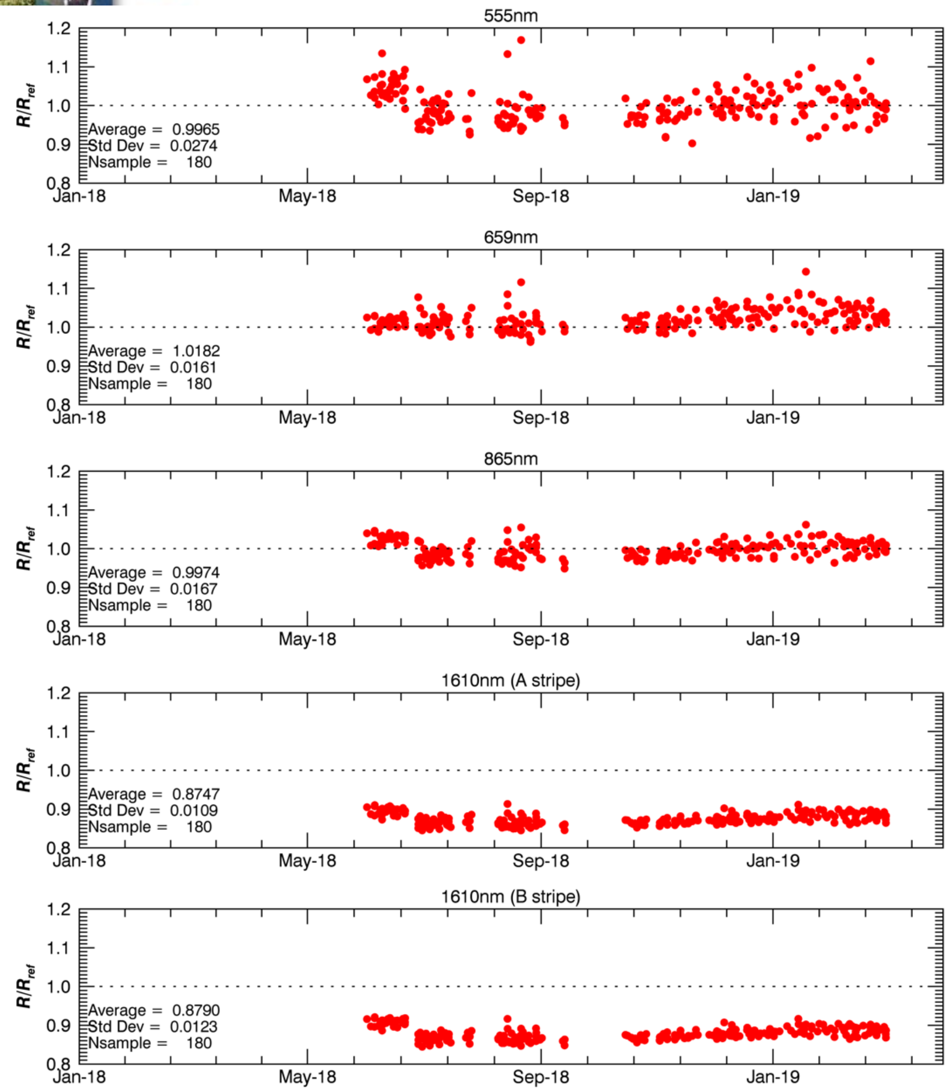
SLSTR-B vs AATSR (Nadir View)



Geometric matching is used to despite different overpass times. Assume same spectral profile

Combined results for all desert sites processed to date

Match-ups constrained to VZA <25 degrees (AATSR < 22degrees)

SWIR A and B stripes show excellent agreement – mean difference < 0.4%

	Average R/R_{ref}	Stddev
S1	0.997	0.027
S2	1.018	0.016
S3	0.997	0.017
S5a	0.875	0.011
S5b	0.879	0.012

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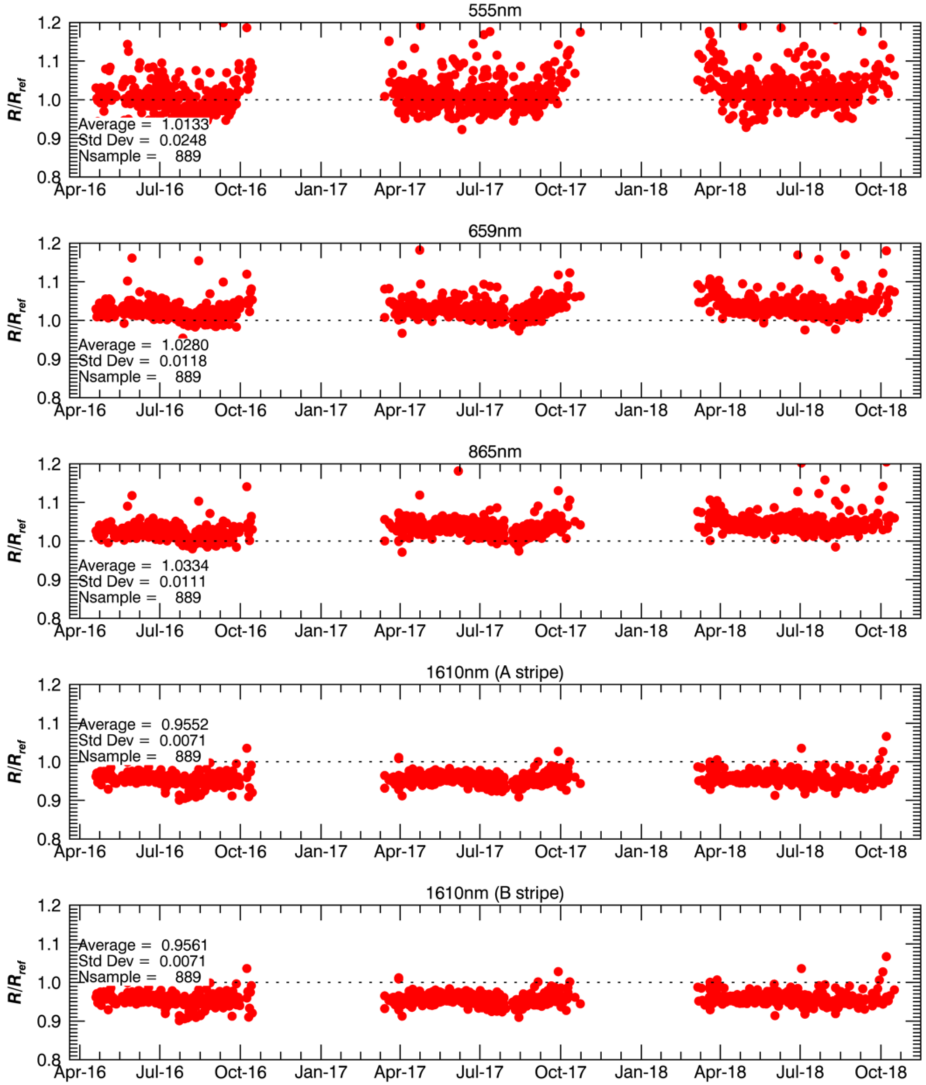
SLSTR-A vs AATSR (Oblique View)



Geometric matching is used to despite different overpass times. Assume same spectral profile

Combined results for all desert sites processed to date

SWIR A and B stripes show excellent agreement – mean difference < 0.1%

	Average R/R_{ref}	Stddev
S1	1.013	0.013
S2	1.028	0.012
S3	1.033	0.011
S5a	0.955	0.007
S5b	0.956	0.007

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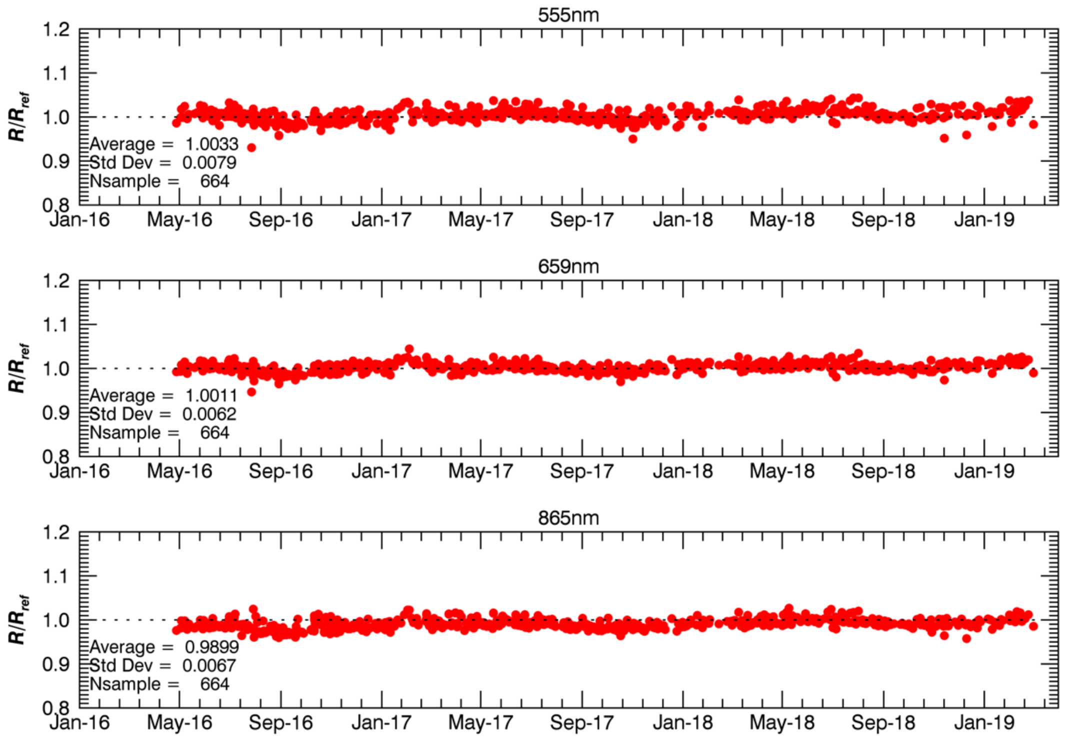
SLSTR-A vs OLCI-A



Combined results for all desert sites processed to date

Match-ups constrained to observations where nadir VZA <25 degrees

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

	Average R/R_{ref}	Stddev
S1	1.003	0.008
S2	1.001	0.006
S3	0.990	0.007

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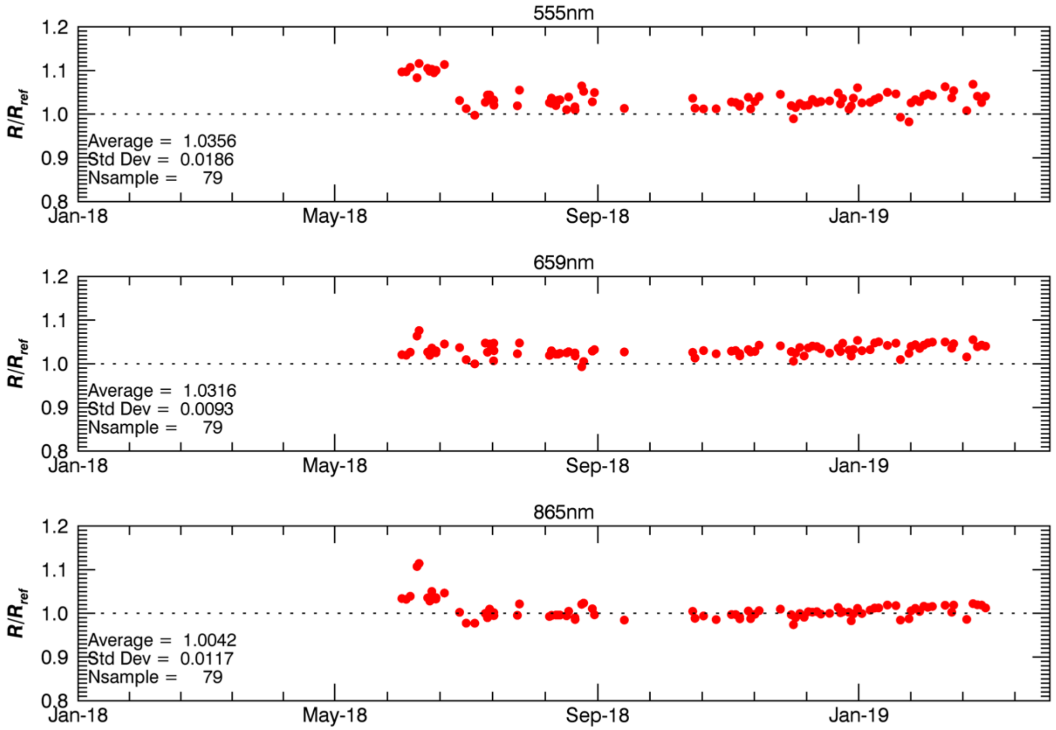
SLSTR-B vs OLCI-B



Combined results for all desert sites processed to date

Match-ups constrained to observations where nadir VZA <25 degrees

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

	Average R/R_{ref}	Stddev
S1	1.036	0.019
S2	1.032	0.009
S3	1.004	0.012

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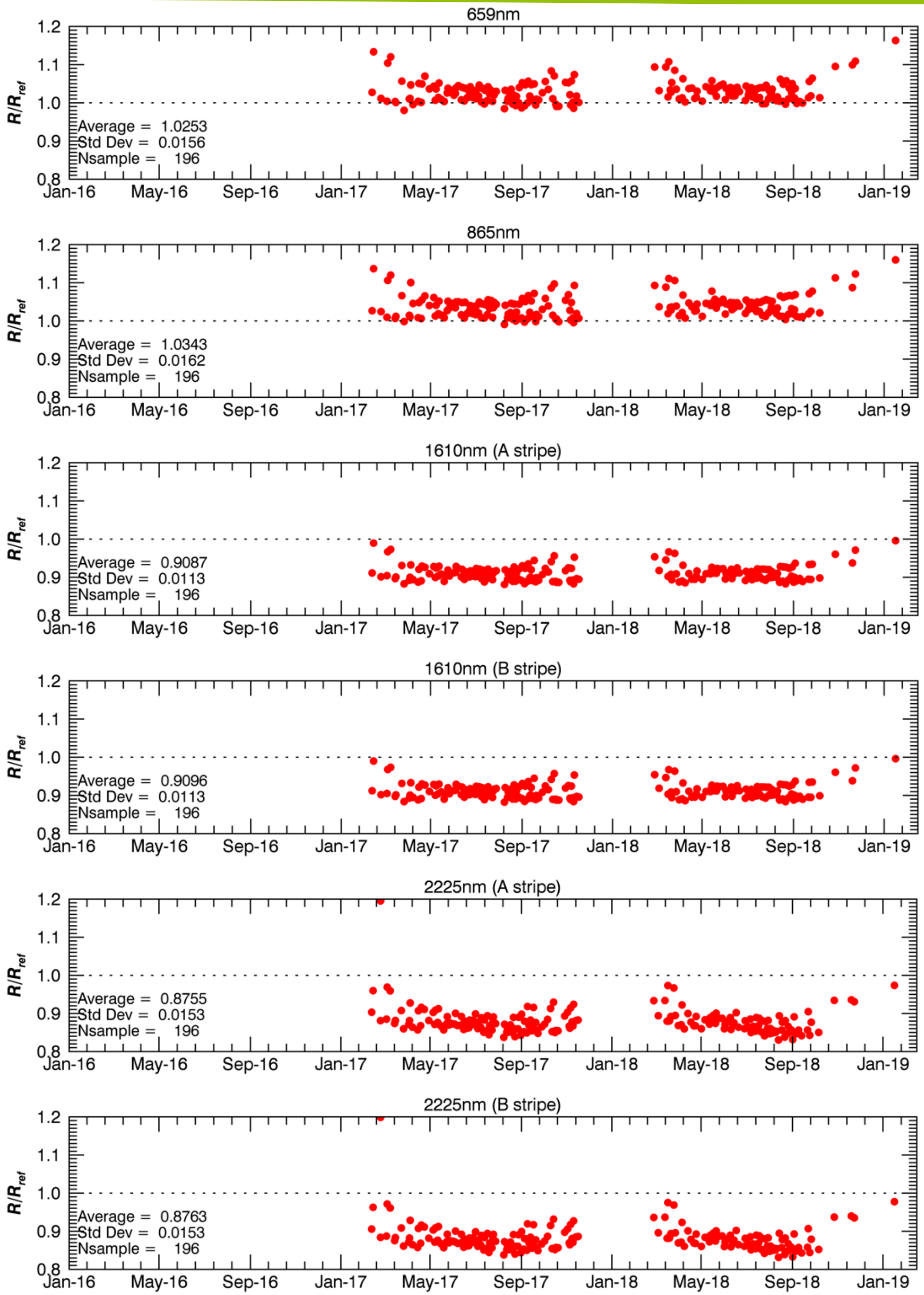

SLSTR-A vs MODIS-Aqua

Data for Libya-4 only

Match-ups constrained to observations where nadir VZA <25 degrees

Geometric corrections and **Corrections for spectral variations**

	Average R/R_{ref}	Stddev
S2	1.025	0.0156
S3	1.034	0.0162
S5a	0.909	0.0113
S5b	0.909	0.0113
S6a	0.876	0.0153
S6b	0.876	0.0153

Default CH4 values used

EUMETSAT

Sun-Glint Calibration Model

- The Sun-glint model is based on Cox and Munk (1954) and accounts for:
  - Surface reflectance (white-cap, wind-roughened surface)
  - Rayleigh scattering
  - Atmosphere transmittance

- For AATSR and MODIS we have used ECMWF data for wind speed and Aerosol values from Aeronet

- All the inputs needed are in the SLSTR Level-1 data products, **except aerosol optical depth**!

- So for SLSTR we need to determine the visibility, aerosol size distribution, and wind velocity by constraining the model to S1, S2 and S3
  - We assume that the relative calibration error is <3% (based on desert analysis)

- This is done for each image!

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SLSTR vs Sunglint Model
North Pacific 22/04/2017

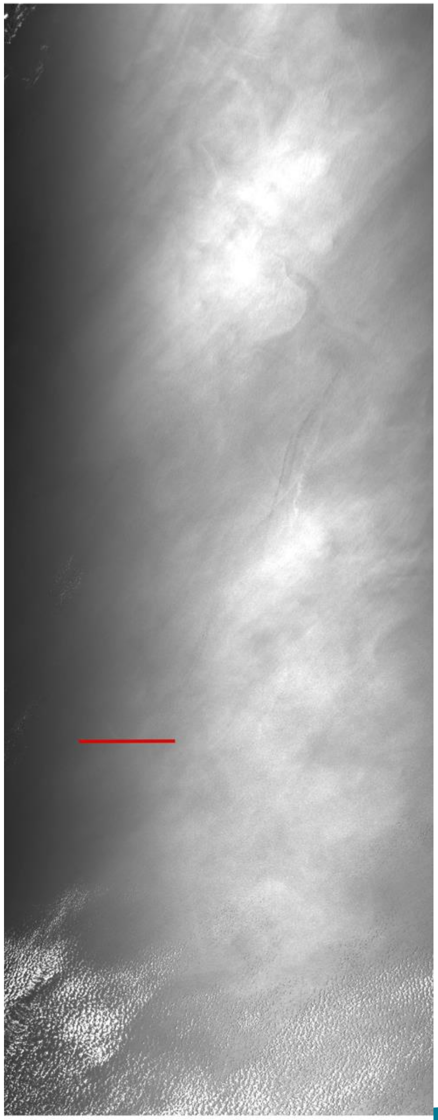
Image from: https://coda.eumetsat.int/#/home

Product Name:

S3A_SL_1_RBT____20170422T185118_20170422T185418_
20170422T205046_0179_017_013_2520_MAR_O_NR_002.SEN3

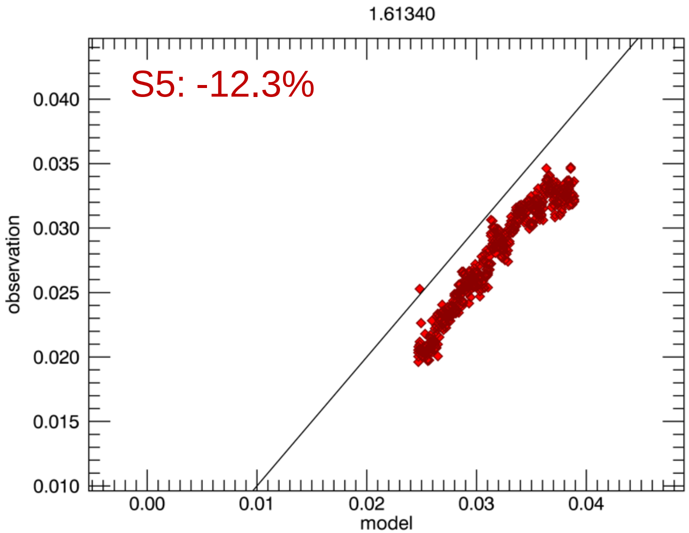
The best solution for this image is for the following conditions:

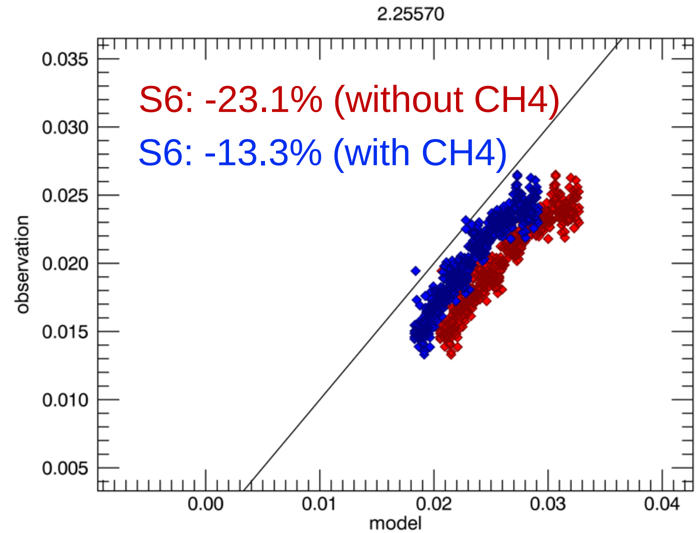
- τ_{aer} (0.55 μm)= 0.099
- wind_x= -2.5 m/s (30% lower than wind_x provided in Level-1)
- wind_y= -6.6 m/s (as provided in the Level-1 image)
- Sunglint coordinates: lat= 22.63 deg., long= -128.36 deg.



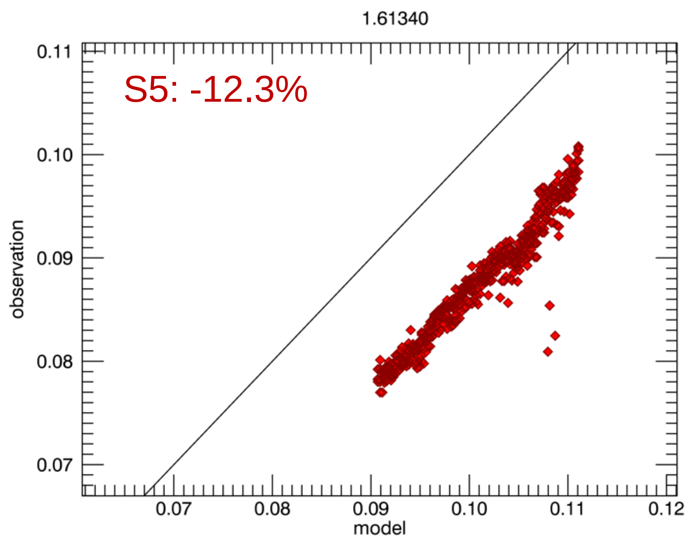
Comparisons against Sun-glint model

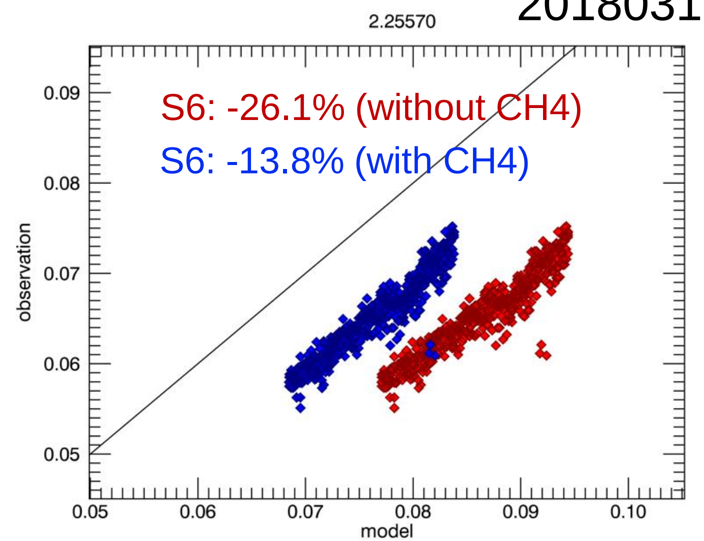
20180102T171405





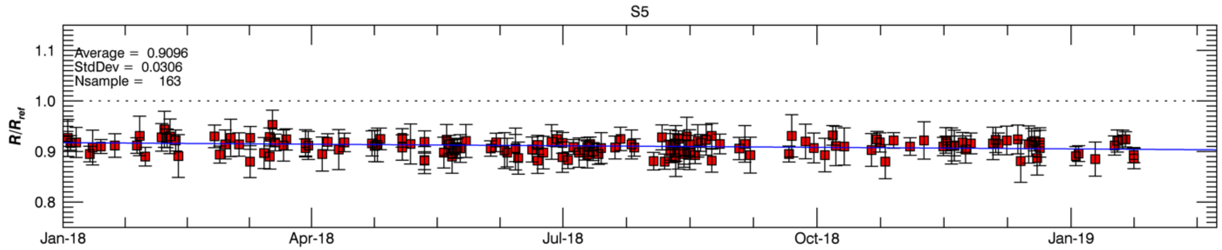
20180318T193911

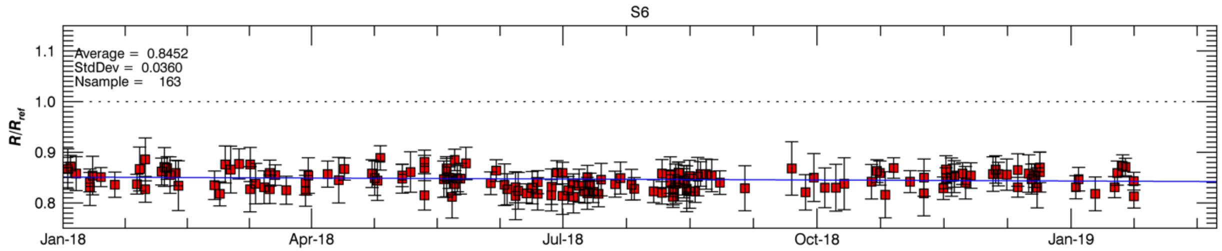




Sun-glint analysis trends

NADIR

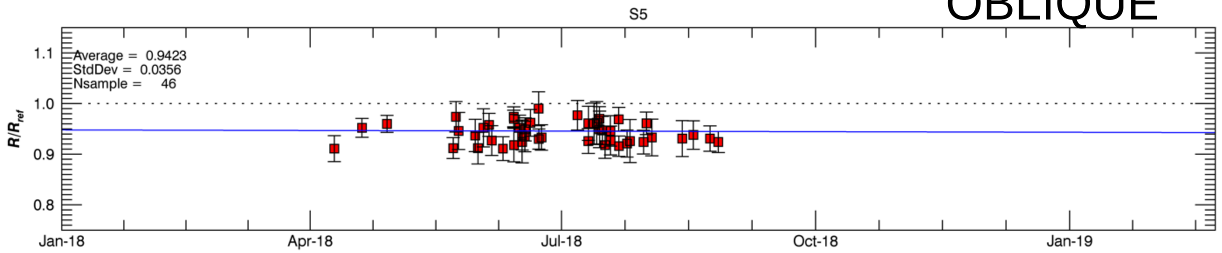


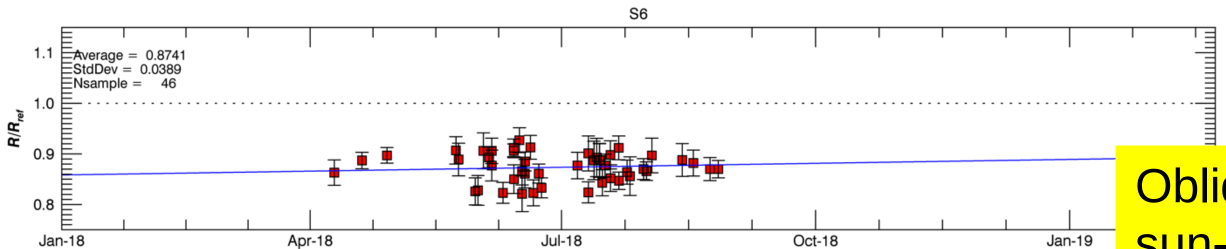


	Average Rel.Diff. (%)	Stddev
S5	0.909	0.031
S6	0.845	0.036

Note: S1-S3 are ‘fixed’ to determine wind speed and AOT

OBLIQUE





	Average Rel.Diff. (%)	Stddev
S5	0.942	0.036
S6	0.874	0.039

Oblique view scenes with sun-glint not available during winter months

SLSTR VIS/SWIR Calibration Status – Mar-2019

	Comparisons over Deserts						Sunglint		Libya4 (Goaverts)
Channel	SLSTR-A/OLCI-A (Nadir Only)	SLSTR-A/MODIS-A (Nadir Only)	SLSTR-A/AATSR (Nadir)	SLSTR-A/AATSR (Oblique)	SLSTR-B/SLSTR-A* (Nadir)	SLSTR-B/SLSTR-A* (Oblique)	SLSTR (Nadir)	SLSTR (Oblique)	SLSTR
S1	1.008 (0.014)	-	0.974 (0.019)	1.013 (0.025)	1.022 (0.027)	1.002 (0.008)			1.042 (0.018)
S2	1.004 (0.011)	1.011 (0.010)	1.006 (0.013)	1.028 (0.012)	1.005 (0.005)	1.000 (0.005)			1.022 (0.014)
S3	0.991 (0.010)	1.018 (0.010)	0.992 (0.012)	1.033 (0.011)	1.000 (0.017)	0.985 (0.005)			1.013 (0.014)
S5a	---	0.899 (0.006)	0.882 (0.012)	0.955 (0.007)	0.992 (0.017)	0.982 (0.003)	0.909 (0.031)	0.942 (0.036)	0.889 (0.012)
S5b	---	0.900 (0.006)	0.883 (0.008)	0.956 (0.007)	0.995 (0.015)	0.983 (0.003)			
S6a	---	0.876 (0.015)	---	---	0.995 (0.015)	1.007 (0.003)	0.845 (0.036)	0.874 (0.039)	0.889 (0.016)
S6b	---	0.876 (0.015)	---	---	0.995 (0.009)	1.016 (0.003)			

- SLSTR-B Data were generated from IPF-D where calibration files were not generated for all orbits – hence comparisons with SLSTR-A have more noise. Comparisons between SLSTR-A and B are for period after CMTR

- Comparisons depend on the calibration of the reference sensor

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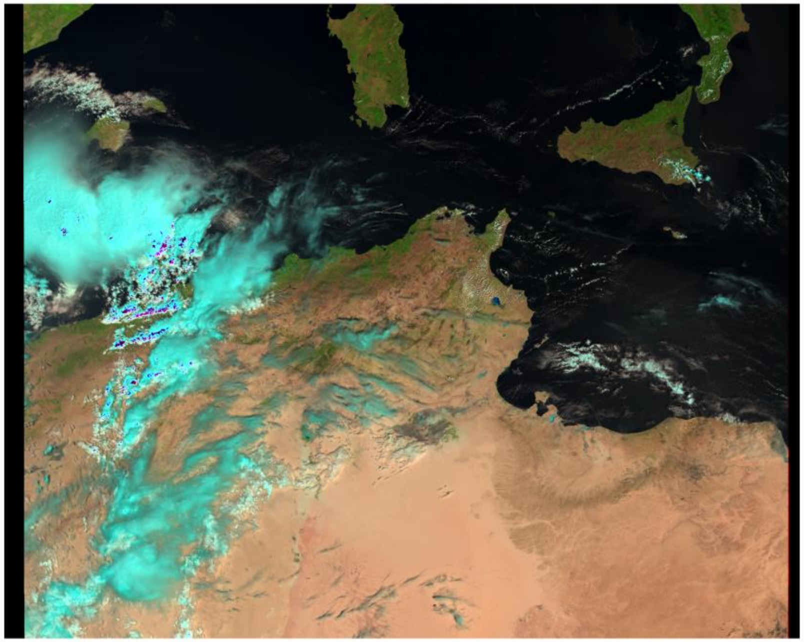
Sentinel-3 Tandem Phase

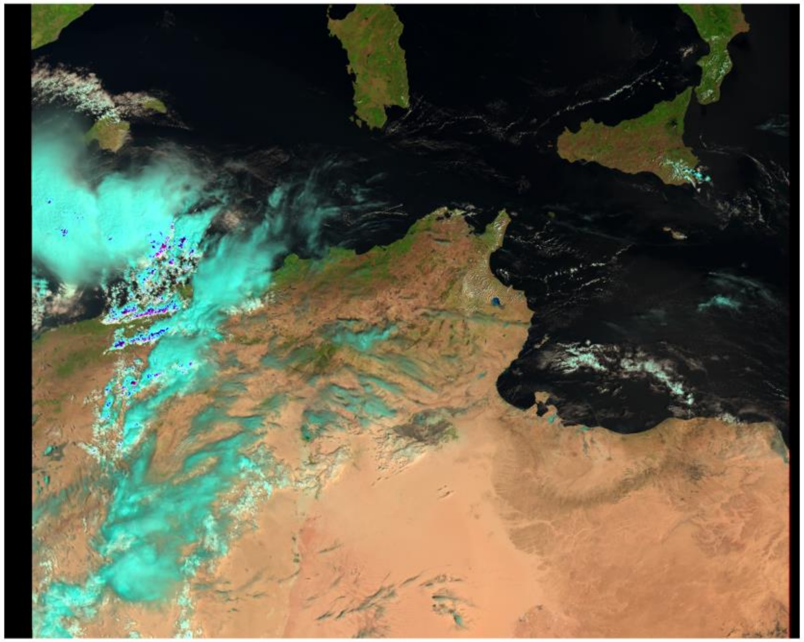
Sentinel-3A

S3A_SL_1_RBT___20180911T093834_20180911T094134_20180912T145054_0179_035_307_2340_LN2_O_NT_003.SEN3



Sentinel-3B

S3B_SL_1_RBT___20180911T093803_20180911T094103_20180912T134511_0179_012_307_2340_LN2_O_NT_003.SEN3



Sentinel-3A flying on Same Track 30s behind Sentinel-3B

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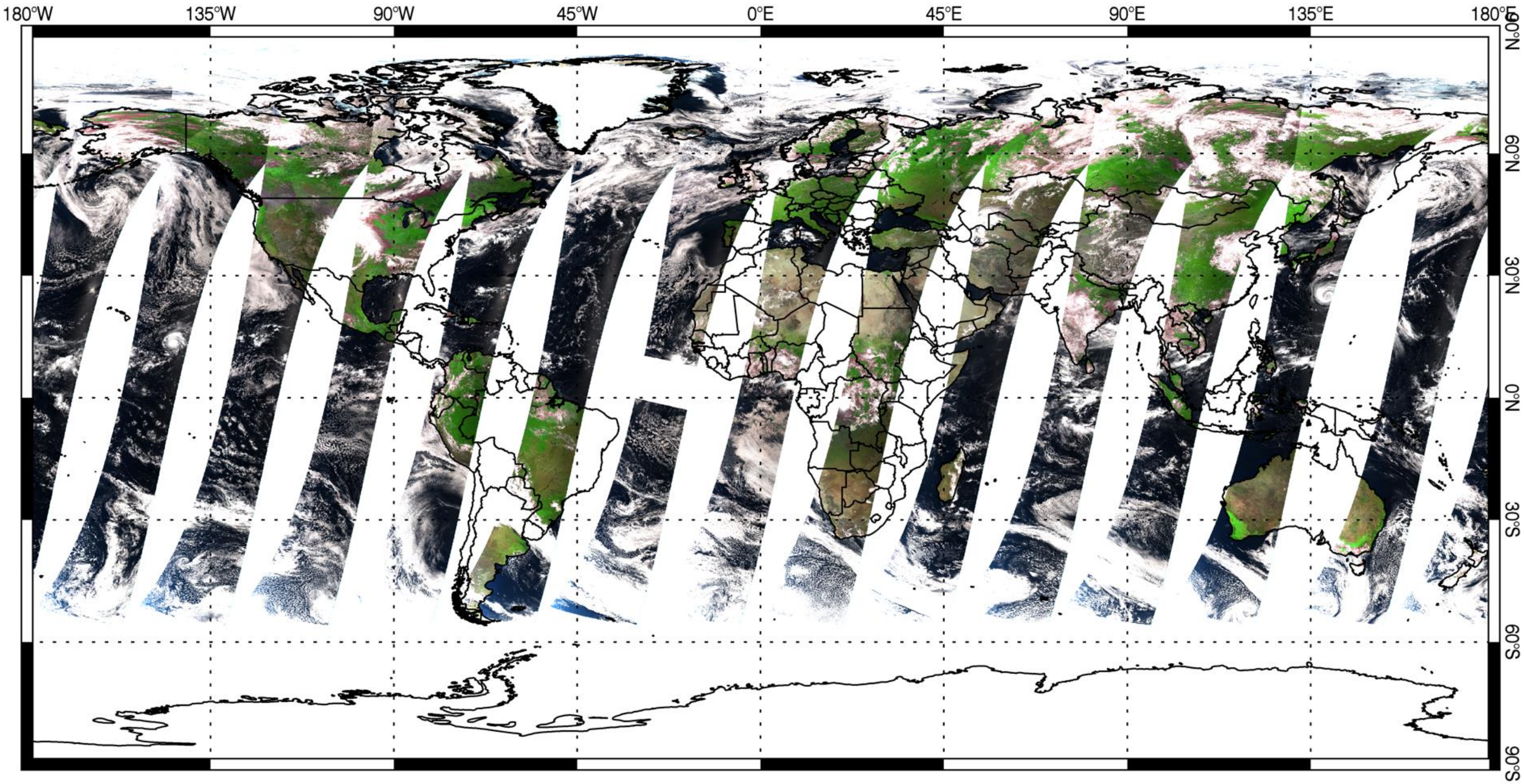
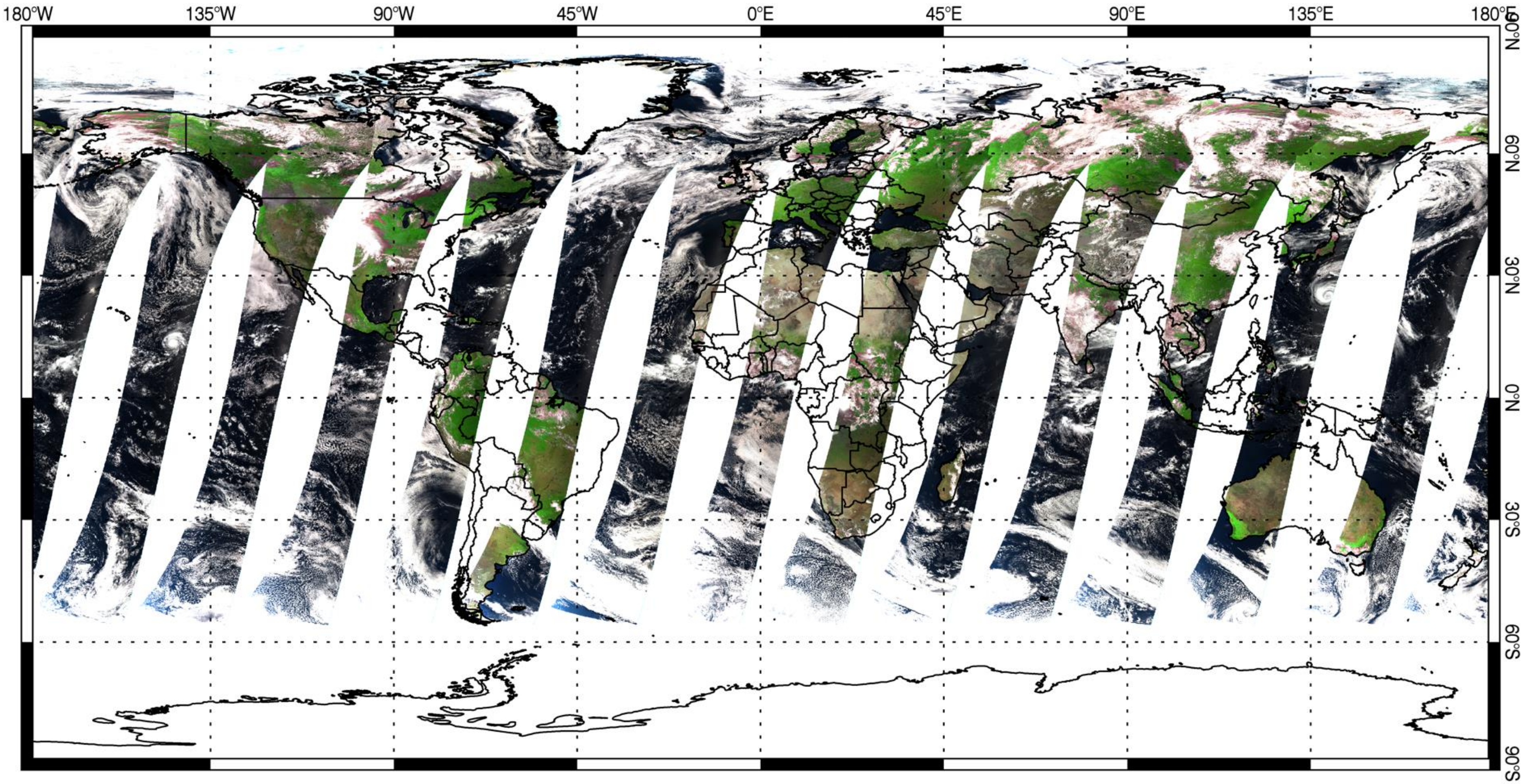
SLSTR-A L3 Solar Channels



Data for 19-August-2018

SLSTR-B L3 Solar Channels



Data for 19-August-2018

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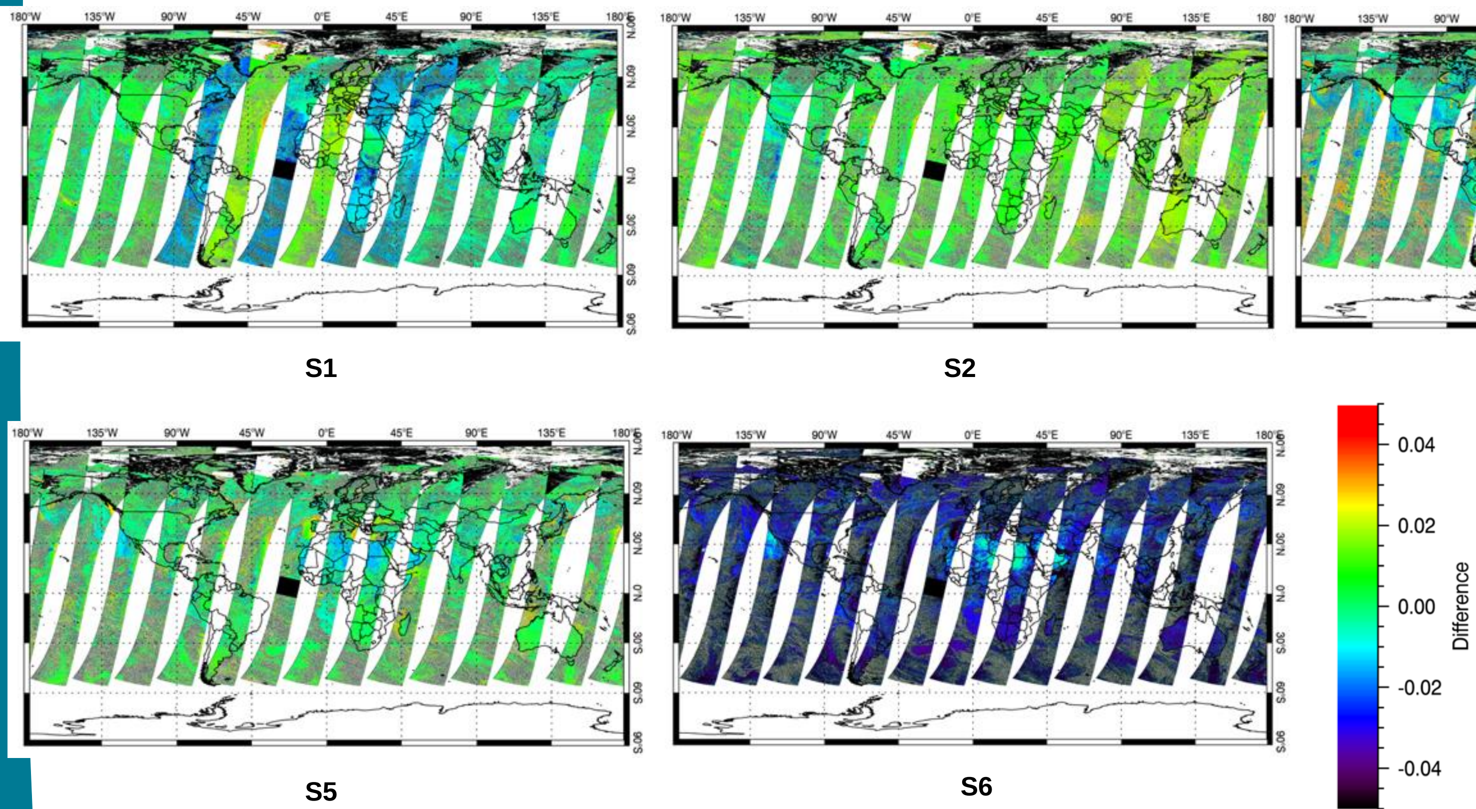
S3B-S3A Tandem Phase Comparisons



Level-3 data for 19th August 2018

Relative Differences S3B/S3A - 1

- S3B are aligned to first order with S3A based on comparisons over Desert sites
- Residual differences most likely due to residual non-linearity errors
- Note S1 and S2 affected by gain changes

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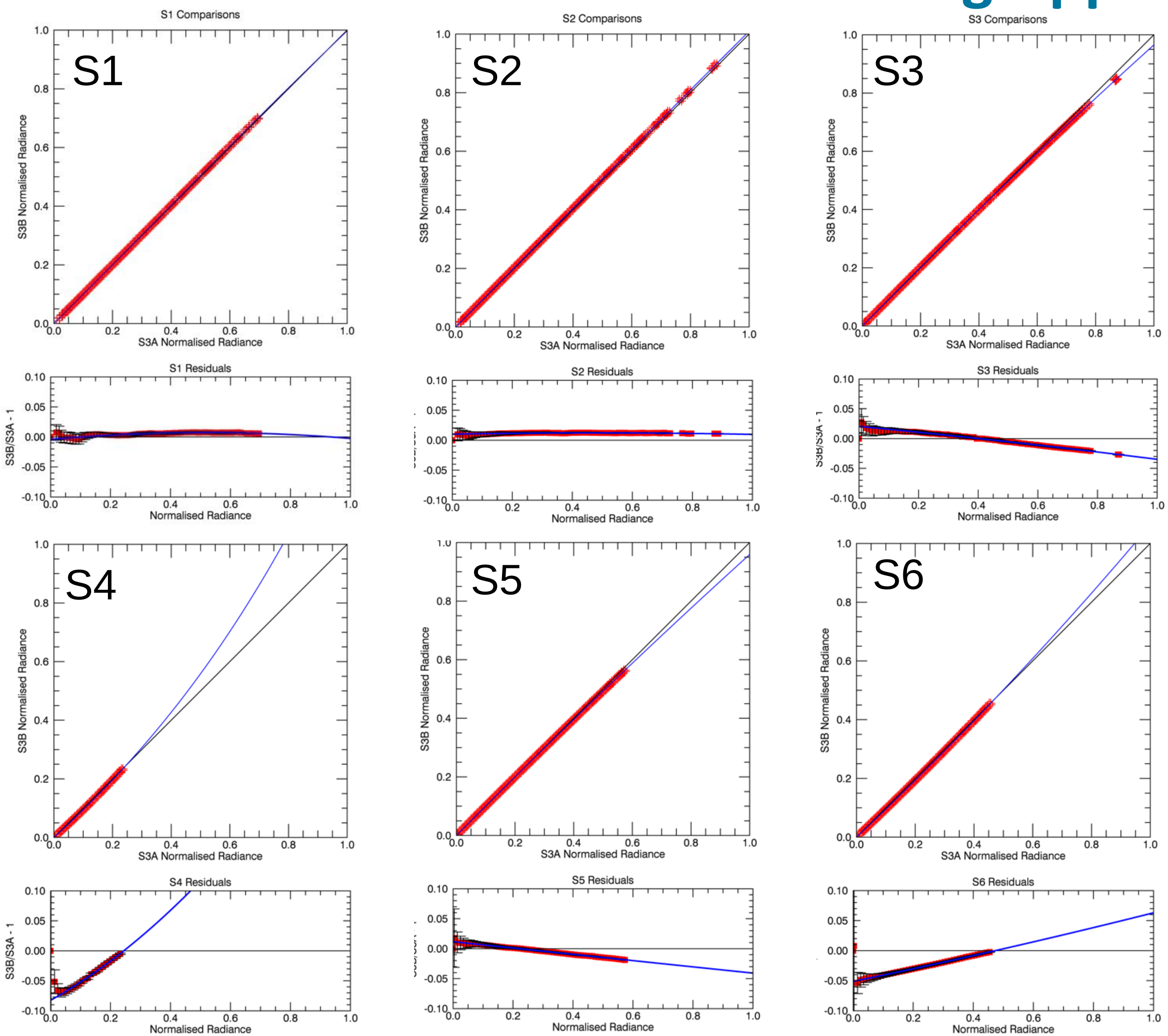
S3B-S3A Comparisons ±10% Trimming Applied

Match ups are for 0.05degree cells filtered radiances in valid range

Comparisons are binned in 1% intervals

Error bars show standard deviation of comparisons



Conclusions

- **VNIR channels show good agreement with OLCI, AATSR (within 3%) ☺**
- **SWIR channels show significant difference compared with reference (12-15%)! ☹**
  - CH_4 seems to account for discrepancy between different methods in 2.25um channel (Desert, Sunglint etc..)
  - Root cause is under investigation – issues with reference spectrometers, instrument geometric effects
- **More effort needed on uncertainty estimates on Desert site analysis**
  - I.e. geometric, spectral differences of the surface reflectance – any corrections are derived from indirect observations. Differences between methodologies…
- **Sun-glint Analysis**
  - Useful for SWIR channels
  - Uncertainty is dominated by knowledge of Aerosols and wind speed which is tied to calibration of VIS channels
- **Tandem Phase gives near perfect conditions for cross-calibration**
  - Is being considered for Sentinel-3C
  - On-going analysis to harmonize SLSTR-B with SLSTR-A