Providing Quality Information in Sentinel-3 Level-1 Data Products

Dave Smith, Mireya Etxaluze, Ed Polehampton

RAL Space, Science and Technologies Facilities Council, United Kingdom

Contents

- Introduction to SLSTR
- Radiometric Calibration Model & Uncertainty Estimates
- Uncertainty Tool
- L0 Monitoring
- Next Steps

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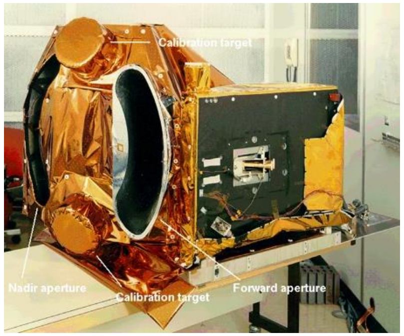
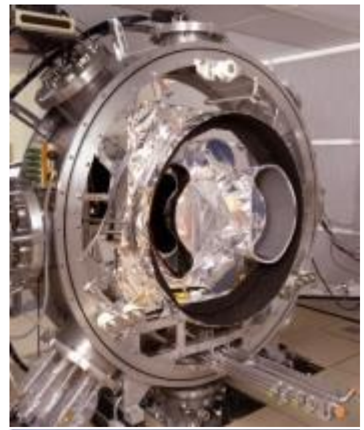
ATSR Series

RAL Space

1991-2000 ATSR-1



1995-2008 ATSR-2



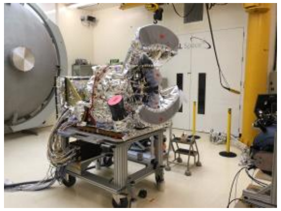
2002-2012- AATSR

SLSTR

2016 – Sentinel 3A

Launched 16-Feb-2016 ☺

2018 – Sentinel 3B



Launched 25-Apr-2018 ☺

- 2023 – Sentinel 3C
  - Spectral Calibration complete
  - Instrument Reduced Calibration Autumn 2019
  - Full Calibration 2021/22

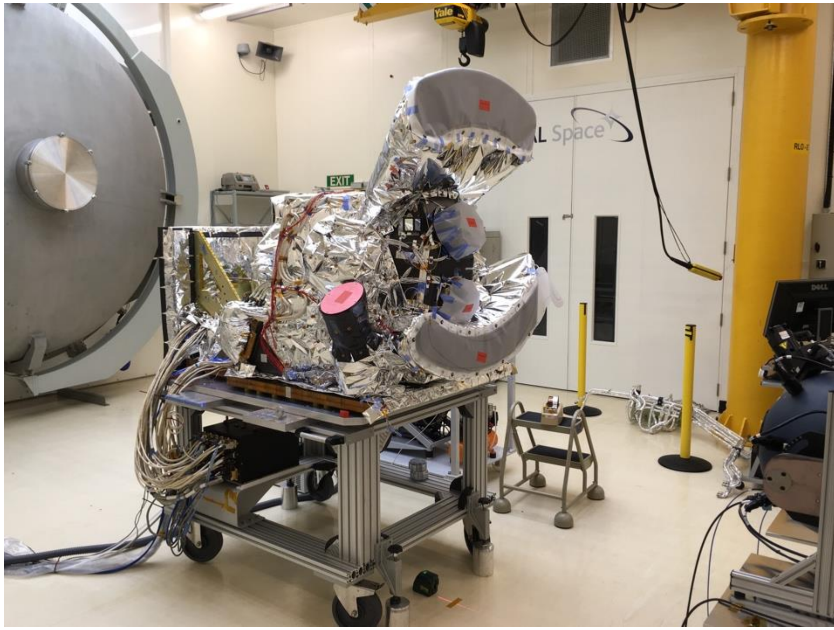
- > 2024 – Sentinel-3D
  - Spectral Response Calibration Summer 2019
  - Full Calibration TBD

…

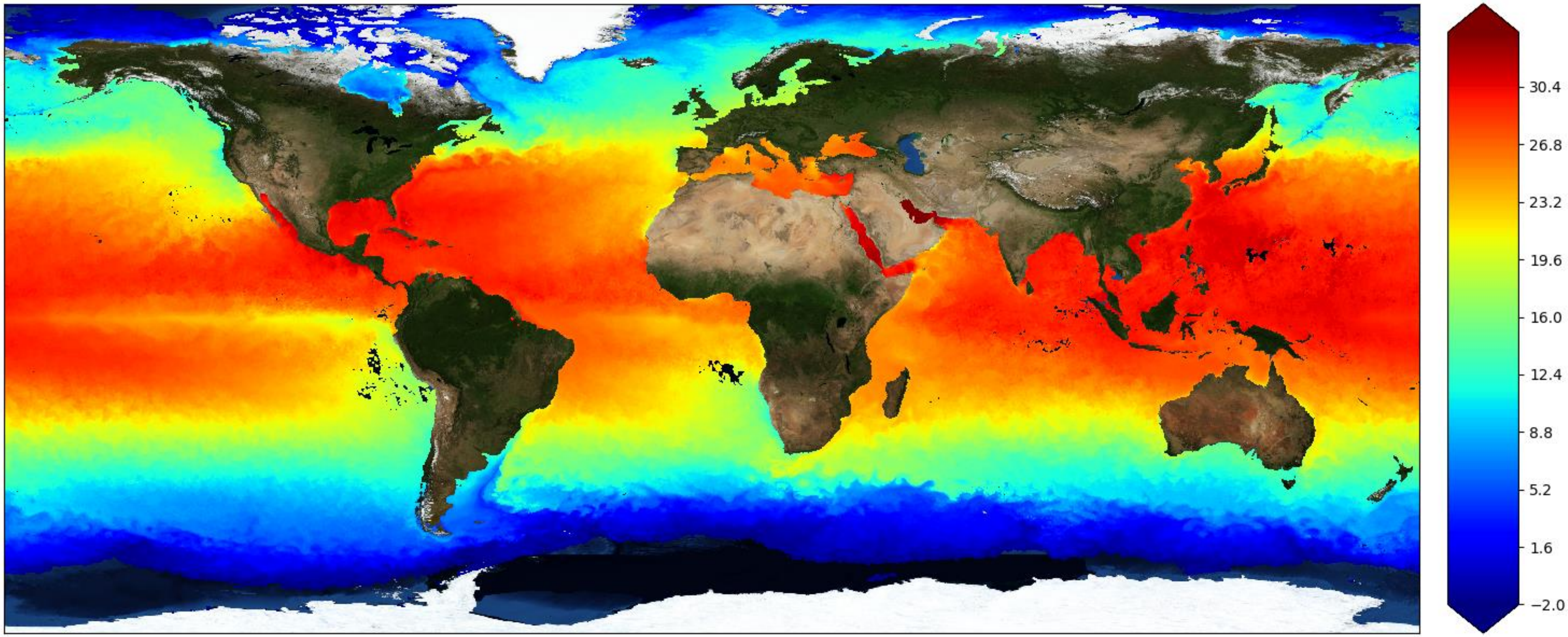
SLSTR instrument

RAL Space

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



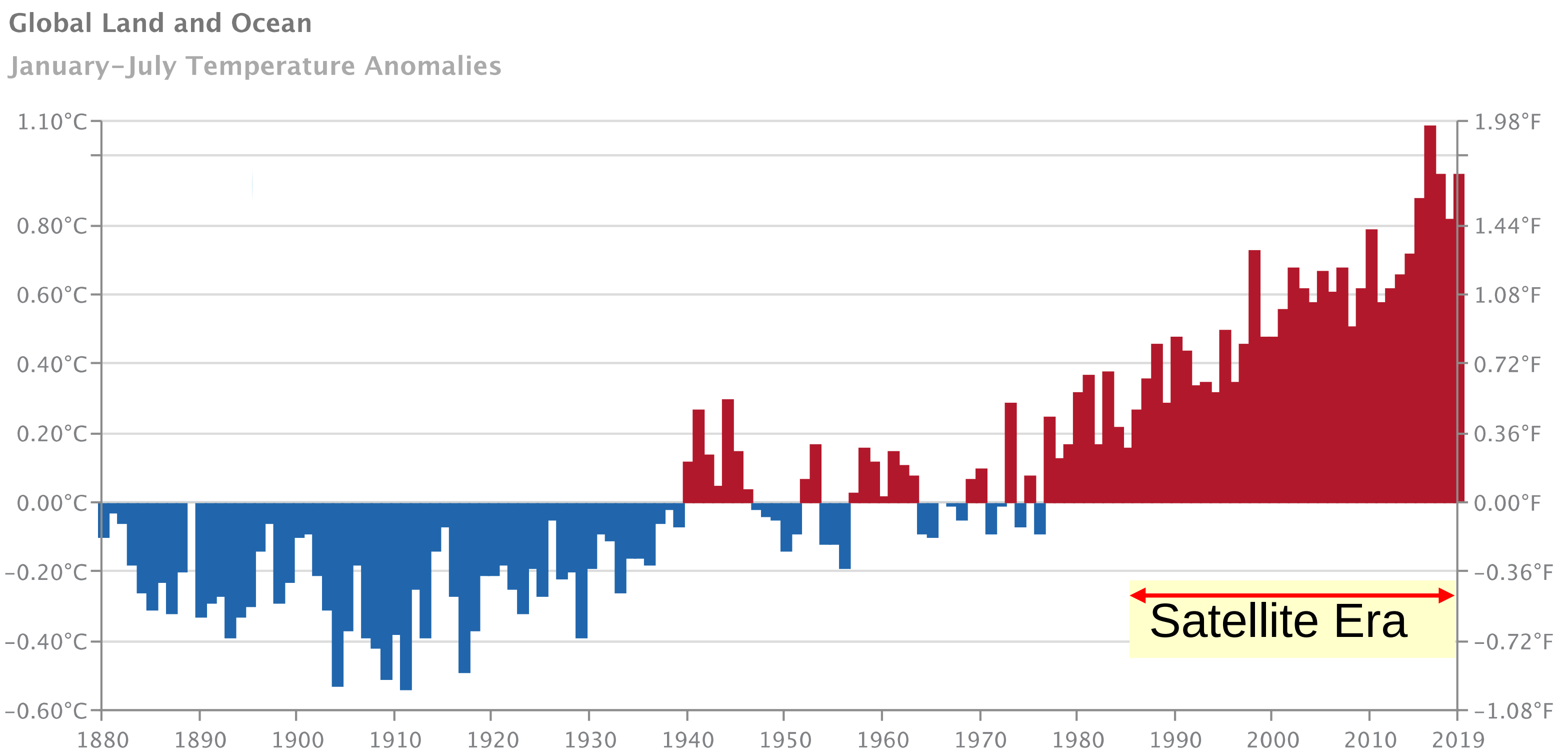
Sentinel-3A SLSTR Sea Surface Temperature – August 2016



"Measuring the small changes associated with long-term global climate change from space is a daunting task. For example, the satellite instruments must be capable of observing atmospheric and surface temperature trends as small as 0.1C decade^{-1}, ozone changes as little as 1% decade^{-1}, and variations in the sun's output as tiny as 0.1% decade^{-1}."

Ohring, G.B., B. A. Wielicki, R. Spencer, B. Emery, and R. Datla, 2005: Satellite instrument calibration for measuring global climate change: Report on a workshop. Bull. Amer. Meteor. Soc., 86, 1303–1313

“2016 hottest year ever recorded – and scientists say human activity to blame” Guardian 18-Jan-2017



NOAA National Centers for Environmental Information, State of the Climate: Global Analysis, published online September 2019, retrieved on 6-September-2019 from http://www.ncdc.noaa.gov/sotc/global/time-series/globe/land-ocean/ytd/7/1880-2019

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Calibration of IR instruments

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

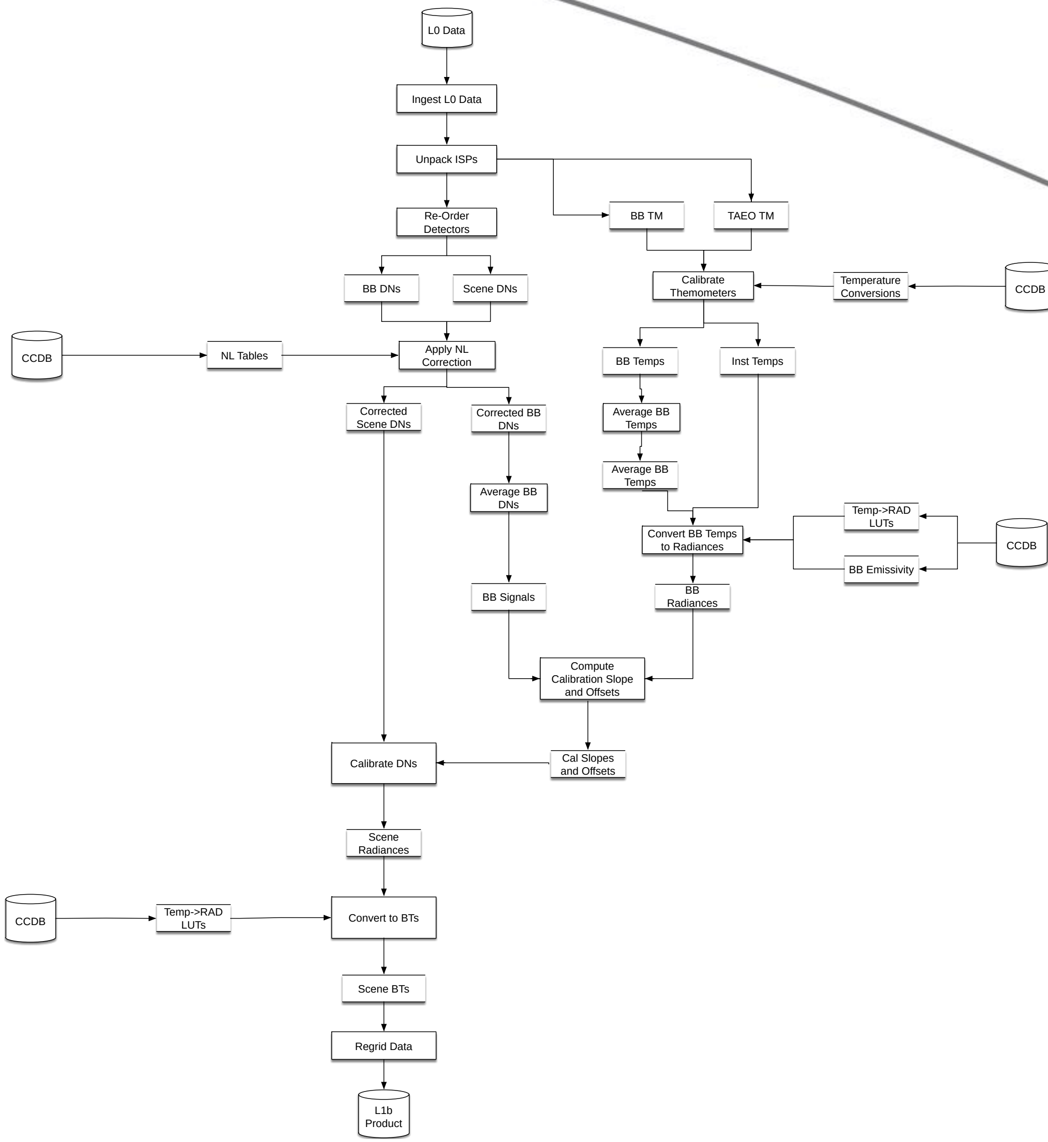
- ATBD -> DPM
- L0 and L1 Product Specifications

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

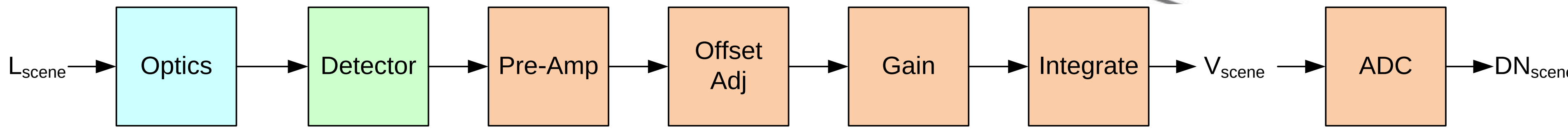
- = 40 for IR channels alone

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

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

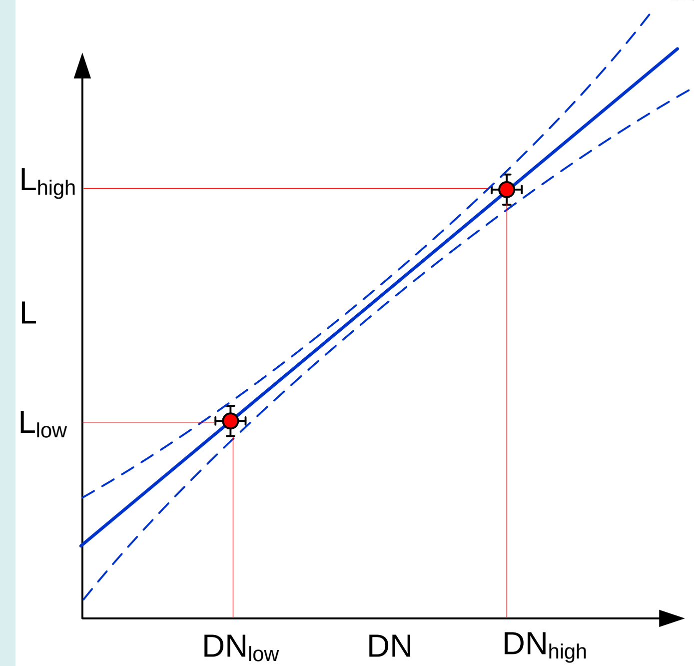
Both gain and offset must be stable during calibration interval

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

$$L_E = X L_{BB1} + (1 - X) L_{BB2} + 0$$

Uniformity around scan

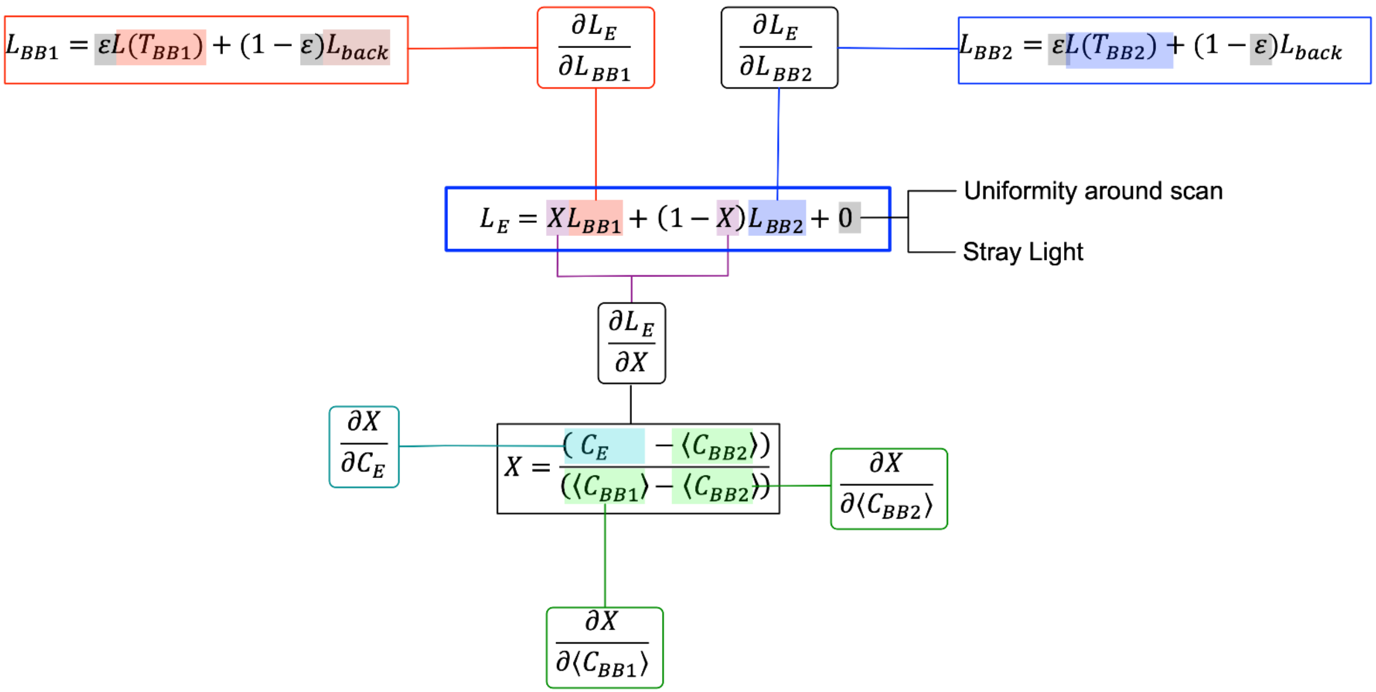
Stray Light

$$\frac{\partial L_E}{\partial X}$$

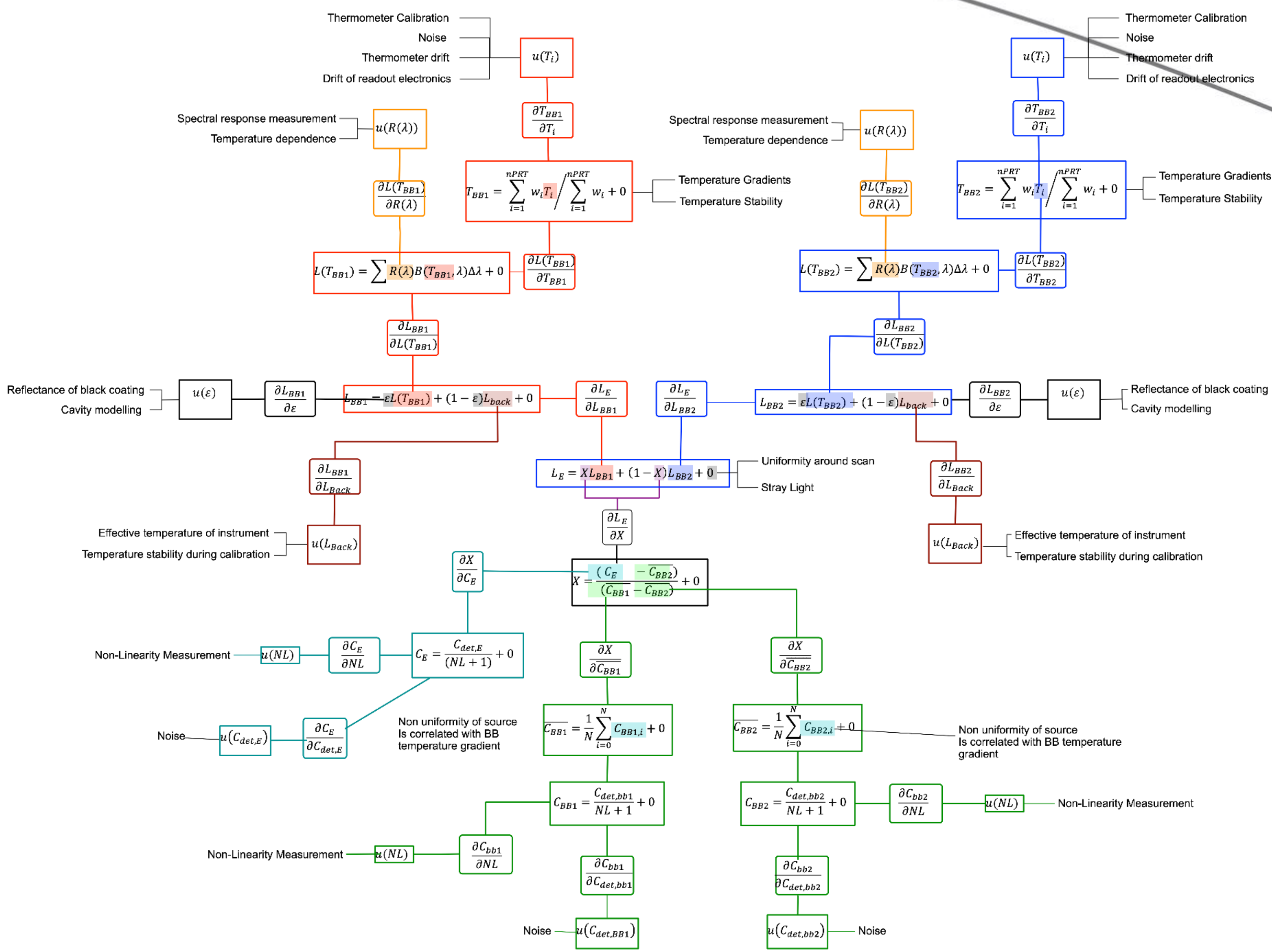
$$X = \frac{(C_E - \langle C_{BB2} \rangle)}{(\langle C_{BB1} \rangle - \langle C_{BB2} \rangle)}$$

SLSTR TIR Calibration Effects Tree

We work outwards to determine all measurement effects



SLSTR TIR Calibration Effects Tree



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

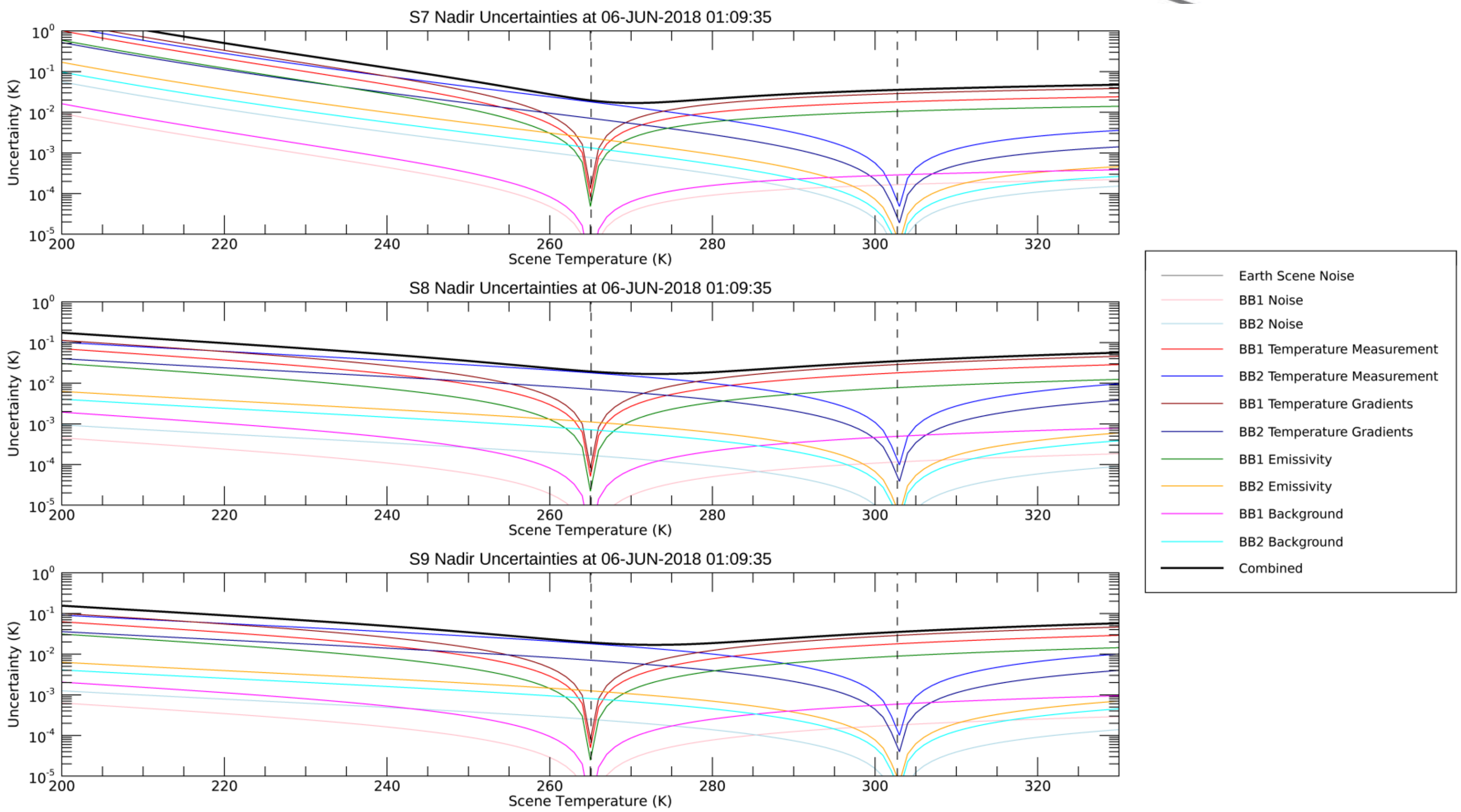
- Detector Noise
  - Instrument level calibration tests, on-board BB sources

Effects Table

Table descriptor				
Name of effect		Calibration of Thermometer	Noise on Thermometer	Temperature Gradients
Affected term in measurement function		$T_{PRT,i}$	$T_{PRT,i}$	T_{Av}
Instruments in the series affected		All	All	All
Correlation type and form	Pixel-to-pixel [pixels]	Rectangular Absolute	Rectangular Absolute	Rectangular Absolute
	from scanline to scanline [scanlines]	Rectangular Absolute	Rectangular Absolute	Rectangular Absolute
	between images [images]	Rectangular Absolute	Rectangular Absolute	Rectangular Absolute
	Between orbits [orbit]	Rectangular Absolute	Rectangular Absolute	Rectangular Absolute
	Over time [time]	Rectangular Absolute	Rectangular Absolute	Rectangular Absolute
Correlation scale	Pixel-to-pixel [pixels]	-∞,+∞	-∞,+∞	-∞,+∞
	from scanline to scanline [scanlines]	-∞,+∞	-∞,+∞	-∞,+∞
	between images [images]	N/A	N/A	N/A
	Between orbits [orbit]	-∞,+∞	-∞,+∞	-∞,+∞
	Over time [time]	-∞,+∞	-∞,+∞	-∞,+∞
Channels/bands	List of channels / bands affected	All	All	All
	Error correlation coefficient matrix	Matrix of 1's	Matrix of 1's	Matrix of 1's
Uncertainty	PDF shape	Gaussian	Gaussian	Gaussian
	units	Kelvin	Kelvin	Kelvin
	magnitude	BB Calibration Report	BB Calibration Report	Flight Measurements
Sensitivity coefficient		$\frac{\partial L_E}{\partial L_{BB}}\frac{\partial L_{BB}}{\partial T_{av}}\frac{\partial L_{av}}{\partial T_i}$	$\frac{\partial L_E}{\partial L_{BB}}\frac{\partial L_{BB}}{\partial T_{av}}\frac{\partial L_{av}}{\partial T_i}$	$\frac{\partial L_E}{\partial L_{BB}}\frac{\partial L_{BB}}{\partial T_{av}}$

Note – Heated and Cold BB thermometers are independent systems

S3B TIR Uncertainty Budget – Jun-2018



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

Current State of SLSTR L1 Uncertainty Estimates

Pre-Launch reports contains most information

- Write up as reviewed papers in progress
- Includes uncertainty estimates of measurements

L1 Products

- Random effects - detector noise expressed as NEDT (TIR channels) and NEDL (VIS/SWIR channels) for each scan line
- Correlated effects - radiometric calibration are included in the quality annotation datasets as a table of uncertainty vs. temperature type-B (a-priori) estimates based on the pre-launch calibration and calibration model (see later slides)

Per pixel estimation of the radiometric uncertainty for either random or correlated (systematic) effects has not been implemented

- Significant impact on product size and processing time
- Poorly defined user requirements during definition of GPP/IPF

Providing Uncertainty Estimates in SLSTR L1 – Random Effects (Noise)

Random 'Noise' estimates are currently provided in quality ADS as per scan 'Noise'

- Provided at the two calibration points

Per pixel 'Noise' estimates can be derived from per scan estimates

- Algorithm to provide per-pixel noise estimates as function of scene temperature/radiance is available.
- Could be done as a post-processing step
- Prototype code has been developed (see next slides)

Modification to IPF would be needed to apply noise model to all scene temperatures/radiances

- Product specification needs to be updated to include separate fields for random and correlated effects
- Significant increase in product size
  - Could be limited if noise estimates saved as bytes

Providing Uncertainty Estimates in SLSTR L1 – Correlated Effects

Correlated uncertainties in radiometric calibration are provided per product

- Derived from the pre-launch calibration parameters
- Derived for fixed internal BB temperatures

Correlated uncertainties can be mapped to all pixels by interpolation

- Prototype tool has been developed (see next slides)
- Could be done as a post-processing step

Modification to IPF would be needed to compute uncertainties for each product

- Current scheme does not account for in-flight configuration
- Instrument temperatures contribute to uncertainty budget which vary with orbit and drift with time.
    - See later slides

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EUMETSAT Study

- To develop a prototype tool to provide per-pixel uncertainty estimates from L1 products.

  - Python code
  - ATBD
  - IODD
  - DPM
  - User manual (draft)

Provided to EUMETSAT

Final meeting 19-Sep-2019

  - Paper describing calibration model is in preparation

Python Tool

MapnoiS3 is a prototype Python code developed to allow the addition of per-pixel uncertainty information to existing SLSTR Level-1 products based on the information contained in the datasets.

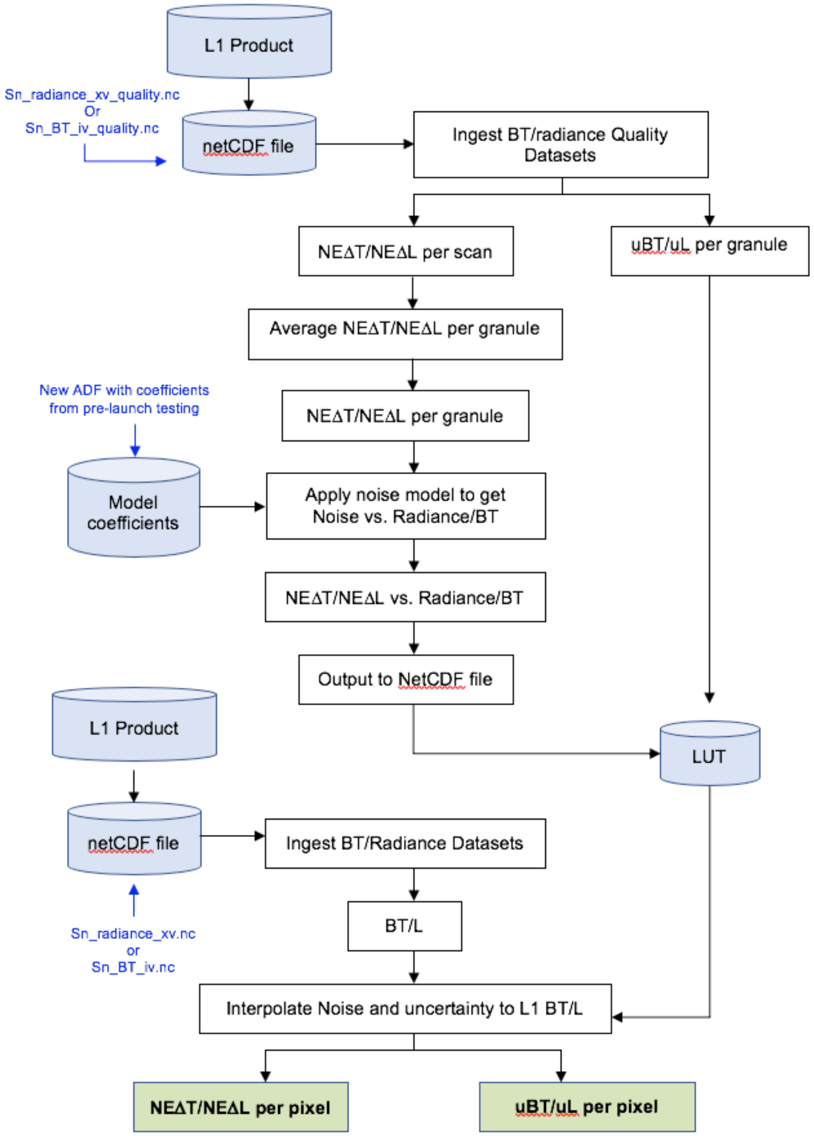
The tool can deal with several SLSTR Level-1 products in one go, and with as many channels and scan views as the user requires.

MapnoiS3 code will be available via EUMETSAT and provided as a *tarball* mapnoiS3.tar.gz

Outputs from code are saved as separate netcdf files following the S3 product format style.

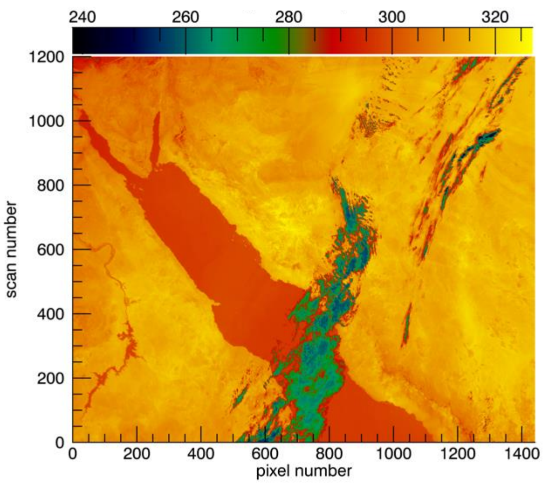
Algorithm

- From L1 product quality datasets we extract per scan random noise and correlated radiometric uncertainty tables.
- Correlated uncertainties are interpolated for each pixel BT/Radiance in L1 image
- For random noise NEΔT and NEΔL, we scale the radiometric noise model to the measured per-scan/detector values and interpolate for each pixel BT/Radiance in L1 image

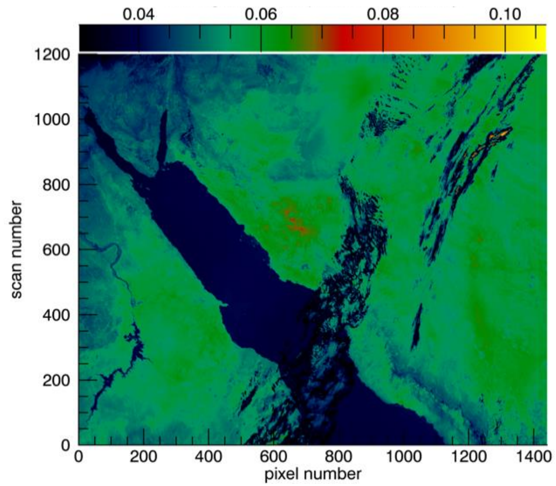


Example Output

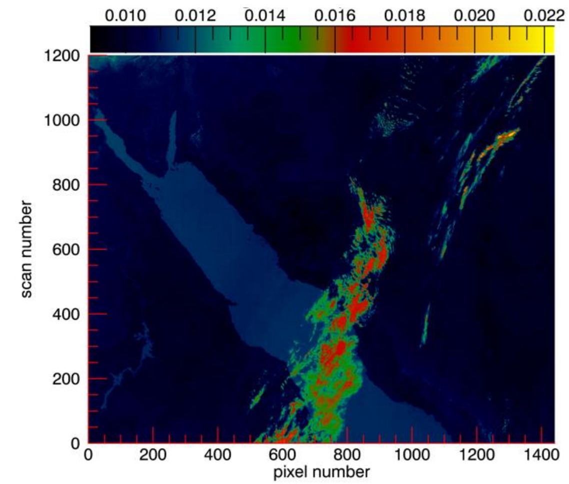
S8 BT (10.8μm)



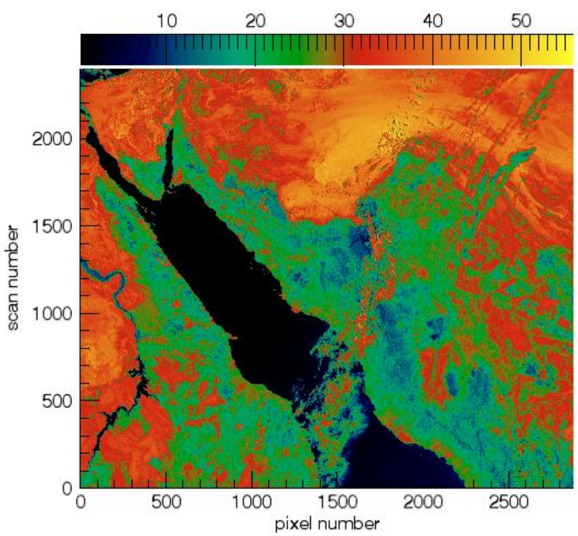
S8 Uncertainty Correlated



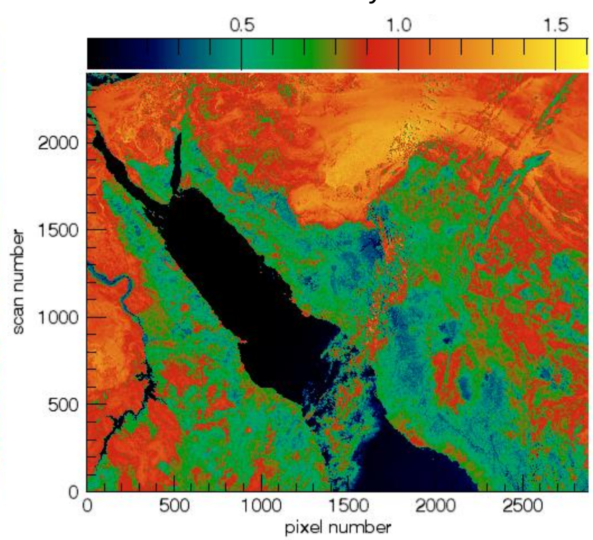
S8 Uncertainty Random (NEΔT)



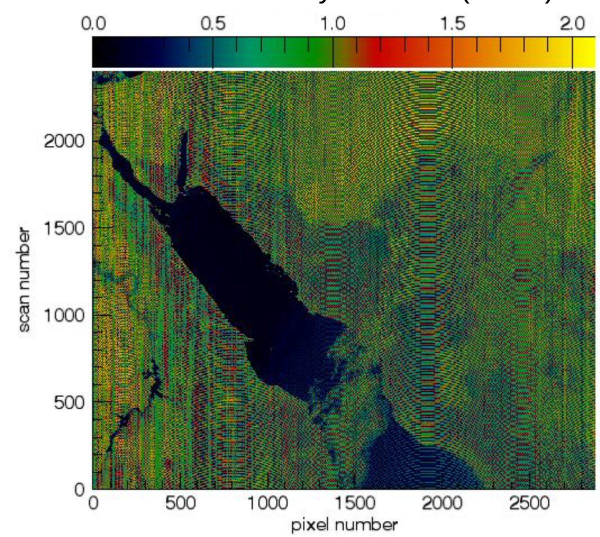
S5 Radiance (1.6μm)



S5 Uncertainty Correlated



S5 Uncertainty Random (NEΔL)



S3A_SL_1_RBT____20180531T073043_20180531T073343_20180531T093806_0179_031_377_2520_MAR_O_NR_003.SEN3

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On-Orbit Performance

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

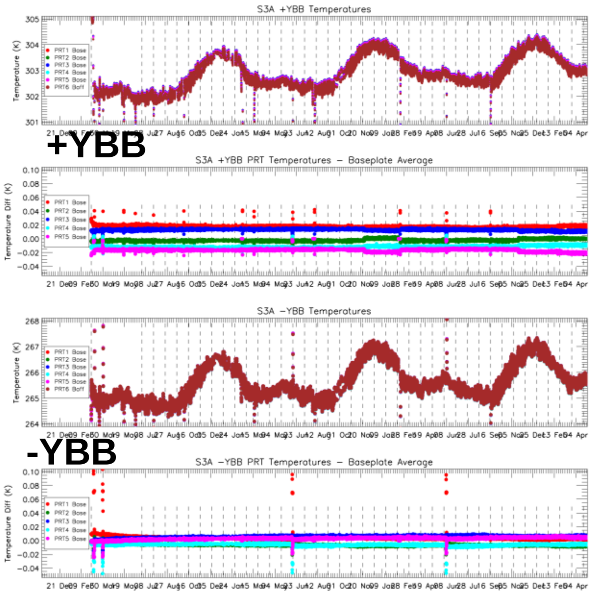
- Knowledge of surface emissivity
- Surface non-uniformity
- Temporal variations over short time (effect of surface winds, cloud shadow, solar elevation)
- Contribution of Atmosphere to the measured signal

Hence limited to:

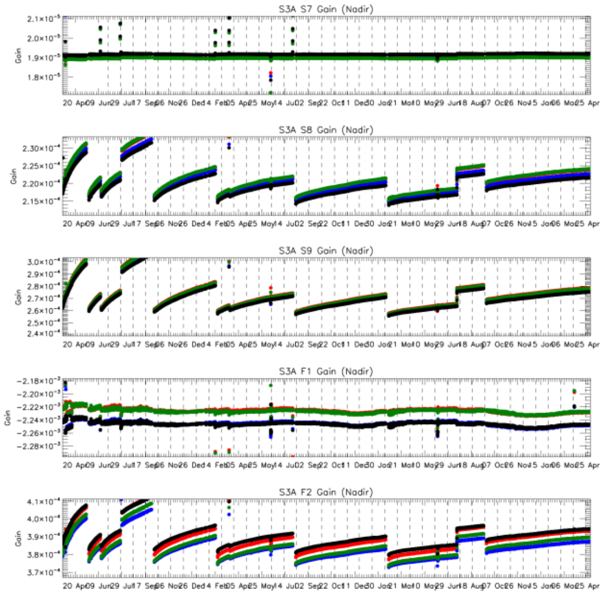
- Monitoring of instrument parameters
- Satellite inter-comparisons
- Validation of L2 data products

On-Orbit Monitoring

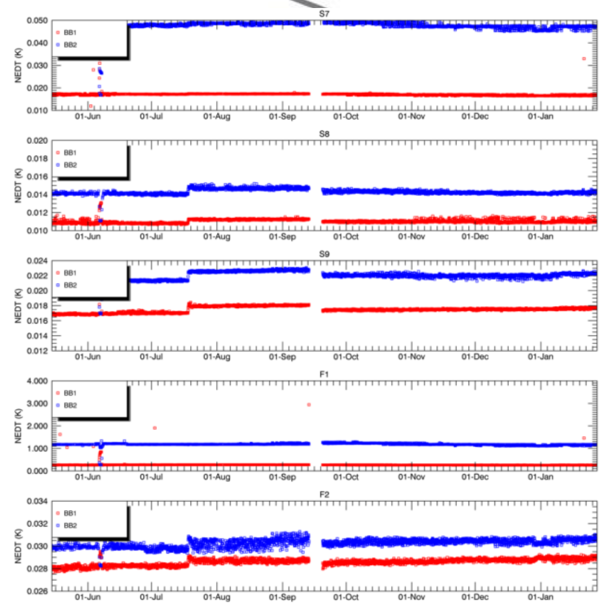
BB Temperatures



Gain Stabiltiy



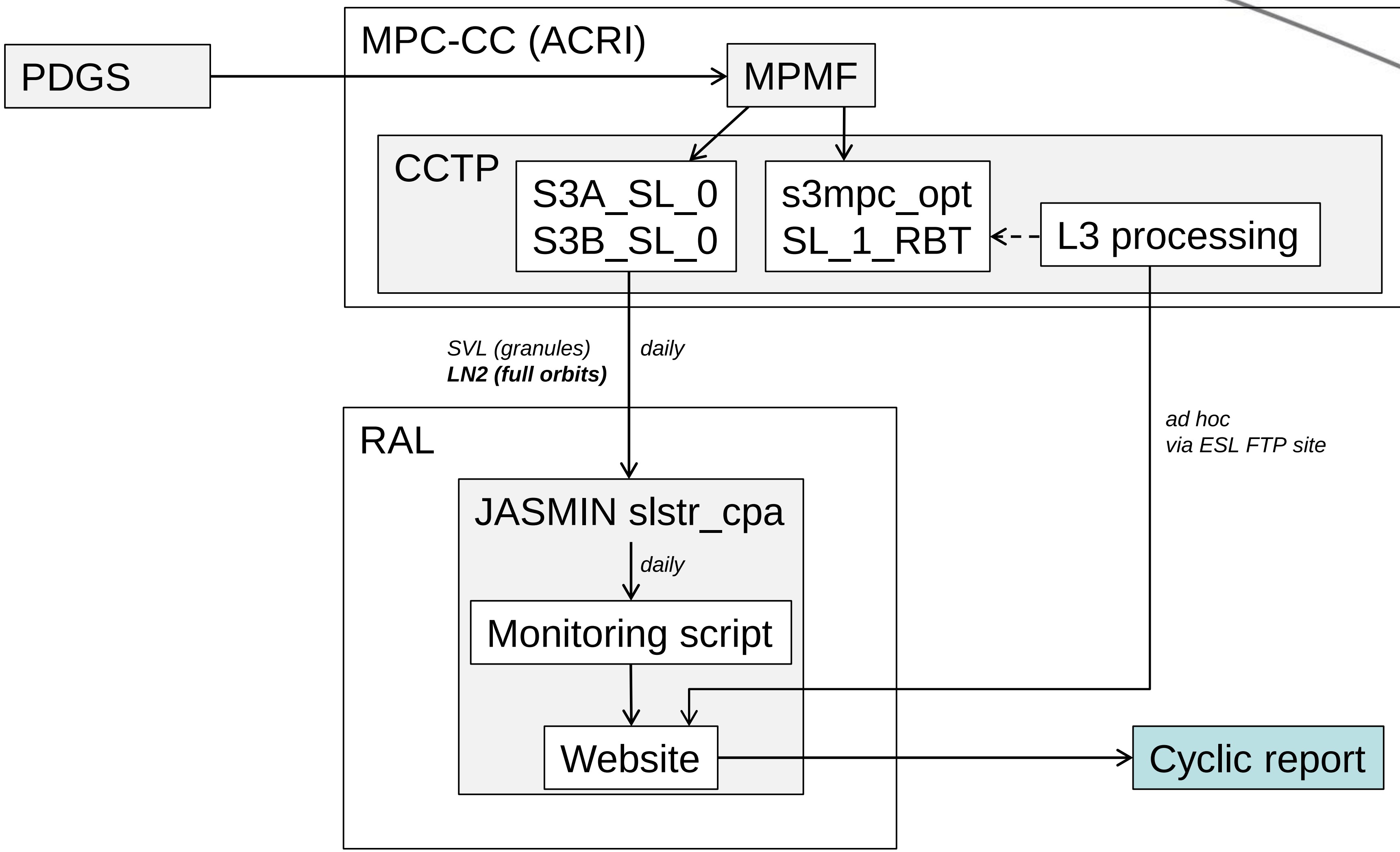
Radiometric Noise



To monitor SLSTR instrument performance, we need to look at raw Level-0 data, for example to:

- Check for gaps in packet stream
- Monitor all HK parameters (i.e. temperatures, cooler status, etc.)
- Monitor detector counts for all targets
- Analyse scanner positions/jitter
- Perform independent checks of L1 calibration parameters

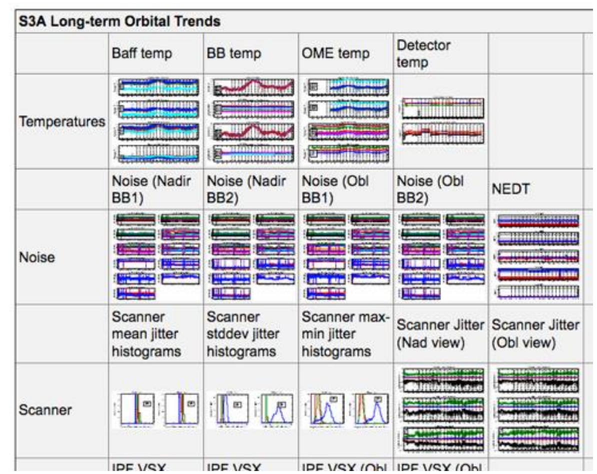
SLSTR L0 Monitoring at RAL



SLSTR L0 Monitoring at RAL

The RAL monitoring system consists of:

- Level-0 reader and housekeeping data conversion
- Extraction and processing tools
- Control script to process individual orbits
  - Plot functions for each parameter over a single orbit
  - Output CSV files on ISP timescales
  - VISCAL processing
  - Orbital averages added to long term trend files
- Control script to process long term trends
  - Cycle-by-cycle trend plots
  - Yearly trend plots
  - Overall mission plots
  - Cycle-by-cycle parameter summary

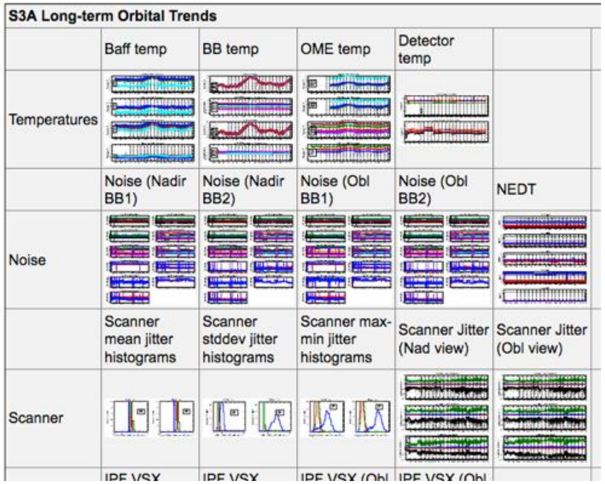


- Web pages to display plots and output parameters

SLSTR L0 Monitoring at RAL

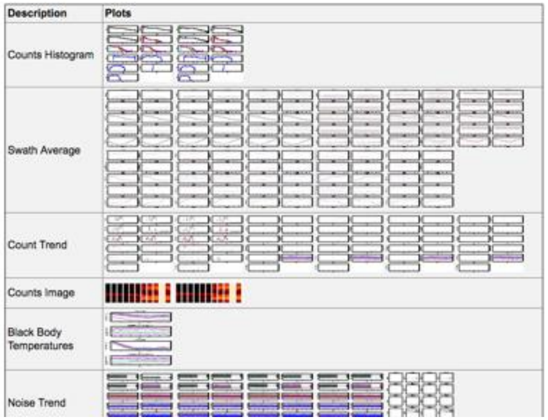
- Plots produced of trends within each orbit, each cycle, each year & whole mission
  - → *gives a reference library of plots to use when investigating issues*
- Calibration parameters independently calculated from L0
- Summary files produced with orbital average parameters
- Summary tables of SNR & NEDT for each cycle
- Refers back to the Cal/Val plan

Date (Cycle_24)	Orbit Number (relative)														
01-Nov-2017	60	61	62												
31-Oct-2017	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
30-Oct-2017	31	32	33	34	35	36	37	38	39	40	41	42	43	44	
29-Oct-2017	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
28-Oct-2017	3	4	5	6	7	8	9	10	11	12	13	14	15	16	



Orbit Number 62

01-Nov-2017 05:01:22 - 06:43:17



Summary of NEDT per cycle for +YBB (hot) averaged over detectors, integrators and views

	CYCLE_6	CYCLE_7	CYCLE_8	CYCLE_9	CYCLE_10	CYCLE_11	CYCLE_12	CYCLE_13	CYCLE_14	CYCLE_15	CYCLE_16	CYCLE_17	CYCLE_18	CYCLE_19	CYCLE_20	CYCLE_21	CYCLE_22	CYCLE_23	CYCLE_24
S7	17.5	17.7	17.5	17.3	17.2	16.9	16.9	16.8	16.9	17.2	17.2	17.2	18.1	17.2	17.2	17.1	17.2	16.9	16.7
S8	11.2	11.7	11.8	11.3	10.9	11.0	11.0	11.1	11.0	10.9	10.9	11.0	11.1	11.0	11.1	10.9	10.9	10.9	10.8
S9	17.5	19.2	19.5	18.1	17.1	17.4	17.7	17.9	17.6	17.0	17.0	17.2	17.5	17.4	17.5	16.7	16.9	17.0	17.0
F1	272.7	274.0	273.7	268.6	264.9	260.1	259.7	260.3	260.3	267.6	268.3	271.0	297.3	276.3	276.4	269.0	269.9	265.3	263.5
F2	27.6	28.5	28.3	27.7	27.5	27.7	28.0	28.0	27.9	27.6	27.6	27.8	27.8	27.8	27.8	27.4	27.6	27.7	27.8

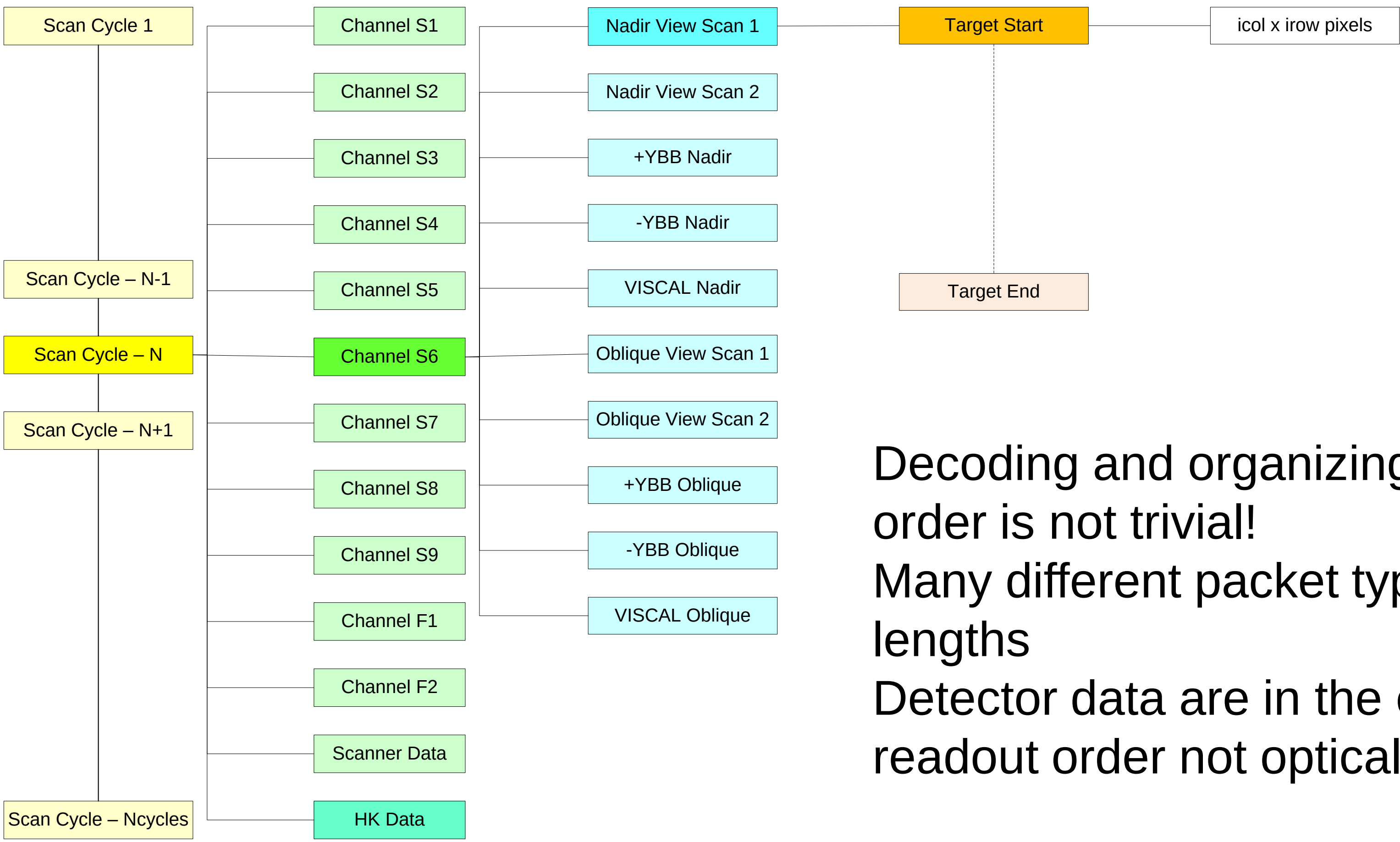
Summary of NEDT per cycle for -YBB (cold) averaged over detectors, integrators and views

	CYCLE_6	CYCLE_7	CYCLE_8	CYCLE_9	CYCLE_10	CYCLE_11	CYCLE_12	CYCLE_13	CYCLE_14	CYCLE_15	CYCLE_16	CYCLE_17	CYCLE_18	CYCLE_19	CYCLE_20	CYCLE_21	CYCLE_22	CYCLE_23	CYCLE_24
S7	50.7	51.3	51.1	49.3	48.1	47.2	46.6	46.8	47.9	48.7	49.0	48.8	46.9	49.2	49.4	49.4	49.0	47.6	48.2
S8	14.5	15.3	15.3	14.7	14.4	14.4	14.5	14.4	14.4	14.2	14.2	14.3	14.2	14.3	14.4	14.2	14.1	14.2	14.9
S9	22.1	24.4	24.7	22.7	21.5	21.8	22.2	22.4	22.1	21.3	21.4	21.6	21.6	22.0	22.0	21.1	21.3	21.4	21.4
F1	1278.8	1226.2	1229.6	1220.1	1209.0	1162.1	1122.6	1129.8	1177.5	1221.6	1190.9	1198.7	1162.8	1231.2	1233.0	1212.4	1201.6	1161.2	1166.1
F2	29.8	31.5	31.8	30.2	29.3	29.5	29.6	29.6	29.6	29.2	29.3	29.3	29.4	29.6	29.7	29.2	29.2	29.3	29.7

SLSTR L0 Reader

Each scan cycle of the instrument contains 122 packets

- Separate packets for each channel and view/target



Decoding and organizing in logical order is not trivial!

Many different packet types and lengths

Detector data are in the electronic readout order not optical

SLSTR L0 Reader

- The IDL L0 Reader sorts through the packet stream to fill a scan-aligned data structure:
  - Detector counts for each channel/view/target
  - Scan/Flip encoder positions for each view/target
  - Housekeeping header information
  - Raw housekeeping data (binary data)
  - Pointers are used to reference the data for each scan cycle

- Housekeeping conversion, and averaging over each view/target is performed in a second step:
  - Statistics (average/max/min/stddev) for each channel/view/target
  - Converted housekeeping data (BBEU, TAEO, FEE, SUE)

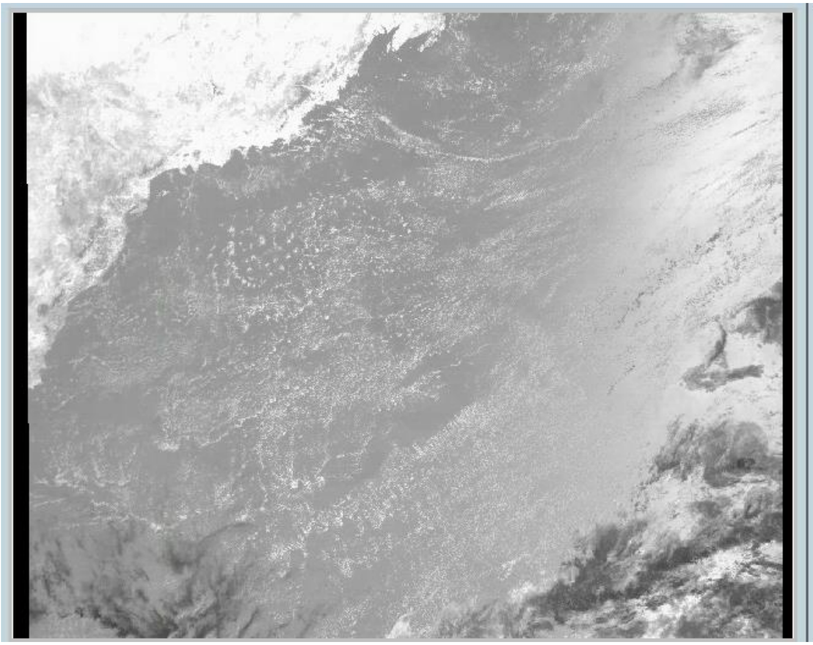
EUMETSAT Study

- Short project updating & improving RAL monitoring tools
  - Now installed and running internally at EUMETSAT
  - Allows outputs from L0 to be plotted in EUM interactive system
  - Improved output formats for consistency
  - More flexible configuration
  - Code extracted into standalone library (separate from ground calibration functions)
  - Alerts for each parameter (threshold tests)
  - Tool for mapping L0 to L1 image grid

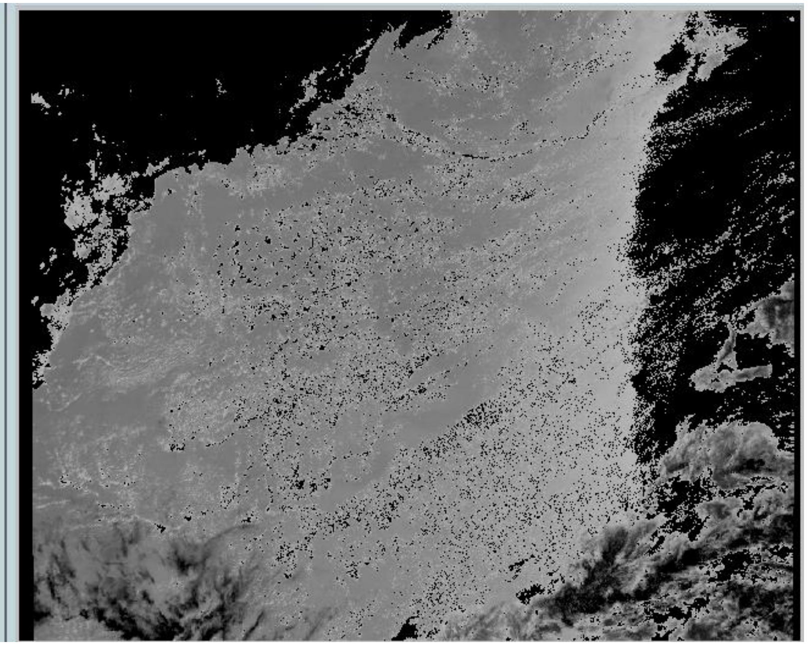
L0/L1 Comparison

- A tool was written to extract L0 data in format that can be directly compared to L1 data
  - Needed for FIDUCEO analysis

S7 Level-0 image



S7 Level-1 image



  - Outputs a NetCDF file with L0 data and indices needed to map to L1 image grid

Monitoring Alerts

- Monitoring alerts are used to
  - Give a quick overview of orbits with problems in each cycle (e.g. data gap)
  - Search for/identify problem orbits
  - Give an idea of the frequency of events
  - Highlight warnings/flags that should be investigated at L1– e.g. pointing

- Not intended to provide exhaustive check of instrument/product anomalies
  - Only checks Level-0 product status based on the existing monitoring plot functions
  - Does not replace MPC Operator checks

Monitoring Alerts

RAL Space

- Alerts are raised for three types of test:
  - Completeness of input data (partial orbit covered, gaps, missing packets)
  - Parameter out of range (e.g. temperature, scanner jitter etc)
  - Calibration problem (noise spike, VISCAL signal jump)
- Four levels of alert severity (defined in config file)
  - Alert: red
  - Warn: orange
  - Noise: grey
  - Incomplete: magenta
- Alerts and severity configured by xml file (i.e. can be changed without updating code)

Key to alerts:

ALERT	WARN	NOISE	INCOMPLETE	NONE

Date (Cycle_27)	Orbit Number (relative)															L3 (VIS)	L3 (S8 TIR)	L3 (cloud)
04-Jul-2019	145	146	147	148	149	150	151	152										
03-Jul-2019	131	132	133	134	135	136	137	138	139	140	141	142	143	144				
02-Jul-2019	117	118	119	120	121	122	123	124	125	126	127	128	129	130				
01-Jul-2019	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116			
30-Jun-2019	88	89	90	91	92	93	94	95	96	97	98	99	100	101				
29-Jun-2019	74	75	76	77	78	79	80	81	82	83	84	85	86	87				
28-Jun-2019	60	61	62	63	64	65	66	67	68	69	70	71	72	73				
27-Jun-2019	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59			

Monitoring Alerts Examples

Colours and alert levels defined in configuration file

incomplete orbit – will be processed again

Date (Cycle_22)	Orbit Number (relative)															L3 (VIS)	L3 (S8 TIR)	L3 (cloud)
17-Feb-2019	117	118	121	122	123													
16-Feb-2019	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116			
15-Feb-2019	88	89	90	91	92	93	94	95	96	97	98	99	100	101				
14-Feb-2019	74	75	76	77	78	79	80	81	82	83	84	85	86	87				
13-Feb-2019	60	61	62	63	64	65	66	67	68	69	70	71	72	73				

Alert (red) – e.g. data gap, missing VISCAL etc.

Noise spikes (e.g. from SSA) – shown in grey

Warnings (orange) – e.g. spike in NEDT

Monitoring Alerts Examples

Key to alerts:

ALERT	WARN	NOISE	INCOMPLETE	NONE

Date (Cycle_27)	Orbit Number (relative)															L3 (VIS)	L3 (S
04-Jul-2019	145	146	147	148	149	150	151	152									
03-Jul-2019	131	132	133	134	135	136	137	138	139	140	141	142	143	144			
02-Jul-2019	117	118	119	120	121	122	123	124	125	126	127	128	129	130			
01-Jul-2019	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116		
30-Jun-2019	88	89	90	91	92	93	94	95	96	97	98	99	100	101			
29-Jun-2019	74	75	76	77	78	79	80	81	82	83	84	85	86	87			
28-Jun-2019	60	61	62	63	64	65	66	67	68	69	70	71	72	73			
27-Jun-2019	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59		
26-Jun-2019	31	32	33	34	35	36	37	38	39	40	41	42	43	44			
25-Jun-2019	17	18	19	20	21	22	23	24	25	26	27	28	29	30			
24-Jun-2019	3	4	5	6	7	8	9	10	11	12	13	14	15	16			

Orbital plots by cycle

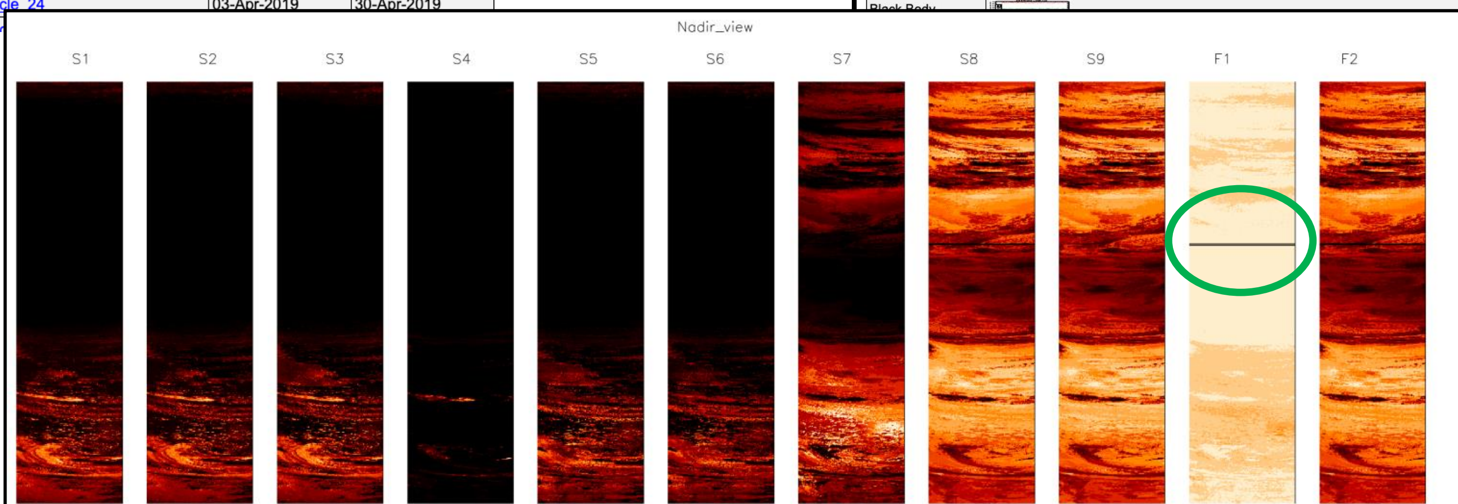
Cycle Number	Start date	End date
Cycle 27	23-Jun-2019	20-Jul-2019
Cycle 26	27-May-2019	23-Jun-2019
Cycle 25	30-Apr-2019	27-May-2019
Cycle 24	03-Apr-2019	30-Apr-2019

S3B SLSTR Monitoring

Orbit Number 66

28-Jun-2019 11:47:32 - 13:27:20

Description	Plots
Missing packets	Missing packets detected
Counts Histogram	
Swath Average	
Count Trend	
Counts Image	
Black Body	



Uses of Monitoring Tools

Output of the monitoring tool:

- Library of static plots
- Summary text files
  - File for each orbit containing instrument temperatures
  - Files for each orbit containing VISCAL and BB signals
  - Long term trend files containing orbit averages

- The output text files are available for interactive plotting with existing EUMETSAT monitoring system
- Can be used in further ad hoc analysis
- Can be used for uncertainty calculations

Uses of Monitoring Tools

RAL Space

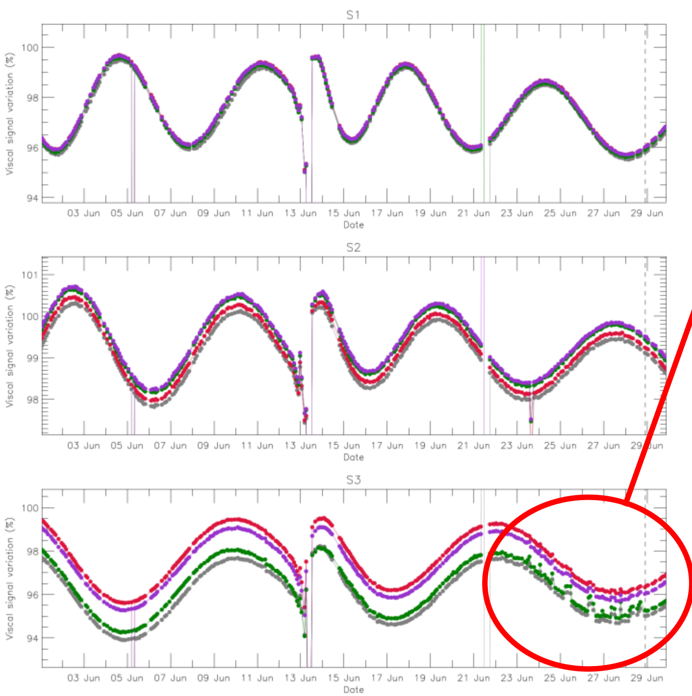
The monitoring page allowed searching previous S3A data as part of and investigation into S3B VISCAL signals

– S3A signal jumps for channel S3 were not considered significant before, but are more interesting in light of S3B signal jumps

S1

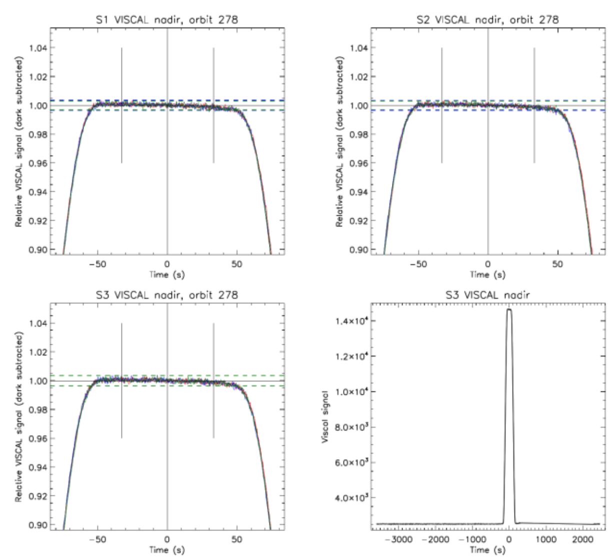
S2

S3

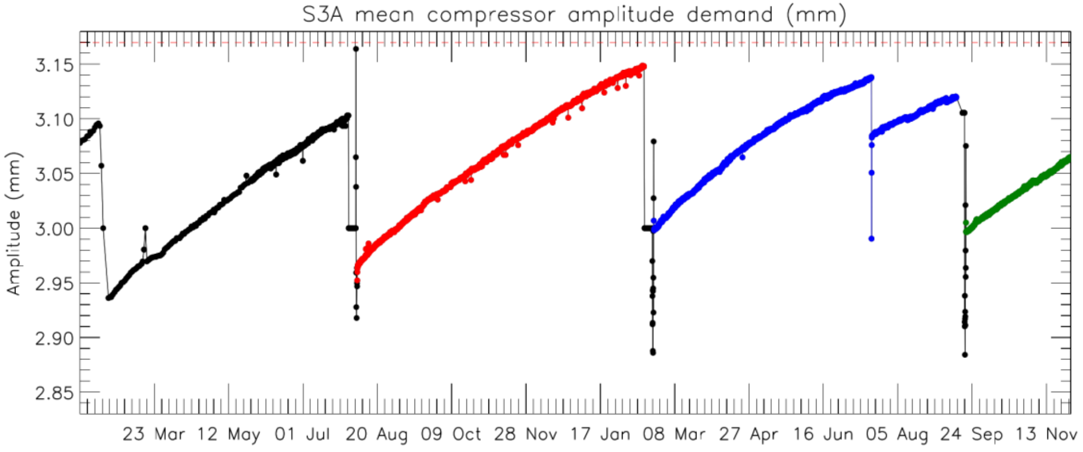


small jumps - started in June 2016

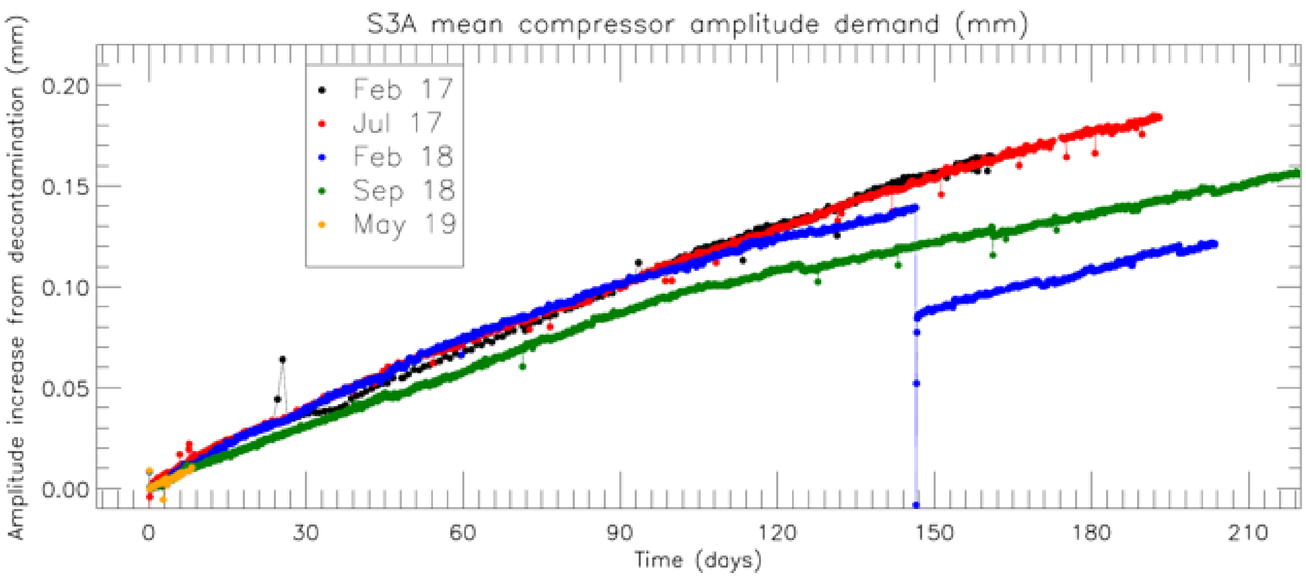
New plots were added for each orbit to show the VISCAL peak values



Uses of Monitoring Tools

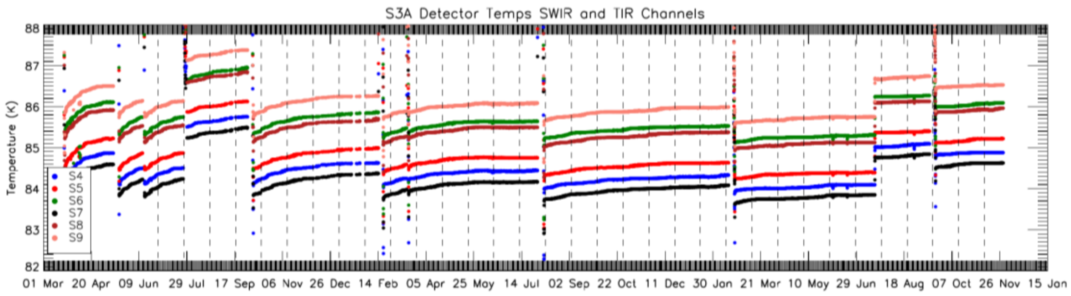


S3A compressor amplitude demand since Feb 2017 (from monitoring page)



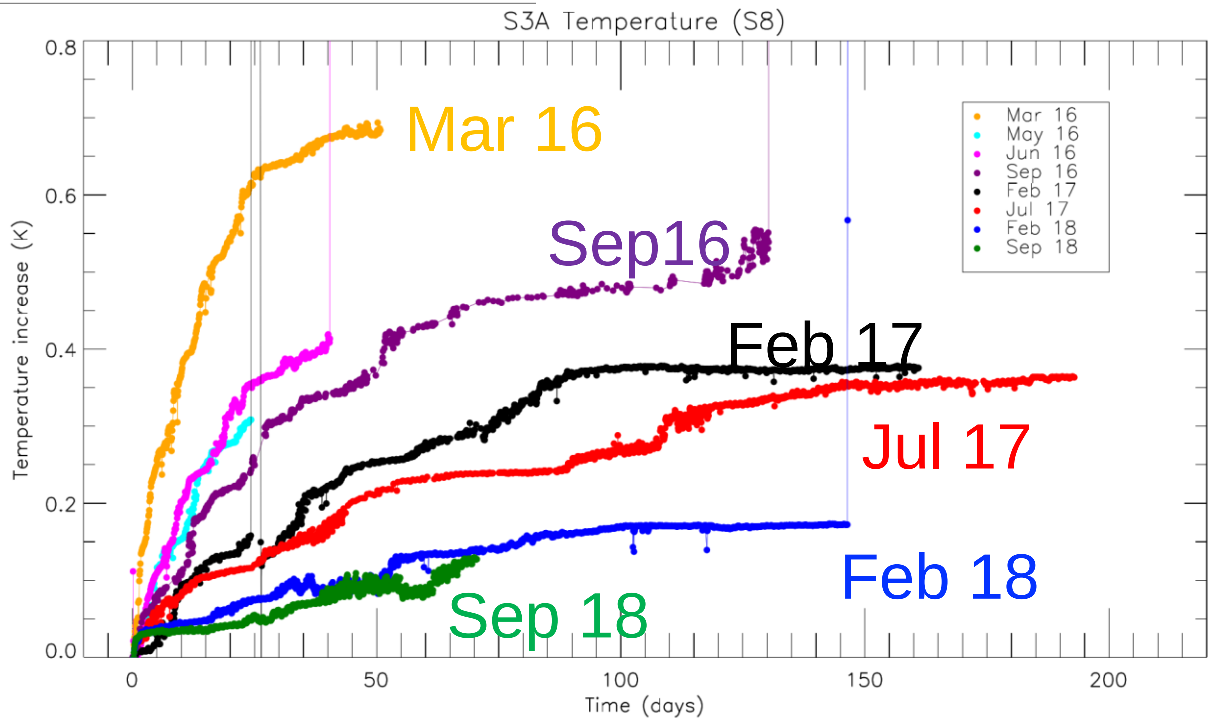
Replotted to show amplitude increase following each decontamination

Uses of Monitoring Tools



S3A detector temps through the mission

S8 detector temperature replotted to show the change following each decontamination



Contents

- Introduction to SLSTR
- Radiometric Calibration Model & Uncertainty Estimates
- Uncertainty Tool
- L0 Monitoring
- Next Steps

Next Steps

L0 Monitoring and L1 Uncertainty tool delivered to Eumetsat

- Uncertainty tool could be made available to L2 users

Adapt ATBD and IODD to IPF

- Can provide per pixel uncertainties but with increase in product size
- Updates to L1 product specification to include tables of noise vs. temperature, additional parameters in Quality datasets

Generate L1 uncertainties from L0 (or L1) data

- Will need ATBD to implement calibration model (see next slides)
- If we adopt 'lite' approach – implementation is not a huge processing.
- Ideally done as a modification to the IPF to derive uncertainties directly from L0
  - I.e. has advantage that the re-gridding process is performed at the same time
- Could be done as a post processing based on content of L1 products but will need modification to the L1 product content (additional fields) – change to L1 IPF needed

Deriving L1 Uncertainties from L0

BB Temps,
Instrument Temps
Counts, Noise
Calibration Coefficients

L0 data + ADFs

Compute
Partial
Derivatives
C

Sensitivity of effect on measurand

Estimate
Uncertainties
U

Type-A from analysis of L0 data
Type-B a-priori from pre-launch calibration, predictions….

Determine
Correlations
R

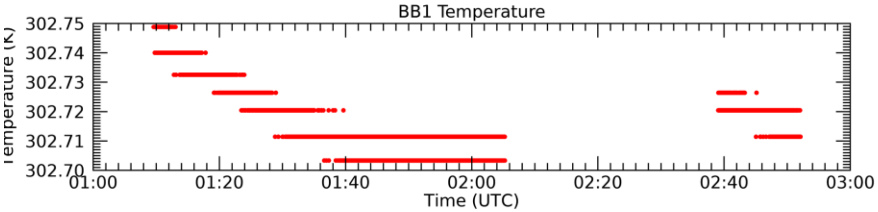
e.g. Emissivity, Instrument Temperature drifts

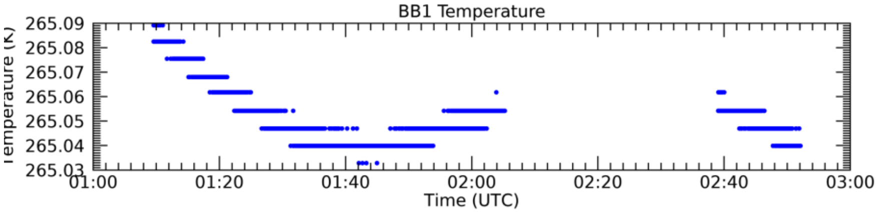
Derive
Covariances
$S = CURU^T C^T$

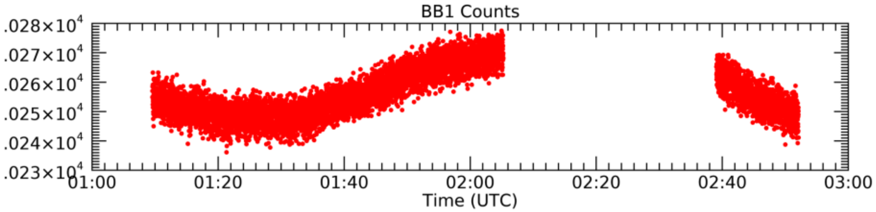
Combined
Uncertainty
$uL^2 = \Sigma S$

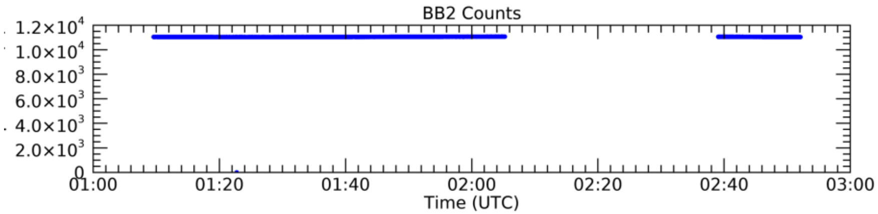
$$(uL_E)^2 = \sum_{i=1}^{N}\left(\frac{\partial L_E}{\partial x_i}ux_i\right)^2 + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\frac{\partial L_E}{\partial x_i}\frac{\partial L_E}{\partial x_j}ux_i\, ux_j v(x_i, x_j)$$

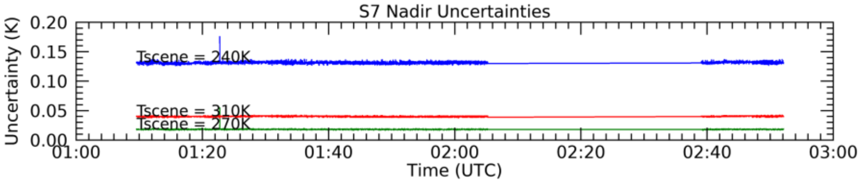
L1 Uncertainties Example Orbit – Typical

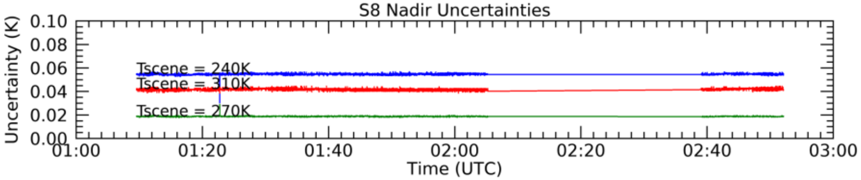


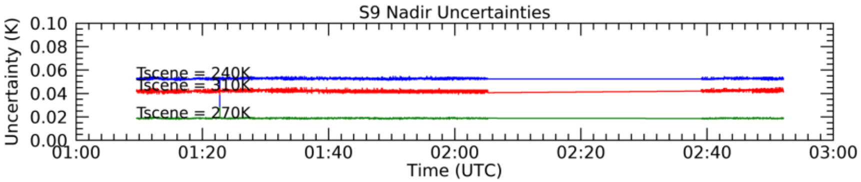


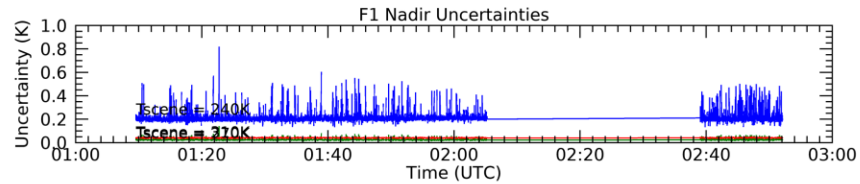


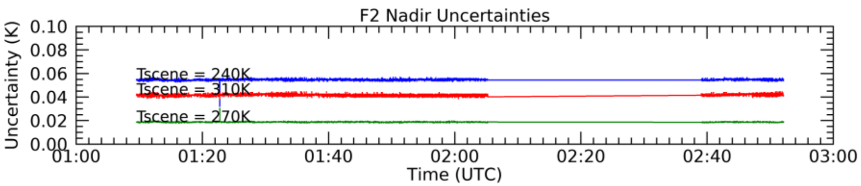




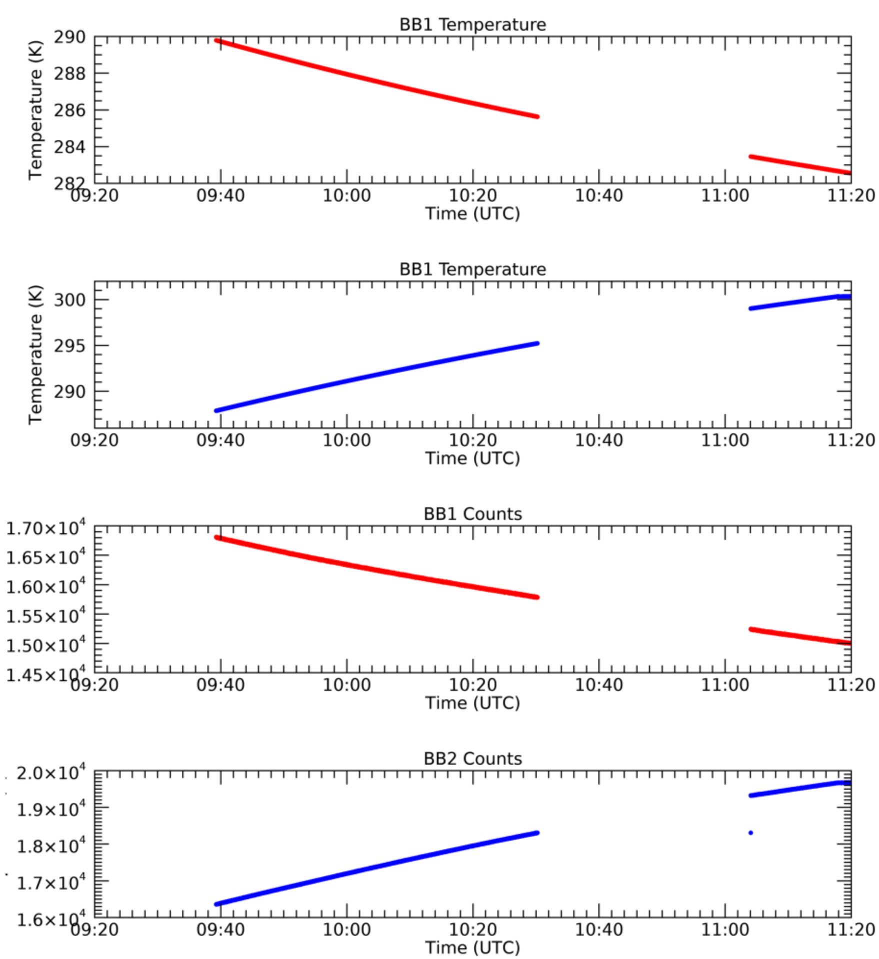


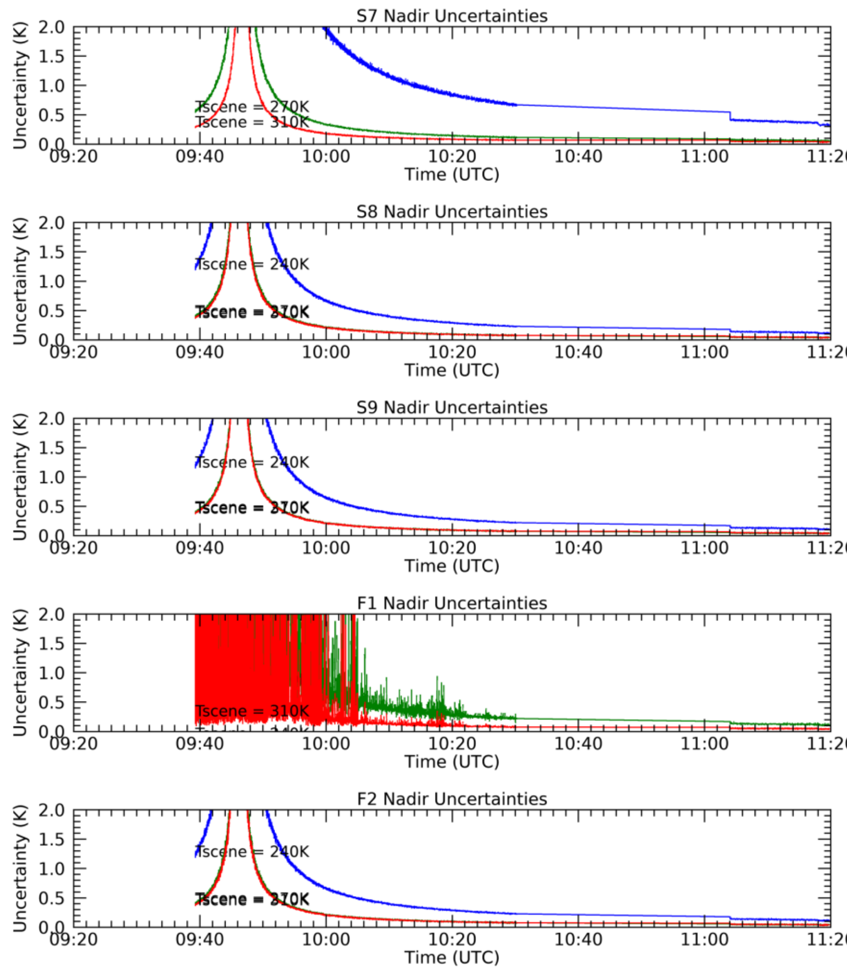






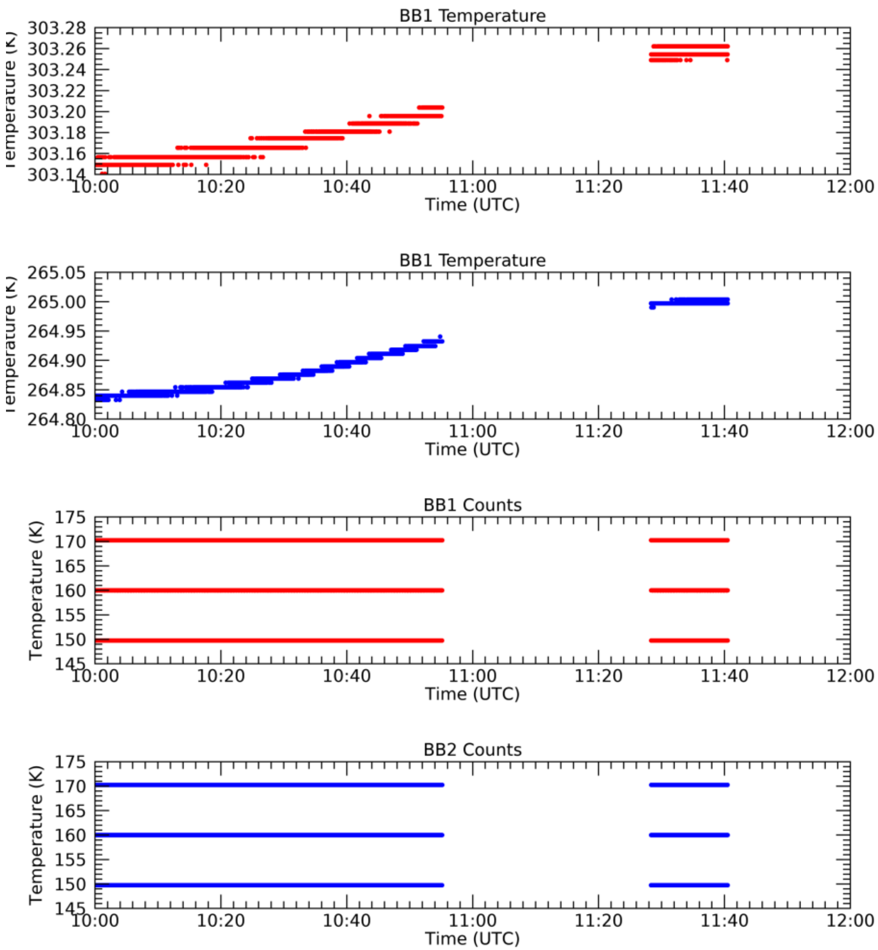
L1 Uncertainties - Example Orbit - BB Cross Over

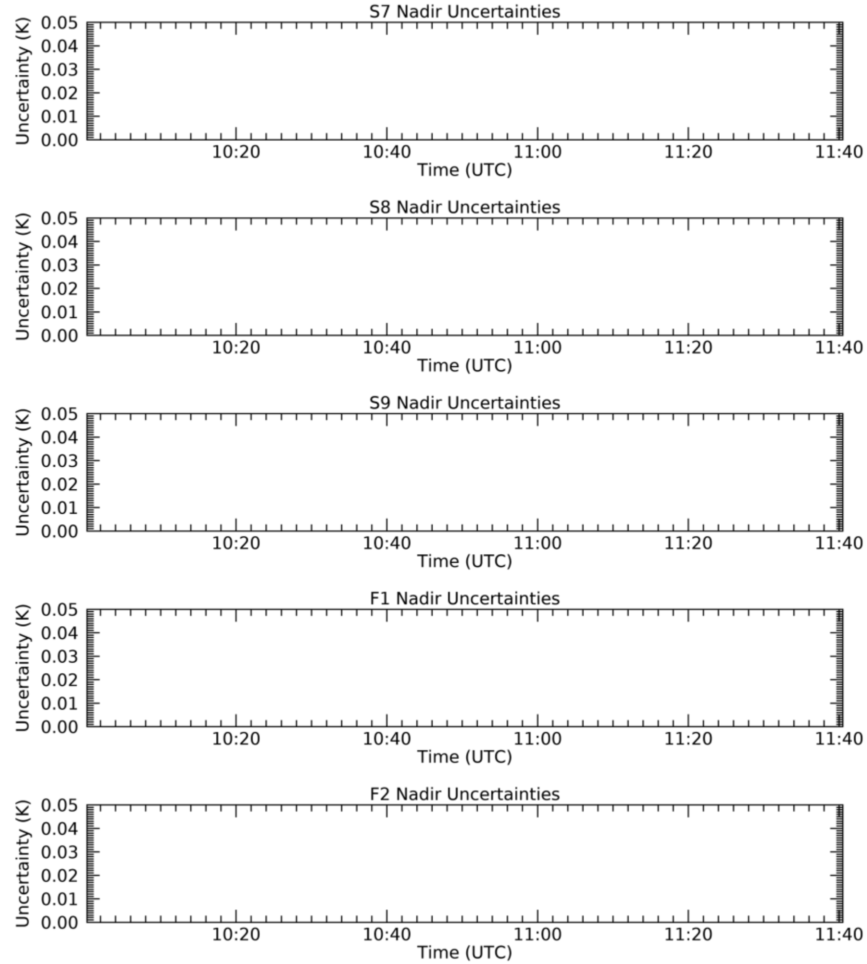




L1 Uncertainties - Example Orbit – Detectors Off

Uncertainties = invalid





Thank you!