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AVHRR FCDR (β)

Mike Taylor, Jon Mittaz, Chris Merchant et al

Overview

- FCDR uncertainty traceability for the AVHRR
  - Measurement equation
  - Traceability tree
  - Effects and uncertainty propagation
- FCDR generation
  - Modeling
  - Workflow
- FCDR characteristics
  - Dataset
  - Sensor/channel uncertainties
  - Example contents
- FCDR enhancement
  - Data standardization
  - Data improvements

Measurement Equation, Traceability tree, Effect tables and GUM

FCDR UNCERTAINTY TRACEABILITY

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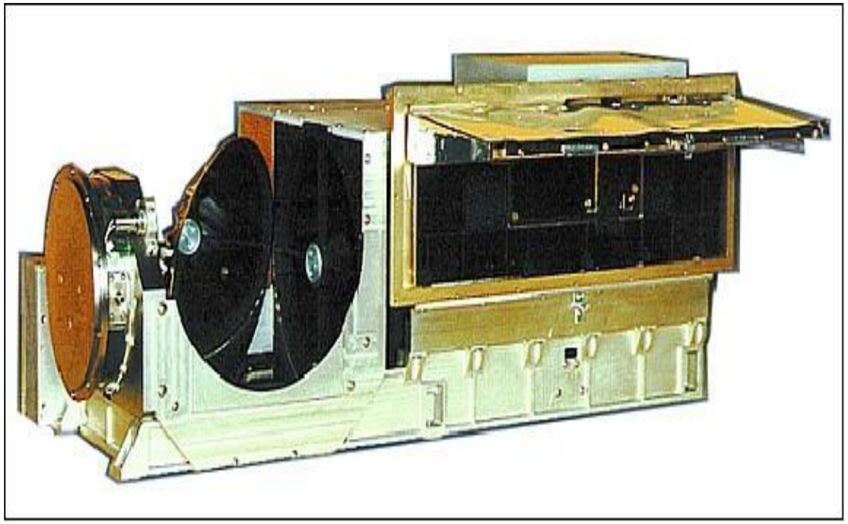
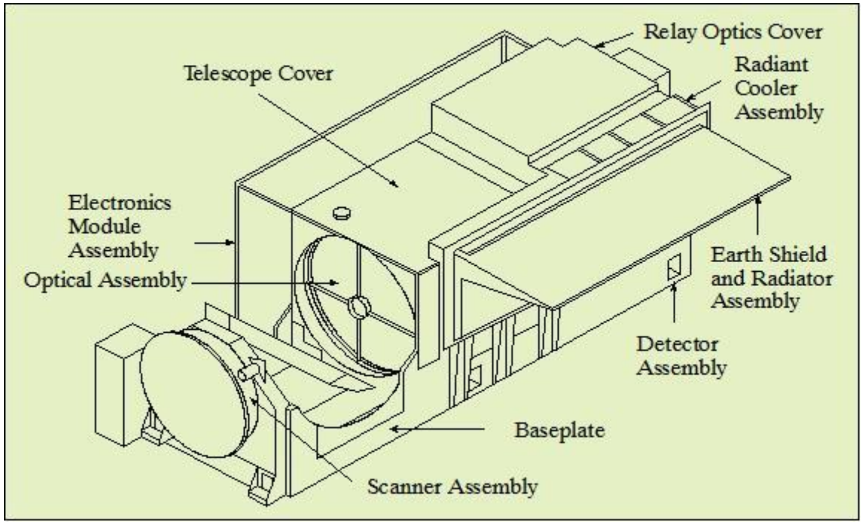
AVHRR

- Sun synchronous POES (~14 orbits/day), swath width (2399km), GAC resolution at nadir (~4km), 10-bit quantisation
- 5 channels (1,2,3A=Reflecance and 3B,4,5=IR in alternation)
- AVHRR/3 has an Earth shield





Measurement Equation

- provides a recalibrated and harmonized FCDR for the AVHRR sensor series (reflectance and IR) with traceable uncertainties
- derives calibrated radiance from ICT radiance and averaged ICT and space counts and earth counts

ICT Radiance, L_{ICT}

$$L = a_0 + \frac{(\epsilon + a_1)L_{ICT} - a_2(\bar{C}_S - \bar{C}_{ICT})^2}{\bar{C}_S - \bar{C}_{ICT}}(\bar{C}_S - C_E) + a_3(\bar{C}_S - C_E)^2 + O$$

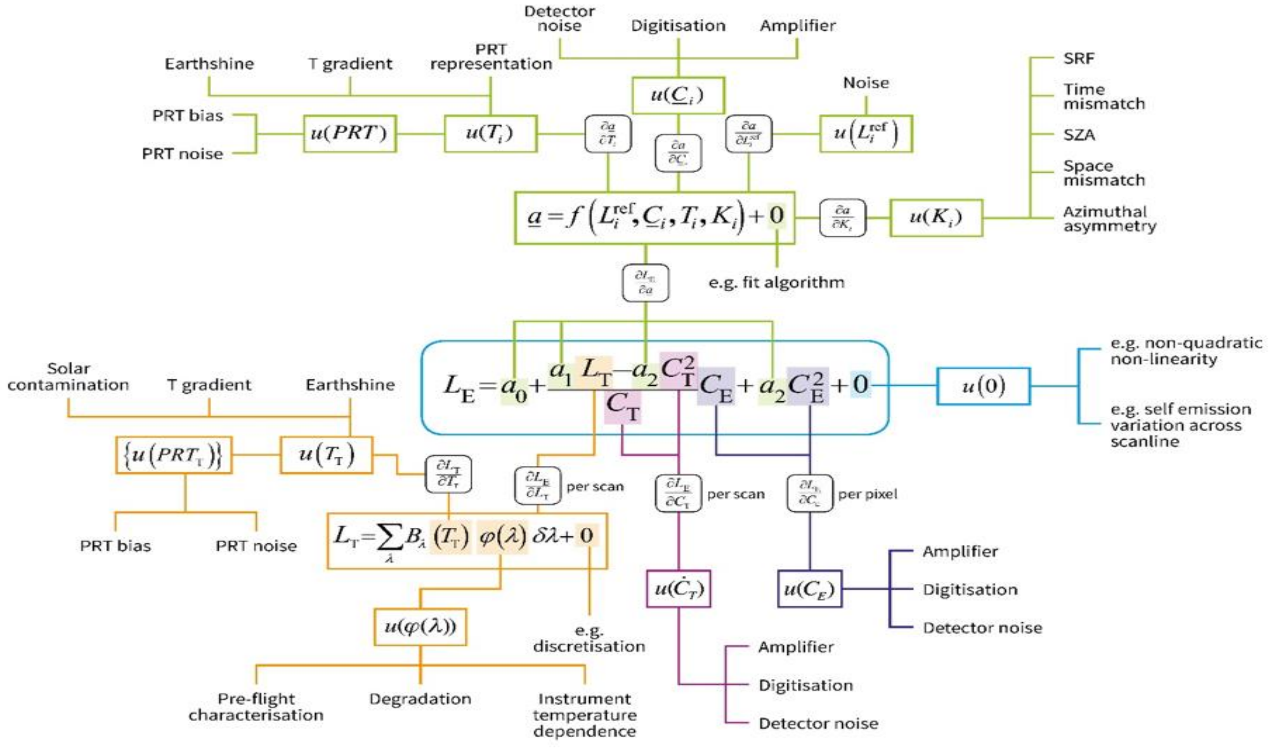
Averaged Space Counts C_S

Averaged ICT Counts C_{ICT}

Earth Counts, C_E

Traceability Tree

- physically-traceable (to SI where possible) effects that contaminate the signal



Jonathan Cherry, NPL

GUM

- Then we correct for effects and use the Guide to the expression of Uncertainty in Measurement (GUM) to propagate uncertainties (independent, structured and common)

$$u_c^2(y) = \sum_{i=1}^{n} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i) + 2 \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \frac{\partial f}{\partial x_i} \frac{\partial f}{\partial x_j} u(x_i, x_j)$$

Adding in quadrature

Sensitivity coefficient times uncertainty

Correlation term

Sensitivity coefficients times covariance

2 because symmetrical

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Effects tables

- 11 sources of uncertainty (effects) identified and grouped by similar correlation structure into 6 effects tables:

1. Earth count noise / averaged space count noise / averaged IWCT count noise – calculated from Allan deviation of ICWT views and space views
2. SRF wavelength shift
3. PRT count noise / PRT bias and offset between baseplate and IWCT temperatures / PRT representiveness (thermal gradients)
4. Solar contamination
5. Temporal bias evolution related to changing thermal environment
6. Non-quadratic nonlinearity / variable nonlinearity coefficient

- **Documented in D2.2d (AVHRR)**

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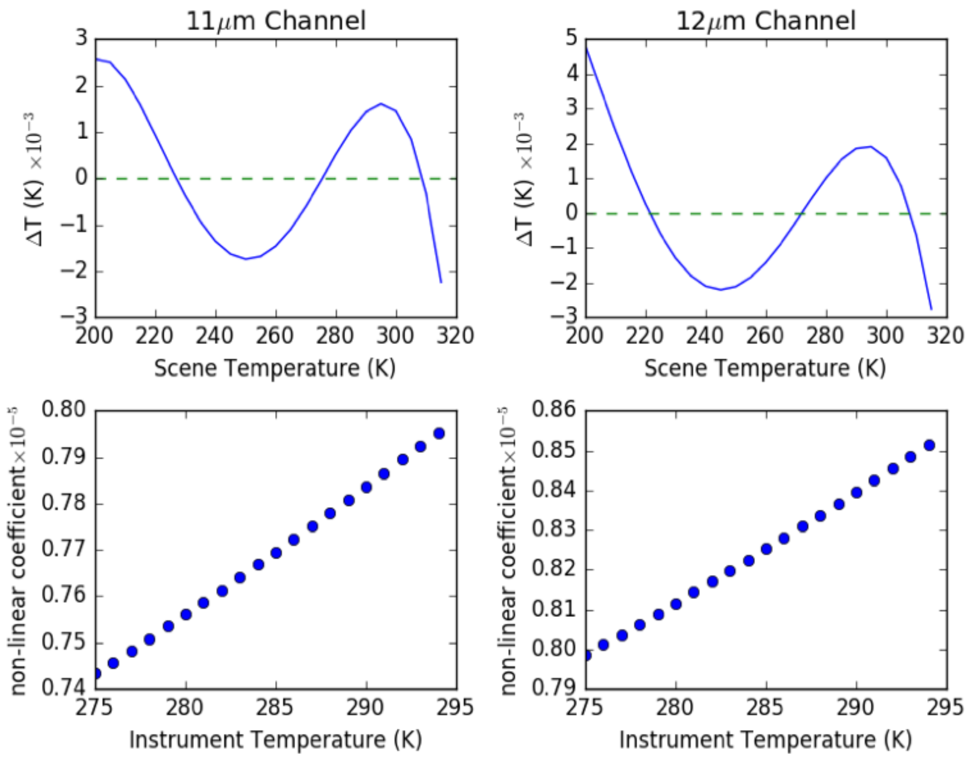
Quadratic Model Assumption



deviation from a quadratic model for an HgCdTe detector for the 11 and 12µm channels using a theoretical model. This indicates that the deviation from a quadratic are at the milli-Kelvin level. The two lower plots show changes in the quadratic nonlinearity coefficient as a function of instrument temperature (a proxy for the total self-emission radiance) and indicates for a typical AVHRR orbit a variation of ~1% change in the coefficient

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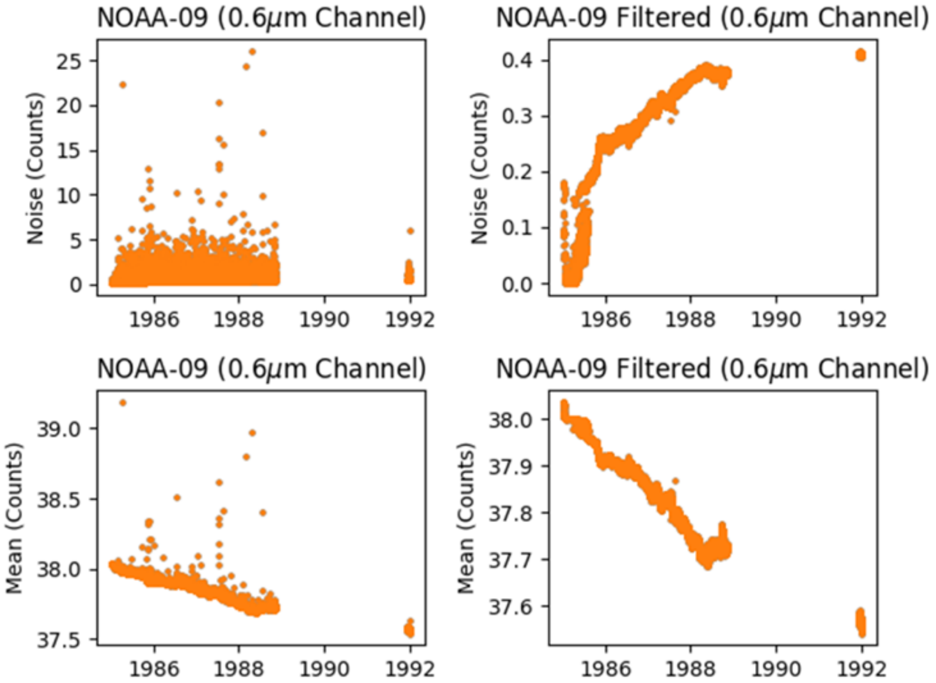
Modeling aspects, Workflow, Example contents

FCDR GENERATION

Modeling aspects

- (robust) outlier filtering applied to remove outliers in ICT, space and PRT counts in 2 steps:
  1. **COARSE** = median statistics thresholds
  2. **FINE** = 12:1:12 scanline filtering ±5 Allan deviations [Mittaz et al 2011]
- Interpolation of solar contamination events
- Thermal state of ICT estimated by mean PRT value
- In-flight smoothing calibration is applied, averaged over sensor-specific number of scanlines
- SRF interpolation and denoising

Outlier filtering (VIS)



Noise and mean counts from NOAA-09 0.6 micron channel. The left hand column shows the estimated noise and mean value before filtering and the right hand column shows the same after filtering (please note change in y-scale). So both a filtered dataset and a variable noise are needed to correctly use the AVHRR visible channel data.

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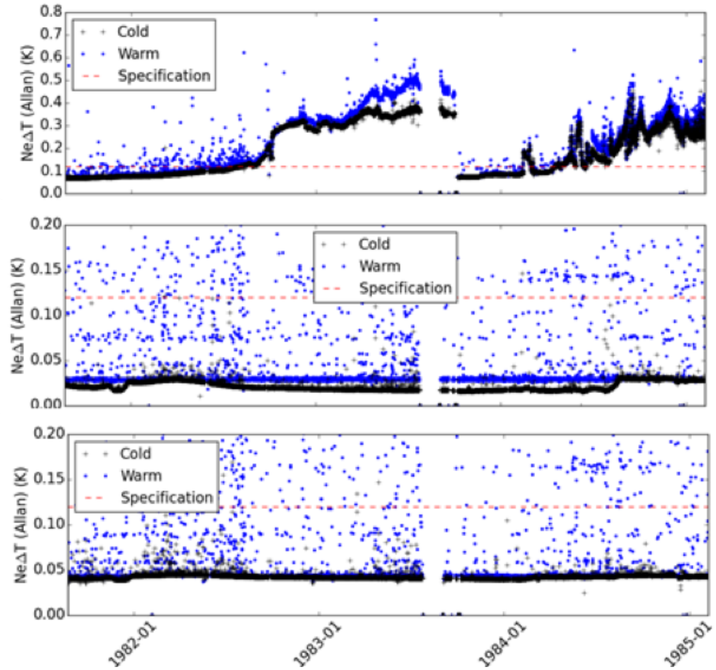
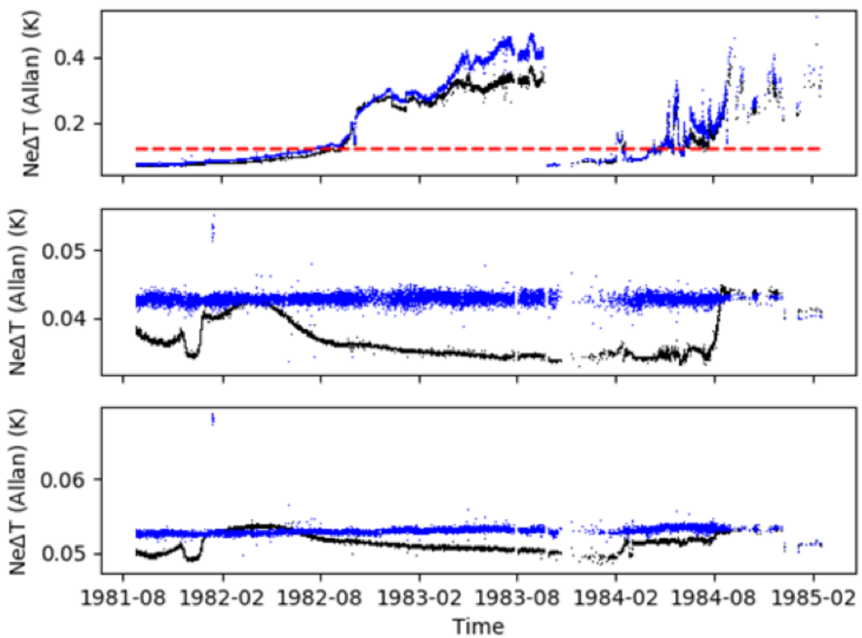
Outlier filtering (IR)





(Left) 3.7, 11 and 12 micron channel NeΔT (@300K) for data where outlier filtering has not been applied. (right) NOAA-7 data where outlier rejection has been applied. Note the time evolution of the noise. The dashed red line shows the design specification NeΔT often used as a noise estimate.

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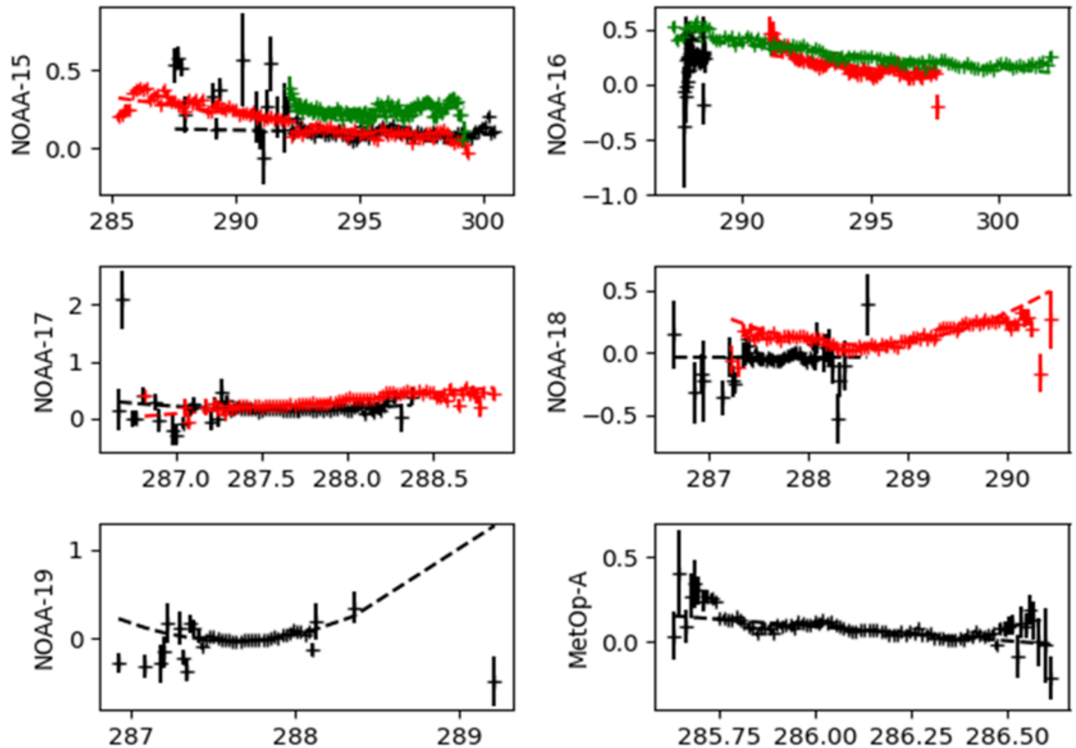
Thermal environment bias (relative to RTM BTs)



Observed bias in the 11 micron channel for a range of AVHRR/3 sensors as a function of 'instrument' temperature. The different colours represent different time periods and shows the evolution of the effect

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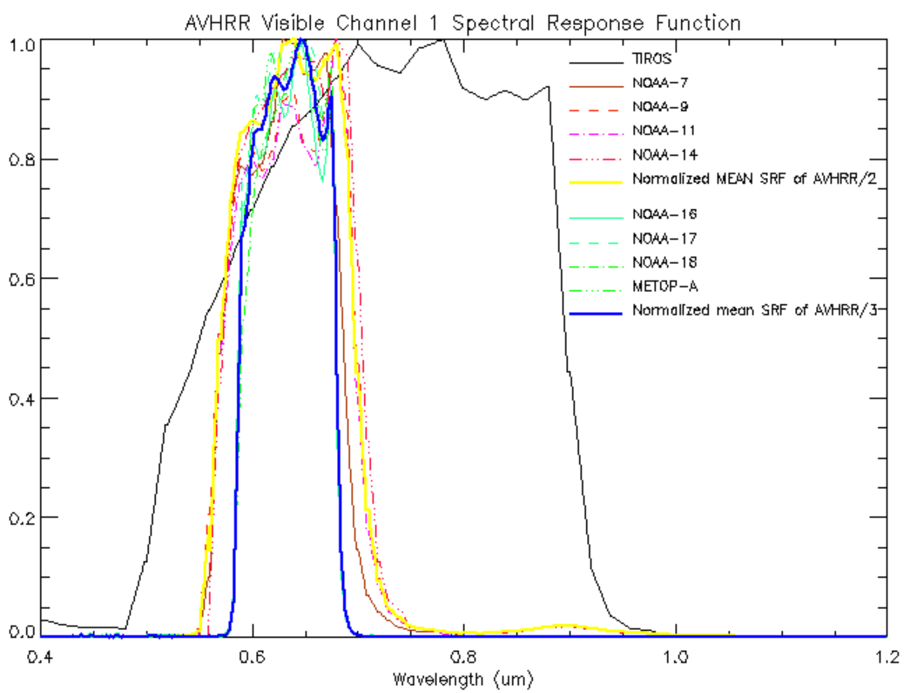
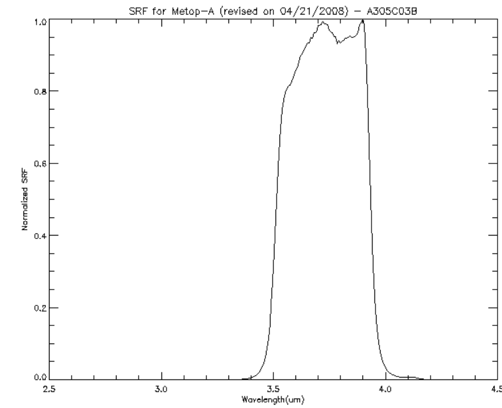
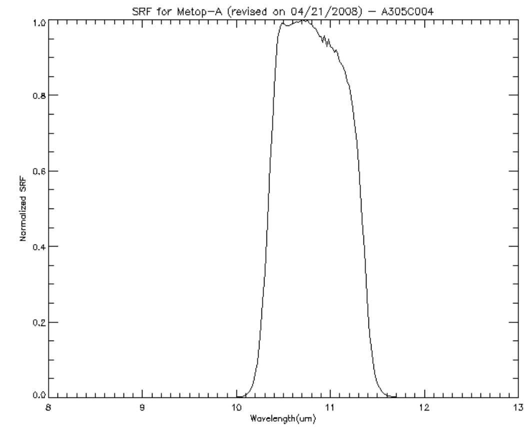
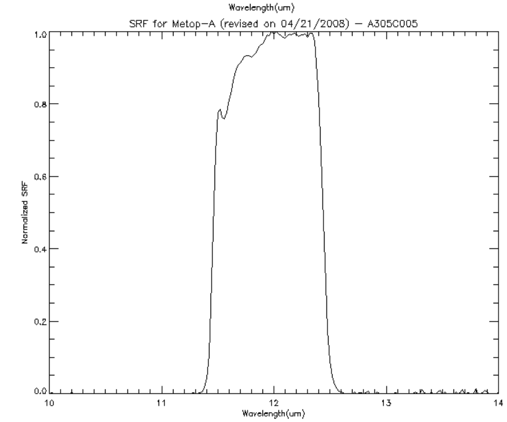
SRF

- SRF source: https://www.star.nesdis.noaa.gov
- Thanks to hard work by to Xiangqian Wu
- Need for SRF interpolation / denoising at tails
- Notable sensor and channel differences
- Need for harmonization over sensor series









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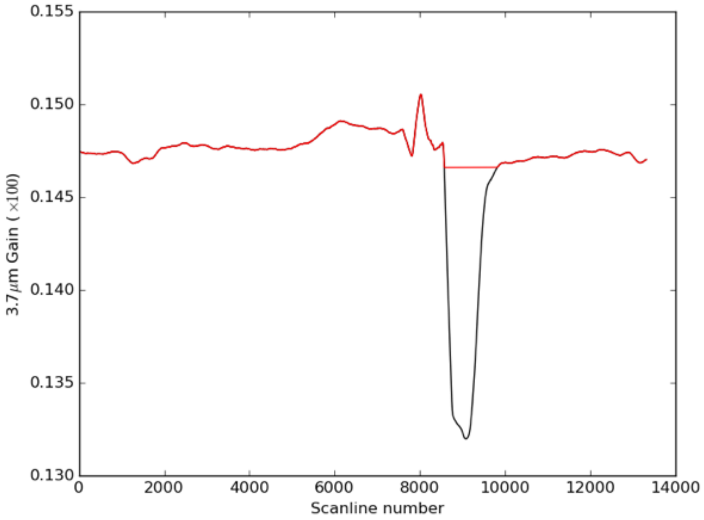
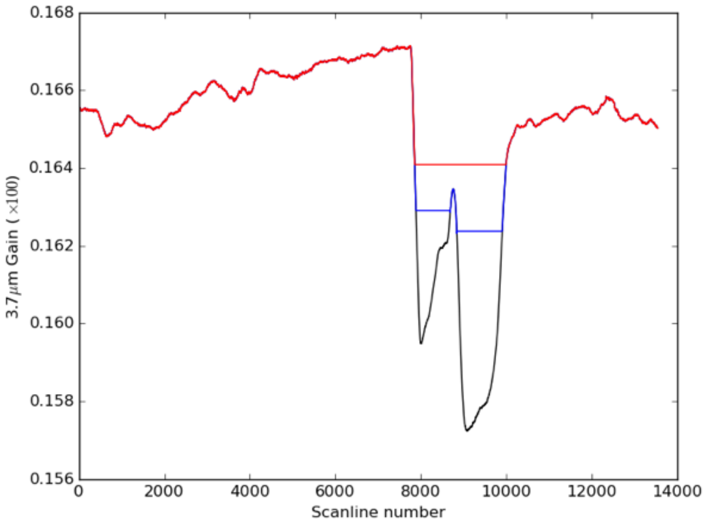
Solar contamination model

Currently a simple solar contamination model is used that interpolate the corrected operational gain

But it works for periods before operational model implemented

- This will be updated as ICT gradient error modification code will change how this works





- Before NOAA algorithm (pre-1995) so nothing to compare with

- NOAA algorithm exists (blue line)
- Works better than NOAA algorithm

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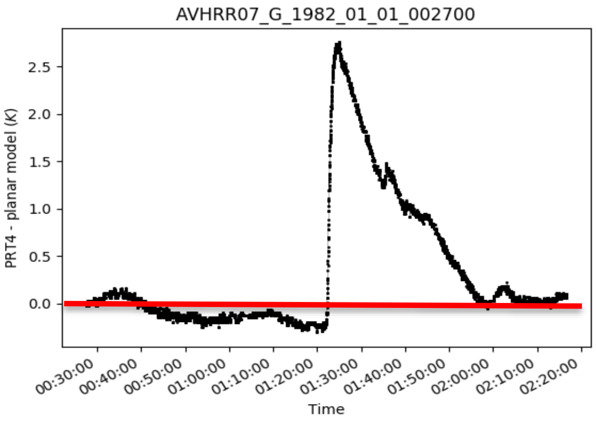
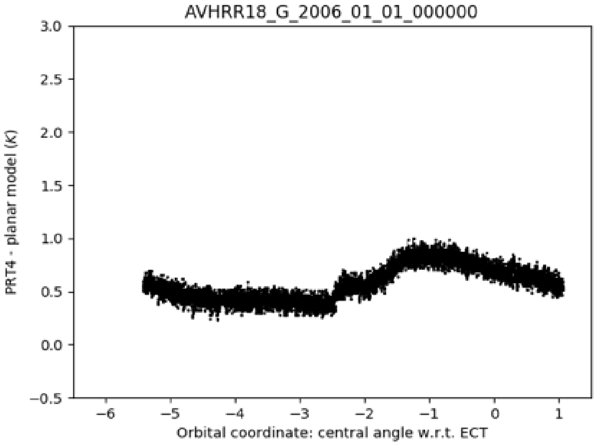
Thermal state of ICT

- The IWCT temperature is not necessarily well represented by a mean PRT temperature due to thermal gradients across the instrument from direct solar heating
- We place the 4 PRTs equidistantly at points in a square and fit a planar model through the measured values of 3 of them to estimate the value of PRT4 (choice is arbitrary). The PRT anomaly is the difference between the measured PRT4 and its estimated value
- The assumption that the mean PRT value is correct means that the gradient must be planar (i.e. zero anomaly)
- We can use the PRT anomaly as a proxy for how the thermal environment around the orbit





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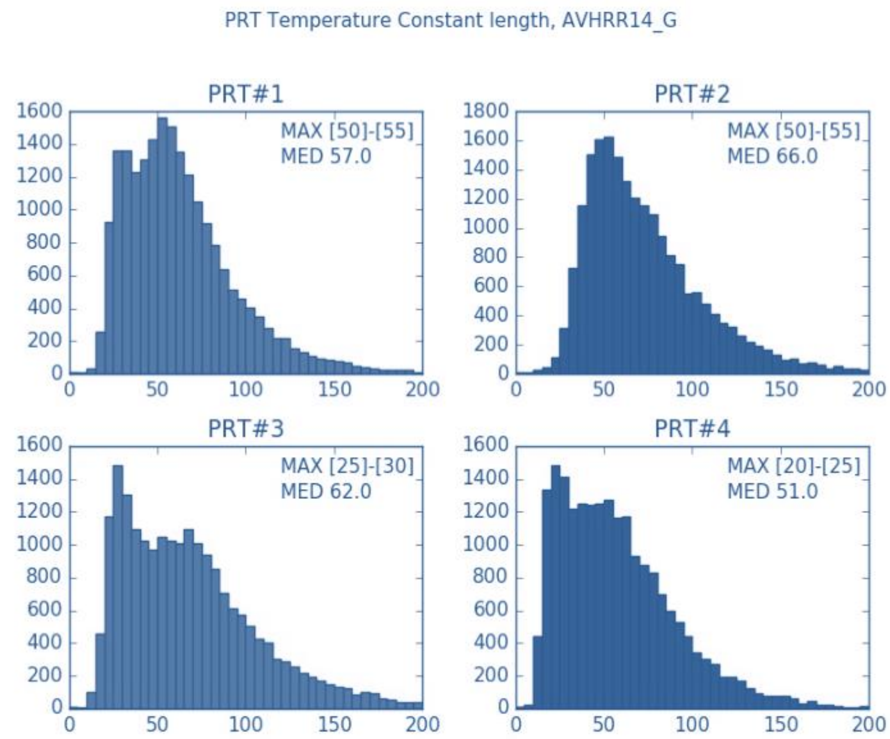
Sensor-specific cross-line correlation smoothing

PRT Smoothing Scale	Prt1	Prt2	Prt3	Prt4	Mean
AVHRR08_G	48	36	42	19	36.25
AVHRR09_G	91	90	85	89	88.75
AVHRR10_G	95	106	95	98	98.5
AVHRR11_G	76	76	78	73	75.75
AVHRR12_G	50	58	49	65	55.5
AVHRR14_G	57	66	62	51	59
AVHRR15_G	99	92	108	99	99.5
AVHRR16_G	59	119	121	112	102.75
AVHRR17_G	37	31	37	31	34
AVHRR18_G	217	220	223	223	220.75
AVHRR19_G	8	8	8	8	8
AVHRRMTA_G	93	81	98	76	87

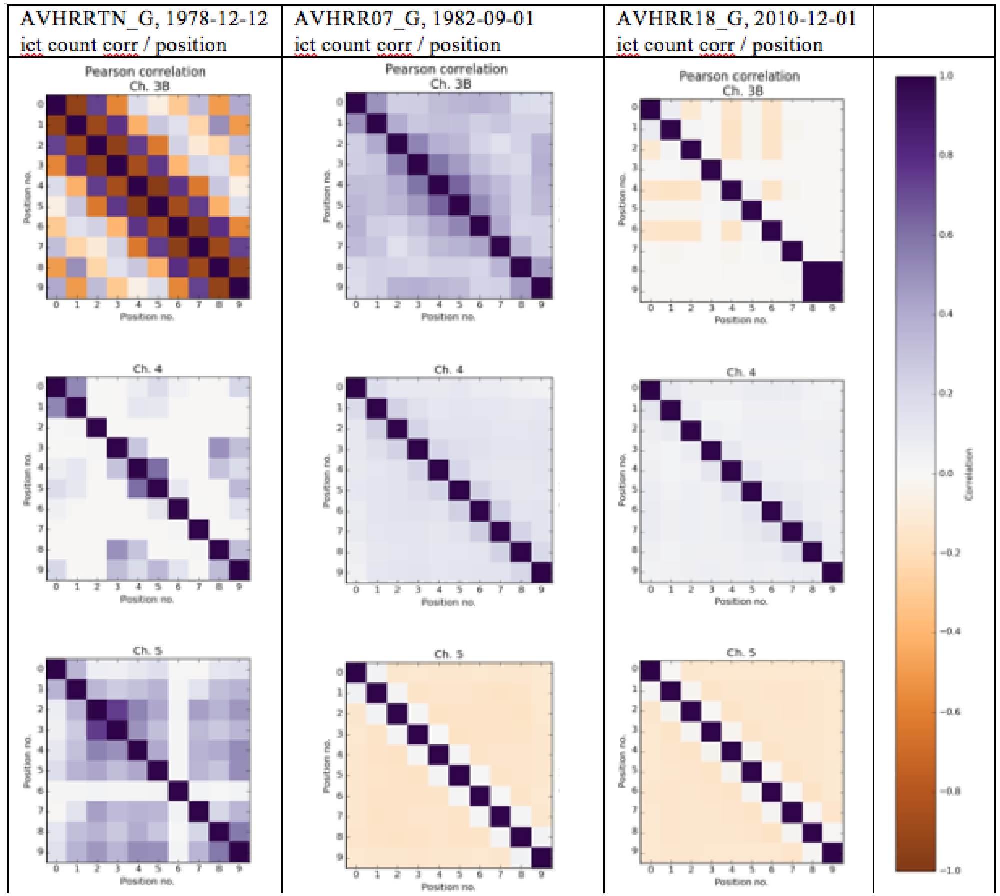


Mean over AVHRR/1 ~ 67
Mean over AVHRR/2 ~ 70
Mean over AVHRR/3 ~ 92

Average spatial_correlation_scale ~ 40 scanlines

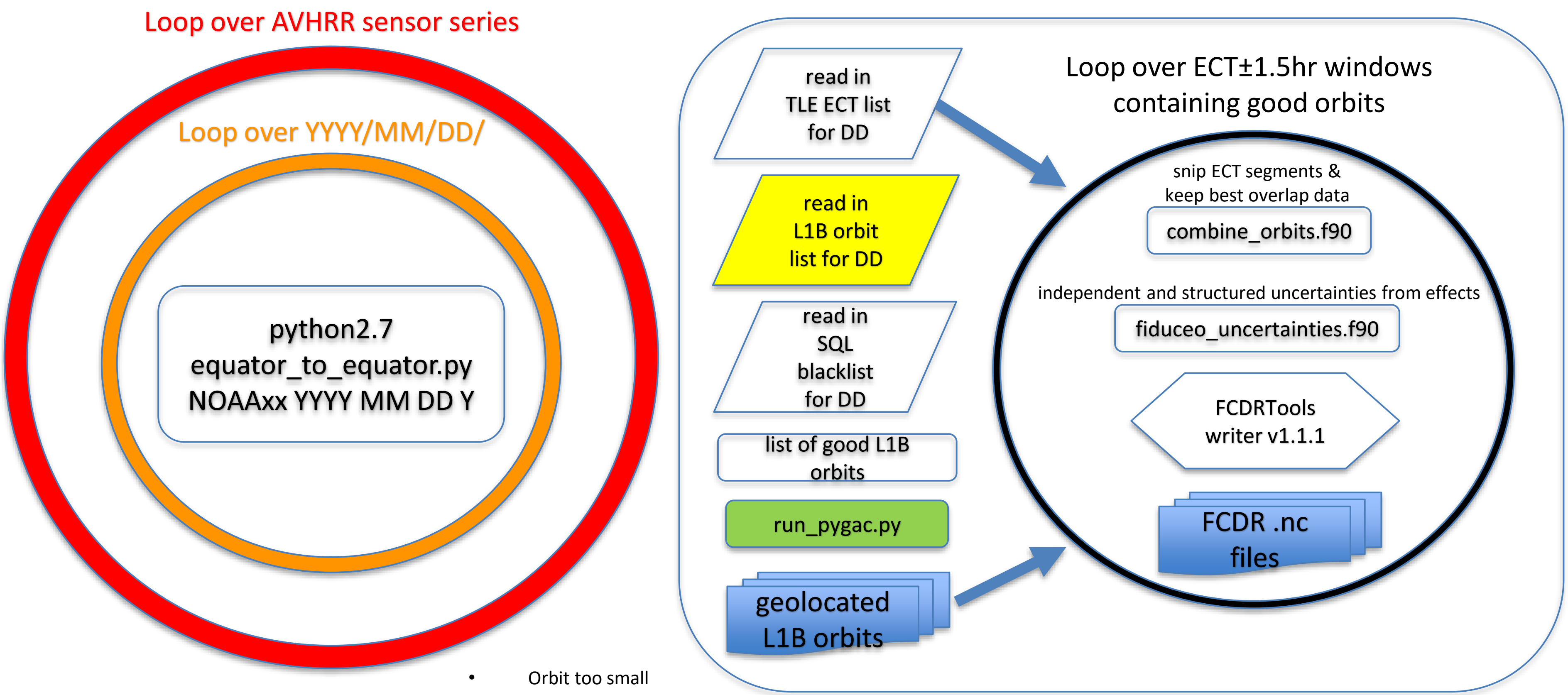
Sensor-specific scale is coded in Easy FCDR

Example: ICT scanline correlations



ICT noise correlations between IR channels for TIROS-N, NOAA-07 and NOAA-18. The Pearson product-moment correlation is shown

Workflow (with PyGAC)



- Orbit too small
- Orbit too long
- Bad L1C quality
- Ground station duplicate

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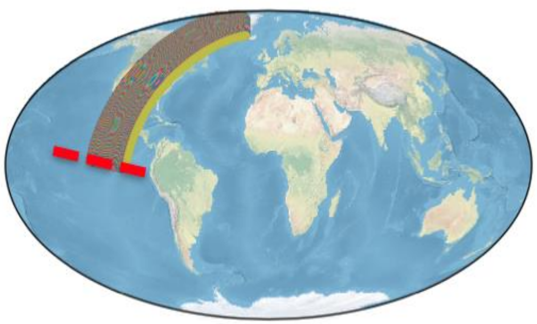
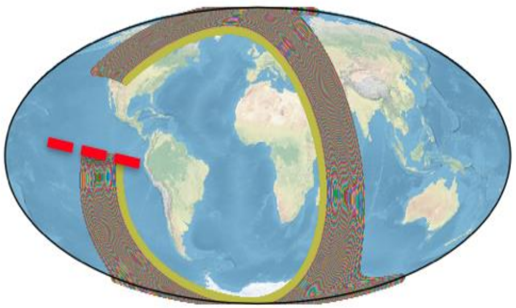
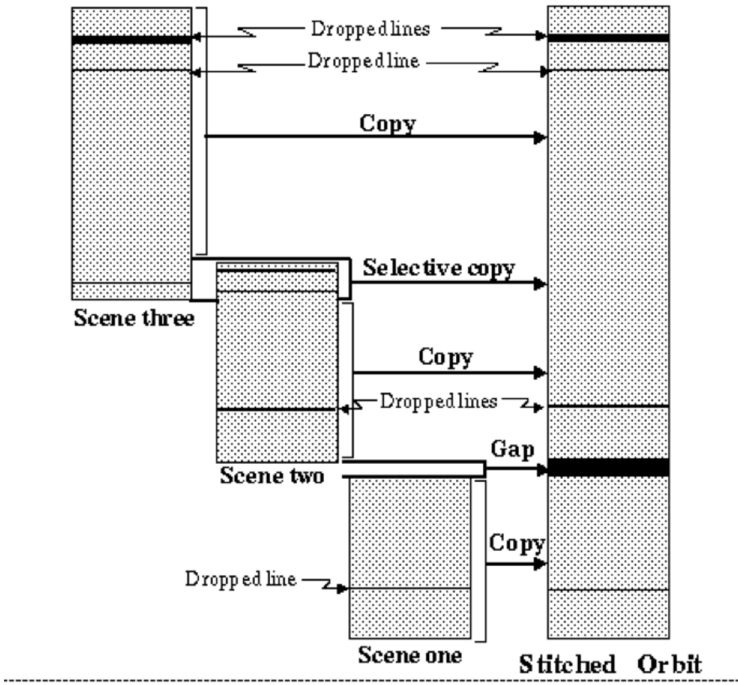
Equator-to-Equator Orbit processing



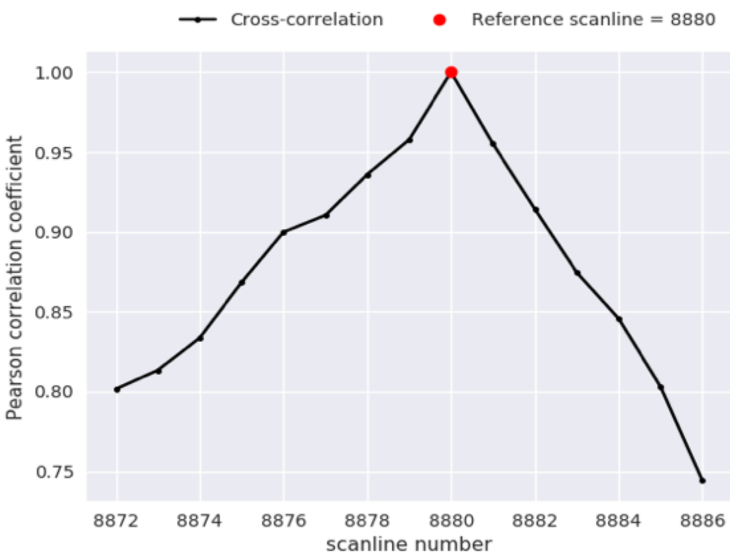


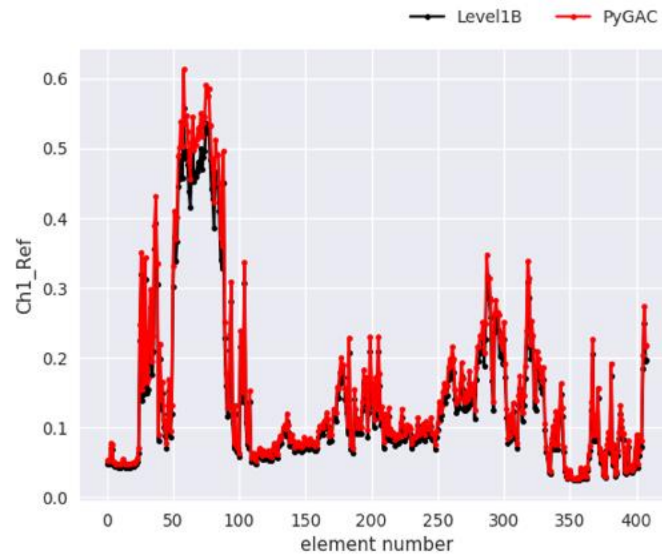
ECT1 = 14:56
ECT2 = 16:25

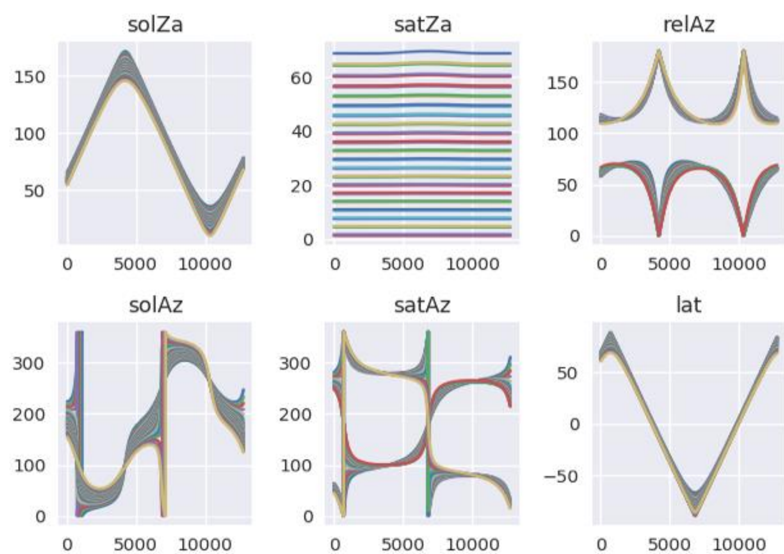
FIDUCEO_FCDR_L1C_AVHRR_NOAA06_19800321143214_19800321145600_EASY_v0.2pre_fv1.1.1
FIDUCEO_FCDR_L1C_AVHRR_NOAA06_19800321145600_19800321162531_EASY_v0.2pre_fv1.1.1



PyGac Geolocation







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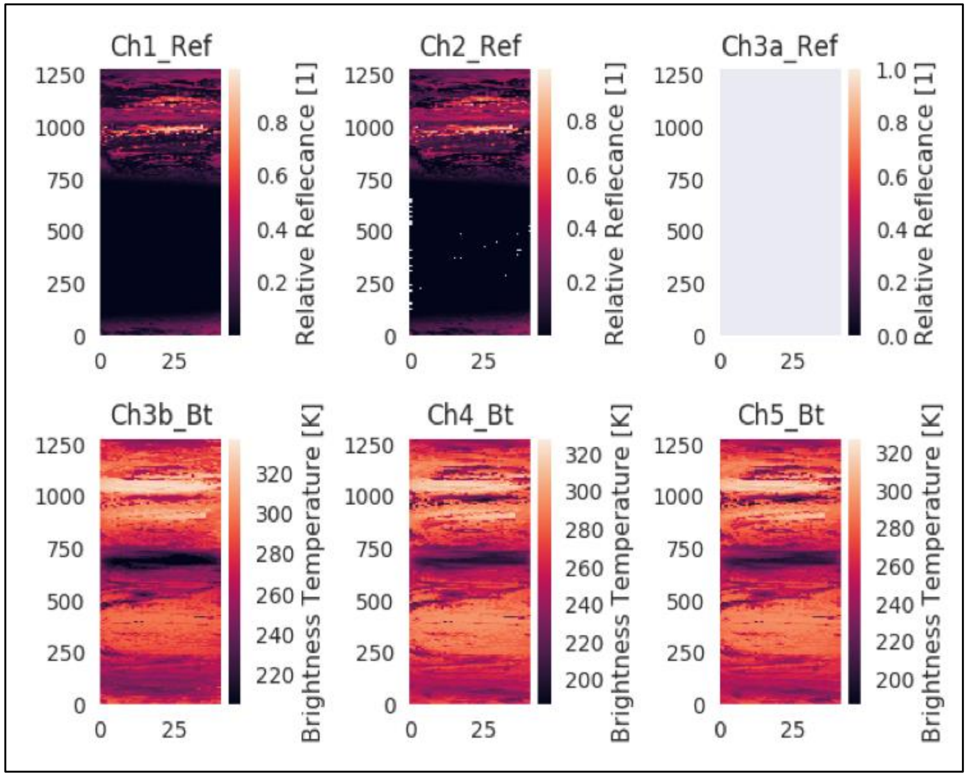
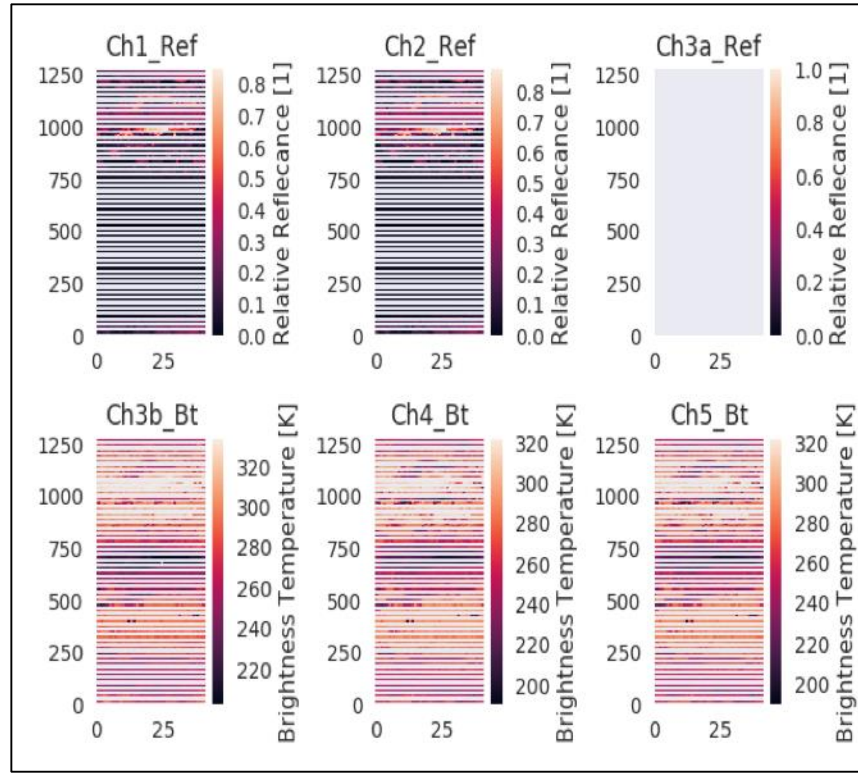
FCDR v PyGac Quality Flagging



PyGAC



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Easy FCDR, Example Contents, Statistical Summaries

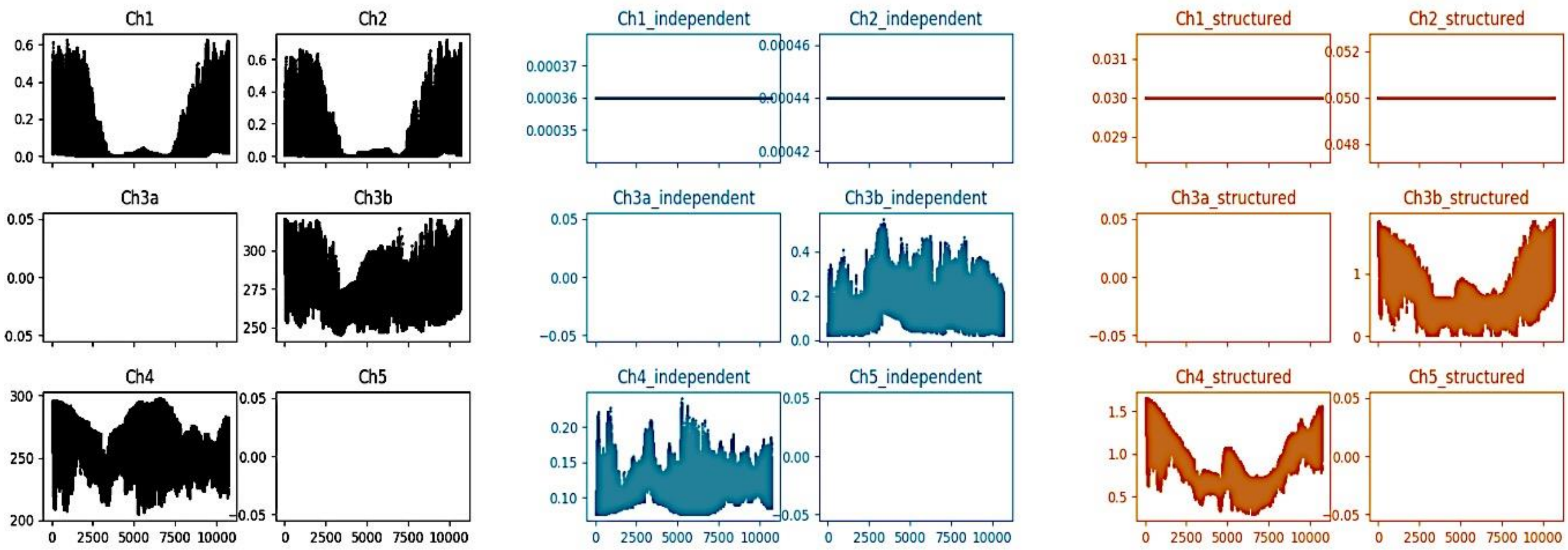
FCDR CHARACTERISTICS

Easy FCDR

- Unharmonized pre-β (full L1C archive) on CEMS = 23.46Tb (~half a million processed orbits)
- Channel level independent & Structured uncertainties calculated for all processed orbits
- Metrologically-traceable independent and structured uncertainties are provided for each measurement
- Brightness temperatures and their uncertainties are stored with a precision of 0.01K

Example: scanline uncertainties

A typical (full) orbit file is ~50Mb.
AVHRR/1 GAC full orbit: NOAA-06 on 1980-03-21 at 14:56 UCT



Black = channel data, **Blue** = independent, **Orange** = structured uncertainty

Total uncertainties

Reflectances

U_INDEPENDENT	CH1_REF		CH2_REF		CH3A_REF	
$[10^{-3}]$	Median	Max	Median	Max	Median	Max
AVHRR06	0.48	0.48	0.68	0.68		
AVHRR07	3.05	3.05	0.68	0.68		
AVHRR08	0.47	0.47	0.80	0.80		
AVHRR09	0.52	0.52	0.78	1.28		
AVHRR10	0.38	0.97	1.12	1.53		
AVHRR11	0.36	0.36	0.66	0.66		
AVHRR12	0.47	0.47	0.48	0.48		
AVHRR14	0.39	0.40	0.55	0.81		
AVHRR15	0.23	0.77	0.27	0.80		
AVHRR16	0.66	0.71	0.98	1.08	2.65	2.65
AVHRR17	0.40	1.19	0.54	1.62	2.03	2.03
AVHRR18	1.71	1.75	1.48	1.54		
AVHRR19	1.13	1.15	0.74	0.75		
METOP-A	0.85	0.96	0.37	1.12	2.19	2.19

U_STRUCTURED	CH1_REF		CH2_REF		CH3A_REF	
	Median	Max	Median	Max	Median	Max
AVHRR06	0.03	0.03	0.05	0.05		
AVHRR07	0.03	0.03	0.05	0.05		
AVHRR08	0.03	0.03	0.05	0.05		
AVHRR09	0.03	0.03	0.05	0.05		
AVHRR10	0.03	0.03	0.05	0.05		
AVHRR11	0.03	0.03	0.05	0.05		
AVHRR12	0.03	0.03	0.05	0.05		
AVHRR14	0.03	0.03	0.05	0.05		
AVHRR15	0.03	0.03	0.05	0.05		
AVHRR16	0.03	0.03	0.05	0.05	0.05	0.05
AVHRR17	0.03	0.03	0.05	0.05	0.05	0.05
AVHRR18	0.03	0.03	0.05	0.05		
AVHRR19	0.03	0.03	0.05	0.05		
METOP-A	0.03	0.03	0.05	0.05	0.05	0.05

Brightness Temperatures

U_INDEPENDENT	CH3B_BT		CH4_BT		CH5_BT	
[K]	Median	Max	Median	Max	Median	Max
AVHRR06	0.39	7.86	0.14	0.38		
AVHRR07	1.36	8.08	0.08	0.37	0.09	0.37
AVHRR08	1.22	8.11	0.09	1.14		
AVHRR09	0.76	7.45	0.07	0.15	0.14	0.32
AVHRR10	0.95	8.11	0.08	0.17		
AVHRR11	1.06	7.25	0.08	0.17	0.09	0.17
AVHRR12	0.93	8.25	0.11	0.26	0.09	0.17
AVHRR14	1.05	8.45	0.78	9.51	1.24	10.59
AVHRR15	0.52	6.00	0.08	1.14	0.10	3.21
AVHRR16	0.31	6.66	0.10	1.33	0.13	4.35
AVHRR17	0.13	6.68	0.09	1.31	0.09	2.68
AVHRR18	0.40	6.40	0.12	1.28	0.11	2.99
AVHRR19	0.25	6.69	0.09	1.26	0.11	2.32
METOP-A	0.12	6.65	0.09	0.47	0.10	0.44

U_STRUCTURED	CH3B_BT		CH4_BT		CH5_BT	
[K]	Median	Max	Median	Max	Median	Max
AVHRR06	1.48	7.10	1.72	2.51		
AVHRR07	1.43	7.60	1.62	2.53	1.56	2.54
AVHRR08	1.23	3.43	1.48	1.94		
AVHRR09	0.58	5.94	0.62	4.23	0.59	4.03
AVHRR10	1.03	7.12	1.10	1.60		
AVHRR11	0.45	1.83	0.48	1.64	0.45	1.54
AVHRR12	1.36	6.85	1.69	2.26	1.65	2.32
AVHRR14	1.29	6.62	1.50	4.61	1.49	4.68
AVHRR15	1.06	4.20	1.10	4.00	1.10	4.02
AVHRR16	0.26	1.68	0.27	0.60	0.25	0.60
AVHRR17	0.28	1.14	0.30	0.53	0.30	0.52
AVHRR18	0.51	1.46	0.52	0.69	0.51	0.69
AVHRR19	0.30	0.87	0.29	0.49	0.28	0.51
METOP-A	0.17	0.61	0.19	0.29	0.19	0.30

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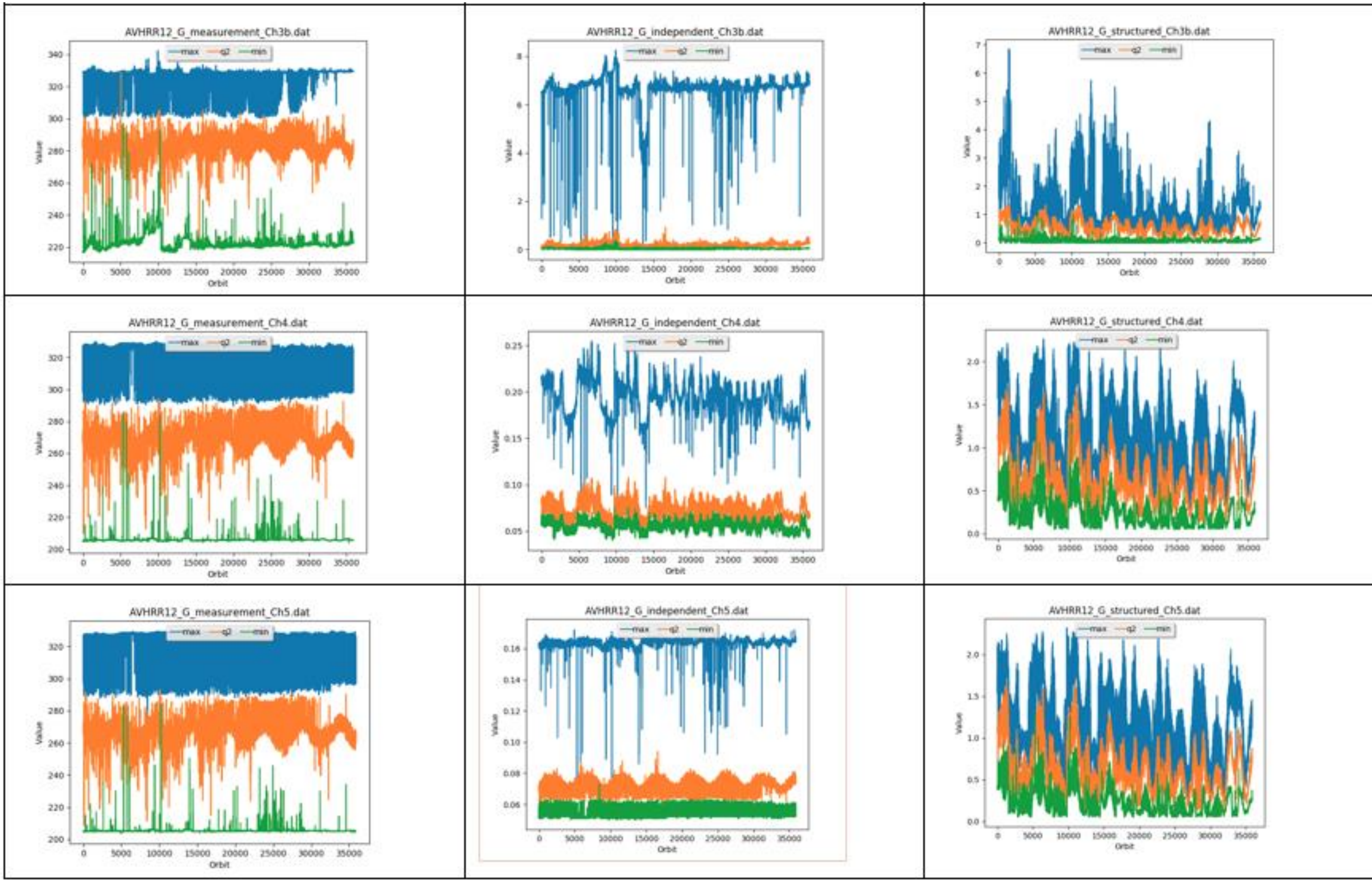
Example: orbit-level uncertainties

- For each orbit file, summary statistics are calculated (min, max, mean, robust standard deviation, variance and the quartiles Q1, Q2 and Q3).



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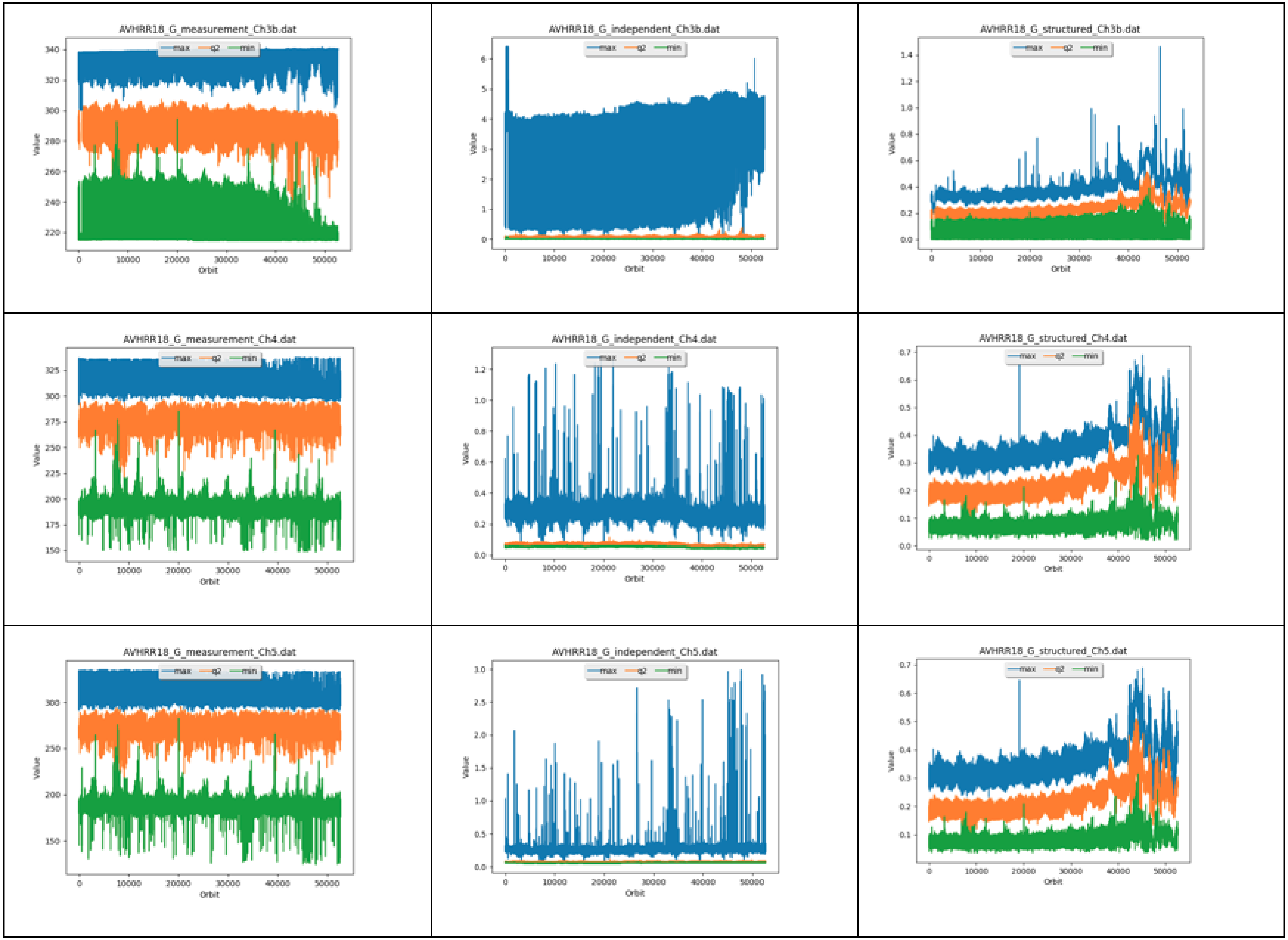
AVHRR18_G_measurement_Ch3b.dat
AVHRR18_G_independent_Ch3b.dat
AVHRR18_G_structured_Ch3b.dat
AVHRR18_G_measurement_Ch4.dat
AVHRR18_G_independent_Ch4.dat
AVHRR18_G_structured_Ch4.dat
AVHRR18_G_measurement_Ch5.dat
AVHRR18_G_independent_Ch5.dat
AVHRR18_G_structured_Ch5.dat
max
q2
min
Value
Orbit

Data standardization, Data improvement, Pending issues, Conclusions

FCDR ENHANCEMENTS

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Data Standardization

Existing Level-1C data

- **Variable length orbits**
- **Variable naming convention (instrument specific)**
- **Dual (POD,KLM) documentation**
- **Externalized dependencies**
- **72 byte top-level quality indicators**
- **TBUS approximate geolocation**

FIDUCEO Easy FCDR

- **Equator-to-Equator**
- **Standardized naming (all instruments plus versioning)**
- **Single PUG**
- **NetCDF with self-contained data (SRF, LUT, offset, scaling)**
- **Scanline and channel quality rules triggering global (pixel bitmask) quality indicators**
- **TLE (PyGAC-derived) geolocation**

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Data Improvement

Existing Level-1C data

- Clock timing errors in early AVHRR/1.2
- Simplified solar contamination modeling pre-1995
- No treatment of noise on space, earth and IWCT counts
- No treatment of IWCT thermal gradient bias
- Documented pre-launch uncertainties and vicarious estimates
- No long-term harmonization (some studies of bias)

FIDUCEO Easy FCDR

- PyGAC timing correction
- Walton Calibration
- Allan deviation used to estimate count noise uncertainties
- ICT thermal gradient bias correction being modeled
- Fully traceable uncertainties and effects
- Formal (ME-based) harmonization using ATSR reference sensor and matchups

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Pending Issues

- Data-driven error correlation scales from error covariance matrices (cross-channel, -scanline, -element, -pixel) based on CM recipes
- Fully correct for complex effects including solar contamination of the ICT and thermal gradients
- Coding of L ←→ BT LUT in netCDF
- Harmonization (next slide)

Harmonization

- Determination of 5 coefficients that represent:
  - ➢ The nonlinearity of the instrument (against the quadratic assumption)
  - ➢ Biases due to stray light difference between the calibration and observation views
  - ➢ Emissivity correction (e=0.98 from ITT manufacturer)
- We will also need to harmonize for differences in channel SRFs between sensors
- Harmonization will also provide the covariance between the 5 parameters

→ talks by NPL and FastOpt

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Conclusions

- AVHRR (Easy) FCDR has:

1. TLE-geolocation and equator-to-equator orbit stitching
2. Improved calibration and quality flagging
3. Fully documented traceable independent and structured uncertainties for included effects

- Next steps:

1. Calculation of error correlation scales (per effect, scanline, channel and pixel element) using mathematical recipes from CM
2. Incorporation of updated calibration coefficients from harmonization
3. Production of ensemble SST CDR → see talk by CM

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Thanks for listening

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Codebase:

https://github.com/FIDUCEO/FCDR_AVHRR

https://github.com/FIDUCEO/FCDRTools/

https://github.com/surftemp/gbcs/

https://github.com/adybbroe/pygac/

Python modules:

fcdr-tools 1.1.1, netCDF4 1.3.1, pygac 1.0.1, numpy 1.13.3, scipy 0.19.0, sympy

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