

An improved bias correction for SSMIS: Assimilation Assessment

Anna Booton, Bill Bell, Ed Pavelin

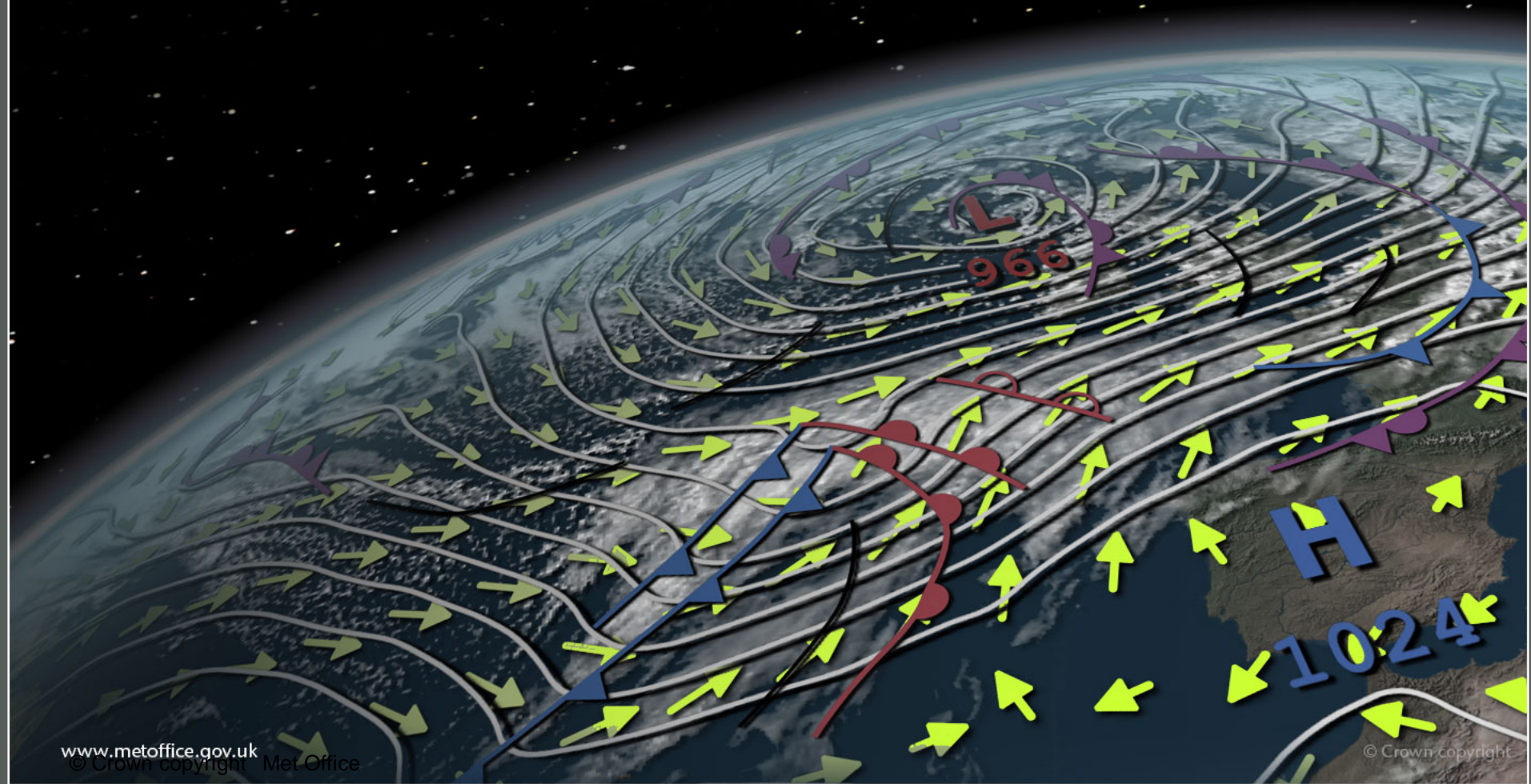




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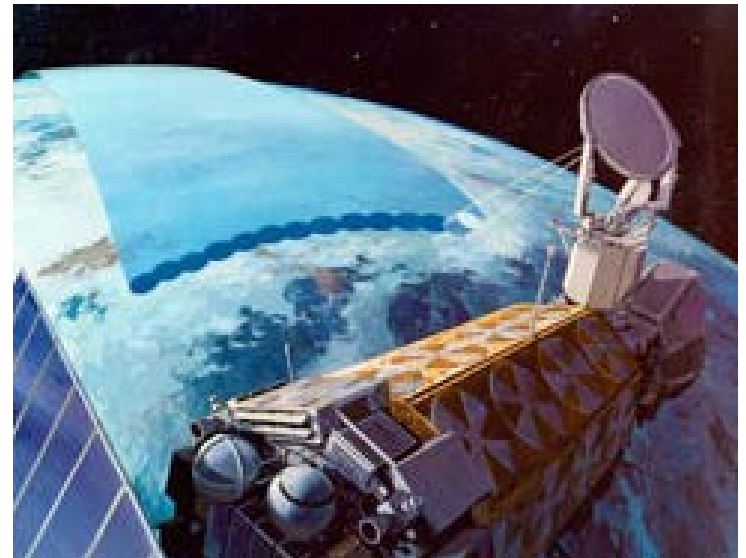


Special Sensor Microwave Imager Sounder (SSMIS) Instruments

The SSMIS instruments flying onboard the US Defense satellites provide

- Temperature (50- 63 GHz)
 - Humidity (183 GHz)
 - Imager dater (90 – 150 GHz)
- } soundings

measuring radiances from the surface to the mesosphere





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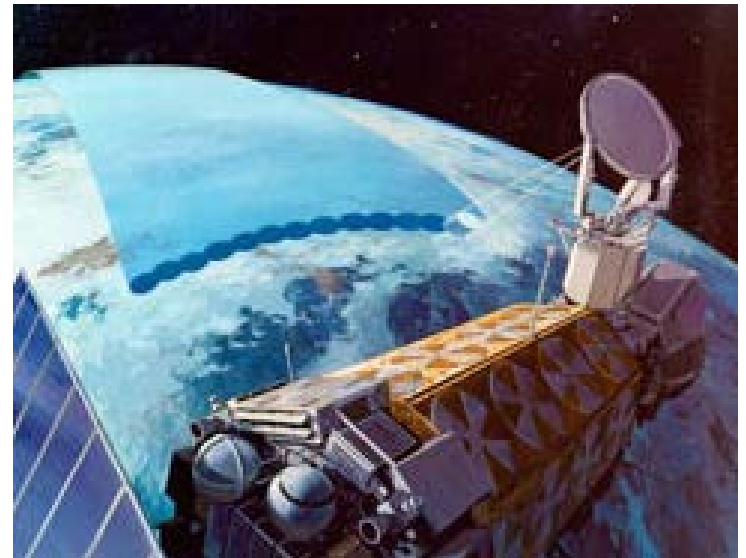
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measuring radiances from the surface to the mesosphere

Unfortunately...

- The instruments' suffer from calibration anomalies making the data difficult to utilize...





Calibration anomalies: Orbital biases

- The anomalies manifest as complex, residual, systematic biases
- Are apparent when comparing the observed brightness temperature (O) with those from NWP model backgrounds (B)



Calibration anomalies: Orbital biases

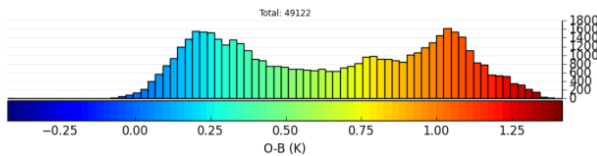
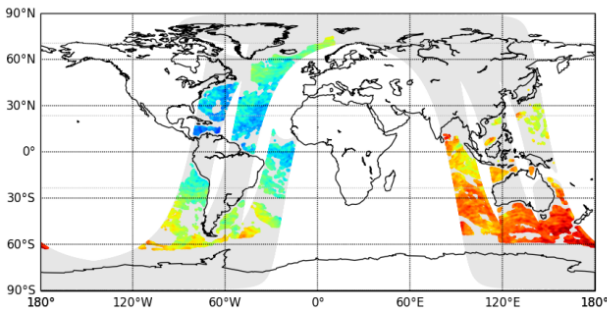
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F18:

Ch 3

2015-06-19T12 F18 SSMIS Ch 3 (53.596 GHz)
O-B BT difference

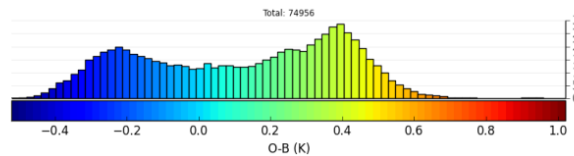
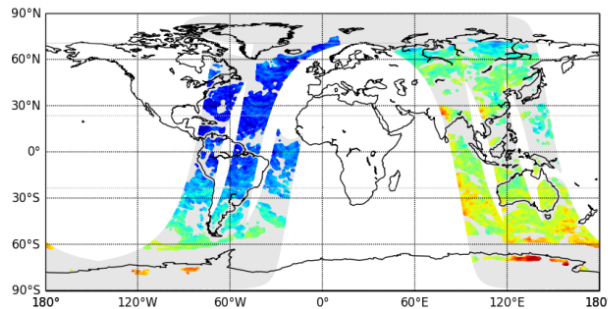
Min: -0.10 Max: 1.42 Mean: 0.642 Std: 0.364 Counts: 49122 Rejects: 464238



Ch 4

2015-06-19T12 F18 SSMIS Ch 4 (54.4 GHz)
O-B BT difference

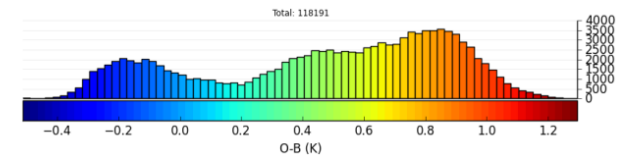
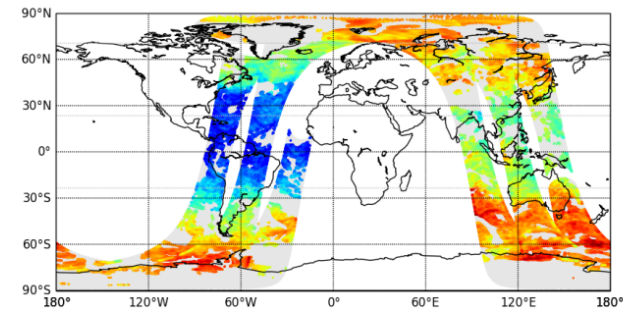
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2015-06-19T12 F18 SSMIS Ch 5 (55.5 GHz)
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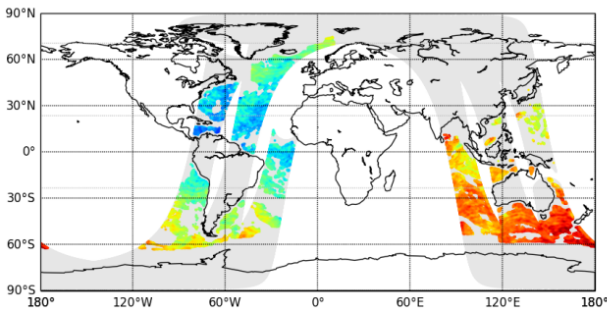
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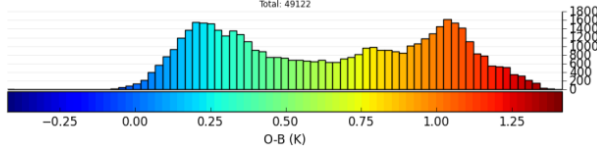
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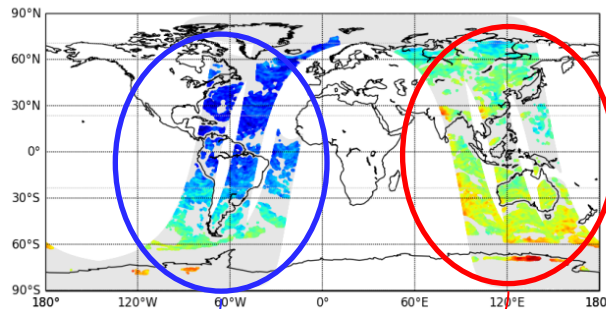
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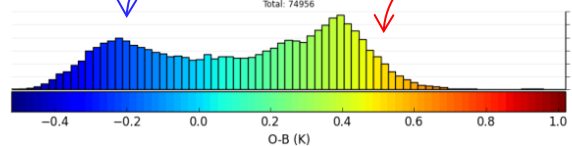
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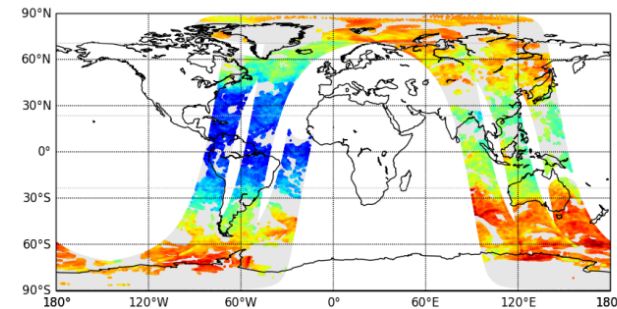
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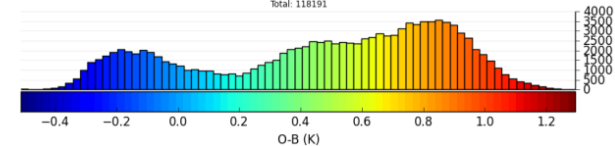
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Cooler descending pass

Warmer ascending pass

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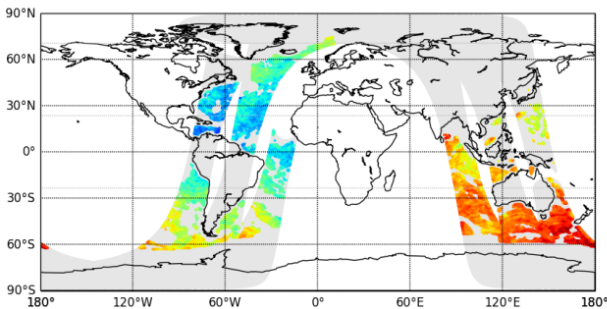
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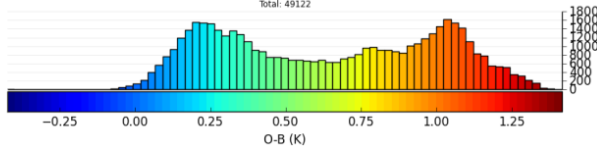
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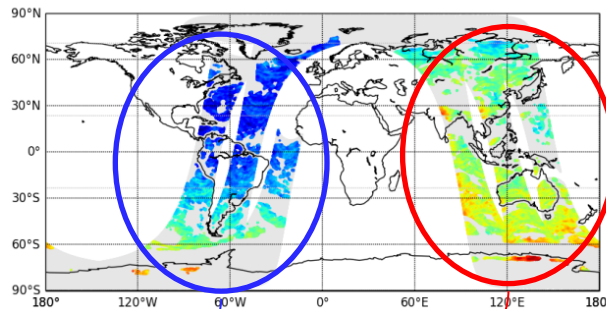
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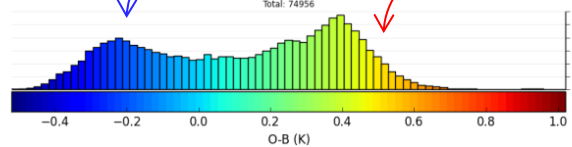
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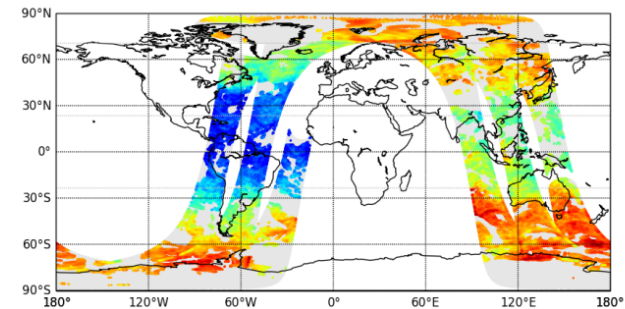
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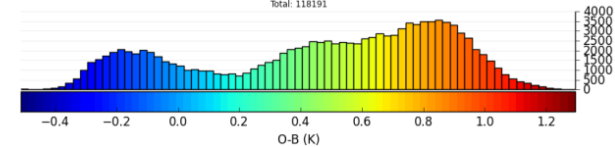
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Orbital bias

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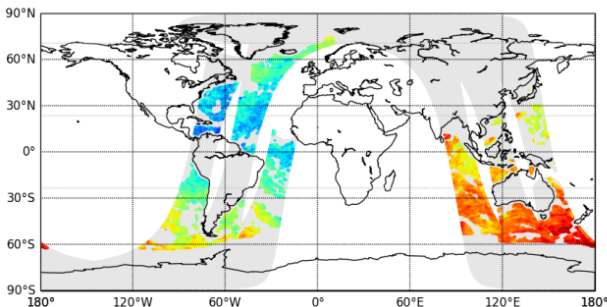
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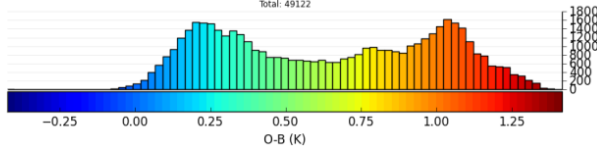
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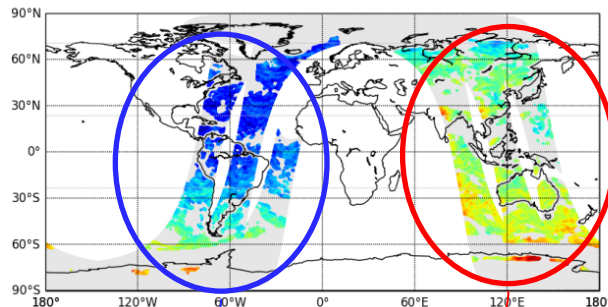
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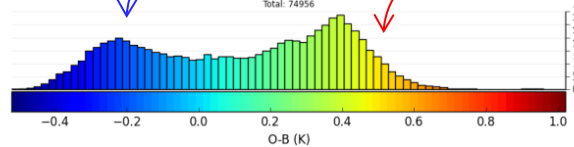
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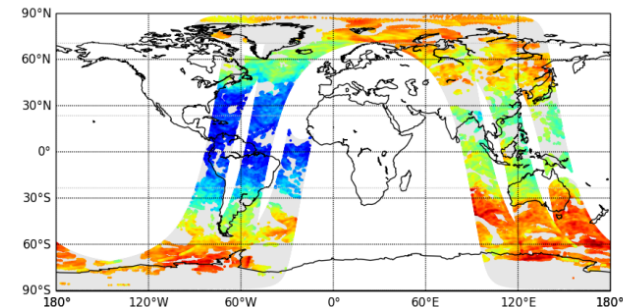
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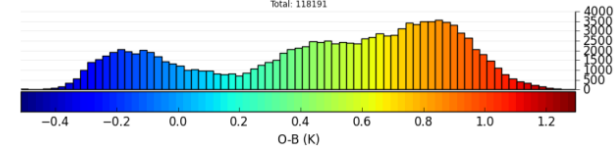
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Orbital bias

If we assess the (O-B) biases with respect to the satellite's orbital angle...

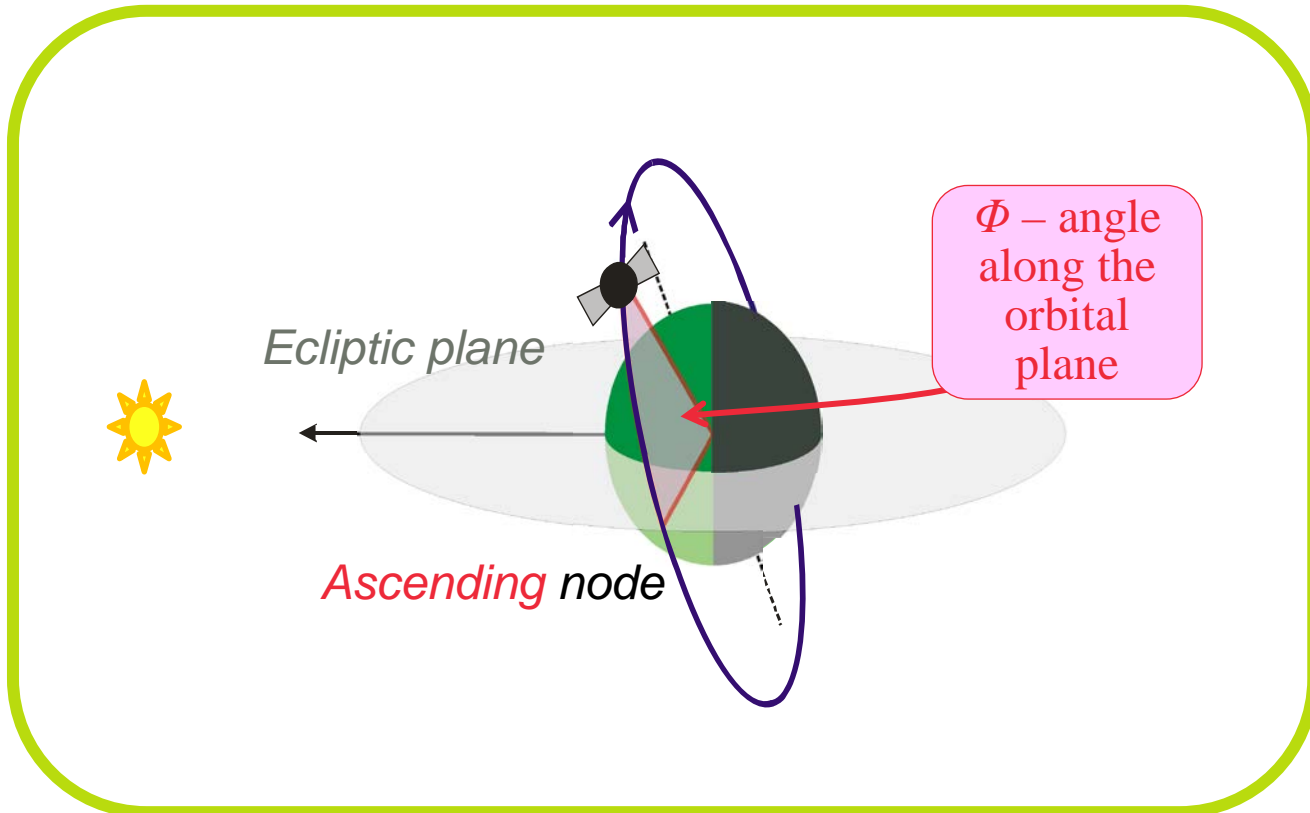


Met Office

The Satellite Orbital Angle

..where the orbital angle is the angle along the orbital plane

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

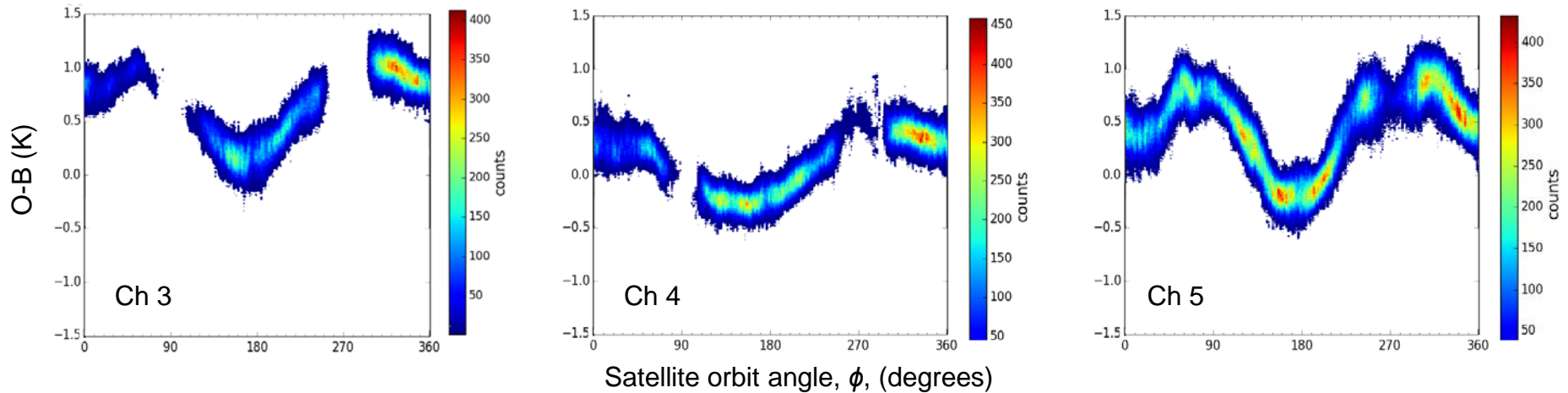


Calibration anomalies: Orbital biases

... the structure of the residual biases is apparent

F18

Cumulative counts for (O-B) for 28 cycles from 17th June – 24th June 2015



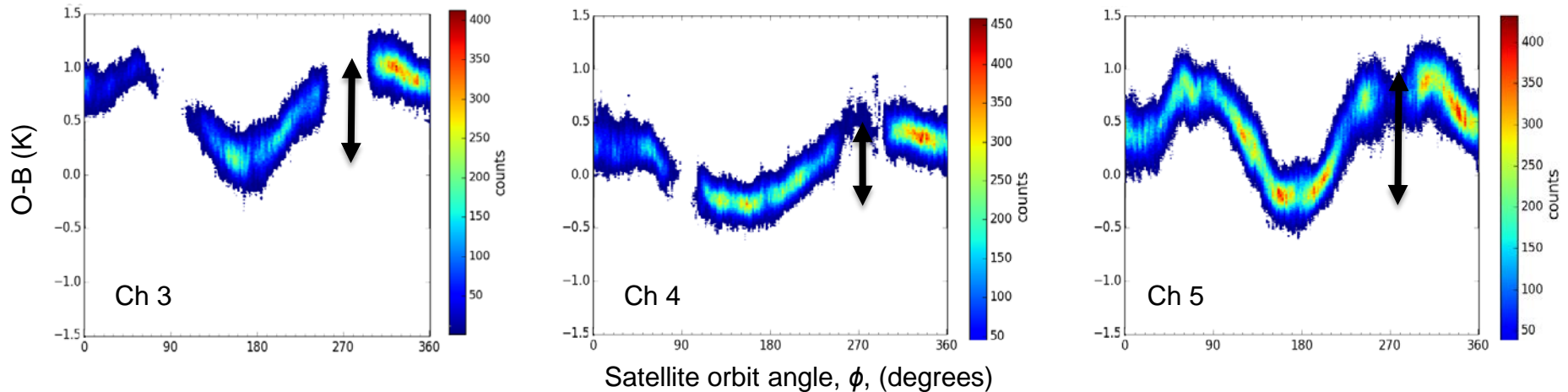
Aggregated O-B's wrt satellite's orbital angle for 7 days

Calibration anomalies: Orbital biases

... the structure of the residual biases is apparent

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Cumulative counts for (O-B) for 28 cycles from 17th June – 24th June 2015



**Pk-Pk
Residual bias** ~ 1K

~ 0.7K

~ 1.2K

- The biases are stable over several days



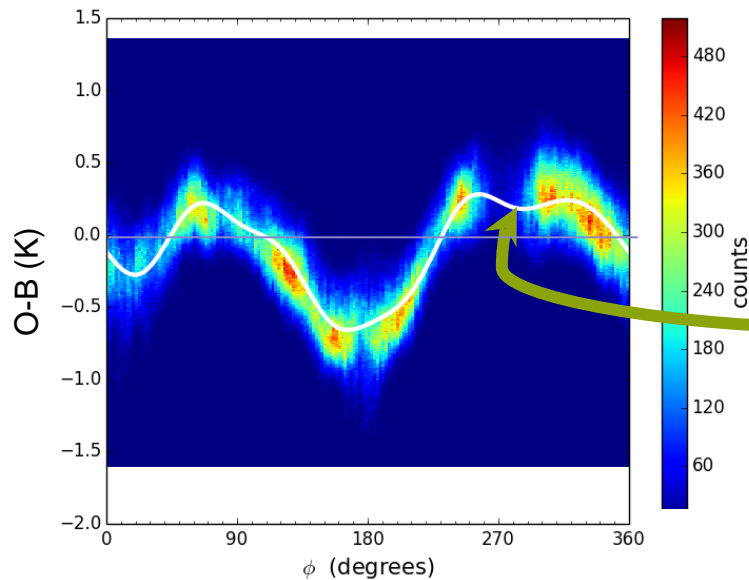
The Orbital Bias Correction

A Fourier Series Approach

The orbital bias correction technique

- We have developed a new orbital bias correction technique
- Uses a Fourier Series 'fit' for characterising the form of the orbital bias.

F18: Ch 6



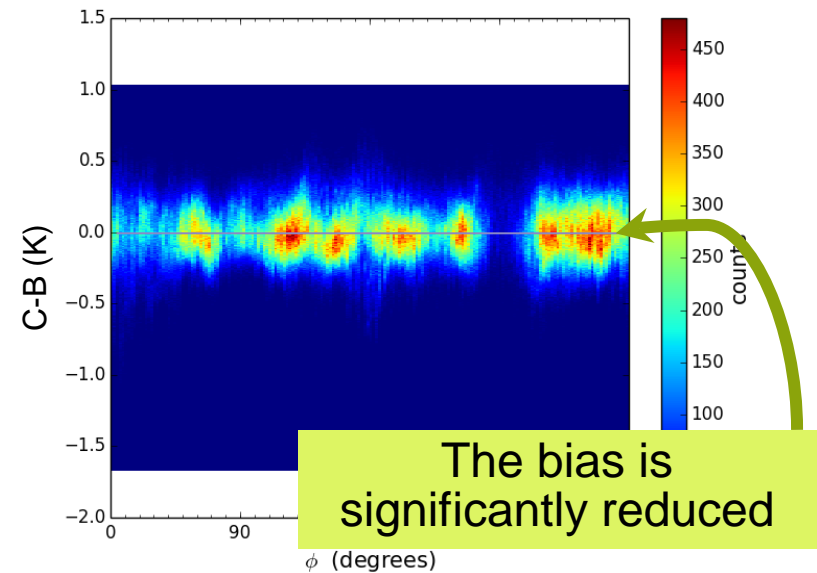
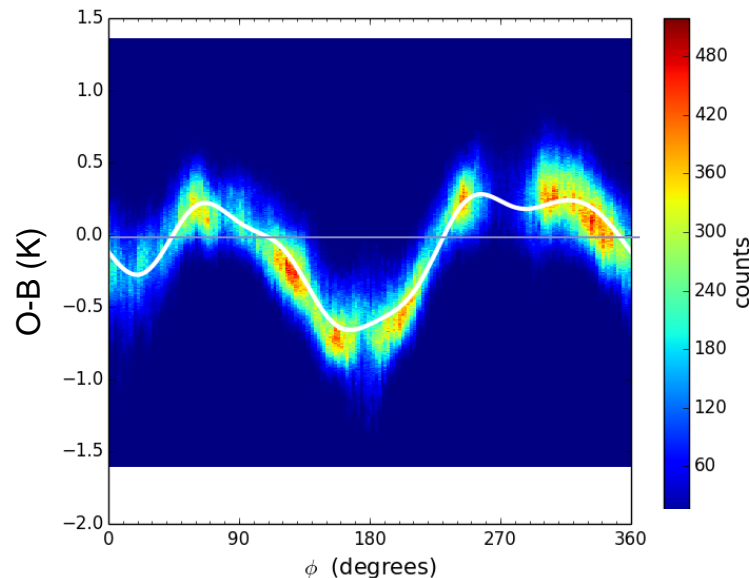
White line shows the
Fourier Series fit to
(O-B)'s

- This 'correcting fit' is then subtracted from the raw brightness temperatures to obtain the corrected (C) values....

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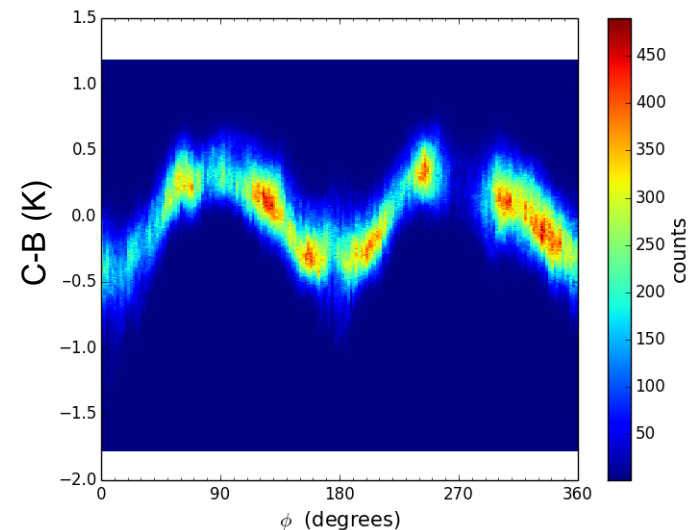
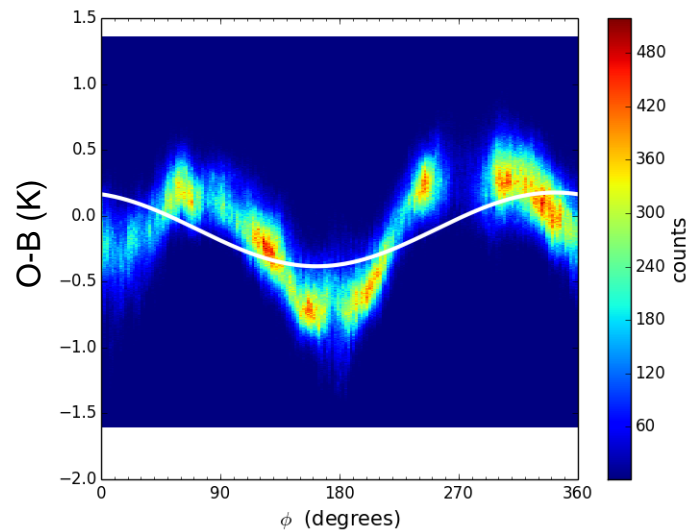
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- The cyclic nature of the bias is well modelled by Fourier Series
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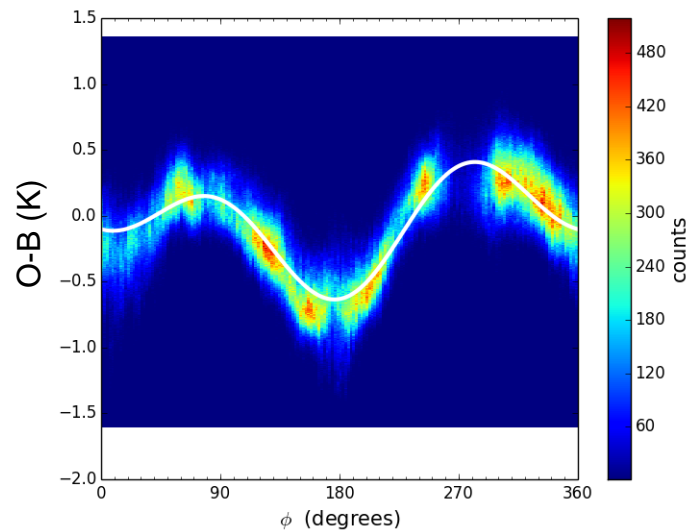


No. Fourier components: $N=1$, constant + $a_1\cos(\phi)$ + $b_1\sin(\phi)$

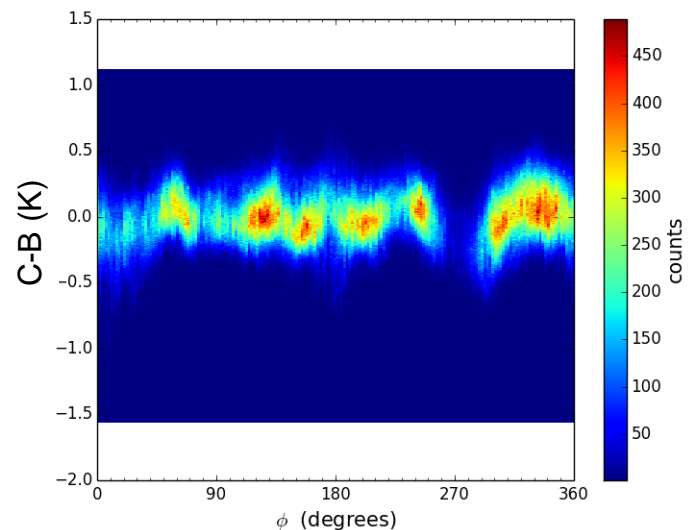
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F18: Ch 6



No. Fourier components: $N=2$,

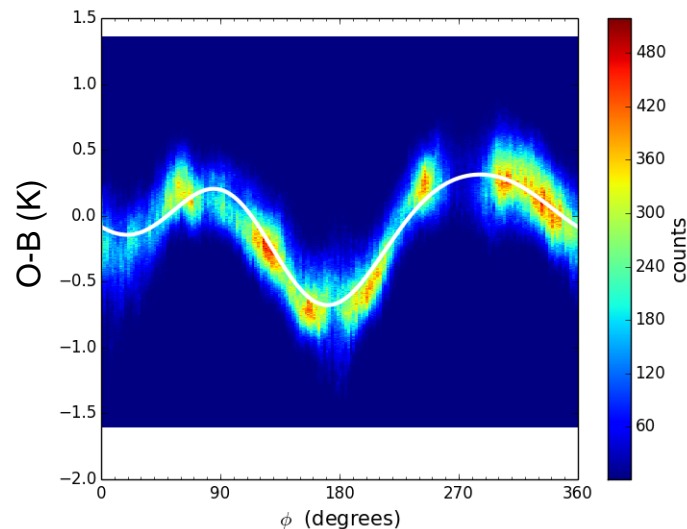


constant + $a_1\cos(\phi) + b_1\sin(\phi)$
 + $a_2\cos(2\phi) + b_2\sin(2\phi)$

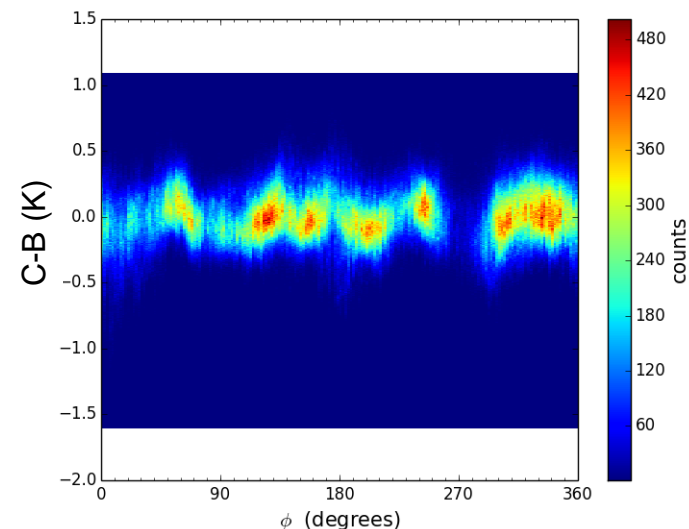
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F18: Ch 6



No. Fourier components: $N=3$,

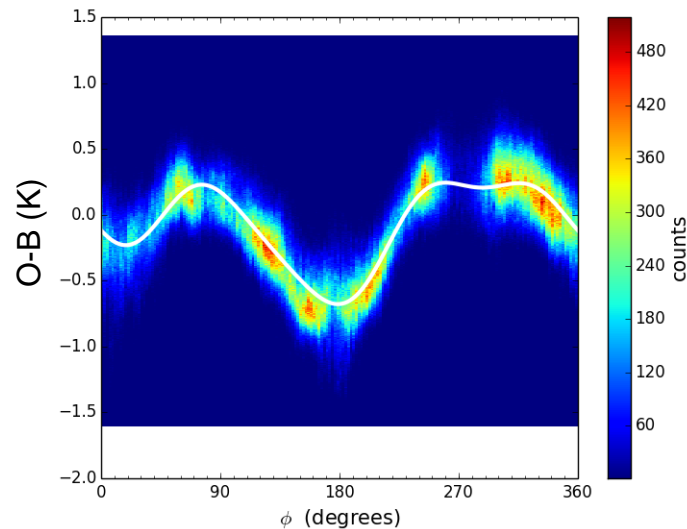


$$\begin{aligned} &\text{constant} + a_1 \cos(\phi) + b_1 \sin(\phi) \\ &\quad + a_2 \cos(2\phi) + b_2 \sin(2\phi) \\ &\quad + a_3 \cos(3\phi) + b_3 \sin(3\phi) \end{aligned}$$

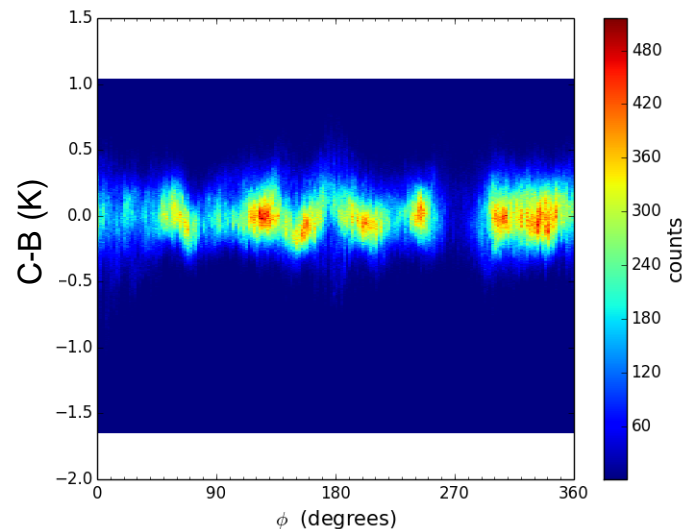
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F18: Ch 6



No. Fourier components: $N=4$,

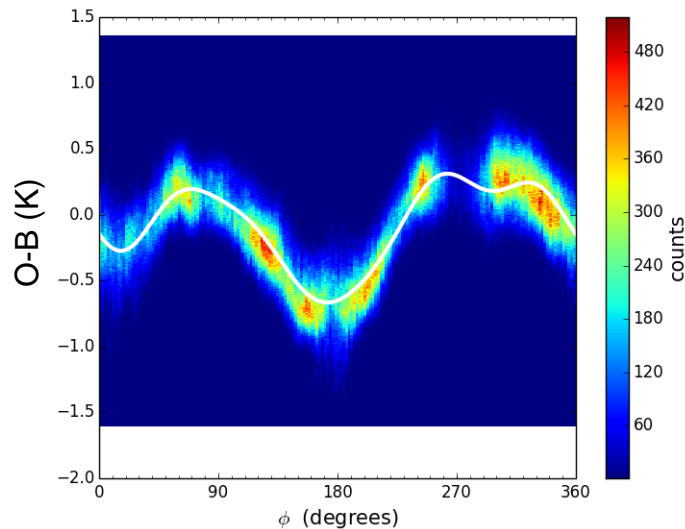


constant + $a_1\cos(\phi) + b_1\sin(\phi)$
 + ...
 + $a_4\cos(4\phi) + b_4\sin(4\phi)$

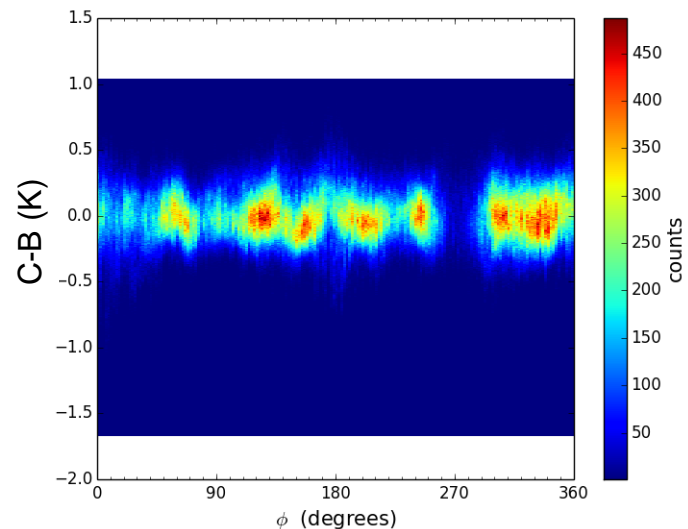
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F18: Ch 6



No. Fourier components: $N=5$,

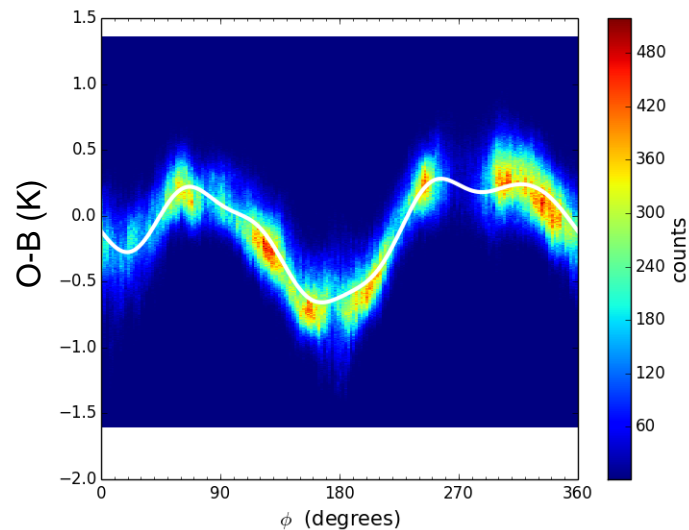


constant + $a_1\cos(\phi) + b_1\sin(\phi)$
 + ...
 + $a_5\cos(5\phi) + b_5\sin(5\phi)$

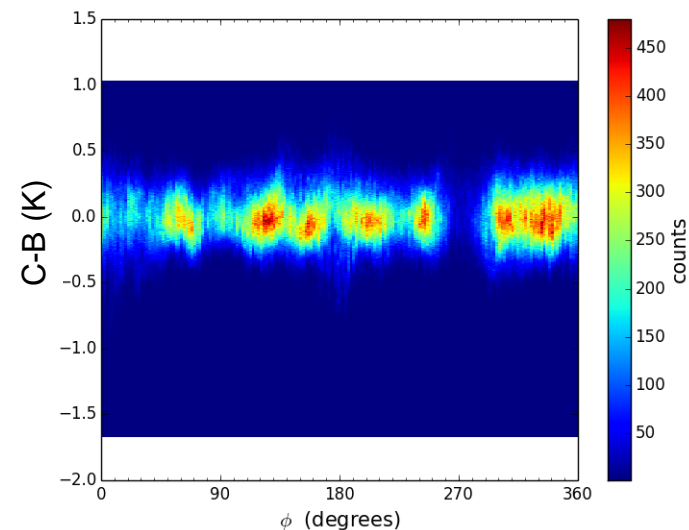
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No. Fourier components: $N=6$,

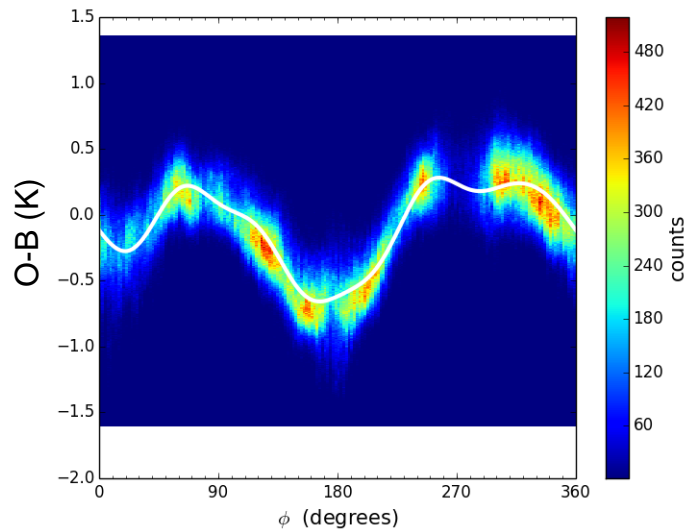


$$\begin{aligned} & \text{constant} + a_1\cos(\phi) + b_1\sin(\phi) \\ & + \dots \\ & + a_6\cos(6\phi) + b_6\sin(6\phi) \end{aligned}$$

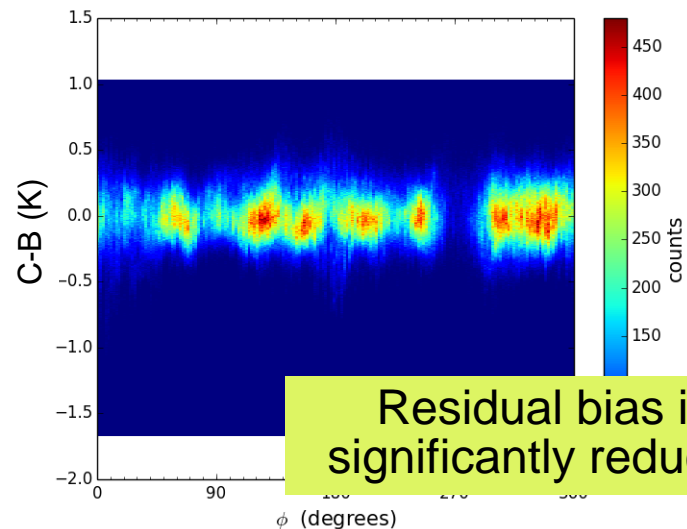
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No. Fourier components: $N=6$,



Residual bias is significantly reduced

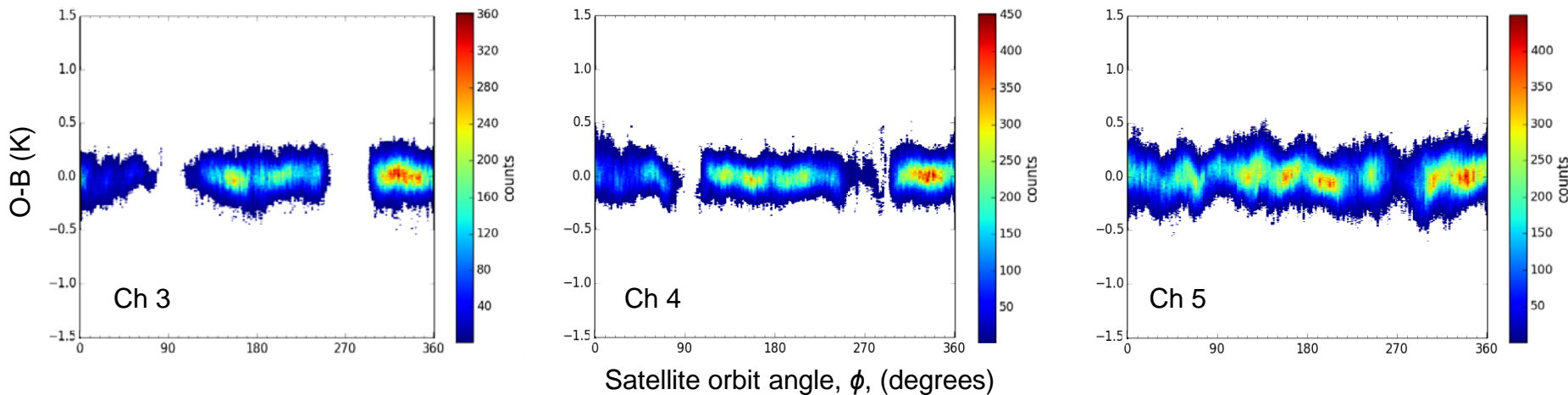
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Applying the correction...

Combining it with cross-scan bias correction proved successful at mitigating these biases

F18

Cumulative counts for (C-B) for 28 cycles from 17th June – 24th June 2015

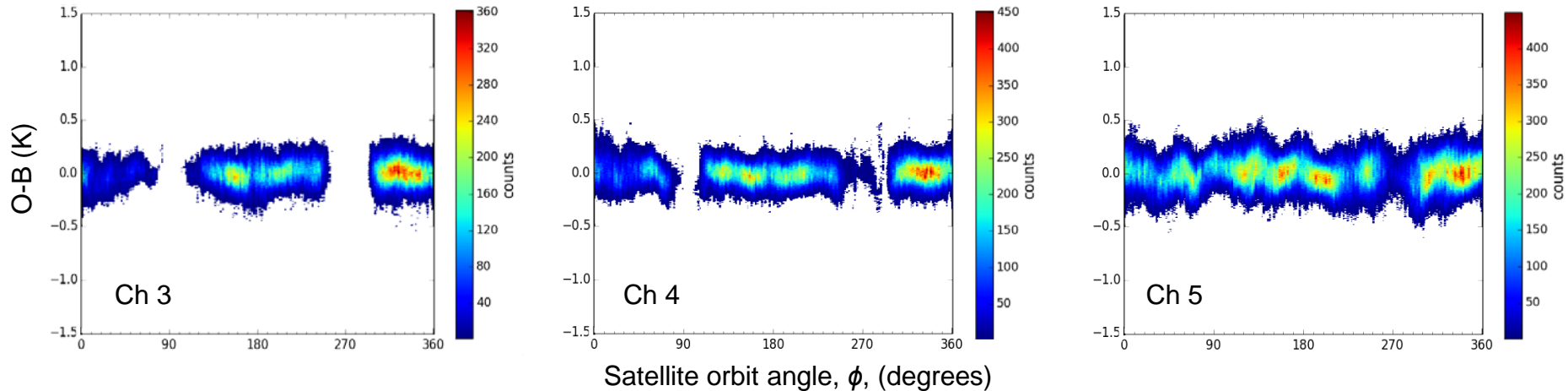


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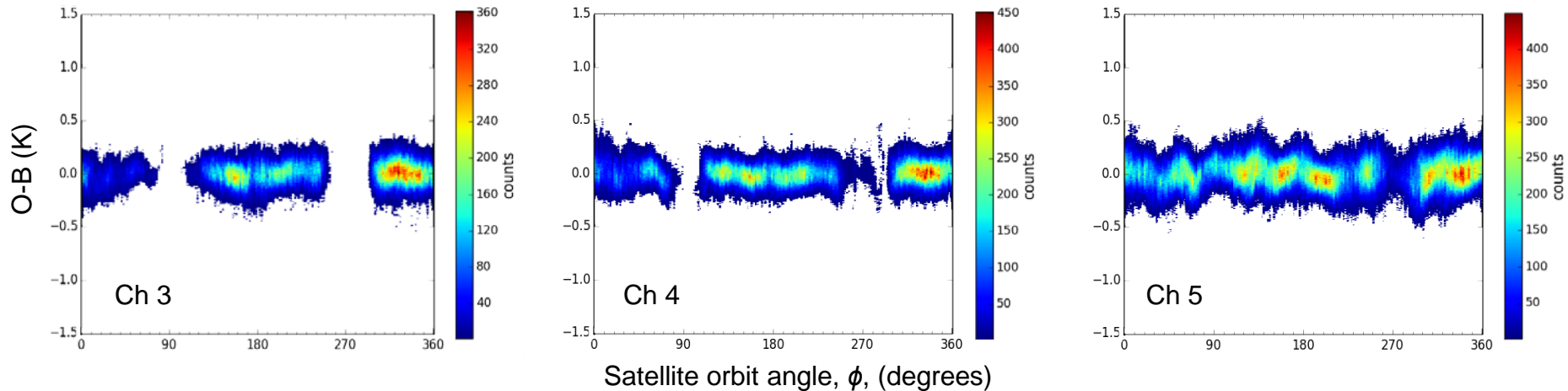
The correction is working well for all channels

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Looking in more detail...

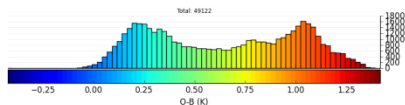
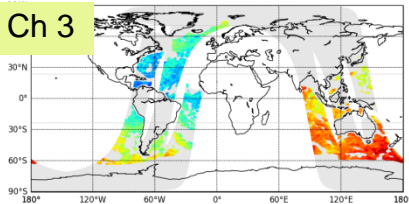


First-guess departure maps: Temperature Sounding channels

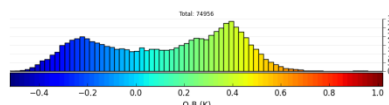
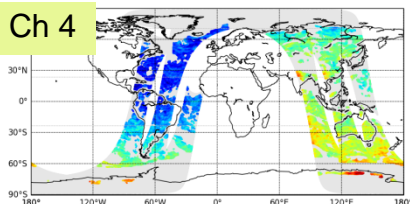
F-18

Pre-bias correction

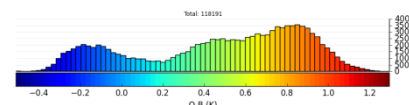
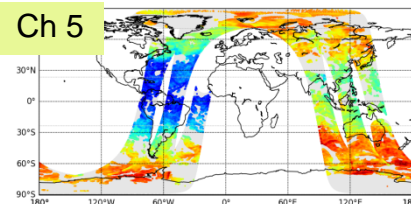
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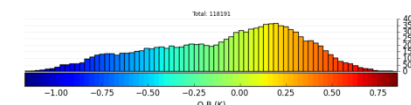
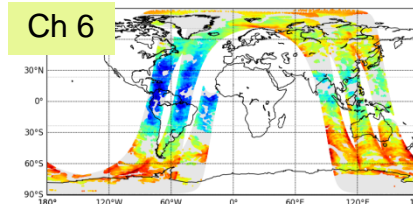
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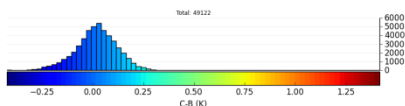
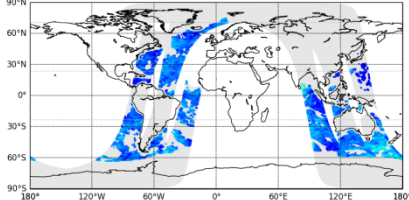
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O-B BT difference
Min: -0.51 Max: 1.30 Mean: 0.475 Std: 0.402 Counts: 118191 Rejects: 395169



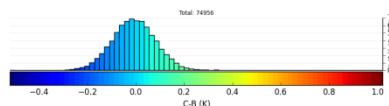
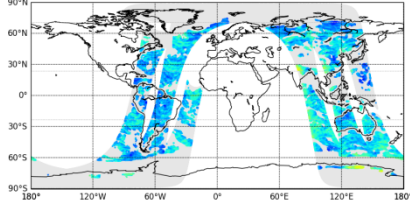
2015-06-19T12 F18 SSMIS Ch 6 (57.29 GHz)
O-B BT difference
Min: -1.17 Max: 0.85 Mean: -0.080 Std: 0.396 Counts: 118191 Rejects: 395169



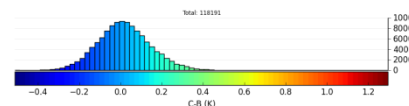
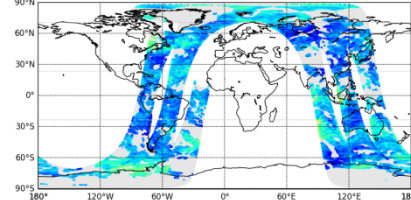
2015-06-19T12 F18 SSMIS Ch 3 (53.596 GHz)
C-B BT difference
Min: -0.42 Max: 0.48 Mean: 0.017 Std: 0.103 Counts: 49122 Rejects: 464238



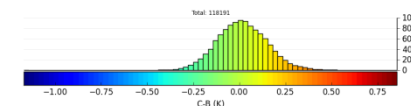
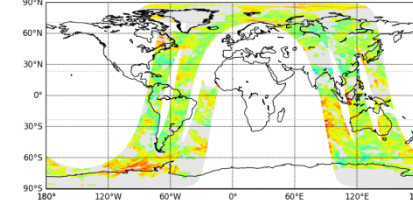
2015-06-19T12 F18 SSMIS Ch 4 (54.4 GHz)
C-B BT difference
Min: -0.37 Max: 0.51 Mean: -0.008 Std: 0.093 Counts: 74956 Rejects: 438404



2015-06-19T12 F18 SSMIS Ch 5 (55.5 GHz)
C-B BT difference
Min: -0.46 Max: 0.71 Mean: 0.018 Std: 0.130 Counts: 118191 Rejects: 395169



2015-06-19T12 F18 SSMIS Ch 6 (57.29 GHz)
C-B BT difference
Min: -0.53 Max: 0.69 Mean: 0.016 Std: 0.139 Counts: 118191 Rejects: 395169



Post-bias correction

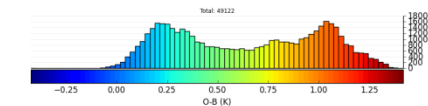
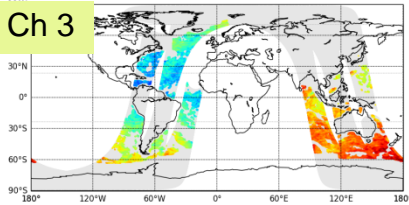


First-guess departure maps: Temperature Sounding channels

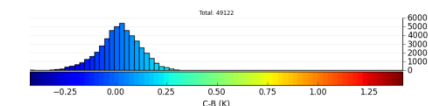
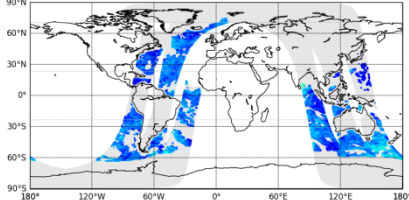
F-18

Pre-bias correction

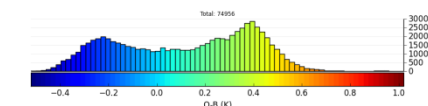
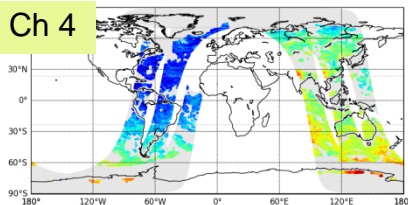
2015-06-19T12 F18 SSMIS Ch 3 (53.596 GHz)
O-B BT difference
Min: -0.10 Max: 1.42 Mean: 0.642 Std: 0.364 Counts: 49122 Rejects: 464238



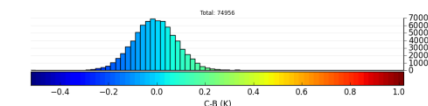
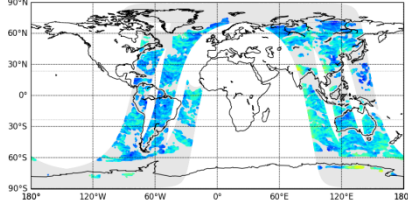
2015-06-19T12 F18 SSMIS Ch 3 (53.596 GHz)
C-B BT difference
Min: -0.42 Max: 0.48 Mean: 0.017 Std: 0.103 Counts: 49122 Rejects: 464238



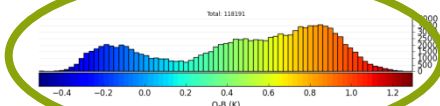
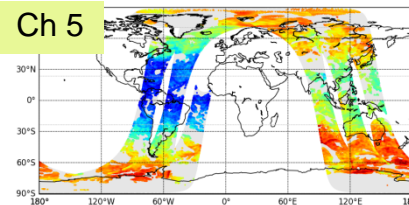
2015-06-19T12 F18 SSMIS Ch 4 (54.4 GHz)
O-B BT difference
Min: -0.52 Max: 1.02 Mean: 0.118 Std: 0.281 Counts: 74956 Rejects: 438404



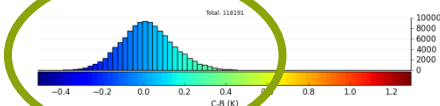
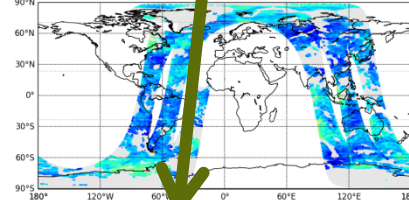
2015-06-19T12 F18 SSMIS Ch 4 (54.4 GHz)
C-B BT difference
Min: -0.37 Max: 0.51 Mean: -0.008 Std: 0.093 Counts: 74956 Rejects: 438404



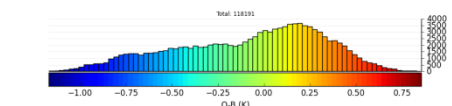
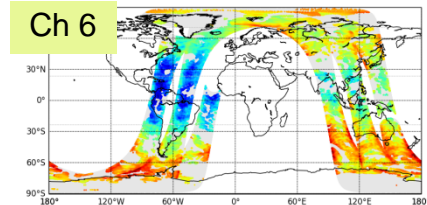
2015-06-19T12 F18 SSMIS Ch 5 (55.5 GHz)
O-B BT difference
Min: -0.51 Max: 1.30 Mean: 0.475 Std: 0.402 Counts: 118191 Rejects: 395169



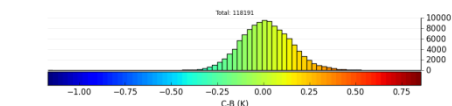
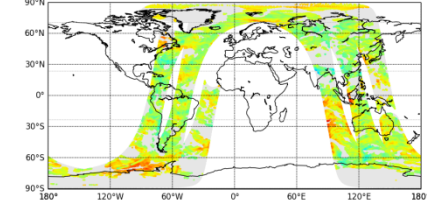
2015-06-19T12 F18 SSMIS Ch 5 (55.5 GHz)
C-B BT difference
Min: -0.46 Max: 0.71 Mean: 0.018 Std: 0.130 Counts: 118191 Rejects: 395169



2015-06-19T12 F18 SSMIS Ch 6 (57.29 GHz)
O-B BT difference
Min: -1.17 Max: 0.85 Mean: -0.080 Std: 0.396 Counts: 118191 Rejects: 395169



2015-06-19T12 F18 SSMIS Ch 6 (57.29 GHz)
C-B BT difference
Min: -0.53 Max: 0.69 Mean: 0.016 Std: 0.139 Counts: 118191 Rejects: 395169



Post-bias correction

The complex structure is well modelled

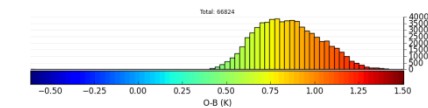
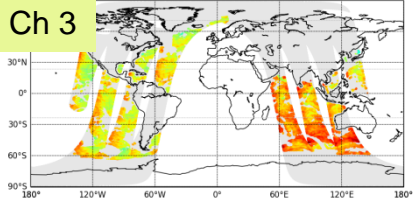


First-guess departure maps: Temperature Sounding channels

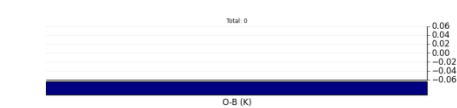
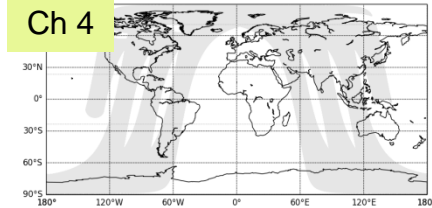
F-17

Pre-bias correction

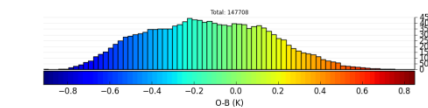
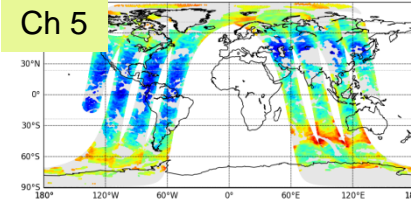
2015-06-19T12 F17 SSMIS Ch 3 (53.596 GHz)
O-B BT difference
Min: 0.19 Max: 1.51 Mean: 0.849 Std: 0.182 Counts: 66824 Rejects: 599416



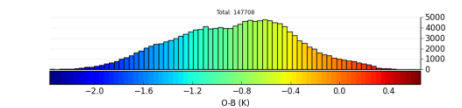
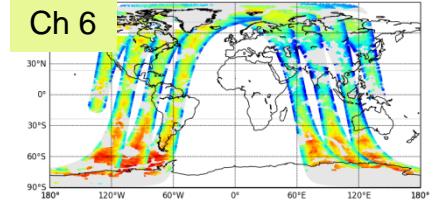
2015-06-19T12 F17 SSMIS Ch 4 (54.4 GHz)
O-B BT difference
Min: -- Max: -- Mean: -- Std: -- Counts: 0 Rejects: 666240



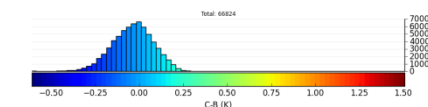
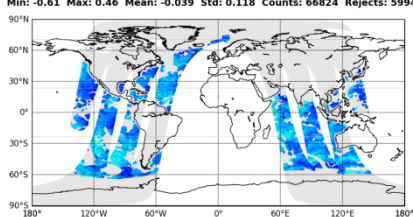
2015-06-19T12 F17 SSMIS Ch 5 (55.5 GHz)
O-B BT difference
Min: -0.91 Max: 0.85 Mean: -0.136 Std: 0.292 Counts: 147708 Rejects: 518532



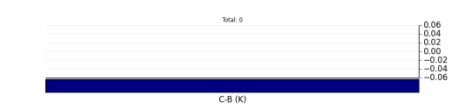
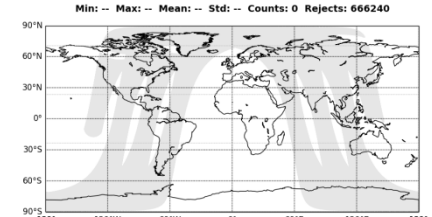
2015-06-19T12 F17 SSMIS Ch 6 (57.29 GHz)
O-B BT difference
Min: -2.37 Max: 0.55 Mean: -0.864 Std: 0.486 Counts: 147708 Rejects: 518532



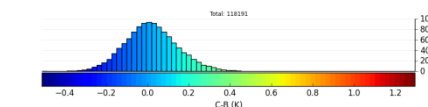
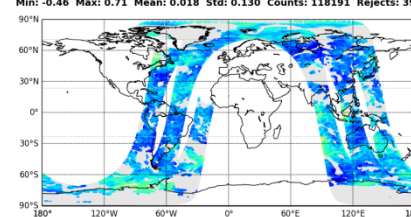
2015-06-19T12 F17 SSMIS Ch 3 (53.596 GHz)
C-B BT difference
Min: -0.61 Max: 0.46 Mean: -0.039 Std: 0.118 Counts: 66824 Rejects: 599416



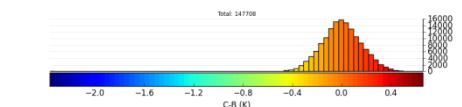
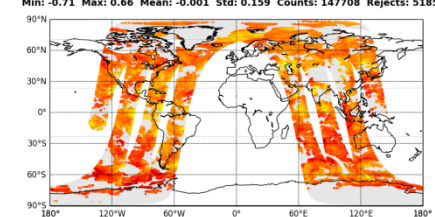
2015-06-19T12 F17 SSMIS Ch 4 (54.4 GHz)
C-B BT difference
Min: -- Max: -- Mean: -- Std: -- Counts: 0 Rejects: 666240



2015-06-19T12 F17 SSMIS Ch 5 (55.5 GHz)
C-B BT difference
Min: -0.46 Max: 0.71 Mean: 0.018 Std: 0.130 Counts: 118191 Rejects: 395169



2015-06-19T12 F17 SSMIS Ch 6 (57.29 GHz)
C-B BT difference
Min: -0.71 Max: 0.66 Mean: -0.001 Std: 0.159 Counts: 147708 Rejects: 518532



Post-bias correction

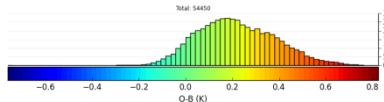
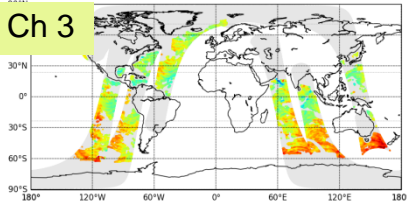


First-guess departure maps: Temperature Sounding channels

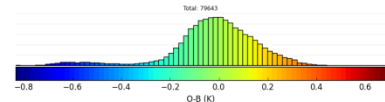
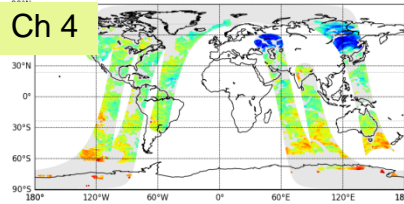
F-19

Pre-bias correction

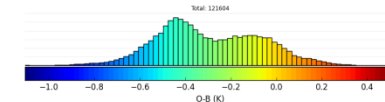
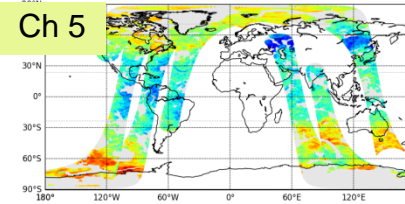
2015-06-19T12 F19 SSMIS Ch 3 (53.596 GHz)
O-B BT difference



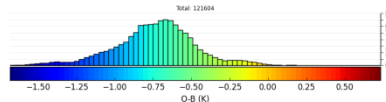
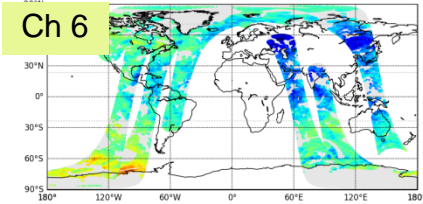
2015-06-19T12 F19 SSMIS Ch 4 (54.4 GHz)
O-B BT difference



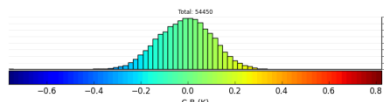
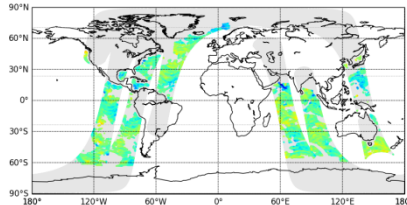
2015-06-19T12 F19 SSMIS Ch 5 (55.5 GHz)
O-B BT difference



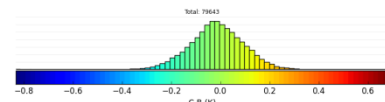
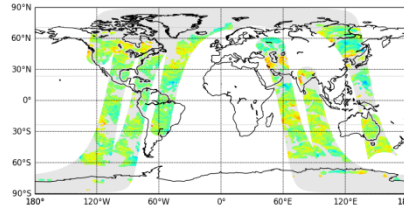
2015-06-19T12 F19 SSMIS Ch 6 (57.29 GHz)
O-B BT difference



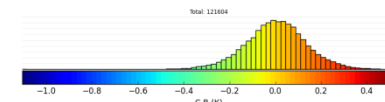
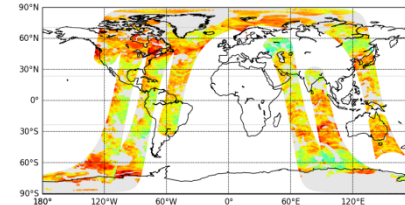
2015-06-19T12 F19 SSMIS Ch 3 (53.596 GHz)
C-B BT difference



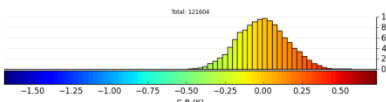
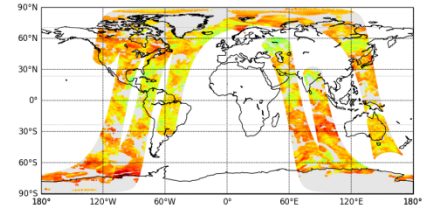
2015-06-19T12 F19 SSMIS Ch 4 (54.4 GHz)
C-B BT difference



2015-06-19T12 F19 SSMIS Ch 5 (55.5 GHz)
C-B BT difference



2015-06-19T12 F19 SSMIS Ch 6 (57.29 GHz)
C-B BT difference



Post-bias correction

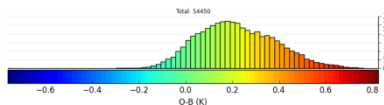
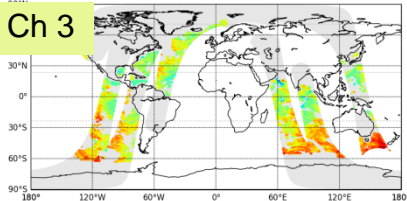


First-guess departure maps: Temperature Sounding channels

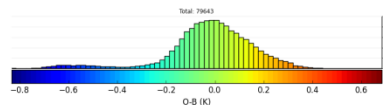
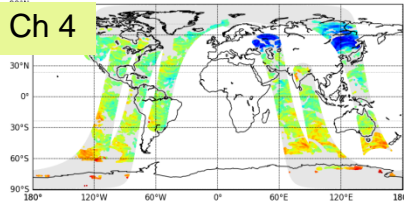
F-19

Pre-bias correction

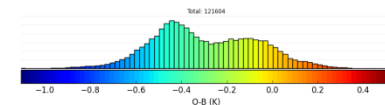
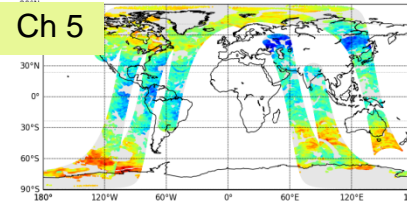
2015-06-19T12 F19 SSMIS Ch 3 (53.596 GHz)
O-B BT difference
Min: -0.55 Max: 0.82 Mean: 0.219 Std: 0.170 Counts: 54450 Rejects: 449970



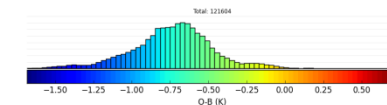
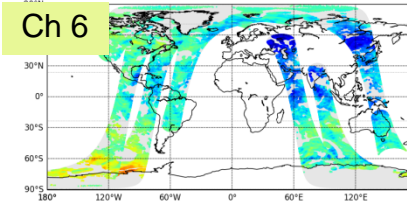
2015-06-19T12 F19 SSMIS Ch 4 (54.4 GHz)
O-B BT difference
Min: -0.83 Max: 0.68 Mean: -0.022 Std: 0.184 Counts: 79643 Rejects: 424777



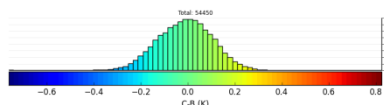
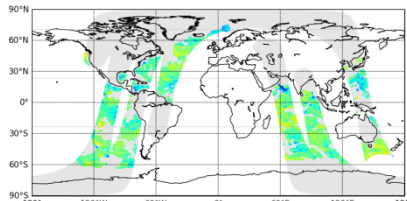
2015-06-19T12 F19 SSMIS Ch 5 (55.5 GHz)
O-B BT difference
Min: -1.11 Max: 0.47 Mean: -0.296 Std: 0.229 Counts: 121604 Rejects: 382816



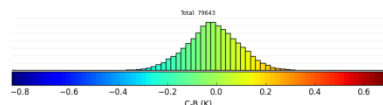
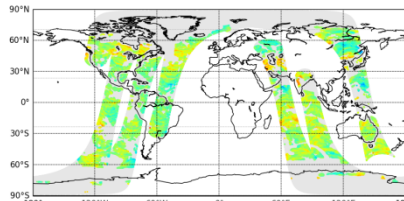
2015-06-19T12 F19 SSMIS Ch 6 (57.29 GHz)
O-B BT difference
Min: -1.68 Max: 0.31 Mean: -0.737 Std: 0.270 Counts: 121604 Rejects: 382816



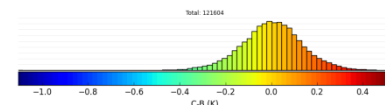
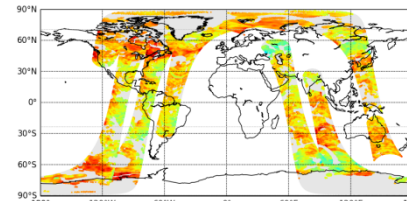
2015-06-19T12 F19 SSMIS Ch 3 (53.596 GHz)
C-B BT difference
Min: -0.76 Max: 0.47 Mean: -0.013 Std: 0.117 Counts: 54450 Rejects: 449970



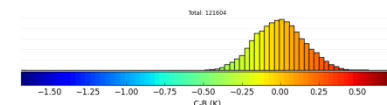
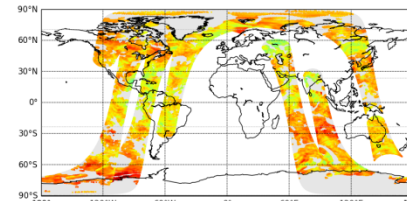
2015-06-19T12 F19 SSMIS Ch 4 (54.4 GHz)
C-B BT difference
Min: -0.46 Max: 0.43 Mean: -0.016 Std: 0.108 Counts: 79643 Rejects: 424777



2015-06-19T12 F19 SSMIS Ch 5 (55.5 GHz)
C-B BT difference
Min: -0.58 Max: 0.52 Mean: 0.002 Std: 0.135 Counts: 121604 Rejects: 382816



2015-06-19T12 F19 SSMIS Ch 6 (57.29 GHz)
C-B BT difference
Min: -0.58 Max: 0.73 Mean: -0.007 Std: 0.161 Counts: 121604 Rejects: 382816



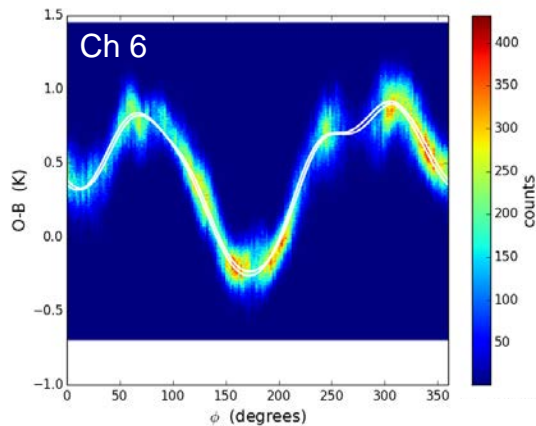
Post-bias correction

And performs equally well for the humidity and imager channels.
Although less Fourier bias predictors were used....

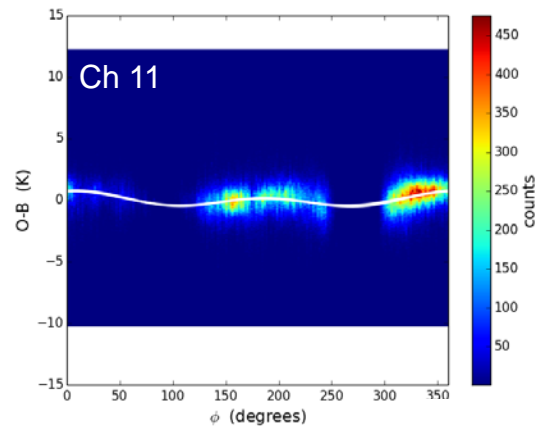
The number of predictors used...

- **12** Fourier predictors + constant (N=6) for correcting the **temperature** sounding channels
- **4** Fourier predictors + constant (N=2) for the **humidity** and **imager** channels
 - To constrain the fit where surface observations are rejected

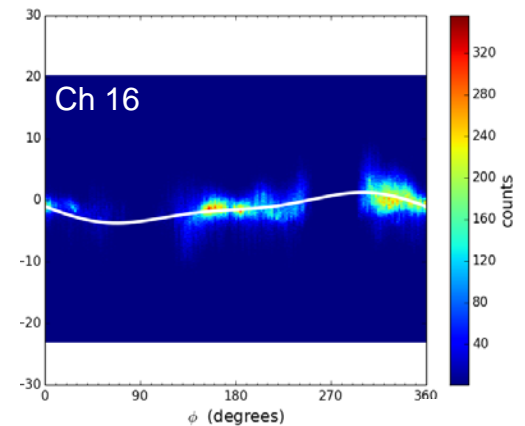
F18



Temperature,
N=6 (Ch 2-7, 23-24)



Humidity,
N=2 (Ch 9-11)



Imager,
N=2 (Ch 12-16)

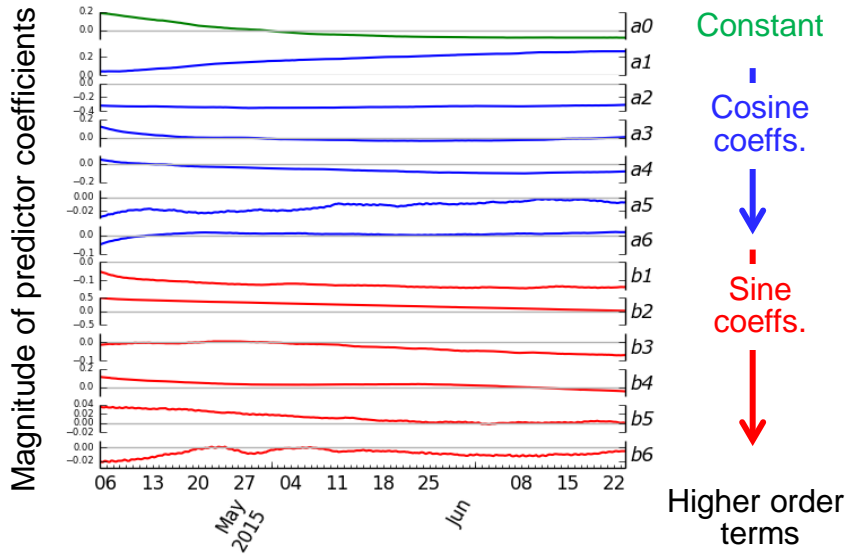


Met Office

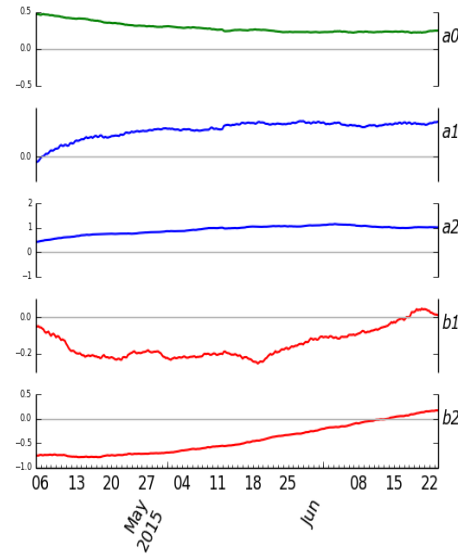
Evolution of the predictor coefficients

- Orbital predictors have been implemented within our variational bias correction system
- We monitored the magnitude of the coefficients over a three month time period.

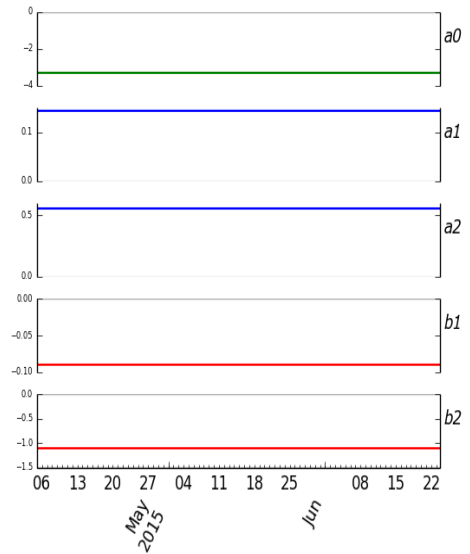
Evolution of Orbital Bias Predictor Coefficients



Temperature: F18 Ch 6



Humidity: F18 Ch 11



Imager: F18 Ch 16

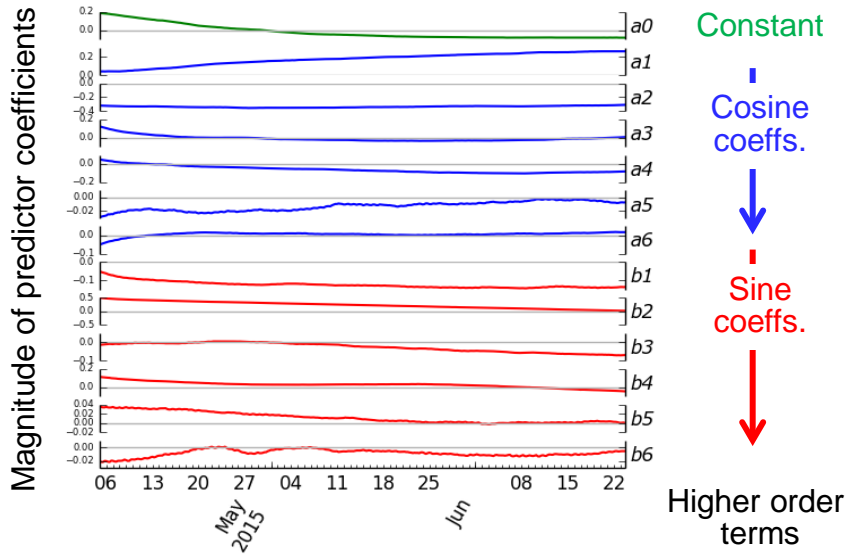


Met Office

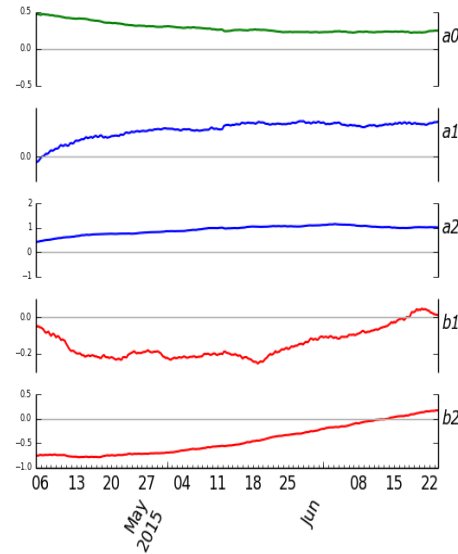
Evolution of the predictor coefficients

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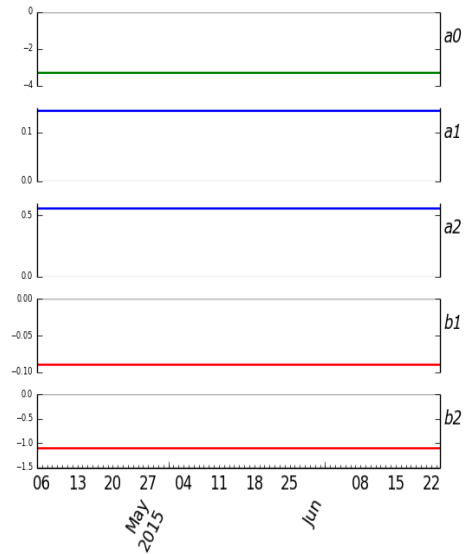
Evolution of Orbital Bias Predictor Coefficients



Temperature: F18 Ch 6



Humidity: F18 Ch 11



Imager: F18 Ch 16

The slow evolution indicates the bias correction is stable



The Assimilation Experiments



Assimilation Experiments

- NWP trials assimilating SSMIS data from F17 & F18 instruments, to separately assess the impact of:
 - **Temperature** sounding (Ch: 2-7,23,24)
 - **Humidity** sounding (Ch: 9-11)
 - **Imager** (Ch: 12-16)

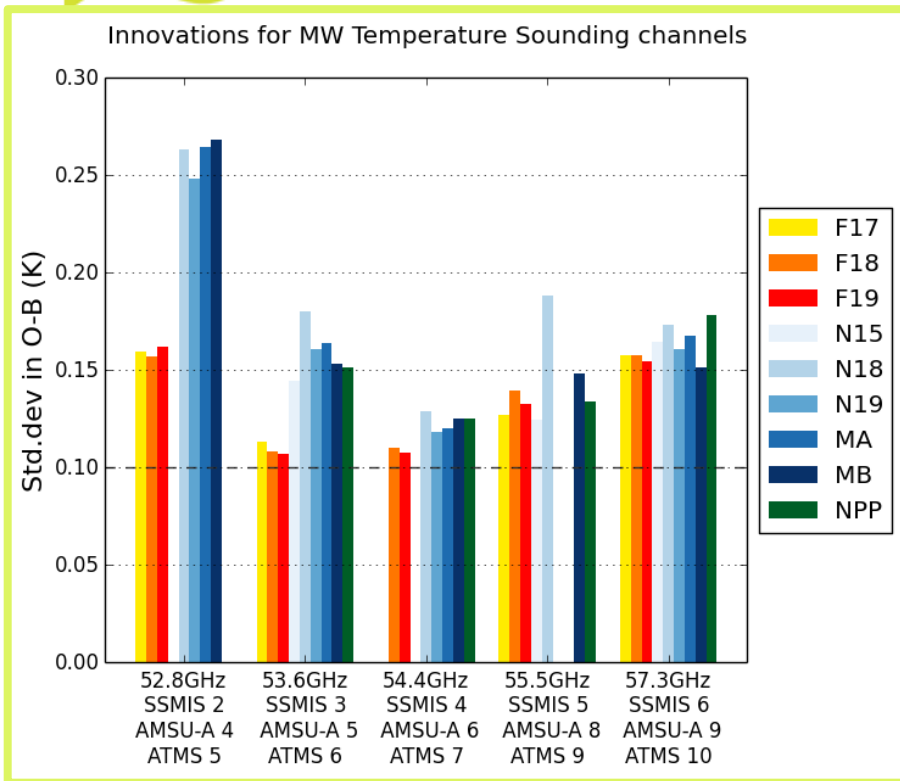
as well as a

- **'Unified'** – temperature & humidity & imager trial

were run for a summer period, June 2014.

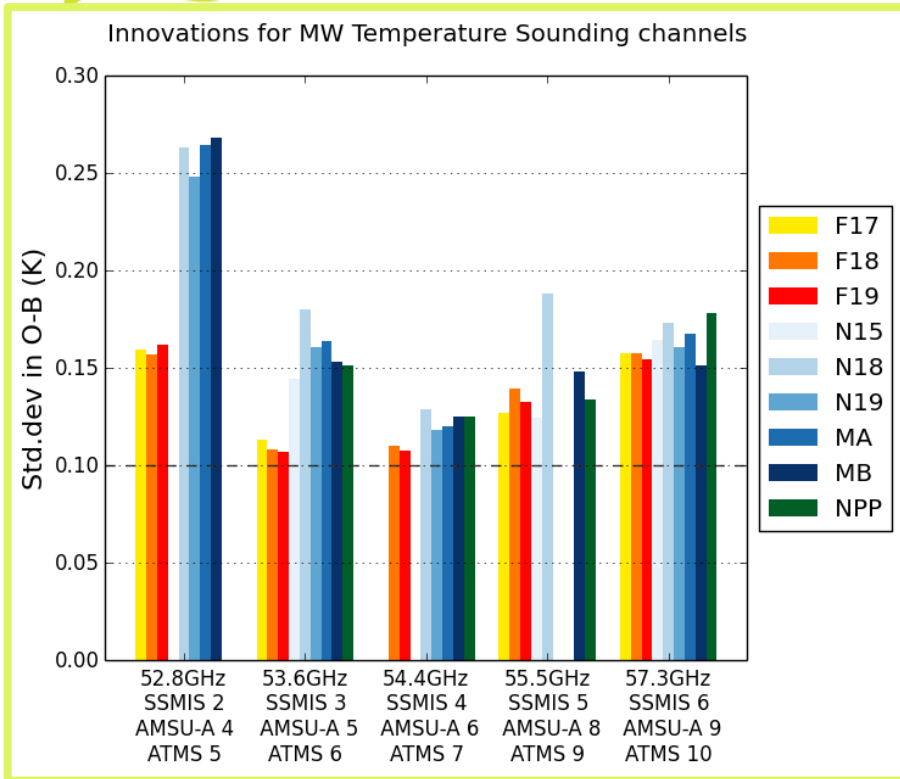


SSMIS innovations for key channels:





SSMIS innovations for key channels:

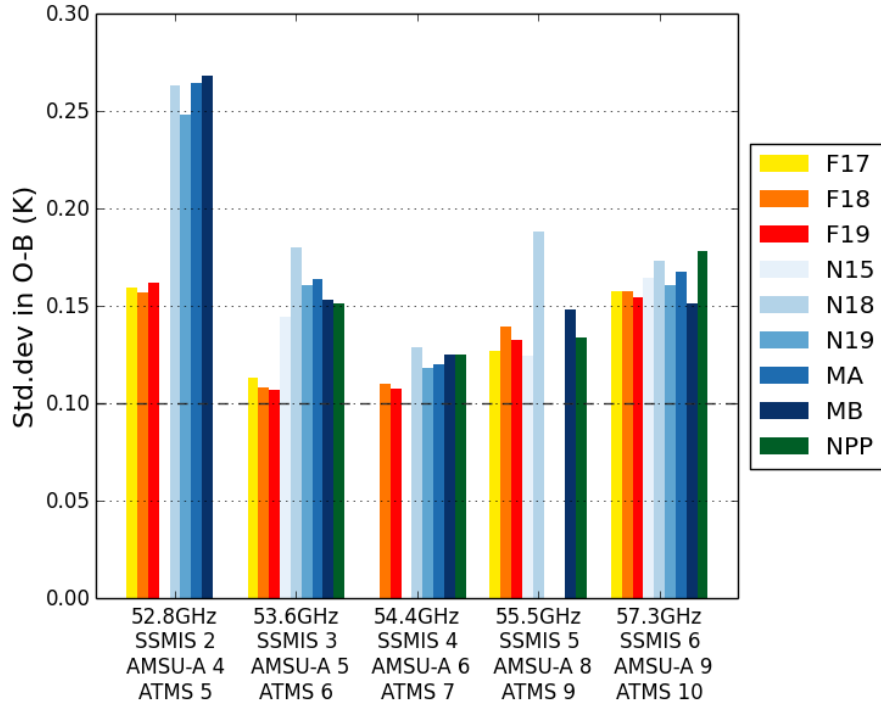


SSMIS departure statistics are: comparable to or better than the equivalent AMSU-A and ATMS channels

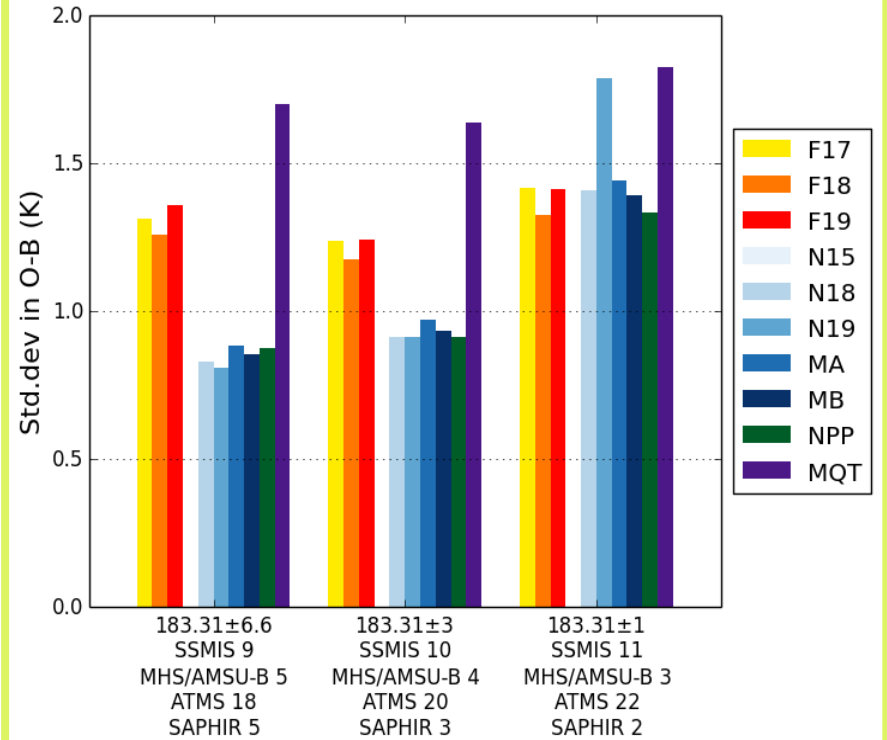


SSMIS innovations for key channels:

Innovations for MW Temperature Sounding channels



Innovations for MW Humidity Sounding channels

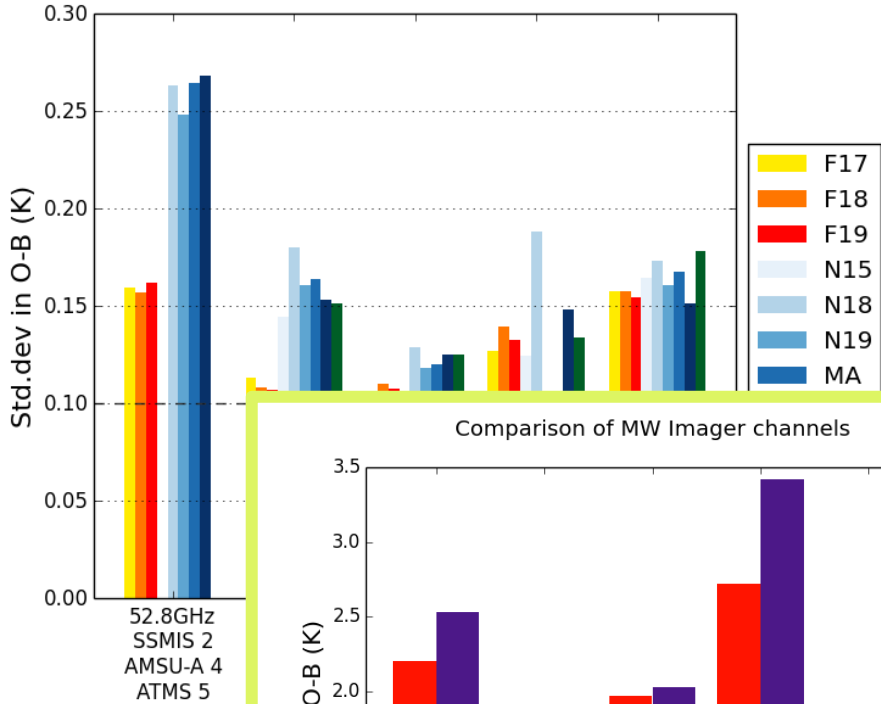


SSMIS departures are slightly larger than MHS/AMSU-B but less than SAPHIR

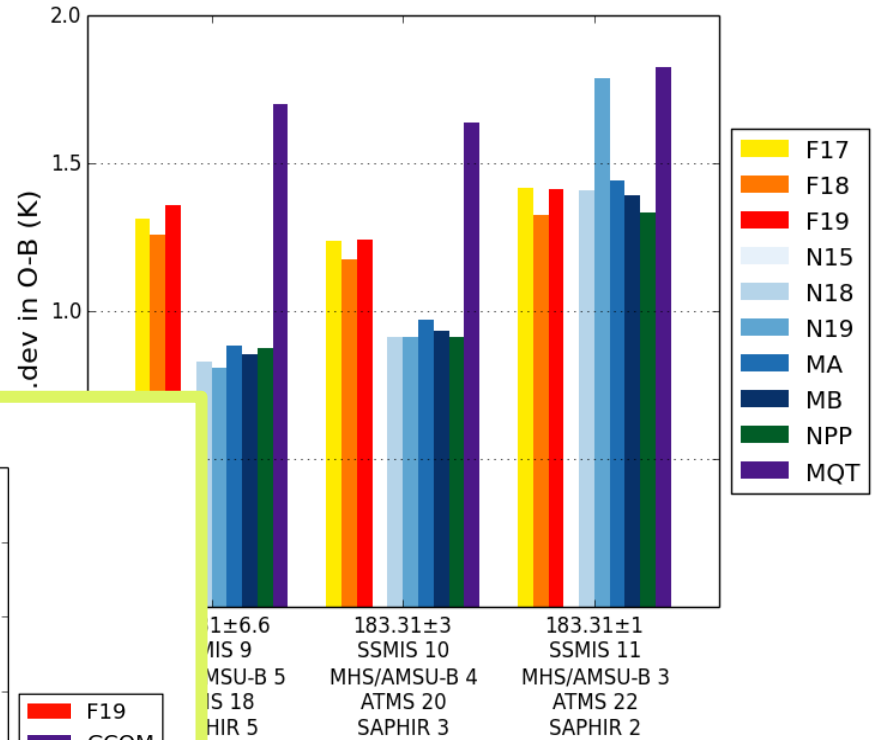


SSMIS innovations for key channels:

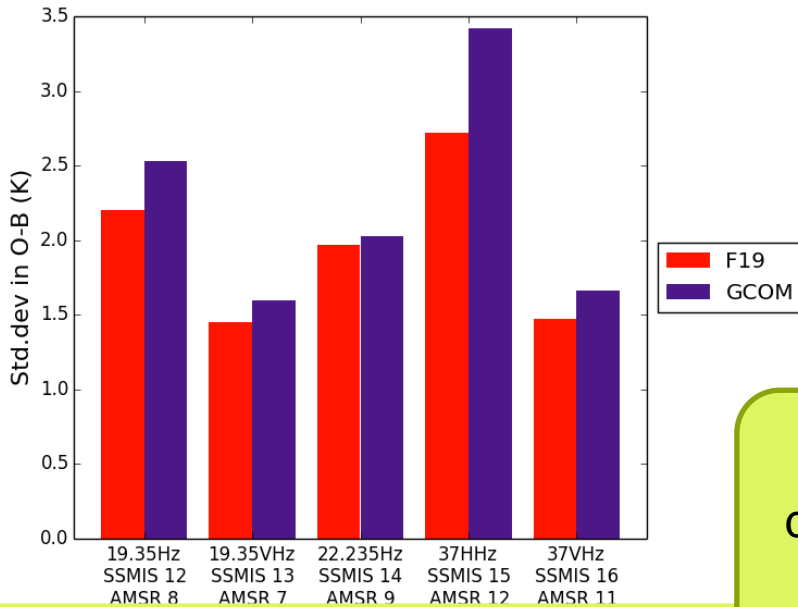
Innovations for MW Temperature Sounding channels



Innovations for MW Humidity Sounding channels



Comparison of MW Imager channels

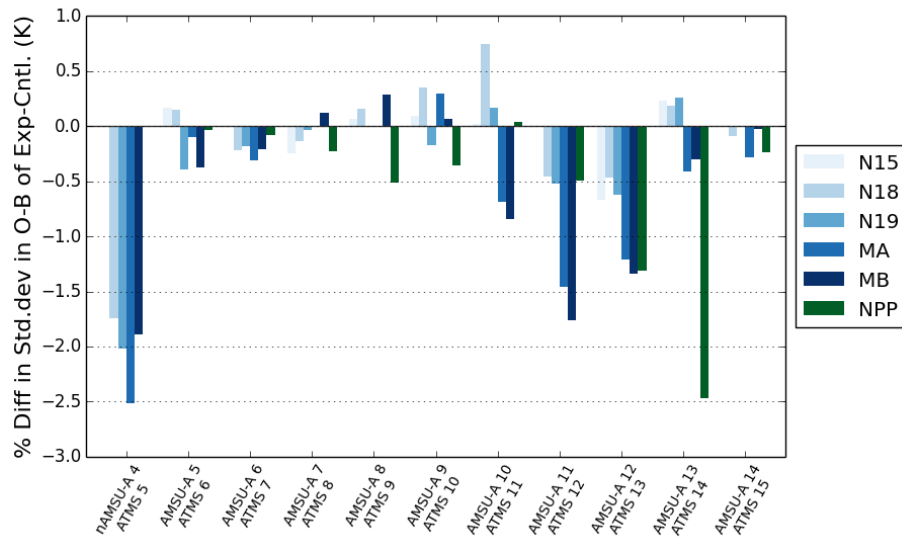


SSMIS Imager channel departure statistics are less than AMSR



Background fits to other observations: Sounding channels of AMSU and ATMS

Temperature Sounding Channels

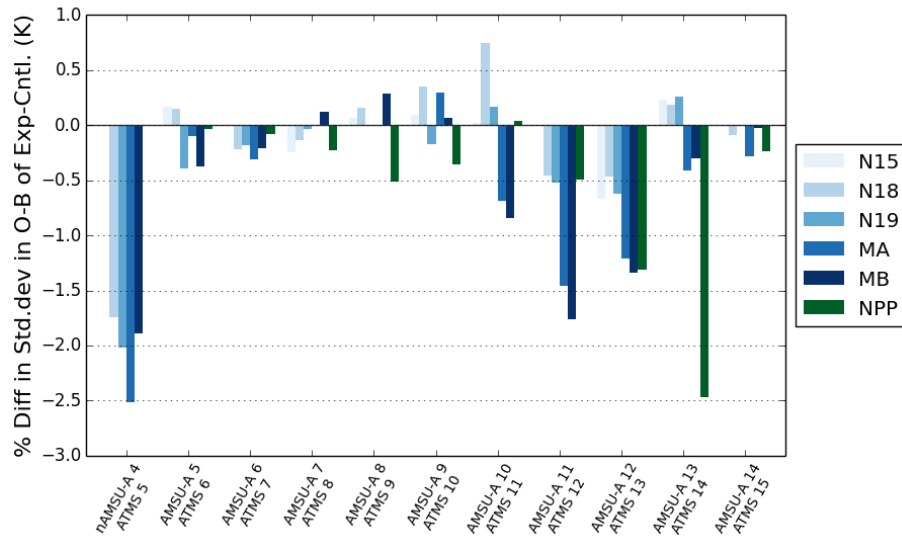


The background fits are generally improved –

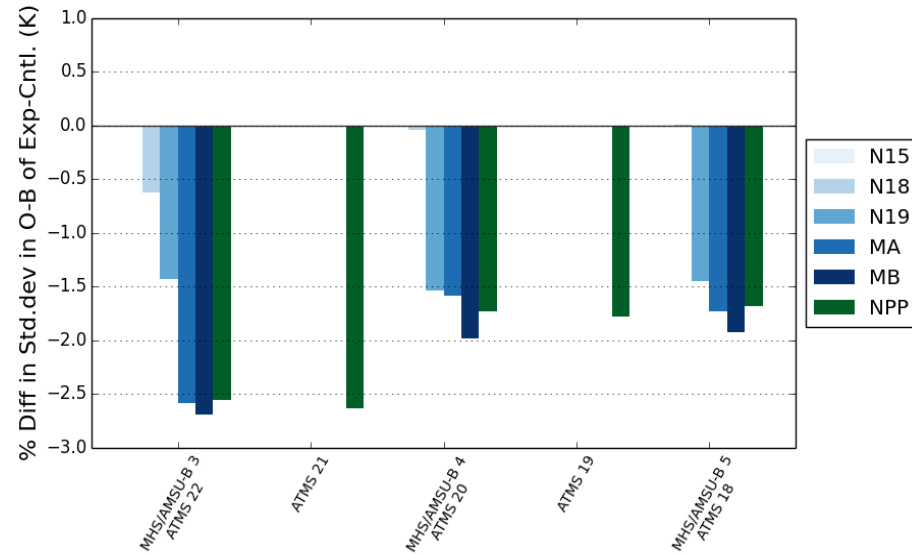
- Particularly in the lowest and highest peaking channels
- More mixed around the tropopause

Background fits to other observations: Sounding channels of AMSU and ATMS

Temperature Sounding Channels



Humidity Sounding Channels



The background fits are generally improved –

- Particularly in the lowest and highest peaking channels
- More mixed around the tropopause

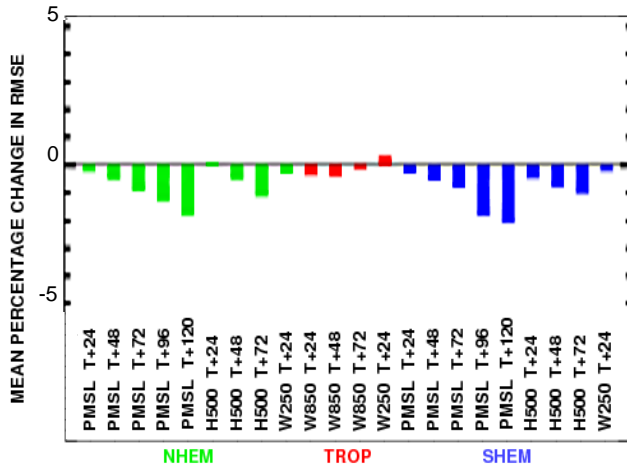
Improved background fits for other humidity observations

Verification vs own analysis for month July 2014

Temperature

VERIFICATION VS ANALYSIS

MEAN PERCENTAGE CHANGE IN RMSE = -0.662



- Assessing the change in RMS errors of (forecast - analysis) wrt control (no SSMIS)

Improvements

- Mean sea level pressure (PMSL)
- Geopotential height at 500 hPa
- Winds
- For the N.Hem, Tropics, and S.Hem.

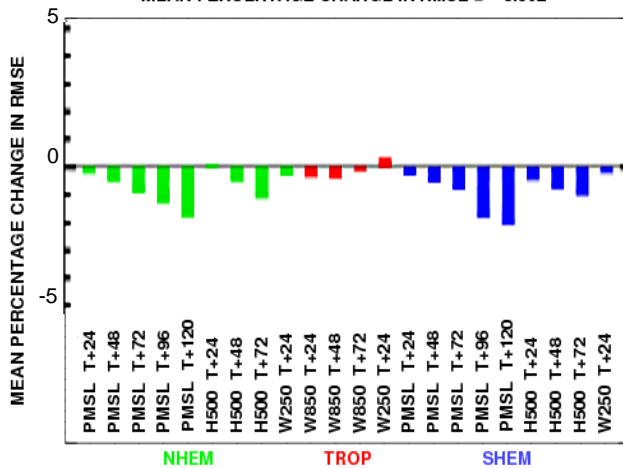


Verification vs own analysis for month July 2014

Temperature

VERIFICATION VS ANALYSIS

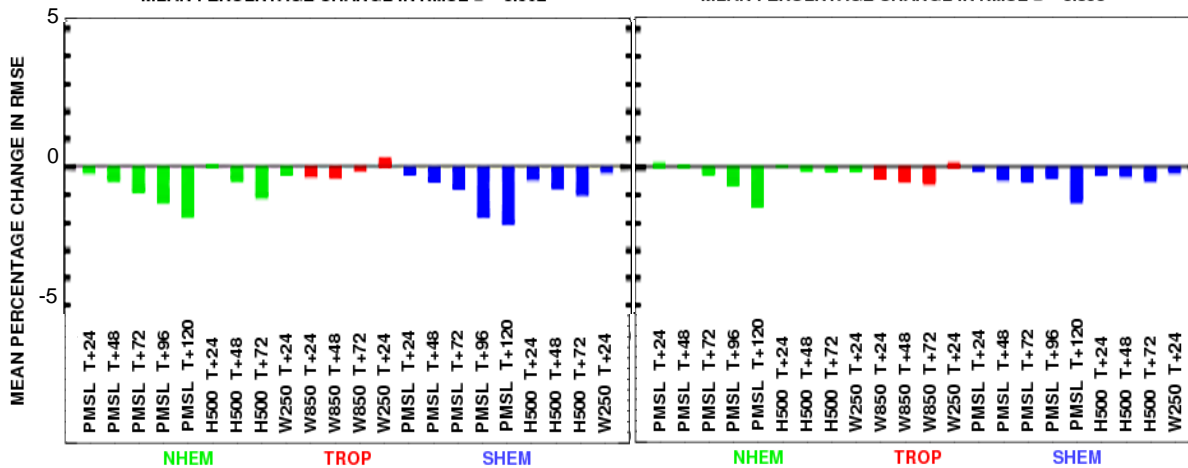
MEAN PERCENTAGE CHANGE IN RMSE = -0.662



Humidity

VERIFICATION VS ANALYSIS

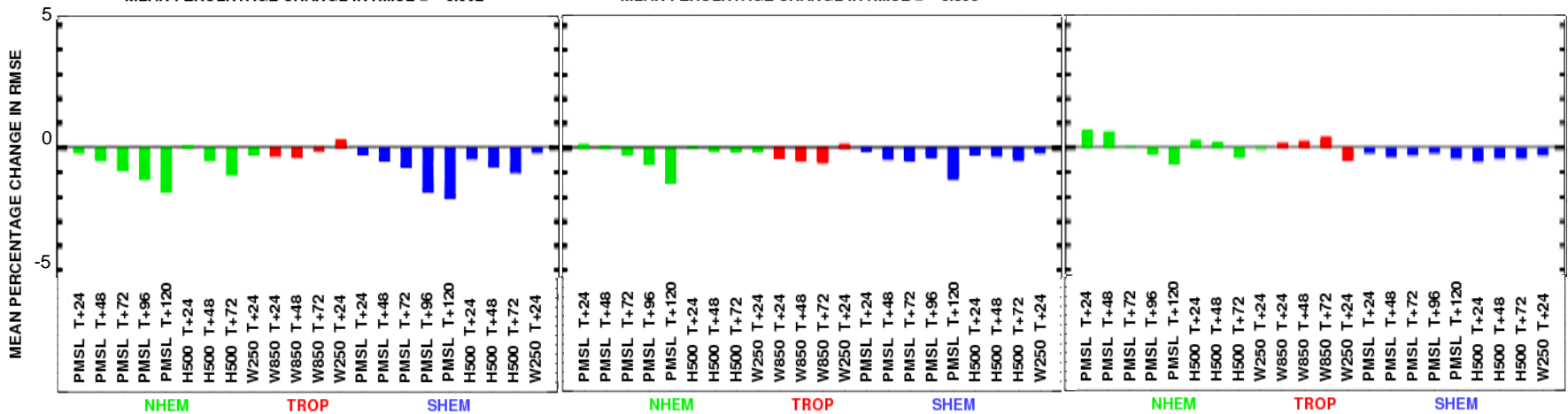
MEAN PERCENTAGE CHANGE IN RMSE = -0.350



Imager

VERIFICATION VS ANALYSIS

MEAN PERCENTAGE CHANGE IN RMSE = -0.115



- Consistent small improvements in most verification metrics
- Particularly in the SH
- Slightly mixed for the imager

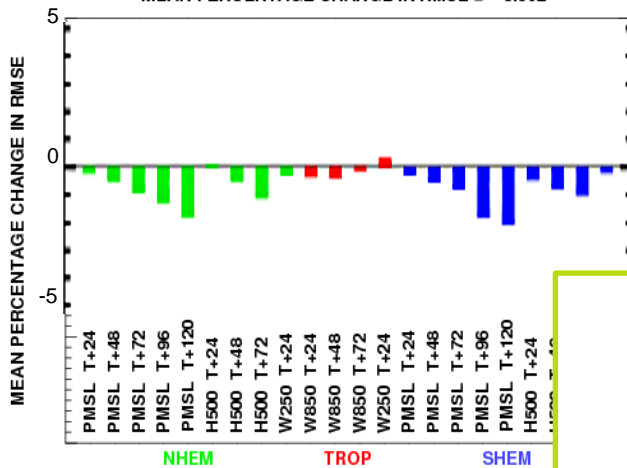


Verification vs own analysis for month July 2014

Temperature

VERIFICATION VS ANALYSIS

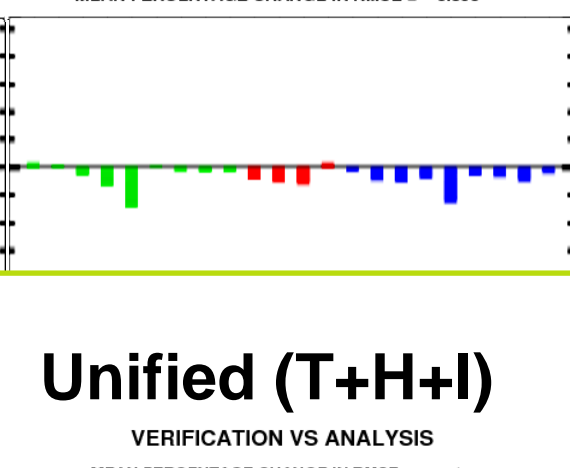
MEAN PERCENTAGE CHANGE IN RMSE = -0.662



Humidity

VERIFICATION VS ANALYSIS

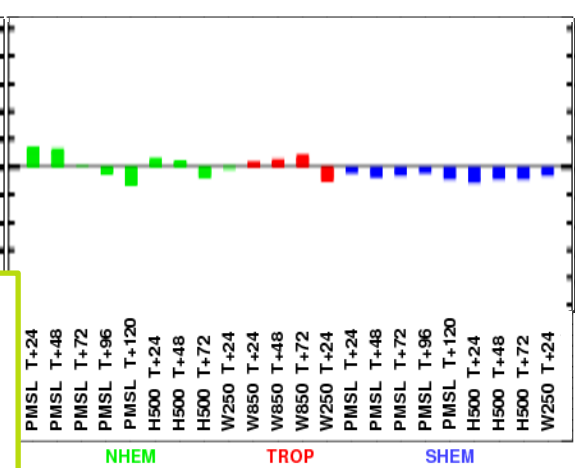
MEAN PERCENTAGE CHANGE IN RMSE = -0.350



Imager

VERIFICATION VS ANALYSIS

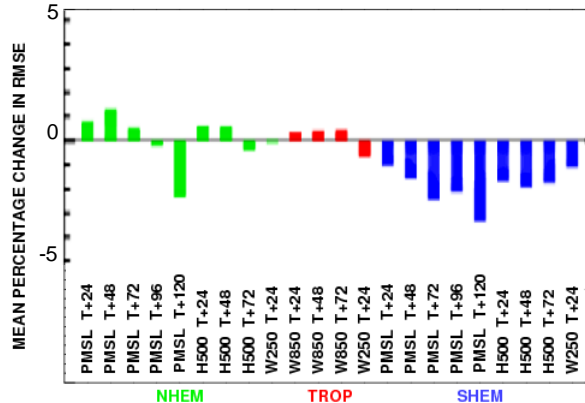
MEAN PERCENTAGE CHANGE IN RMSE = -0.115



Unified (T+H+I)

VERIFICATION VS ANALYSIS

MEAN PERCENTAGE CHANGE IN RMSE = -0.715



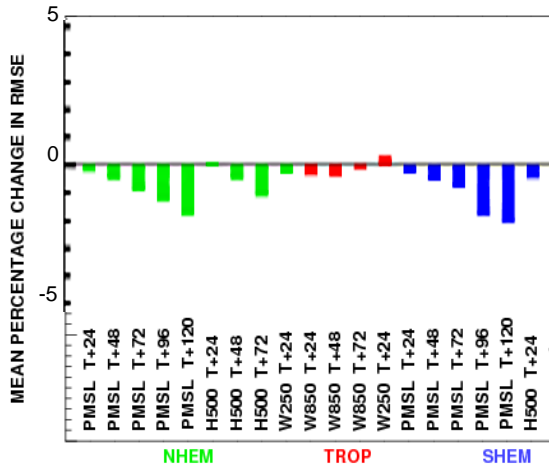


Verification vs own analysis for month July 2014

Temperature

VERIFICATION VS ANALYSIS

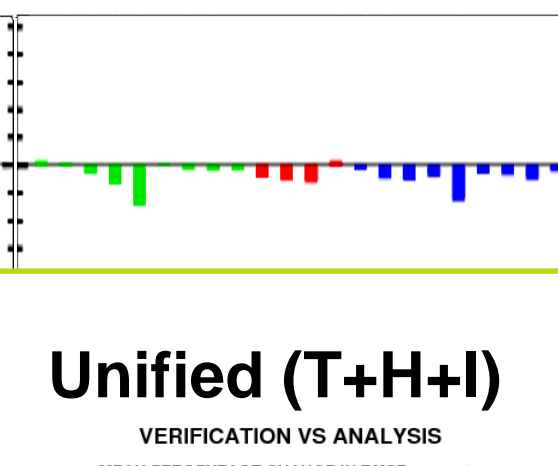
MEAN PERCENTAGE CHANGE IN RMSE = -0.662



Humidity

VERIFICATION VS ANALYSIS

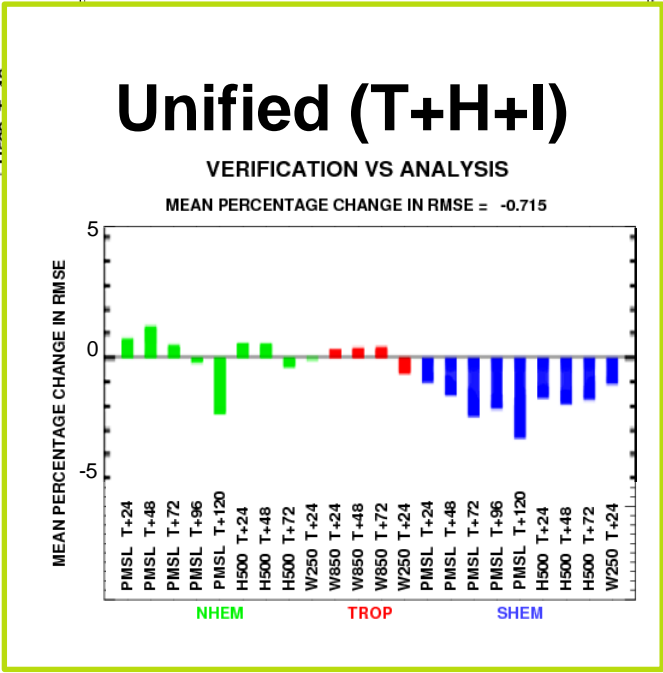
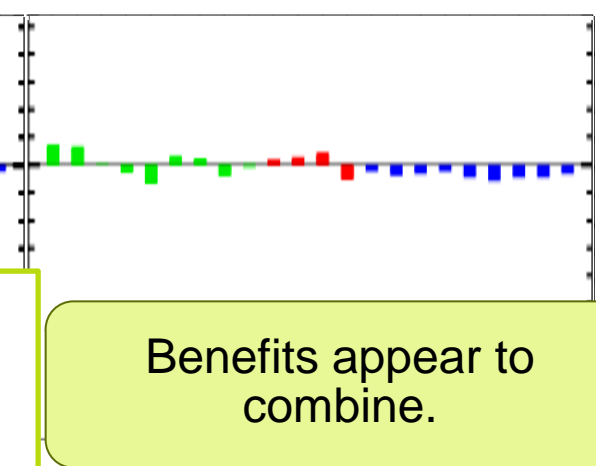
MEAN PERCENTAGE CHANGE IN RMSE = -0.350



Imager

VERIFICATION VS ANALYSIS

MEAN PERCENTAGE CHANGE IN RMSE = -0.115



Benefits appear to combine.

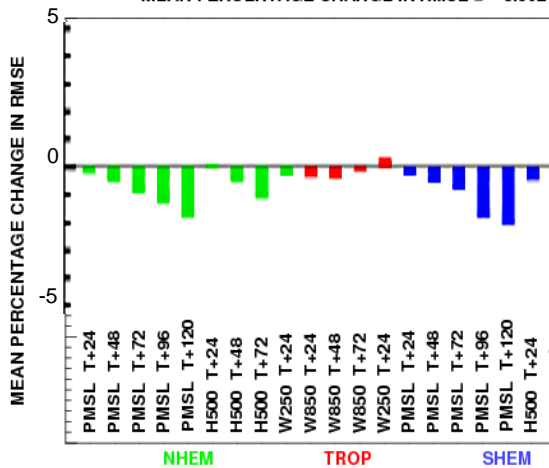


Verification vs own analysis for month July 2014

Temperature

VERIFICATION VS ANALYSIS

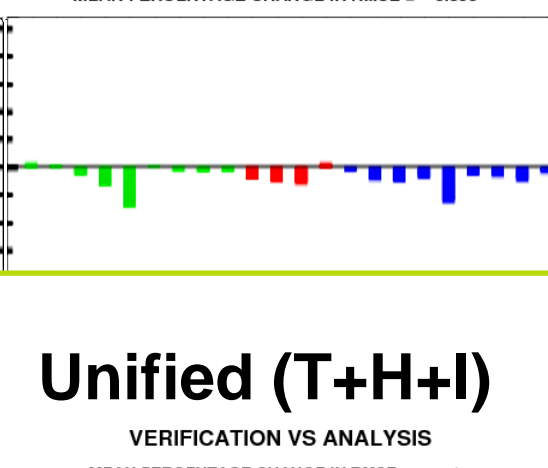
MEAN PERCENTAGE CHANGE IN RMSE = -0.662



Humidity

VERIFICATION VS ANALYSIS

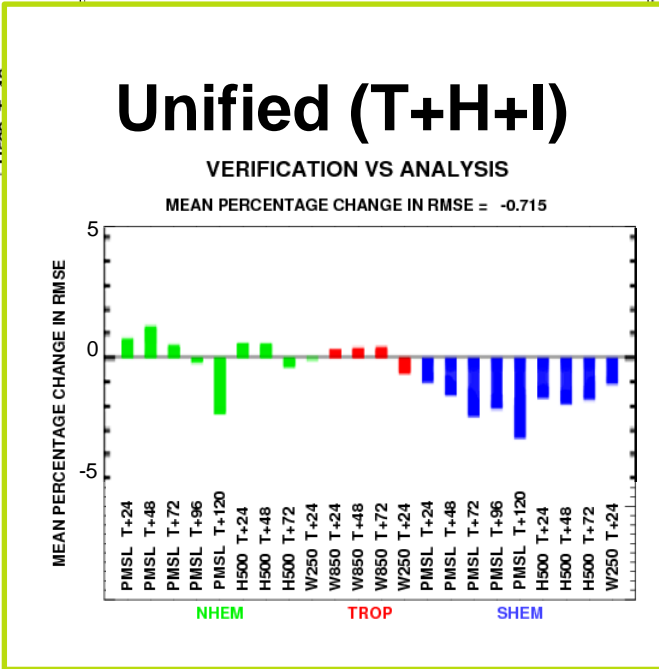
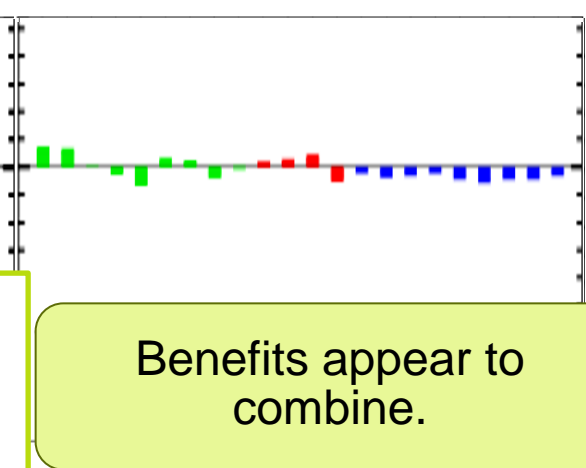
MEAN PERCENTAGE CHANGE IN RMSE = -0.350



Imager

VERIFICATION VS ANALYSIS

MEAN PERCENTAGE CHANGE IN RMSE = -0.115



Benefits appear to combine.

Stronger positive impact in SH, as seen in individual components

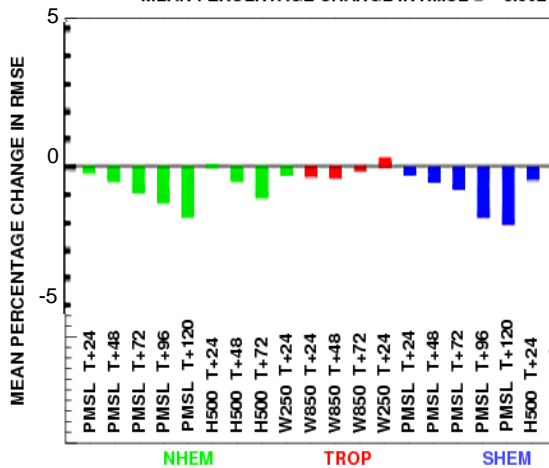


Verification vs own analysis for month July 2014

Temperature

VERIFICATION VS ANALYSIS

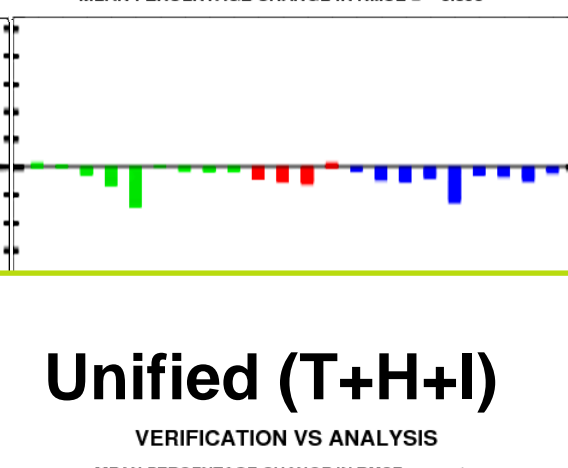
MEAN PERCENTAGE CHANGE IN RMSE = -0.662



Humidity

VERIFICATION VS ANALYSIS

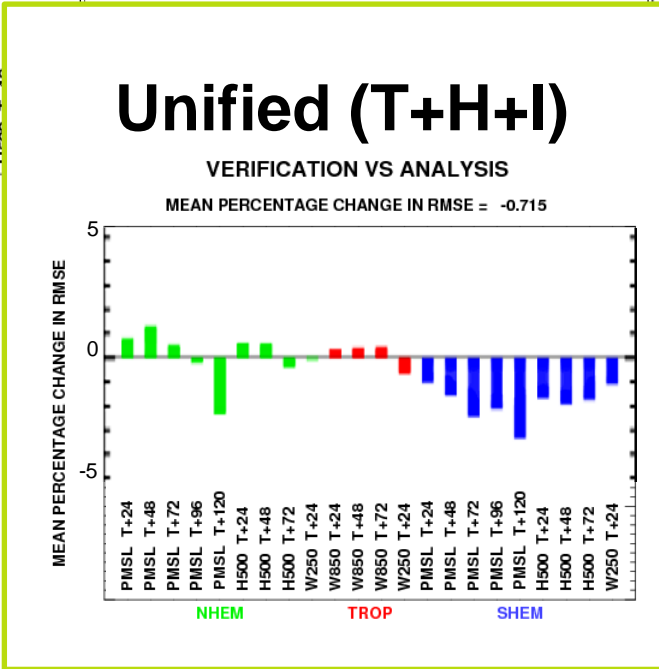
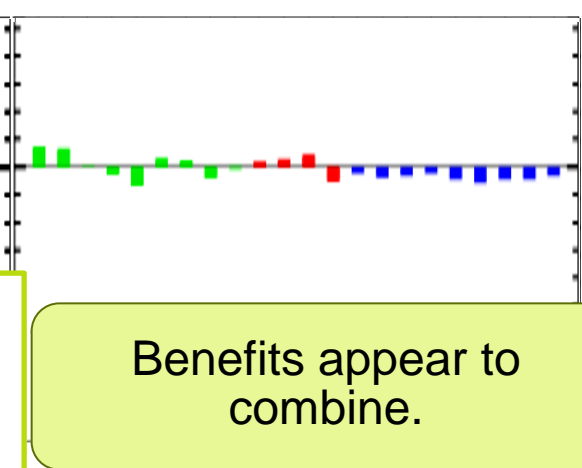
MEAN PERCENTAGE CHANGE IN RMSE = -0.350



Imager

VERIFICATION VS ANALYSIS

MEAN PERCENTAGE CHANGE IN RMSE = -0.115



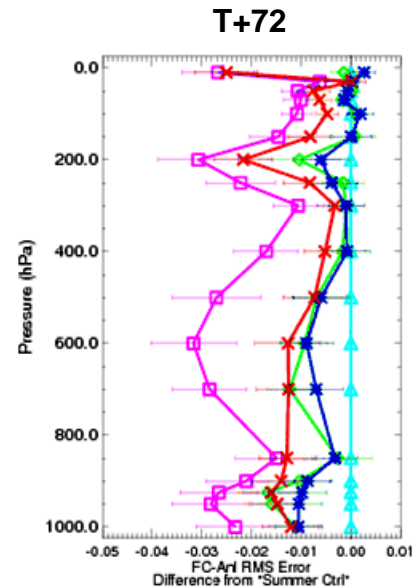
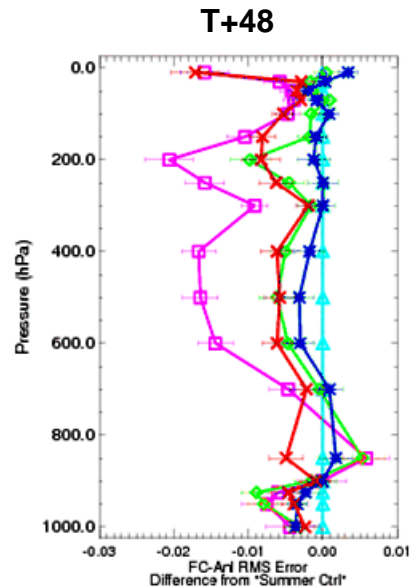
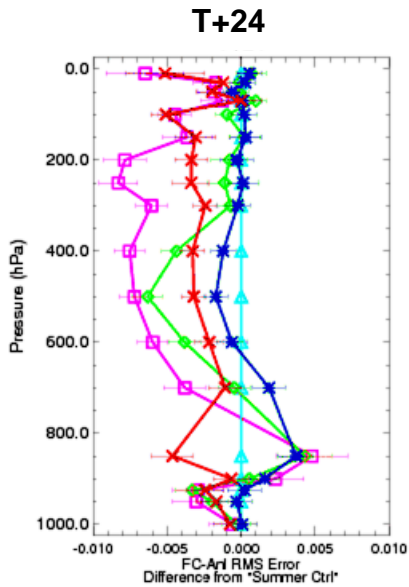
Benefits appear to combine.

Stronger positive impact in SH, as seen in individual components

Looking in more detail...



SH Profiles: Temperature

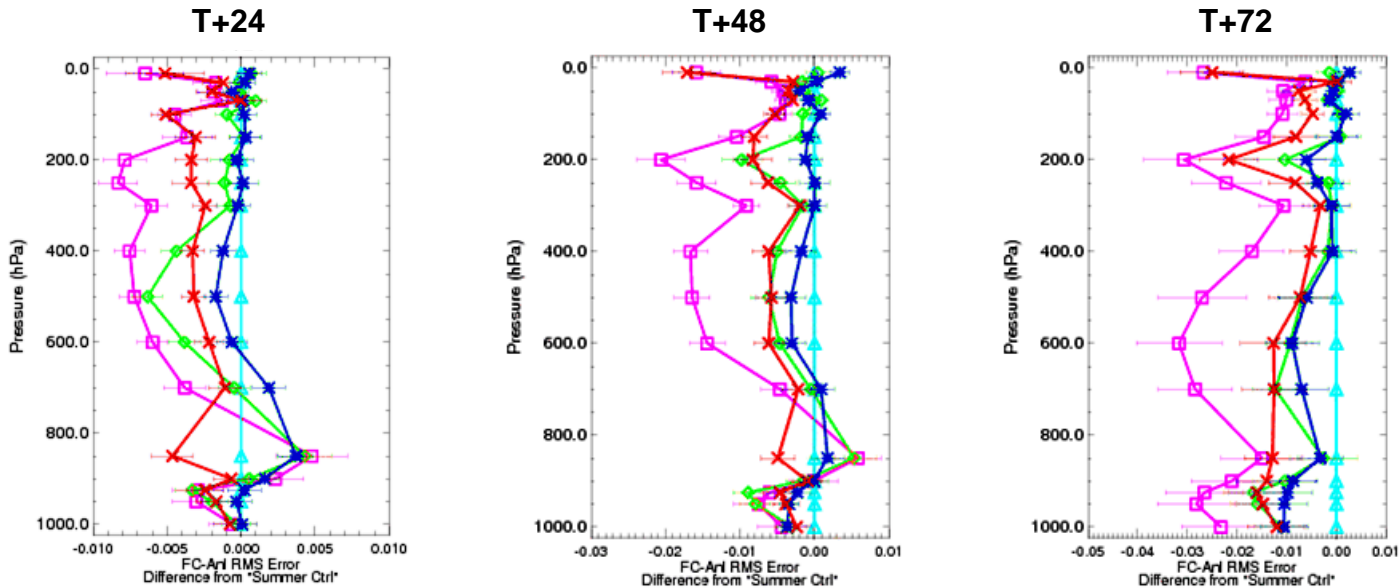


Improvement

Trials: Temperature, Humidity, Imager, Unified



SH Profiles: Temperature

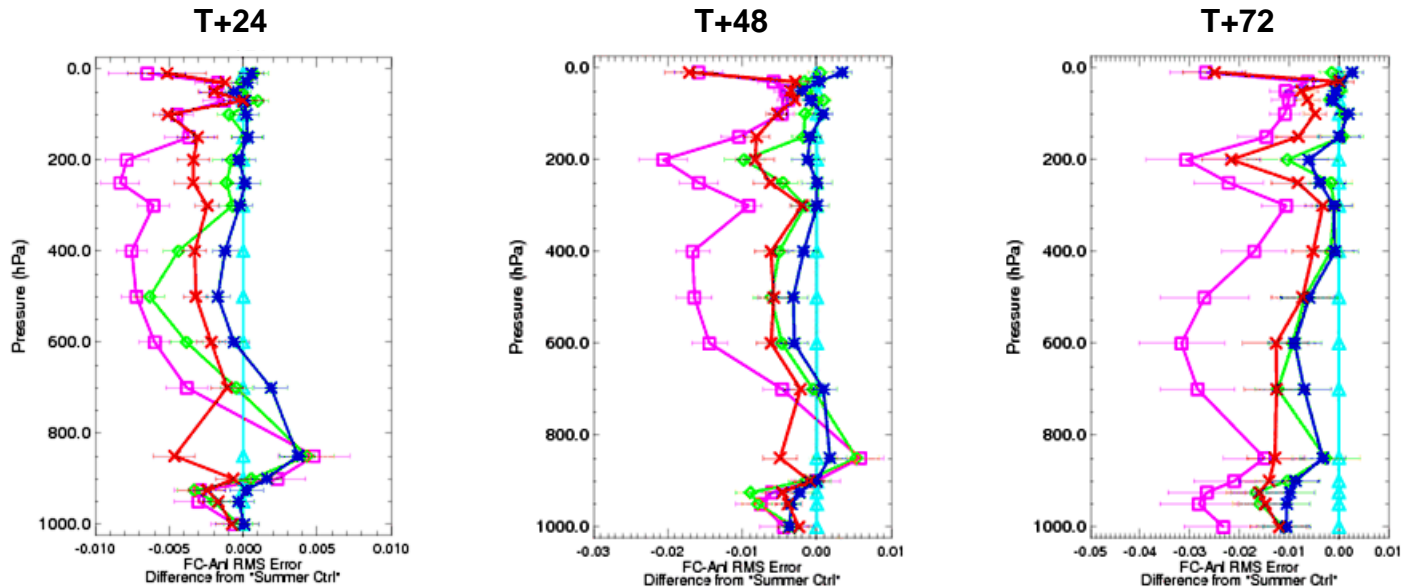


Temperature channels provide consistent benefit.

Trials: Temperature, Humidity, Imager, Unified



SH Profiles: Temperature

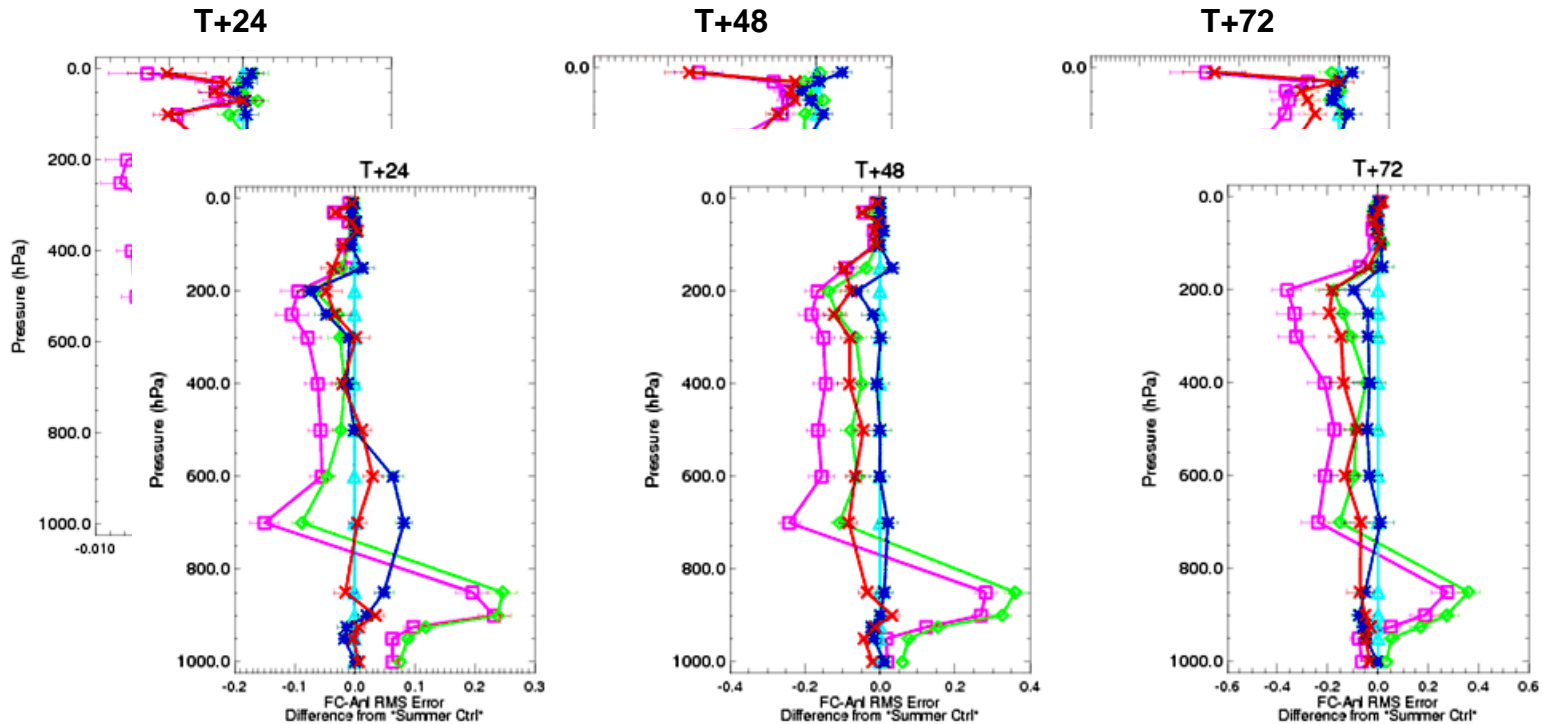


Temperature channels provide consistent benefit.

Combination of T, H, and I channels provides best impact, particularly in the mid-troposphere

Trials: Temperature, Humidity, Imager, Unified

SH Profiles: Relative humidity

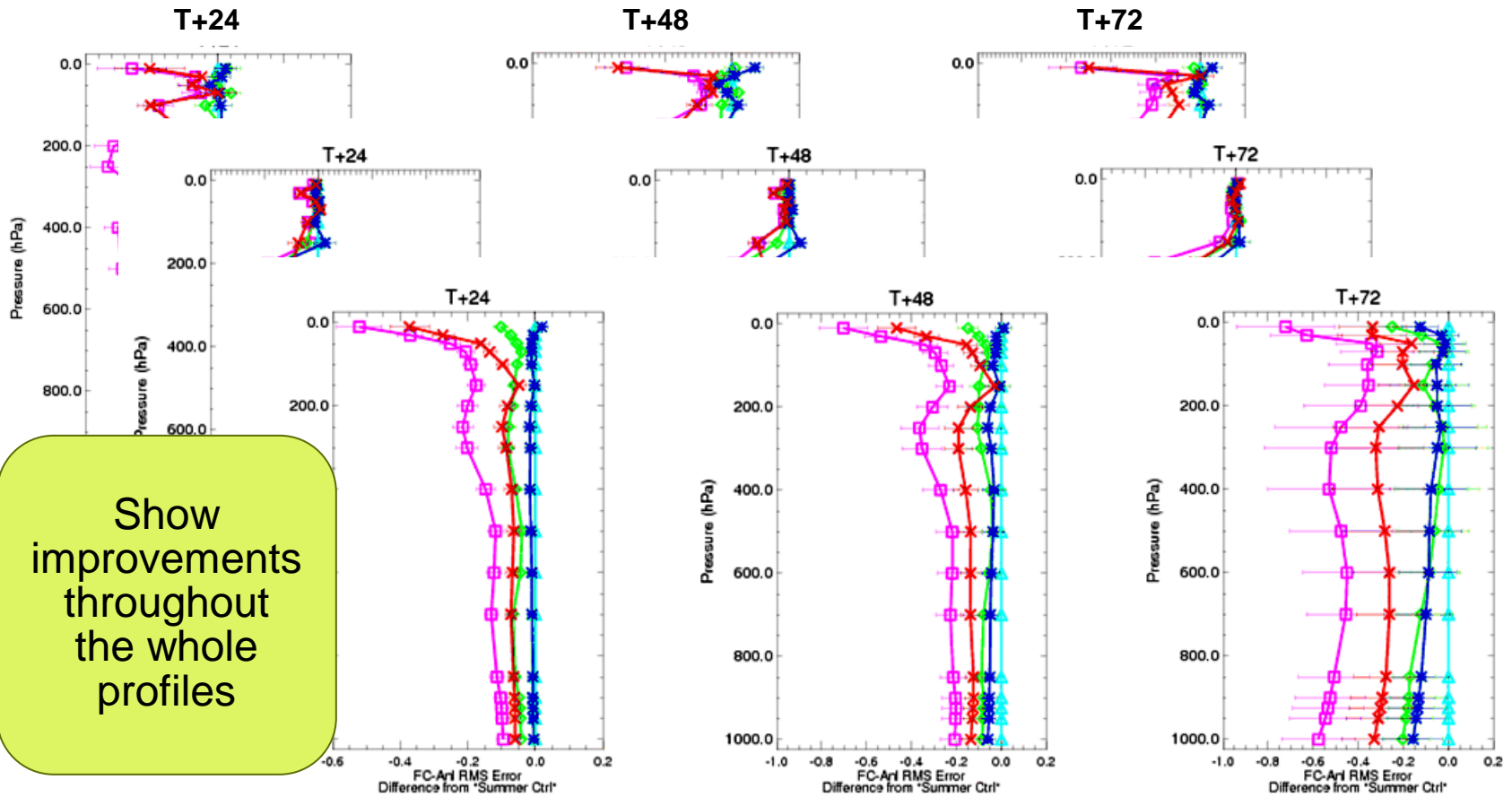


Generally improved –
they show apparent degradation at 850hPa.

Trials: Temperature, Humidity, Imager, Unified



SH Profiles: Height analysis

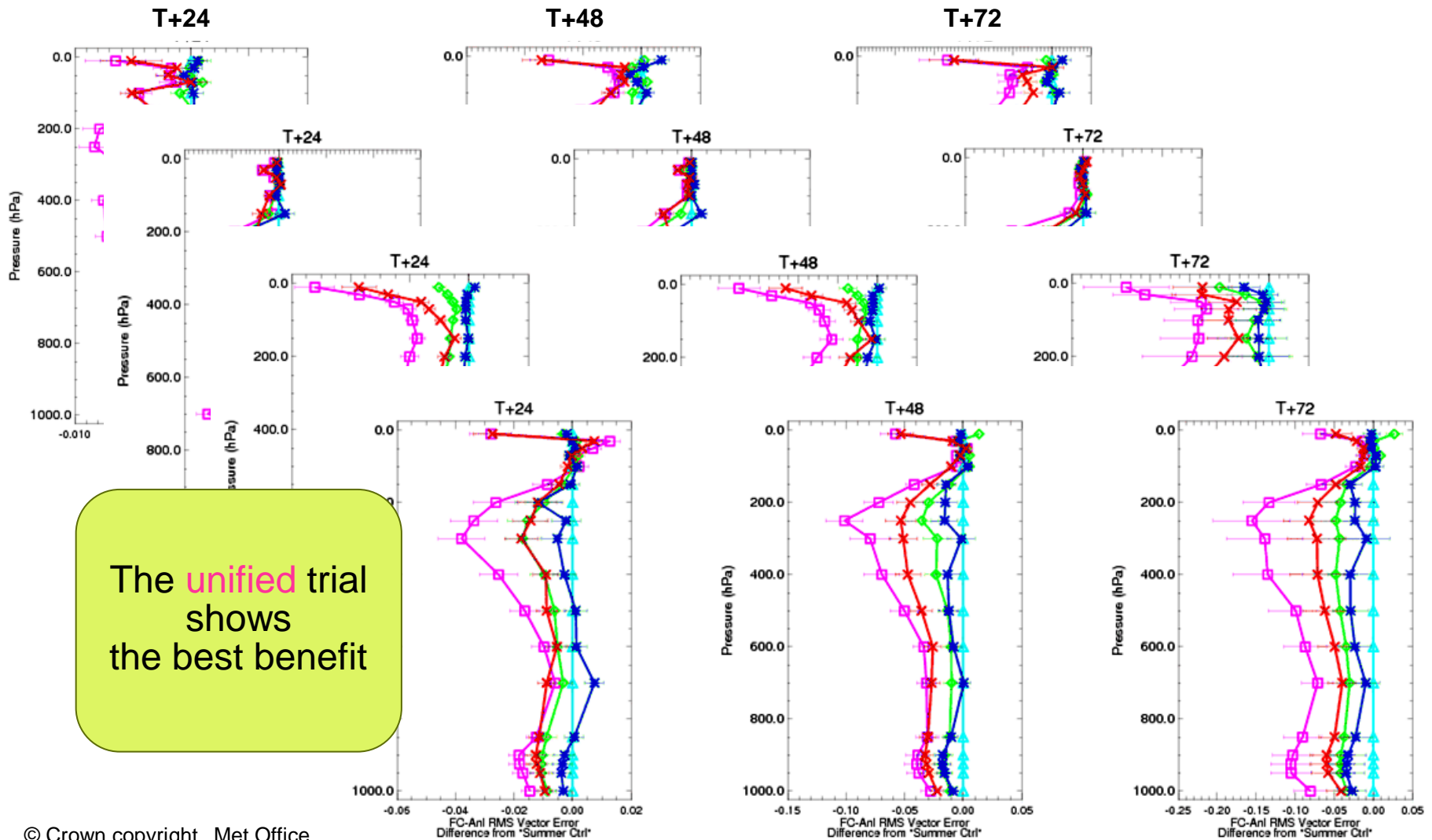


Show improvements throughout the whole profiles

Trials: Temperature, Humidity, Imager, Unified



SH Profiles: Winds





Conclusions

- New orbital correction in VarBC works well for all SSMIS instruments
- Data quality for bias corrected observations is better than the equivalent AMSU/ATMS and AMSR-3, worse for MHS/AMSU-B
- Assimilation experiments carried out using two SSMIS instruments
- Showed benefit to temperature, geopotential heights and winds
- F17 & F19 included in latest operational upgrade (starts November due to go operational March 2016)



Thank you for listening!