Investigating possible sources of error in the calibration of the Microwave Sounding Unit

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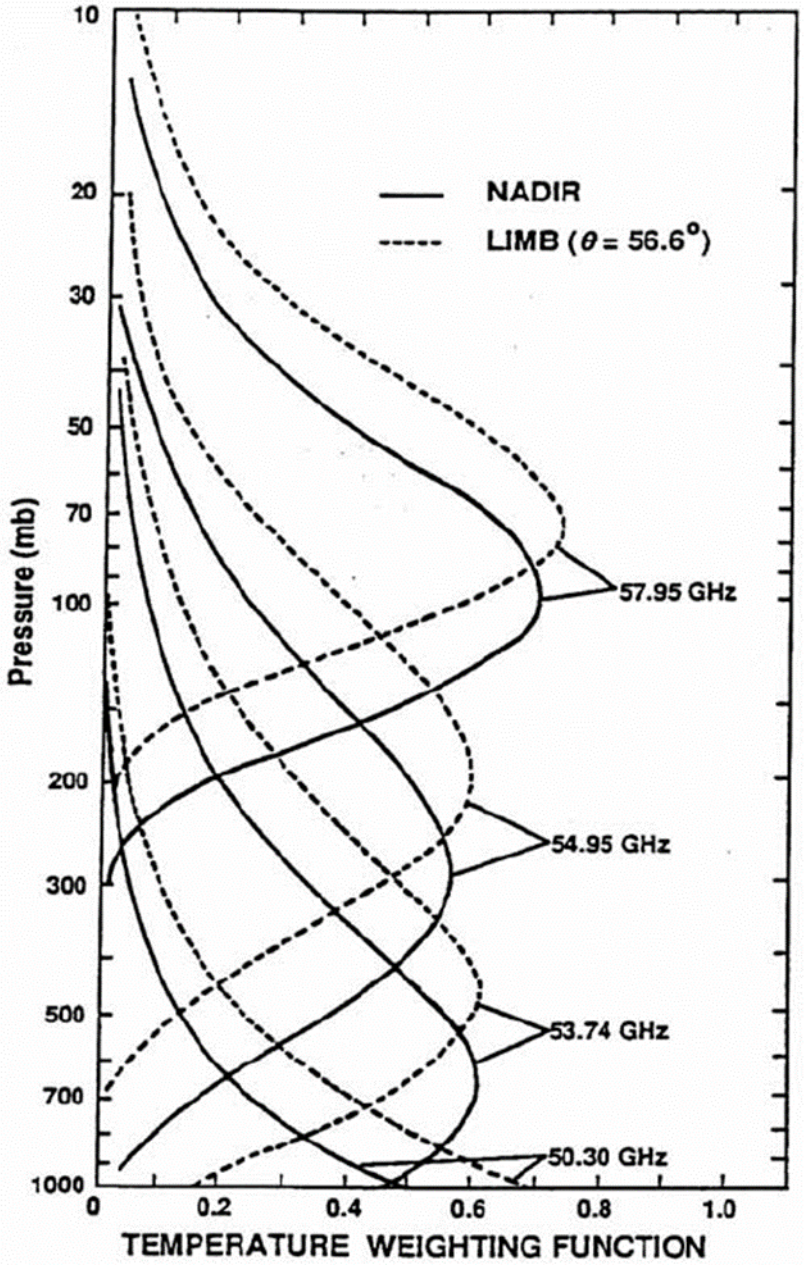
Microwave Sounding Unit

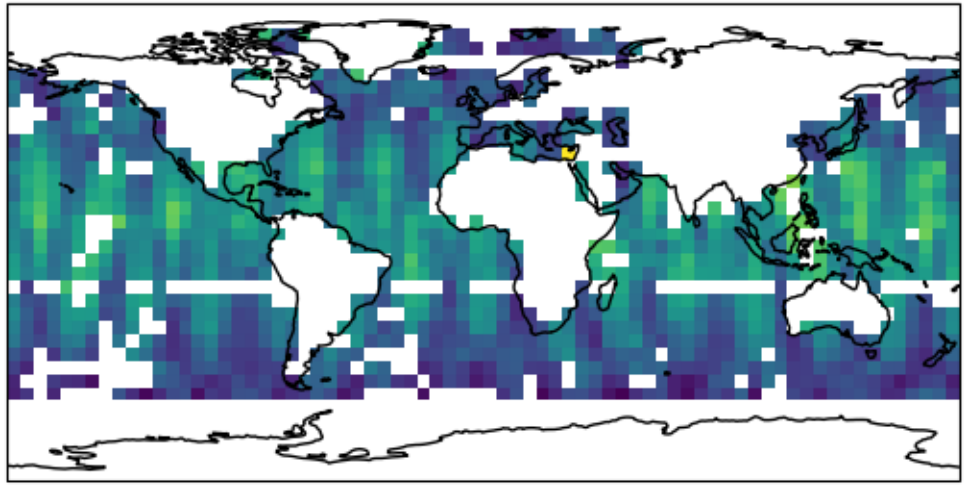
- A Microwave sounder flown on the NOAA satellites
  - Tiros-N to NOAA14 (1978 – 2000)
  - 4 channels
    - 50.30, 53.74, 54.96, 57.95GHz
    - Surface, Mid-Troposphere, Near Tropopause, Lower-Stratosphere
  - Used to generate climate data records
    - Many different examples E.g. from NOAA: Zou et al. 2014
    - Assimilated by ECMWF into ERA5
      - ECMWF looking into possible improvements in MSU characterisation for ERA6
    - Part of this work was done under an C3S/ECMWF project
      - See Bill Bell's talk next session after coffee



MSU vs a pseudo reference

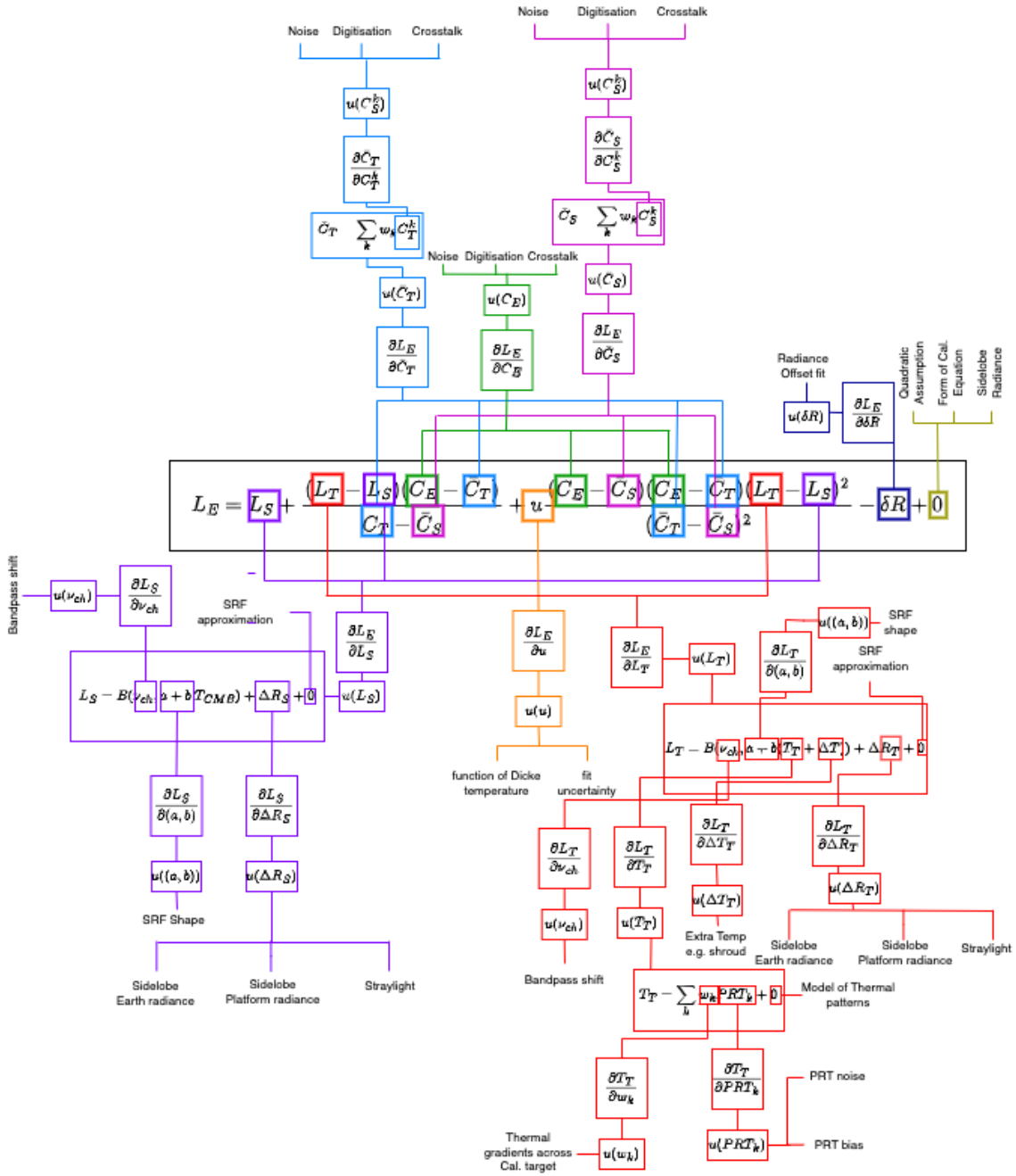
- ERA5+RTTOV 13.0 can act as a reference which
  - Is not a true reference as will have embedded errors/trends BUT:
    - Has great orbital coverage
    - Cannot generate a CDR but it is very good for studying sources of error in the data record
  - Date filtered using Level 1 flags plus outlier rejection and bad time rejection
  - Nadir only cases considered for the moment
  - Requires a cloud mask for best accuracy and channel coverage
- MSU Cloud mask
  - Based on AVHRR CCI SST cloud mask (IR)
  - MSU clear when 50% of footprint has clear SST pixels
  - For NOAA06-NOAA14
    - Tiros-N AVHRR not included in ESA CCI SST
- Use O-A data to look at error patterns including difference between measurement equations

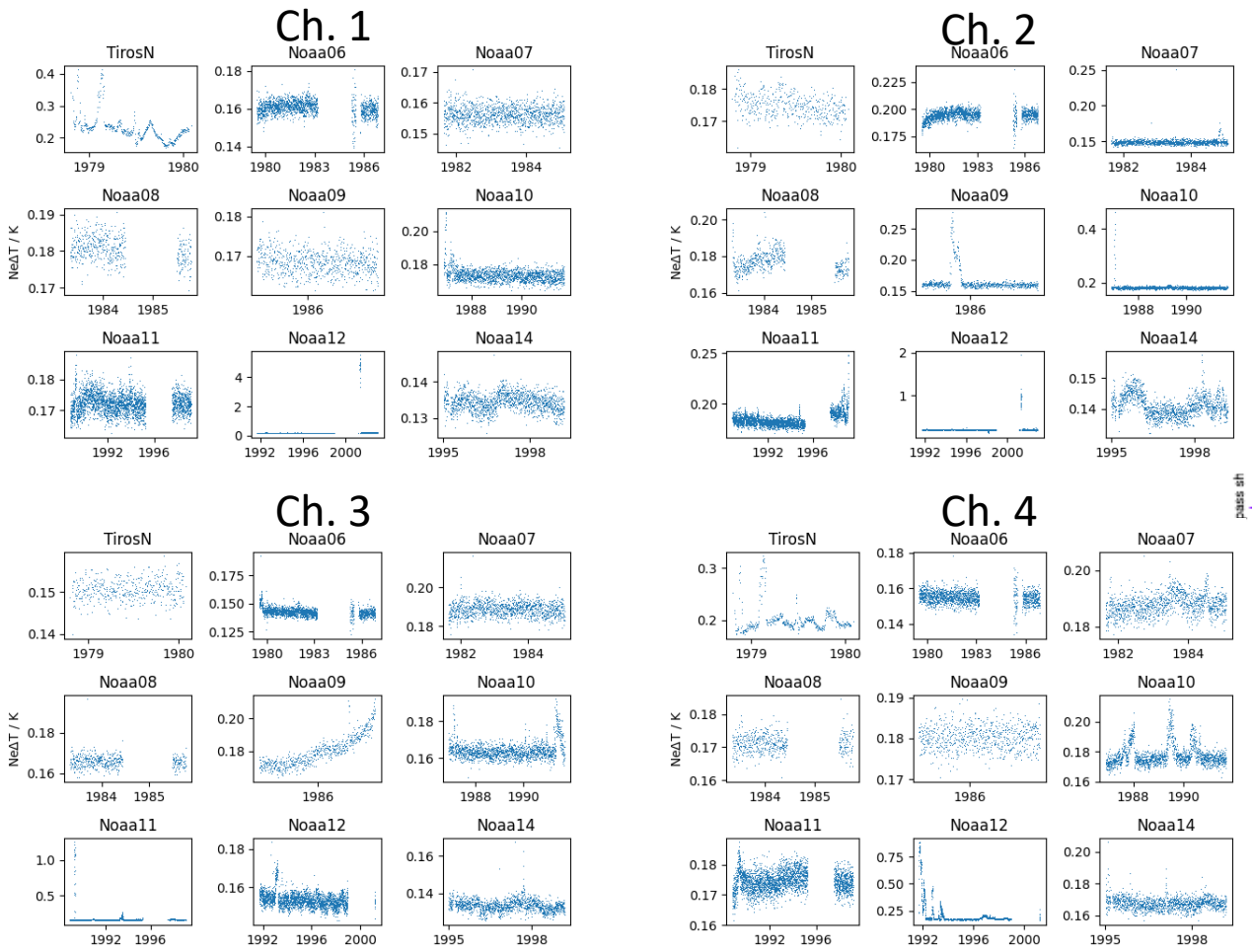
Clear Sky Radiances Channel 1
NOAA12 1994/06/15

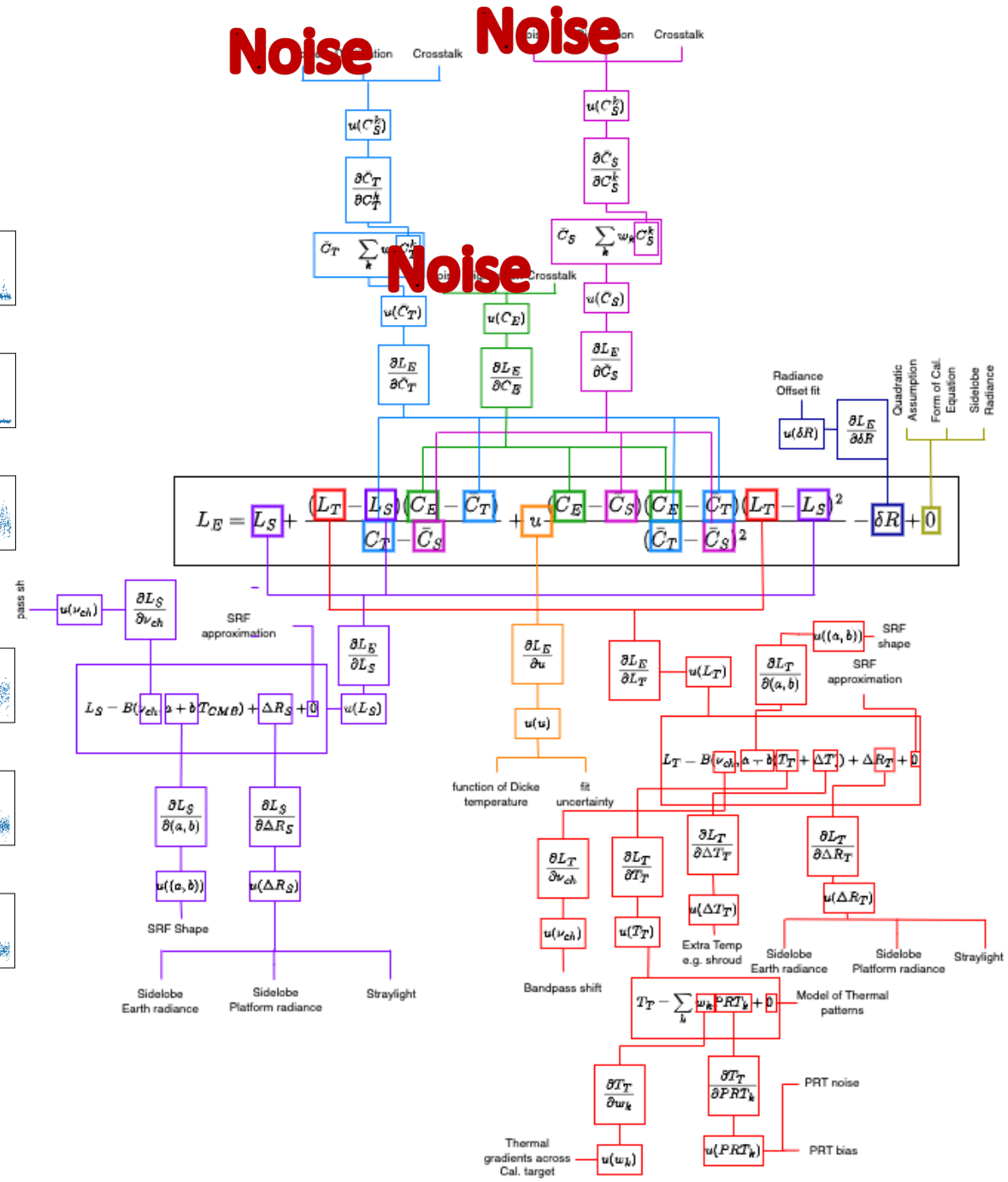


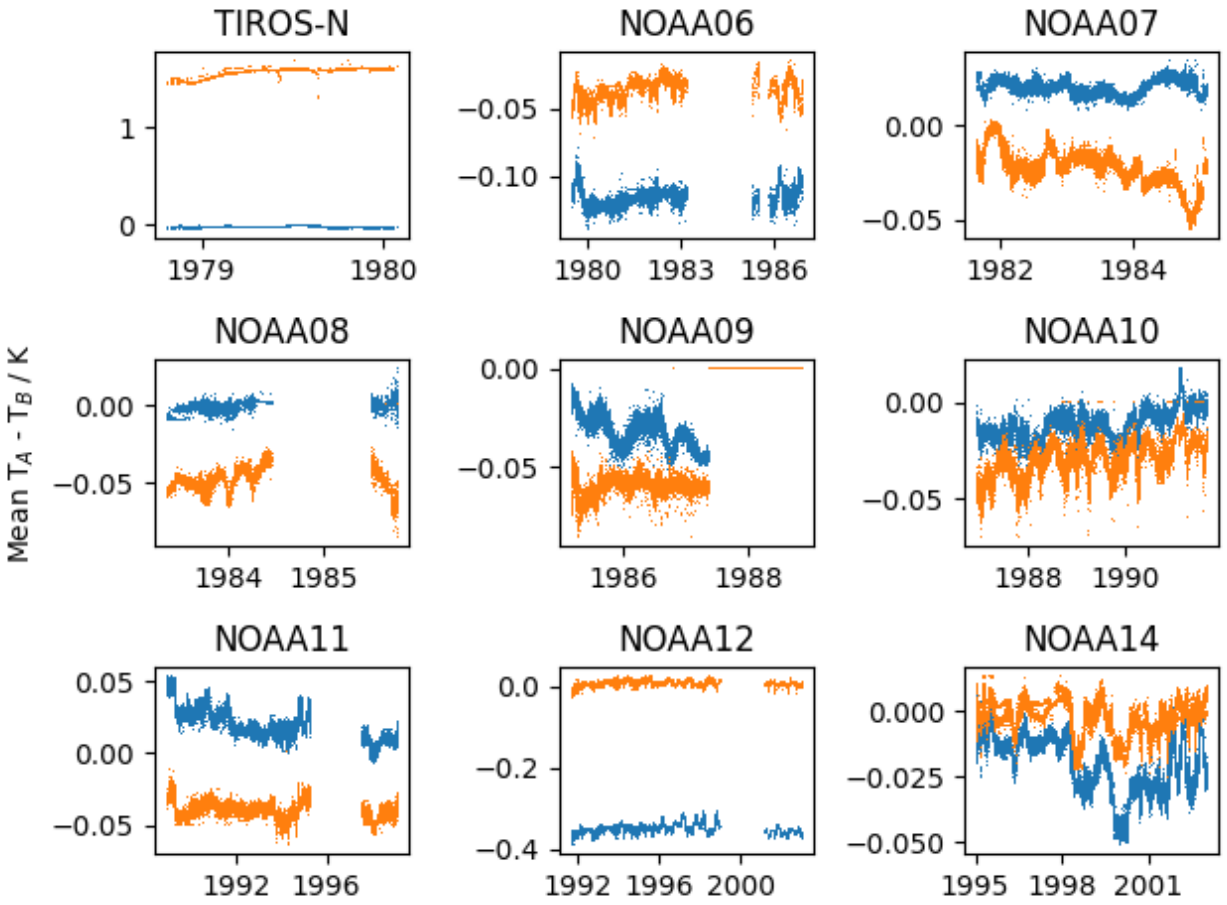
MSU Uncertainty Tree

- Example of AMSU measurement equation for MSU
  - Metrological approach to uncertainty e.g. FIDUCEO or QA4EO (www.qa4eo.org) or Mittaz, Merchant & Woolliams (2019) doi: 10.1088/1681-7575/ab1705
- For each term in the measurement equation traces back to sources of error
  - Including +0 term designed to highlight assumptions
- Each ‘twig’ comes with an effects table which also includes error correlation scales

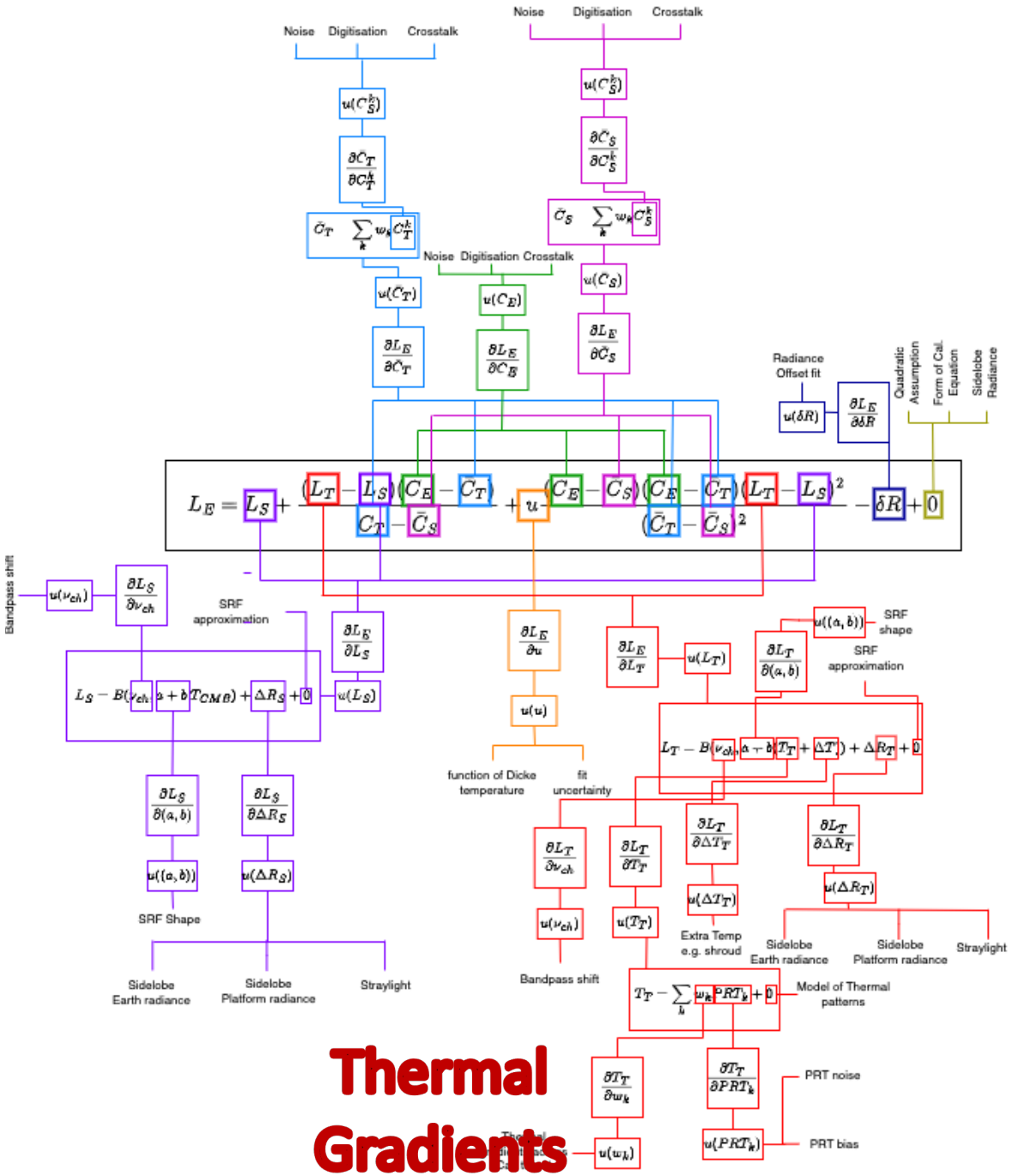



Ch. 1
Ch. 2
Ch. 3
Ch. 4
TirosN
Noaa06
Noaa07
Noaa08
Noaa09
Noaa10
Noaa11
Noaa12
Noaa14
NeΔT / K

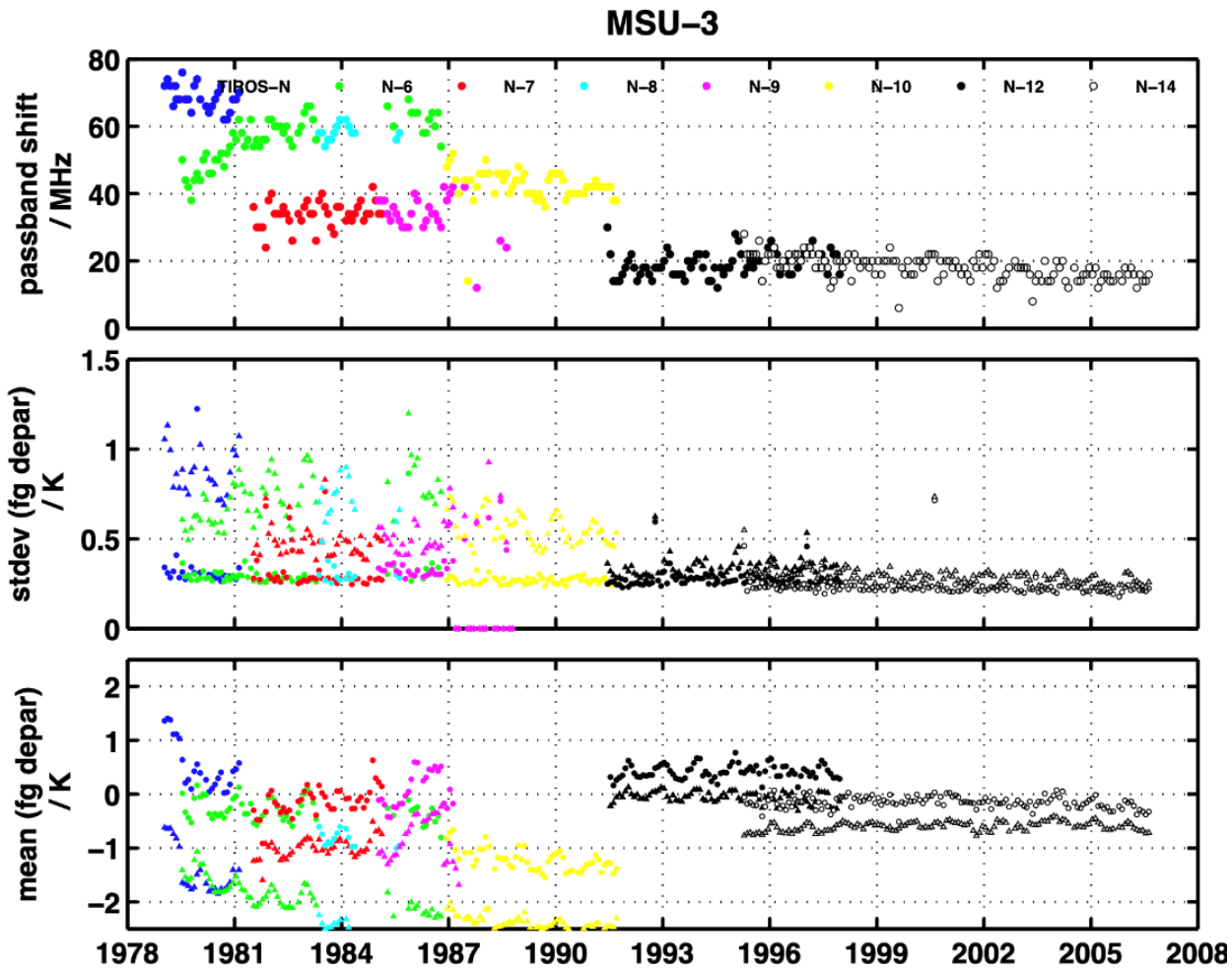

Noise
Noise
Noise
Crosstalk
Radiance Offset fit
Quadratic Assumption
Form of Cal. Equation
Sidelobe Radiance
SRF approximation
SRF shape
SRF Shape
function of Dicke temperature
fit uncertainty
Bandpass shift
Extra Temp e.g. shroud
Sidelobe Earth radiance
Sidelobe Platform radiance
Straylight
Model of Thermal patterns
Thermal gradients across Cal. target
PRT noise
PRT bias



Thermal gradients seem to be small.
Some problem with PRT estimates on TIROS-N/NOAA12?

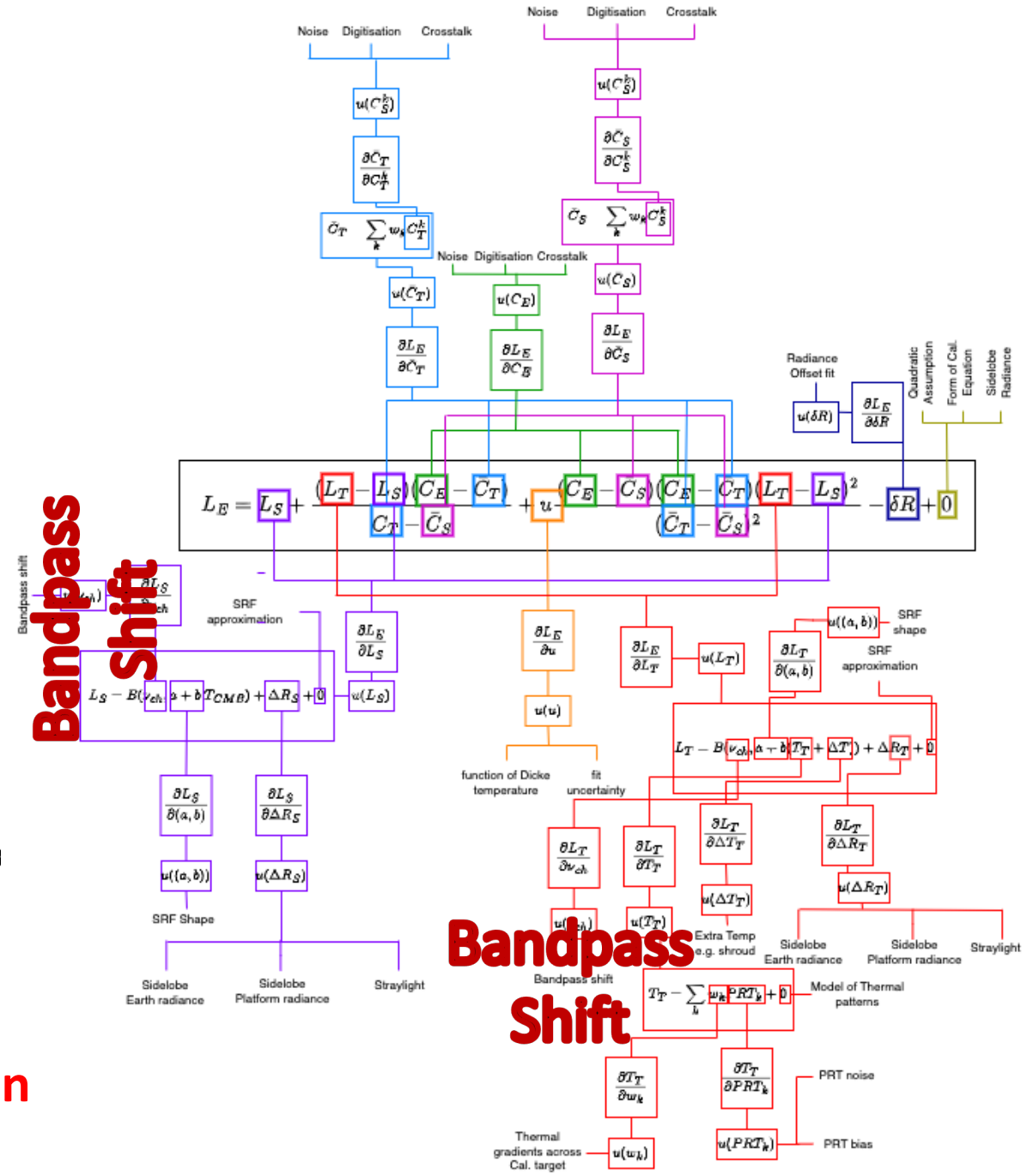


Thermal Gradients



From Lu & Bell 2014

Needs updating to include possible change in non-linear response



1. $C' = \sum_0^2 d_i C^i$; $N_E = N_{sp} + \frac{N_{sp}-N_T}{C'_{sp}-C'_T}(C'_E - C'_{sp})$ *Original calibration*

2. $N_E = N_T + \frac{C_E-\bar{C}_T}{G} + Q$; $G = \frac{\bar{C}_T-\bar{C}_S}{N_T-N_S}$; $Q = u\frac{(C_E-\bar{C}_T)(C_E-\bar{C}_S)}{G^2}$ *Mo 2001 variable u (using Dicke temperature)*

3. $T_{Meas} = T_0 + A_i + \alpha_i T_{Target,i} + \beta_i T_{Scene} + \varepsilon_i$ *Operational plus* UAH *corrections*

4. *Corrections including diurnal corrections from RSS*

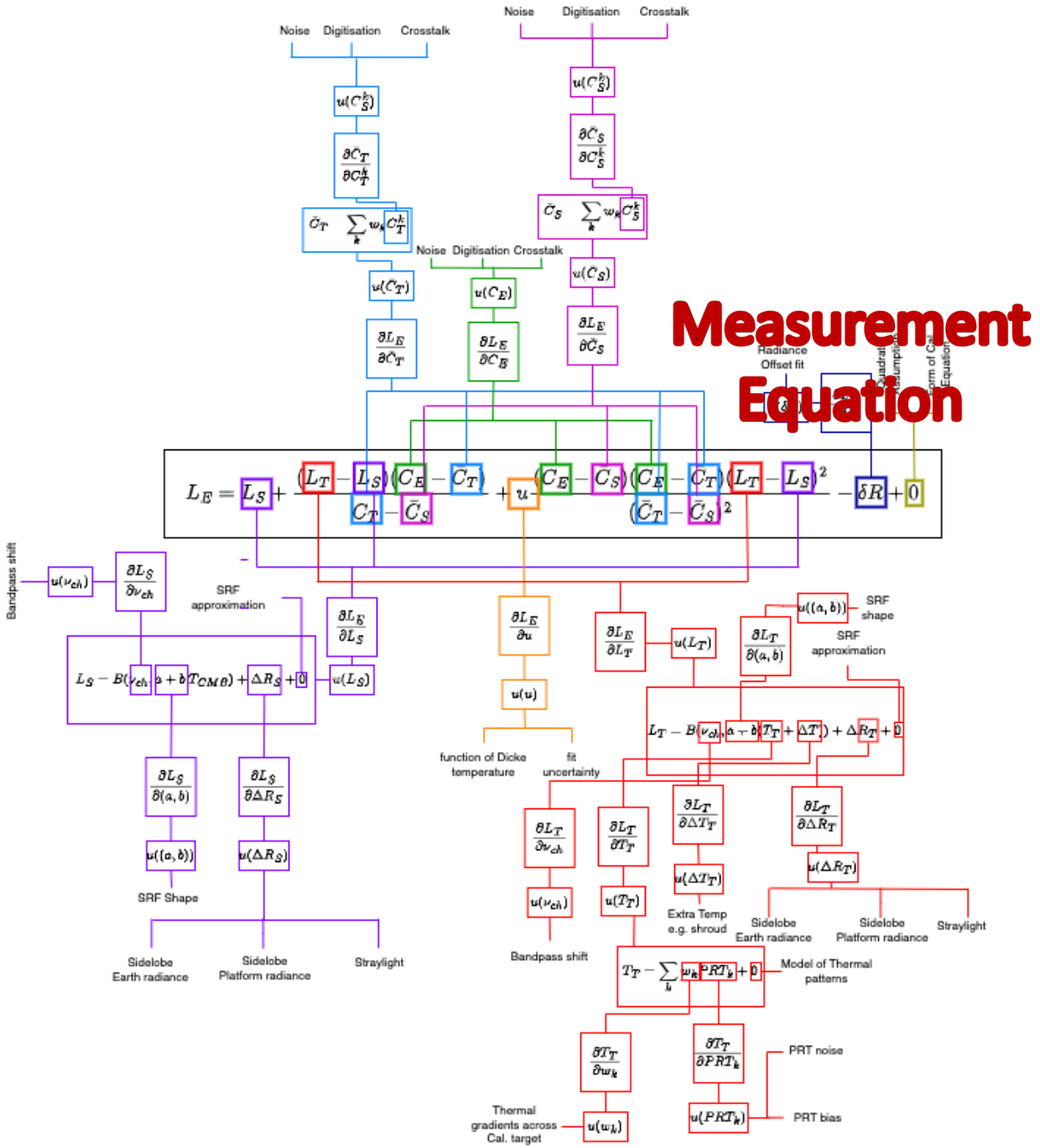
5. $N_E = N_S + S(C_E - \bar{C}_S) + uZ - \delta R$; $S = \frac{N_T-N_S}{\bar{C}_T-\bar{C}_S}$; $Z = S^2(C_E - \bar{C}_T)(C_E - \bar{C}_S)$ *Zou calibration like equation 2 but constant u (latest NOAA CDR)*

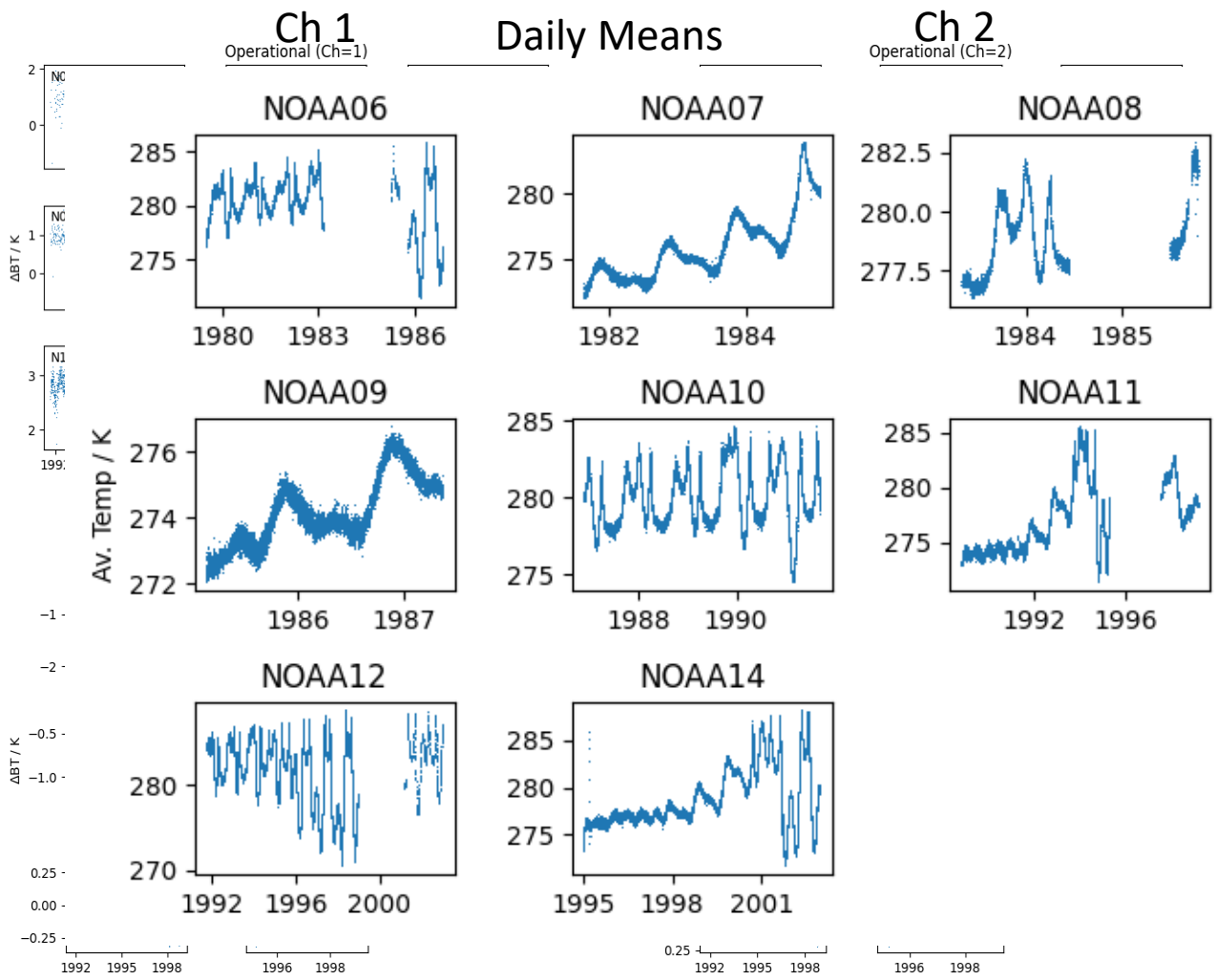
6. $N_E = \frac{(N_S-N_T(T_{Target}))-b_0-b_1N(T_{Target})-u(C_S^2-C_T^2)}{(C_S-C_T)}(C_E - C_S) + u(C_E^2 - C_S^2) + N_S + a_0 + a_1N(T_{Target})$; AVHRR like *(built in constant non-linearity) just assuming a quadratic non-linear term*

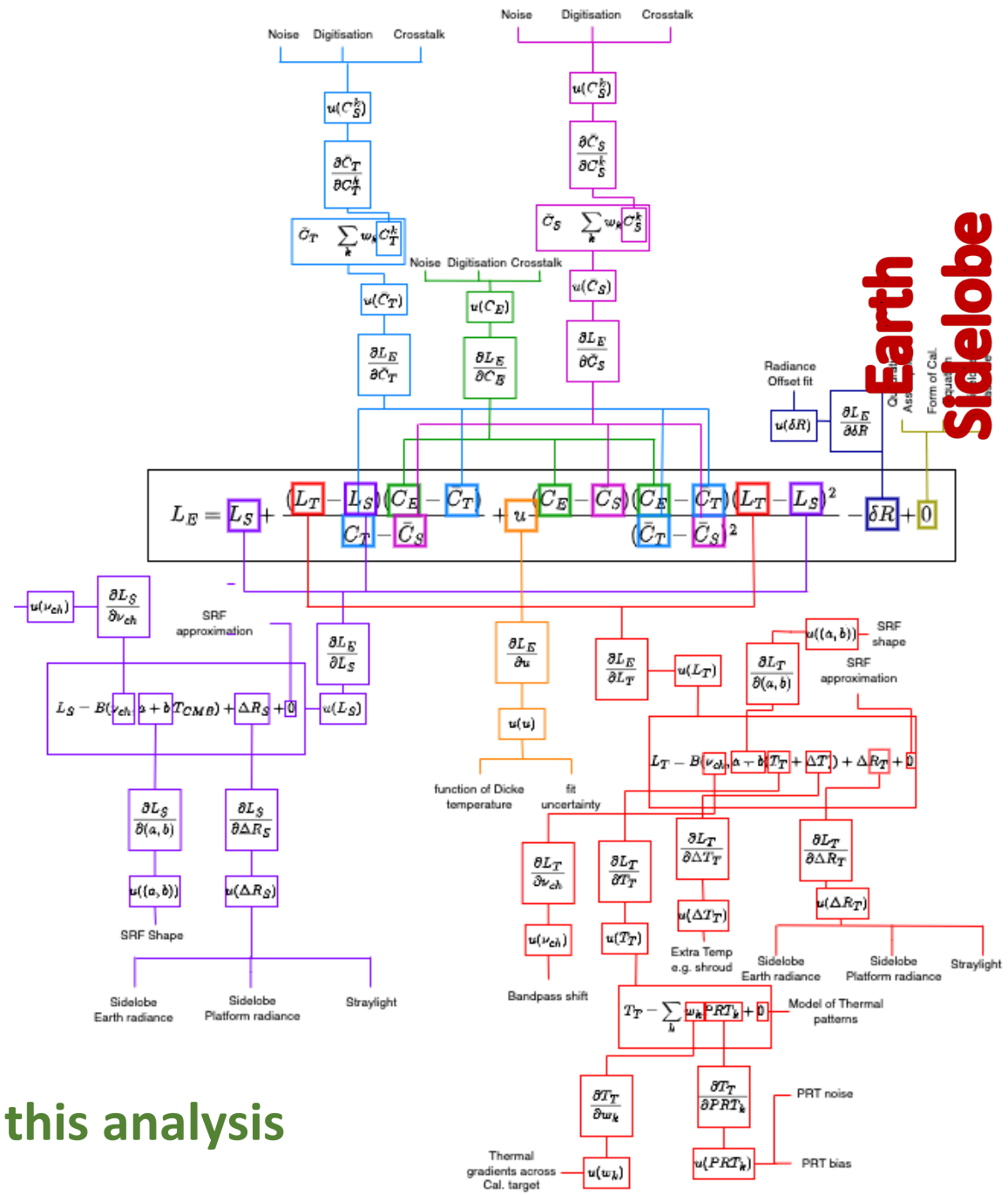
7. *And others (e.g. NCEI CDRs)…*

8. Plus combinations of above e.g. 2 + T_{Meas} from 3 and/or add in T_{inst} terms to gain

Many different measurement equations have been used so which one is best?







O-A (Obs-RTM) time series shows significant variation

Clear Instrument temperature dependence for many channel

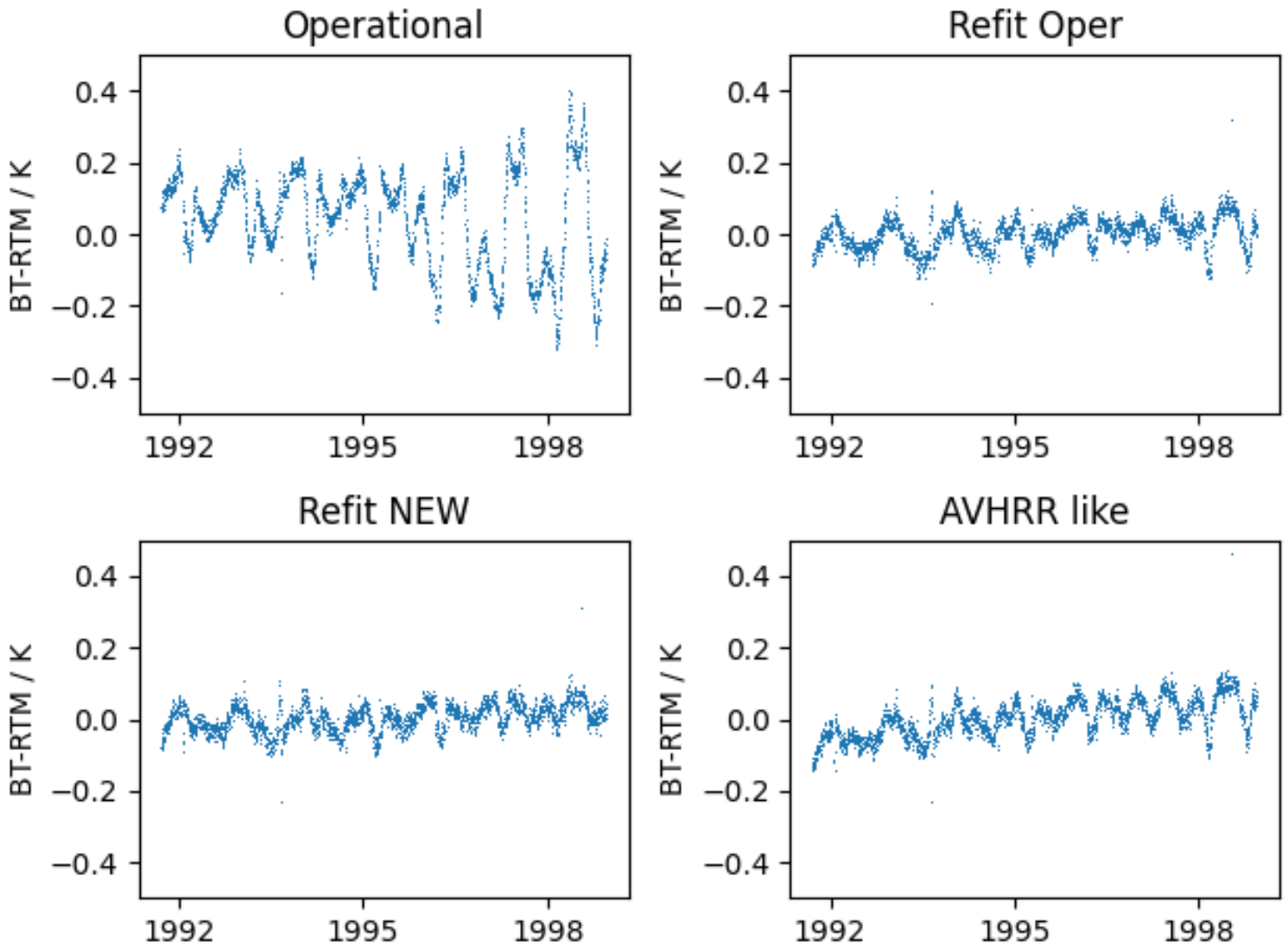
Previously known as an issue, but very clear in this analysis

Fit different measurement equations

- We can refit calibration parameters to RTM reference
  - 3 different measurement equations
    - Oper: $C' = \sum_0^2 d_i C^i$; $N_E = N_{sp} + \frac{N_{sp} - N_T}{\overline{C'}_{sp} - \overline{C'}_T}\left(C'_E - C'_{sp}\right) + a_1 N(T_{ICT}) + a_0$
    - New: $N_E = N_T + \frac{C_E - \bar{C}_T}{G} + Q + a_1 N(T_{ICT}) + a_0$; $G = \frac{\bar{C}_T - \bar{C}_S}{N_T - N_{Sp}}$; $Q = u\frac{(C_E - \bar{C}_T)(C_E - \bar{C}_{Sp})}{G^2}$
    - AVHRR: $N_E = \frac{(N_{Sp} - N_T) - b_0 - b_1 N_T - u(C_S^2 - C_T^2)}{(C_S - C_T)}(C_E - C_S) +$
      $u(C_E^2 - C_S^2) + a_0 + a_1 N_T$
  - Added instrument temperature term/offset
  - For AVHRR like equation added calibration target sidelobe term (platform radiance) explicitly

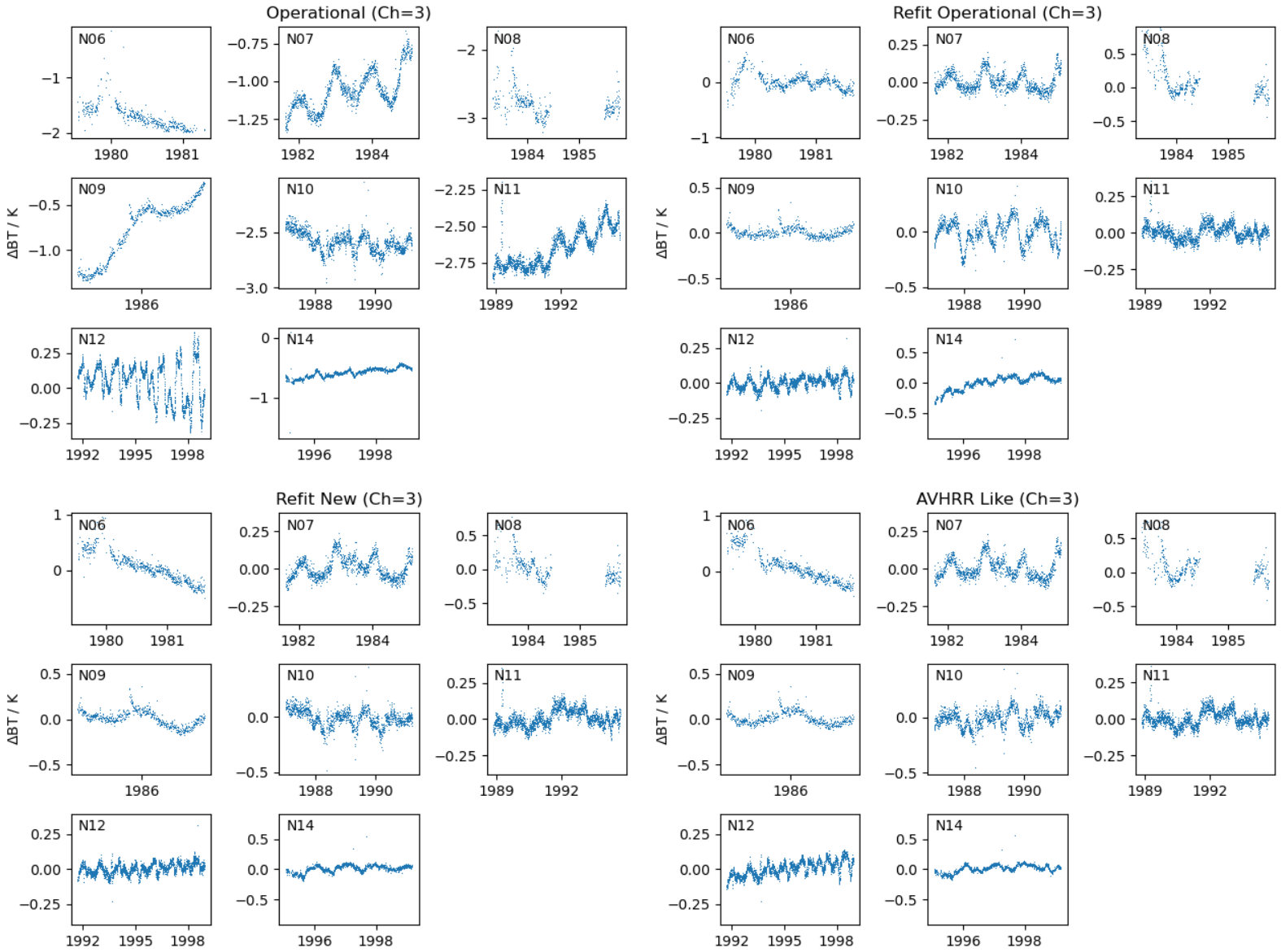
Example NOAA12 Channel 3

- Reduction in instrument temperature problem with extra terms
- Small trends still exist
  - Unclear of this is a problem with the calibration or ERA5
    - Note ERA5 will have assimilated the Operational case



Refit for All Sensors/Channels

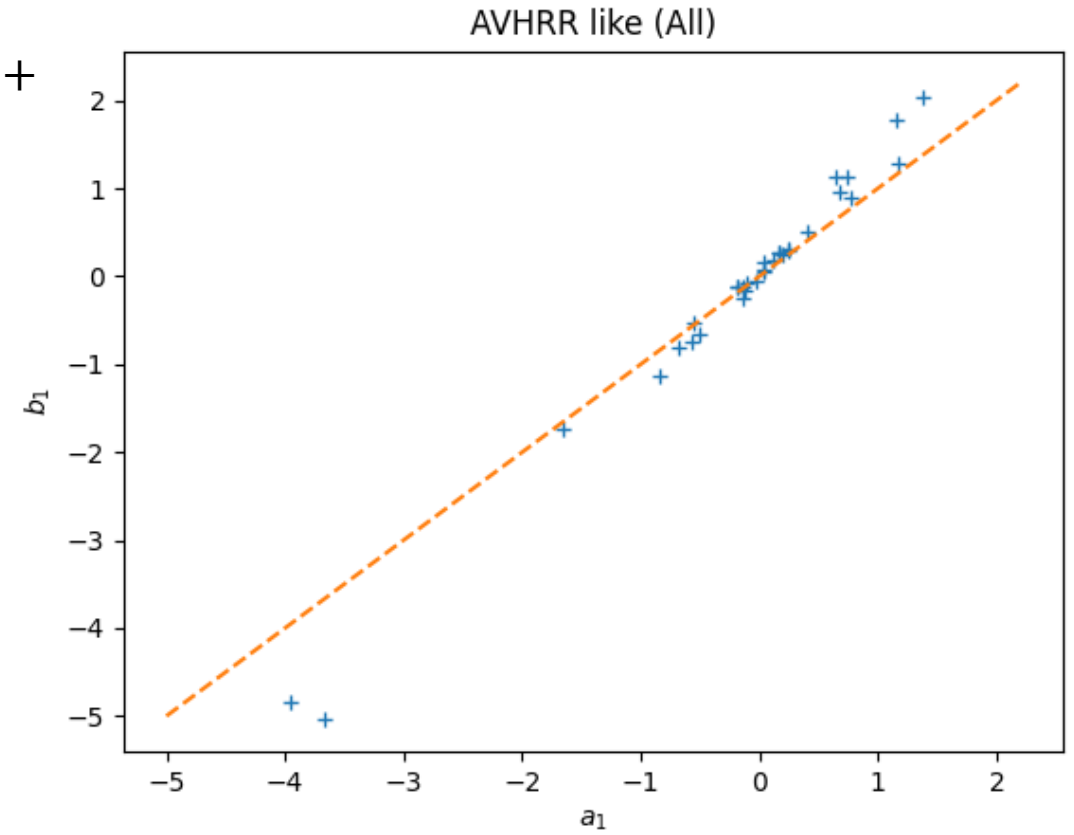
- Channel 3 example shown here
- Improvements for many sensors but some remaining issues
  - NOAA06 ‘New’ and ‘AVHRR’
  - NOAA07 variation (within a < 0.2K range)



Sidelobe correction terms for Earth and Calibration terms terms

$$\text{AVHRR: } N_E = \frac{(N_{Sp} - N_T) - b_0 - b_1 N_T - u(C_S^2 - C_T^2)}{(C_S - C_T)}(C_E - C_S) + u(C_E^2 - C_S^2) + a_0 + a_1 N_T$$

- Corrections to both Earth-Space view and Calibration-space view view dependent on platform temperature
  - For AVHRR like equation strong near 1:1 correlation between a1 and b1 terms implies Calibration view correction is real
  - Doesn't work as well for AMSU like equation…
    - Factor of 10 difference

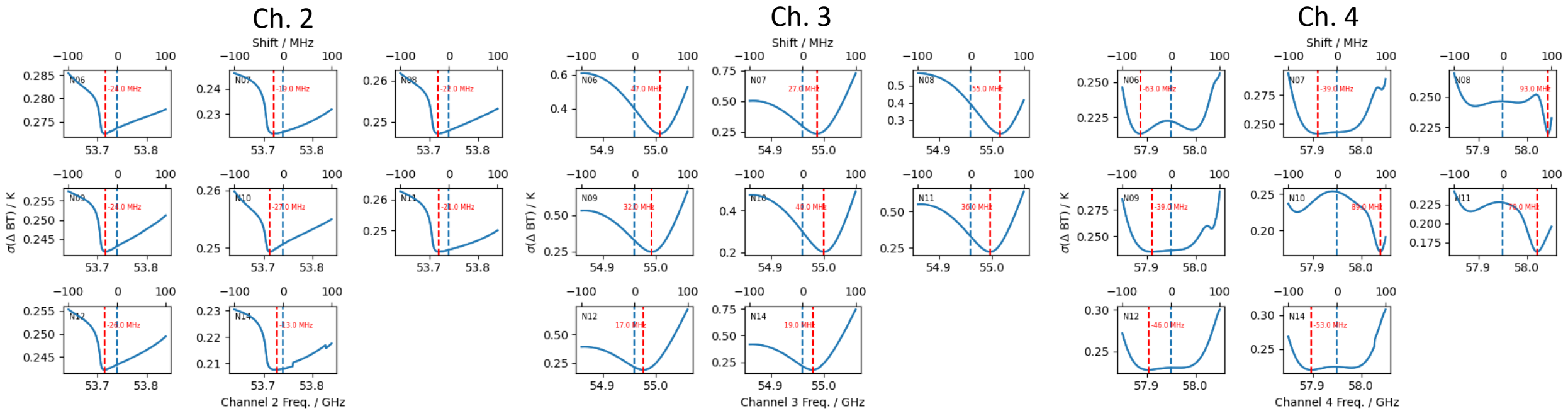


AMSU case NOAA12 Channel 3

	u	a_0 10^{-4}	a_1	b_0 10^{-4}	b_1	RSD 10^{-6}
All	4.002	0.774	-0.011	9.59	-0.105	5.791

Fit bandpass shift/non-linearity

- For consistency with current NOAA CDR (adding in sidelobe terms) refitted non-linearity with shifted bandpass (Shifted RTTOV Coefficients from Emma Turner UK Met Office) using global minimum fit

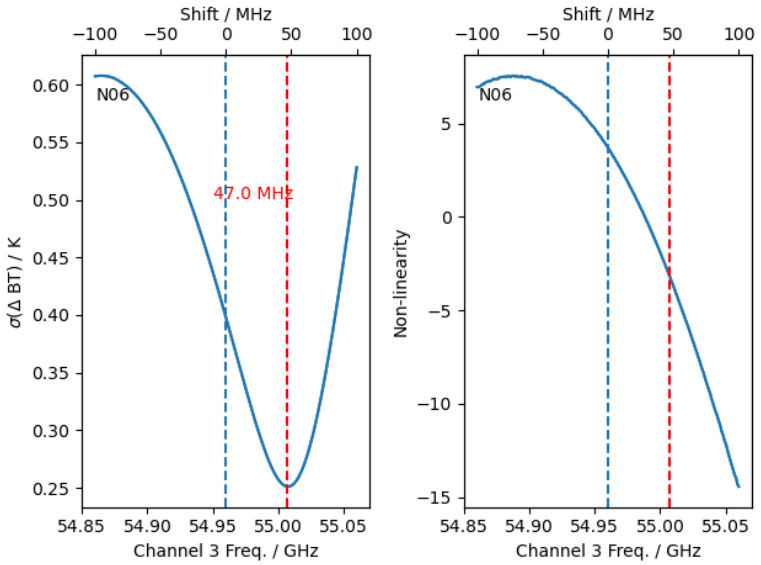


Apart from Ch 4. (which is relatively insensitive to bandpass shifts), Ch. 2 and Ch. 3 require shifts (Ch. 3 have shifts in the same direction though smaller that in Lu & Bell 2014)

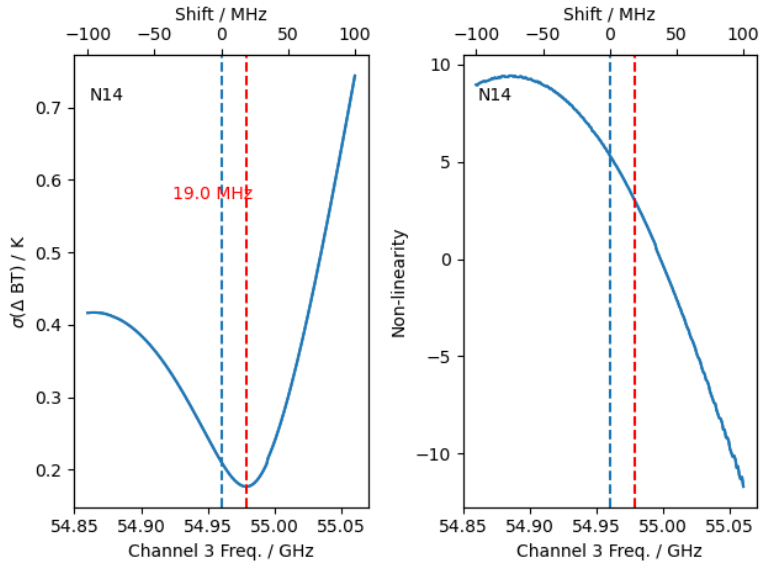
But some possible issues with shifts (or measurement equation?)

- Non-linearity value can change a lot – maybe too much

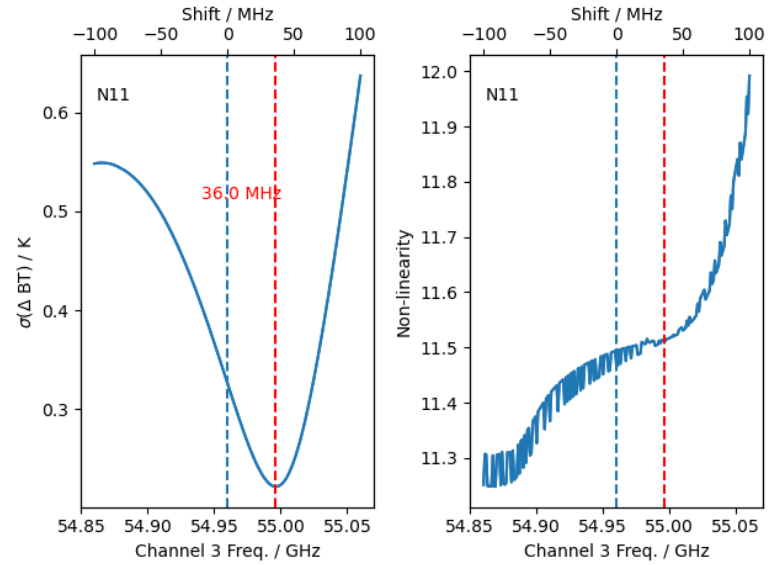
NOAA06 Ch. 3



NOAA14 Ch. 3



NOAA11 Ch. 3



For NOAA06 the sign of the non-linearity changes with the fitted bandpass shift. **Is this physically reasonable?**

- Need to check other measurement equations and/or missing terms (NOAA06 didn't fit well)
- Or another example of some level of model error (ERA6) for early sensors?

SUMMARY

- Taken a metrological look at the Microwave Sounding Unit calibration
  - Looked at form of measurement equation, Noise, Thermal gradients, sidelobe contamination terms etc.
  - Haven’t fully resolved all questions with more work to do including off nadir cases
- Definite Platform radiance terms needed
  - In both Earth view and Calibration target views
- Bandpass shifts found for both Ch. 2 and Ch 3.
  - But for some sensors/channels makes non-linear term switch sign
- Next steps
  - Investigate bandpass shifts for other measurement equations/terms
  - Use independent data sources to refine calibration terms/look for model error
  - Check possible improvement to ERA6 data assimilation and variational bias correction