S3 SLSTR Calibration and Traceability

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Sentinel 3 Mission Performance Centre

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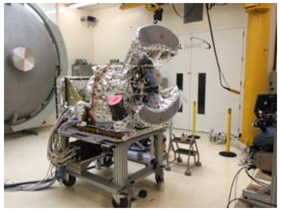
Sea and Land Surface Temperature Radiometer (SLSTR)

2016 – Sentinel 3A

Launched 16-Feb-2016 ☺

2018 – Sentinel 3B



Launched 25-Apr-2018 ☺

2021 – Sentinel 3C

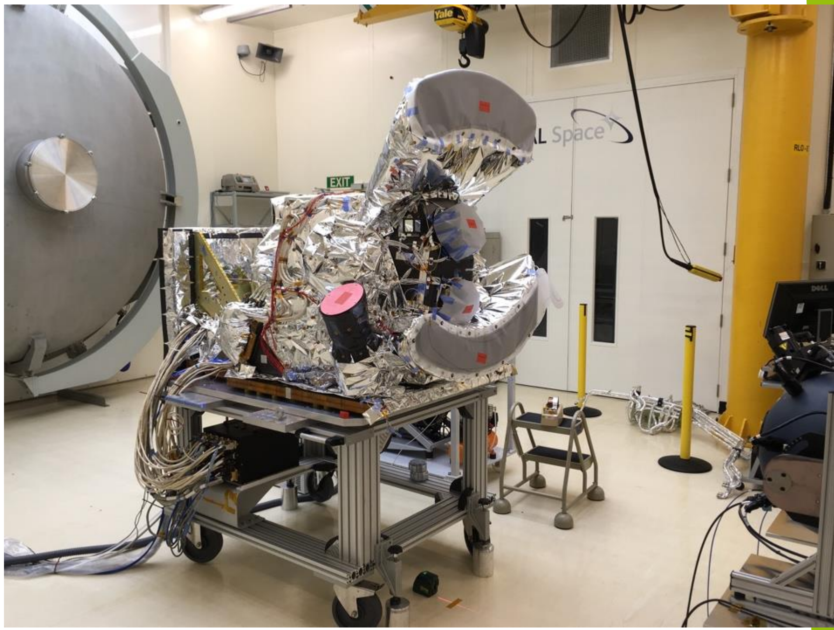
- Spectral Calibration in progress
- Instrument Calibration Spring 2019

2023 – Sentinel-3D

...

SLSTR instrument

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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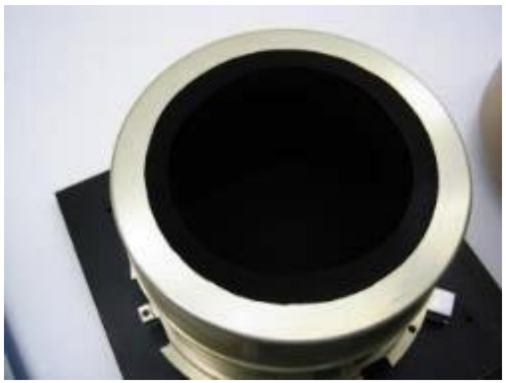
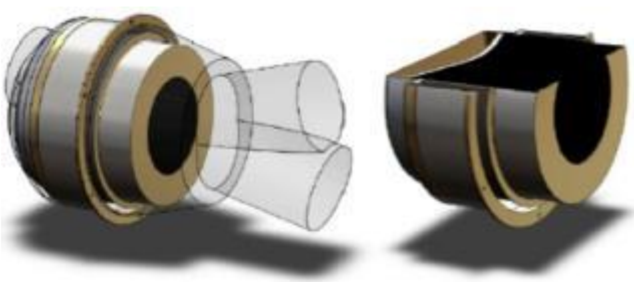
On-Board Calibration systems

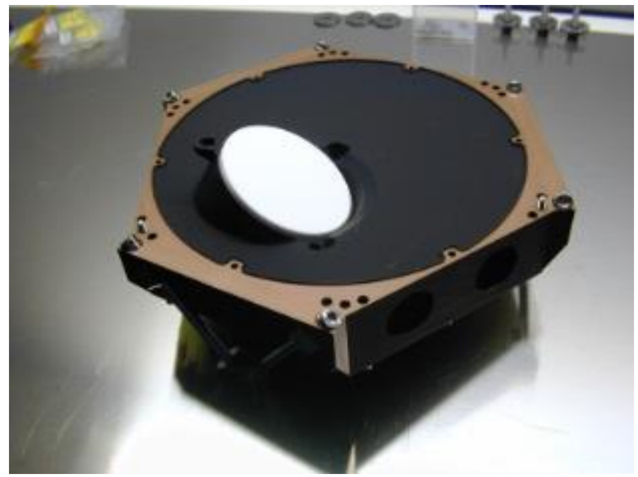
Thermal InfraRed Blackbodies





Effective e >0.998
T non-uniformity < 0.02 K
T Abs. Accuracy 0.07 K
T stability < 0.3 mK/s
8 PRT sensors + 32 Thermistors

VIS-SWIR Channels VISCAL



Zenith diffuser +
relay mirrors
Uncertainty <2%

The Goal

To ensure the interoperability of satellite datasets it is a requirement for their measurements to be calibrated against standards that are traceable to SI units

For temperature this is the International Temperature Scale of 1990

For IR instruments such as SLSTR the traceability is achieved via internal BB sources

Instrument

←

Blackbody Source

←

S-PRT

←

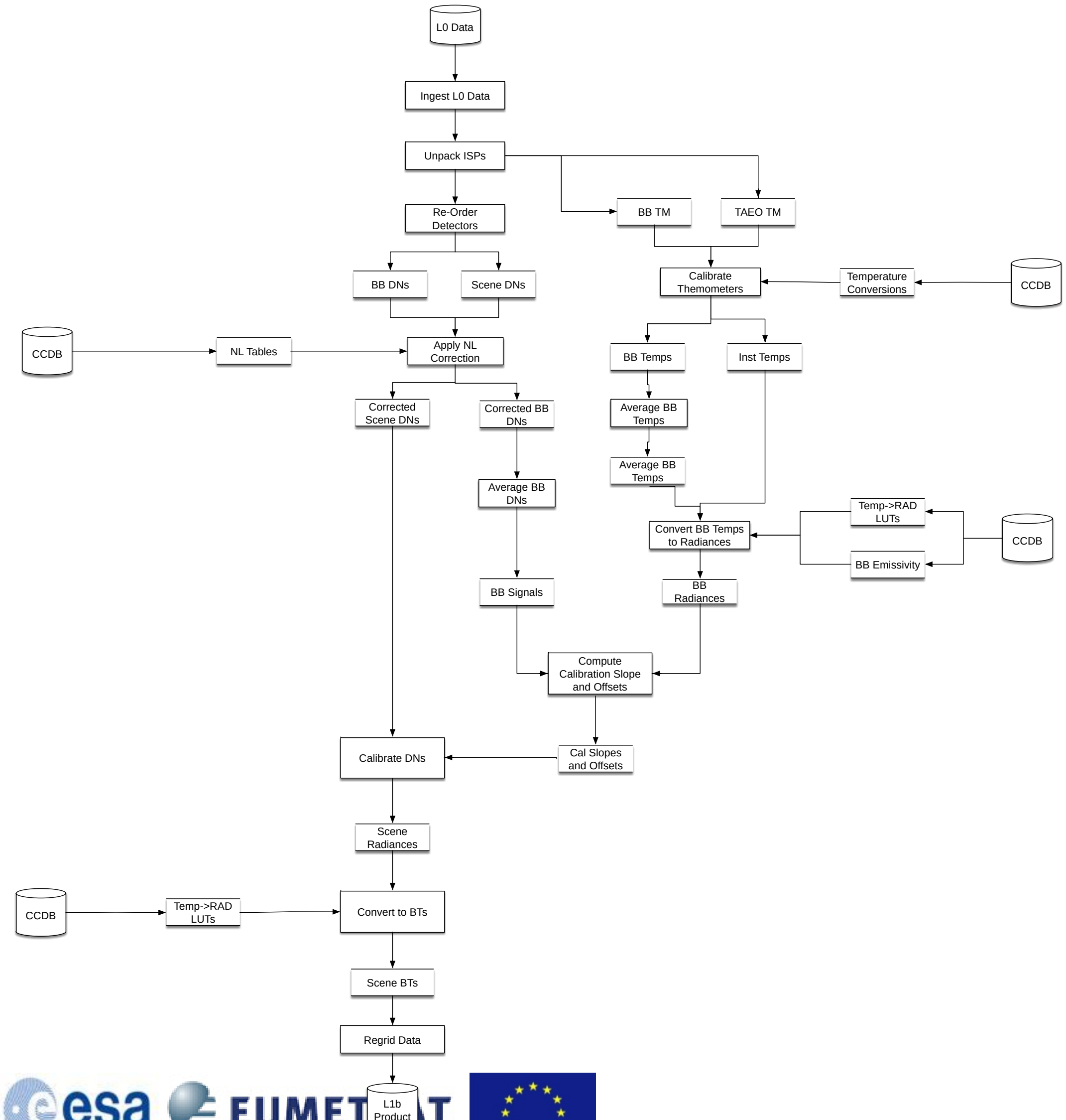
Fixed Point Cells

SLSTR L1 Processing

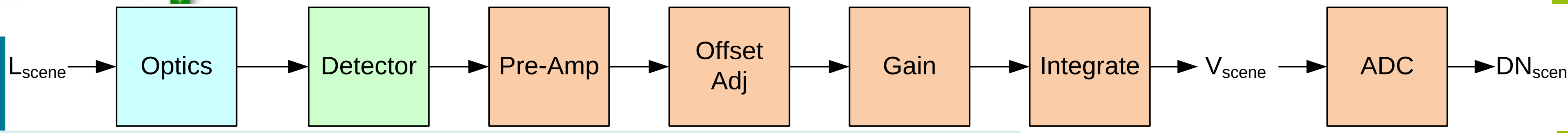
Processing specification defined by
- ATBD -> DPM
- L0 and L1 Product Specifications

Each spectral band (5 thermal bands) and detector element (2x2) for each for each earth view (separate for nadir and oblique) has unique set of calibration calibration coefficients
- = 40 for IR channels alone

Contained in Satellite Characterisation and Calibration Database Document (S-CCDB)
- Configuration controlled by MPC



Calibration Model



Typically detector counts will be some function of the earth scene radiance

$$C_E = F_{ADC}\left(V\left\{A\Omega\left(\left(\tau_{opt}L_E + (1-\tau_{opt})L_{inst}\right)\right\} + V_{off}\right)\right.$$

which reduces to

$$C_E = gain(L_E) + offset$$

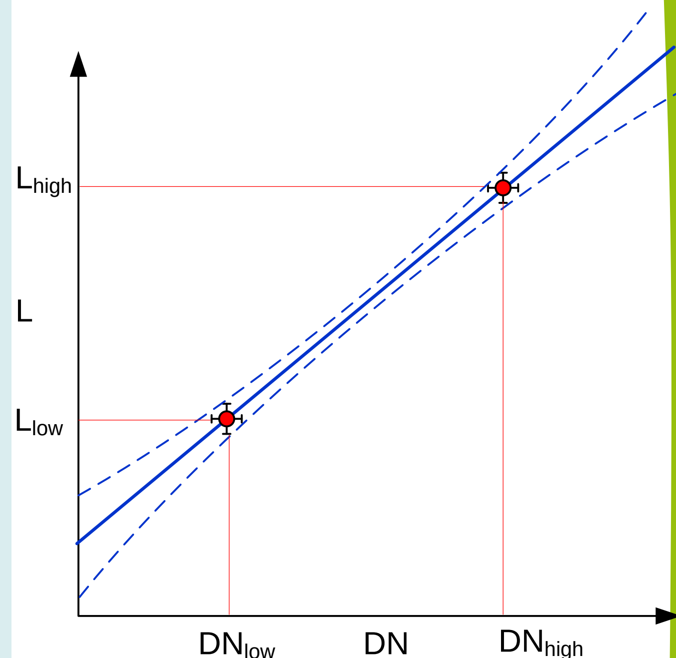
Both gain and offset must be stable during calibration interval

We invert this to get scene radiance as a function of detector counts

$$L_E = gain^{-1}(C_E - C_{offset})$$
$$\approx a_0 + a_1 C_E \text{ (assuming linear function)}$$

Uncertainty in scene radiance

$$(uL_E)^2 = \sum_{i=1}^{N}\left(\frac{\partial L_E}{\partial x_i}ux_i\right)^2 + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\frac{\partial L_E}{\partial x_i}\frac{\partial L_E}{\partial x_j}ux_i\,ux_j v(x_i, x_j)$$



We obtain calibration coefficients via reference to known calibration sources

SLSTR TIR Calibration Effects Tree

Starting point is the measurement equation

We include +0 term to account for additional effects

$$! _{"} = \$!_{\%/\%\&} + (1 - \$) !_{\%/\%} + 0$$

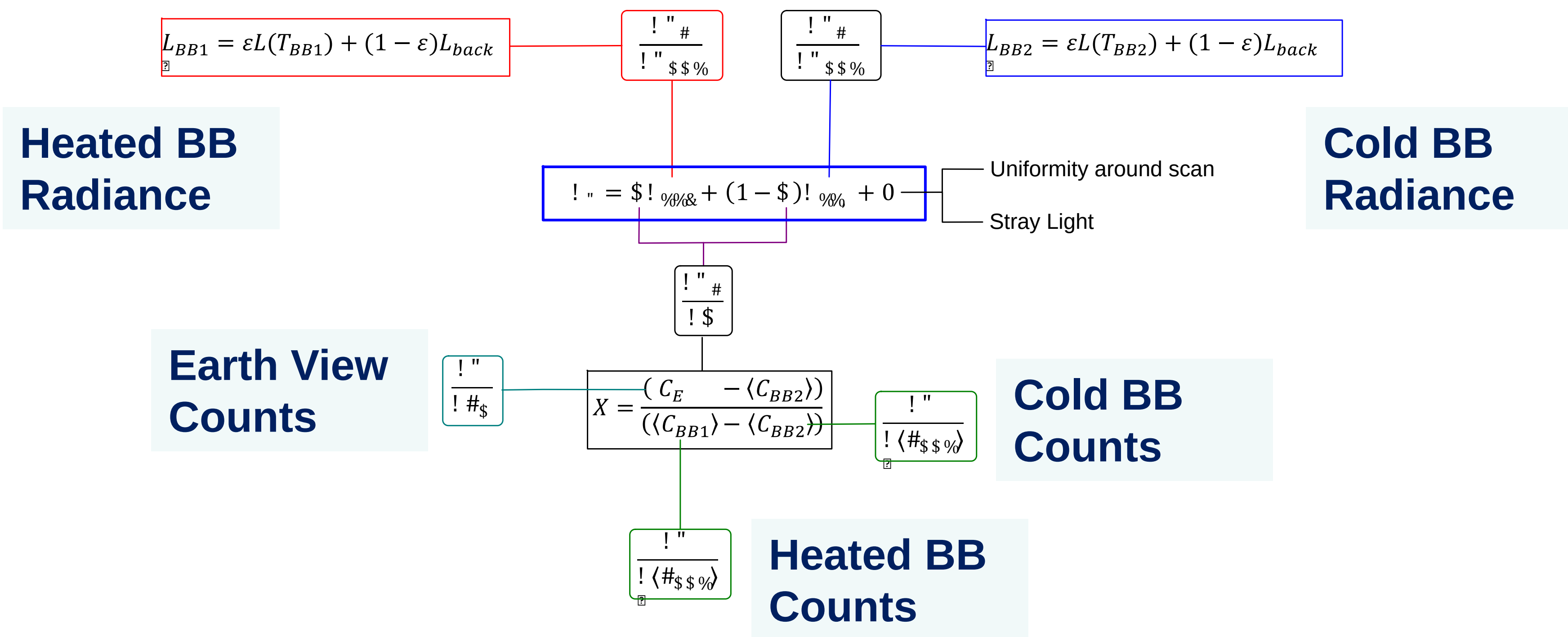
- Uniformity around scan
- Stray Light

$$\frac{!\ "_{\#}}{!\ \$}$$

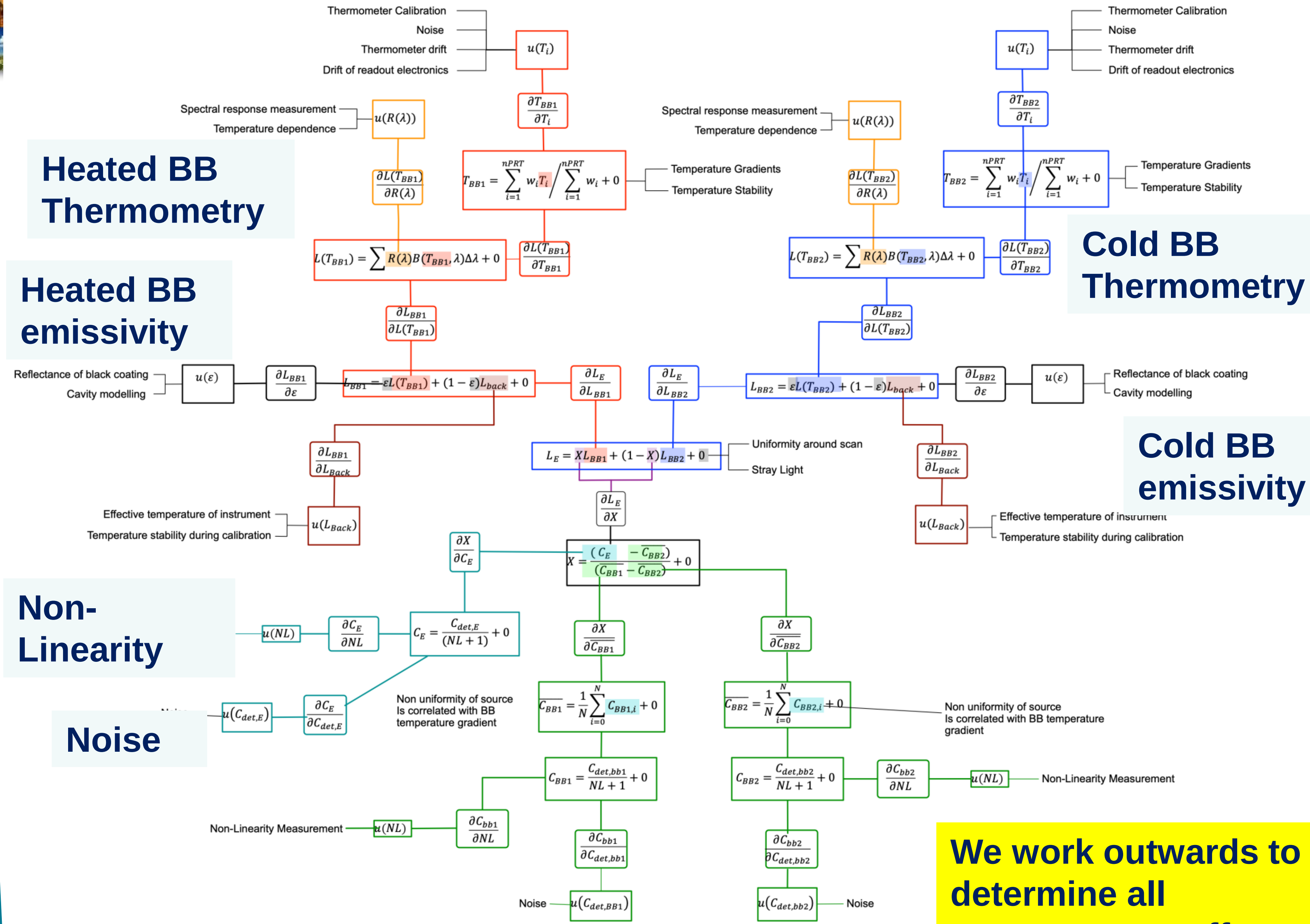
$$X = \frac{(C_E - \langle C_{BB2} \rangle)}{(\langle C_{BB1} \rangle - \langle C_{BB2} \rangle)}$$

SLSTR TIR Calibration Effects Tree

We work outwards to determine all measurement effects



SLSTR TIR Calibration Effects Tree



We work outwards to determine all measurement effects

Primary Sources of Uncertainty in TIR calibration

- **Black-Body Temperatures**
  - PRT calibration at subsystem level – traced to SPRT (ITS-90) – NPL/NIST
  - Blackbody gradients, thermal analysis - RAL

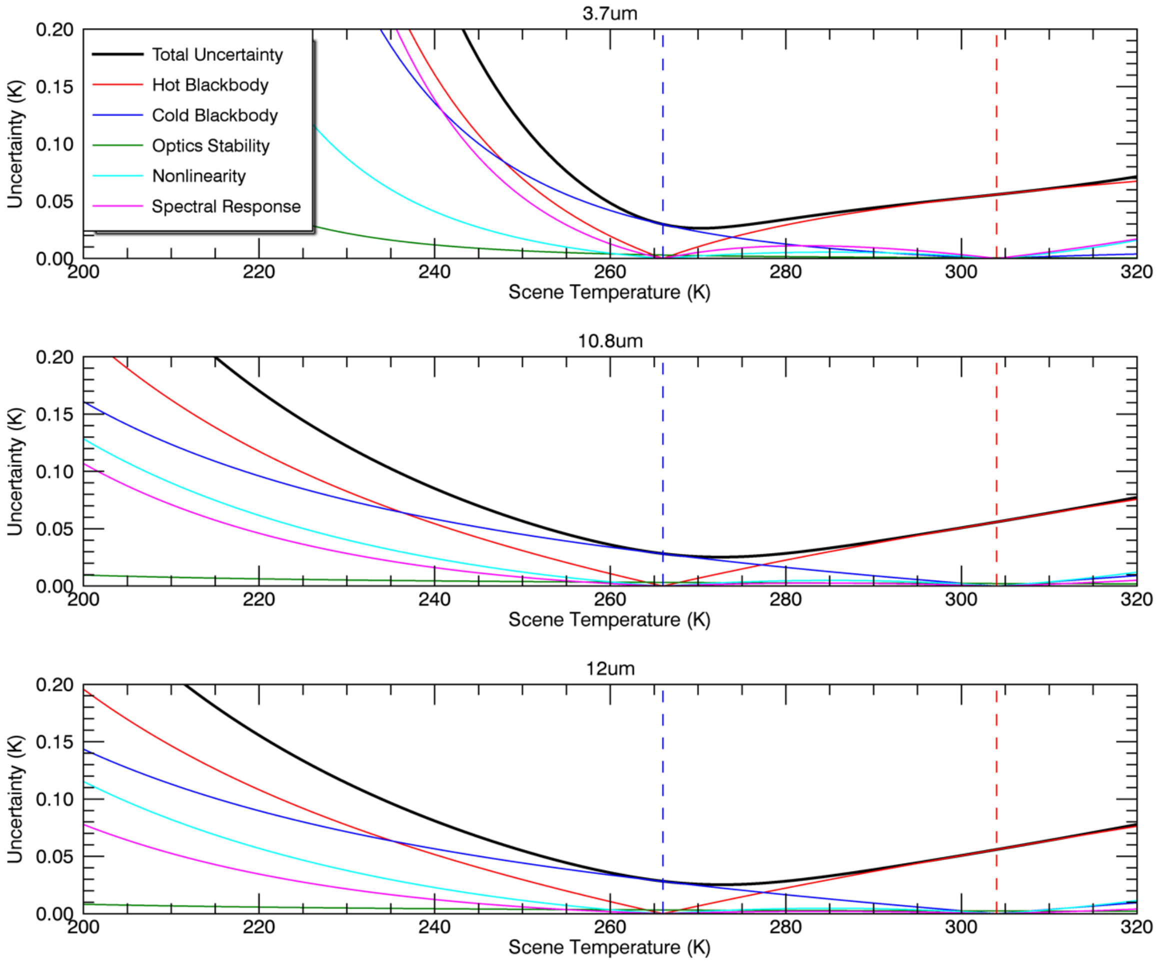
- **Black-Body Cavity Emissivity**
  - Spectral Reflectance of Black Coating – NIST/NPL
  - Cavity Model – STEEP323 or SMART3D (ABSL model)

- **Spectral Response**
  - FPA measurements – RAL reports [S3-RP-RAL-SL-102 (S3A), S3-RP-RAL-SL-114 (S3B)]

- **Non-Linearity**
  - Instrument level calibration tests – RAL reports

- **Detector Noise**
  - Instrument level calibration tests, on-board BB sources

S3B TIR Uncertainty Budget – Jun-2018



Uncertainties vs. Temperature from pre-launch are included in L1 products

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Uncertainties in L1 products

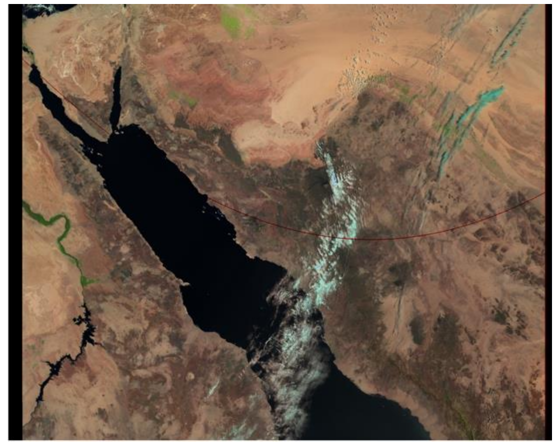
L1 Products contain information to generate per pixel uncertainty estimates

Noise estimates (random) from on-board sources

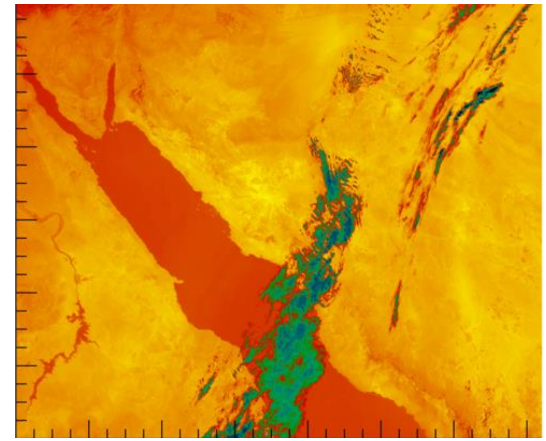
Uncertainty in calibrated (correlated) is derived from pre-launch calibration

User tool under development by RAL to generate uncertainty 'images'

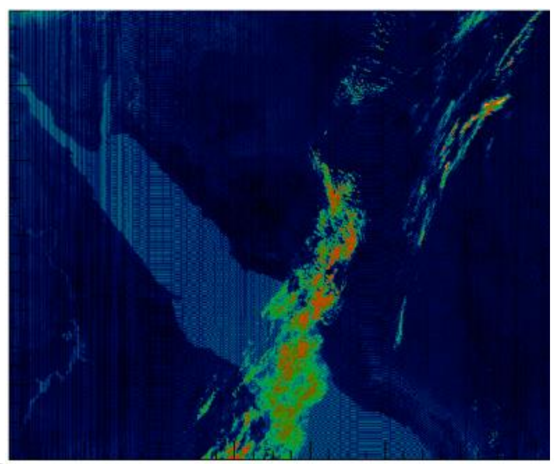
RGB False Colour



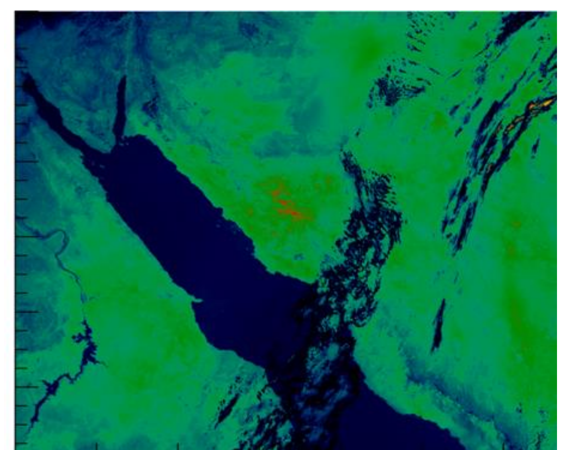
S8 BT



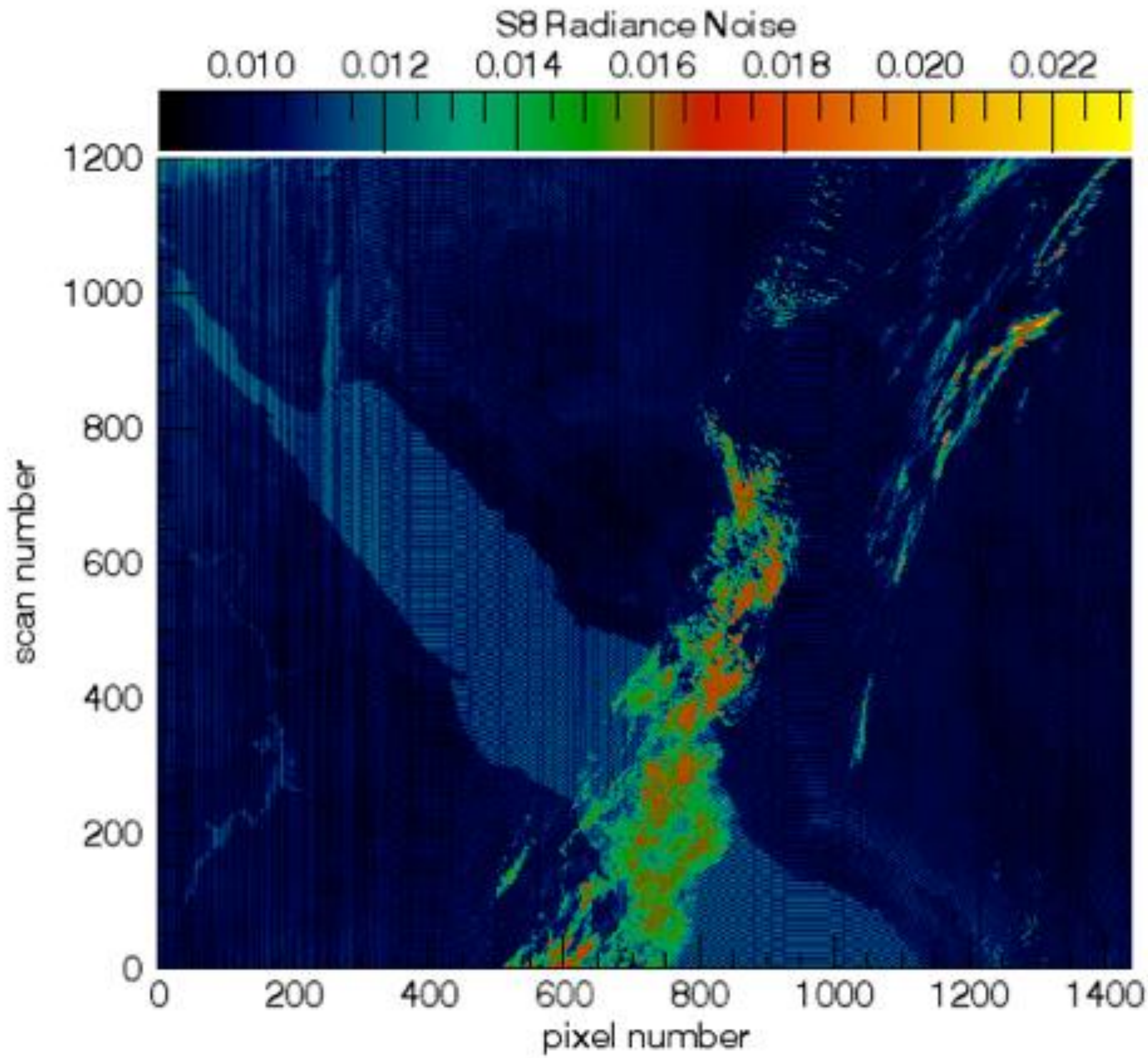
S8 NEDT
(Random Effects)



S8 Calibration Uncertainty
(Correlated Effects)



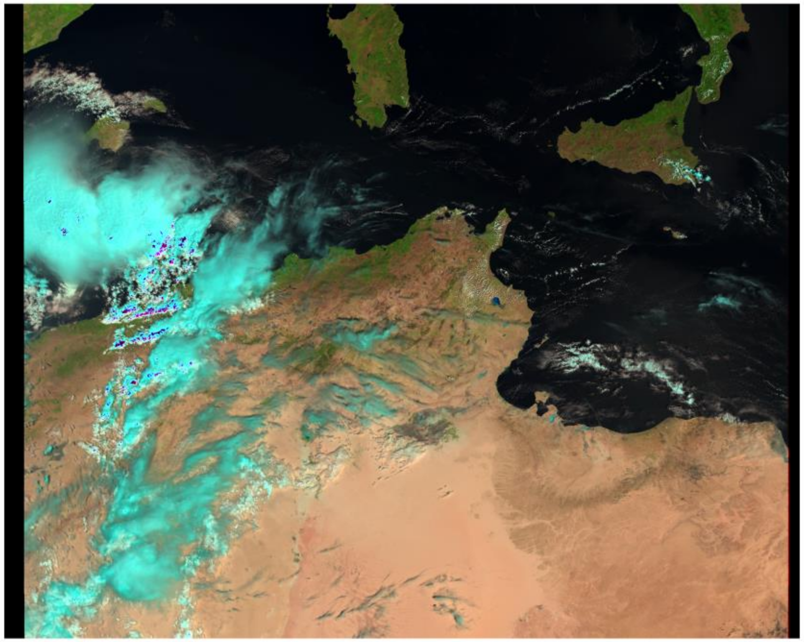
S3A_SL_1_RBT____20180531T073043_20180531T073343_20180601T145917_0179_031_377_2520_MAR_O_NT_003


S8 Radiance Noise
0.010 0.012 0.014 0.016 0.018 0.020 0.022
scan number
0 200 400 600 800 1000 1200
pixel number
0 200 400 600 800 1000 1200 1400

Application for Sentinel-3 Tandem Phase

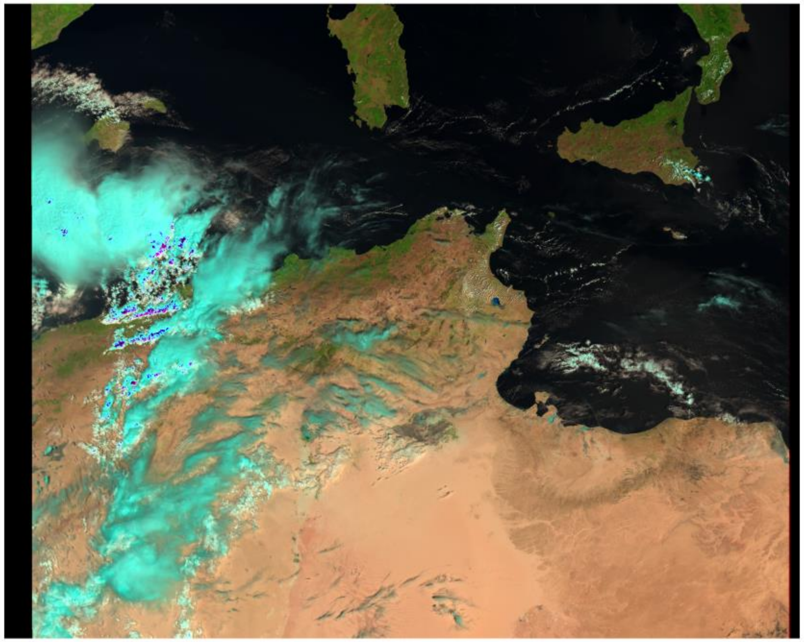
Sentinel-3A

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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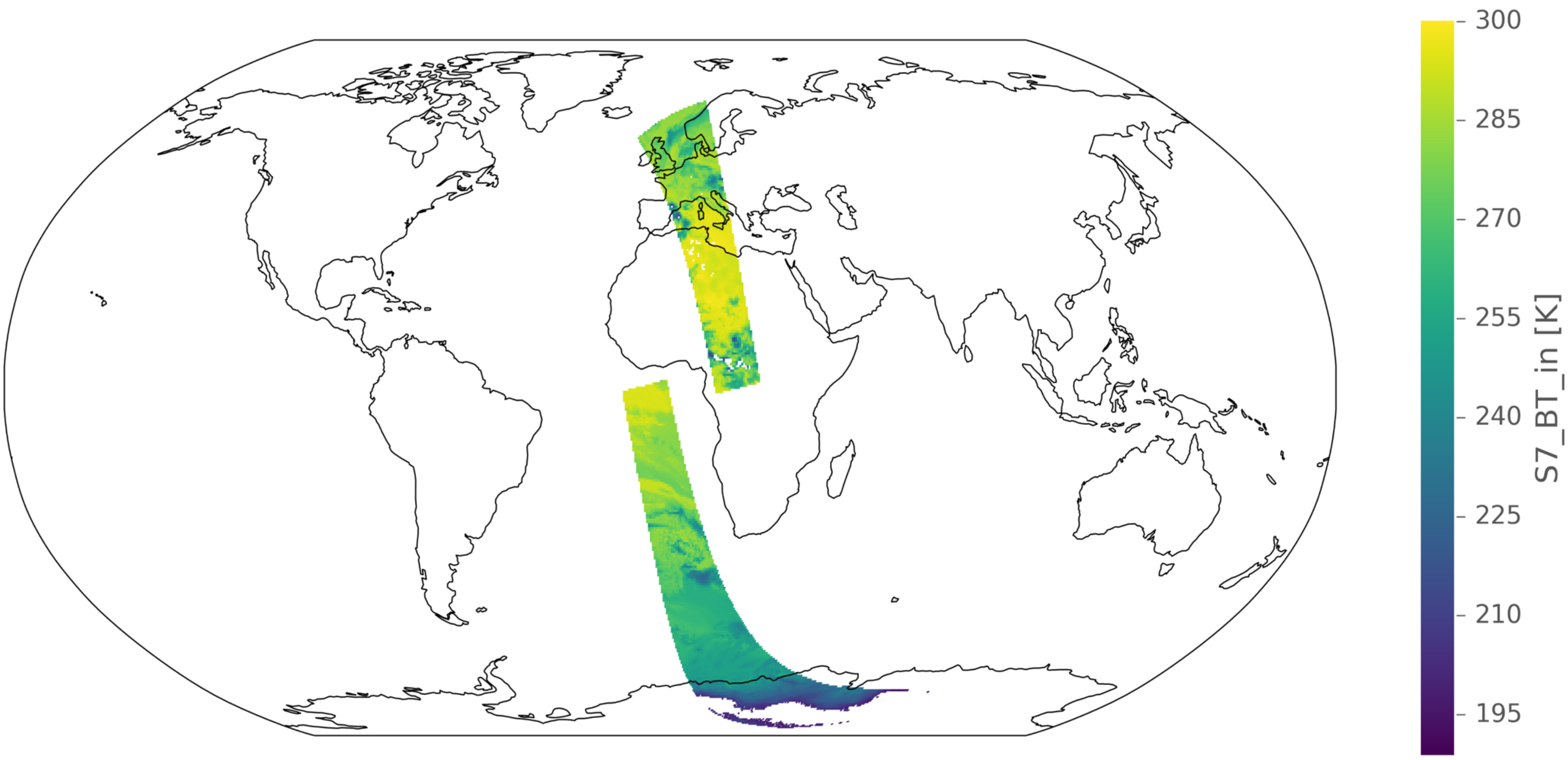
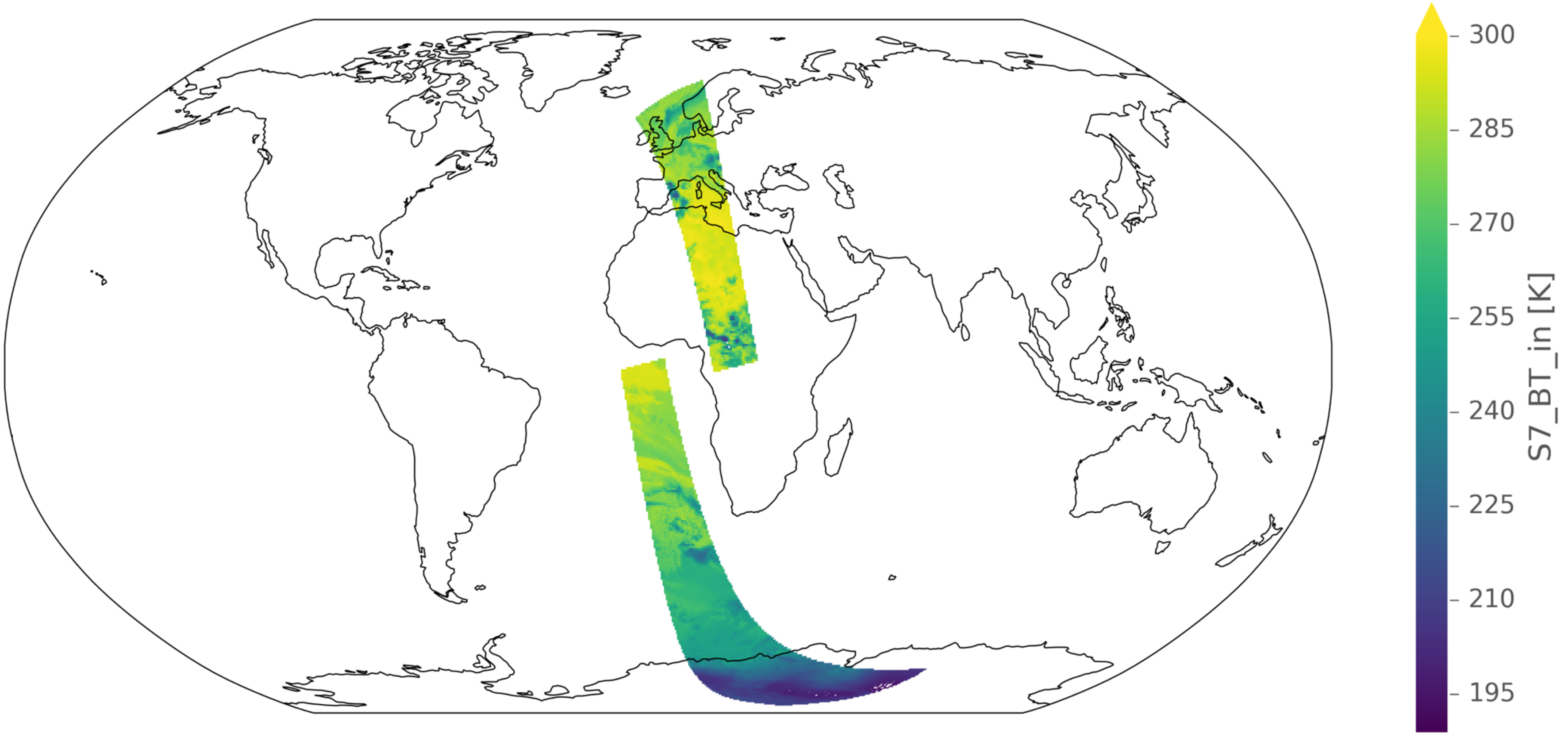
SLSTR-A Brightness Temperature Gridded Data (3.7µm)



SLSTR-B Brightness Temperature Gridded Data (3.7µm)



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Gridding Uncertainty Propagation

Spatial Gridding

$$\langle L \rangle_{\mathrm{G}} = \frac{1}{N_L} \sum_{i=1}^{N_L} L_i$$

With uncertainty,

$$u^2(\langle L \rangle_{\mathrm{G}}) = u^2_{L,\mathrm{ind.}}(\langle L \rangle_{\mathrm{G}}) + u^2_{L,\mathrm{com.}}(\langle L \rangle_{\mathrm{G}})$$

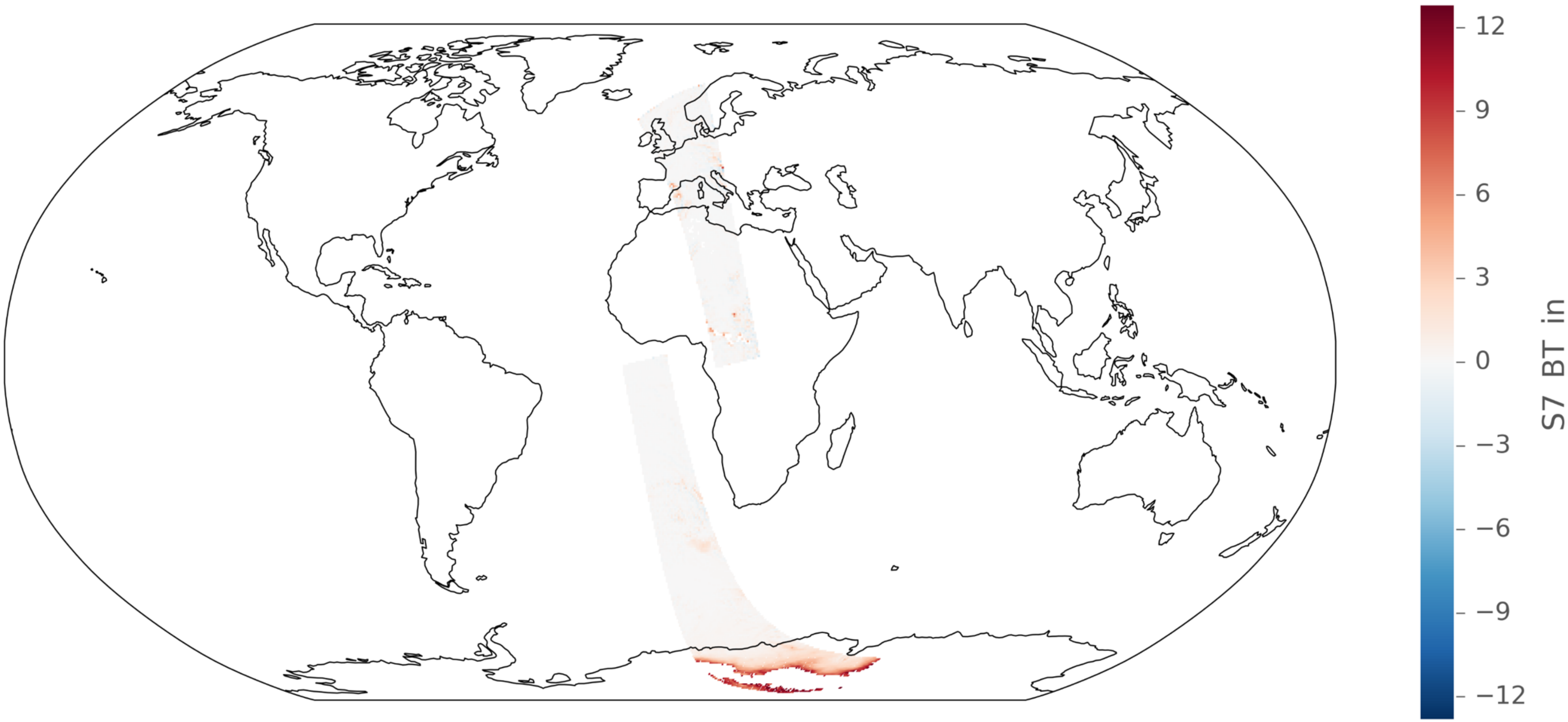
$u^2_{L,\mathrm{ind.}}(\langle L \rangle_{\mathrm{G}})$ - caused by random errors in pixel radiance

$$u^2_{L,\mathrm{ind.}}(\langle L \rangle_{\mathrm{G}}) \rightarrow 0 \quad \text{for large } N_L$$

$u^2_{L,\mathrm{com.}}(\langle L \rangle_{\mathrm{G}})$ - caused by systematic error in instrument calibration

$$u^2_{L,\mathrm{com.}}(\langle L \rangle_{\mathrm{G}}) = \langle u_{\mathrm{com.}}(L_i) \rangle^2_{\mathrm{G}}$$

Brightness Temperature Difference



Gridded Difference Uncertainty Propagation

Difference between S3A and S3B,

$$\Delta\langle L\rangle_{\mathrm{G}} = \langle L_{\mathrm{B}}\rangle_{\mathrm{G}} - \langle L_{\mathrm{A}}\rangle_{\mathrm{G}}$$

With uncertainty,

$$u^2(\Delta\langle L\rangle_{\mathrm{G}}) = u^2_{\langle L_{\mathrm{B}}\rangle_{\mathrm{G}}}(\Delta\langle L\rangle_{\mathrm{G}}) + u^2_{\langle L_{\mathrm{A}}\rangle_{\mathrm{G}}}(\Delta\langle L\rangle_{\mathrm{G}}) + u^2_{\mathrm{matchup}}\,(\Delta\langle L\rangle_{\mathrm{G}})$$

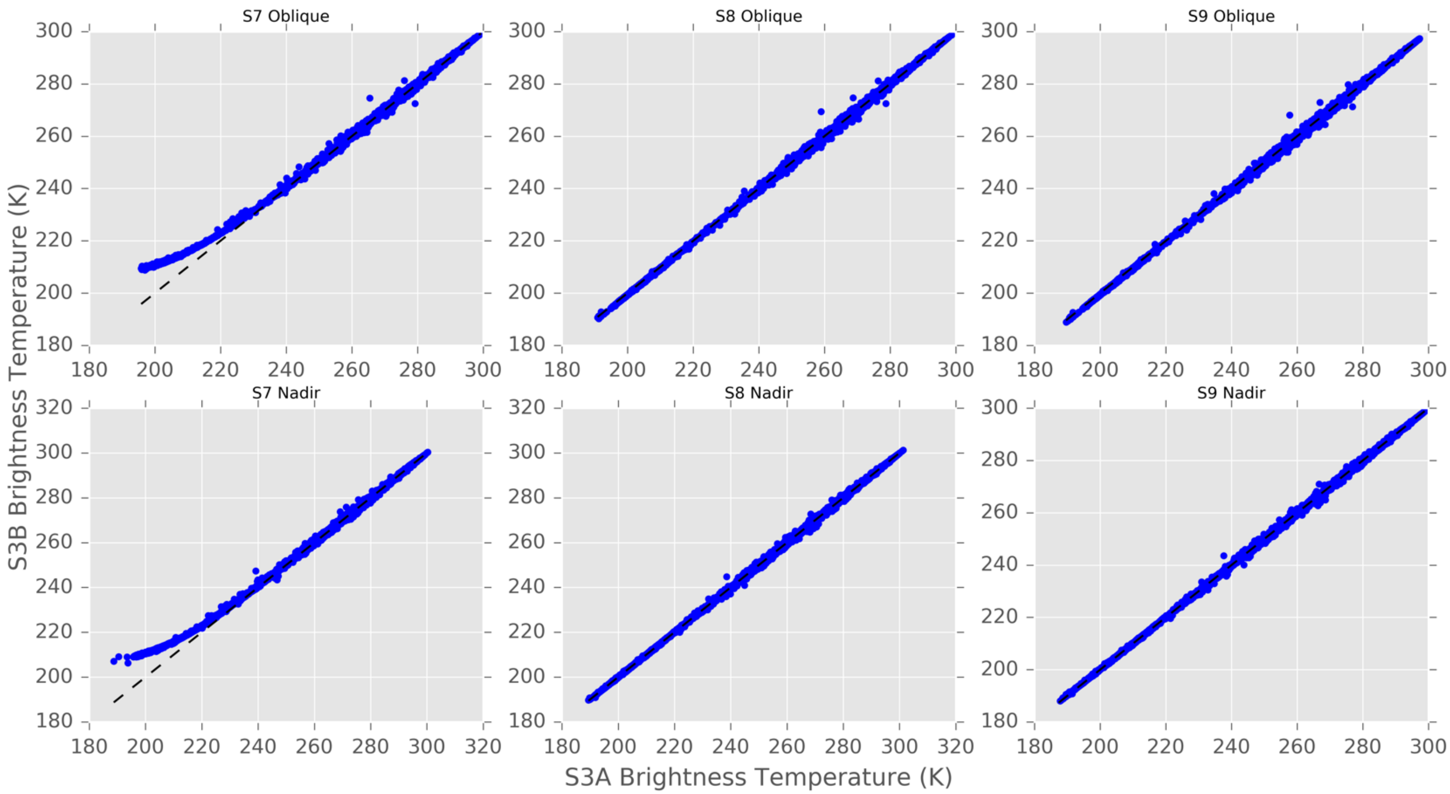
$u^2_{\langle L_{\mathrm{A/B}}\rangle_{\mathrm{G}}}(\Delta\langle L\rangle_{\mathrm{G}})$ – propagated uncertainty of gridded data.

$$u^2_{\langle L_{\mathrm{A/B}}\rangle_{\mathrm{G}}}(\Delta\langle L\rangle_{\mathrm{G}}) = u\left(\langle L_{\mathrm{A/B}}\rangle_{\mathrm{G}}\right)^2$$

← Potential covariance untreated

$u^2_{\mathrm{matchup}}\,(\Delta\langle L\rangle_{\mathrm{G}})$ - match-up error between error S3A and S3B gridded data, from e.g. uniformity. Not yet treated.

S3A BT vs S3B



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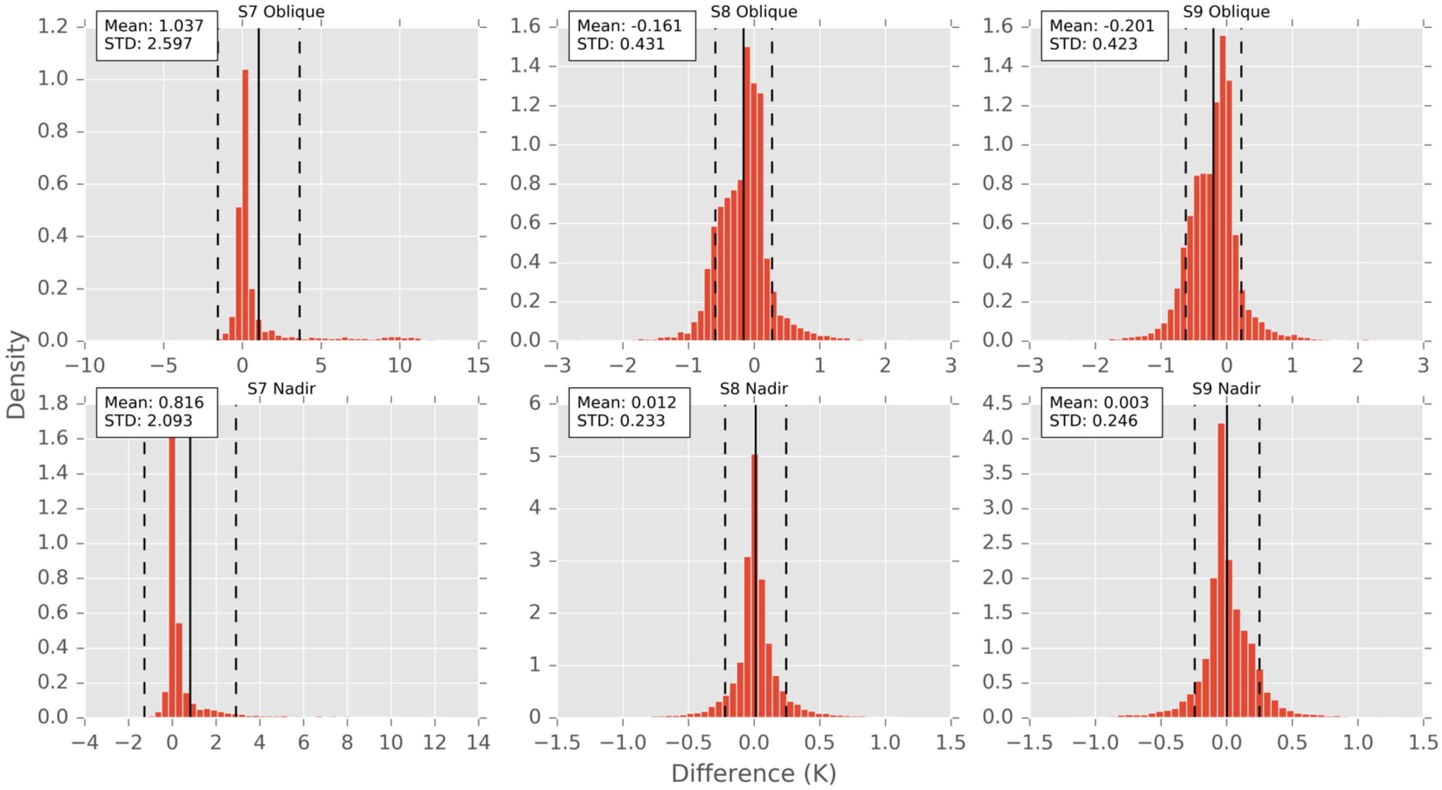
Brightness Temperature Difference



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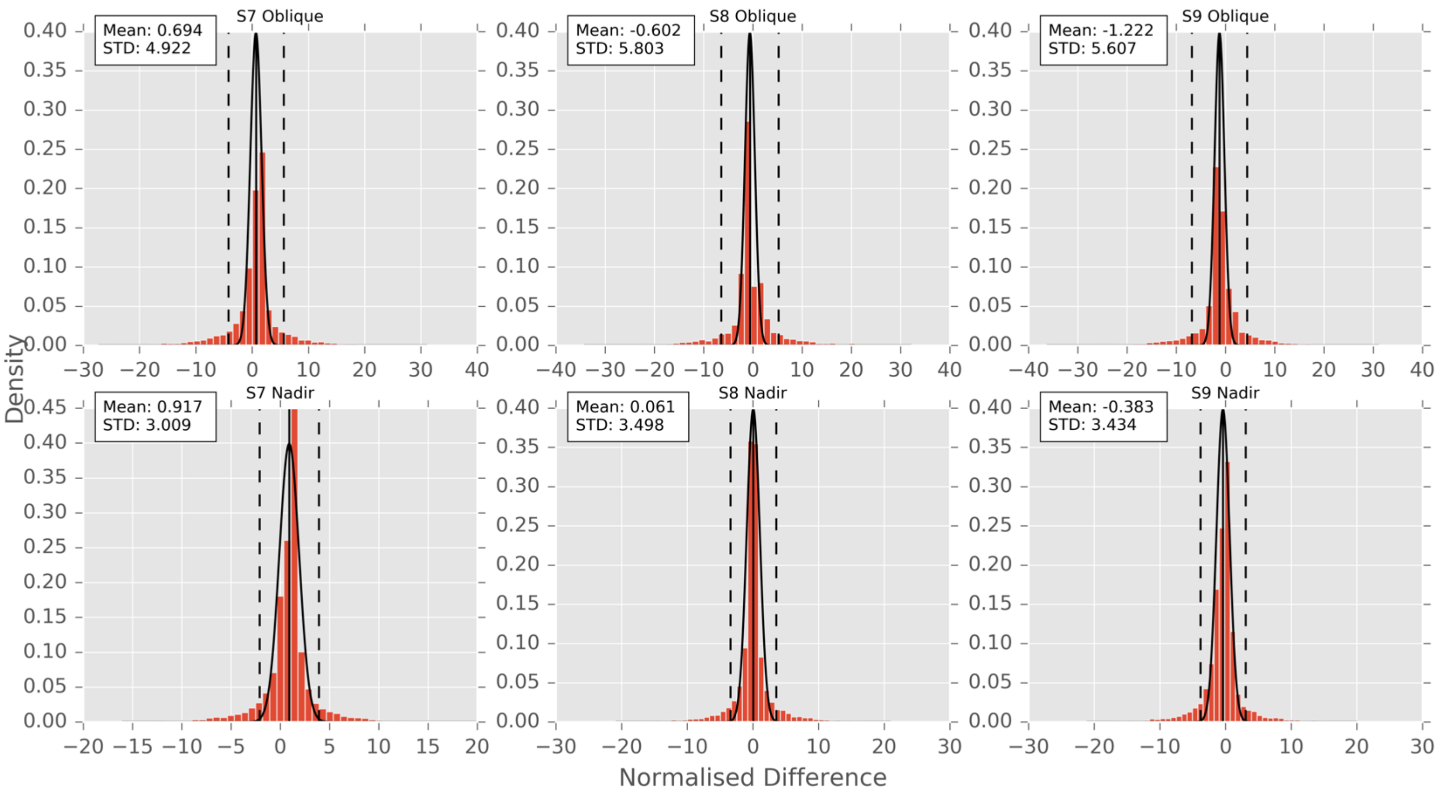
Brightness Temperature Difference Normalised by Uncertainties



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Radiometric Binning Uncertainty Propagation

Bin by radiance

$$\langle \Delta\langle L\rangle_{\mathrm{G}}\rangle_{\mathrm{L}} = \frac{1}{N_L}\sum_{i=1}^{N_{\mathrm{G}}} \Delta\langle L\rangle_{\mathrm{G},i}$$

With uncertainty,

$$u^2(\langle \Delta\langle L\rangle_{\mathrm{G}}\rangle_{\mathrm{L}}) = u^2_{\Delta\langle L\rangle_{\mathrm{G}},\mathrm{ind.}}(\langle \Delta\langle L\rangle_{\mathrm{G}}\rangle_{\mathrm{L}}) + u^2_{\Delta\langle L\rangle_{\mathrm{G}},\mathrm{com.}}(\langle \Delta\langle L\rangle_{\mathrm{G}}\rangle_{\mathrm{L}})$$

$u^2_{\Delta\langle L\rangle_{\mathrm{G}},\mathrm{ind.}}(\langle \Delta\langle L\rangle_{\mathrm{G}}\rangle_{\mathrm{L}})$ - caused by match-up errors in differences.

$u^2_{\Delta\langle L\rangle_{\mathrm{G}},\mathrm{ind.}}(\langle \Delta\langle L\rangle_{\mathrm{G}}\rangle_{\mathrm{L}}) \rightarrow 0$ for large N_G

$u^2_{\Delta\langle L\rangle_{\mathrm{G}},\mathrm{com.}}(\langle \Delta\langle L\rangle_{\mathrm{G}}\rangle_{\mathrm{L}})$ - caused by systematic calibration error.

$$u^2_{L,\mathrm{com.}}(\langle \Delta\langle L\rangle_{\mathrm{G}}\rangle_{\mathrm{L}}) = \langle u_{\mathrm{com.}}(\Delta\langle L\rangle_{\mathrm{G}})\rangle^2_{\mathrm{L}}$$

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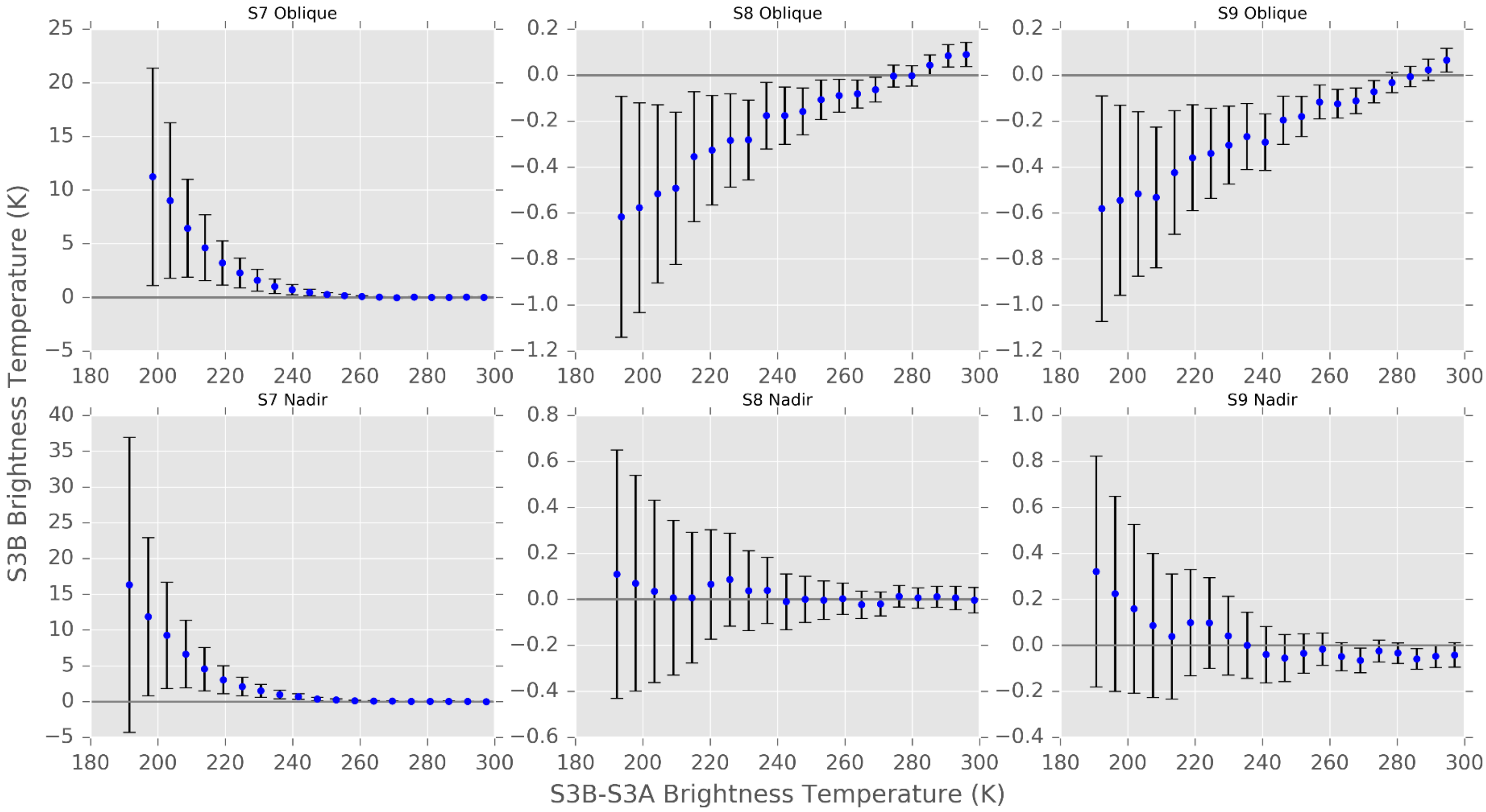
Results – Thermal Infrared



Results (presented as k=1) show agreement for all channels at k=2.

Oblique View Stray Light Correction

- **The radiometric calibration model depends on the thermal background being constant around the scan**

- **What if the thermal background is different between the earth view and the hot and cold blackbody sources?**

- **Recalling the calibration model**

  $L_E = XL_{hbb} + (1 - X)L_{cbb}$

  where

  $X = (C_E - C_{cbb})/(C_{hbb} - C_{cbb})$

- **We make use of the +0 term in the BB radiance model to get**

  $\Delta L_E = X\Delta L_{hbb} + (1 - X)\Delta L_{cbb}$

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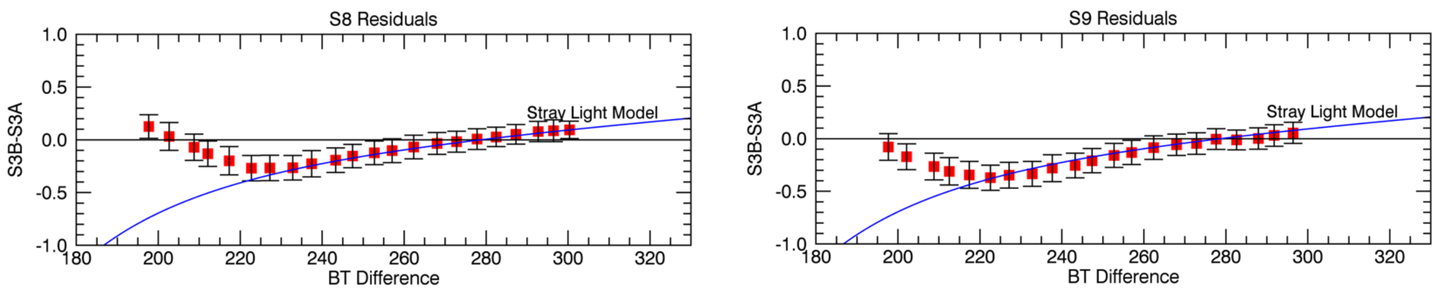
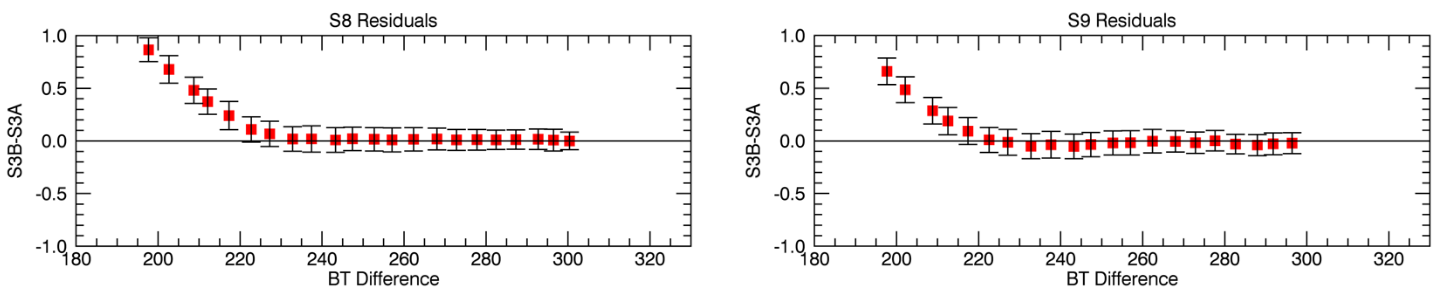
Potential Impact of Correction on S3B-S3A Comparisons

As measured



With Correction



The model shows that the differences between SLSTR-A and B are consistent with the pre-launch calibration errors and can be corrected with a reduced version of the stray-light model developed for the IPF-P.

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Conclusions

- **Documentation of the traceability chain for SLSTR TIR channels is in progress**
  - Effects Tree, Effects Tables, Correlation scales, Sources of Uncertainties
  - Target is to produce paper this year
  - Focus on TIR but to be applied also to VIS-SWIR channels

- **Random and Correlated uncertainties are available in L1 products**
  - User tool is under development to map uncertainty information to provide per pixel uncertainties
  - Work in progress to improve information in L1 products

- **Preliminary metrological analysis of Sentinel-3 tandem phase data show that comparisons of S3a and S3b are within uncertainties**
  - Assumes that SLSTR A and B are uncorrelated!