# Status of the Sentinel-3 SLSTR Performance and Calibration

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# Post Launch Calibration – The Challenge

## Establishing absolute radiometric calibration of TIR sensors using terrestrial sites is restricted by:

- Knowledge of surface emissivity
- Surface non-uniformity
- Temporal variations over short time (effect of surface winds, cloud shadow, solar elevation)
- Contribution of Atmosphere to the measured signal

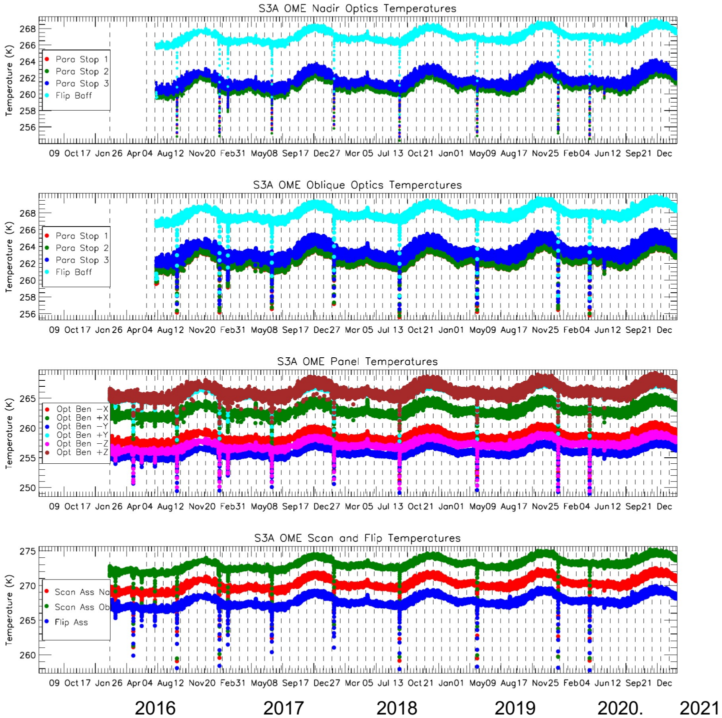
## Hence limited to:

- Monitoring of instrument parameters
- Monitoring of on-board calibration sources
- Satellite inter-comparisons
- Validation of L2 data products

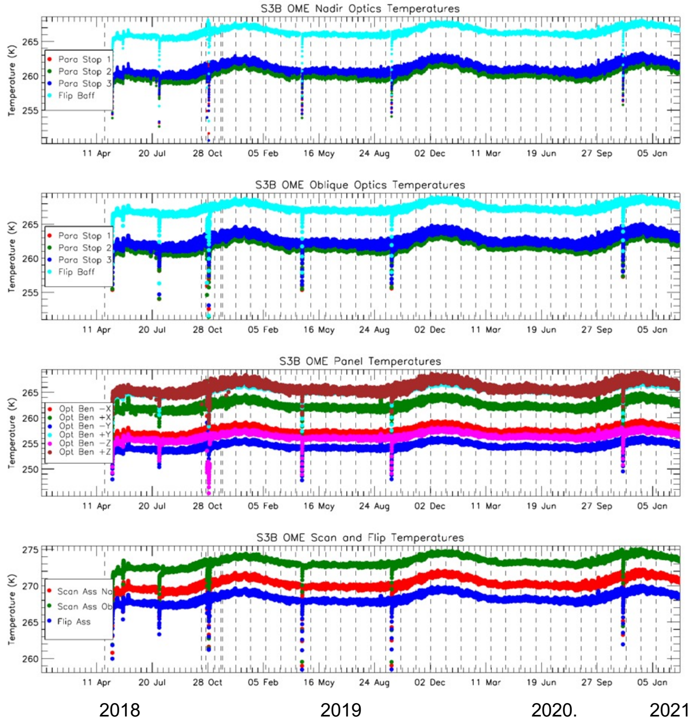
# SLSTR Thermal Performance

As a thermal IR instrument, stability & uniformity of instrument temperatures is critical to radiometric calibration

## SLSTR-A




## SLSTR-B

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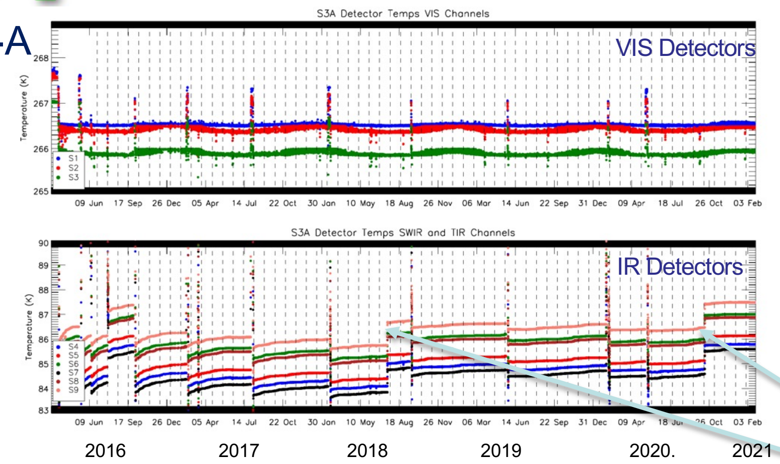
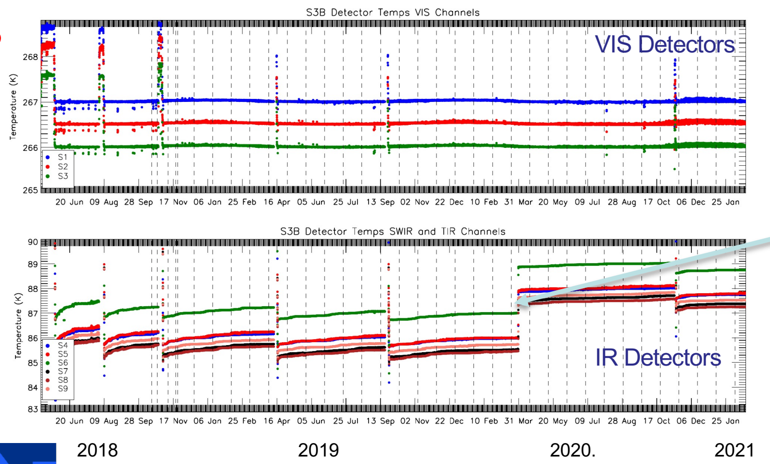
# Detector Temperatures

SLSTR-A




SLSTR-B




IR detector temperatures maintained between 84 K and 89 K

Periodic de-contamination is needed to remove water ice from cold surfaces

SLSTR-A FPA Cooler set-point increased by 1 K in July 2018 and 1 K in Oct 2020 to increase running time between decontaminations

SLSTR-B FPA Cooler set-point increased by 2 K in March 2020

## Cryocooler Performance

Cryocooler control maintains the cold-tip to a constant set point temperature

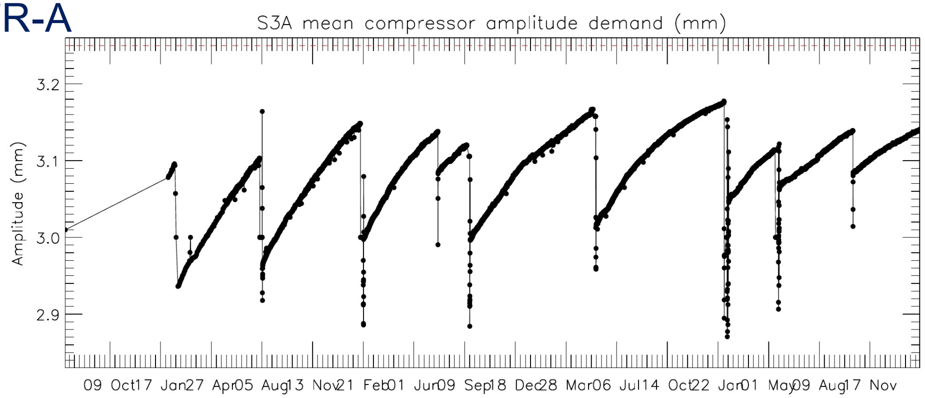
FPA and detector temperatures are not directly controlled and increase during operational cycle due to increase in heat load caused by build up of water ice on heat shield

Periodic decontamination is performed to remove ice and ‘reset’ cooler.

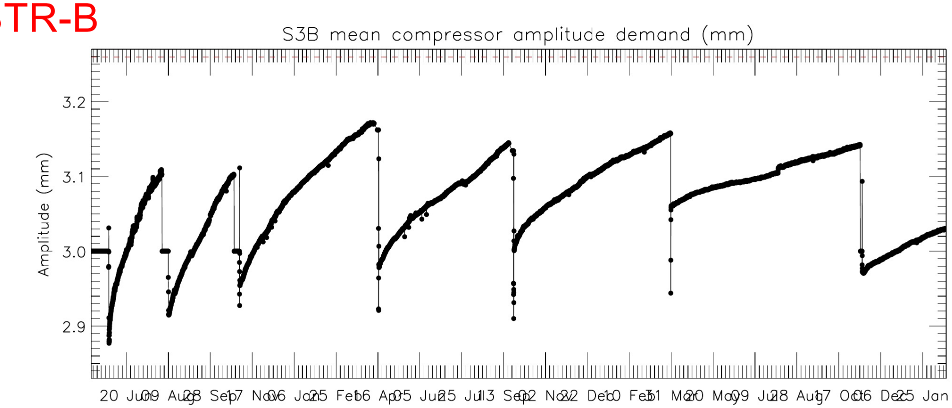
Despite reduction in water ice, successive decontaminations have shown steady increase in compressor amplitude at start of operational cycle.

To reduce frequency of decontaminations and to maintain the cooler lifetime set point temperature has been increased AND compressor amplitude limit has been increased.

SLSTR-A



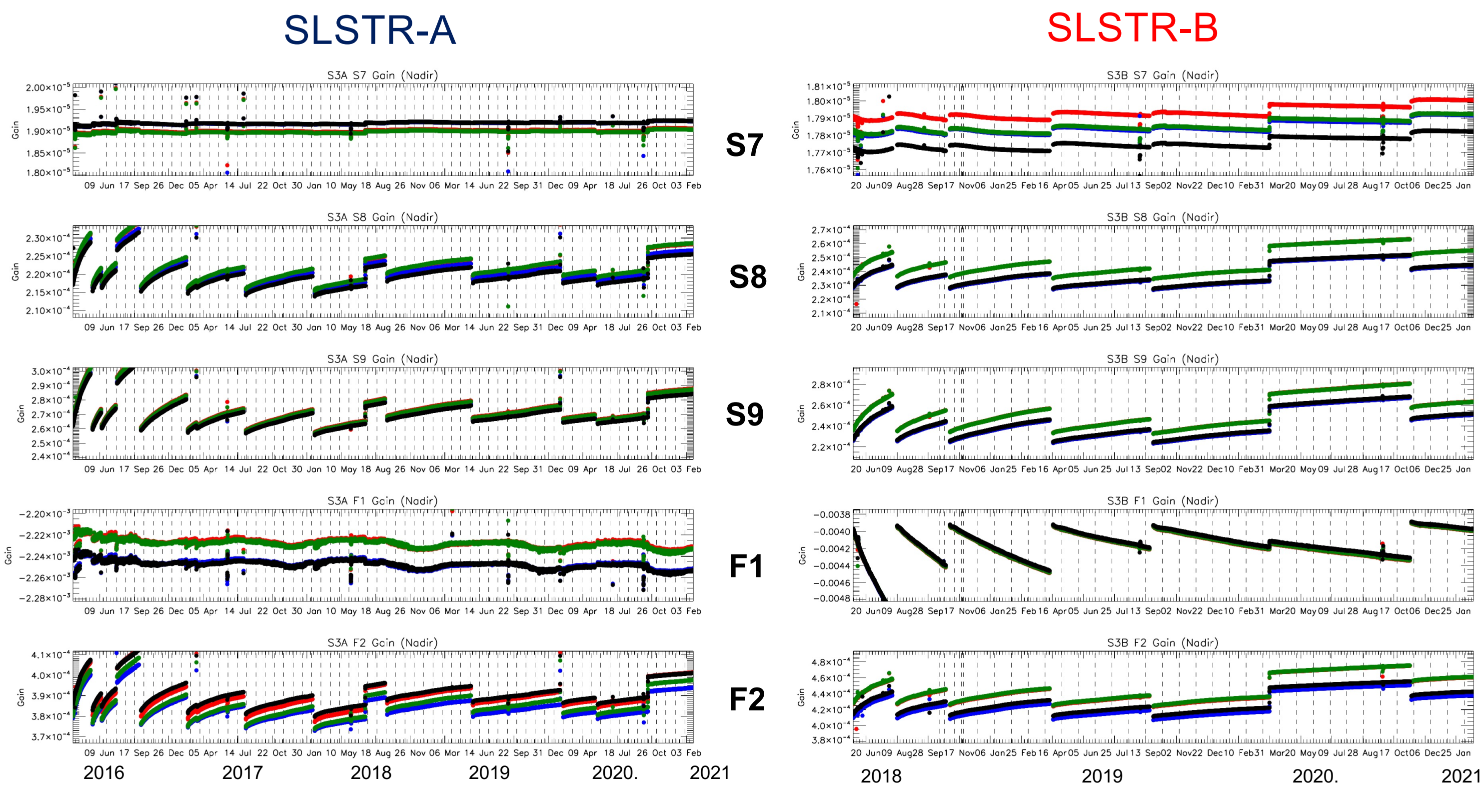

SLSTR-B



# IR Channels Gains

All detectors are performing as at launch within expected ranges

Gains and offsets show slow drift with detector temperature as expected.

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# IR Channels Offsets

Offset variation is dependent on detector temperature and thermal background drift.

S3A:

S8 offsets updated 26th Jan 2021:

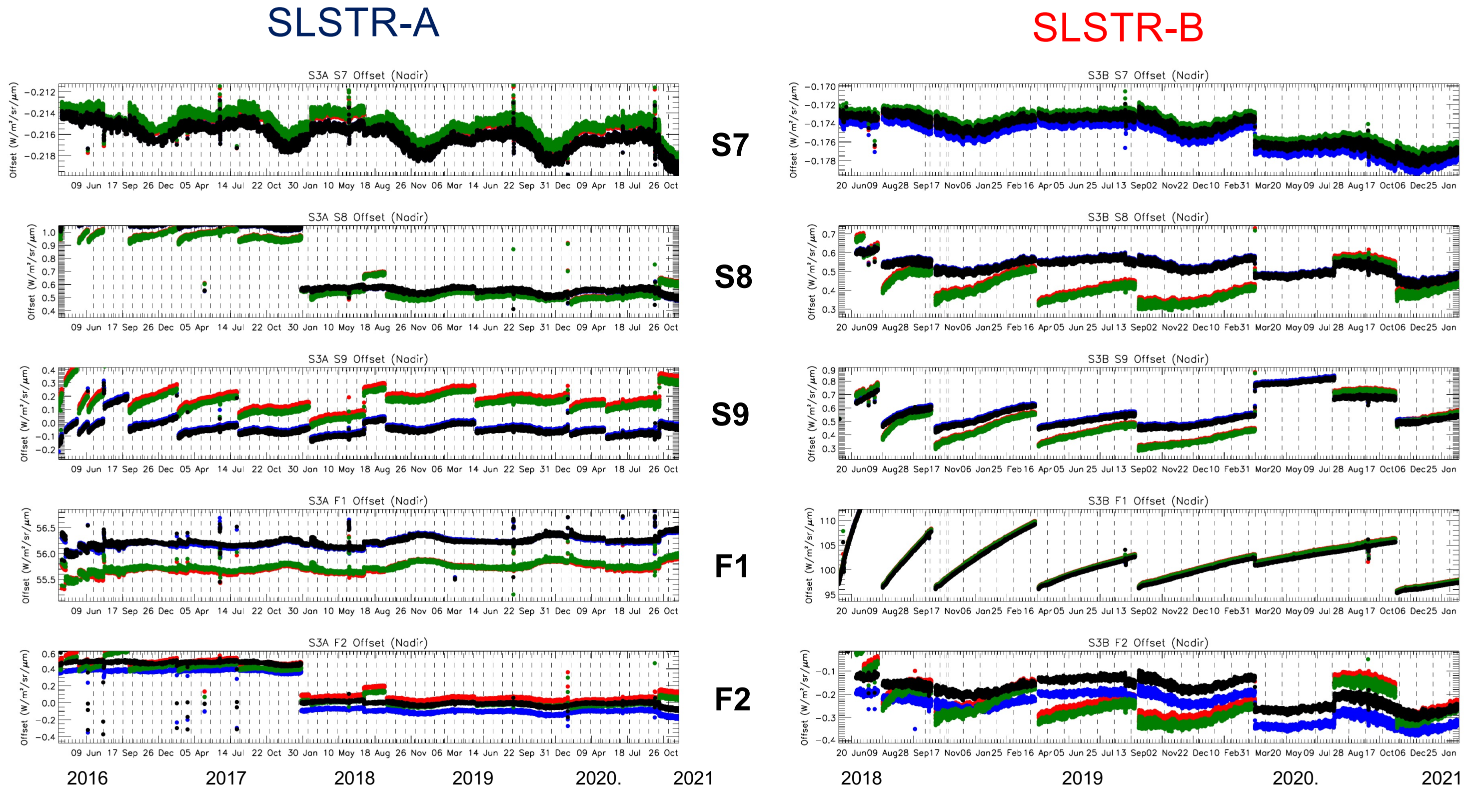
Lower limit of dynamic range following update is ~180 K for S8, and <165K for S9

S3B:

S8 and S9 offsets updated 5th Aug 2020

Lower limit for both S8 and S9 following update was 180-185K until decontamination in November

Following the decontamination lower limit is now 177-179 K for both S8 and S9.



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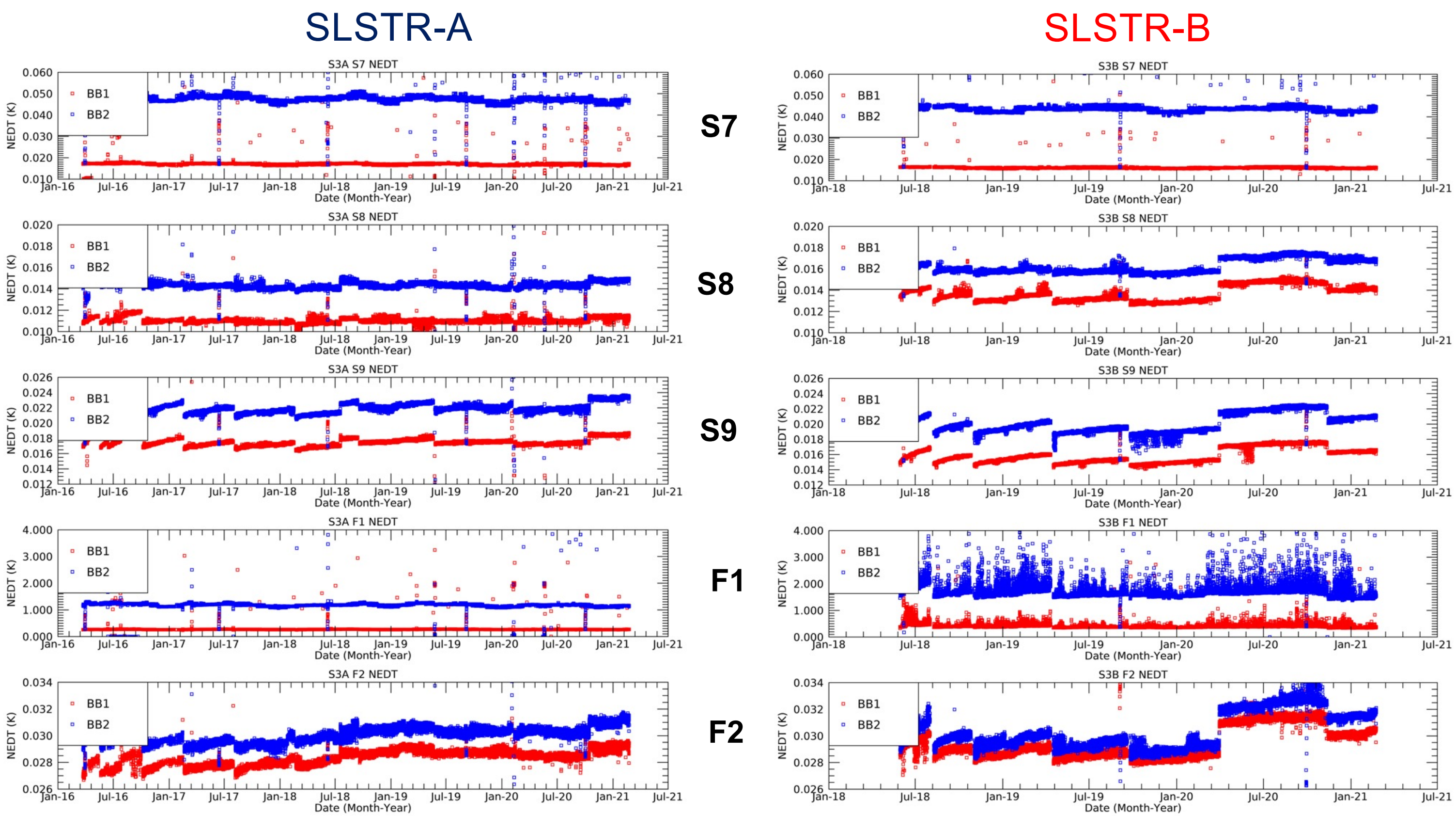
# IR Channels Noise

Radiometric noise levels for the TIR channels have remained stable throughout at pre-launch values.

NEDT for the S8 and S9 channels are below 20mK with no indication of degradation. Small increase in NEDT after change of cooler set-point temperature.

S3B F1 shows periodic increases in noise – possibly due to motional chopping

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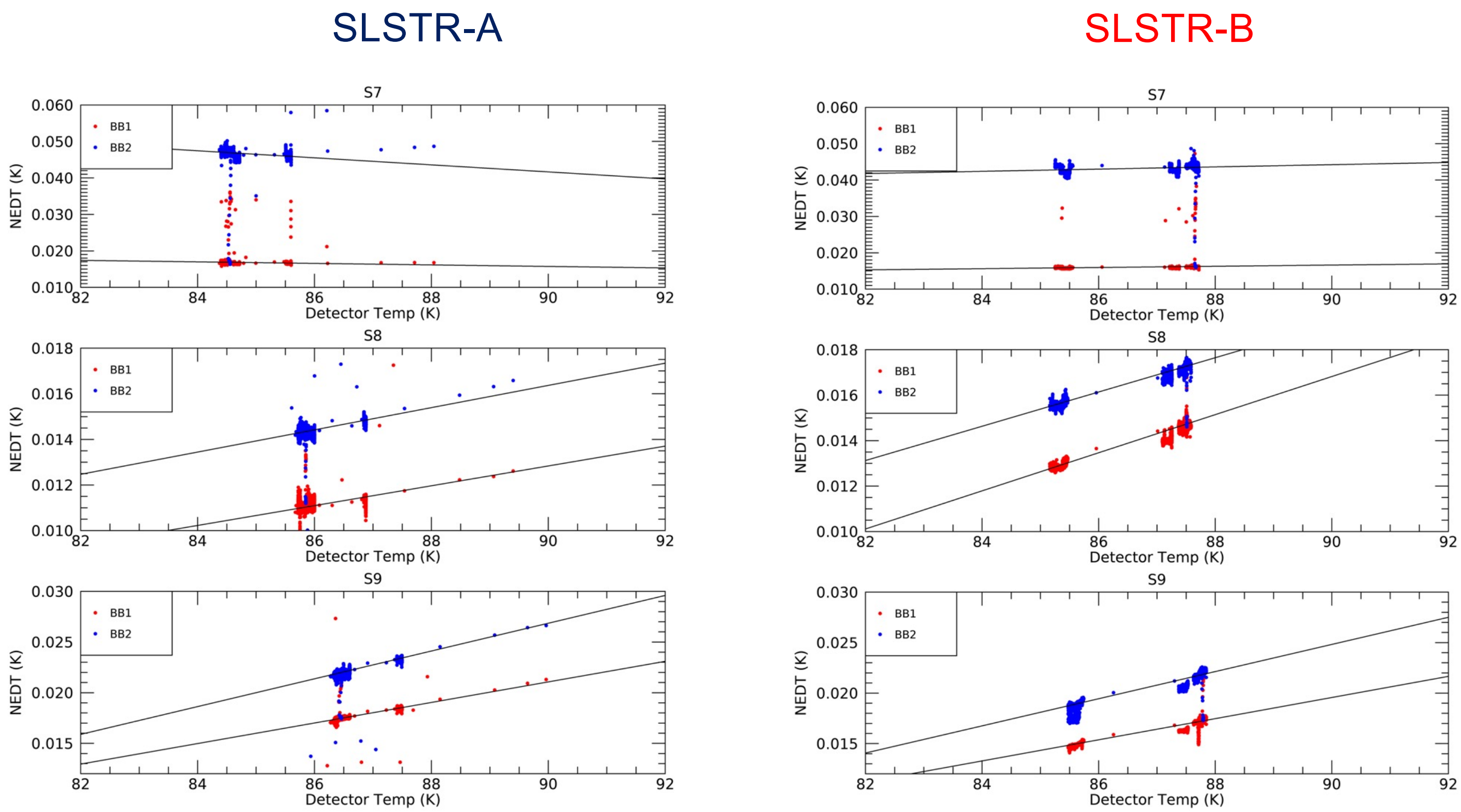
# IR Channels Noise vs Detector Temperature

From mission trends we can assess the sensitivity of the NEDT as a function of detector temperature.

Analysis suggests that NEDT would be within target requirement for temperatures up to 90K – although this has other consequences i.e. Spectral response variaton

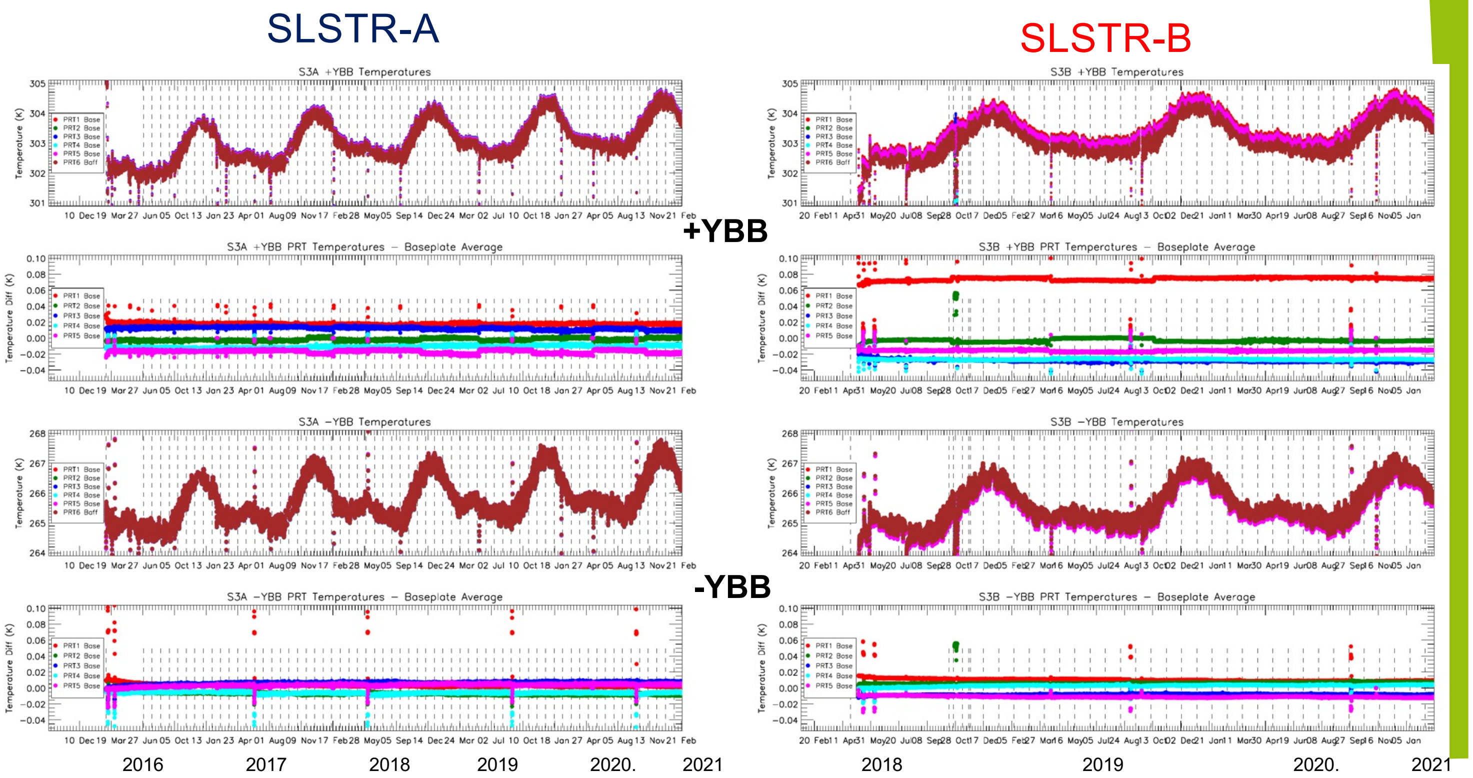


# Black-Body Performance

Blackbody temperatures have a seasonal cycle on top of the daily/orbital temperature cycles. Heated BB remains below 305K limit necessary for S7 calibration.

Temperature gradients consistent with pre-launch values for SLSTR-A and B

Note higher gradient in heated BB for SLSTR-A



# Blackbody Cross-Over Tests

- The basic idea is to compare the radiometric signals in the thermal channels when the two blackbodies are at identical temperatures.
- Any significant difference would imply a drift in the blackbody thermometer calibration or change in target emissivity caused by a deterioration of the black surface finish.
- This follows the approach taken for AATSR and will be performed for SLSTR in-flight during commissioning and at yearly intervals to determine any changes in the blackbody performance.
- The test was performed by switching the heated blackbody from the +YBB to the –YBB (and vice versa) and allowing the temperatures to cross over and stabilise.

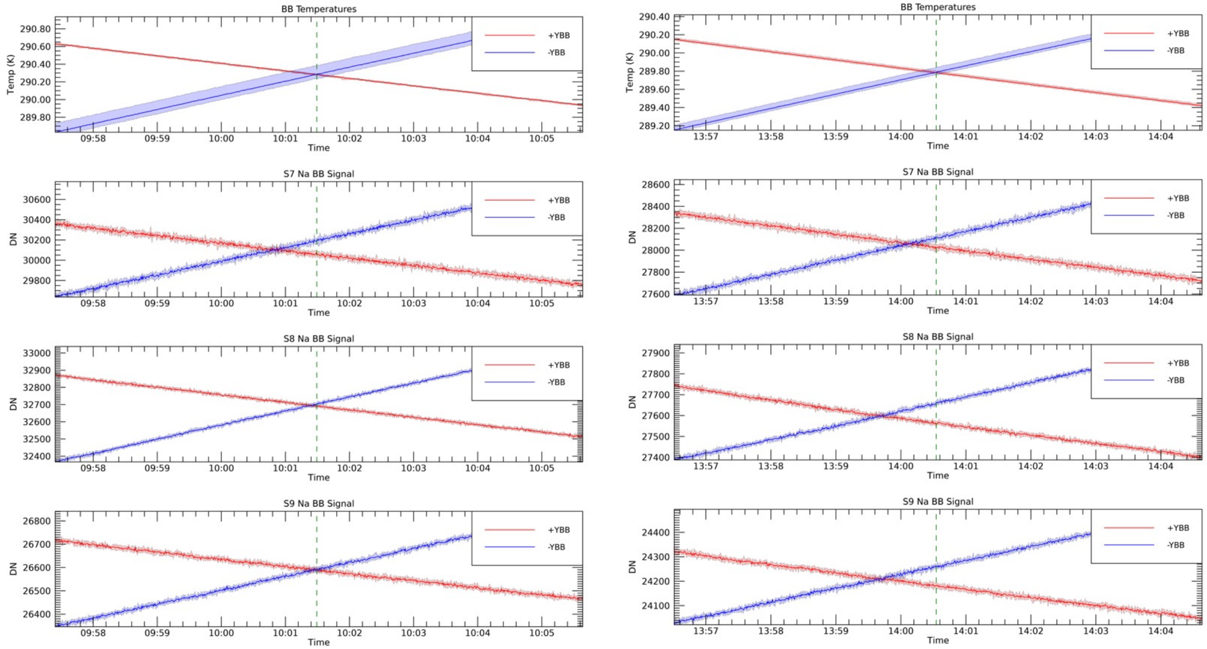
# Blackbody Cross-Over Test Execution

- **Part-1 of the test +YBB off and –YBB heated**
  - **S3A** Crossover occurred at 01-OCT-2020 10:01:29
    - ✓ BB Temperatures were 290.284K
  - **S3B** Crossover occurred at 28-SEP-2020 14:00:32
    - ✓ BB Temperatures were 289.785K

- **Part-2 was performed -YBB off and +YBB heated**
  - **S3A** Crossover occurred at 02-OCT-2020 10:49:52
    - ✓ BB Temperatures were 291.774K
  - **S3B** Crossover occurred at 29-SEP-2020 14:41:11
    - ✓ BB Temperatures were 291.070K

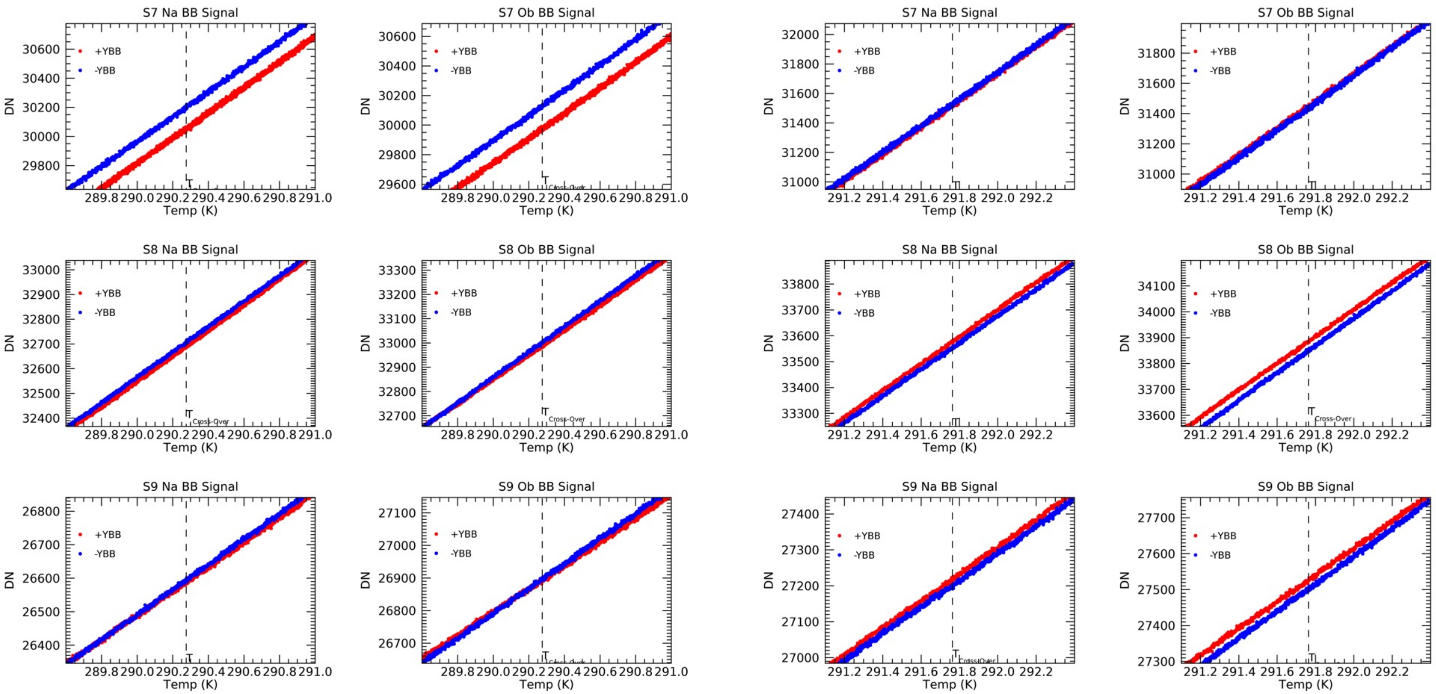
S3A Nadir – Part 1

S3B Nadir – Part 1



# BB Cross-Over Test Analysis – SLSTR-A

Part 1 | Part 2




Difference in counts at cross-over equates to temperature difference where

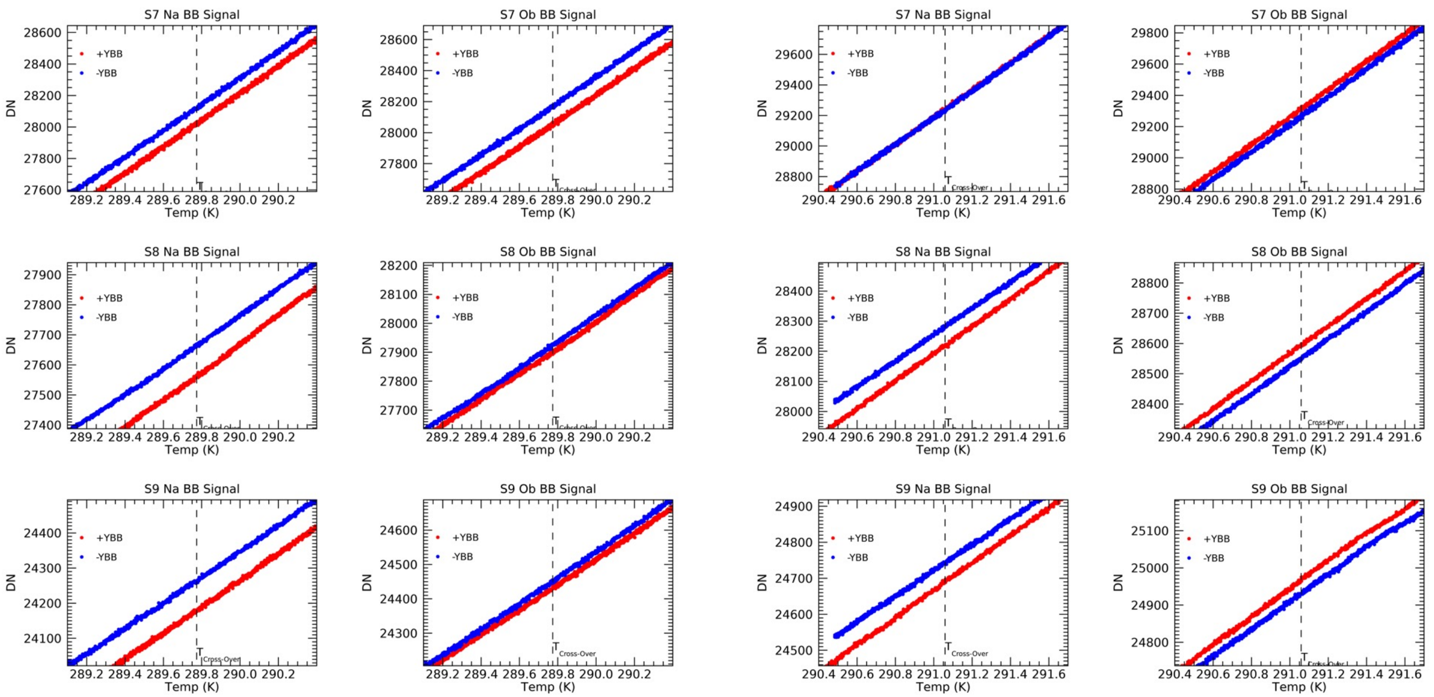
$$\Delta T = \frac{dT}{dC}\Delta C$$

Note difference between Parts 1 and 2 of test

# BB Cross-Over Test Analysis – SLSTR-B

Part 1

Part 2




Difference in counts at cross-over equates to temperature difference where

$$\Delta T = \frac{dT}{dC}\Delta C$$

Note difference between Parts 1 and 2 of test

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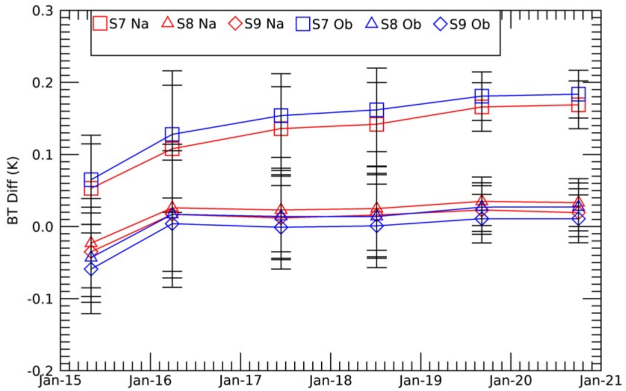
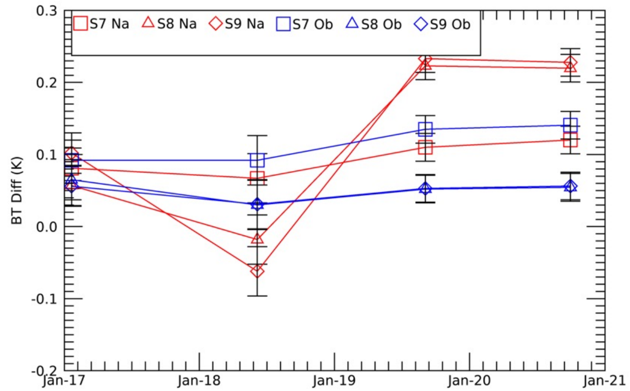
# BB Cross-Over Test Results Time-Series

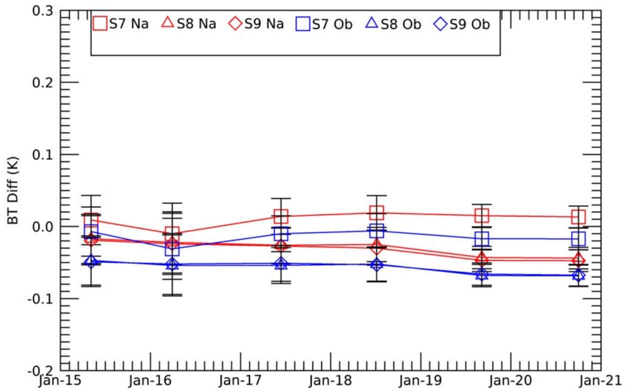
### SLSTR-A Part-1



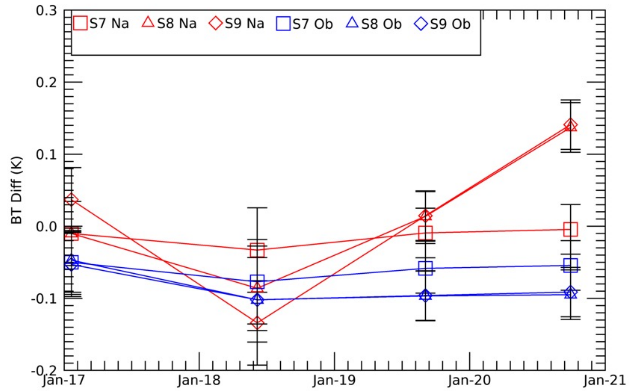

### SLSTR-B Part-1




### SLSTR-A Part-2




### SLSTR-B Part-2




Results show S8 and S9 are stable over mission duration for both S

S3A S7 shows gradual drift with part 1 (-YBB heated)

S3B S7 appears to be less stable.

Further investigation needed (Need to regenerate orbital trends from L0 data for 2018 and 2019)

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# Sentinel-3 Tandem Phase

For the first 6 months of the Sentinel-3B it flew in tandem with it's twin Sentinel-3A, separated by just 30 seconds.

This Tandem Phase provides a unique opportunity to investigate differences and validate uncertainties for S3A/B


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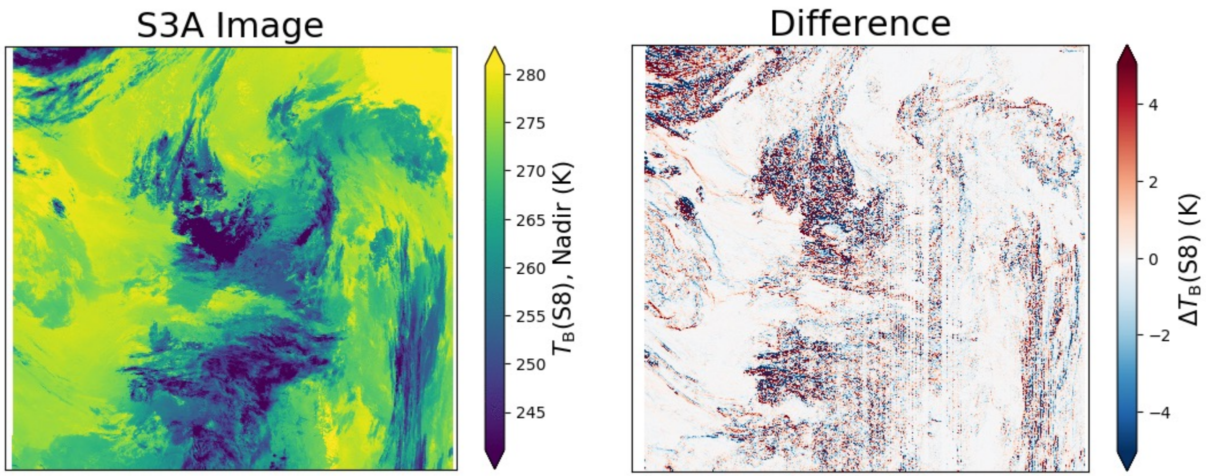
# Comparison Approach

## Despite small time delay pixel-level match-up errors can dominate sensor-to-sensor differences

- Caused by e.g. geolocation differences, cloud movement

## Motivates comparing larger areas of binned pixels in homogeneous regions



# Comparison Approach

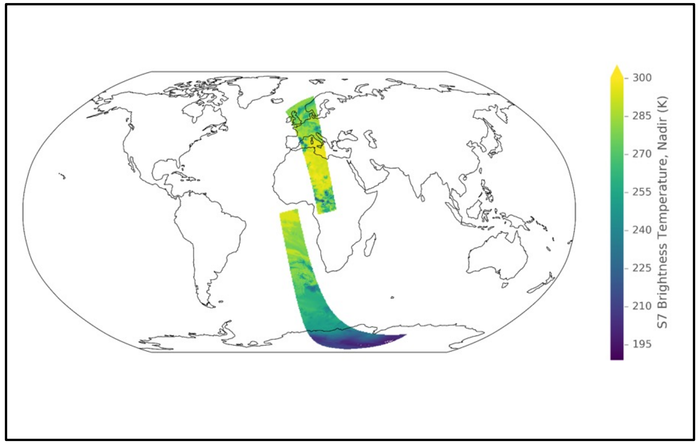
## Efficient way of achieving this to enable global analysis is to grid the data onto a regular latitude longitude grid

- 0.5 degree grid used

## Nearest neighbour gridding algorithm used

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

## Compare homogeneous pixels, in linear region of detectors




*One orbit of SLSTR-B BT measurements gridded onto a 0.5 degree grid in the S7 channel, nadir view.*

# SLSTR-A/B Differences

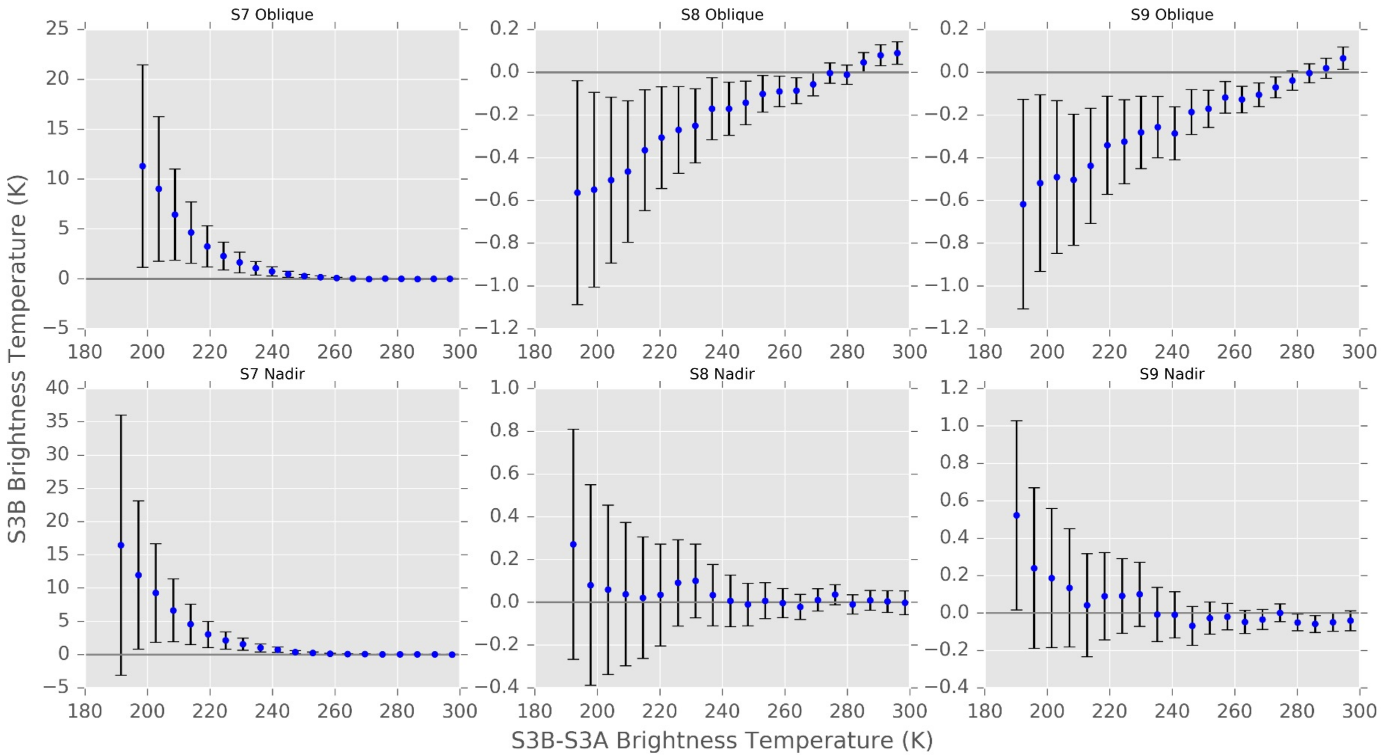
| Channel / View | Mean Difference (Linear Region) |
|---|---|
| S7 Oblique | 0.05 K |
| S8 Oblique | -0.02 K |
| S9 Oblique | -0.07 K |
| S7 Nadir | 0.05 K |
| S8 Nadir | 0.001 K |
| S9 Nadir | -0.04 K |

*Mean difference between SLSTR-A and B (data: 3/9/2018 orbit 200)*

- Evaluate average difference between SLSTR-A and B for one gridded orbit
- Shows small differences between sensors, of order 10 mK

# Sensitivity to Scene Temperature

## Grid cell differences binned by scene temperature, with propagated uncertainties




- ***S7/8/9 Nadir & S7 Oblique: Uncertainties explain differences between sensors***
- ***S8/9 Oblique: Scene temperature dependent bias not explained by uncertainties***

# Correction for Straylight Effect

## Initially straylight effect correction proposed by Leonardo

- Comparisons of SLSTR-A w.r.t. IASI-A suggested that correction not valid

## Simplified version of the straylight model derived from pre-launch and on-orbit measurements:

$$\Delta L_{\mathrm{Total}} = X \Delta L_{\mathrm{BB1}} - (1 - X)\Delta L_{\mathrm{BB2}}$$

with

$$\Delta L_{\mathrm{BB1/BB2}} = g\left(L(T_{\mathrm{Stray}}) - L(T_{\mathrm{BB1/BB2}})\right)$$

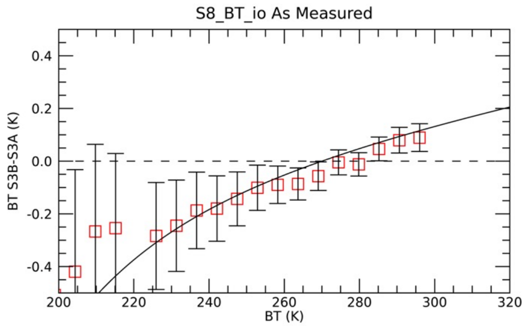
## Test performance of this correction using tandem dataset

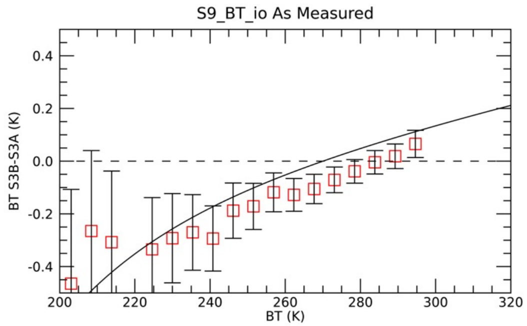
# Tandem Analysis of Straylight Effect Correction

SLSTR-A: $g \approx 0.007\,,\ T_{\mathrm{stray}} \approx 270\ \mathrm{K}$
SLSTR-B: $g \approx 0.002\,,\ T_{stray} \approx 270\ \mathrm{K}$

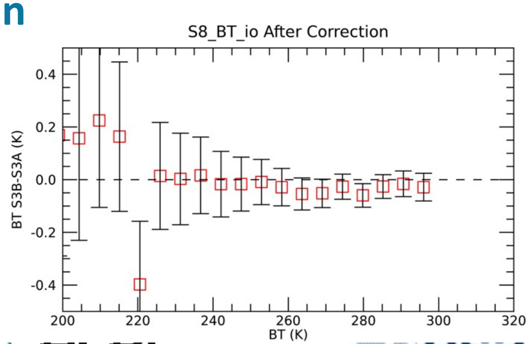
} Adjusted coefficients

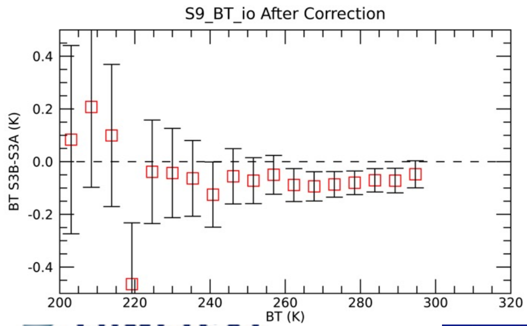
## As measured



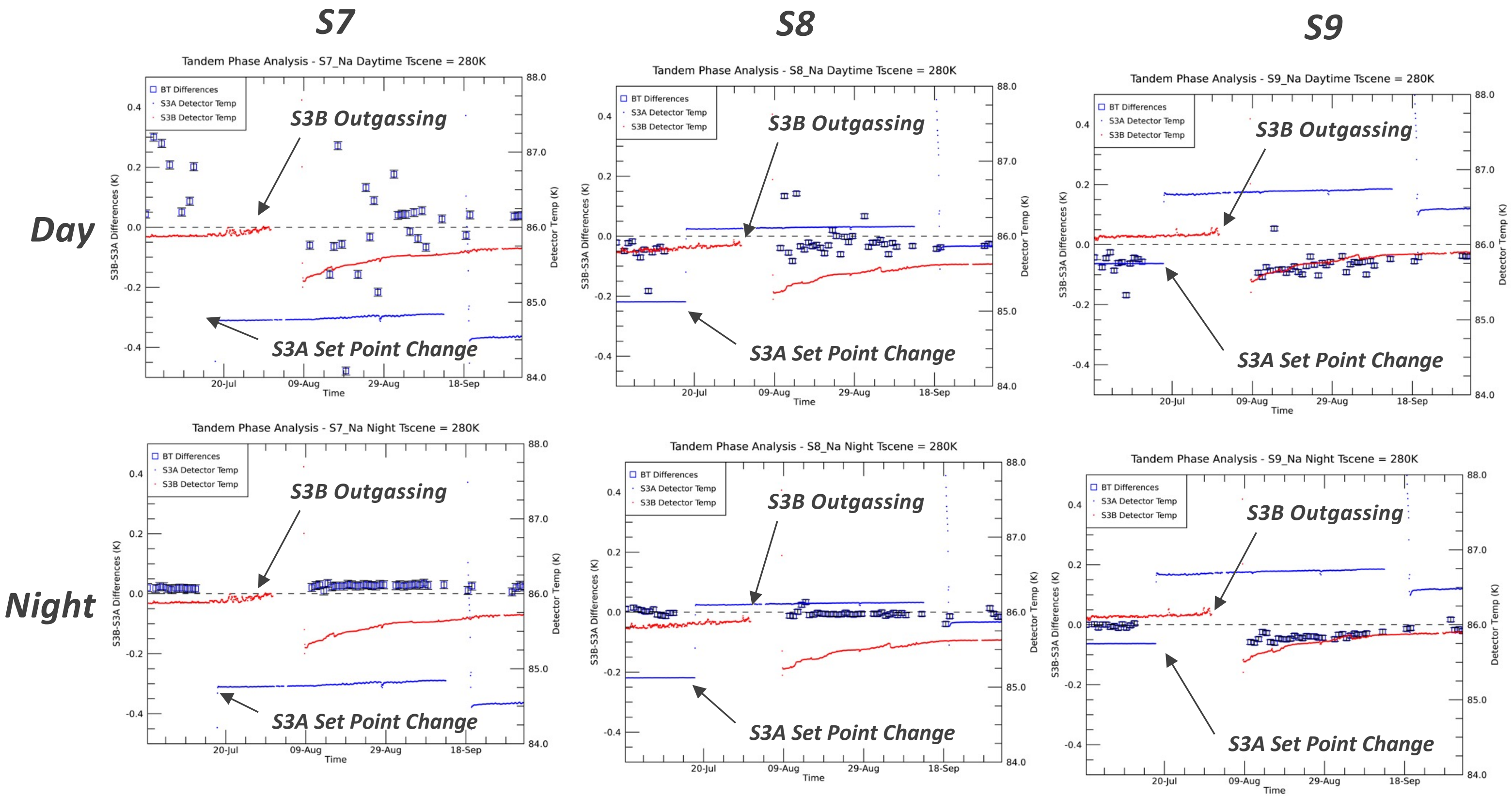




## With correction



# Tandem Comparison Time Series




- *Time series suggest good stability of TIR channels during tandem phase*
- *S9 shows 'step' before and after increase of S3A FPA temperature and S3B decontamination at the end of July*

# L1 Uncertainties

- Traceability of L1 calibration documented
- *Remote Sens.* 2021, *13*(3), 374; [https://doi.org/10.3390/rs13030374](https://doi.org/10.3390/rs13030374)

- Tool provided to map the uncertainties in the L1 products to each pixel
  - All channels
  - Tool allows propagation of uncertainty information to L2

remote sensing MDPI

*Article*

**Traceability of the Sentinel-3 SLSTR Level-1 Infrared Radiometric Processing**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**Abstract:** Providing uncertainties in satellite datasets used for Earth observation can be a daunting prospect because of the many processing stages and input data required to convert raw detector counts to calibrated radiances. The Sea and Land Surface Temperature Radiometer (SLSTR) was designed to provide measurements of the Earth's surface for operational and climate applications. In this paper the authors describe the traceability chain and derivation of uncertainty estimates for the thermal infrared channel radiometry. Starting from the instrument model, the contributing input quantities are identified to build up an uncertainty effects tree. The characterisation of each input effect is described, and uncertainty estimates provided which are used to derive the combined uncertainties as a function of scene temperature. The SLSTR Level-1 data products provide uncertainty estimates for fully random effects (noise) and systematic effects that can be mapped for each image pixel, examples of which are shown.



**Keywords:** calibration; uncertainty; traceability; SLSTR; Sentinel-3; temperature; blackbody; radiometer; data processing; Earth observation; metrology

check for updates

**Citation:** Smith, D.; Hunt, S.E.; Etxaluze, M.; Peters, D.; Nightingale, T.; Mittaz, J.; Woolliams, E.R.; Polehampton, E. Traceability of the Sentinel-3 SLSTR Level-1 Infrared Radiometric Processing. *Remote Sens.* **2021**, *13*, 374. https://doi.org/10.3390/rs13030374

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## 1. Introduction

Satellite datasets used for Earth observation and climate research need an indication of quality to allow users to assess the suitability of the data for their particular application [1]. At the most basic level, the quality of a measurement is defined in terms of its uncertainty and traceability to standard references. The processing of raw satellite data (Level-0 data) to radiometrically calibrated and geo-referenced data products (Level-1 data) involves a number of stages and relies on several auxiliary data files (ADFs) that contain calibration coefficients and tables used for converting digital counts to physical quantities [2]. These coefficients are derived from characterization measurements of different components of the instrument system. Furthermore, the derivation of the calibration source radiances is dependent not just on a single parameter, e.g., a temperature measurement, but other input quantities such as thermal gradients. Thus, the uncertainty of the data products is dependent on all effects contributing to the data processing. Furthermore, the uncertainty associated with a single observation in a single pixel is unlikely to be a single value but can vary with scene radiance.

The Sea and Land Surface Temperature Radiometer (SLSTR) on the Copernicus Sentinel-3 mission is an instrument designed to retrieve global sea surface temperatures (SSTs) for climate monitoring [3]. Two satellites (model A and B) provide near complete daily global coverage. SLSTR is a development of the along-track scanning radiometer series [4] and shares many of the key design features [5] needed for accurate measurement

*Remote Sens.* **2021**, *13*, 374. https://doi.org/10.3390/rs13030374 https://www.mdpi.com/journal/remotesensing

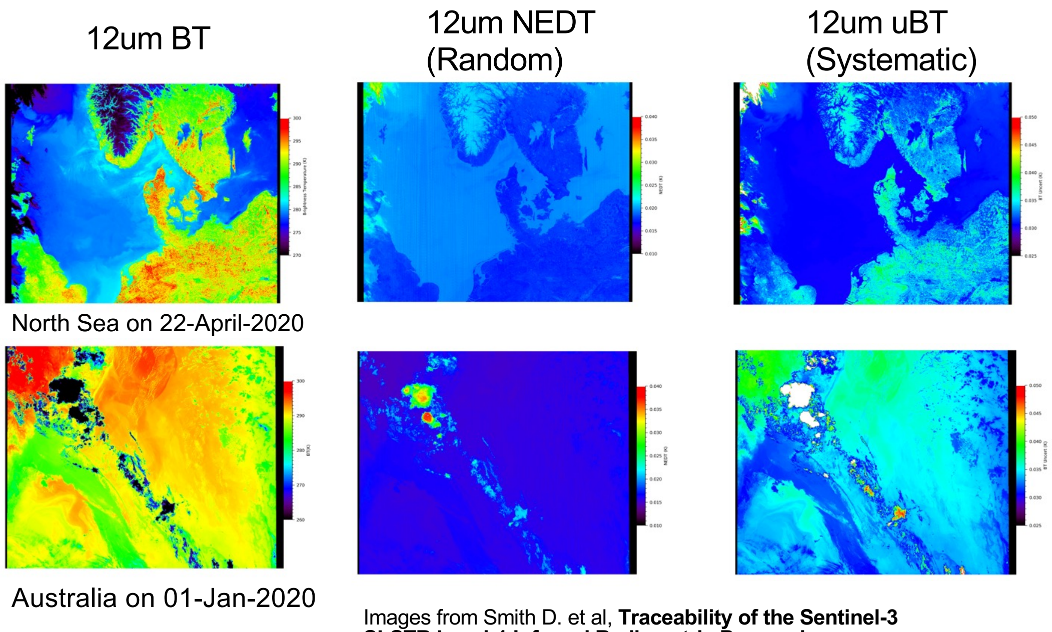
# Uncertainties in SLSTR L1 Products

Random effects - detector noise expressed as NEDT (TIR channels) and NEDL (VIS/SWIR channels) for each scan line

Systematic effects – radiometric calibration - tables of uncertainty vs. temperature type-B (a-priori) estimates based on the pre-launch calibration and calibration model

Uncertainties in L1 quality datasets for all channels

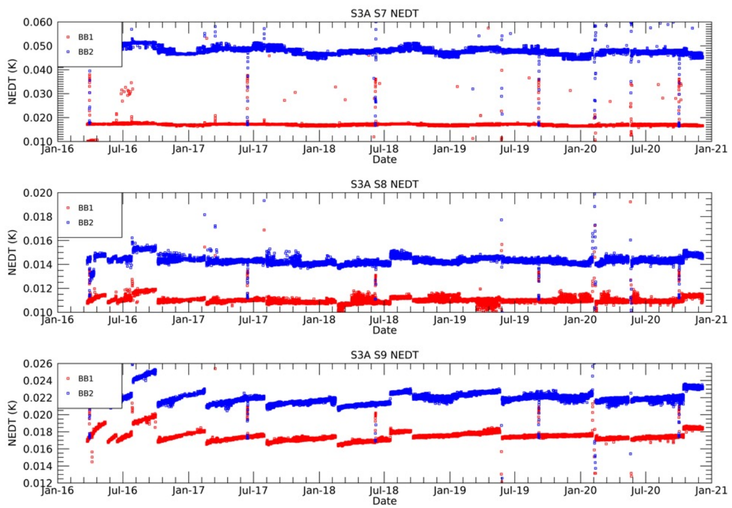
MapnoiS3 tool developed by RAL allows mapping of uncertainty information to L1 images



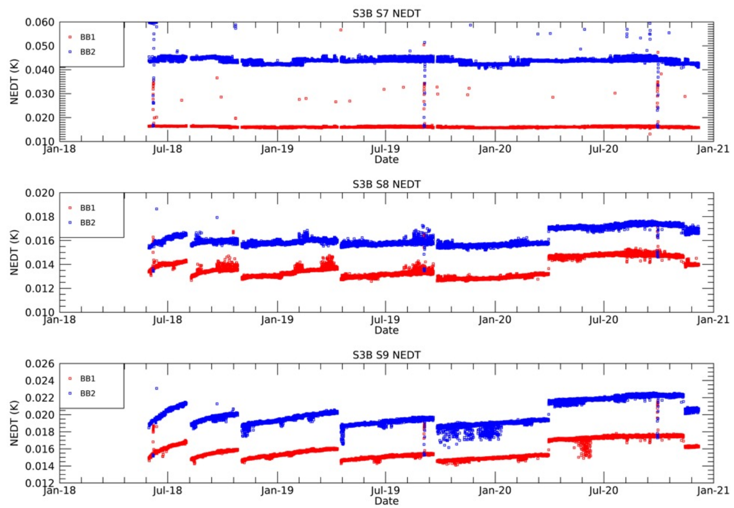

Images from Smith D. et al, **Traceability of the Sentinel-3 SLSTR Level-1 Infrared Radiometric Processing**

# Uncertainty Time Series
# Random Effects - NEDT

SLSTR-A



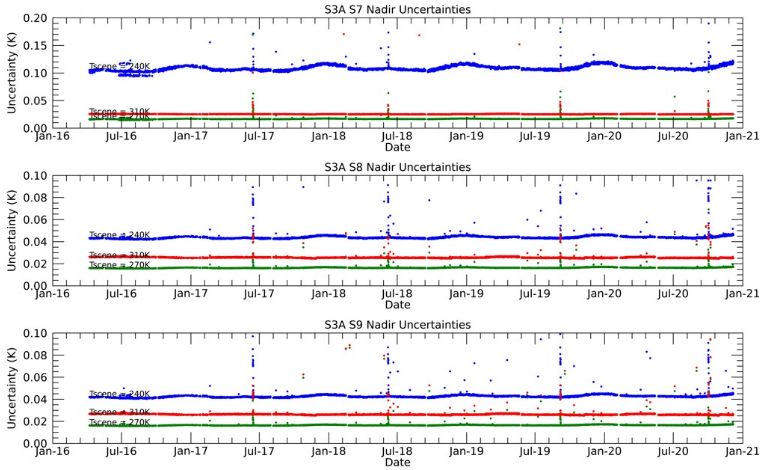

SLSTR-B



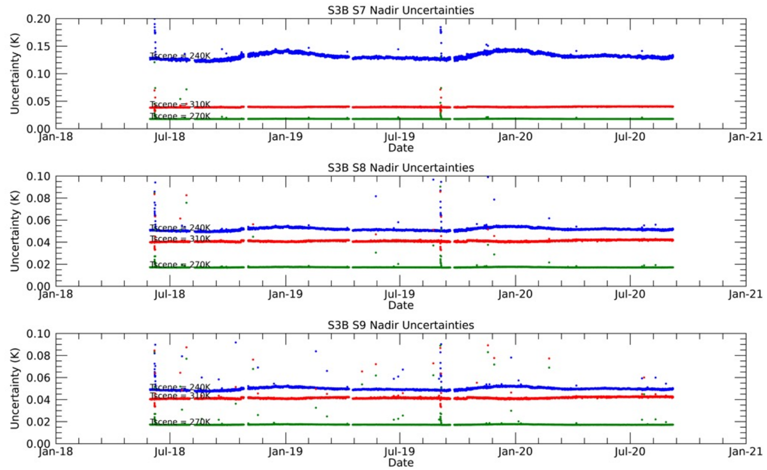

Noise estimates derived from on-board BB sources

# Uncertainty Time Series
# - Systematic Effects

SLSTR-A




SLSTR-B




Uncertainties derived from analysis of L0 data from Instrument Temperatures, BB signals,
Gain-Offset variations, Noise…

# Next Steps

- **Perform ongoing review of uncertainty budgets**
  - Uncertainty estimates are based on known effects
  - Further analysis will reveal additional contributors – i.e. long-term drift, internal stray light effects.

- **Perform corresponding uncertainty analysis for VIS-SWIR Channels**
  - Current versions of ADFs are based on pre-launch calibrations.
  - VISCAL ‘noise’ computation is incorrect - ref SIIIMPC-3084
  - Re-analysis to be done for VIS/SWIR channel calibration following approach developed for TIR Channels
  - ‘Improved’ estimates to be derived based on in-orbit performance (noise, stability, vicarious calibration).

- **Update uncertainty estimates in L1 future reprocessing of L1 data**