HIRS FCDR
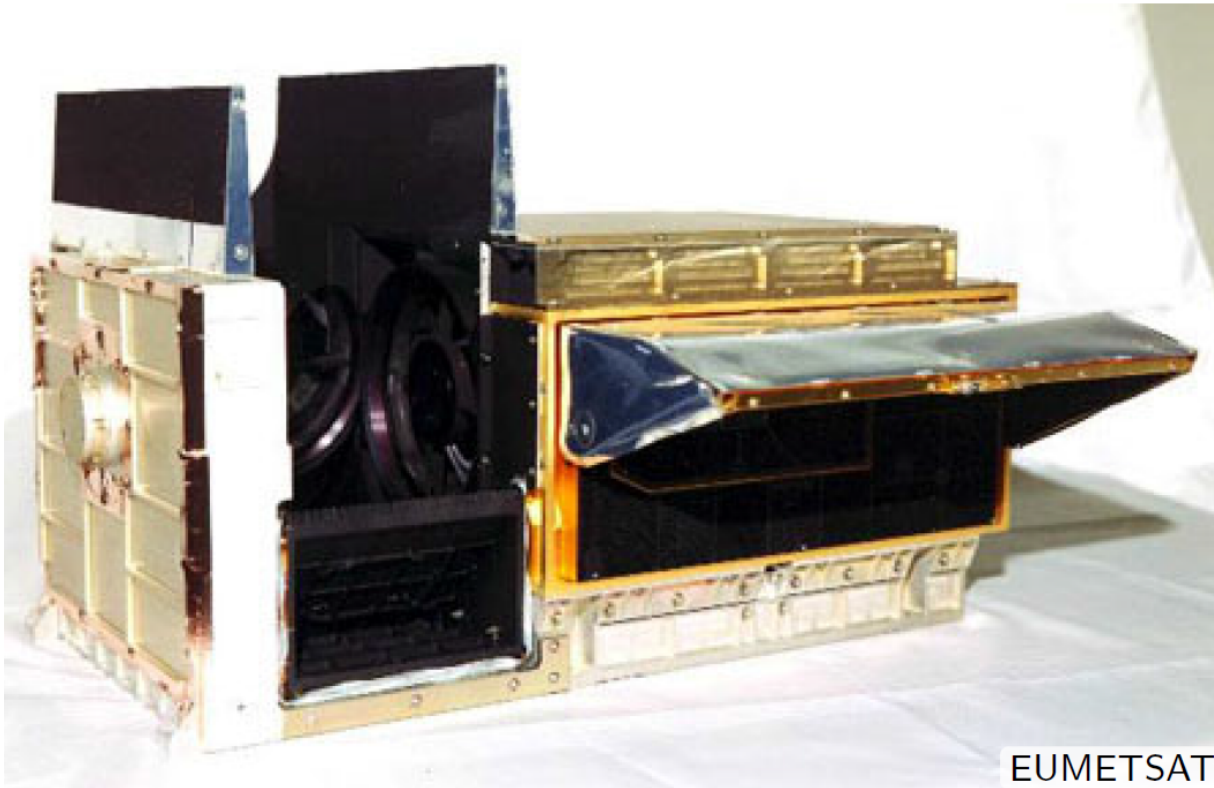
G. Holl, J. Mittaz, V. John, R. Quast, R. Giering, E. Woolliams, S. Hunt

HIRS Instrument

| Ch.	Wl [μm]	Ch.	Wl [μm]
1	14.95	11	7.33
2	14.70	12	6.7 / 6.52
3	14.47	13	4.57
4	14.21	14	4.52
5	13.95	15	4.67
6	13.65	16	4.42
7	13.34	17	4.18
8	11.11	18	3.97
9	9.71	19	3.76
10	8.2 / 12.47	20	0.69

Ch. 10: HIRS/2 8.2 μm, HIRS/2I/3/4 12.5 μm
Ch. 12: HIRS/2/2I 6.7 μm, HIRS/3/4 6.5 μm

EUMETSAT

- Three different detectors
  - Channels 1–12: Mercury cadmium telluride (HgCdTe)
  - Channels 13–19: Indium antimonide (InSb)
  - Channel 20: Silicon (Si)

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Available from 1979 to present

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Pre-FIDUCEO: HIRS uncertainties

- In current available datasets (NOAA Level 1B, HIRS Channel 12 NOAA CDR Program) no explicit uncertainties are available

- NOAA STAR Cal/Val provides visual estimates of NeΔN
 - Shows time variability but no available output values
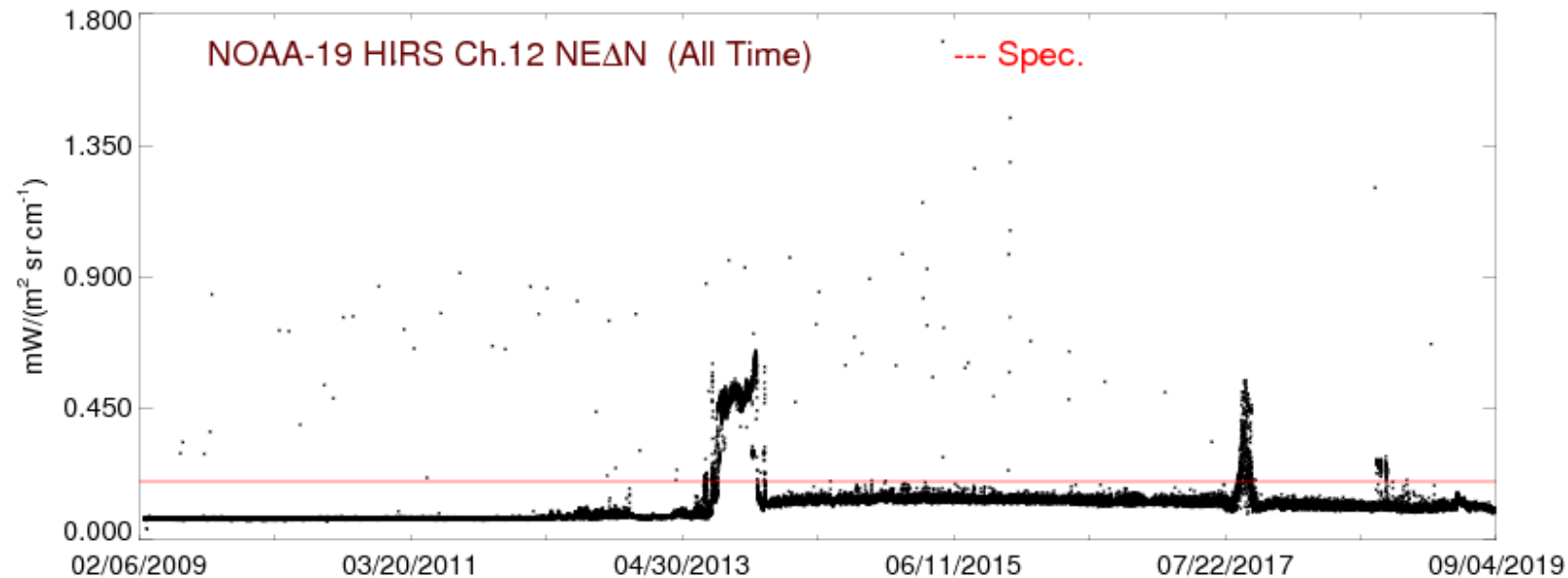
Pre-FIDUCEO: HIRS Calibration cycle

- Unlike AVHRR there is are no continuous observations of calibration sources
  - One scan of 48 space views followed by one scan of IWCT (or ICCT/IWCT for HIRS/2)
  - 37 (HIRS/2/2I) or 38 (HIRS/3/4) scan lines of 56 Earth views.
- In between calibration scan lines, instrument self emission changes which needs to be modelled
  - Self-emission model. Operationally 5 different attempts
    - Version 1: nearest-neighbour "interpolation" for calibration coefficients (used for HIRS/2 only)
    - Version 2: calibration cycle measurements combined with pre-launch static correlation measurements between (not used operationally)
    - Version 3: assuming 24-hour average stable gain, corrects intercepts using secondary mirror baffle temperature
      - Version 5: EUMETSAT: similar to NOAA version 3 with small differences
    - Version 4: assuming 8-minute average stable gain, iterative computation of intercept
  - Operational models also assume some level of static coefficients which does not seem to be the case in reality
- Variations in calibration methodology make use of HIRS for climate problematic
- Above calibrations have concentrated mainly on modelling the gain but self-emission is an extra *radiance* source

Pre-FIDUCEO: HIRS non-linearity/SRF

- Operational calibration assumes linear measurement equation
  - BUT HgCdTe detectors are inherently non-linear
    - If linear should see no gain variations but variations are seen
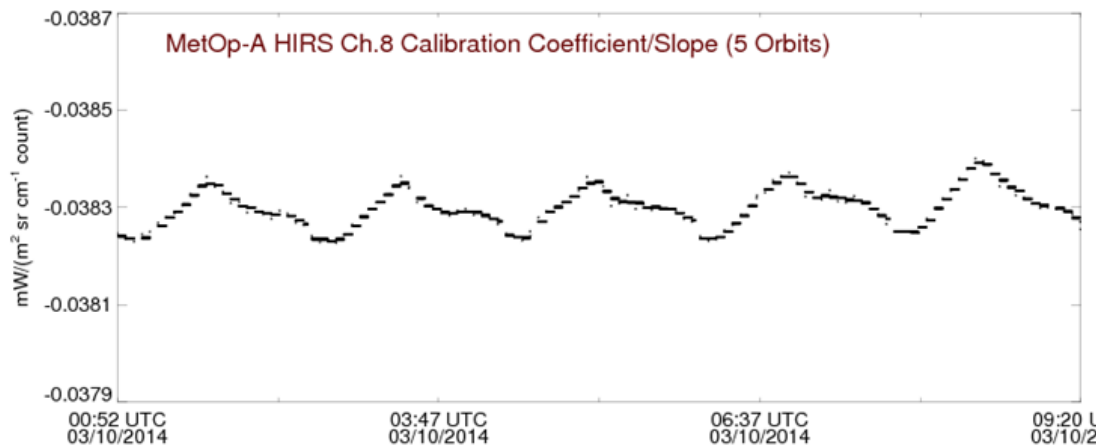
HIRS channel 8 (11μm) gain variations showing the non-linearity of the HIRS channels. Plot taken from the NOAA/STAR Integrated calibration/Validation System (http://www.star.nesdis.noaa.gov/icvs/status_MetOPA_HIRX.php)

- Also 'known' spectral response issues
  - Shifts/non-linear corrections estimated for a small number of channels (Channels 4,5,6,7 NOAA-09 to MetOp-A (Chen, Cao & Menzel 2013), Shifts for Channel 12 (Shi & Bates 2011))

HIRS before FIDUCEO

- Multiple calibration algorithms
  - Variations in methodology will introduce differences between sensors
  - Sensors not harmonised

- Self-emission model not in radiance
  - Mainly done as modelling the gain
  - Current experience for other instruments shows that not modelling the exact error source will itself introduce errors

- Non-linearity
  - Operationally no no-linear term
  - For a few selected instruments/channels an estimate is available but is not available for a wide range of channels/sensors

- SRF
  - SRF shifts have been estimated for 4 CO_2 channels and 1 WV channel
    - These are included in FIDUCEO dataset
  - Note non-linearity and SRF shifts are highly correlated
    - For FIDUCEO non-linear term will provide some correction for possible shifts for those channels with no recorded shift

- Uncertainties
  - Not available at the pixel level
  - No error correlation information

FIDUCEO HIRS measurement equation

- Current measurement equation

Observed Counts

Self-emission model

$$L_{\mathrm{E}} = \alpha \left(C_{\mathrm{E}} - \overline{C}_{\mathrm{S}} \right) + a_2 \left(C_{\mathrm{E}}^2 - \overline{C}_{\mathrm{S}}^2 \right) - \left(L_{\mathrm{self,E}} \left(T_{\mathrm{inst}} \right) - L_{\mathrm{self,S}} \left(T_{\mathrm{inst}} \right) \right) + a_4 + 0$$

+0 term

Gain term derived from IWCT measurements including C_{IWCT}

Non-linear term

Bias term

- Uncertainties provided for all components

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Uncertainty tree diagram.

$$T_{TWCT} = \left(\frac{1}{N}\sum_i T_{PRT,i}\right) + 0$$

$$\frac{\partial T_{TWCT}}{\partial T_{PRT,i}}$$

$$T_{PRT,i} = \sum_k d_{PRT,ki} C_{PRT,ki} + 0$$

$$\frac{\partial T_{PRT,i}}{\partial C_{PRT,ki}}$$

$u(C_{PRT,ki})$ — Detector noise, Digitisation

$$\frac{\partial L_{TWCT}}{\partial T_{BB}}\frac{\partial T_{BB}}{\partial T_{TWCT}}$$

As for L_E — $u(L_{refl})$

$$\frac{\partial T_{PRT,i}}{\partial d_{PRT,k}}$$

$u(0)$ — Non-quadratic non-linearity

FOV estimation for element — $\{u(\Omega_{TWCT,i})\}$

Emissivity estimation for element — $\{u(\varepsilon_{TWCT,i})\}$

Temperature estimation for element — $\{u(T_{TWCT,i})\}$

$u(0)$ — PRT representitiveness, Temperature gradients

$$\frac{\partial L_{TWCT}}{\partial L_{refl}}$$

$u(d_{PRT,k})$ — PRT calibration

$$\bar{L}_{TWCT} = \int\big((\varepsilon_{ch} + a_3) L_{BB}(\lambda, T_{TWCT}) + (1 - \varepsilon_{ch} - a_3) L_{refl}(\lambda)\big)\xi_{ch}(\lambda)\, d\lambda + 0$$

$u(0)$ — Model incompleteness

$$\frac{\partial \alpha}{\partial L_{TWCT}} \qquad \frac{\partial \alpha}{\partial L_{self,TWCT}}$$

$$\left[\frac{\partial L_{selfTWCT}}{\partial \Omega_{TWCT,i}}\right] \quad \left[\frac{\partial L_{selfTWCT}}{\partial \varepsilon_{TWCT,i}}\right] \quad \left[\frac{\partial L_{selfTWCT}}{\partial T_{TWCT,i}}\right]$$

$$L_{self,TWCT}(T_{inst}) = \sum_i \left[\Omega_{TWCT,i} \int \xi_{ch}(\lambda)\,\varepsilon_{TWCT,i}(\lambda_{ch,c}, T_i)\, L_{BB}(\lambda, T_{TWCT,i})\, d\lambda\right] + 0$$

$u(0)$ — Model incompleteness

SRF centre, SRF shape — $\{u(\xi_i)\}$ — $\dfrac{\partial L_{TWCT}}{\partial \xi_i}$

$$\frac{\partial L_E}{\partial C_S} \qquad \bar{C}_S = \frac{1}{n}\sum_i^n C_{S,k} \qquad \frac{\partial \bar{C}_S}{\partial C_{S,k}}$$

$u(C_{S,k})$ — Noise, Digitisation, Crosstalk

Noise, Digitisation, Crosstalk — $u(C_E)$ — $\dfrac{\partial L_E}{\partial C_E}$

$$L_E = \alpha(C_E - \bar{C}_S) + a_2(C_E^2 - \bar{C}_S^2) - (L_{self,E}(T_{inst}) - L_{self,S}(T_{inst})) + a_4 + 0$$

$u(0)$ — Non-quadratic non-linearity, Undesired electronics effects, Other unmodelled effects

$$\frac{\partial L_E}{\partial \alpha} \qquad \frac{\partial L_E}{\partial L_{self,E}} \qquad \frac{\partial L_E}{\partial L_{self,S}} \qquad \frac{\partial L_E}{\partial a}$$

$u(a)$ — Harmonisation

$$\alpha = \frac{\bar{L}_{TWCT} + L_{self,TWCT}(T_{inst}) - L_{self,S}(T_{inst}) - a_2(\bar{C}_{TWCT}^2 - \bar{C}_S^2)}{\bar{C}_{TWCT} - \bar{C}_S}$$

$$\frac{\partial \alpha}{\partial \bar{C}_{TWCT}} \qquad \bar{C}_{TWCT} = \frac{1}{n}\sum_k^n C_{TWCT,k} \qquad \frac{\partial \bar{C}_{TWCT}}{\partial C_{TWCT,k}}$$

$u(C_{TWCT,k})$ — Digitisation, Crosstalk, Noise

$$L_{self,E}(T_{inst}) = \sum_i \left[\Omega_{E,i} \int \xi_{ch}(\lambda)\,\varepsilon_{E,i}(\lambda_{ch,c}, T_i)\, L_{BB}(\lambda, T_{E,i})\, d\lambda\right] + 0$$

$$L_{self,S}(T_{inst}) = \sum_i \left[\Omega_{S,i} \int \xi_{ch}(\lambda)\,\varepsilon_{S,i}(\lambda_{ch,c}, T_i)\, L_{BB}(\lambda, T_{S,i})\, d\lambda\right] + 0$$

$$\left[\frac{\partial L_{selfE}}{\partial \Omega_{E,i}}\right] \quad \left[\frac{\partial L_{selfE}}{\partial \varepsilon_{E,i}}\right] \quad \left[\frac{\partial L_{selfE}}{\partial T_{E,i}}\right]$$

$\{u(\Omega_{E,i})\}$, $\{u(\varepsilon_{E,i})\}$, $\{u(T_{E,i})\}$, $u(0)$

FOV estimation for element, Emissivity estimation for element, Temperature estimation for element, Model Incompleteness

$$\left[\frac{\partial L_{selfS}}{\partial \Omega_{S,i}}\right] \quad \left[\frac{\partial L_{selfS}}{\partial \varepsilon_{S,i}}\right] \quad \left[\frac{\partial L_{selfS}}{\partial T_{S,i}}\right]$$

$\{u(\Omega_{S,i})\}$, $\{u(\varepsilon_{S,i})\}$, $\{u(T_{S,i})\}$, $u(0)$

FOV estimation for element, Emissivity estimation for element, Temperature estimation for element, Model Incompleteness

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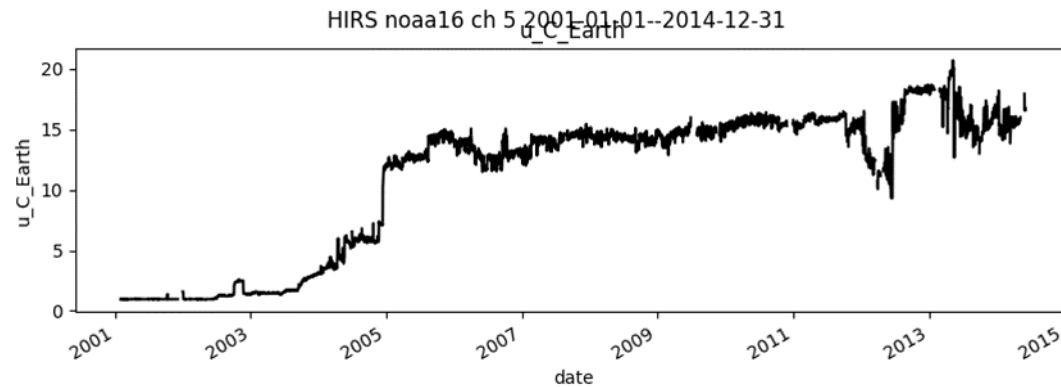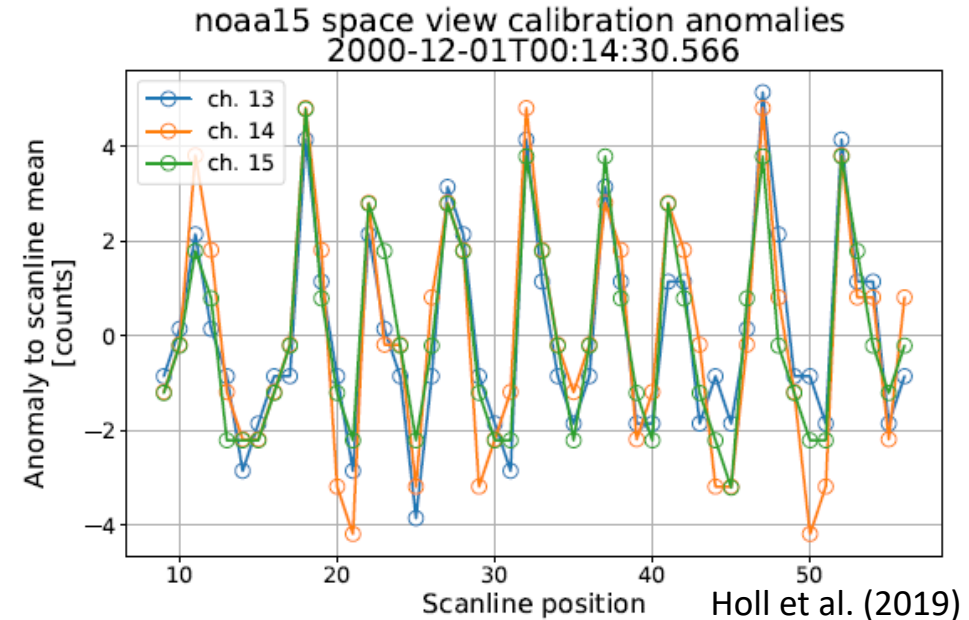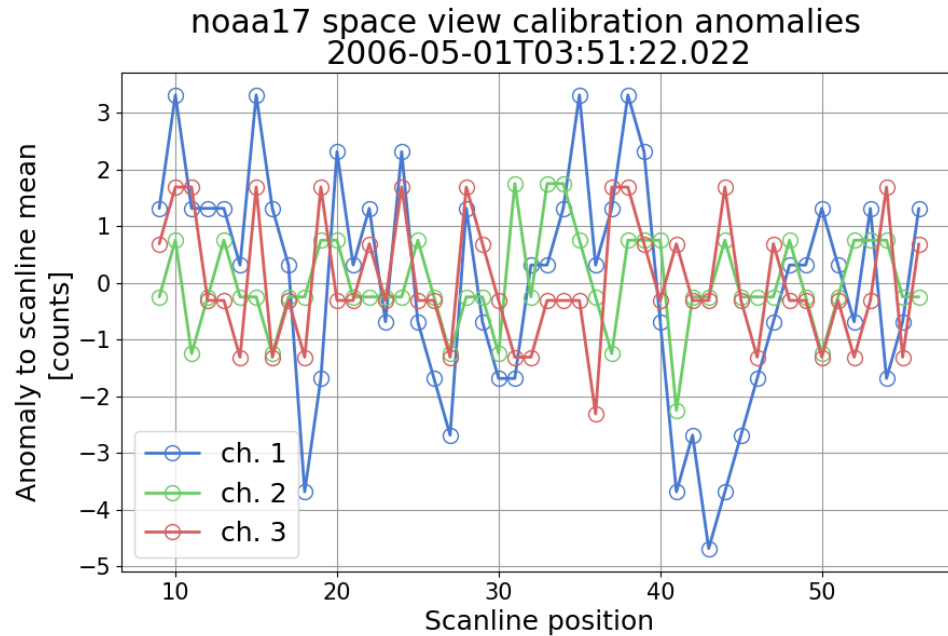
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FIDUCEO Noise estimates

- Much more comprehensive study
  - Track noise variations with time and included in FIDUCEO uncertainty (independent)

  - Sometimes the changes can be abrupt

HIRS noaa16 ch 5 2001-01-01--2014-12-31
u_C_Earth

Calibration noise (Allan deviation) for space and IWCT views

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FIDUCEO Noise estimates (2)

- Highlighted previously unknown effects
  - Sometimes have highly correlated 'noise' across channels

noaa17 space view calibration anomalies
2006-05-01T03:51:22.022

noaa15 space view calibration anomalies
2000-12-01T00:14:30.566

Holl et al. (2019)

- Correlation can also change time when noise behaviour changes

FIDUCEO Noise correlations

- The Channel to Channel correlations as a function of channel

  - Also see clear division by detector type (Channels 1-12 HgCdTe, Channels 13-19 InSb)
- **Will be important for retrievals**
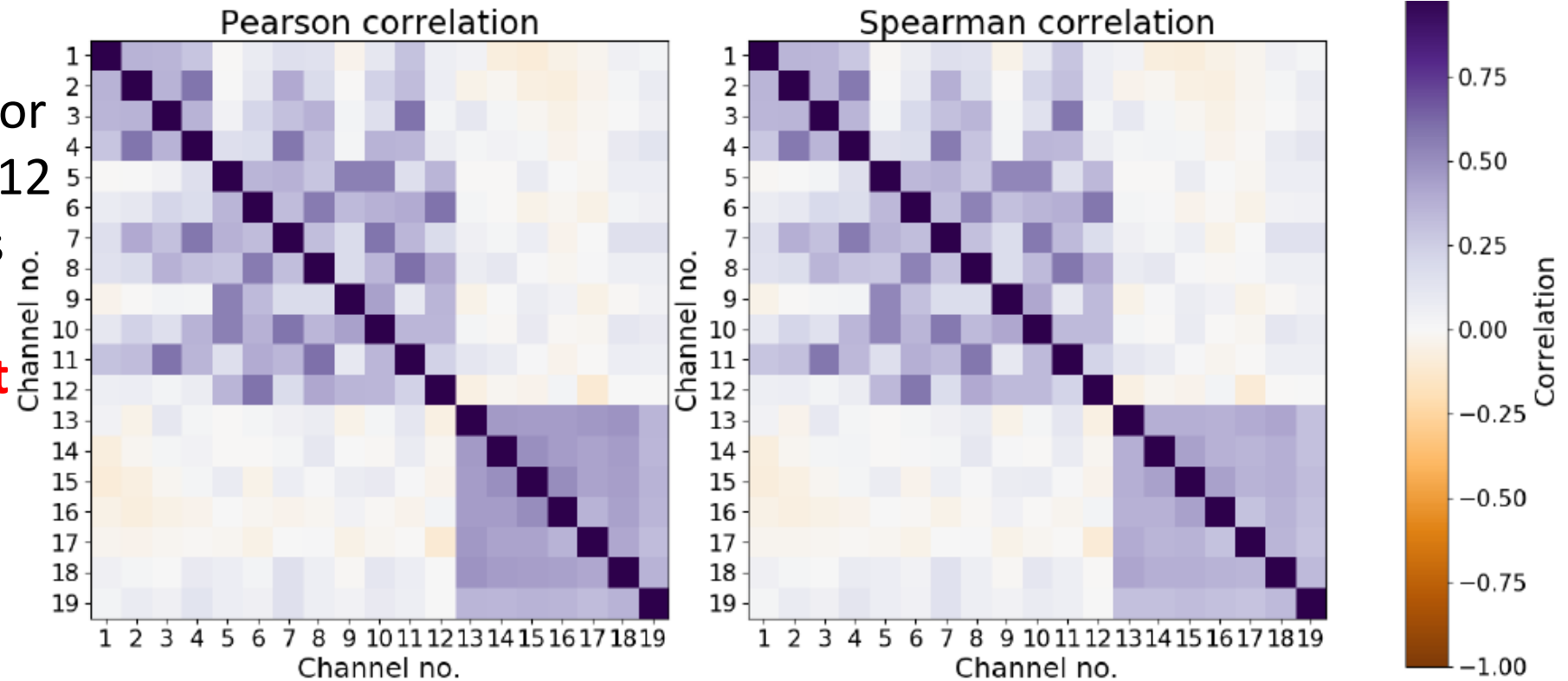
FIDUCEO Self-emission model

- Current model a function of various temperatures (6) and are modelled on the fly
- Solves the problem with the operational model
  - Consistent across series
  - Naturally follow non-static variations
- But does not force the solution through the calibration measurements
  - May be leading to some blockiness in final radiances (from Viju)
- Have implemented a simple linear interpolation version but not harmonised

Brightness temperature

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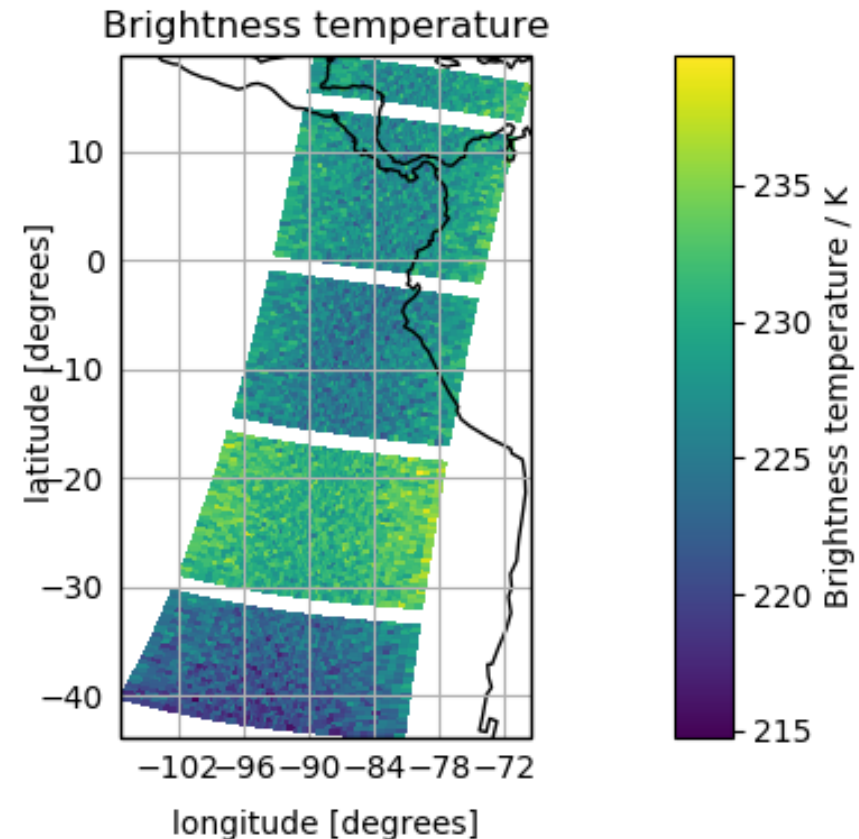
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HIRS Uncertainty components

- Provide FIDUCEO uncertainties
  - Independent component shows large variability for some cases
  - Structured includes self-emission model uncertainties which can be large currently
  - Common uncertainty dominated by harmonisation uncertainties
- This sort of information hasn't been available before
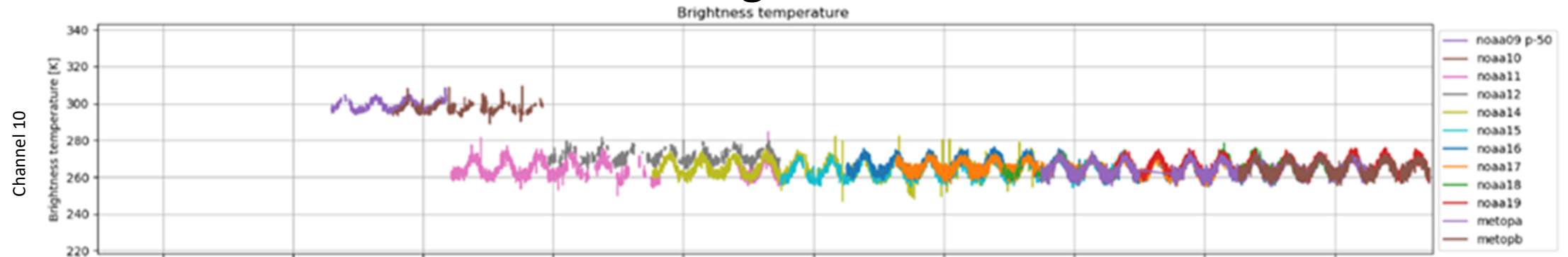 - Shows complexity of HIRS uncertainties
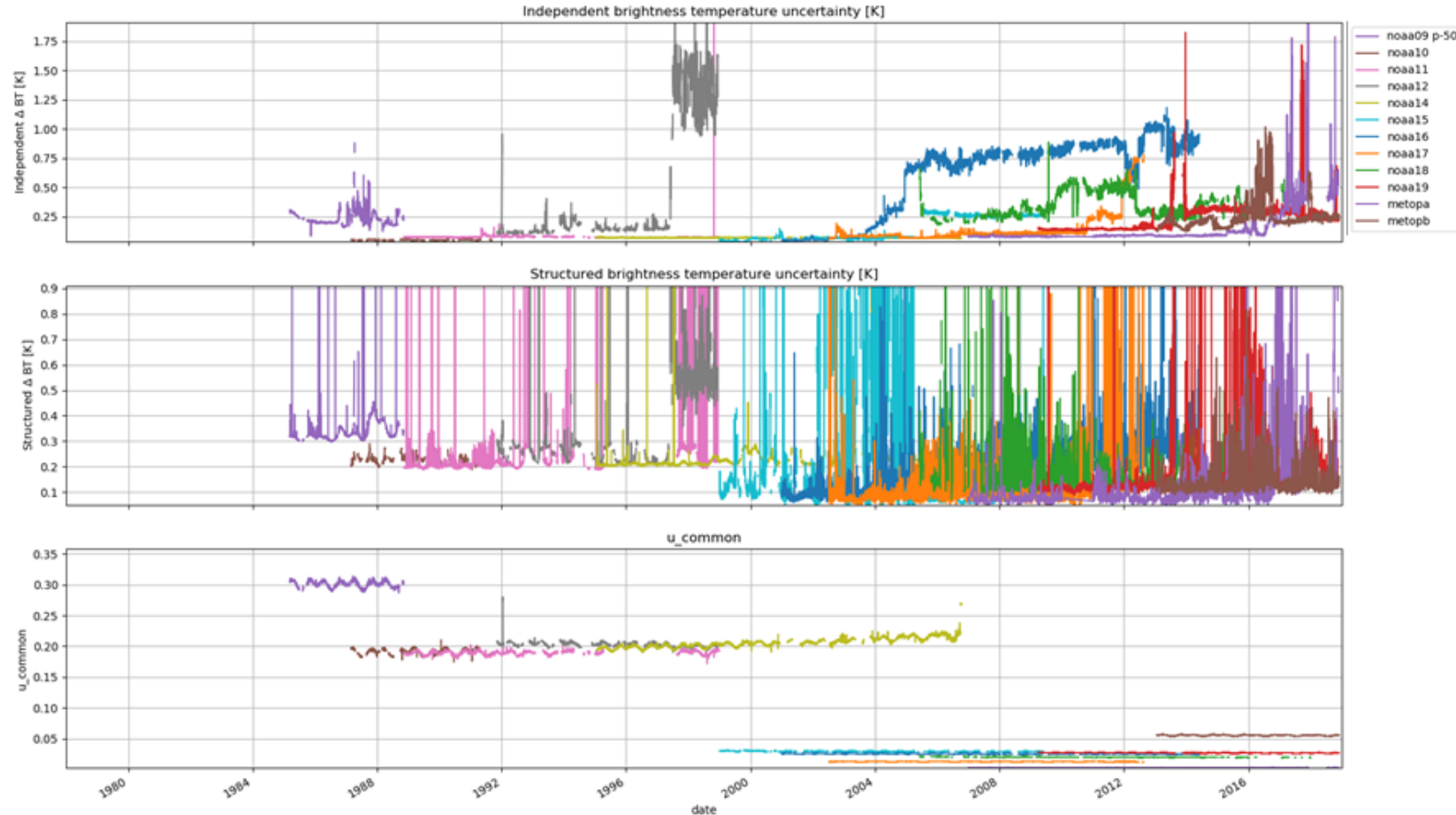
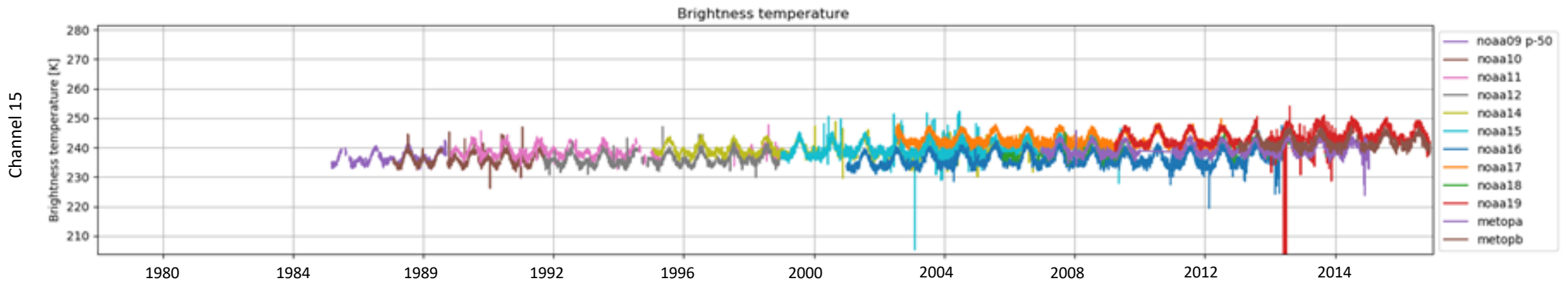# HIRS Harmonisation

- For channels > 4µm most channels link up well
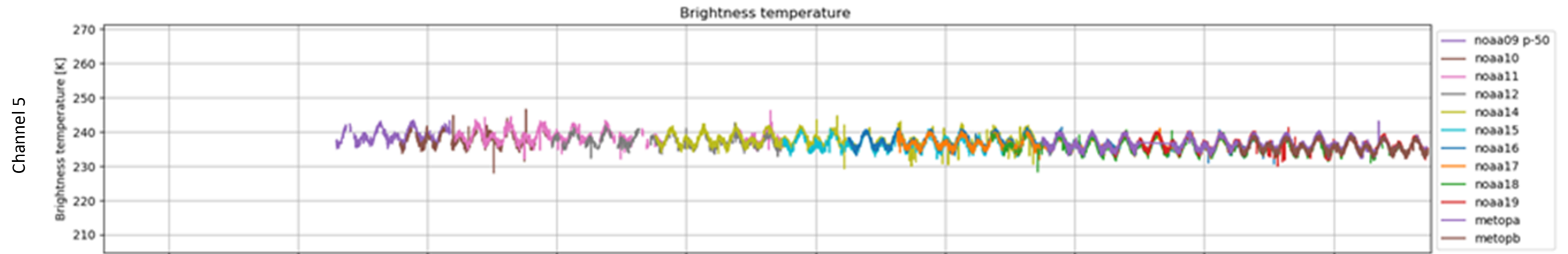
- Some channels are shifted during the sensor series see offsets so not

HIRS Harmonisation (2)

- For 4μm channels (Channels 12-19) also see offsets so not as well harmonised

- Still investigating this
  - Issues with matchups?
  - Issues with measurement equation (much more likely to be linear)

Conclusions

- Detailed noise study
  - Including channel to channel correlated 'noise'
  - Time variation/spectral correlations studied and included
    - Not all behaviour is fully explained though…

- Updated measurement equation with self emission term explicitly in radiance
  - Non-linearity explicitly included
  - Self emission dynamic parameterisation to deal with observed variations
    - Current model tries to model change in thermal state
    - May be introducing some steps in the radiances
    - Simple model self emission implemented but not included in current harmonisation

- Harmonisation works for some channels (>5μm)
  - Needs more study/thought for rest
    - Significant changes in SRFs for some channels
    - 4μm channels seem more problematic
    - Gaps in matchups currently to get to earliest sensors
      - Current FCDR from 1985-2018 (NOAA-09 to MetOp-A)
  - Techniques for including SRF shifts were studied but need more work to implement into Harmonisation
    - Previous SRF shift work did not include proper uncertainties