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AVHRR Errors and Uncertainties: The FIDUCEO Approach

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What is FIDUCEO?

- FIDUCEO stands for "Fidelity and Uncertainty in Climate data records from Earth Observations"
  - Horizon 2020 project applying the techniques of **Metrology** to selected satellite Level 1 (FCDR)/Level 2 (CDR) datasets for historic sensors
  - Includes a new FCDR from the AVHRR (Level 1) (currently being generated back to 1978) and there will be a new SST CDR from the AVHRR data with uncertainty as an ensemble (early 2019)
  - Website www.fiduceo.eu

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Metrology and Traceability

- **Metrology** is the science of measurement
  - Defines internationally accepted units of measurement (SI)
  - Provides a realisation of these units in practice
  - Provides Traceability linking measurements to a reference standard
- FIDUCEO concentrates on **Traceability**
  - Measurement can be related to a reference through a documented unbroken chain of calibrations each contributing to the measurement uncertainty
- Forces a consideration of all possible sources of error and how they link together
  - Obtaining uncertainties means removing all known sources of systematic error
    - GUM (2008) Section 3.2.4
      - It is assumed that the result of a measurement has been corrected for all recognized significant systematic effects and that every effort has been made to identify such effects.
- Taking a metrological approach not only means having traceable (and therefore justifiable) set of uncertainties. The removal of known systematic errors (to the best of our knowledge) **actually improves the data values themselves**

The FIDUCEO Approach

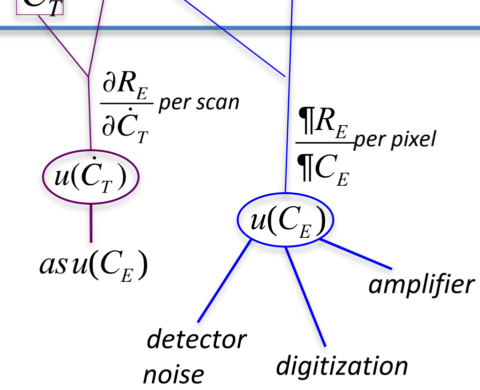
- At Level 1 we start with the "Traceability Tree"
  - Starts with the measurement equation

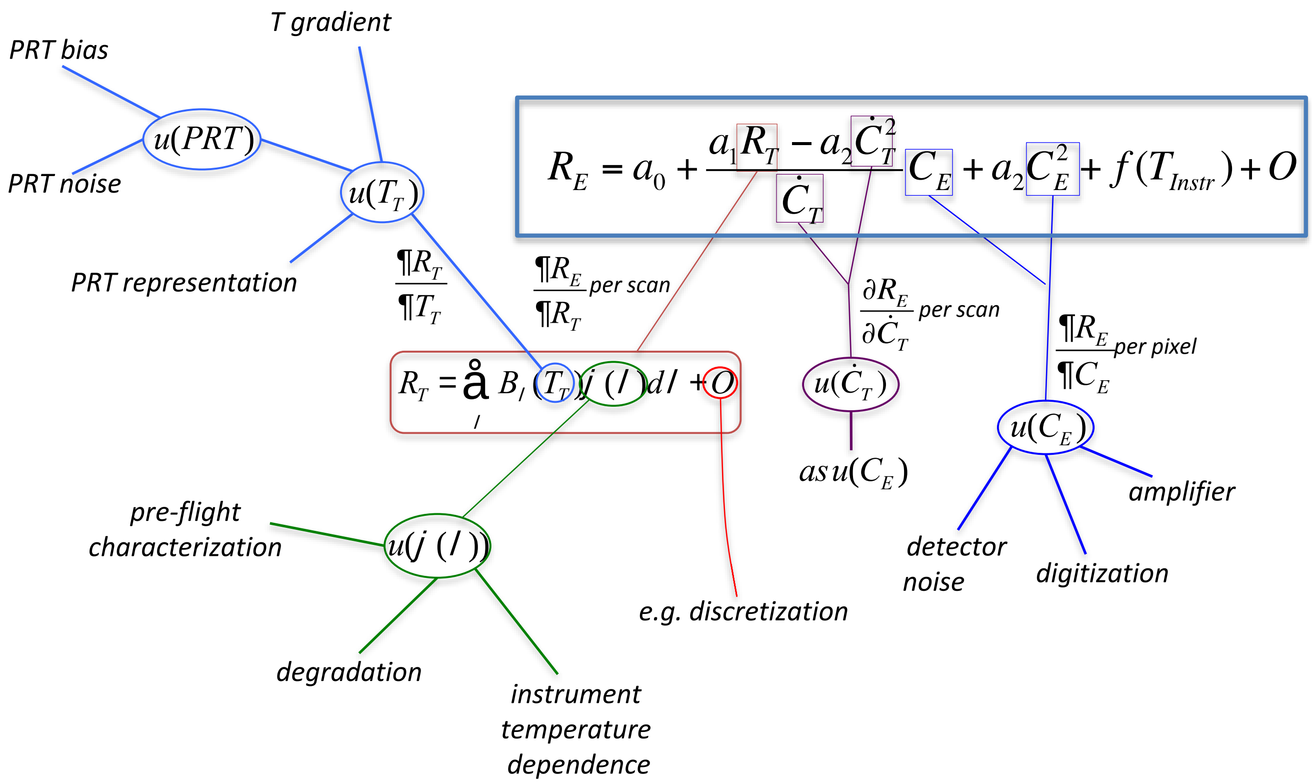
$$R_E = a_0 + \frac{a_1 R_T - a_2 \dot{C}_T^2}{\dot{C}_T} C_E + a_2 C_E^2 + f(T_{Instr}) + O$$

  - Looks at each term and breaks it down into however many underlying processes are needed to get back to root process
  - Links lowest level processes to their impact and associated uncertainty on the observed Earth radiance

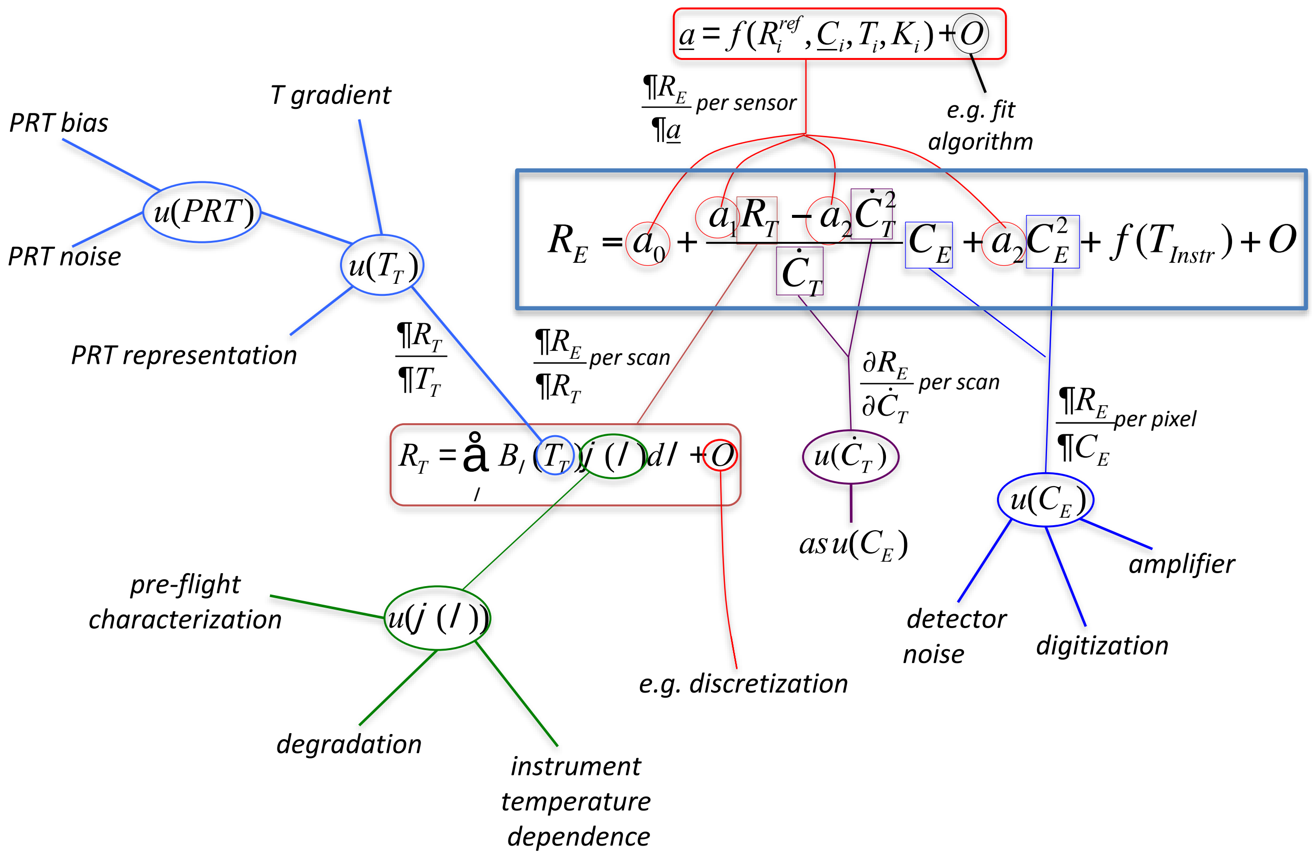
$$\boxed{R_E = a_0 + \frac{a_1 R_T - a_2 \dot{C}_T^2}{\dot{C}_T} C_E + a_2 C_E^2 + f(T_{Instr}) + O}$$

$$R_E = a_0 + \frac{a_1 R_T - a_2 \boxed{\dot{C}_T^2}}{\boxed{\dot{C}_T}} \boxed{C_E} + a_2 \boxed{C_E^2} + f(T_{Instr}) + O$$





PRT bias
T gradient
u(PRT)
PRT noise
u(T_T)
PRT representation
¶R_T / ¶T_T
¶R_E / ¶R_T per scan
R_E = a_0 + (a_1 R_T − a_2 Ċ_T^2) / Ċ_T · C_E + a_2 C_E^2 + f(T_Instr) + O
∂R_E / ∂Ċ_T per scan
¶R_E / ¶C_E per pixel
R_T = å_l B_l (T_T) j (l) dl + O
u(Ċ_T)
as u(C_E)
u(C_E)
amplifier
pre-flight characterization
u(j (l))
detector noise
digitization
e.g. discretization
degradation
instrument temperature dependence



a = f(R_i^ref, C_i, T_i, K_i) + O
e.g. fit algorithm
¶R_E / ¶a per sensor
T gradient
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u(PRT)
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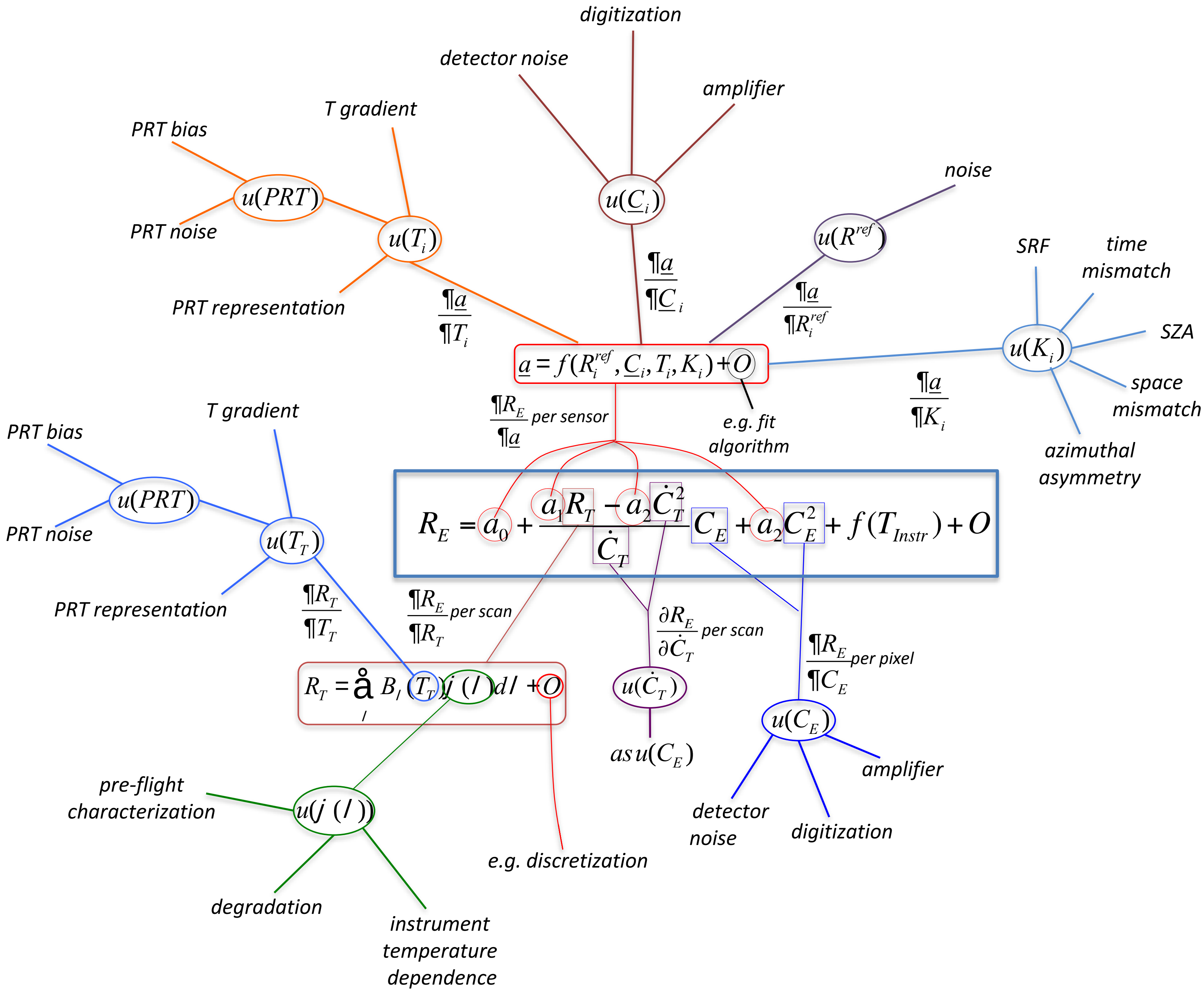
digitization
detector noise
amplifier
PRT bias
T gradient
u(PRT)
PRT noise
u(T_i)
PRT representation
u(C_i)
noise
u(R^ref)
SRF
time mismatch
SZA
u(K_i)
space mismatch
azimuthal asymmetry
¶a / ¶T_i
¶a / ¶C_i
¶a / ¶R_i^ref
¶a / ¶K_i
a = f(R_i^ref, C_i, T_i, K_i) + O
e.g. fit algorithm
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R_T = å B_l (T_T) j (l) dl + O
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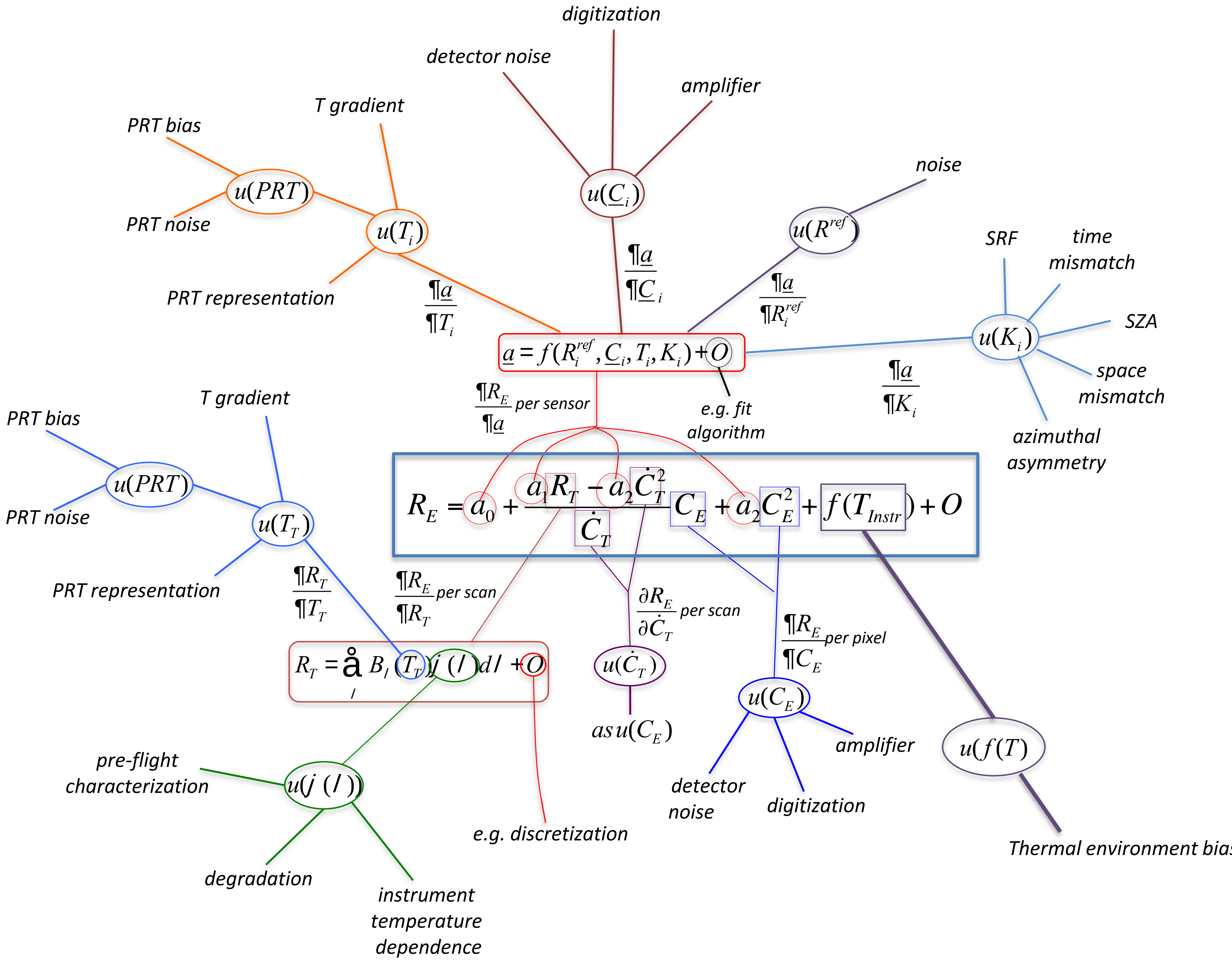
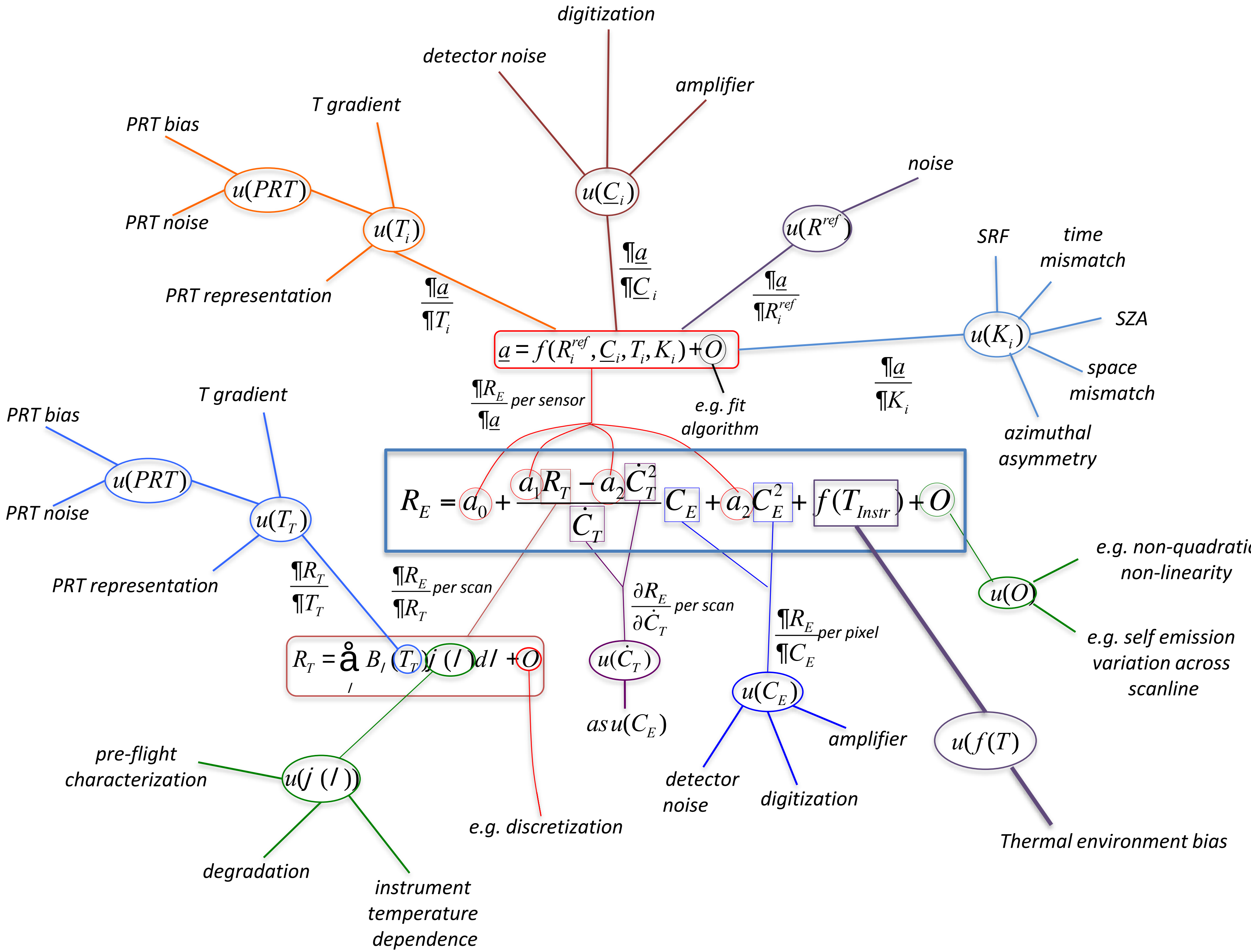
amplifier
detector noise
digitization
pre-flight characterization
u(j (l))
degradation
instrument temperature dependence
e.g. discretization



digitization
detector noise
amplifier
PRT bias
T gradient
PRT noise
PRT representation
noise
SRF
time mismatch
SZA
space mismatch
azimuthal asymmetry
e.g. fit algorithm
per sensor
per scan
per scan
per pixel
PRT bias
T gradient
PRT noise
PRT representation
pre-flight characterization
degradation
instrument temperature dependence
e.g. discretization
detector noise
digitization
amplifier
Thermal environment bias
$u(PRT)$
$u(T_i)$
$u(\underline{C}_i)$
$u(R^{ref})$
$u(K_i)$
$\underline{a} = f(R_i^{ref}, \underline{C}_i, T_i, K_i) + O$
$R_E = a_0 + \frac{a_1 R_T - a_2 \dot{C}_T^2}{\dot{C}_T} C_E + a_2 C_E^2 + f(T_{Instr}) + O$
$u(T_T)$
$u(\dot{C}_T)$
as $u(C_E)$
$u(C_E)$
$u(f(T))$



digitization
detector noise
amplifier
T gradient
PRT bias
u(PRT)
PRT noise
u(T_i)
PRT representation
u(C_i)
noise
u(R^ref)
SRF
time mismatch
SZA
u(K_i)
space mismatch
azimuthal asymmetry
a = f(R_i^ref, C_i, T_i, K_i) + O
e.g. fit algorithm
per sensor
T gradient
PRT bias
u(PRT)
PRT noise
u(T_T)
PRT representation
per scan
per scan
per pixel
e.g. non-quadratic non-linearity
u(O)
e.g. self emission variation across scanline
u(Ċ_T)
as u(C_E)
u(C_E)
amplifier
u(f(T))
detector noise
digitization
Thermal environment bias
pre-flight characterization
u(φ(λ))
e.g. discretization
degradation
instrument temperature dependence

The +0 term

- Appears in a number of places
- Intended to force investigation of assumptions
  - To think about and characterize **known unknowns**
  - Mostly via Type-B uncertainty estimates
    - Not measured but via expert knowledge including modeling
  - AVHRR examples
    - Quadratic assumption for non-linearity effect
    - Constant non-linear coefficient
    - Numerical issues (digitisation/numerical integration)
    - Etc.
- Will be much more important for geophysical retrievals (Level 2+)

AVHRR Effect Tables

- How FIDUCEO codifies different uncertainty components
  - Uncertainties caused by random effects
  - Uncertainties caused by systematic effects
  - Uncertainties due to correlated errors
    - Include correlation length scale/shape
- Effects tables covers
  - Effect size, correlation type and scale, covariance information and sensitivity coefficient

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Example Effects Table

Table descriptor		How this is codified
Name of effect		Space view counts uncertainty
Affected term in measurement function		Space view counts ($\overline{C}_S$)
Channels / bands		Channel 3B, 4 and 5 (3.7µm, 11µm and 12µm)
3. Correlation type and form	within scanline [pixels]	Rectangular absolute systematic
	from scanline to scanline [scanlines]	Triangular
	between images/orbits [orbits]	Random
	between channels / bands	Random
4. Correlation scale	within scanline [pixels]	[-∞,+∞]
	from scanline to scanline [scanlines]	[±25]
	between images/orbits [orbits]	None
	between channels / bands	None
Uncertainty PDF shape		Digitised Gaussian
Uncertainty units		Counts
Uncertainty magnitude		Estimated from Allan deviation from space views accumulated over a complete orbit
Sensitivity coefficient		$\frac{\partial R_E}{\partial \overline{C}_{ICT}} = \frac{((\varepsilon + a_1)R_{ICT} - a_2(\overline{C}_S - \overline{C}_{ICT})^2)}{(\overline{C}_S - \overline{C}_{ICT})^2}(\overline{C}_S - C_E) + \frac{((\varepsilon + a_1)R_{ICT} - a_2(\overline{C}_S - \overline{C}_{ICT})^2)}{(\overline{C}_S - \overline{C}_{ICT})}$

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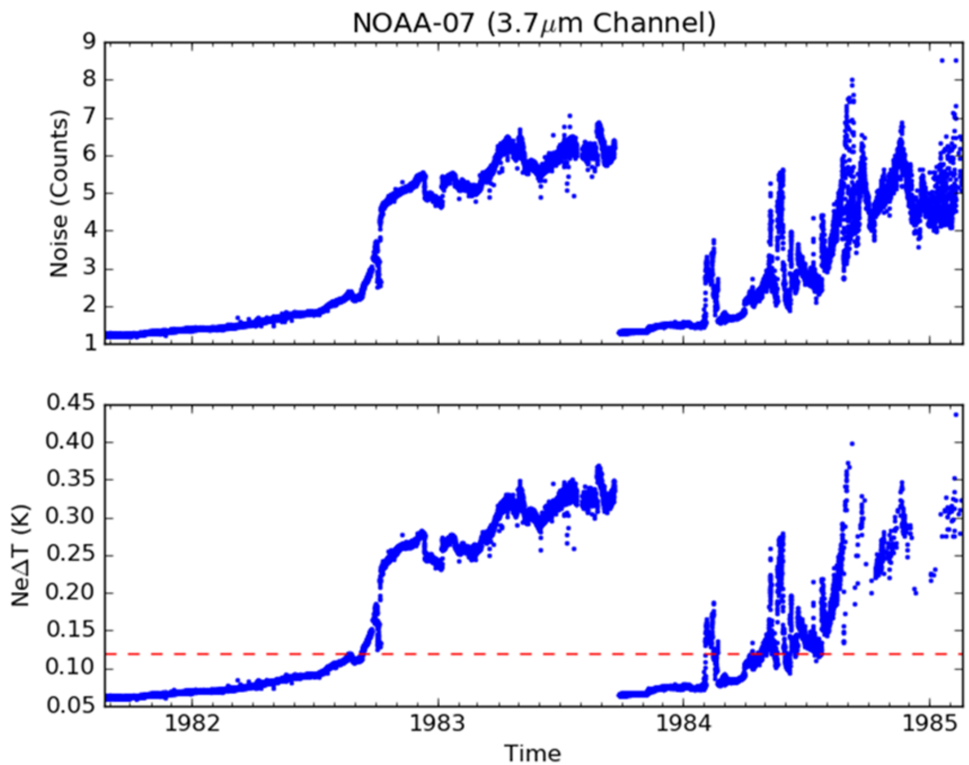
AVHRR effects

- For the AVHRR currently have around 12 effects tables
- Three highlight examples are
  - Detector Noise
  - Effect of Solar contamination of ICT
  - Thermal environment bias

Detector Noise

- Random but temporally variable
  - We will provide pixel level uncertainty due to all random effects



  - Similar NeDT problem shown in He & Ignatov (this meeting)

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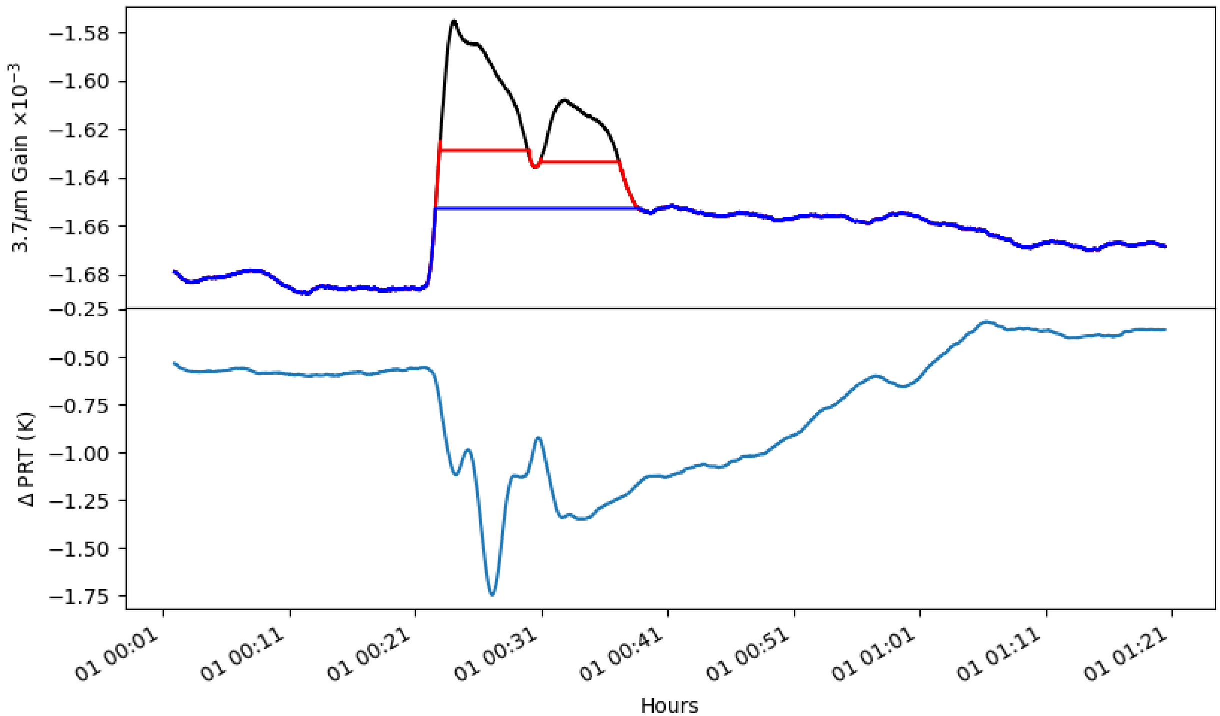
Solar Contamination of Internal Calibration Target

- Direct solar contamination plus changes in thermal gradients



As much error as possible will be removed with appropriate uncertainties

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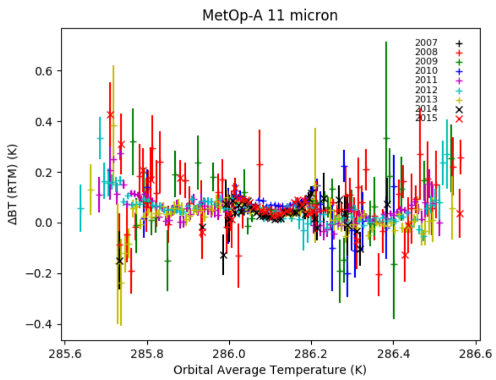
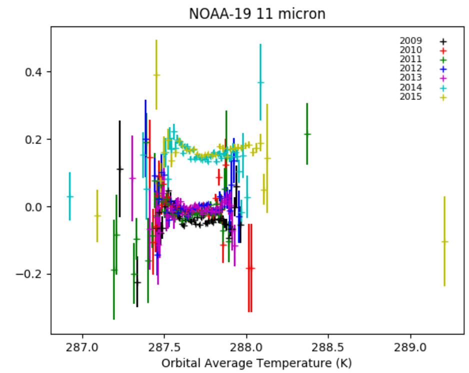
Thermal Environment Bias

- As orbits drift the thermal environment changes introducing a time variable term which correlates with 'instrument temperature'

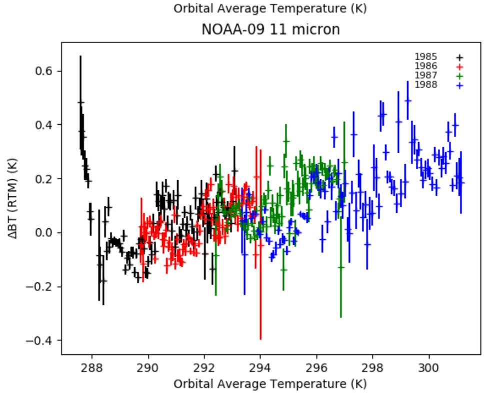
Close to being flat

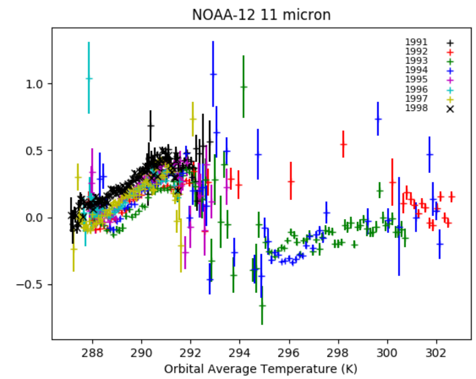




Different offsets

~ single slope (may be +ve or –ve)





Multiple component model

- Will be modeled as a function of instrument temperature and time together with associated uncertainty

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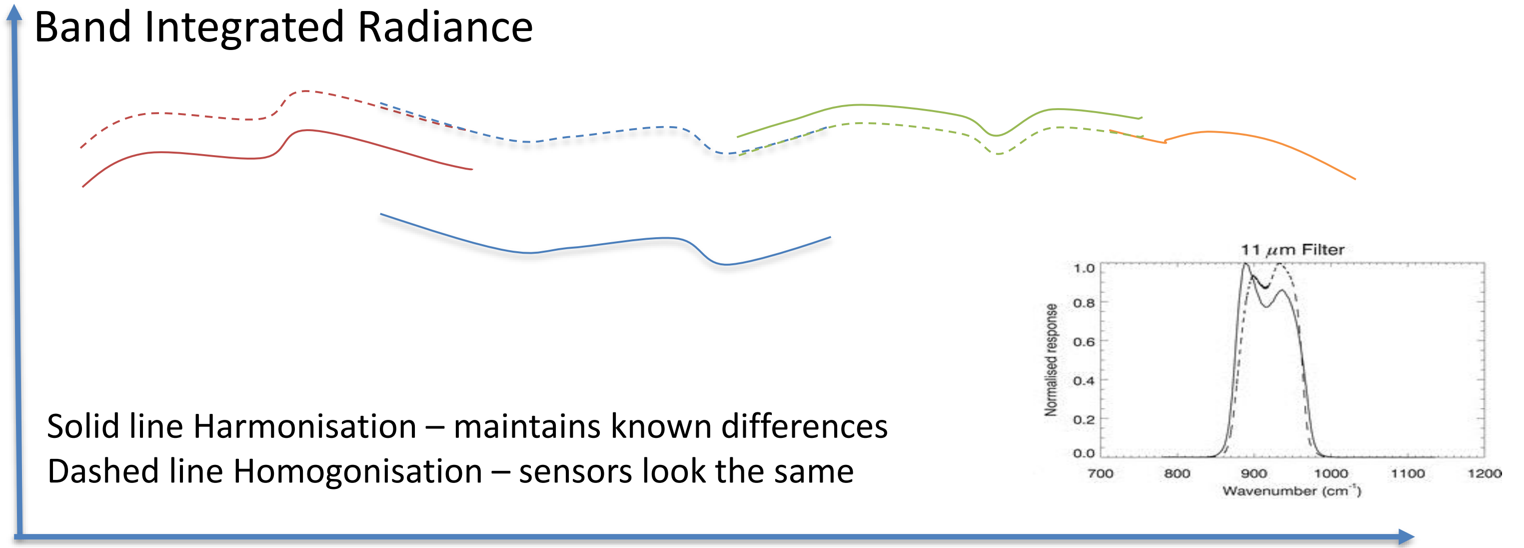
Sensor-to-Sensor Harmonisation

- For FCDR crucial to reduce any sensor-to-sensor error
- FIDUCEO approach is Harmonisation



- Measurement equation fitted to sensor-to-sensor matchup data
- Full uncertainty information including correlated error terms
- Fit process using Error-in-Variable (uncertainty in both 'X' and 'Y')
  - OLS will give biased result (e.g. backup slide)

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FCDR File formats

- There will be three sets of data
  - Easy FCDR
    - Contains lat/lon/angles/quality plus BTs
    - Two components of uncertainty for all channels at the pixel level
      - Random and non-Random
      - Includes for non-Random a typical scale
  - Full FCDR
    - Contains all Effects Tables information
      - Uncertainties and all covariances and error correlation information
  - Ensemble FCDR
    - Contains set of N deviations from Easy FCDR BTs which will have the correct statistical properties derived from full FCDR
- Files in NetCDF4 including internal compression
- Beta Easy FCDR should be available before end of year for testing
  - If you are interested let us know
- **Due to metrological methodology FCDR will provide improved radiances as well as pixel level and above uncertainties and components.**

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Conclusion

- FIDUCEO is generating a new FCDR for the AVHRR
- Takes a metrological approach which
  - Reduces systematic errors in the data as much as possible
    - Current operational data has significant biases
  - Provides traceable uncertainties
- Data will be provided in Easy, Full and Ensemble datasets
  - Pixel level and above uncertainties including correlated error terms in Full/Ensemble FCDR
    - Easy contains random and non-random plus a correlation length scale
  - Available shortly
- SST CDR with ensemble uncertainties will be generated by end of next year/early 2019
- FIDUCEO Workshop on Level 1 Uncertainties
  - April/May 2018 in Lisbon

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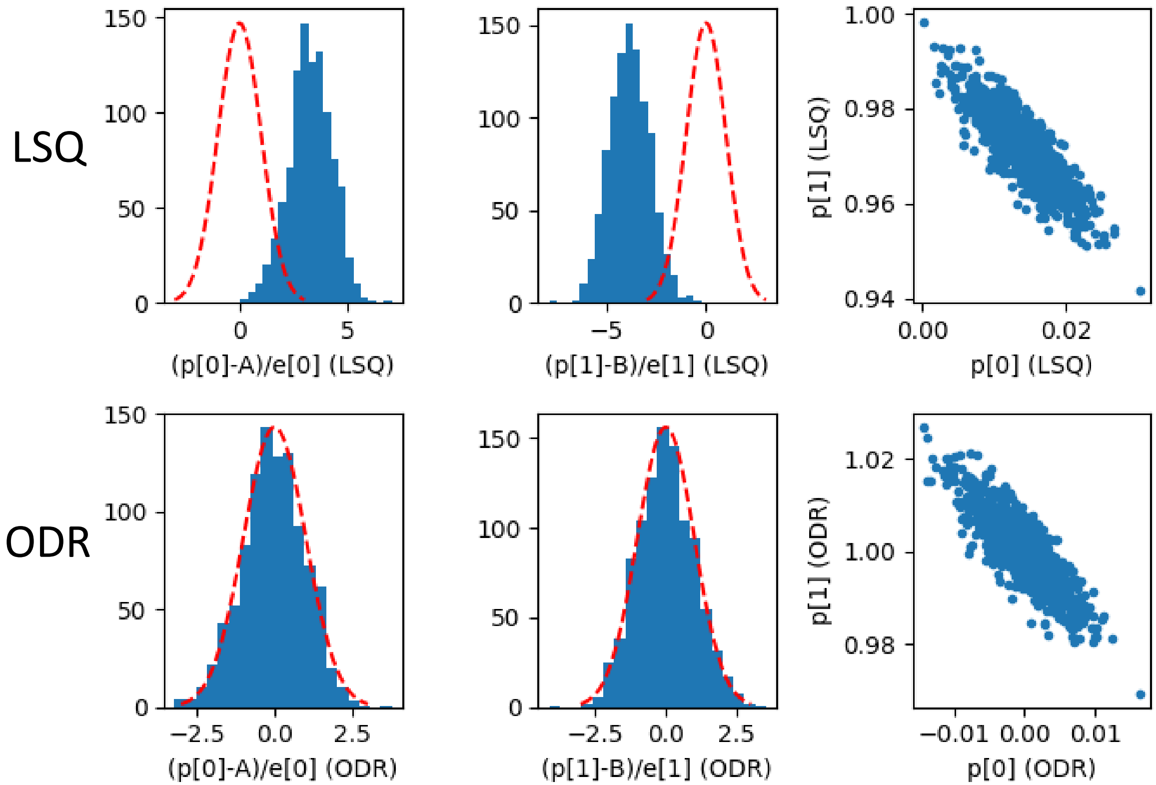
Backup slide - Simple simulation study LSQ vs ODR

- Straight line fit (Y=A+B*X)



- Uncertainties in X and Y
- ODR works, LSQ doesn't
- For uncertainties need to take correlation between A/B into account
- FIDUCEO uses Error-in-Variable techniques (ODR is an example of E-in-V)

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