An improved bias correction scheme for SSMIS

Anna Booton and Bill Bell

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Outline

- Introduction to SSMIS
- A new orbital bias correction scheme
- Implementation within the Met Office's variational bias correction framework

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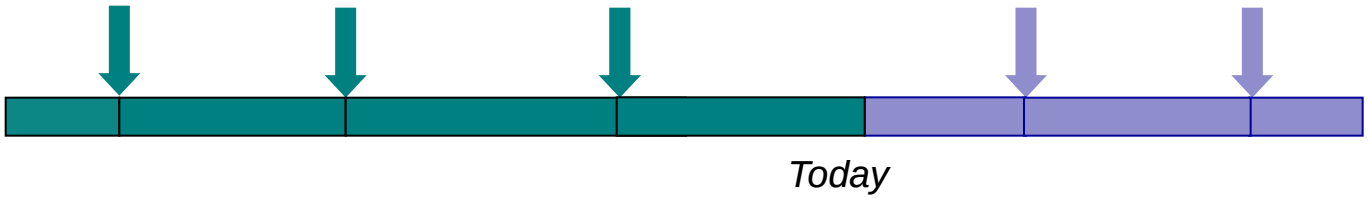
The Special Sensor Microwave Imager Sounder (SSMIS) Instruments

The US Defense* have three satellites flying SSMIS instruments.

	F-16	**F-17**	**F-18**	**F-19**	**F-20**
WMO Id:	(249)	(285)	(286)		
	Oct 2003	Nov 2006	Oct 2009	2014?	2020?



They provide both..

- temperature (50 – 63 GHz)
- humidity (183GHz)

} soundings

- imager data (90 -150 GHz)

measuring radiances from the surface, into the upper atmosphere (mesosphere)

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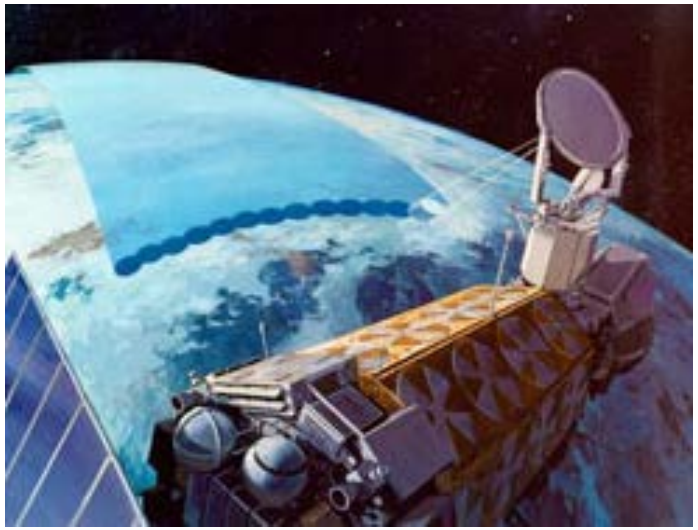
*on the Defense Meteorological Satellite Program (DMSP) platforms

The Special Sensor Microwave Imager Sounder (SSMIS) Instruments' Design

- The instruments are conical scanning radiometers
- Operate by reflecting upwelling radiation off a large rotating mirror into a group of apertures



- Unfortunately this design suffers several calibration anomalies, such as:
  - Reflector emissions - *the mirror isn't perfect*
  - Solar intrusions - *into the warm calibration target*

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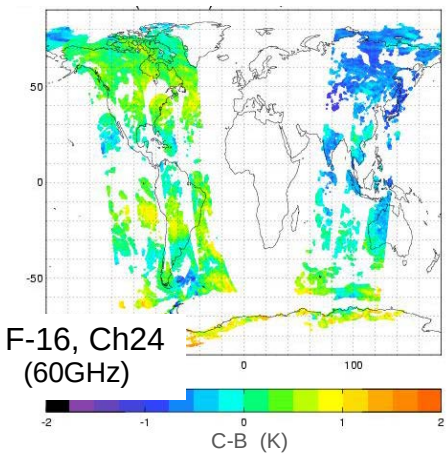
Calibration anomalies

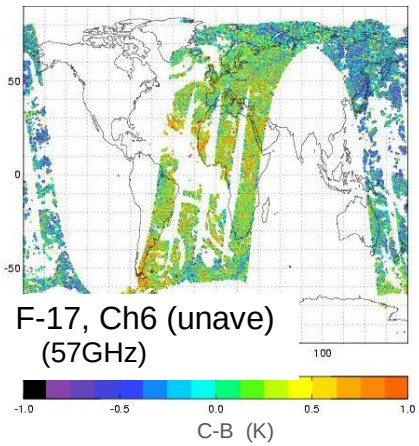
- The calibration anomalies manifest as complex, systematic biases
- Elucidated through comparisons of observed brightness temperatures (O) with those from NWP model backgrounds (B)

For example…

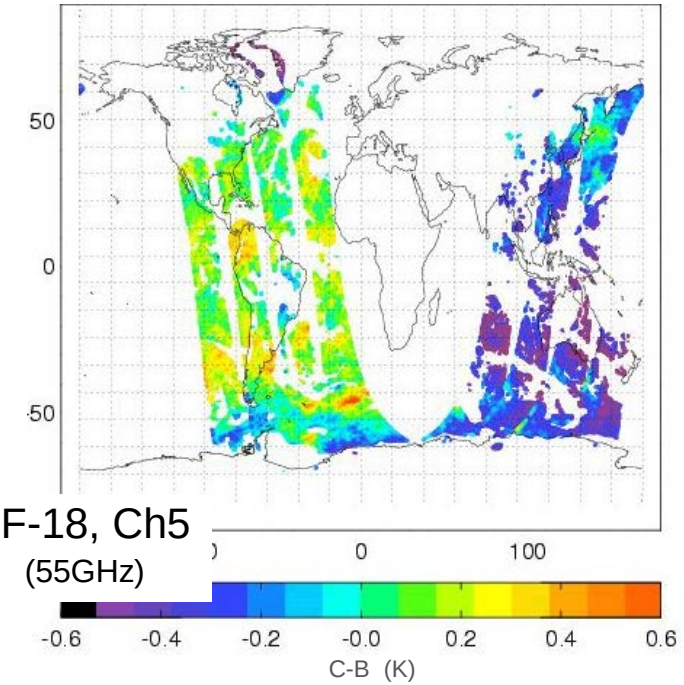
all three instruments exhibit “ascending/descending” biases



F-16, Ch24
(60GHz)



F-17, Ch6 (unave)
(57GHz)



F-18, Ch5
(55GHz)

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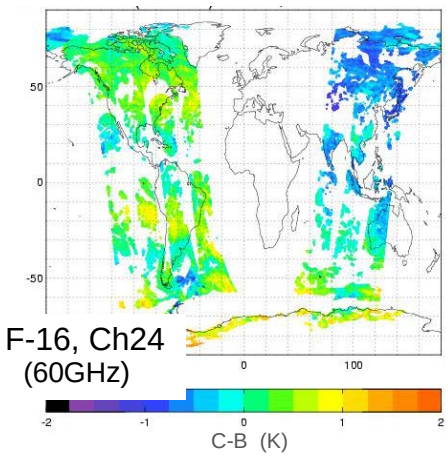

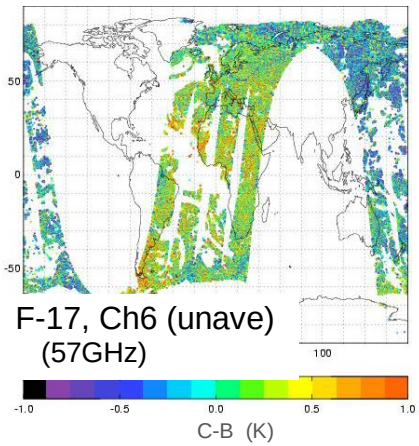

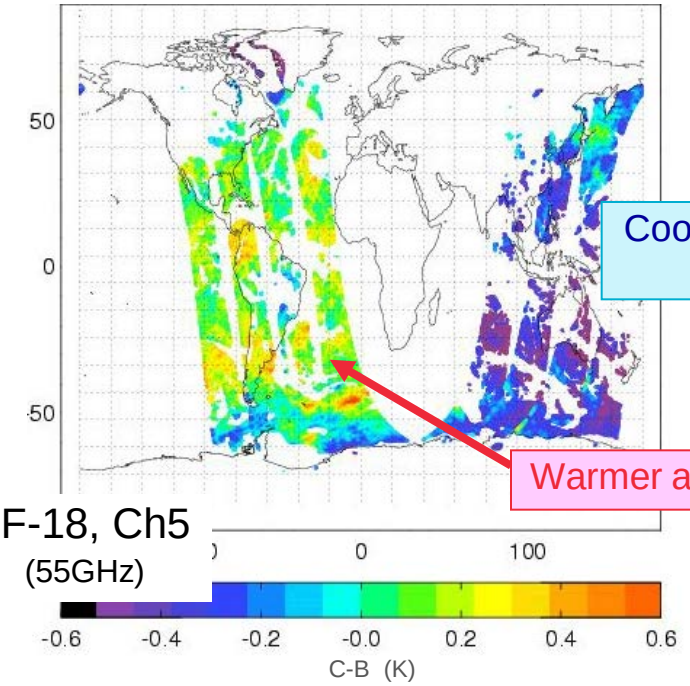

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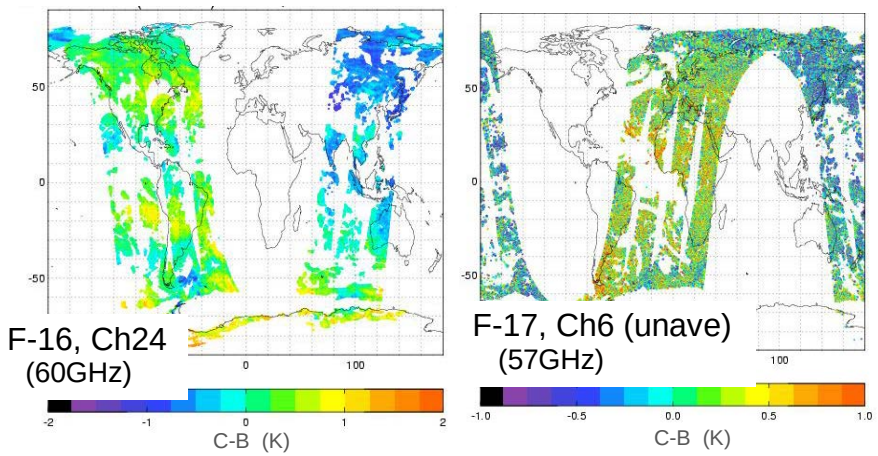
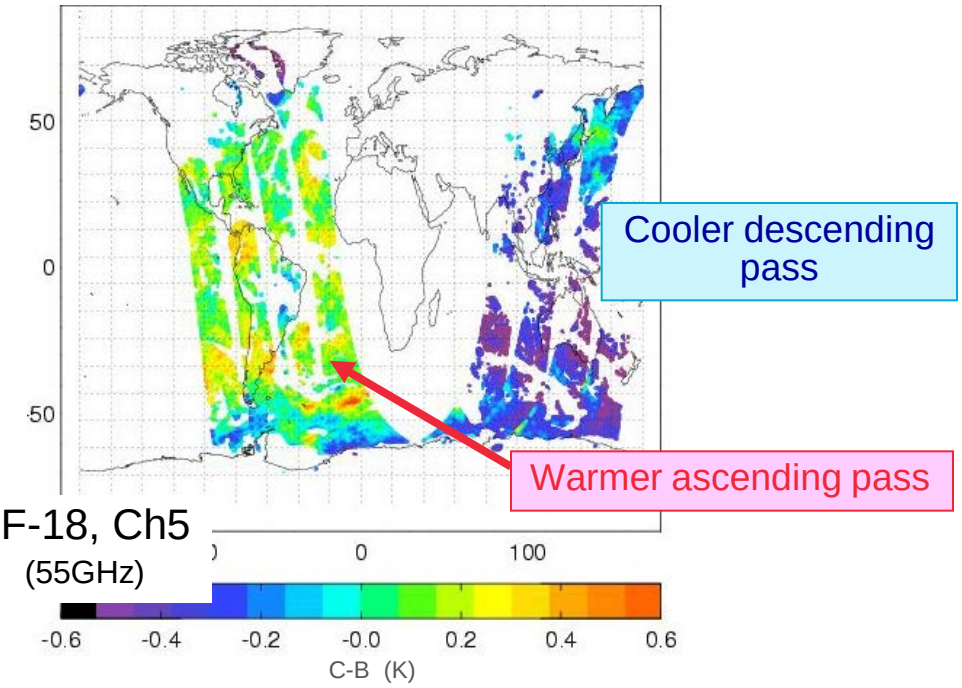
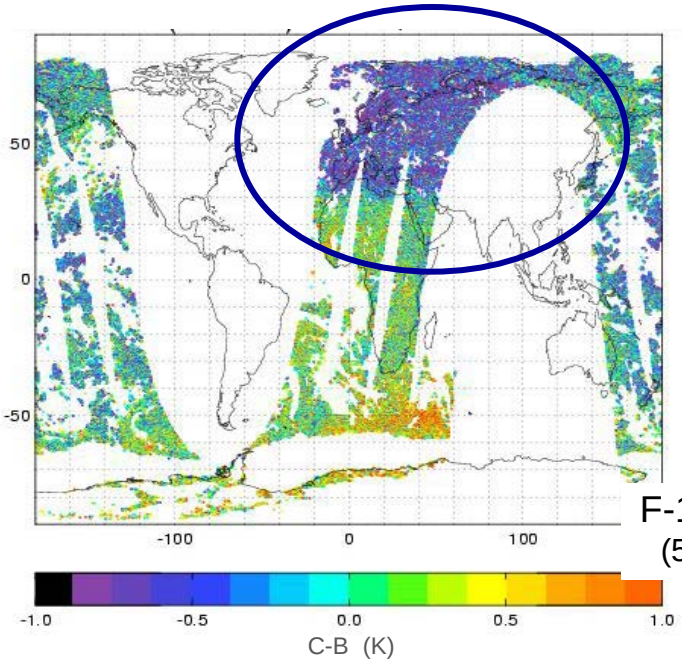




..this data has been corrected (C) through pre-processing and using the Harris & Kelly scheme

Calibration anomalies

Also get different types of features..



F-16, Ch6 (unave)
(57GHz)

Reflector emissions manifests as sudden, cold region

These sharp transitions are particularly difficult to correct

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Corrections have had some success…

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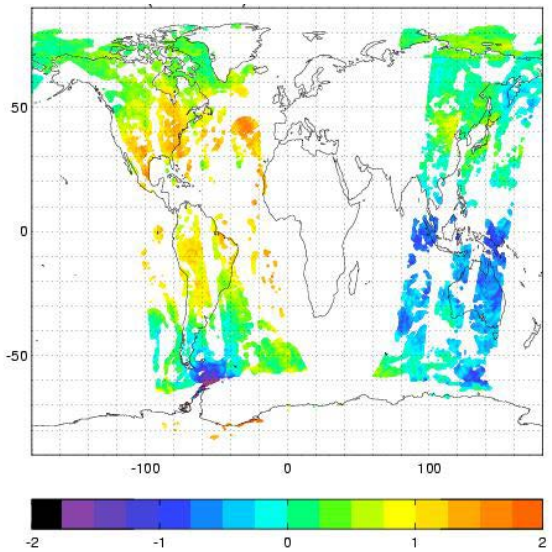
An ascending/descending bias predictor

A co-sinusoidal ‘ascending/descending’ bias predictor was developed:

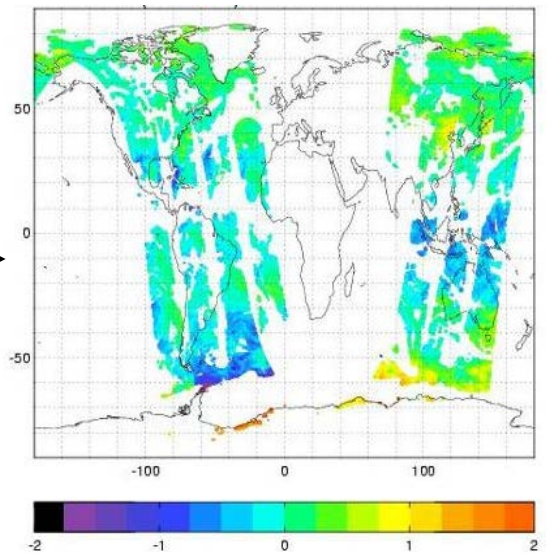
$$\Delta T_B = \beta \cos(L + \theta)$$

that effectively reduced the departures.

β – bias coefficient
L – latitude
θ – phase shift from equator



(C-B) pre-’asc/dsc’ correction



(C-B) post-’asc/dsc’ correction

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The correction was only partially successful…

1. Within two months the bias correction being applied was no longer applicable
   - The biases were found to be *seasonally* dependent

Ideally require the correction to be applied in a variational bias correction scheme in order for it to evolve with time

2. Worked well as a first order correction
   - Couldn't compensate for biases such as those resulting from reflector emissions

Extend the ascending/descending scheme in order to fit the complex structure

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An Orbital Bias Predictor

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A Fourier Approach

An orbital predictor needs..

- to be a periodic function to represent the cyclic nature of the orbital bias

so a Fourier series expansion would be appropriate:

$$\Delta T_B = \sum \beta P$$

$$= \sum_{i=0}^{N} a_i \cos(i\phi) + b_i \sin(i\phi)$$

β – bias coefficient
P – bias predictor
ϕ – orbital angle

2N coefficients (β)
$a_0..a_N$, $b_0..b_N$,

2N predictors (P)
$\cos(0\Phi)..\cos(N\Phi)$, $\sin(0\Phi)..\sin(N\Phi)$,

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2N predictors (P)
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- is an extension from the 'asc/dsc' predictor
- should capture the complex features that the original did not
- Propose the new predictor is a function of the orbital angle rather than latitude …

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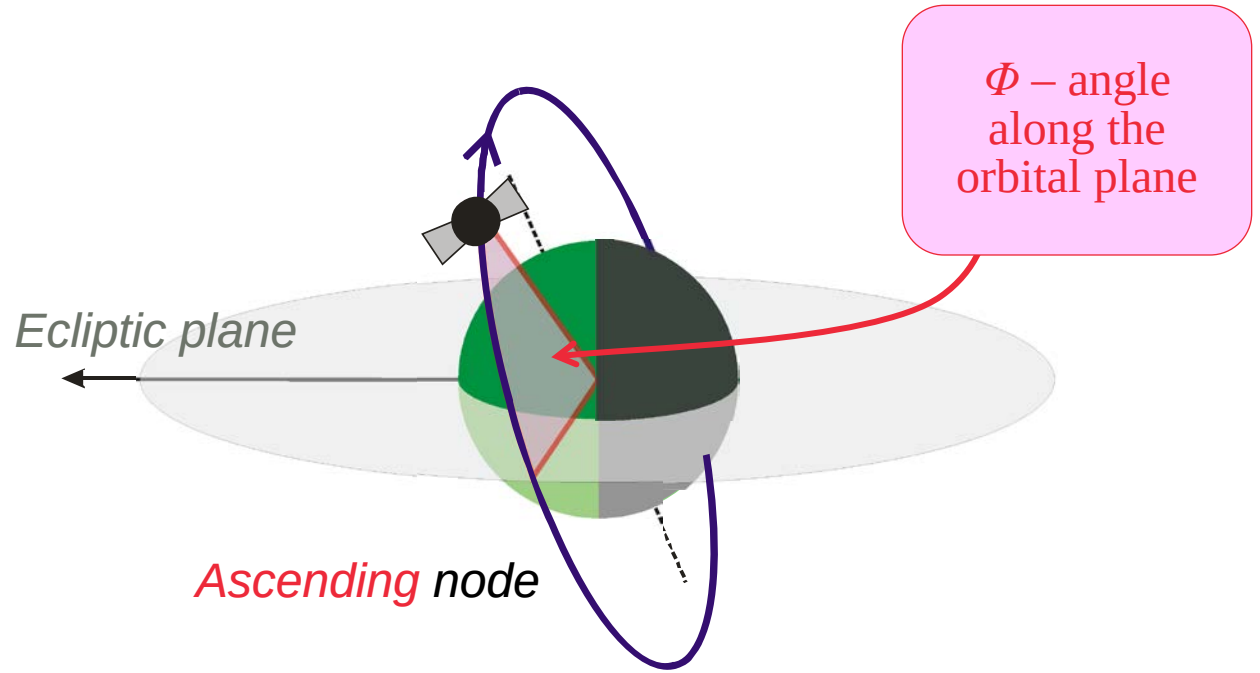
The orbital angle, Φ

- Referenced from the intersection of the satellite's ascending node with the ecliptic plane



Using reference relative to the position of the sun should result in a more stable predictor

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Implementing the predictor…

within the Met Office's variational bias correction framework

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Toy Model

- A toy model representative of the Met Office's variational bias correction (VarBC) data assimilation system was developed to investigate the performance of the scheme.

- Inputs to the toy model are:
  - Residual biases (O-B) vs. Φ
  - Prior estimate of the coefficients a_i, b_i

- At each cycle:
  - The corrected 'C' temperatures are obtained
  - The coefficients a_i, b_i, are updated

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Toy Model

The update is computed by minimising the cost function:

$$J = J_o + J_B$$

observations background

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$$J = J_o + J_B$$

$$= \underbrace{\frac{\left(\sum^{All\ Obs} \left((\text{O-B}) - \beta' P \right) \right)^2}{\sigma_o^{\,2}}}_{\text{fit of predictor to observations}} + \underbrace{\frac{\left(\beta - \beta' \right)^2}{\sigma_B^{\,2}}}_{\text{fit of predictor to previous background}}$$

(O-B) – observation minus model background

$\beta' P$ – *'prediction'* of the residual bias

β – bias coefficients from current cycle

β' – bias coefficients from previous cycle

σ_o, σ_B – weightings

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… have two unknowns, to estimate…

- the number of predictors, N and
- relative weightings of observation and background component, σ_o, σ_B

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What weighting is best?

- The magnitude of the weightings, (σ_o,σ_B) are a function of the number of observations assimilated

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What weighting is best?

- The magnitude of the weightings, (σ_o,σ_B) are a function of the number of observations assimilated
- The weightings are optimized for each channel accordingly

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How many coefficients give a good fit?

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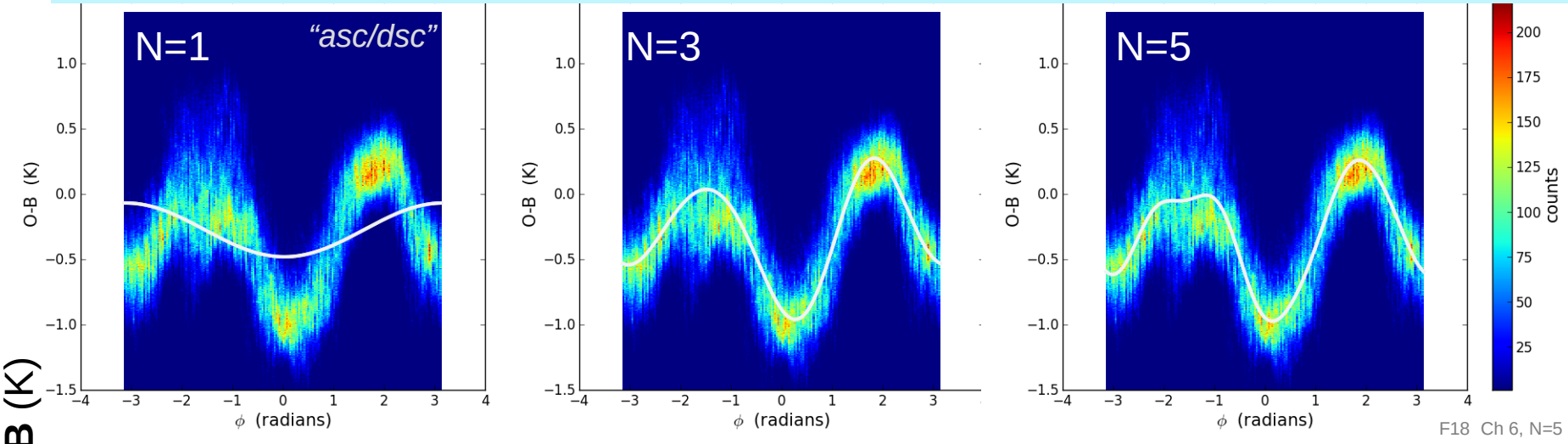
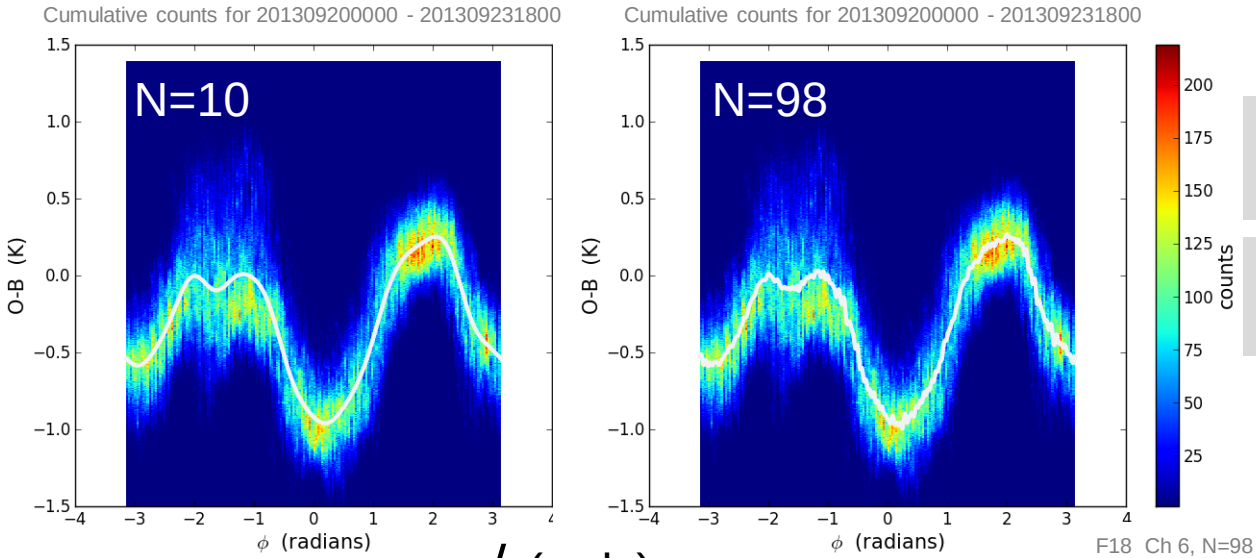
How many coefficients give a good fit?

Before run toy model...

Collected (O-B) data over a 3 day period (13 cycles) and fit a Fourier Series to it..





Data binned per temperature, per ϕ

Fourier Series fits are over-plotted in white

ϕ (rads)

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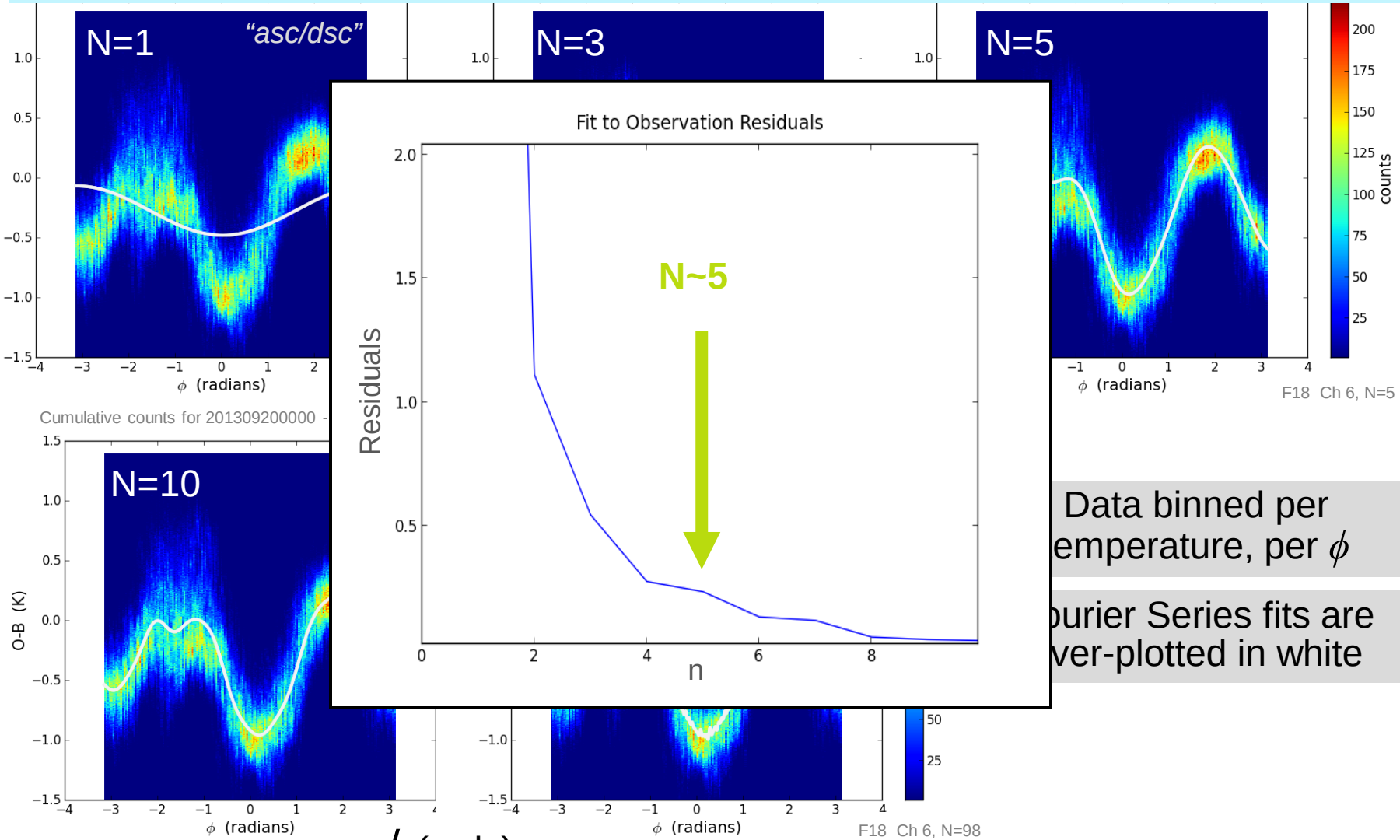

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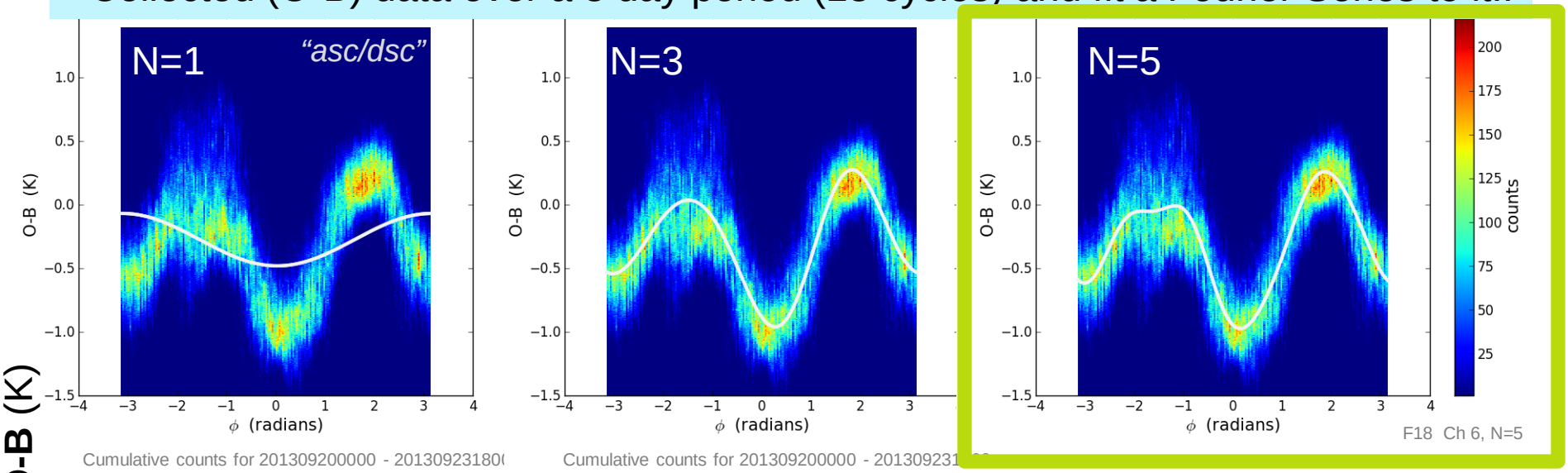

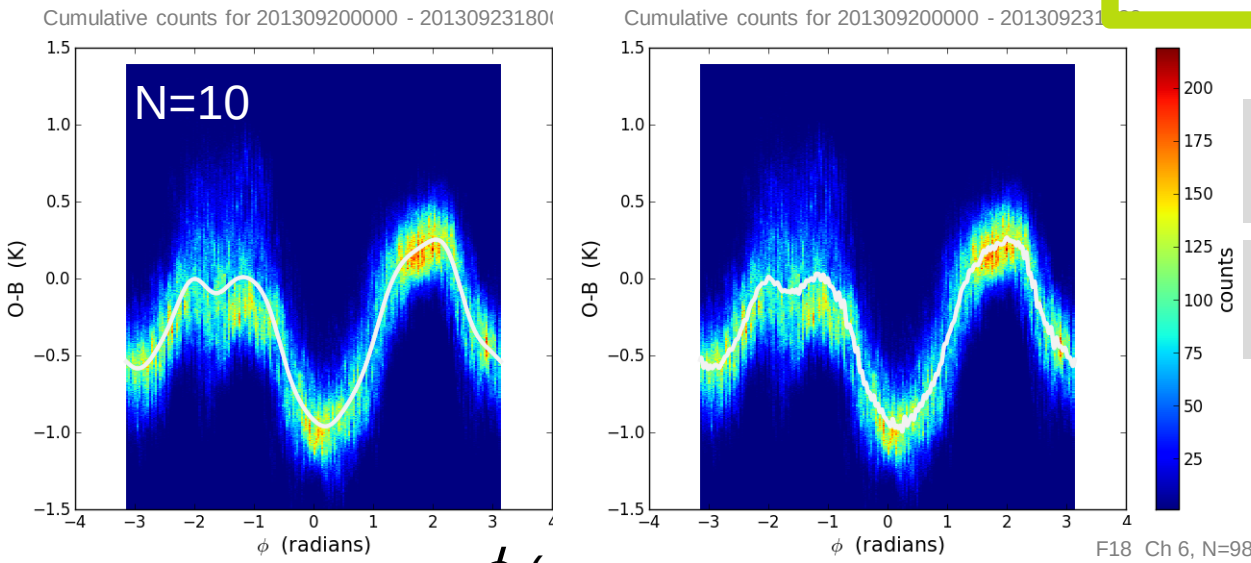

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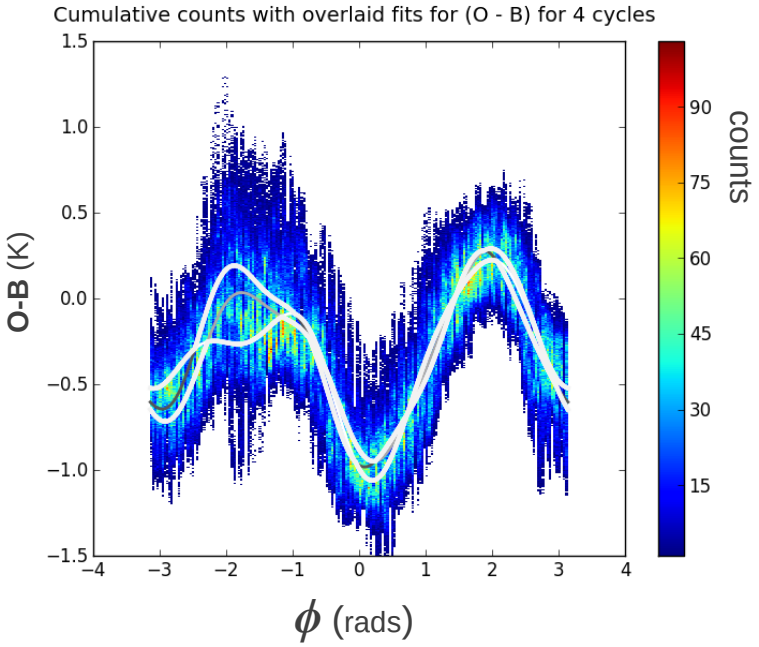
How well does the predictor work within a VarBC framework?

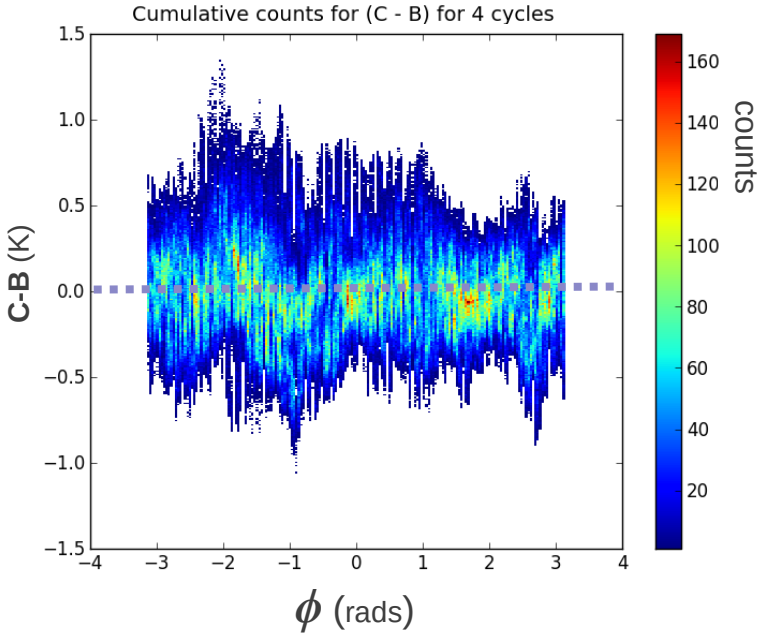
Using the toy model...

- Using a predictor comprised of 10 components (N=5), and optimally tuned background weighting

For 24 hours (4 cycles)...

F-18, Ch6
(57GHz)





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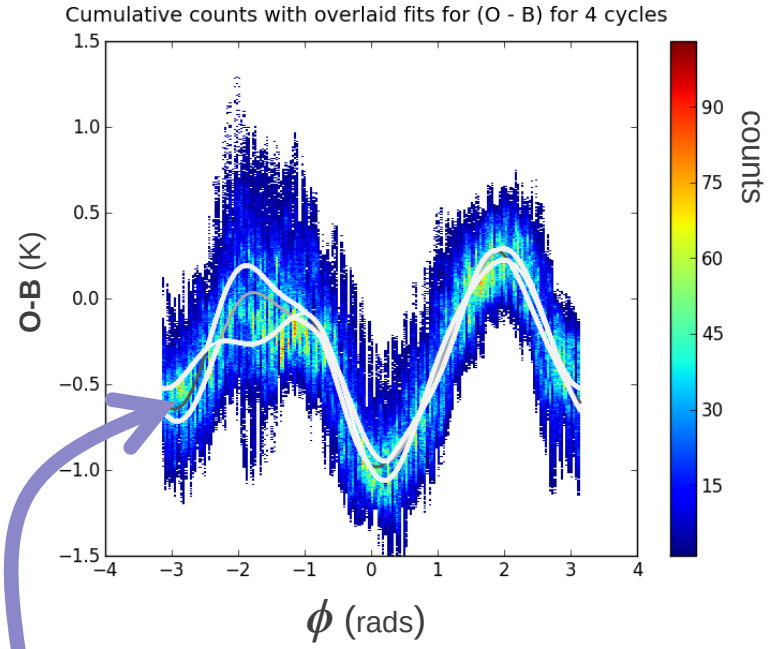
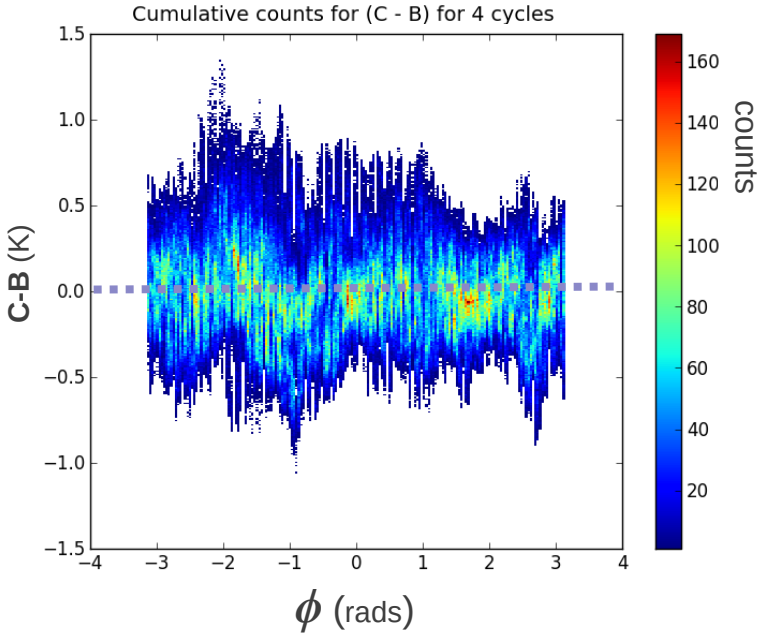




Envelope of the variational fits (white) shows a reasonable fit to the (O-B)'s

Corrected brightness temperatures are reduced to near zero

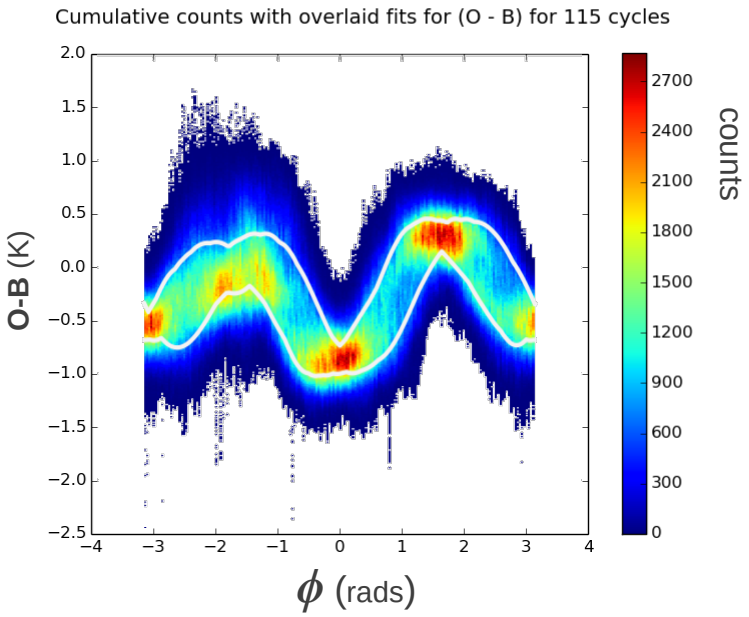
© Cr

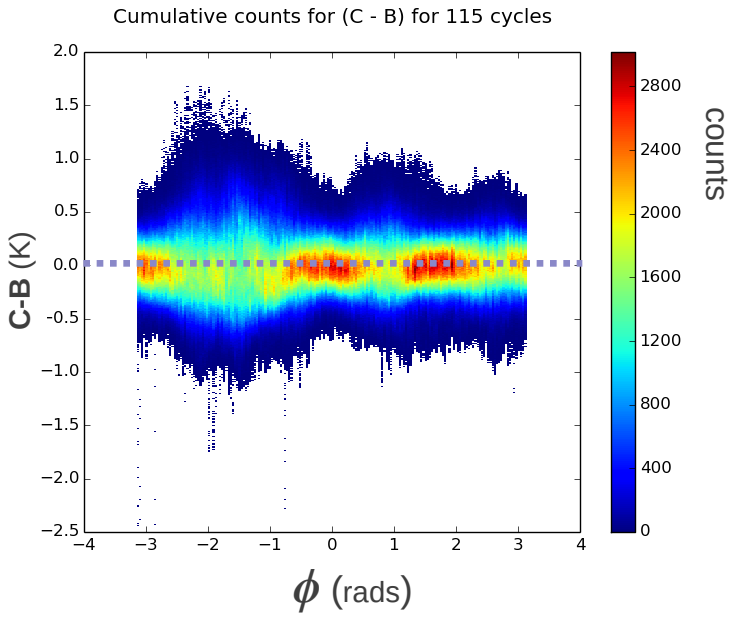
But was there any evolution in the bias over time?

Over a 30 day period (115 cycles)…

(20th Sept – 20th Oct 2013)

F-18, Ch6
(57GHz)





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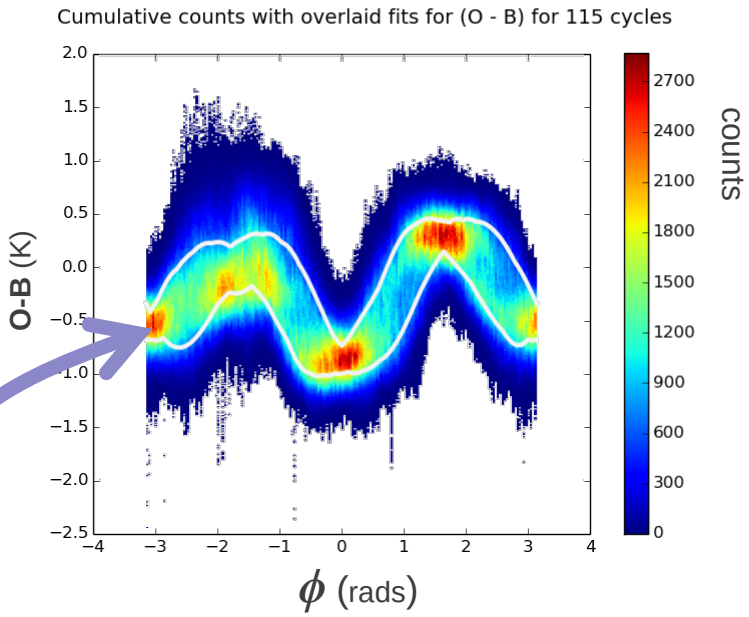

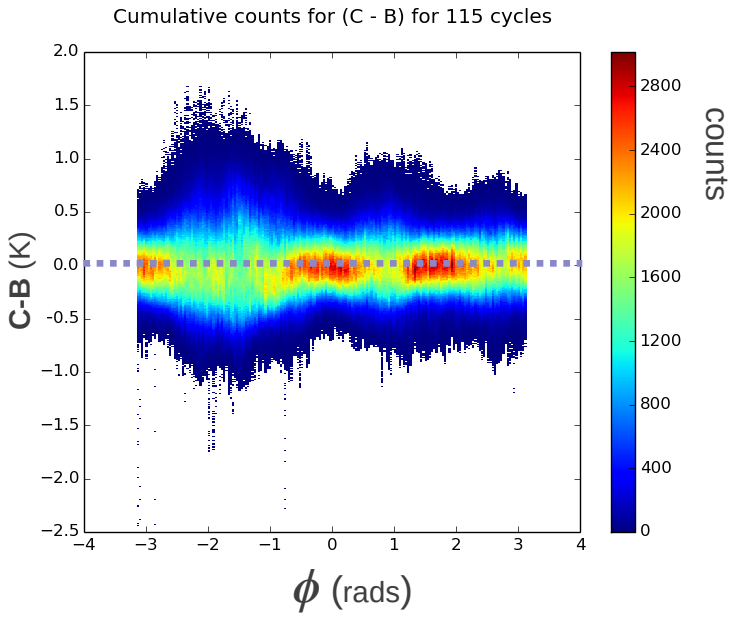

The general orbital structure is ‘predicted’ well

Resulting C-B exhibit little structure

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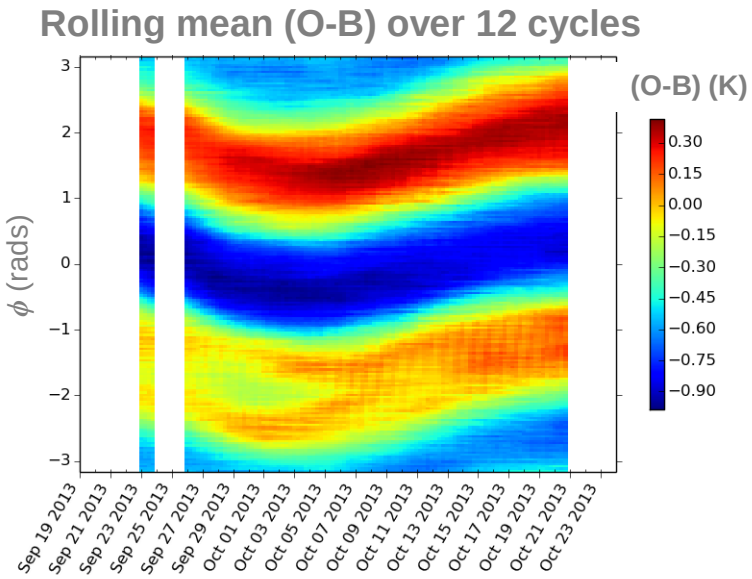
More detailed analysis...



The structure of the orbital biases has evolved with time

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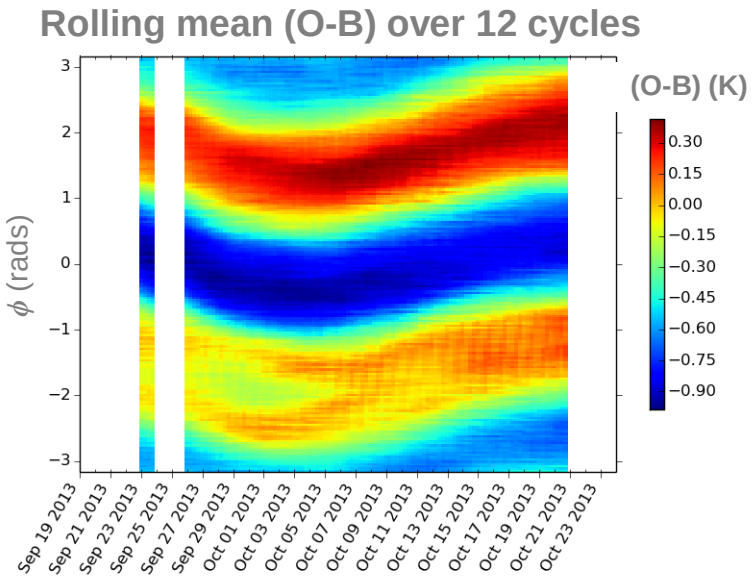
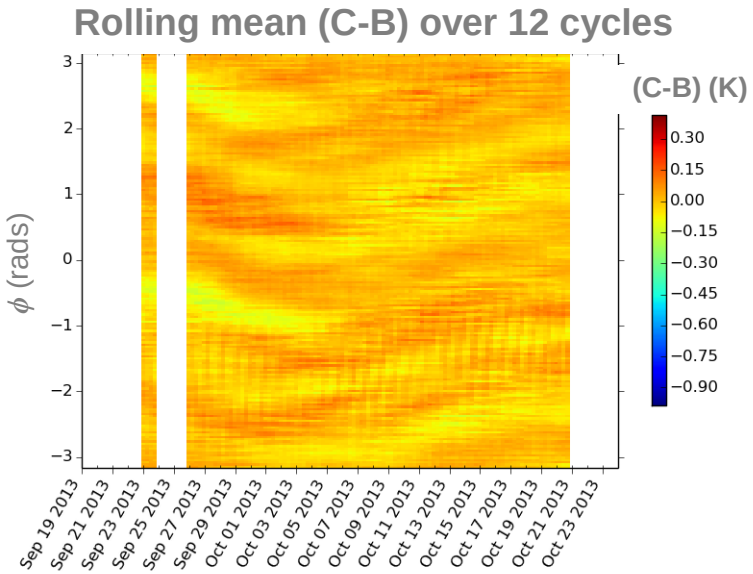
More detailed analysis...





The structure of the orbital biases has evolved with time

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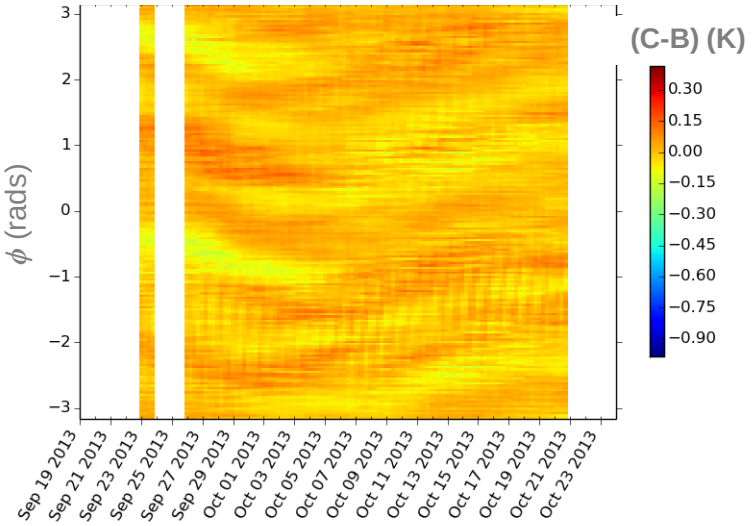
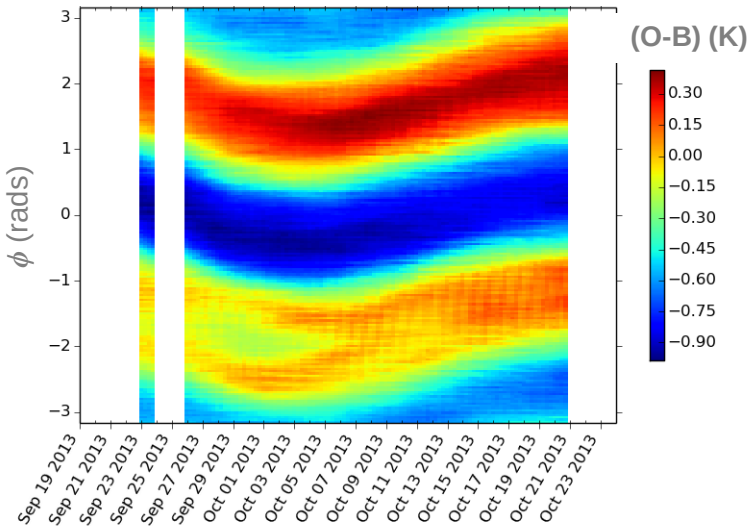
More detailed analys

The Fourier Series fit has also evolved with time – residual biases reduced to ~50mK

Rolling mean (C-B) over 12 cycles



Rolling mean (O-B) over 12 cycles



The structure of the orbital biases has evolved with time

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More detailed analys

The Fourier Series fit has also evolved with time –

Introduce QC

~50mK

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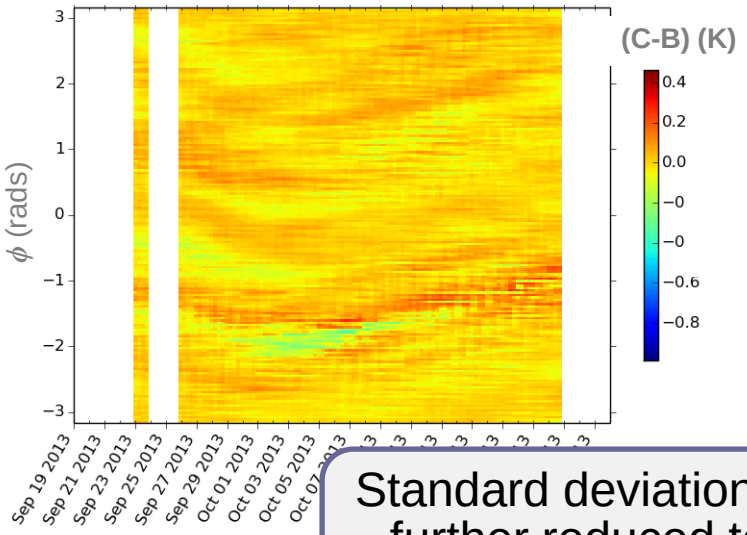

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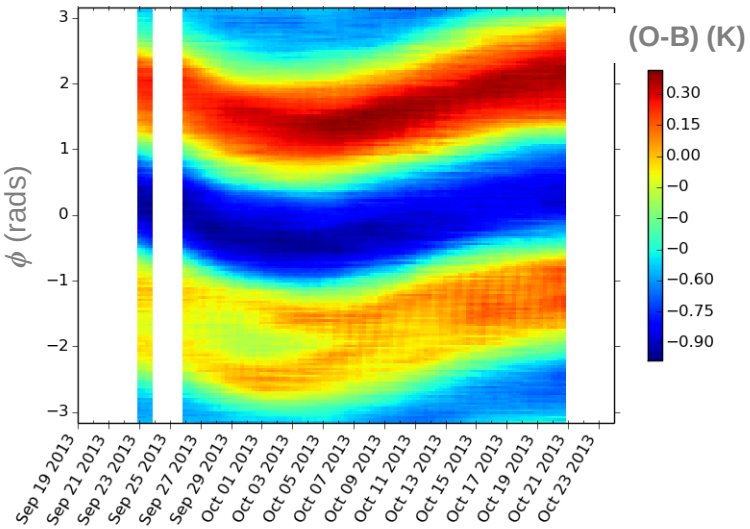
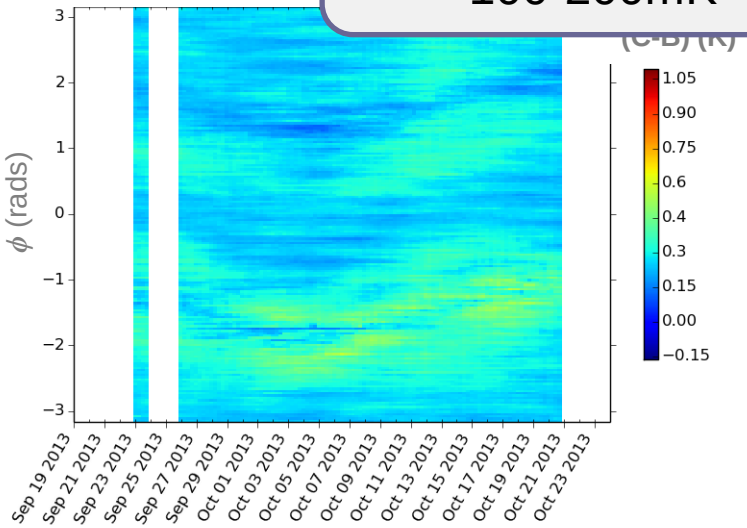


Standard deviation is further reduced to ~100-200mK

Rolling standard deviat



The structure of the orbital biases has evolved with time

Post- correctio
standard deviatio
~200-300mK
over majority of c

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But...

Can it be applied to surface sensitive channels?

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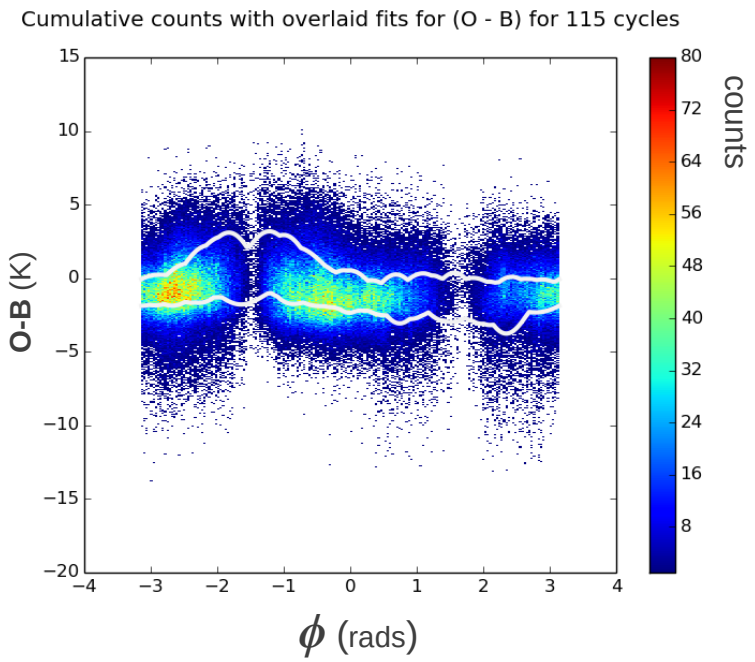
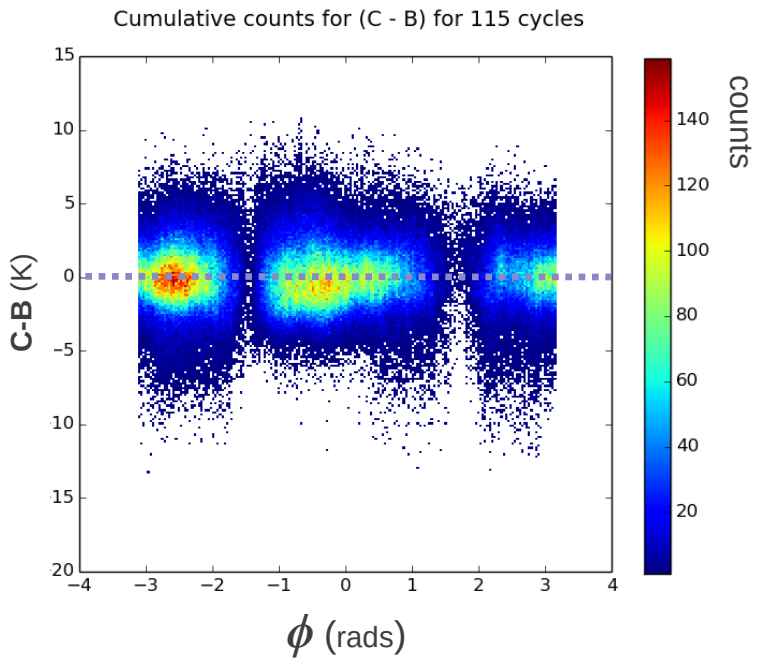
But...

Can it be applied to surface sensitive channels?

Including QC, and selecting sea-only observations...

F-18, Ch16
(37GHz)





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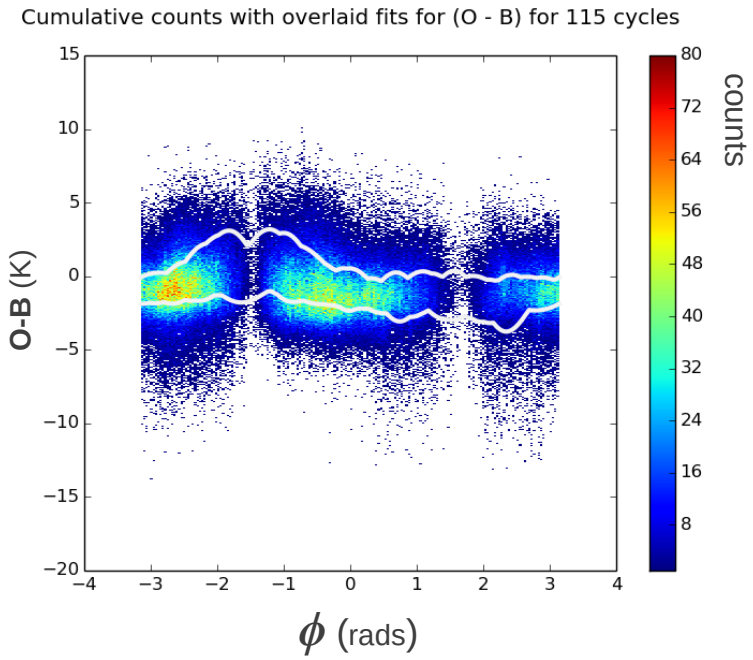
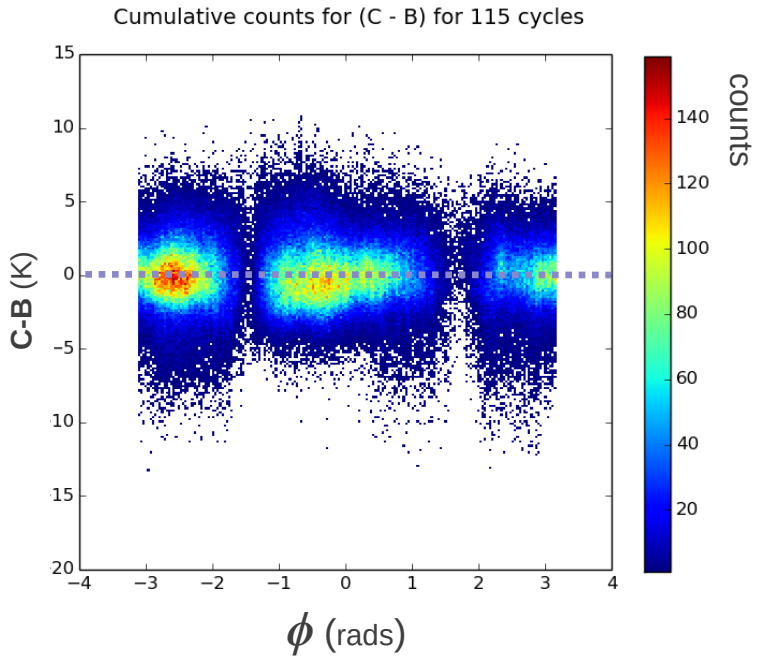
(37GHz)





Corrected brightness temperatures are again reduced to zero – it is providing some benefit

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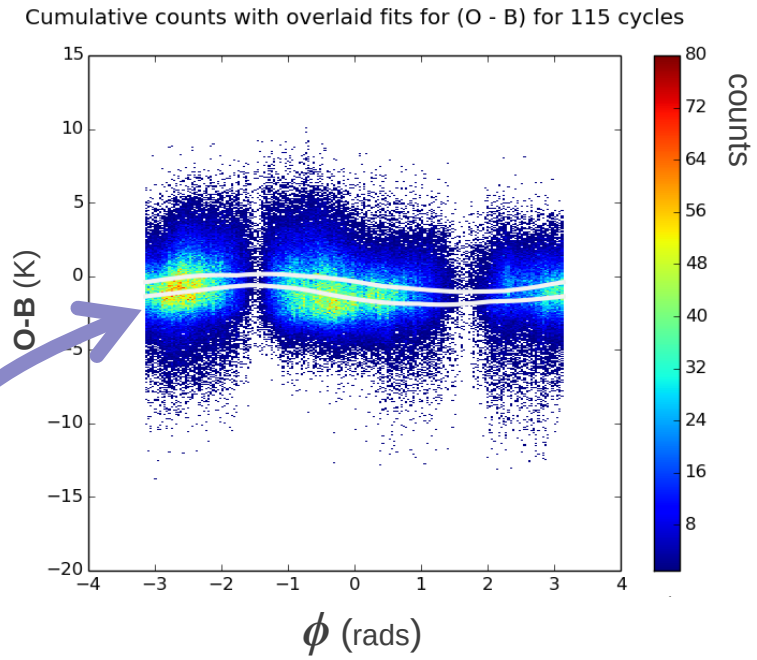
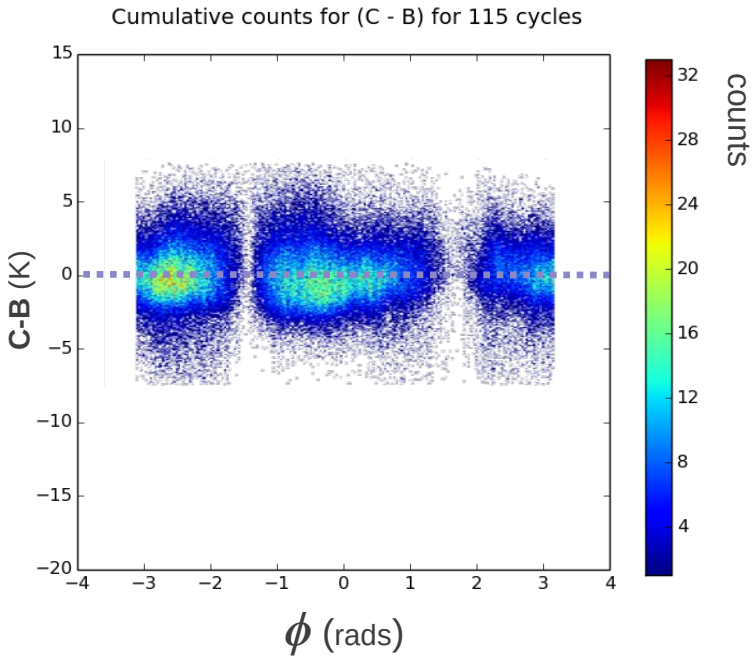
But...

Can it be applied to surface sensitive channels?

Including QC, and selecting sea-only observations...

F-18, Ch16
(37GHz)





Using a correction of two components (N=1) fits this structure

Correction still provides slight benefit

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Conclusions

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Conclusions

- SSMIS exhibits complex, orbital biases – even after physical corrections
- A new orbital bias correction scheme is under development using a Fourier Series in ϕ
- Investigations with a variational toy model show:
  - Good fits obtained using 10 components,
    2 components for surface sensitive channels
  - Tuning of background/observation weightings gives good stability in time
  - Residual biases reduced to ~50mK over a month of orbits
    - for a 30 day test with real F-18, Ch6 data
  - Surface sensitive channels benefit slightly
- Results are consistent for F16, F17 and F18

- Next steps include:
  - Implementing in operational system

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Thank you for listening!

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