FIDUCEO has received funding from the European Union's Horizon 2020 Programme for Research and Innovation, under Grant Agreement no. 638822

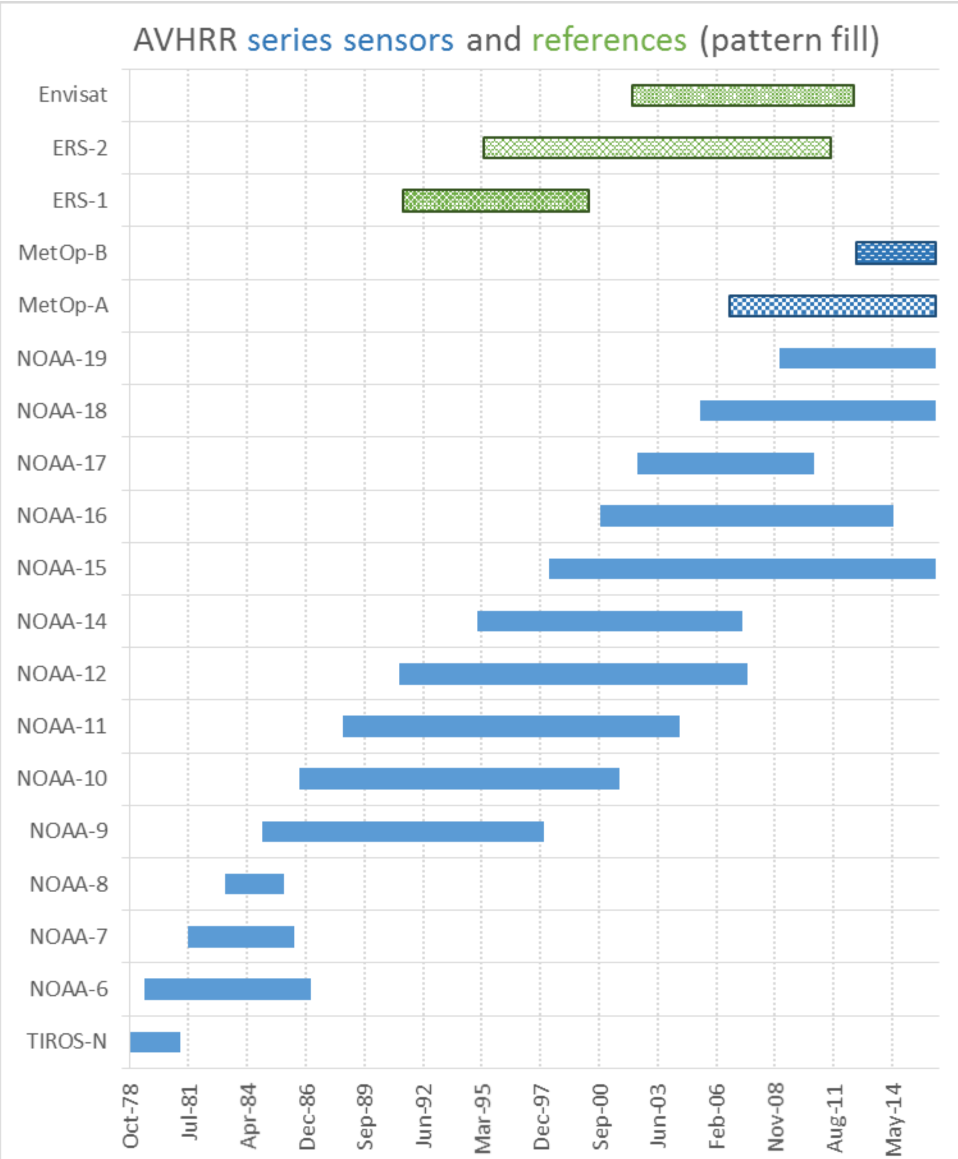
Activities of the FIDUCEO project: www.fiduceo.eu

Emma Woolliams

National Physical Laboratory

Project PIs: Jon Mittaz (NPL/Reading) and Chris Merchant (Reading)

Information in historical sensors



- How to get meaningful trend analysis?
- Recalibration (traceably) of historical sensors

FIduceo

FIDUCEO FCDRs (L1)

FCDR: fundamental climate data record (calibrated radiances) from which climate data can be derived

DATASET	NATURE	POSSIBLE USES
AVHRR FCDR	Harmonised infra-red radiances and best available reflectance radiances, 1982 - 2016	**SST, LSWT**, **aerosol**, LST, phenology, cloud properties, surface reflectance …
HIRS FCDR	Harmonised infra-red radiances, 1982 - 2016	**Atmospheric humidity**, NWP re-analysis, stratospheric aerosol …
MW Sounder FCDR	Harmonised microwave BTs for AMSU-B and equivalent channels, 1992 – 2016	**Atmospheric humidity**, NWP re-analysis …
Meteosat VIS FCDR	Improved visible spectral response functions and radiance 1982 to 2016	**Albedo, aerosol**, NWP re-analysis, cloud, wind motion vectors,…

NPL National Physical Laboratory

Fiduceo

How do we get metrological rigour in historical sensors?

Start from the measurement equation

Understand and quantify correlation

Use harmonisation approaches to recalibrate sensors

National Physical Laboratory

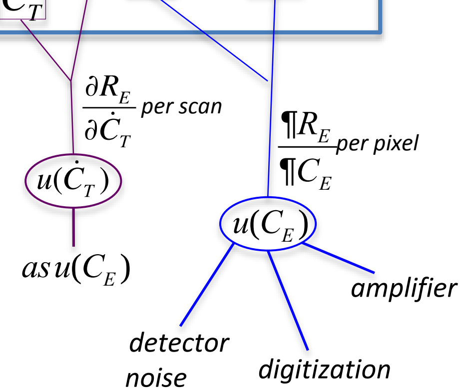
FIduceo

The measurement equation defines the relationship between counts and radiance (or reflectance)

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

Each term in the measurement equation has associated uncertainty from one or more effects

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



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

$\frac{\partial R_E}{\partial R_T}$ *per scan*

$$\boxed{R_T = \sum_{\lambda} B_{\lambda}(T_T)\varphi(\lambda)d\lambda + O}$$

$\frac{\partial R_E}{\partial \dot{C}_T}$ *per scan*

$u(\dot{C}_T)$

$as\, u(C_E)$

$\frac{\partial R_E}{\partial C_E}$ *per pixel*

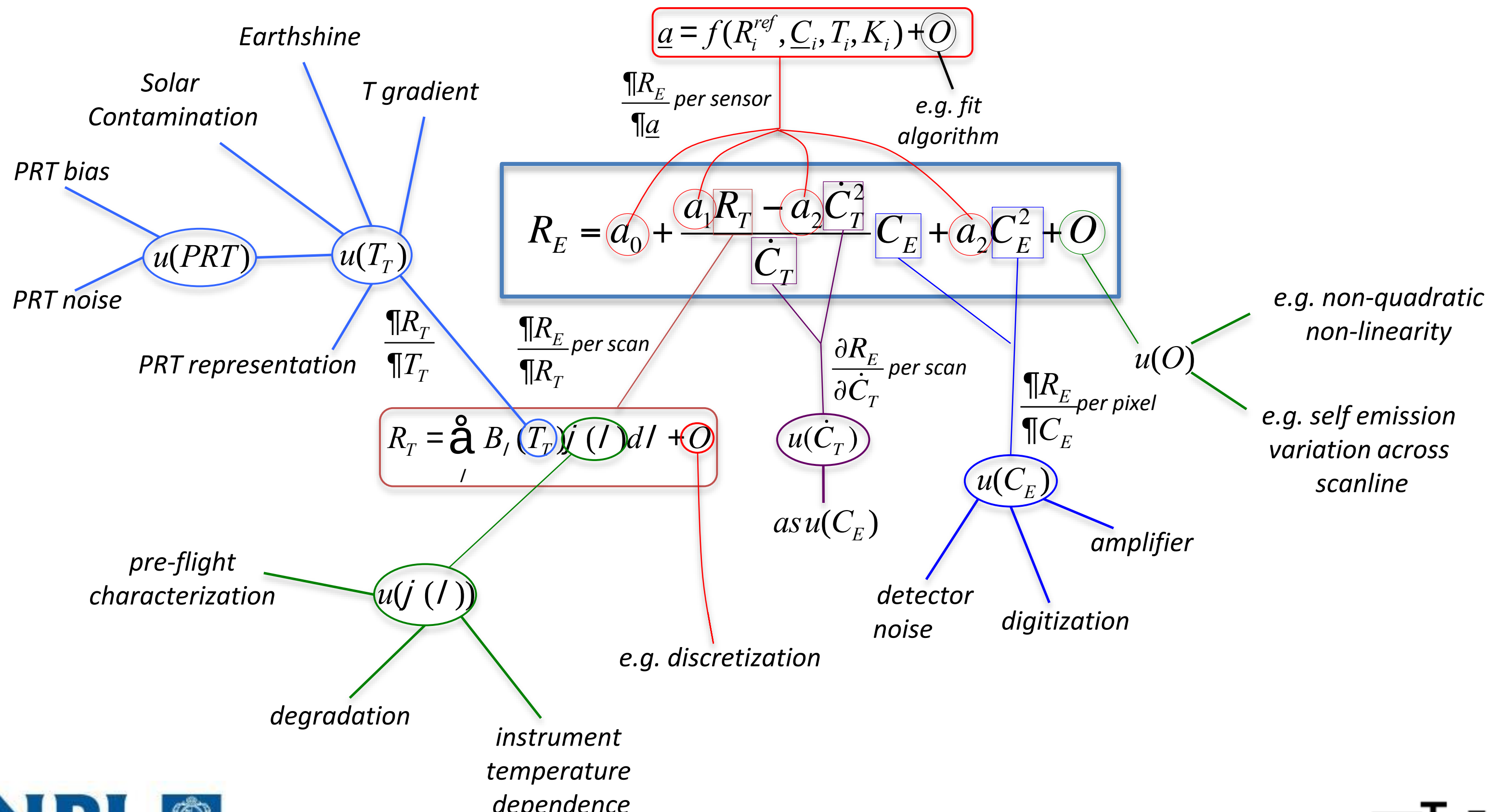
$u(C_E)$

amplifier

detector noise

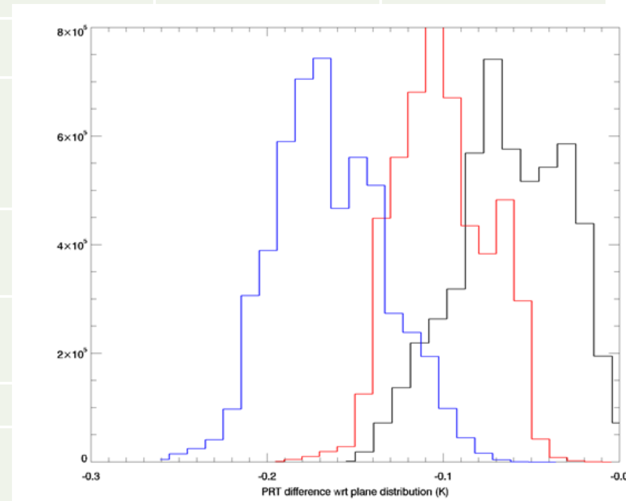
digitization

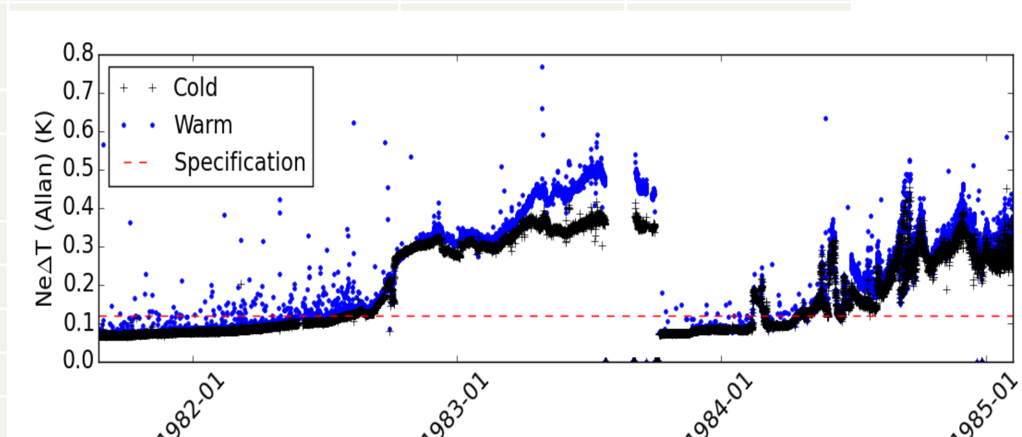
We include a +0 to relate to errors due to approximations in the equation form



Capture in an effects table

Table descriptor		Value / Expression	How this is provided	Notes
Name of effect				
Affected term in measurement function				
Correlation type and form	within scanline [pixels]			
	from scanline to scanline [scanlines]			
	between orbits [orbits]			
	Across time [e.g. days, months, years]			
Correlation scale	within scanline [pixels]			
	from scanline to scanline [scanlines]			
	between orbits [orbits]			
	Across time			
Channels / bands	List channels and bands affected			
	Correlation matrix			
Uncertainty	PDF shape			
	Uncertainty units			
	Uncertainty magnitude			
Sensitivity Coefficient				





Traceable uncertainty

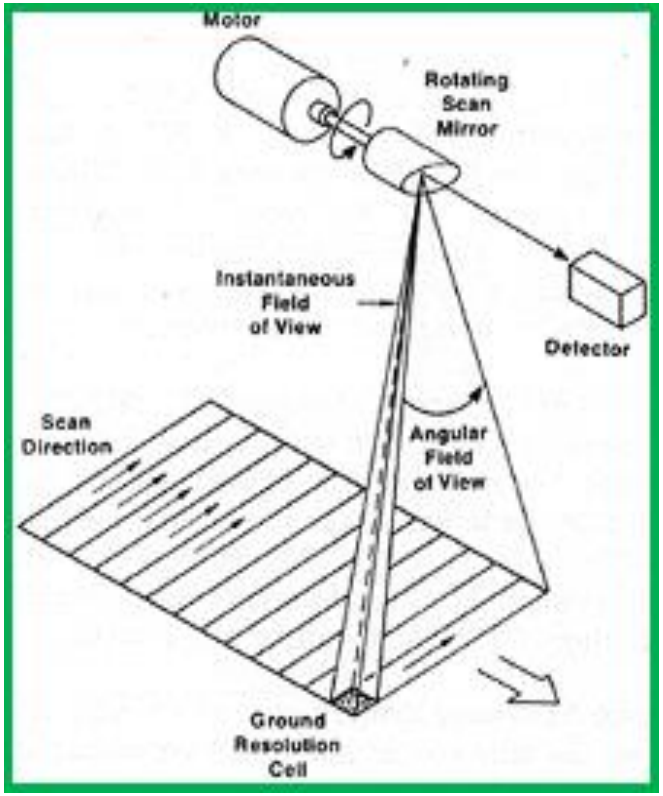
- Traceability diagram, measurement centred
  - to organise
  - to document
- Branching structure reflects the nature of the problem
- Standardised “effects table” per “twig”
  - systematic documentation
  - this is codified into FCDR format
- Same for deriving higher-order products (CDRs)
  - uncertainty from L1 is simply one of the effects in L2

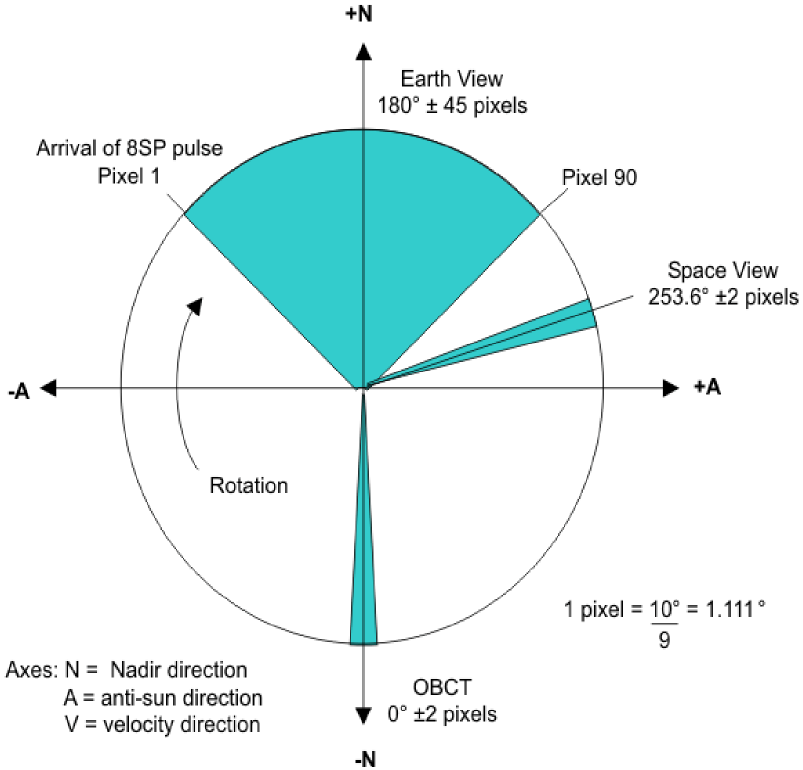
Error correlation

- Is different from effect correlation
- (Metrologists often forget to say “error”)

- Matters in higher level processing:
  – Combining values from different channels
  – Combining values from different pixels

Error correlation: something in common





When it can be described explicitly

- Error between bands due to common blackbody calibration target

$$\tilde{L}_{\mathrm{ICWT,A}} = \frac{\varepsilon_{\mathrm{A}} c_{1,L}}{\lambda_{\mathrm{A}}^{5}\left(\mathbf{exp}\left[c_2/\lambda_{\mathrm{A}} T\right]-1\right)}$$

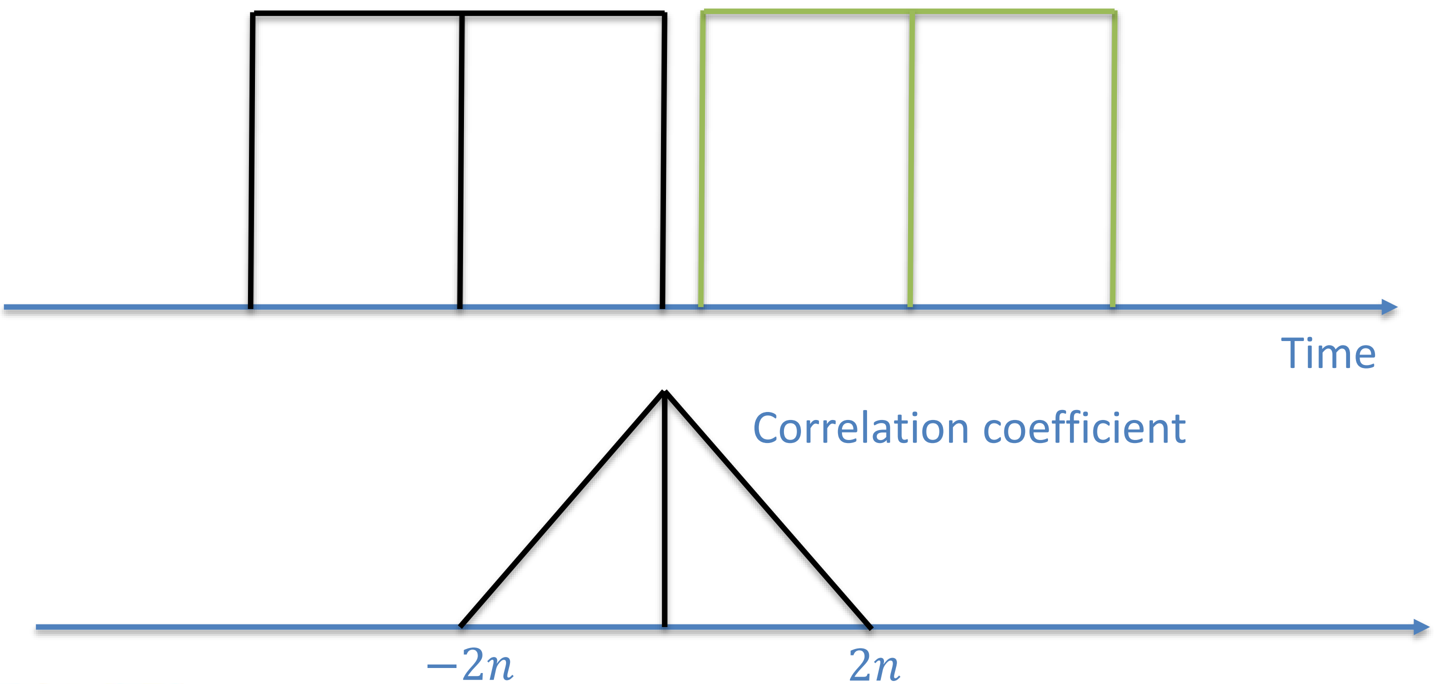
$$\tilde{L}_{\mathrm{ICWT,B}} = \frac{\varepsilon_{\mathrm{B}} c_{1,L}}{\lambda_{\mathrm{B}}^{5}\left(\mathbf{exp}\left[c_2/\lambda_{\mathrm{B}} T\right]-1\right)}$$

$$u\left(\tilde{L}_{\mathrm{ICWT,A}}, \tilde{L}_{\mathrm{ICWT,B}}\right) = \frac{\partial \tilde{L}_{\mathrm{ICWT,A}}}{\partial T} \frac{\partial \tilde{L}_{\mathrm{ICWT,B}}}{\partial T} u^2\left(T\right)$$

Rolling averages

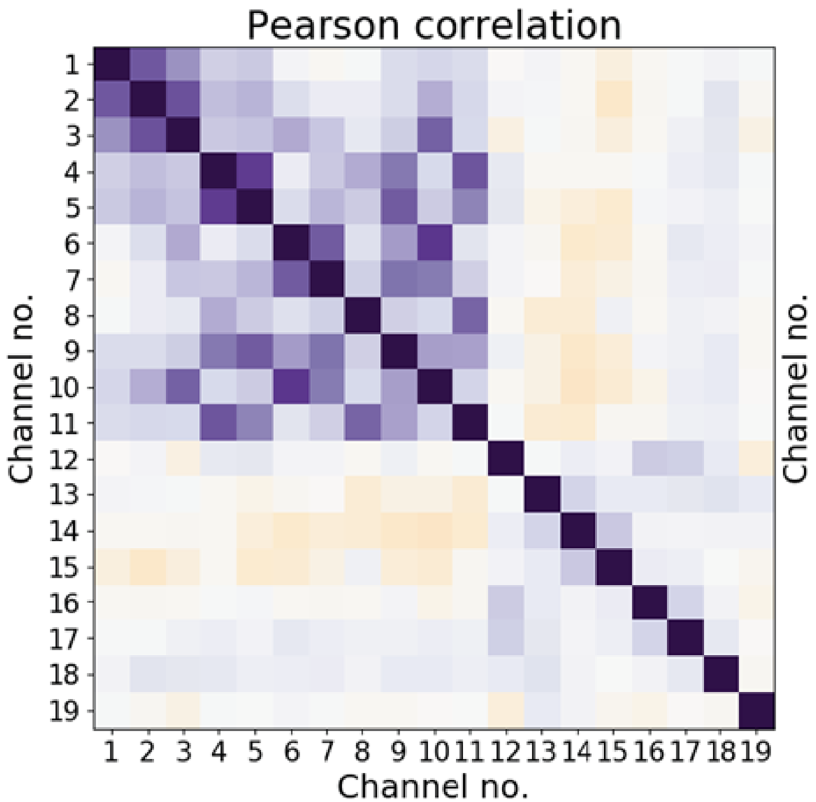
$$\bar{C} = \frac{1}{2n+1} \sum_{i=-n}^{n} C_i$$

Moving simple average



Numerical approach to correlation analysis

$$r(x,y)=\frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}}=\frac{1}{n-1}\sum_{i=1}^{n}\left(\frac{x_i-\bar{x}}{s_x}\right)\left(\frac{y_i-\bar{y}}{s_y}\right)$$



Correlation between noise in different channels for HIRS

Capture in an effects table

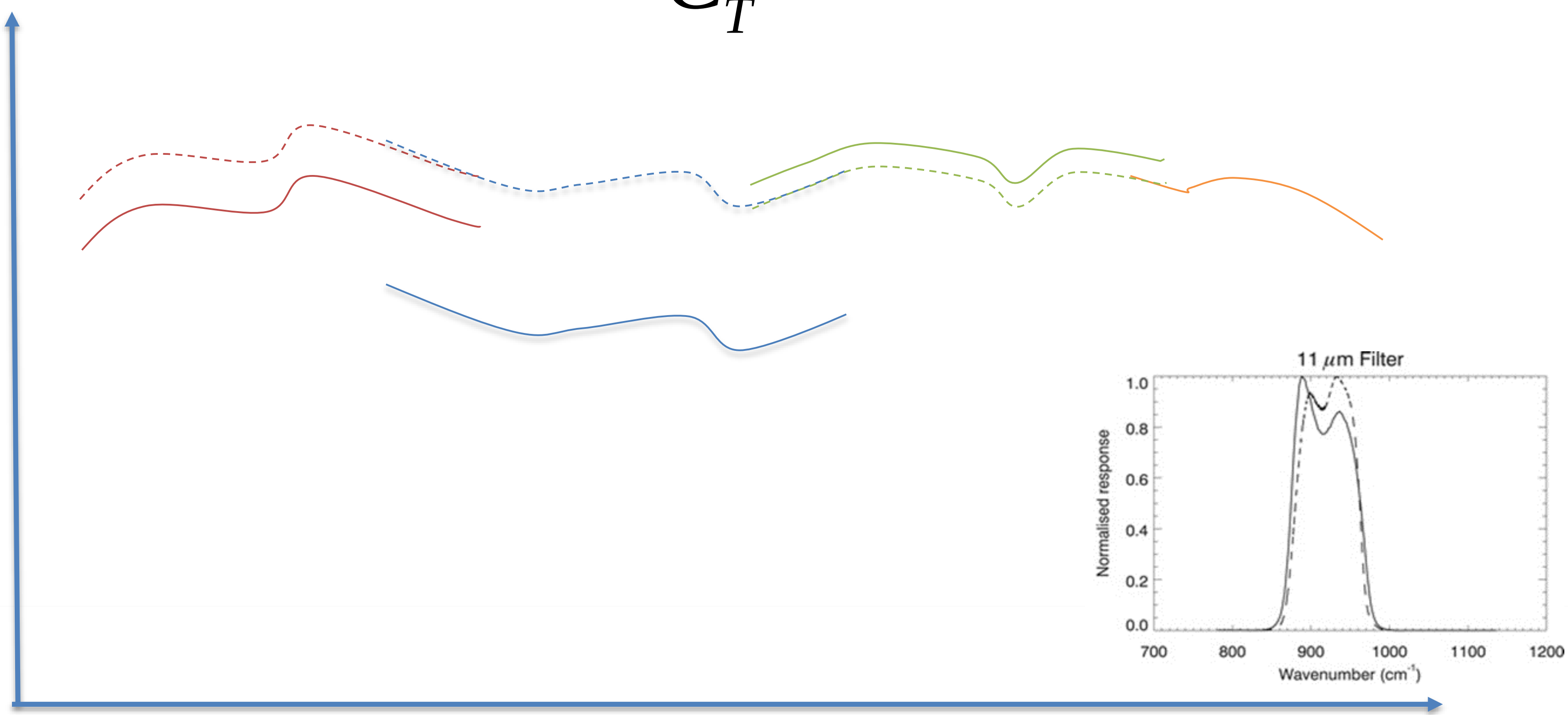
Table descriptor		Value / Expression	How this is provided	Notes
Name of effect				
Affected term in measurement function				
Correlation type and form	within scanline [pixels]			
	from scanline to scanline [scanlines]			
	between orbits [orbits]			
	Across time [e.g. days, months, years]			
Correlation scale	within scanline [pixels]			
	from scanline to scanline [scanlines]			
	between orbits [orbits]			
	Across time			
Channels / bands	List channels and bands affected			
	Correlation matrix			
Uncertainty	PDF shape			
	Uncertainty units			
	Uncertainty magnitude			
Sensitivity Coefficient				

Correlation forms:

- Random
- Systematic / Rectangular absolute
- Triangular (simple average)
- Truncated Gaussian (weighted average and other effects)
- Repeating truncated Gaussian (orbital effects)

Harmonisation

$$R_E = a_0 + \frac{a_1 R_T - a_2 \dot{C}_T^2}{\dot{C}_T} C_E + a_2 C_E^2 + 0$$



Time (years)

Harmonisation model

- Model for spectral radiance measured by each sensor

$$L = f(\boldsymbol{a}; x, y, \dots)$$

- Model for adjustment between pairs of sensors

$$K = h[f(\boldsymbol{a}_s; x_s, y_s, \dots)] - \begin{cases} h[f(\boldsymbol{a}_t; x_t, y_t, \dots)] \\ h[L_{\text{ref}}] \end{cases}$$

$\boldsymbol{a}$ (unknown) sensor calibration parameters

$x, y, \dots$ stimulus variables

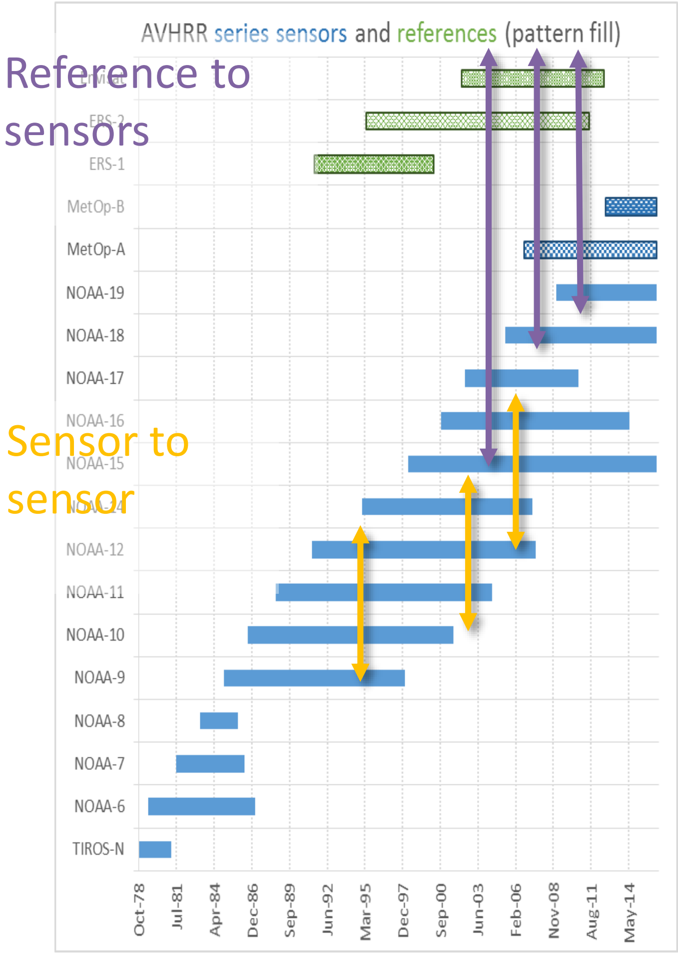
earth counts, temperatures, …

L_{ref} radiances from single reference sensor

K adjustment factor

Data with uncertainty information

Match-ups



- Reference radiance, or sensor-to-sensor
- Many (50 million +)
- Correlated!

National Physical Laboratory

Solving the harmonisation problem

Harmonisation problem is a non-linear regression, with correlated data and millions of match-ups.

Approaches:

- Orthogonal distance regression + Monte Carlo
- Full errors-in-variables approach, taking advantage of sparsity in covariance matrix

Work in progress!

National Physical Laboratory

How do we get metrological rigour in historical sensors?

Start from the measurement equation

Understand and quantify correlation

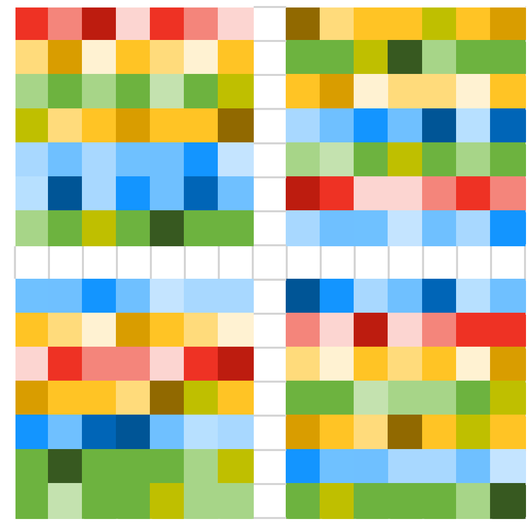
Use harmonisation approaches to recalibrate sensors

Sharing the FCDR

- Full FCDR:
  - Uncertainty data by correlation structure

$$\begin{aligned}
u^2\left(R_{\mathrm{E},ijk}\right) = {} & c_{a_0}^2 u^2\left(a_0\right) + c_{C_{\mathrm{E},ijk}}^2 u^2\left(C_{\mathrm{E},ijk}\right) \\
& + c_{R_{\mathrm{ICT},jk}}^2 u^2\left(R_{\mathrm{ICT},jk}\right) \\
& + c_{\delta R_{\mathrm{ICT},0}}^2 u^2\left(\delta R_{\mathrm{ICT},0}\right) \\
& + c_{\delta R_{\mathrm{ICT},0,\mathrm{grad},jk}}^2 u^2\left(\delta R_{\mathrm{ICT},0,\mathrm{grad},jk}\right) \\
& + c_{C_{\mathrm{ICT},jk}}^2 u^2\left(C_{\mathrm{ICT},jk}\right)
\end{aligned}$$

- Ensemble of realisations



- "Easy FCDR" with guidance

independent random

systematic and structured random

FIDUCEO has received funding from the European Union's Horizon 2020 Programme for Research and Innovation, under Grant Agreement no. 638822

Thank you!

www.fiduceo.eu