ISMAR data quality

Stuart Fox

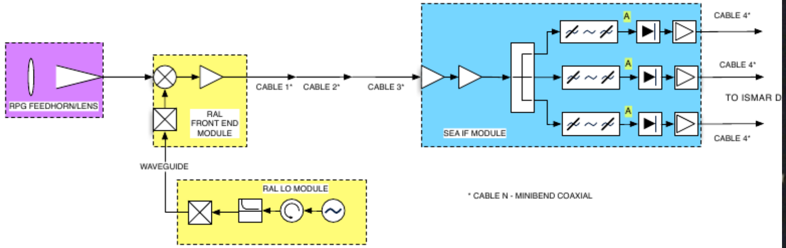
ISMAR workshop, Paris, September 2015

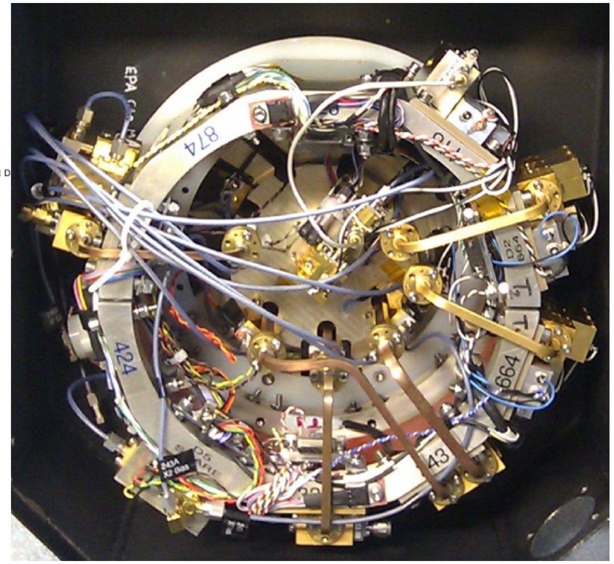
Met Office

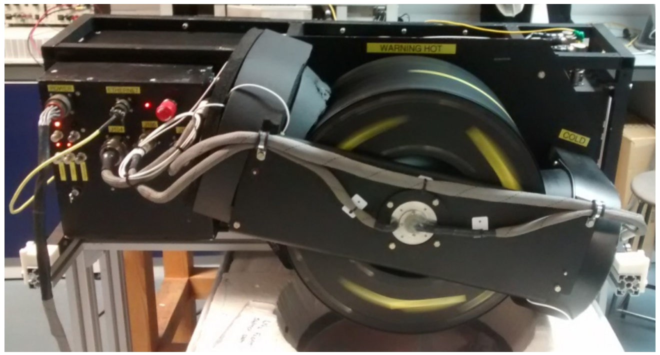
Aspects of ISMAR performance

- How can we assess performance?
  - Basic sanity checks
  - Laboratory tests
  - Comparison with RT models
- What factors influence performance?
  - Thermal stability of receivers
  - Calibration target behaviour
  - Receiver linearity
  - Random noise

Receiver design





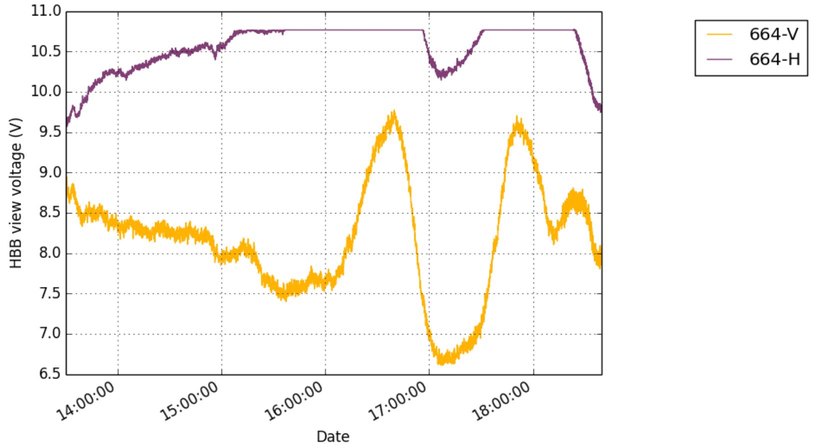


www.metoffice.gov.uk

Met Office

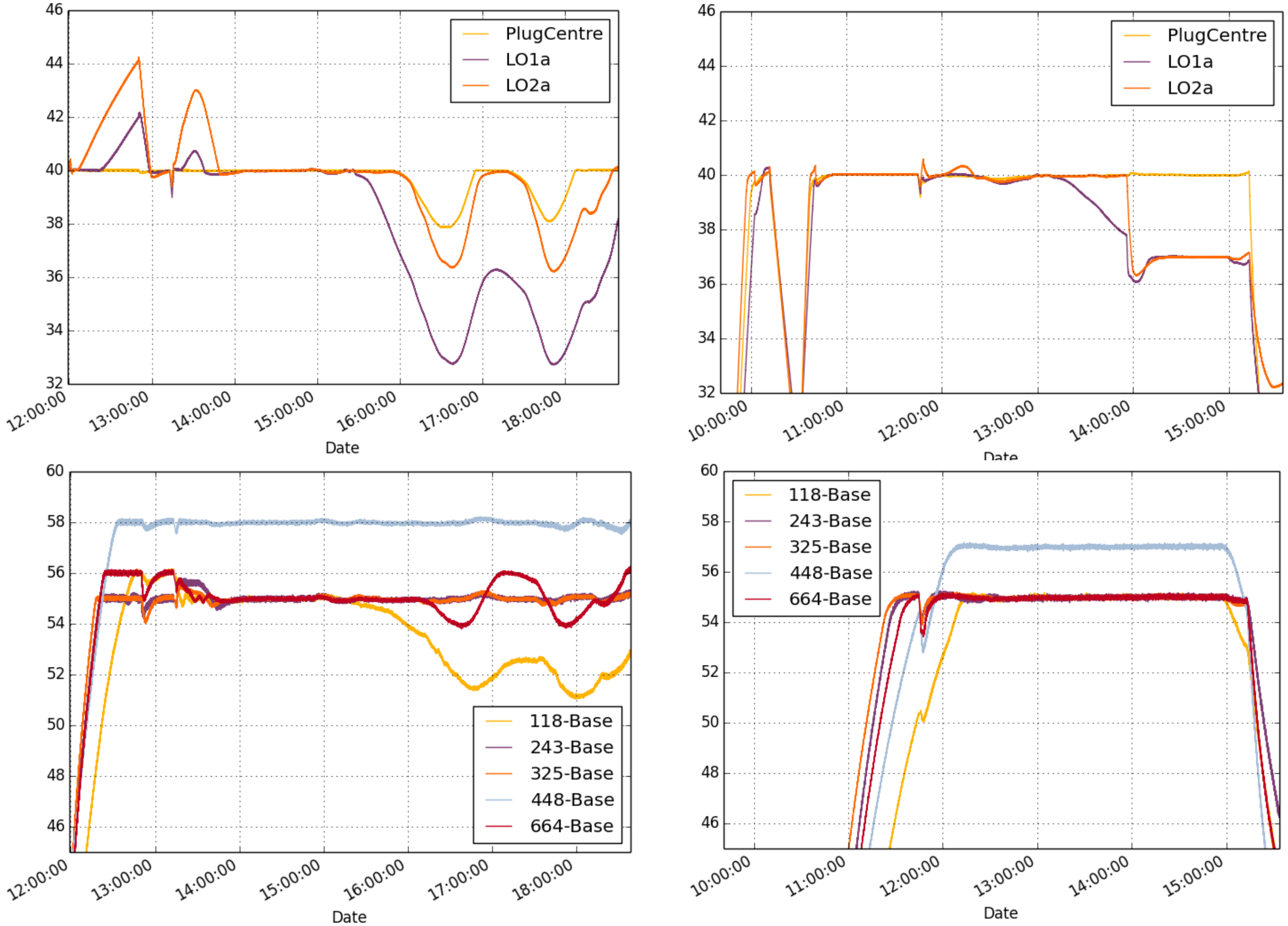
Receiver thermal stability

- Gain of RF amplifiers is strongly dependent on temperature
  - Need to maintain stable temperature between scene and calibration views
  - Need to ensure output voltages remain in range of digitiser



- Frequency of Local Oscillators can be affected by temperature drifts

Receivers in flight



Front-end and IF temperatures during STICCS – B884

Front-end and IF temperatures during COSMICS – B897

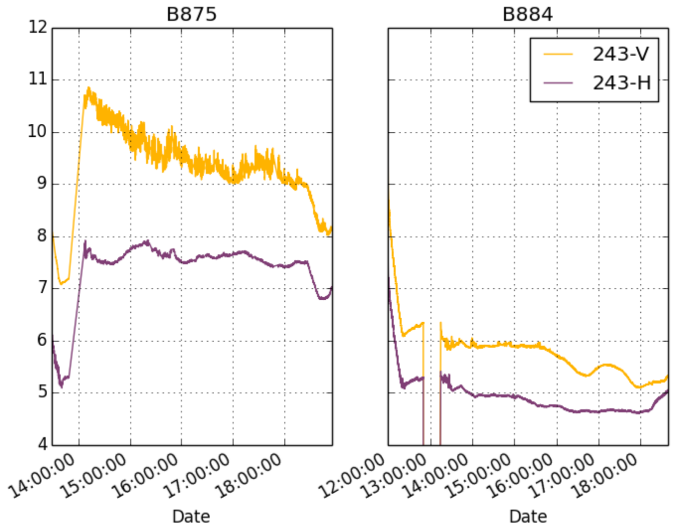
Met Office

Impact of Rx temperature control

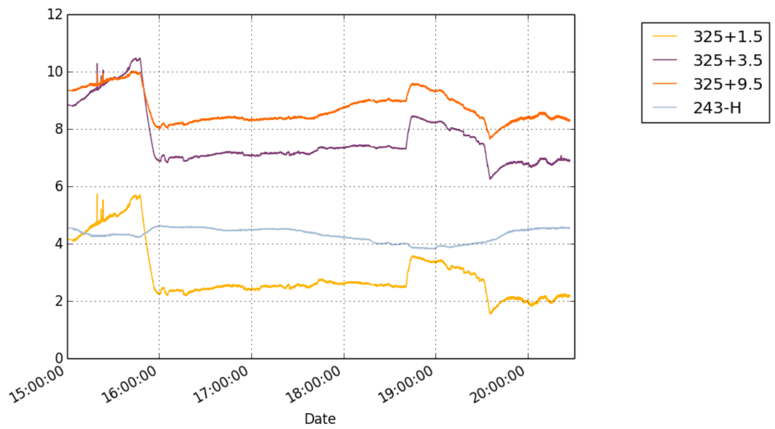
- During STICCS 664-H channel was particularly susceptible to voltage saturation due to lack of temperature control
- Improvements prior to COSMICS (low-temperature cut-out on front-end cooling fan, extra insulation in IF enclosure) improved temperature stability and allowed voltages to mostly remain within digitizer range
- Power management issues during COSMICS meant optimum temperatures could not always be used (also an issue for hot calibration target)

Receiver voltage instability

- 243-V initially noisy during STICCS – cabling issue resolved during campaign



- 325 GHz receiver has ongoing issues with instability and noise



www.metoffice.gov.uk

Met Office

Calibration system

- Voltage measured during scene view converted to brightness temperature using

$$T_s = V_s \cdot G + O$$

- Gain and offset calculated from frequent views of calibration targets:

$$G = \frac{T_h - T_c}{V_h - V_c} \qquad O = \frac{V_h T_c - V_c T_h}{V_h - V_c}$$

(in reality power is used)

- Errors in calibration target temperatures lead to errors in scene brightness temperatures:

$$\epsilon_{Tb_{scene}} = K\epsilon_{Tb_{hot}} + (1-K)\epsilon_{Tb_{cold}}$$

$$K = \frac{V_{scene} - V_{cold}}{V_{hot} - V_{cold}} = \frac{Tb_{scene} - Tb_{cold}}{Tb_{hot} - Tb_{cold}}$$

Met Office

Calibration targets

$$\epsilon Tb_{scene} = K\epsilon Tb_{hot} + (1-K)\epsilon Tb_{cold}$$

$$K = \frac{V_{scene} - V_{cold}}{V_{hot} - V_{cold}} = \frac{Tb_{scene} - Tb_{cold}}{Tb_{hot} - Tb_{cold}}$$

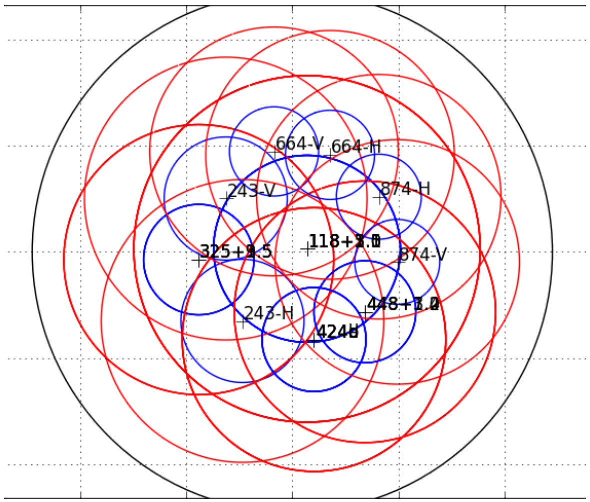
- To minimise errors in scene temperature:
  - Small errors in power received when viewing target (i.e. target brightness temperature)
    - Accurate knowledge of target temperature across beam footprint
    - Target emissivity very close to 1
  - Large target temperature separation

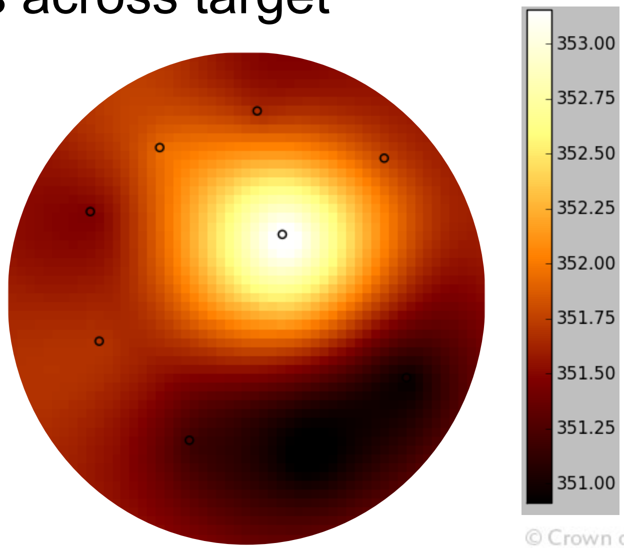
Met Office

Target temperature calculation

- Each target contains a number of PRTs for temperature measurement. Original processing used “closest” PRT for each channel. Update interpolates PRTs to channel positions and averages across beam footprints. All STICCS and COSMICS data now processed with update

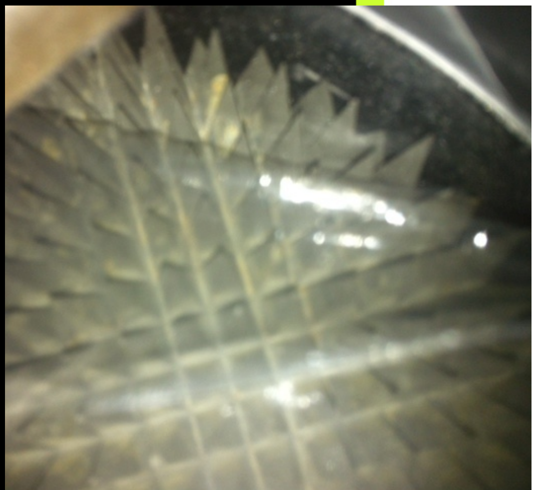
- PRTs only provide coarse spatial sampling – want to minimise thermal gradients across target

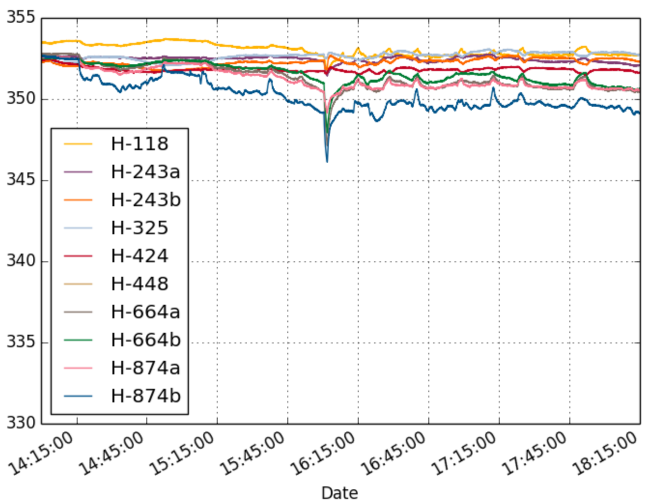




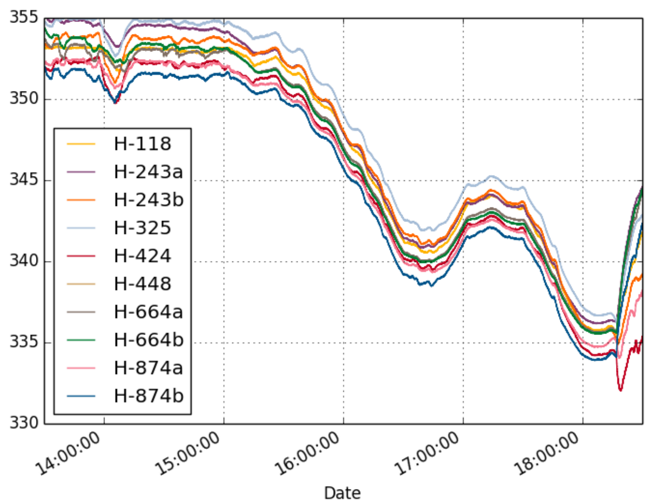
Hot target temperatures

- Want heated target as hot as possible with uniform temperature
- Initial flight trials showed that hot target struggled to maintain temperature due to airflow
- PP film installed prior to STICCS – failed during first flight and deteriorated throughout campaign





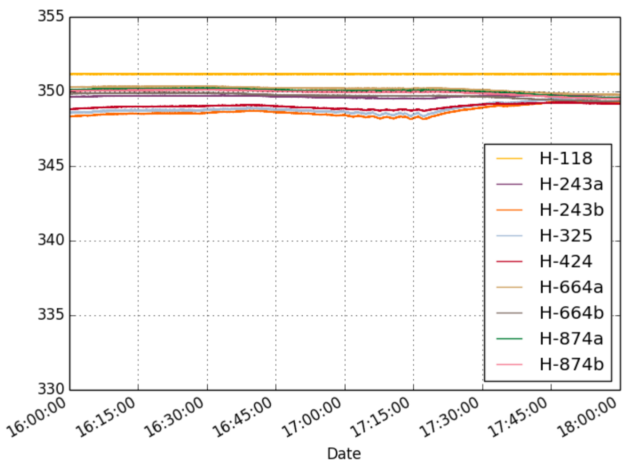
B875



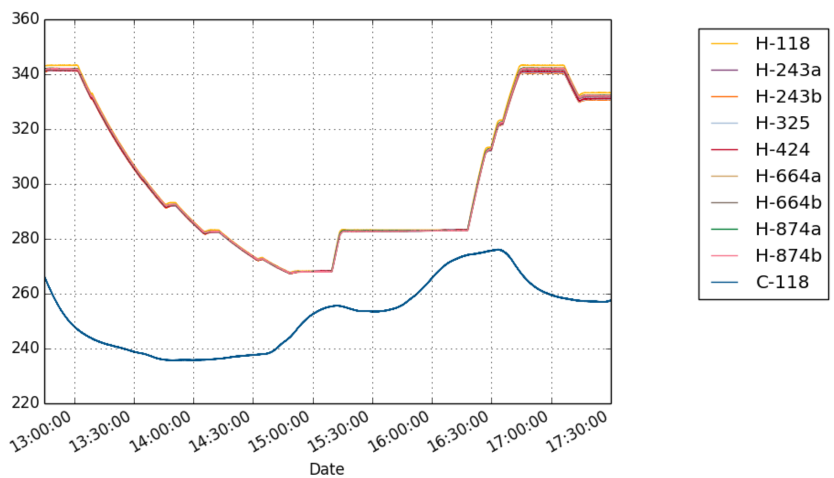
B884

Hot target temperatures

- Repaired film for COSMICS, care taken to ensure no sharp edges – much improved hot target stability and lasted for duration of campaign
- BUT – requirement to manage heater power conservatively meant target was not always heated to optimum temperature



B893 (part)



B896

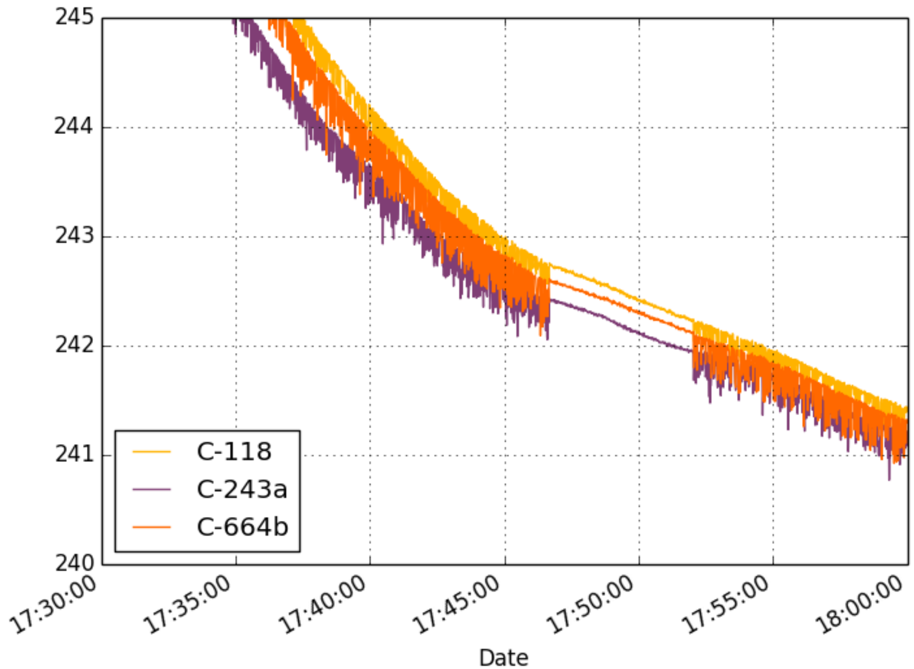
Met Office

www.metoffice.gov.uk

Met Office

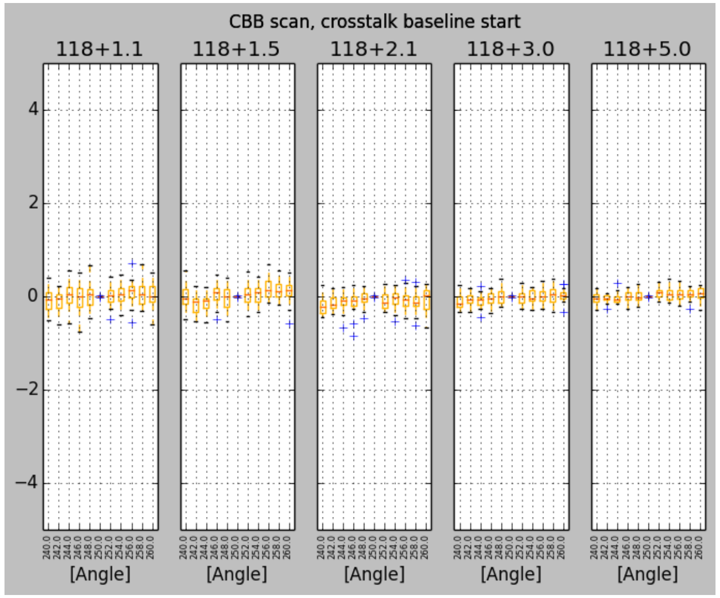
Cold target temperatures

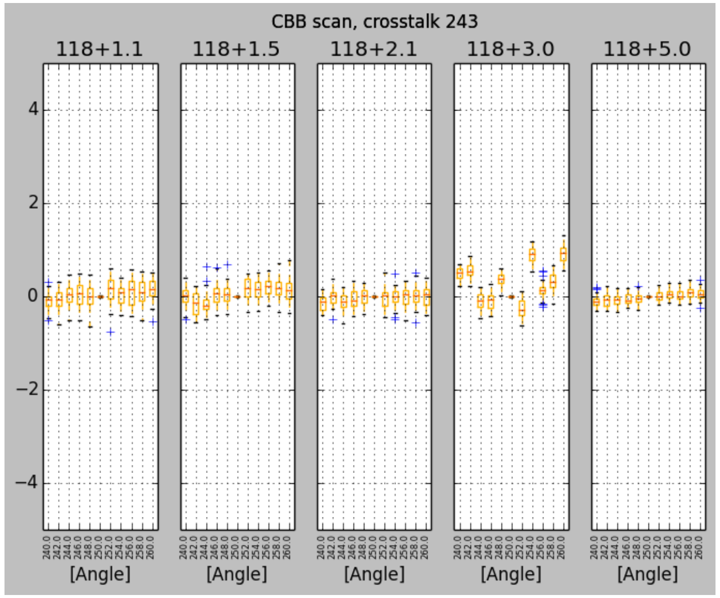
- During STICCS, interference from scan motor causes noise and offsets on cold target PRTs
- Software work-around implemented during COSMICS pending improvements to hardware



Target radiometric effects

- Is temperature measured by PRTs representative of the radiating parts of the target?
- Non-blackbody effects?

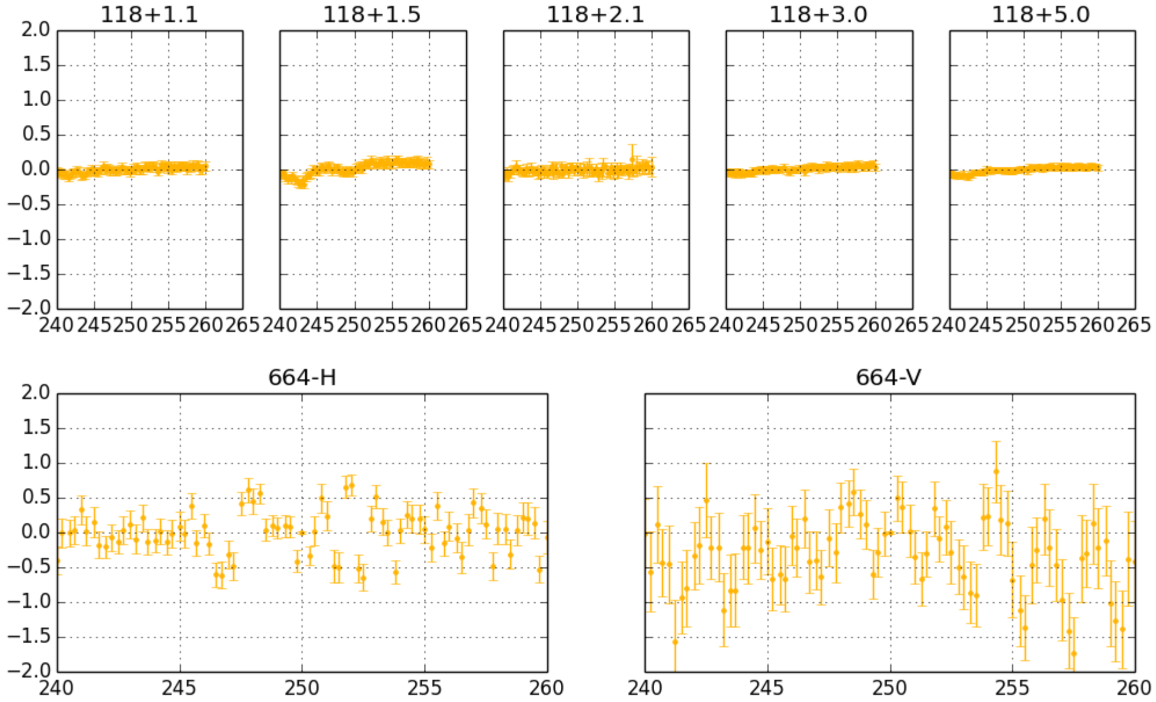




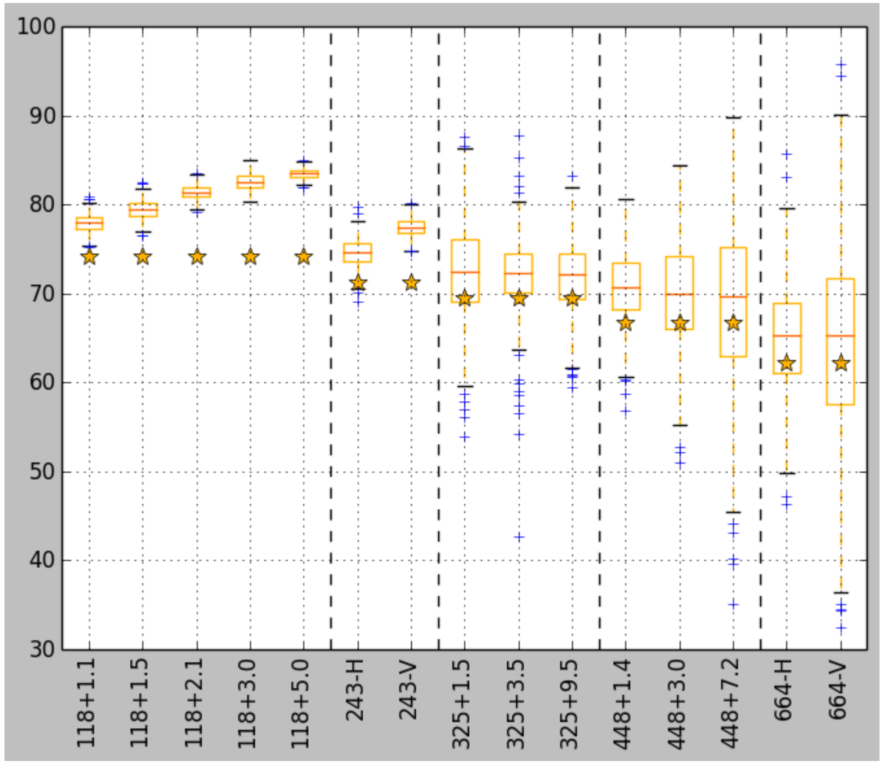
Met Office

Target radiometric effects

- Is temperature measured by PRTs representative of the radiating parts of the target?
- Non-blackbody effects?



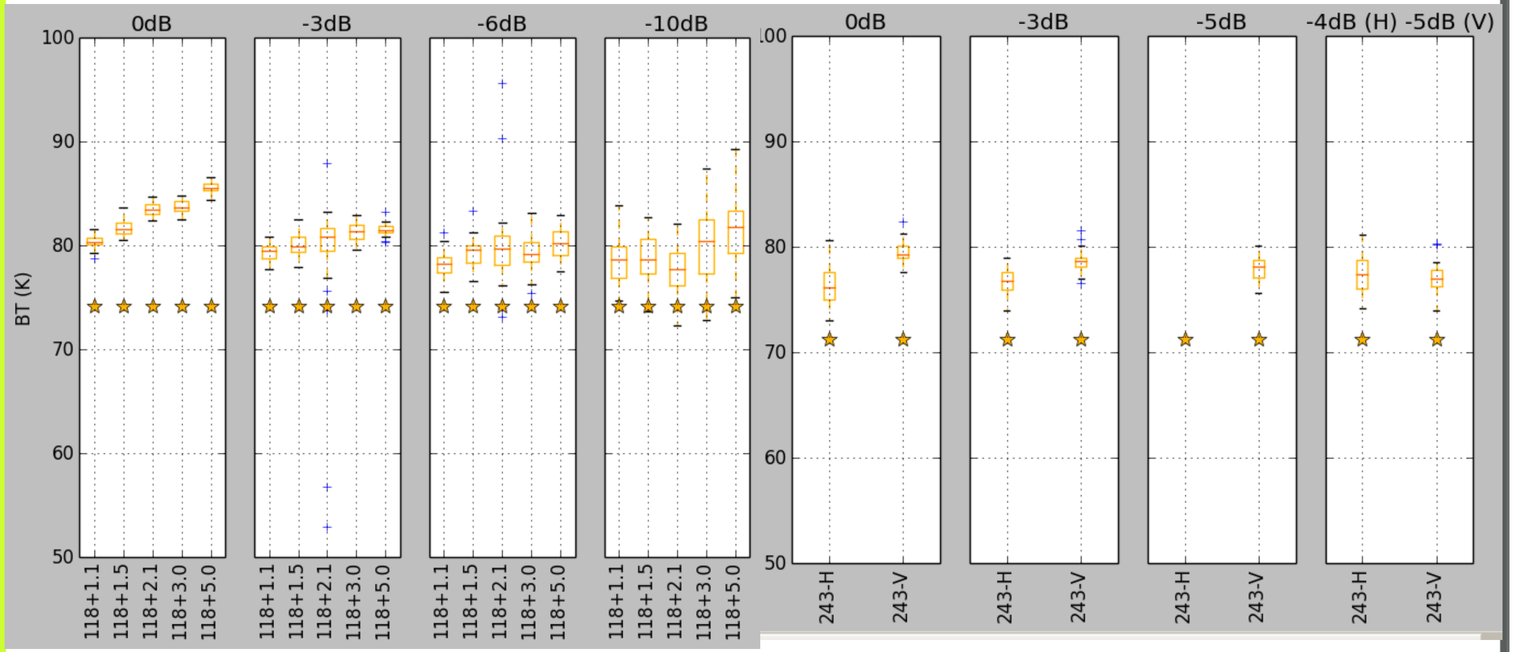
Receiver linearity



Brightness temperature of LN2 cooled calibration target

Receiver linearity - attenuation

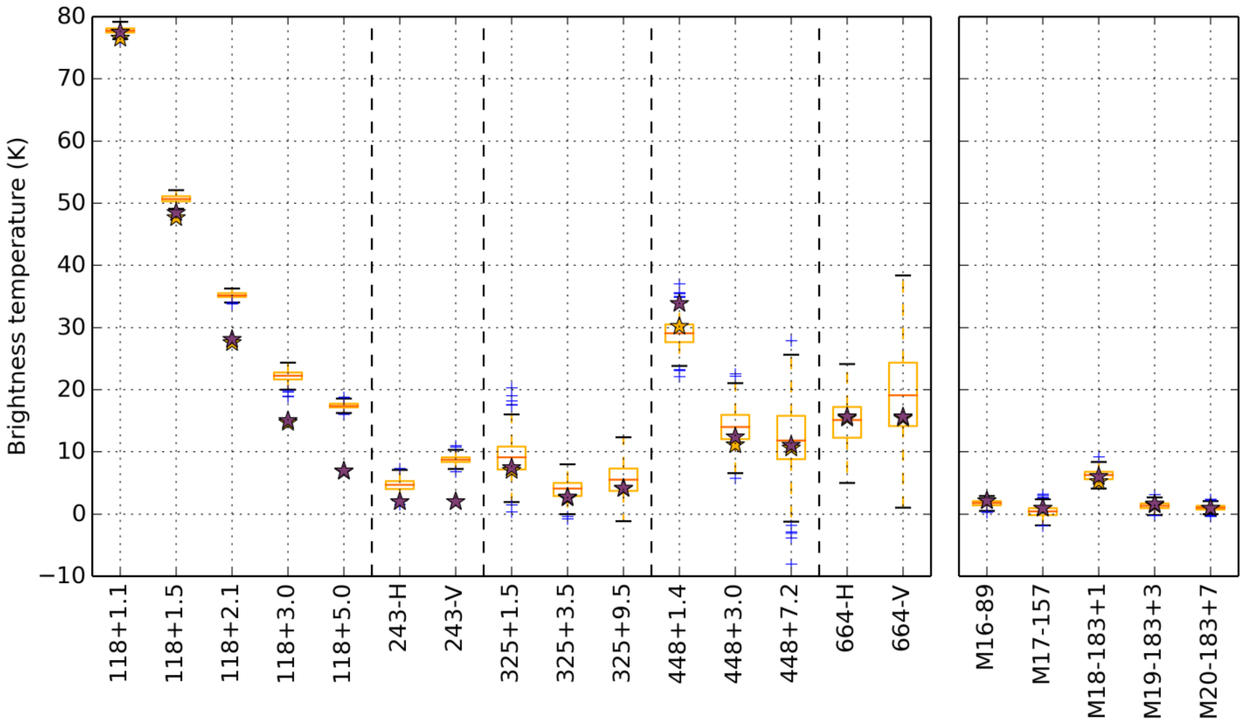
- Attenuation reduces differences between 118GHz and 243GHz channels. Unable to test other channels as video amplifier re-tuning required



No additional attenuation was fitted during STICCS or COSMICS

B893 high altitude zenith views

- Aircraft flying just above tropopause
- Comparison with ARTS simulation using NWP model atmosphere. H_2O, O_2, N_2 and O_3 (climatology). H_2O and O_2 use PWR98 complete absorption models



Met Office

Receiver noise

- So far mostly considered biases. Random variation also important as it will affect ability to resolve cloud features

- Assuming *constant* Rx gain and offset:

$$\sigma^2_{V_s} = \frac{1}{G^2}\frac{(T_s + T_{sys})^2}{B\tau}$$

- With single view of each calibration target:

$$\mathrm{NE\Delta T}^2 = \frac{(T_s + T_{sys})^2}{B\tau} + \left(\frac{T_s - T_h}{T_h - T_c}\right)^2 \frac{(T_c + T_{sys})^2}{B\tau} + \left(\frac{T_s - T_c}{T_h - T_c}\right)^2 \frac{(T_h + T_{sys})^2}{B\tau}$$

Met Office

Voltage deviations

- System noise temperatures as specified/measured during development (Y-factor test)
- Voltage deviations estimated using $\sigma_{V_h} \approx \sqrt{0.5\overline{\Delta V^2}}$ to eliminate effects of long-term drifts

Channel	G (K/V)	T_{sys} (K)	B (GHz)	Calculated σ_{V_h}	Measured σ_{V_h}
118+1.1	63.2	700	0.4	0.003	0.003
118+1.5	67.2	700	0.4	0.002	0.003
118+2.1	72.5	700	0.8	0.002	0.002
118+3.0	71.3	700	1.0	0.001	0.002
118+5.0	68.9	700	2.0	0.001	0.001
243-H	64.4	1700	3.0	0.002	0.004
243-V	70.5	1850	3.0	0.002	0.002
325+1.5	83.3	2150	1.6	0.002	0.010
325+3.5	73.8	2100	2.4	0.002	0.007
325+9.5	73.3	2050	3.0	0.002	0.009
448+1.4	64.9	2500	1.2	0.004	0.008
448+3.0	71.1	3000	2.0	0.003	0.010
448+7.2	79.3	3500	3.0	0.003	0.015
664-H	69.5	2500	5.0	0.002	0.011
664-V	61.1	2000	5.0	0.002	0.021

NEDT

- *Estimate* NEDT from high altitude zenith views during B893 (assumes atmospheric variability small between successive views)

Channel	T_s (K)	T_h (K)	T_c (K)	T_{sys} (K)	B (GHz)	Calculated NEΔT	Measured NEΔT
118+1.1	78	325	276	700	0.4	1.0	0.5
118+1.5	51	325	276	700	0.4	1.1	0.5
118+2.1	35	325	276	700	0.8	0.9	0.4
118+3.0	22	325	276	700	1.0	0.8	0.7
118+5.0	17	325	276	700	2.0	0.6	0.4
243-H	5	325	276	1700	3.0	1.0	1.0
243-V	9	325	276	1850	3.0	1.1	0.6
325+1.5	9	325	276	2150	1.6	1.6	2.9
325+3.5	4	325	276	2100	2.4	1.3	1.4
325+9.5	6	325	276	2050	3.0	1.2	2.3
448+1.4	29	325	276	2500	1.2	2.0	2.1
448+3.0	14	325	276	3000	2.0	2.0	2.9
448+7.2	12	325	276	3500	3.0	1.9	5.1
664-H	15	326	276	2500	5.0	1.0	3.5
664-V	19	325	276	2000	5.0	0.8	7.0

Met Office

Allan variance

- Standard variance estimate:

$$\frac{1}{N-1}\sum_{i=1}^{N}(y_i-\overline{y})^2$$

- does not converge with increasing N for non-white (i.e. time-correlated) noise
- Instead use difference between successive samples:

$$\frac{1}{2(M-1)}\sum_{i=1}^{M-1}[\bar{y}_{i+1}-\bar{y}_i]^2$$

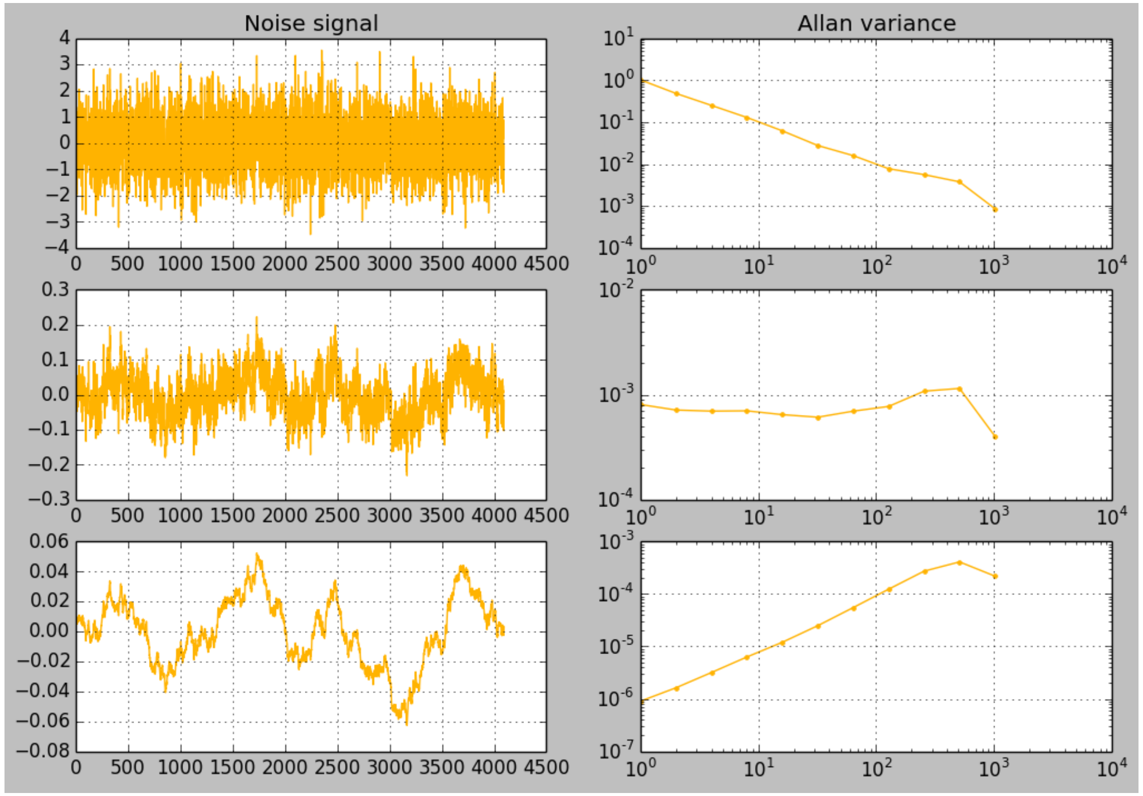
- Same as standard variance for white noise, but also converges for non-white noise
- Let y_i be the mean of j successive samples. Plot Allan variance as a function of j

Allan variance examples

White

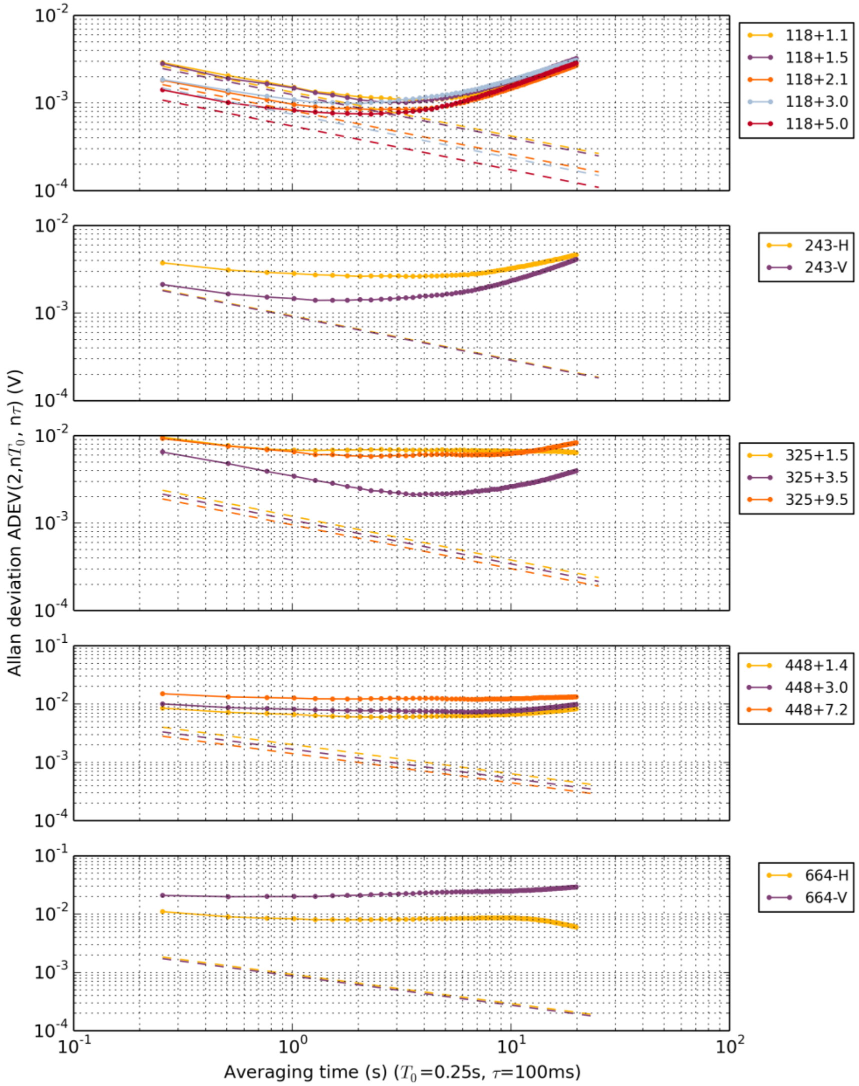
1/f

$1/f^2$



Met Office

Allan deviation of Rx voltages



www.metoffice.gov.uk

Met Office

Summary

- Overview of instrument performance during STICCS & ISMAR
- Improvements in thermal stability of receivers and calibration targets between the two campaigns
- Reasonable agreement with modelled zenith brightness temperatures at high altitude
- Calibration target temperature separation not always optimal during COSMICS due to power supply issue
- Issues with crosstalk, nonlinearity and possibly standing waves from calibration targets in some channels. Nonlinearity can be reduced with additional attenuation
- Excess noise on some receivers – may be improved by increasing gain in IF chain

Met Office

Questions?