Satellite Instrument Calibration Issues: Experience Gained from SSMIS

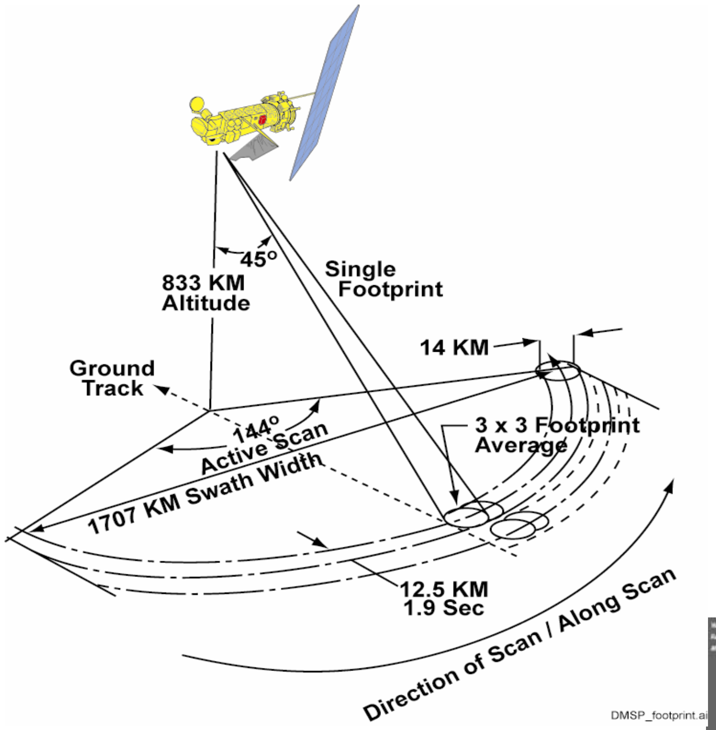
W. Bell, S. English, S. Swadley[1] & G. Kelly[2]
[1] Naval Research Laboratory, Monterey, CA, US
[2] ECMWF, Reading , UK

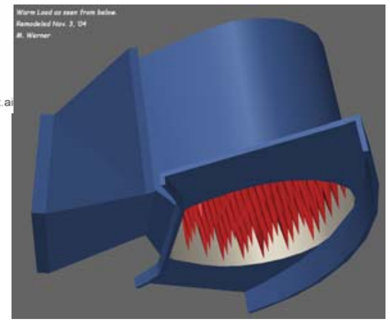
Acknowledgements : B.Candy, F.Hilton, A. Smith, N.Atkinson, J. Eyre
organisers & participants in *SSMIS mini-workshop* , NRL, Oct 2005

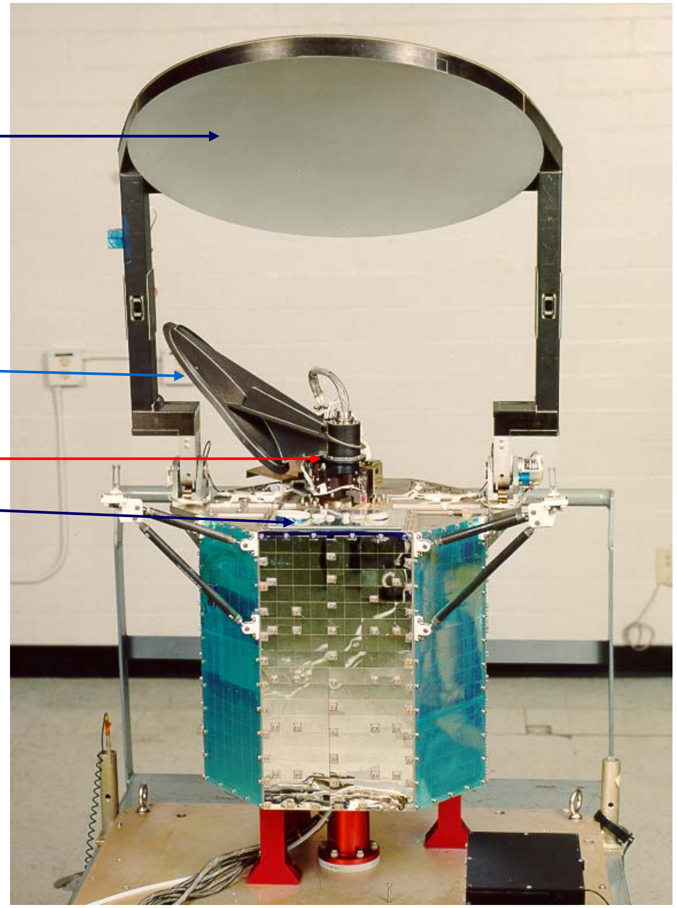
Outline

- Background
- Instrumental biases & correction strategies :
  - Warm load solar intrusions
    - ➢Intrusion mapping (Met Office)
    - ➢Gain correction (NRL, NOAA)
  - Reflector emission
    - ➢Empirical correction
    - ➢Physical basis
- Radiance monitoring & analysis increments
- Initial forecast impact studies at ECMWF
- Future developments
- Summary & conclusions

Background: Instrument and scan geometry



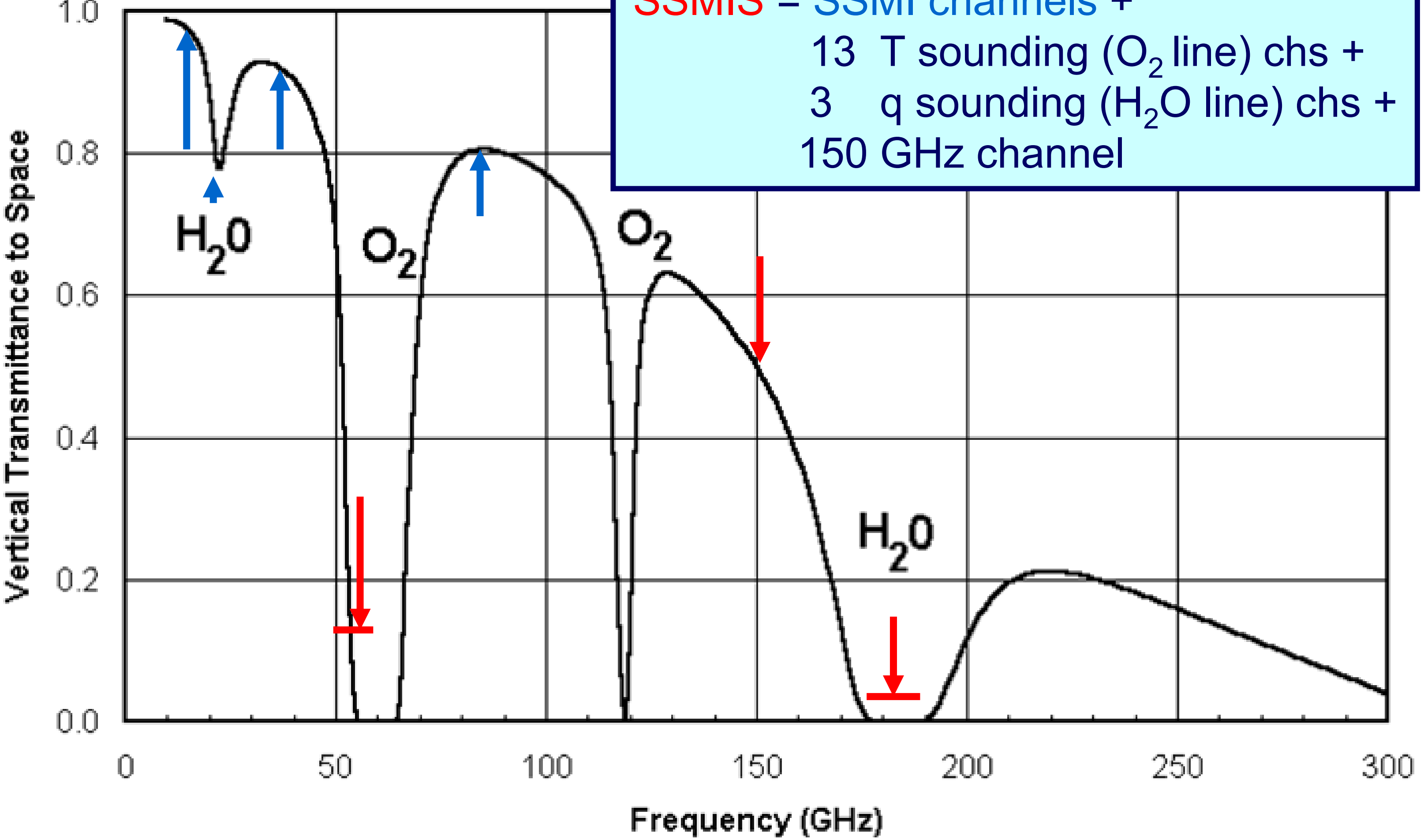




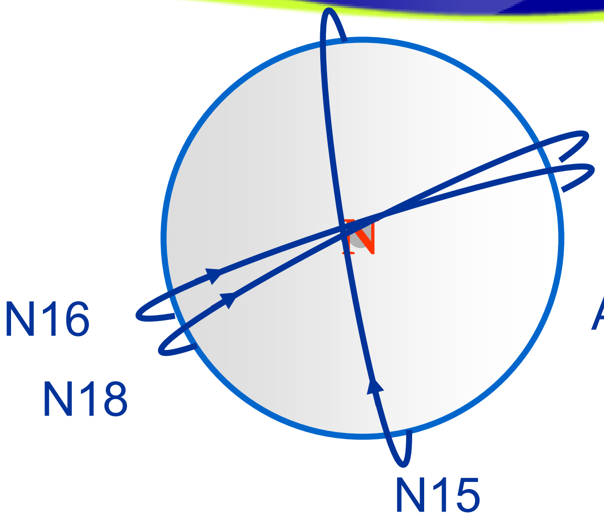
Special Sensor Microwave Imager/Sounder (SSMIS)

Background: SSMIS Channels

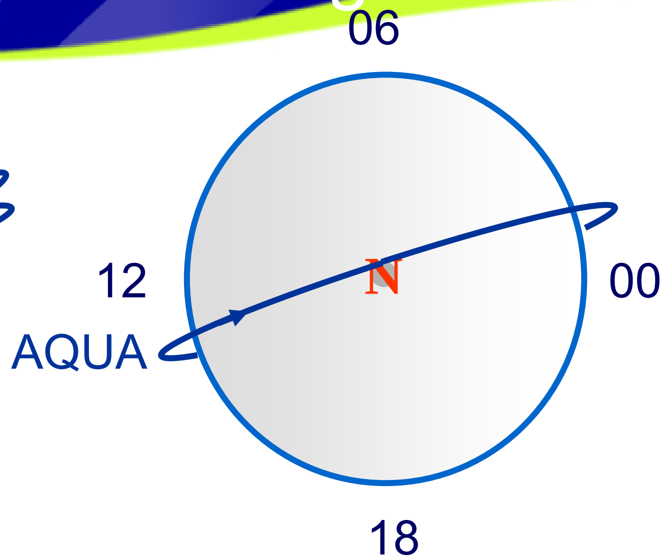
SSMIS = SSMI channels +
13 T sounding (O_2 line) chs +
3 q sounding (H_2O line) chs +
150 GHz channel



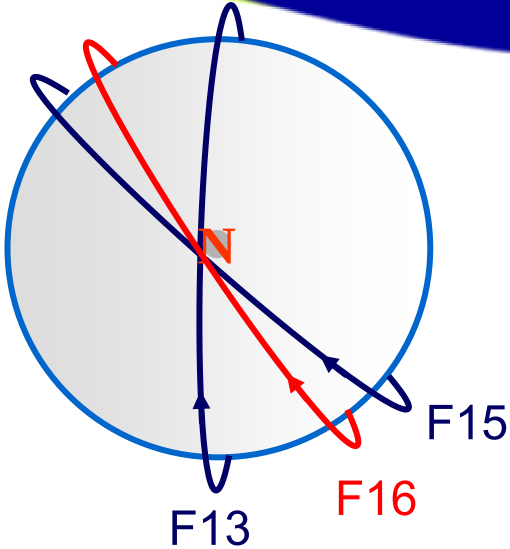
Background - orbit coverage of operationally assimilated sounders / imagers



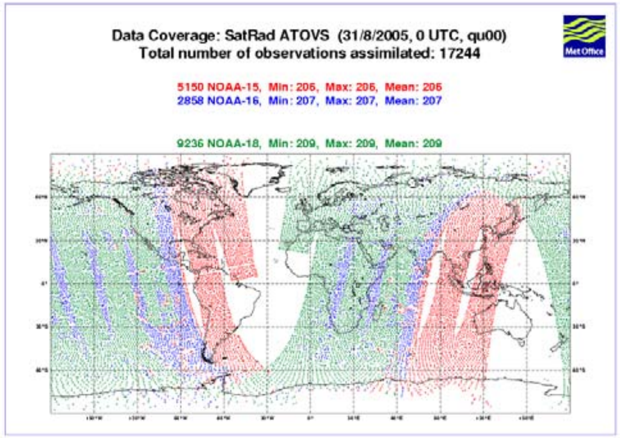
ATOVS (T & q)

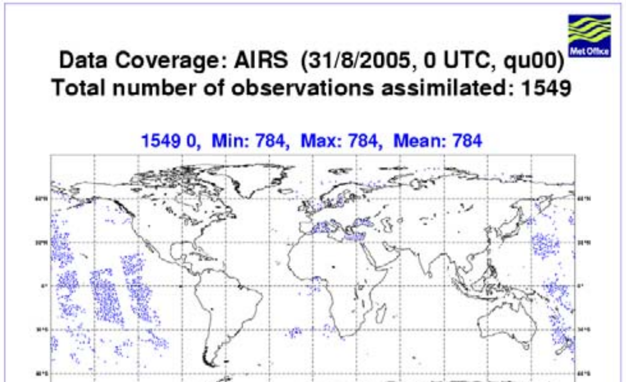


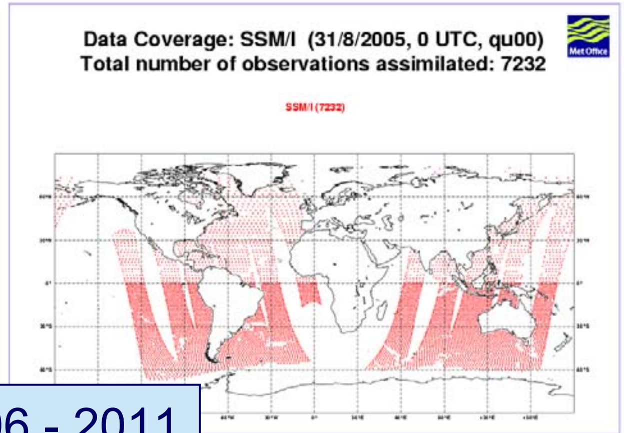
AIRS (T & q)



SSMI (WS)
SSMIS (T, q, WS)

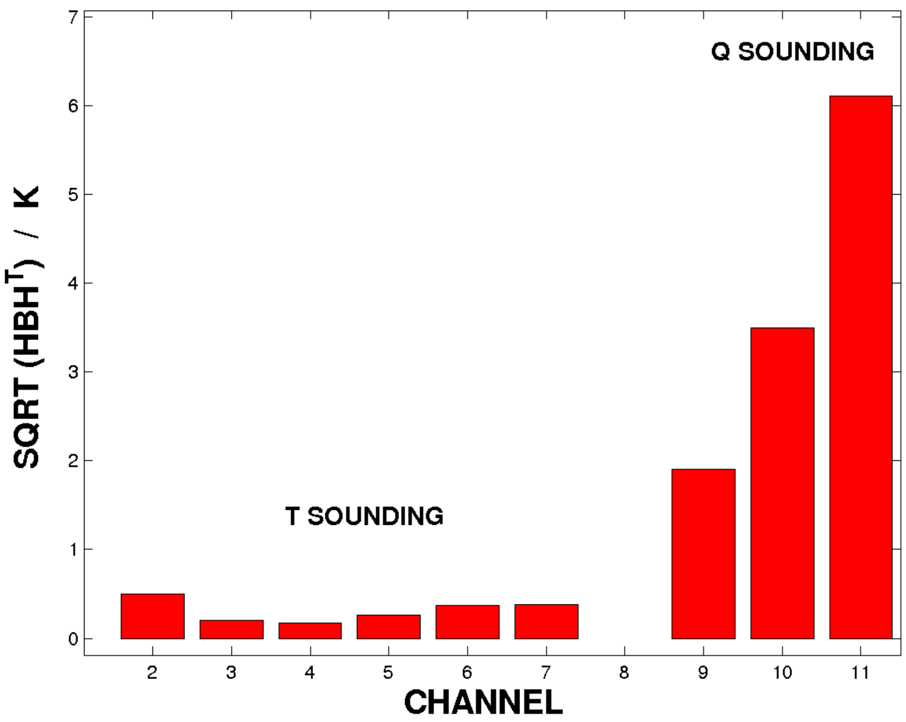


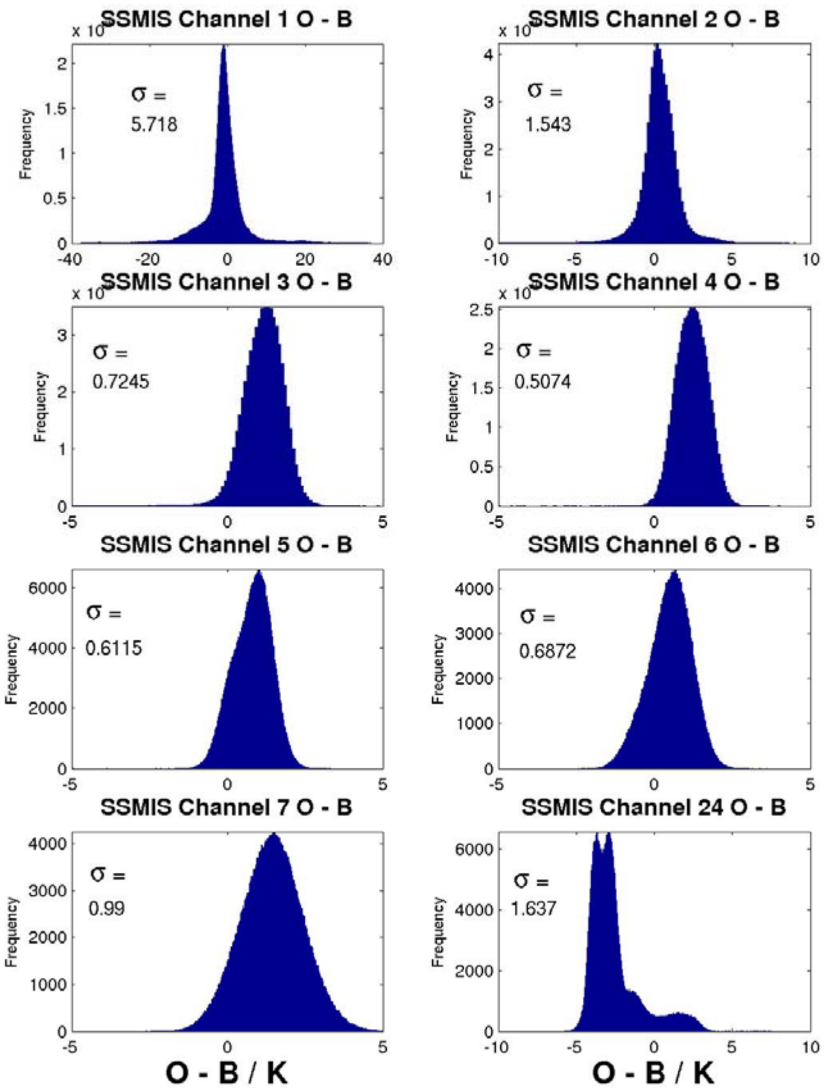




F17 – F20 planned for 2006 - 2011

Background: Accuracy Requirements and Initial Performance





Background: two step approach to bias correction

Pre-Processor → **1D-Var** → **4D-Var**

Pre-Processor:
Remapping
Averaging
Intrusion flagging
Reflector correction
BUFR I/O

1D-Var:
Analysis of :
T, Q_{tot} (ql + q),
WS.
QC & channel selection

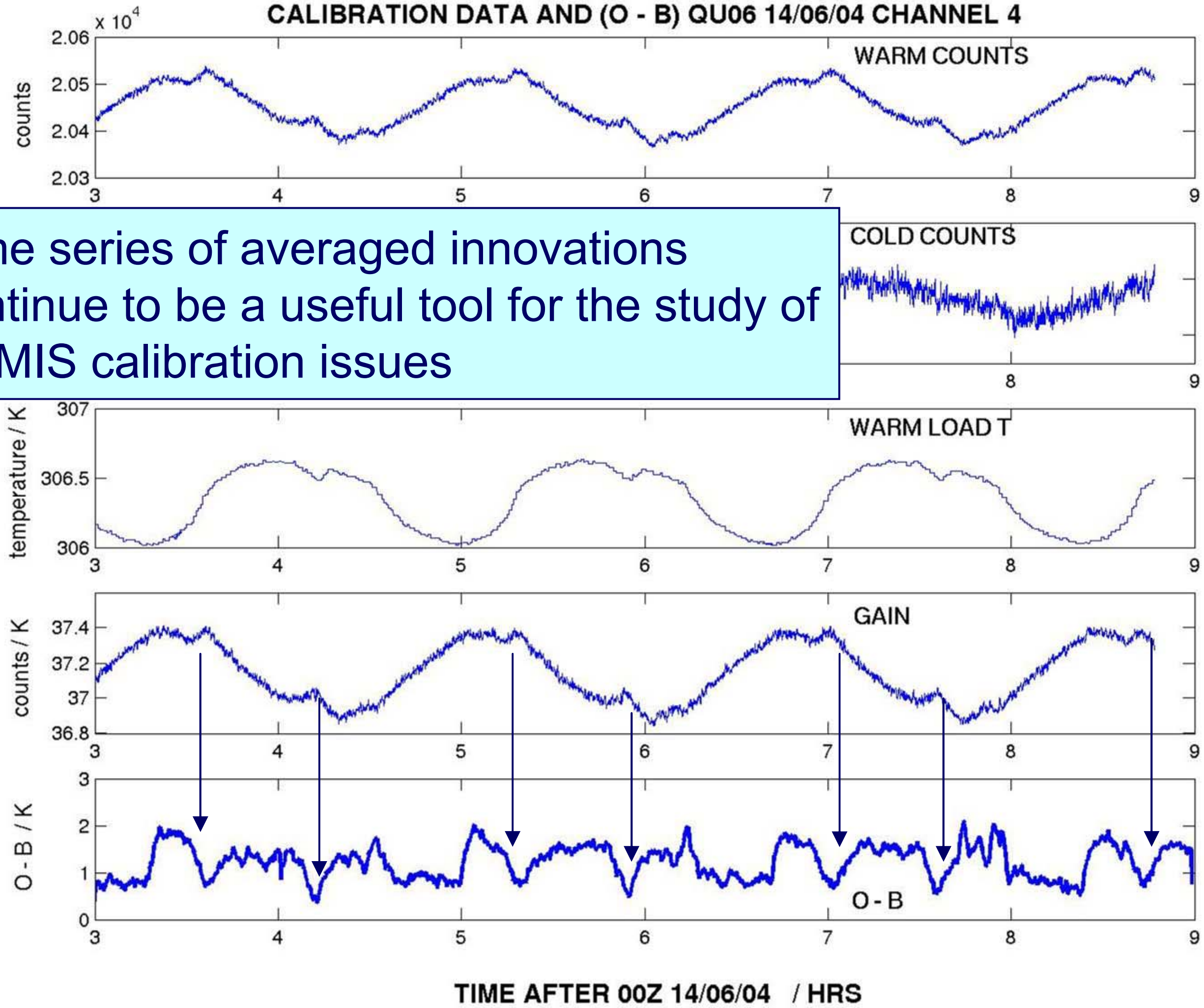
4D-Var:
Control variables:
T, q, u10, v10
(ql from 1D Var used in forward calculation)

1st Step: correct instrumental biases (→ Pre-Processor)

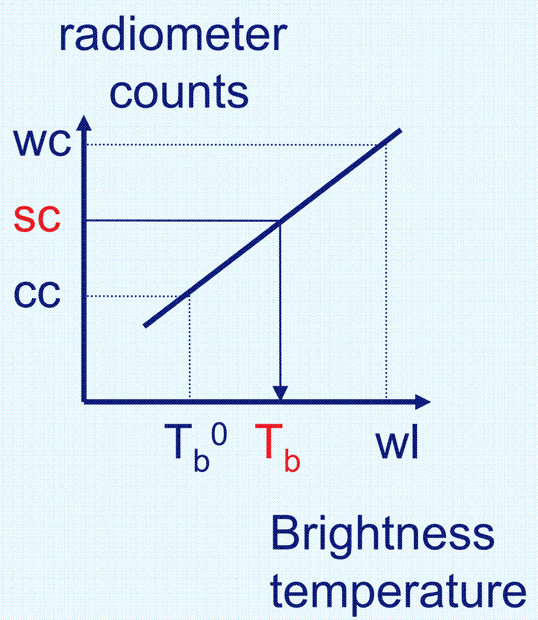
2nd Step: correct cross scan, RT and model biases using predictor scheme (→ 1D-Var)

See Nigel Atkinson presentation tomorrow for details.

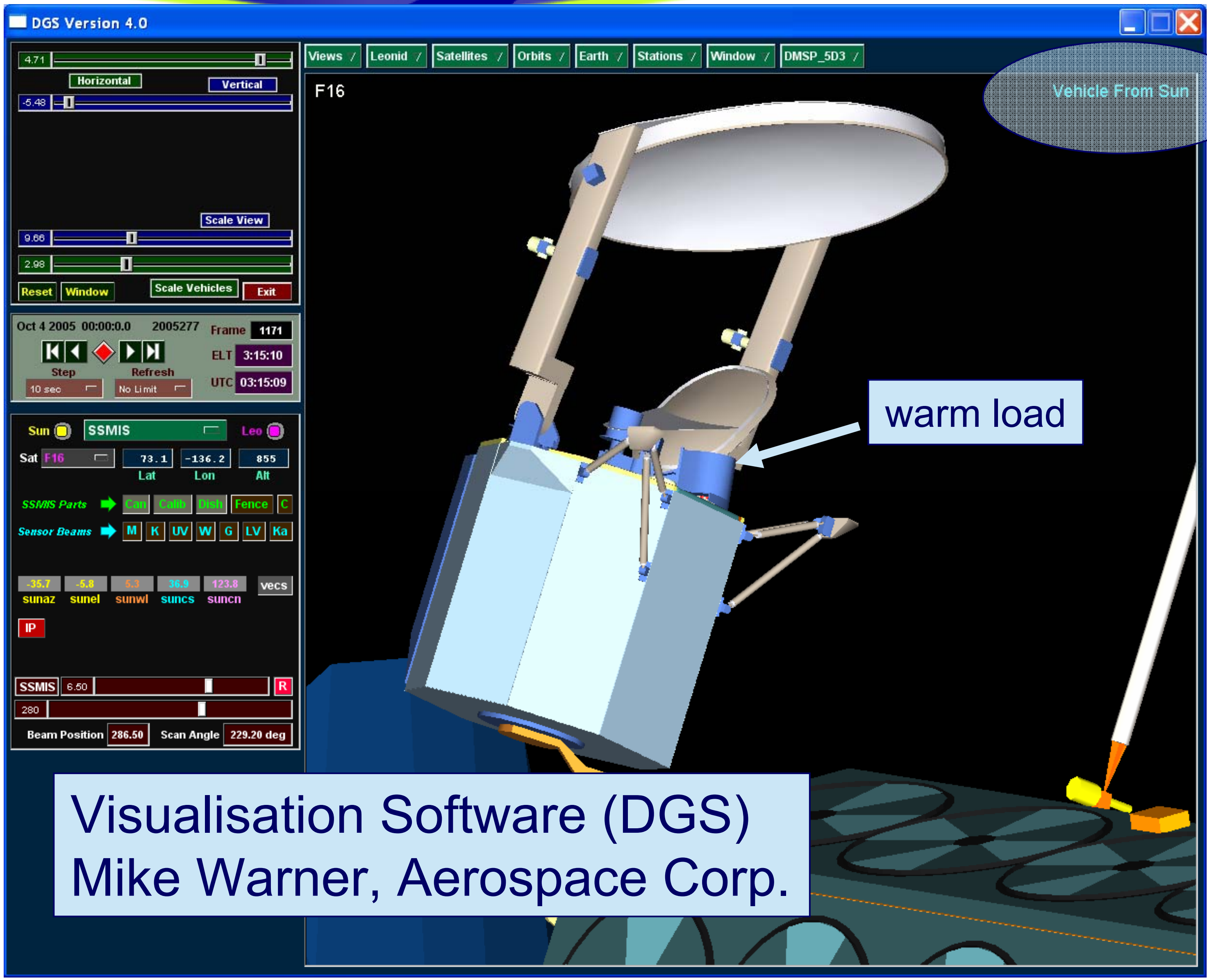
Instrumental Biases: warm load solar intrusions



Time series of averaged innovations continue to be a useful tool for the study of SSMIS calibration issues

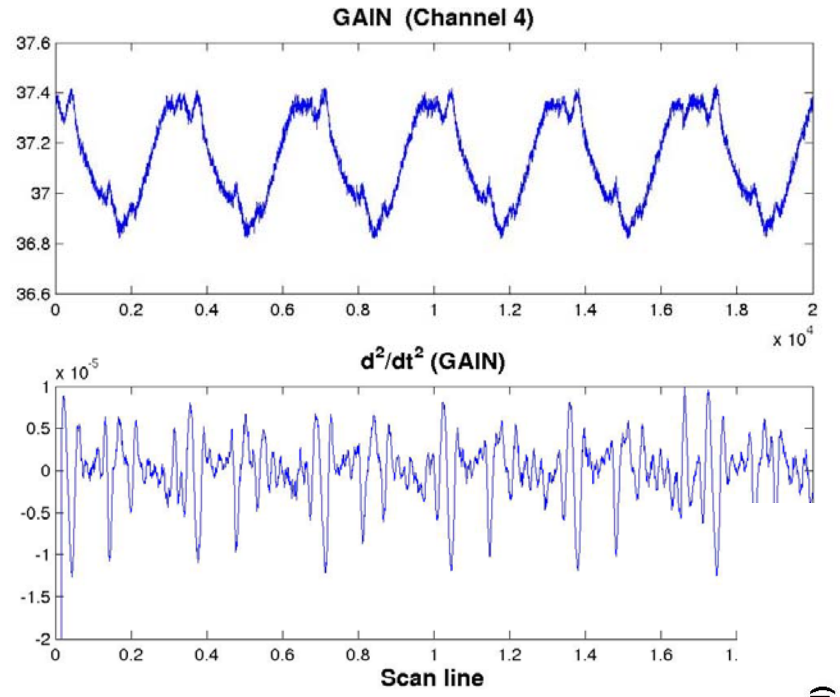


Instrumental Biases: warm load solar intrusions

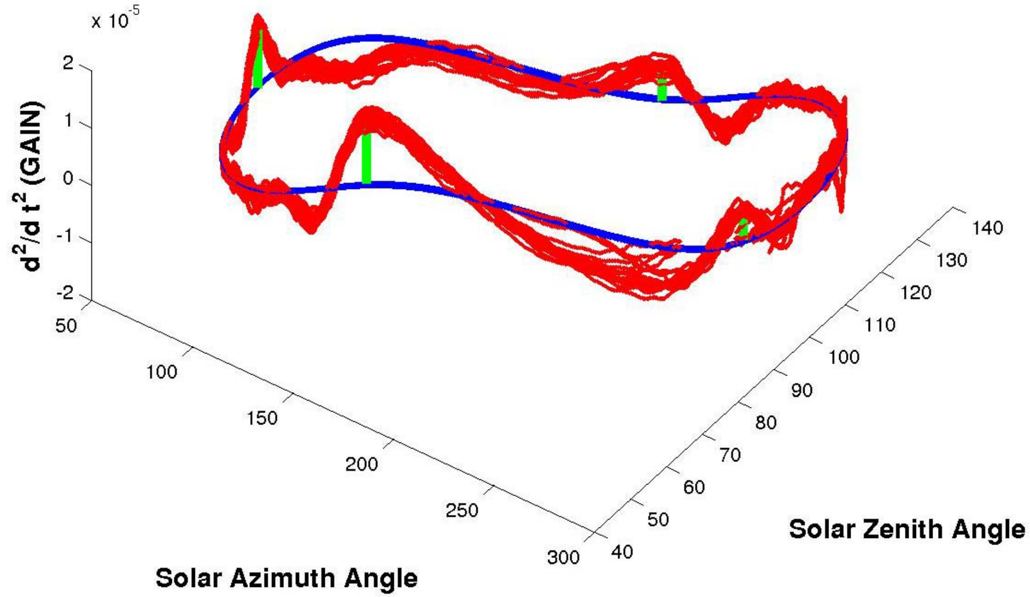


Visualisation Software (DGS)
Mike Warner, Aerospace Corp.

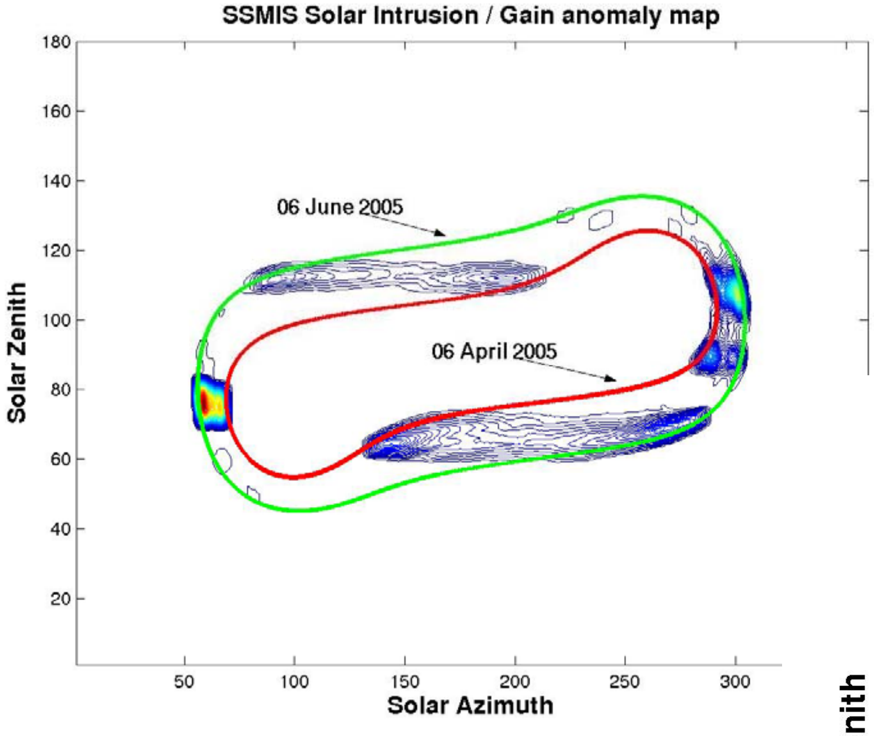
Offline signal processing to detect solar intrusions / gain anomalies



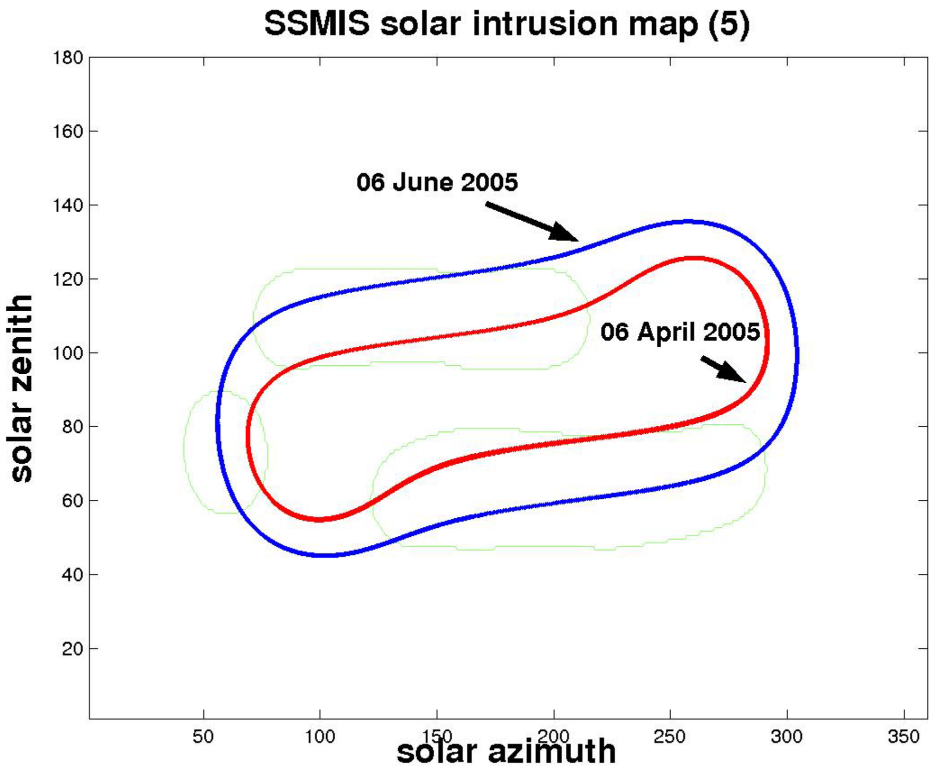
2^{nd} derivative of gain wrt time plotted as a fn of local solar zenith/azimuth angle



Solar intrusion map



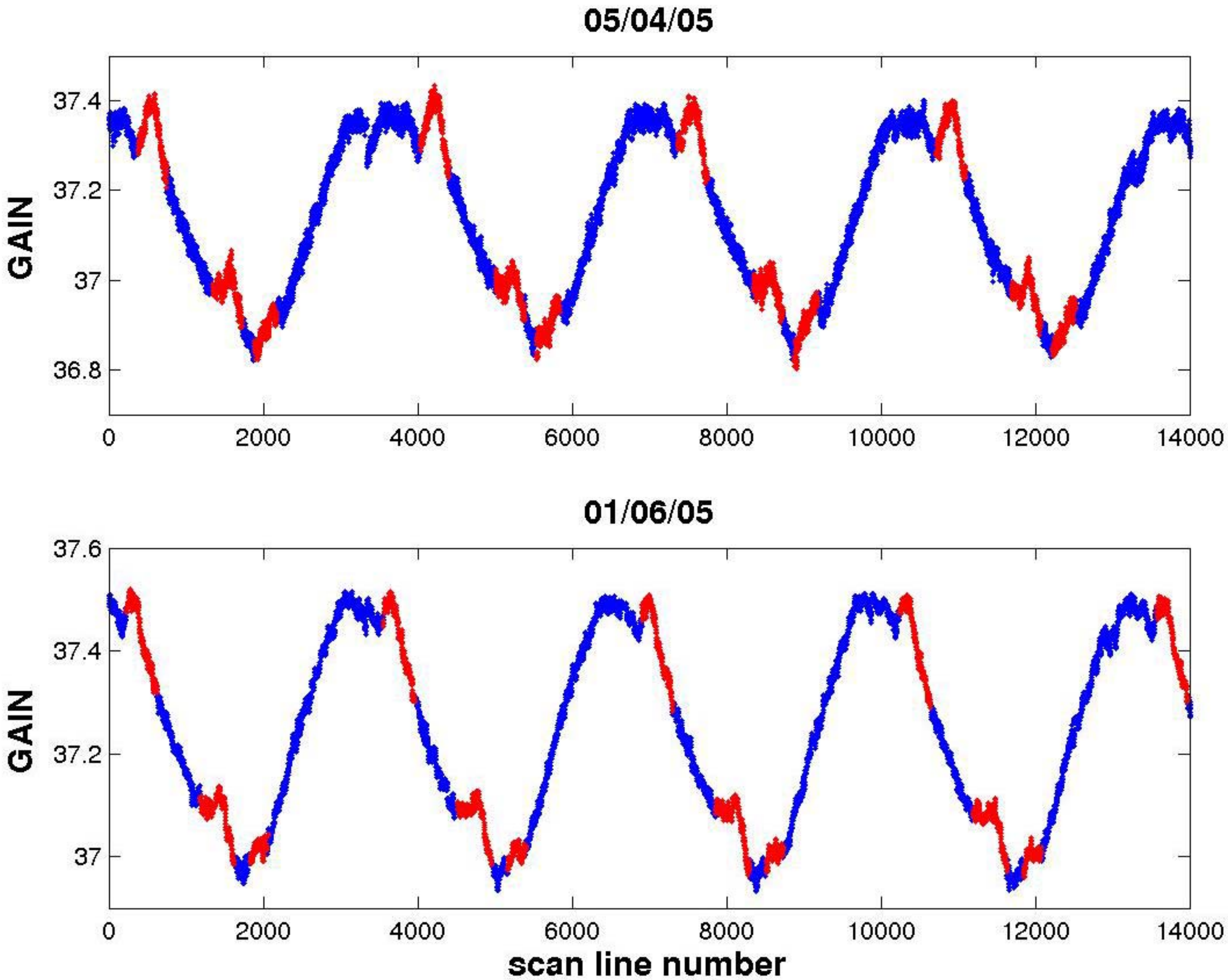
Final map produced by 2D convolution of original map with gaussian – to account for temporal extent of intrusions



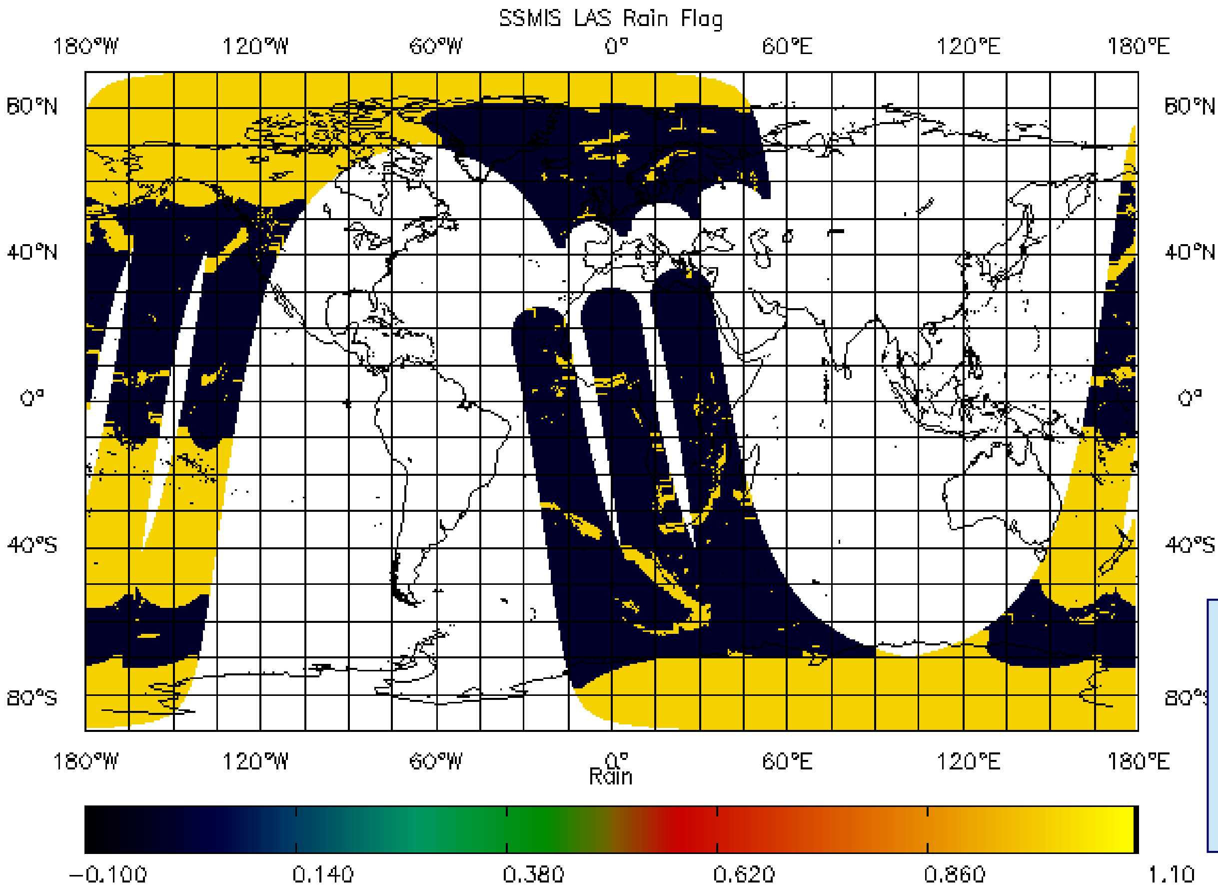
Map is 2D array (360×180) of 0's & 1's, indexed by az , zen

Should be complete after 1 year (assuming orbit stable) ?

Performance: April – June 2005



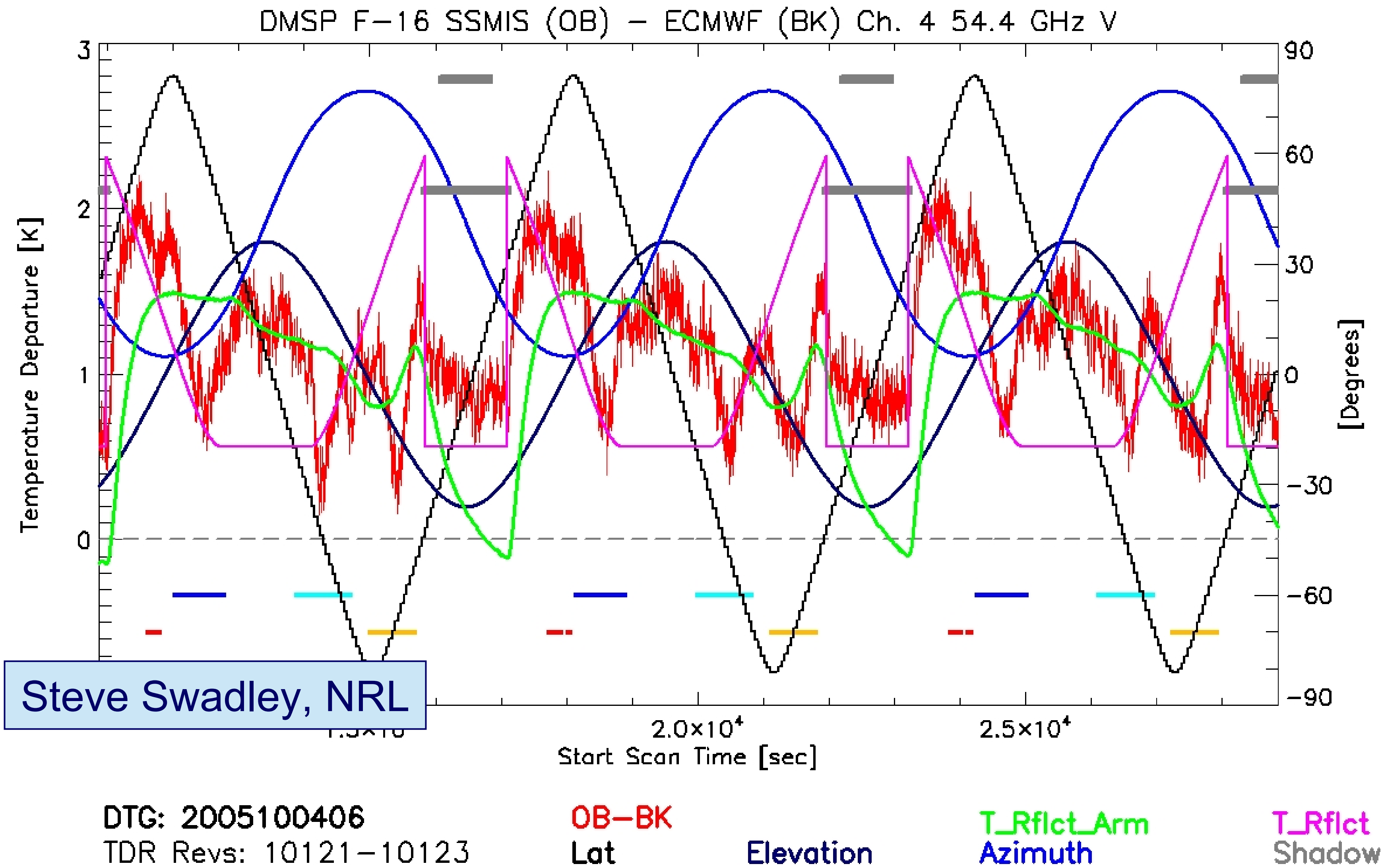
Intrusion flagging: coverage



Yellow : rejected
Black: OK

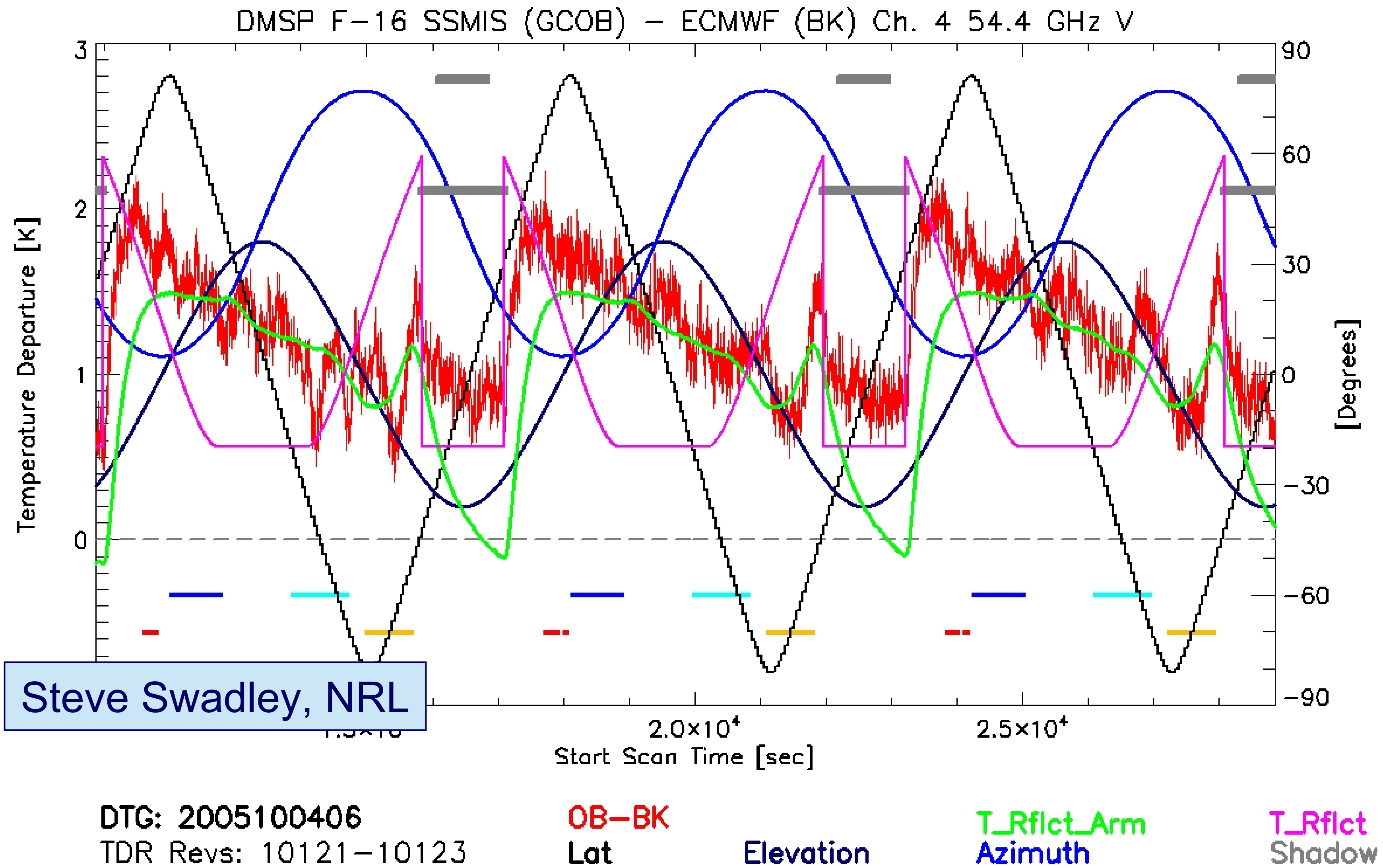
(30 - 40% data flagged)

Gain Correction using Fourier Filtering: no correction



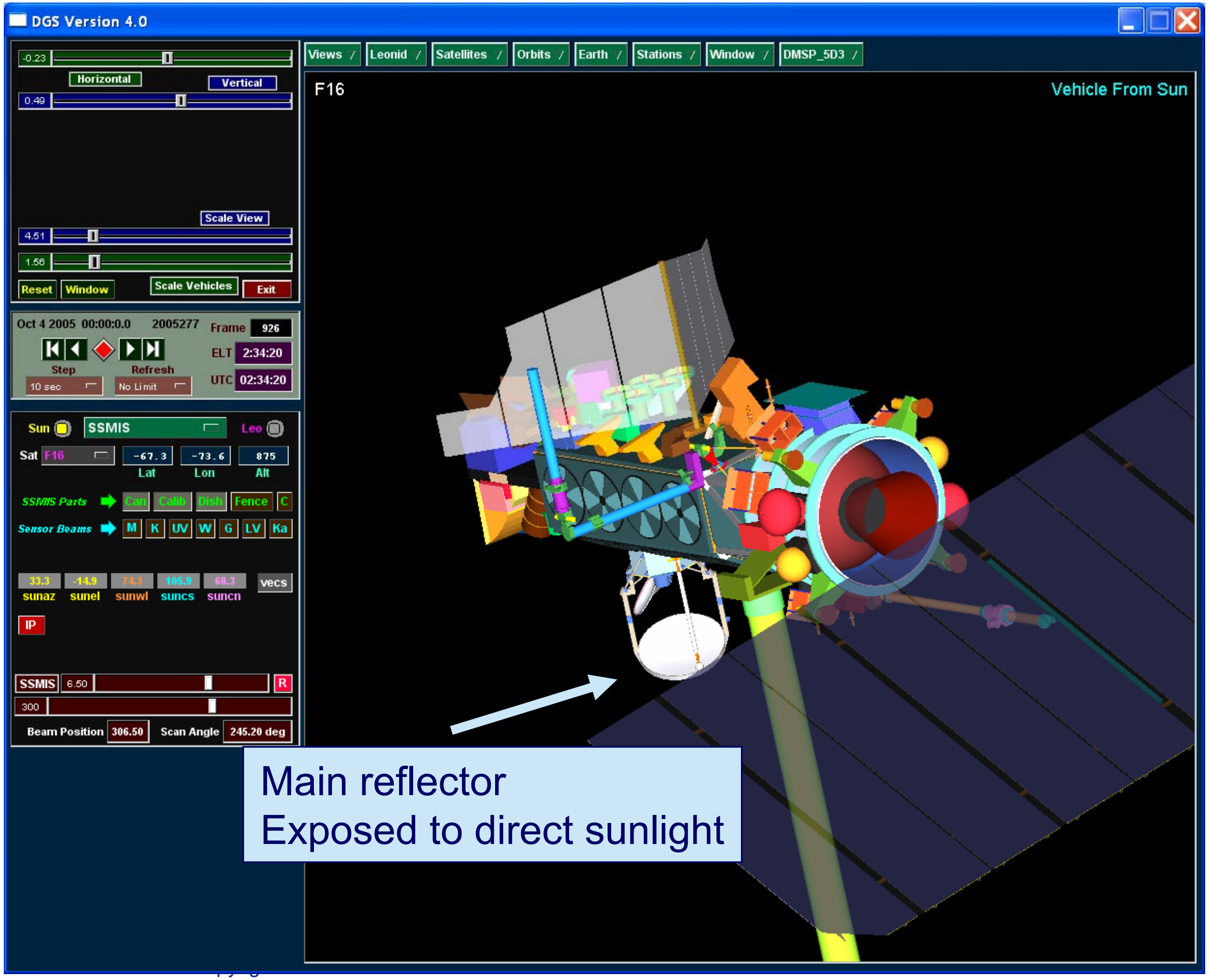
Steve Swadley, NRL

Gain Correction using Fourier Filtering: corrected



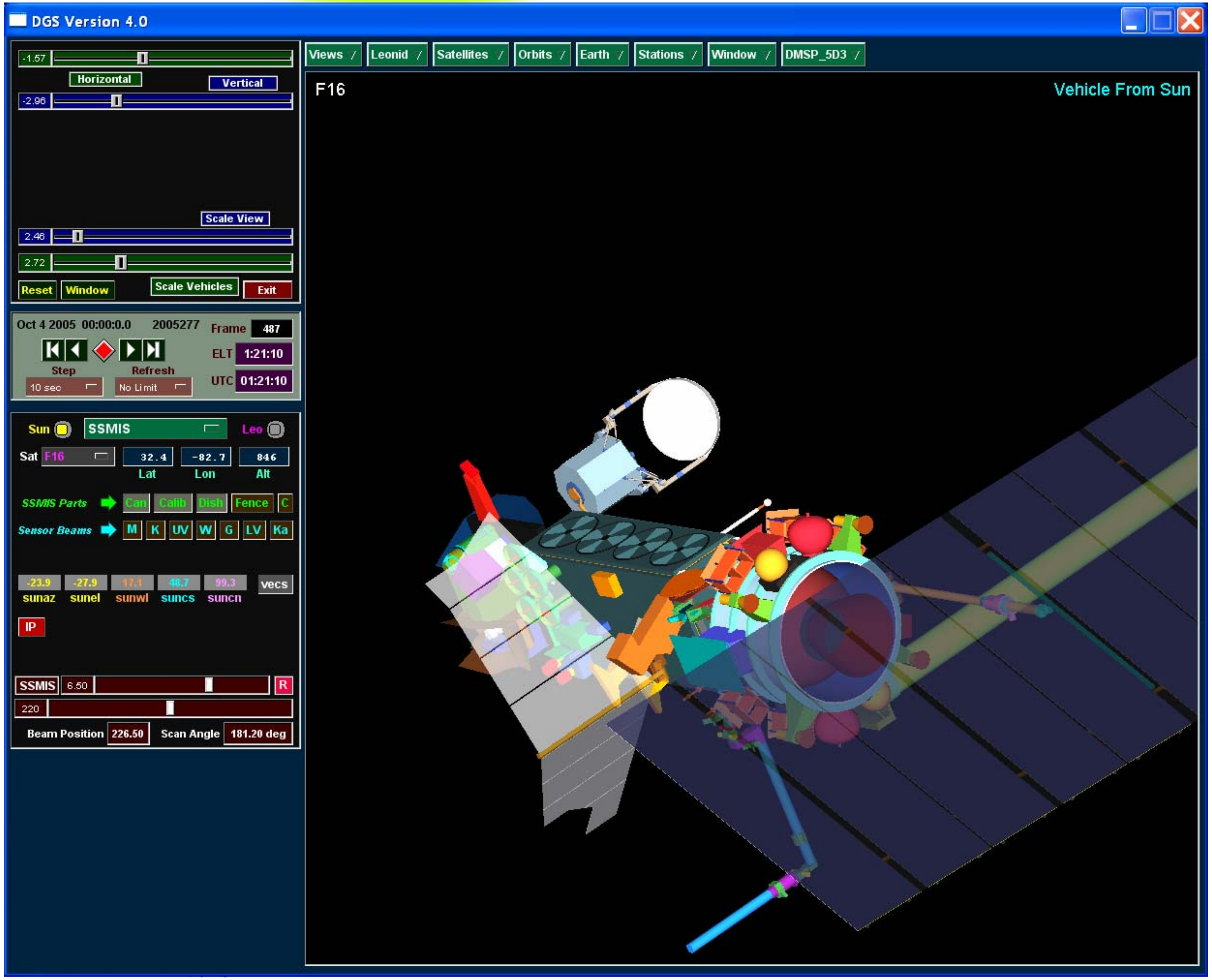
Steve Swadley, NRL

Reflector Emission: entering Earth shadow



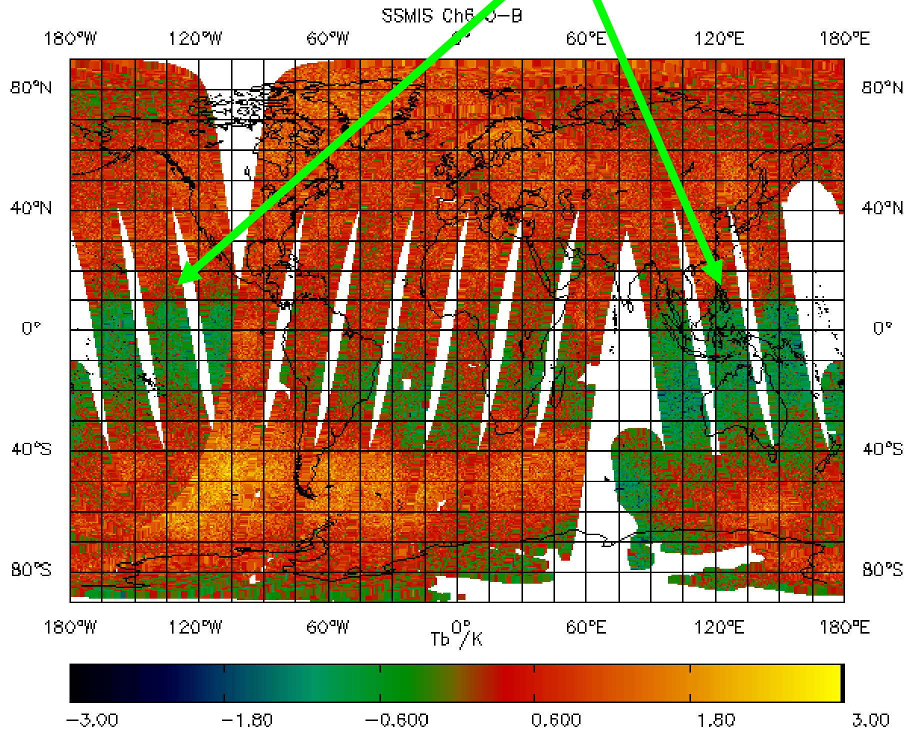
Main reflector
Exposed to direct sunlight

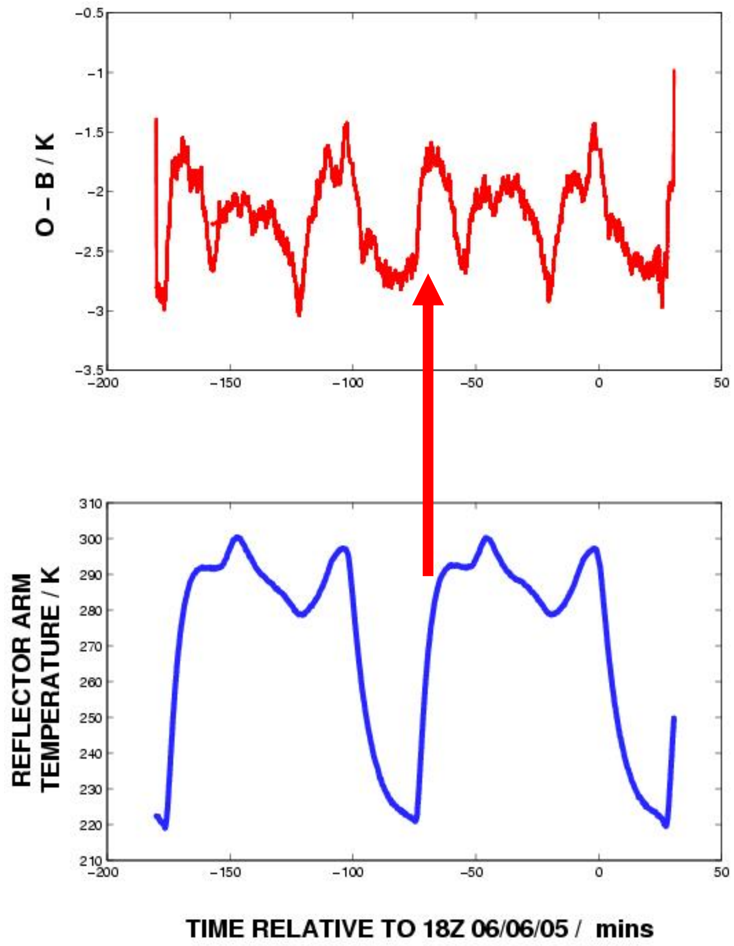
Reflector Emission: emerging from Earth shadow



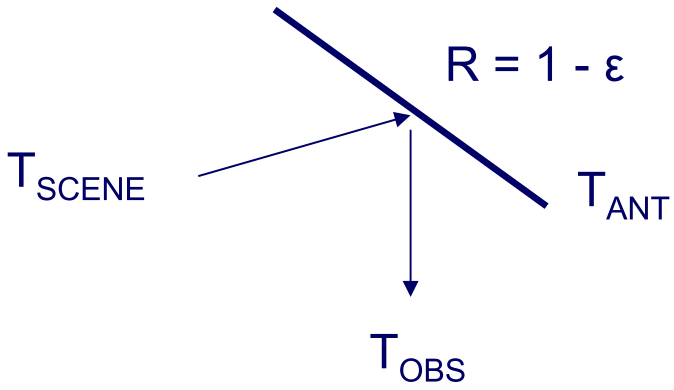
Reflector emission

Problems in ascending node not evident in descending node





Reflector emission correction



$$T_{obs} = (1-\varepsilon)T_{scene} + \varepsilon T_{ant}$$

$$T_{scene} = \frac{T_{obs} - \varepsilon T_{ant}}{(1-\varepsilon)}$$

$$\Delta\varepsilon = \Delta T_{scene}\left[\frac{\partial T_{scene}}{\partial \varepsilon}\right]^{-1}$$

$$\Delta T_{ant} = \Delta T_{scene}\left[\frac{\partial T_{scene}}{\partial T_{ant}}\right]^{-1}$$

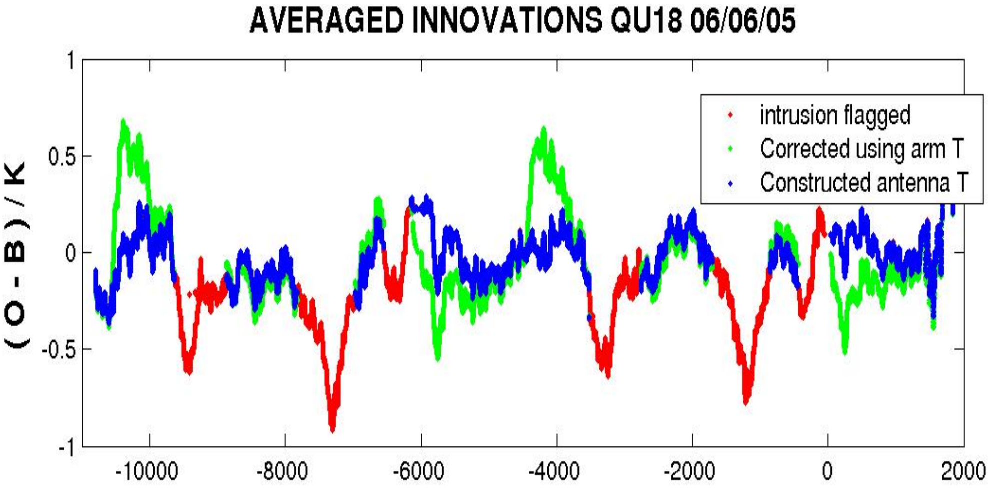
Compute tolerable errors in ε and T_{ANT} ($\Delta\varepsilon$ & ΔT_{ANT}) given tolerable errors in T_{SCENE} (ΔT_{SCENE})

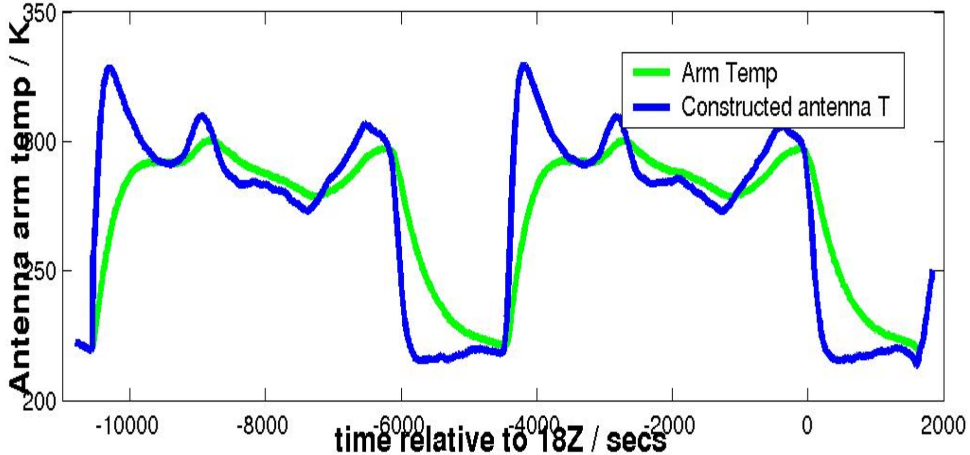
Required accuracy in estimate of antenna emissivity and temperature

Ch #	pol	ΔT_{scene} /K	ε_{nom}	$\Delta\ \varepsilon$	ΔT_{ant} /K
1 - 5	V	0.1	0.01	0.0008	10
6,7,19-24	RC	0.1	0.02	0.0010	5
9 - 11	H	0.5	0.04	0.0060	12
12 - 16	V/H	0.5	0.00	N/A	N/A

⇒ Require T_{ANT} to be accurate to 5K and emissivity estimates to be good to ~0.0008 for T sounding channels to keep T_{SCENE} errors below 0.1K

SSMIS – antenna emission correction using constructed antenna T

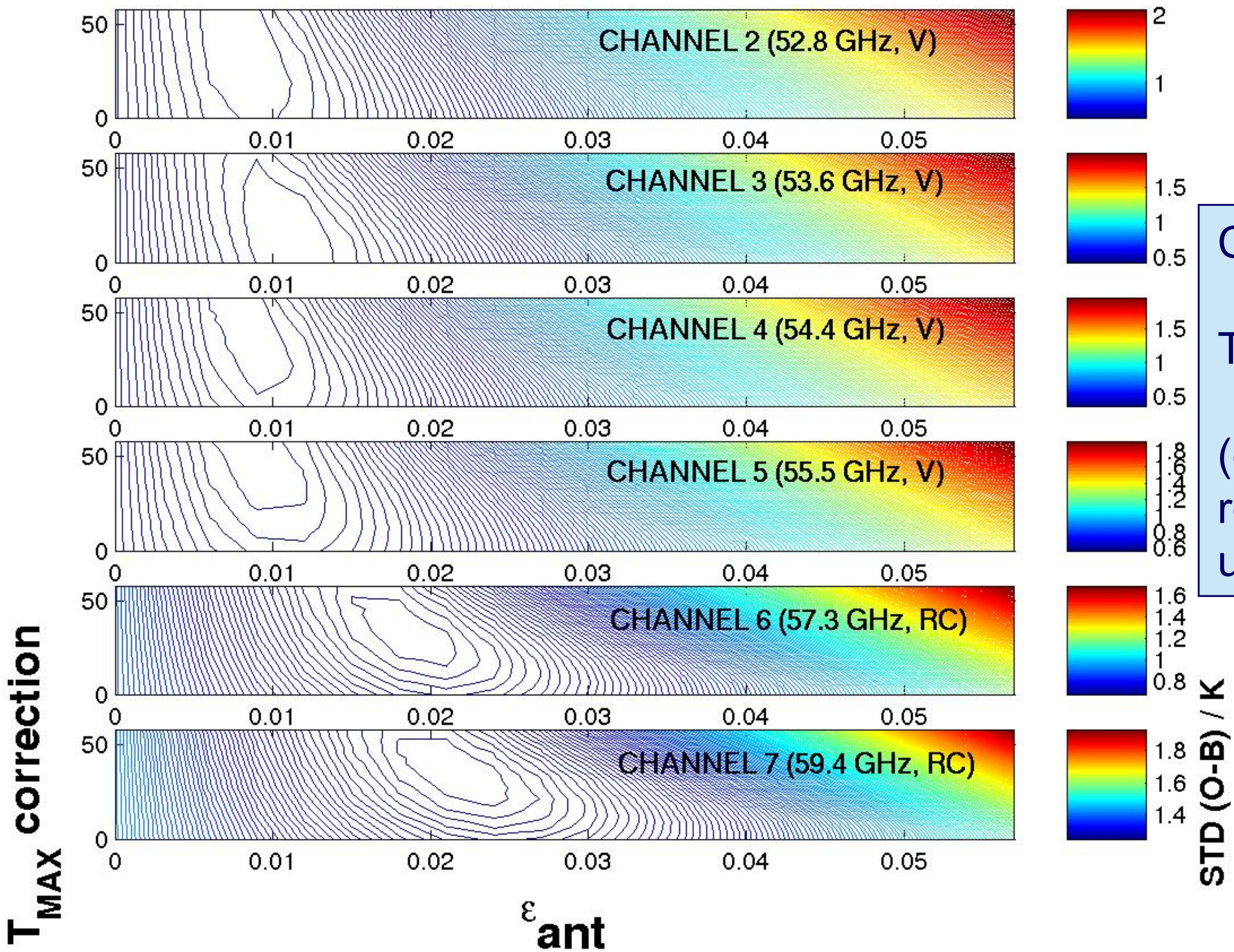




$$T_{ant}(t) = T_{arm}(t) + c_1 \frac{dT_{arm}}{dt}$$

$$T_{ant}(t) = T_{arm}(t) + c_1 \int_0^T c_2 e^{-\tau/\sigma} \frac{dT_{arm}}{dt}(t-\tau)\,d\tau$$

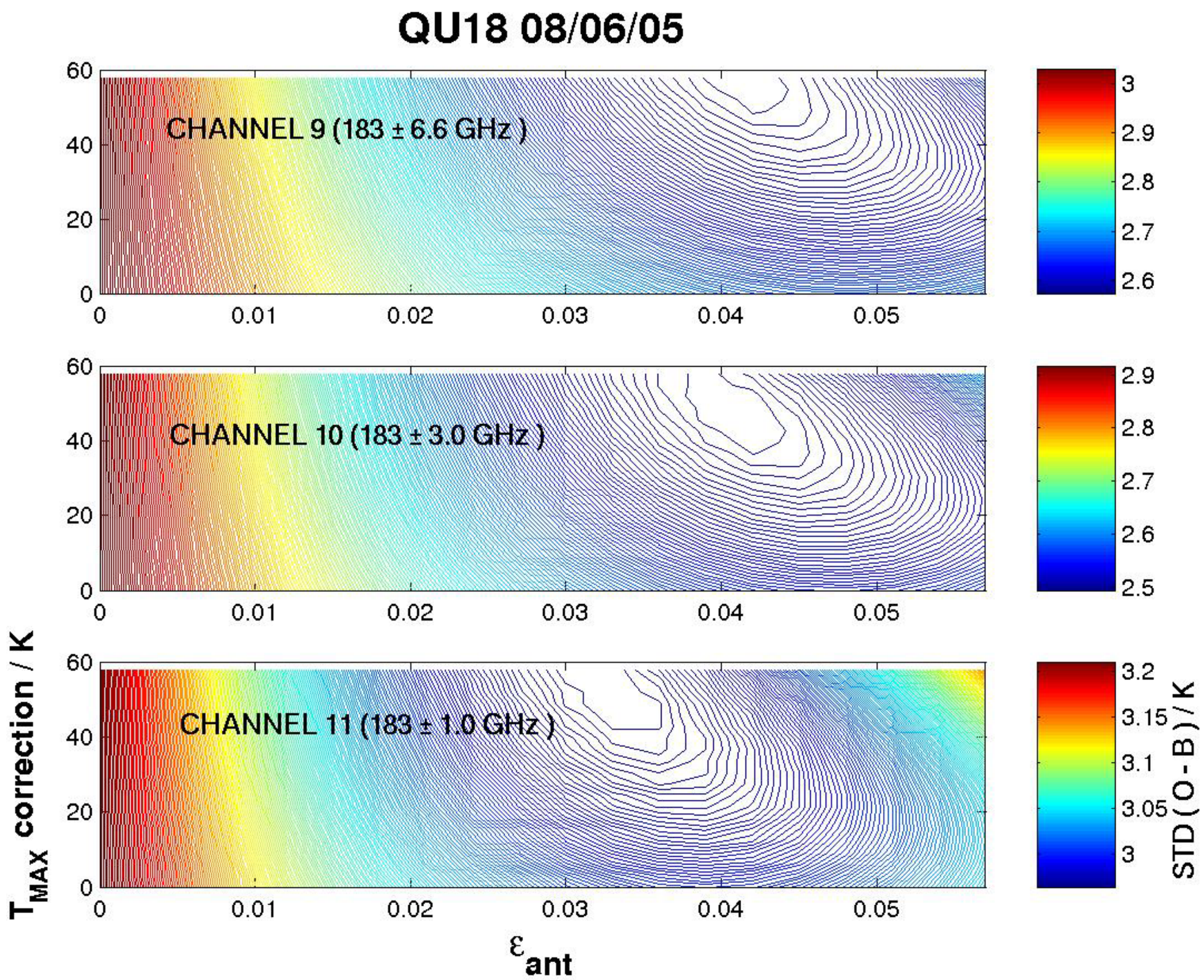
Characterising T_{ANT} & ε : Chs 2 – 7



Ch 1 - 5 : ε = 0.01
6,7 : ε = 0.02
T corr = 30 – 40 K

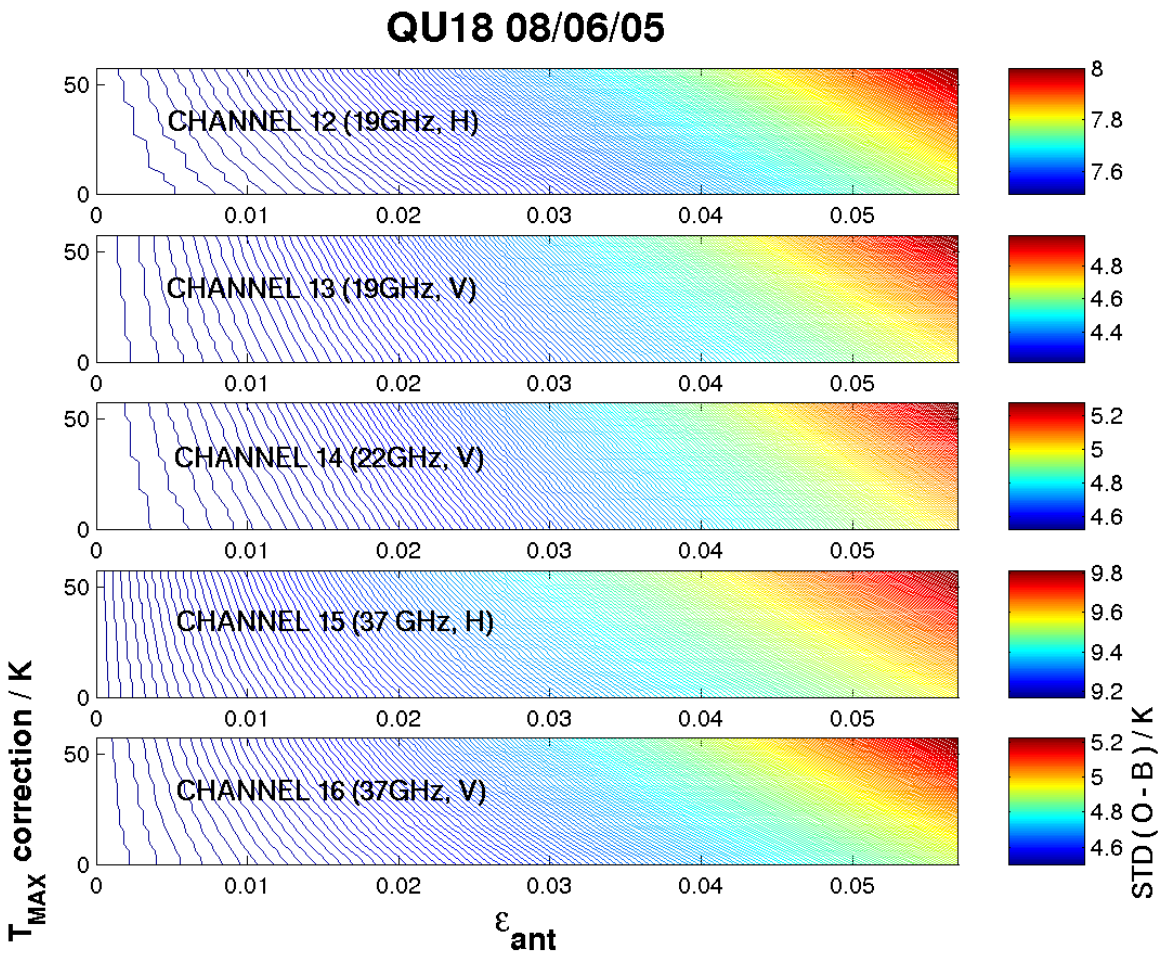
(effectively calibrating reflector emissivity using NWP T fields!?)

Characterising T_{ANT} & ε : Chs 9 - 11



Determination of ε and T less Precise due to larger uncertainties in NWP q fields

Characterising T_{ANT} & ε : Chs 12 - 16



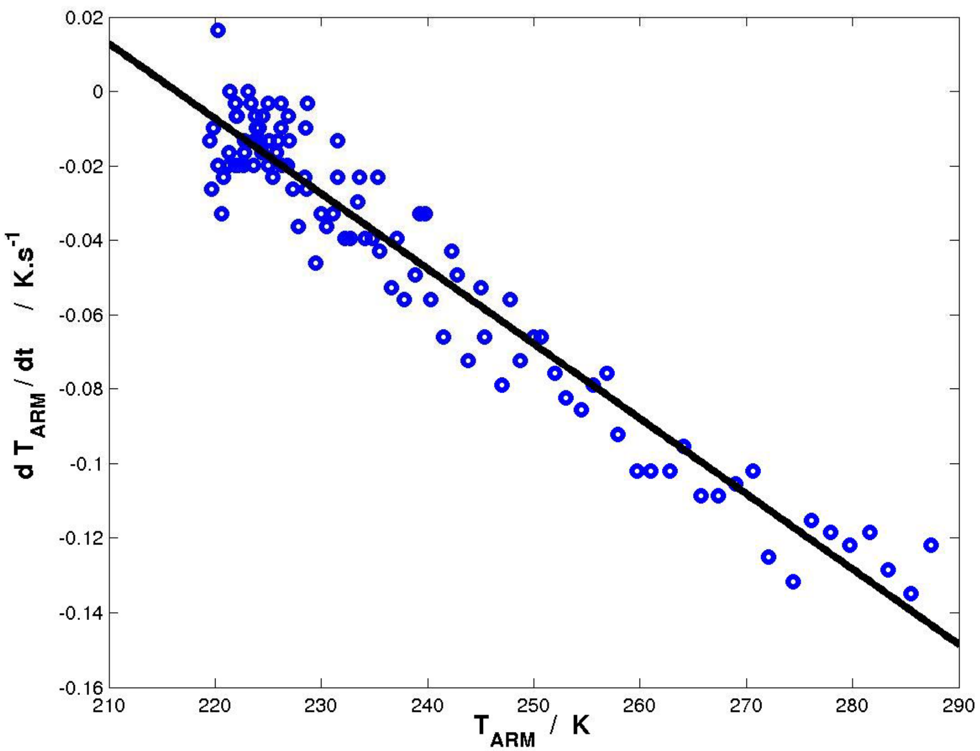
ε = 0
(*ie* reflector emissivity shouldn't be a problem for SSMI like - channels)

Physical basis for empirical reflector correction (1)

Heat transfer equation for support arm :

$$c_1 \frac{\partial T_{arm}}{\partial t} = c_2 f(t) - (c_3 T_{arm}^n - c_4 T_0^n)$$

Solar forcing — sink



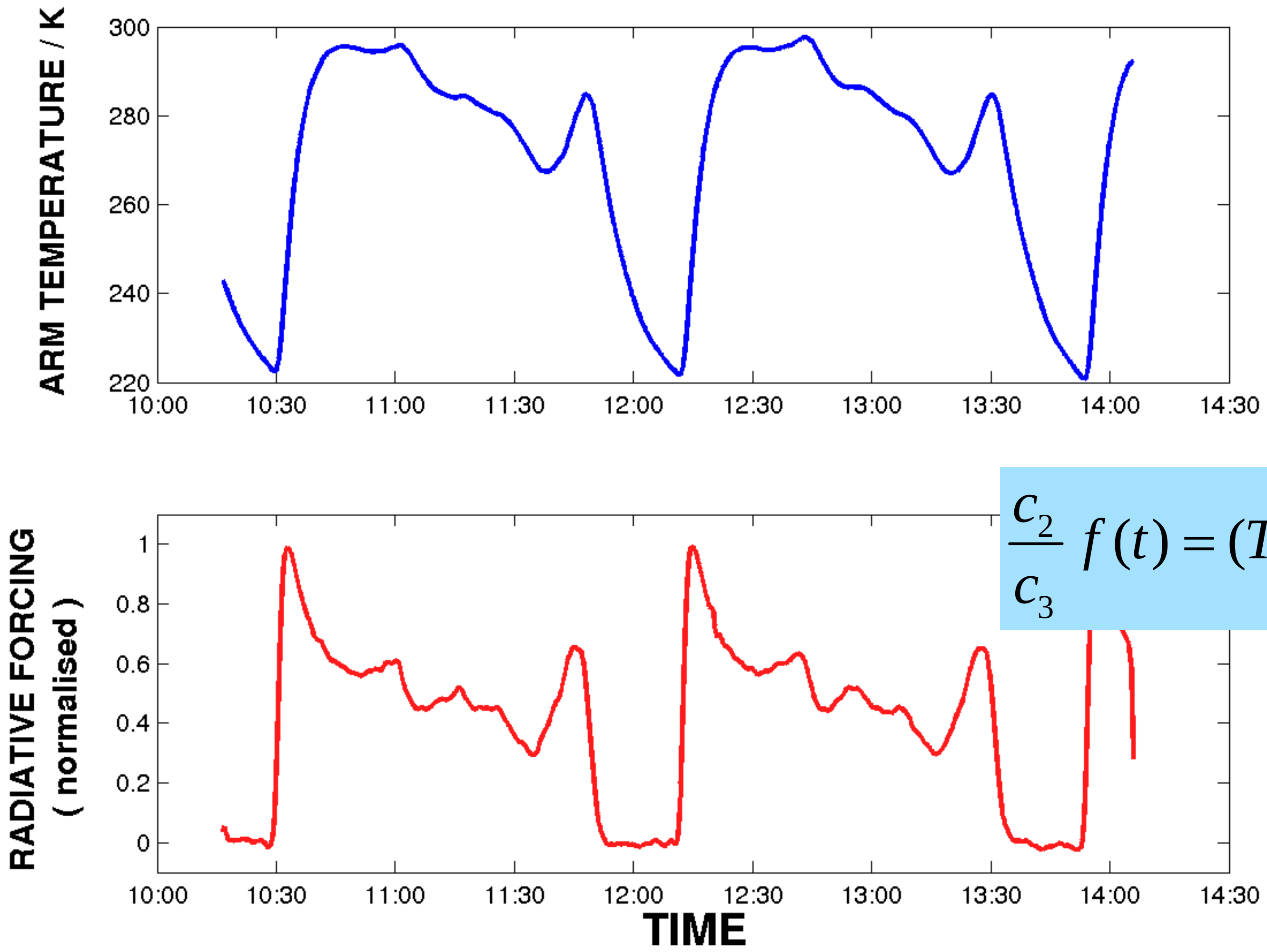
In earth shadow, f(t) = 0

Plot time derivative of T_{arm} vs T_{arm}

Indicates n = 1.

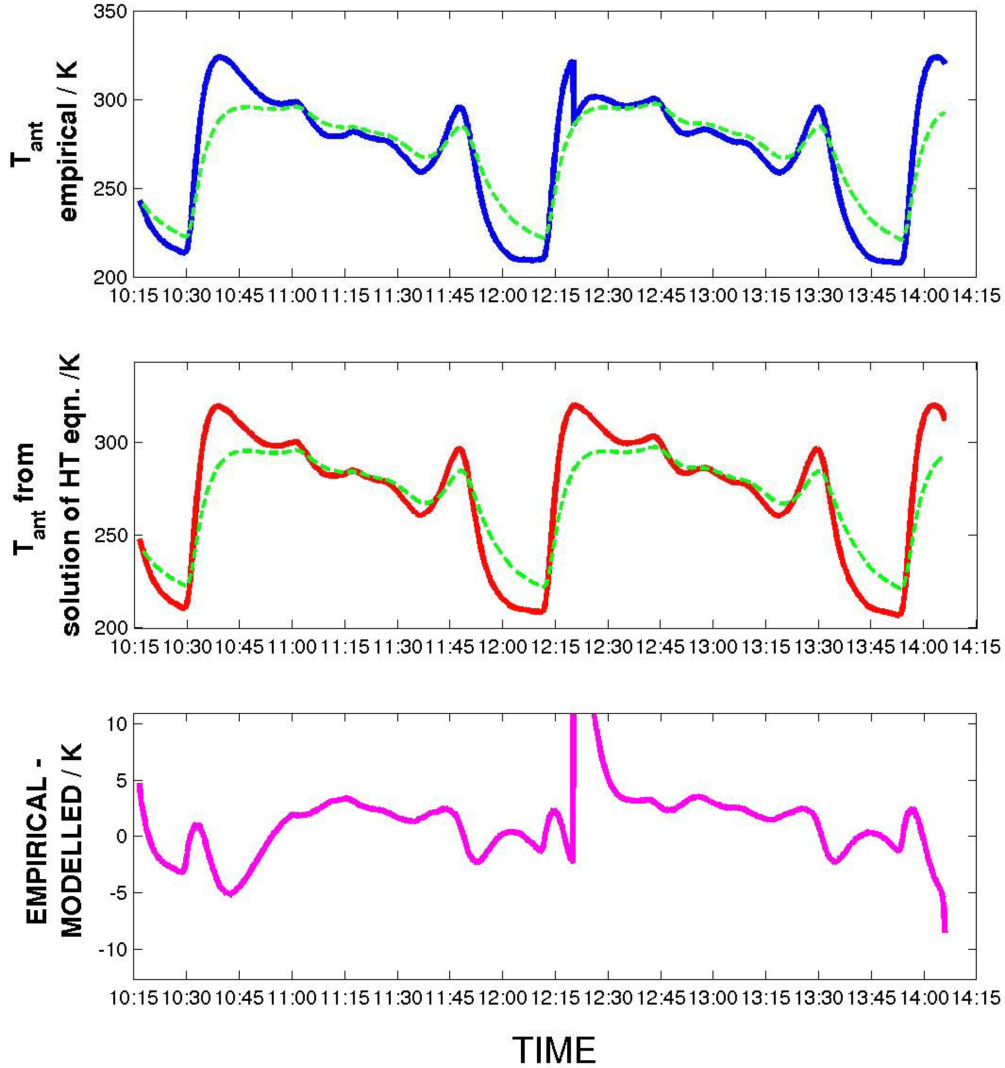
ie arm cools conductively to sink at 218K

Physical basis for empirical reflector correction (2)



$$\frac{c_2}{c_3} f(t) = (T_{arm} - T_0) + \frac{c_1}{c_3} \frac{\partial T_{arm}}{\partial t}$$

Physical basis for empirical reflector correction (3)



$$T_{ant}(t) = T_{arm}(t) + c_1 \int_0^T c_2 e^{-\tau/\sigma} \frac{dT_{arm}}{dt}(t-\tau)\, d\tau$$

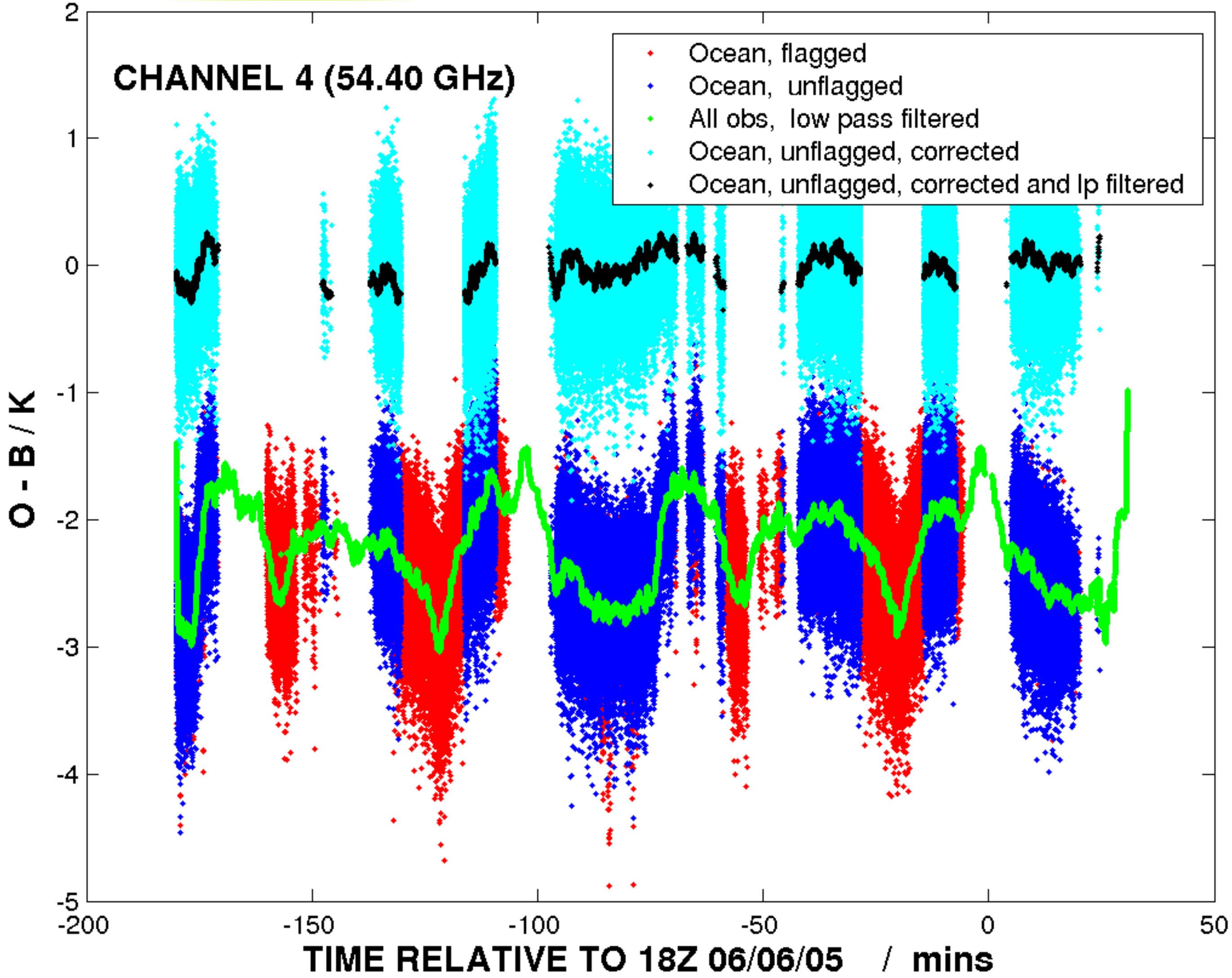
Assuming reflector cools conductively, T_{ant} (t) can be obtained from the solution of :

$$\frac{\partial T_{ant}}{\partial t} = a_1 f(t) - a_2 (T_{ant} - T_0)$$

← Difference usually < 5K

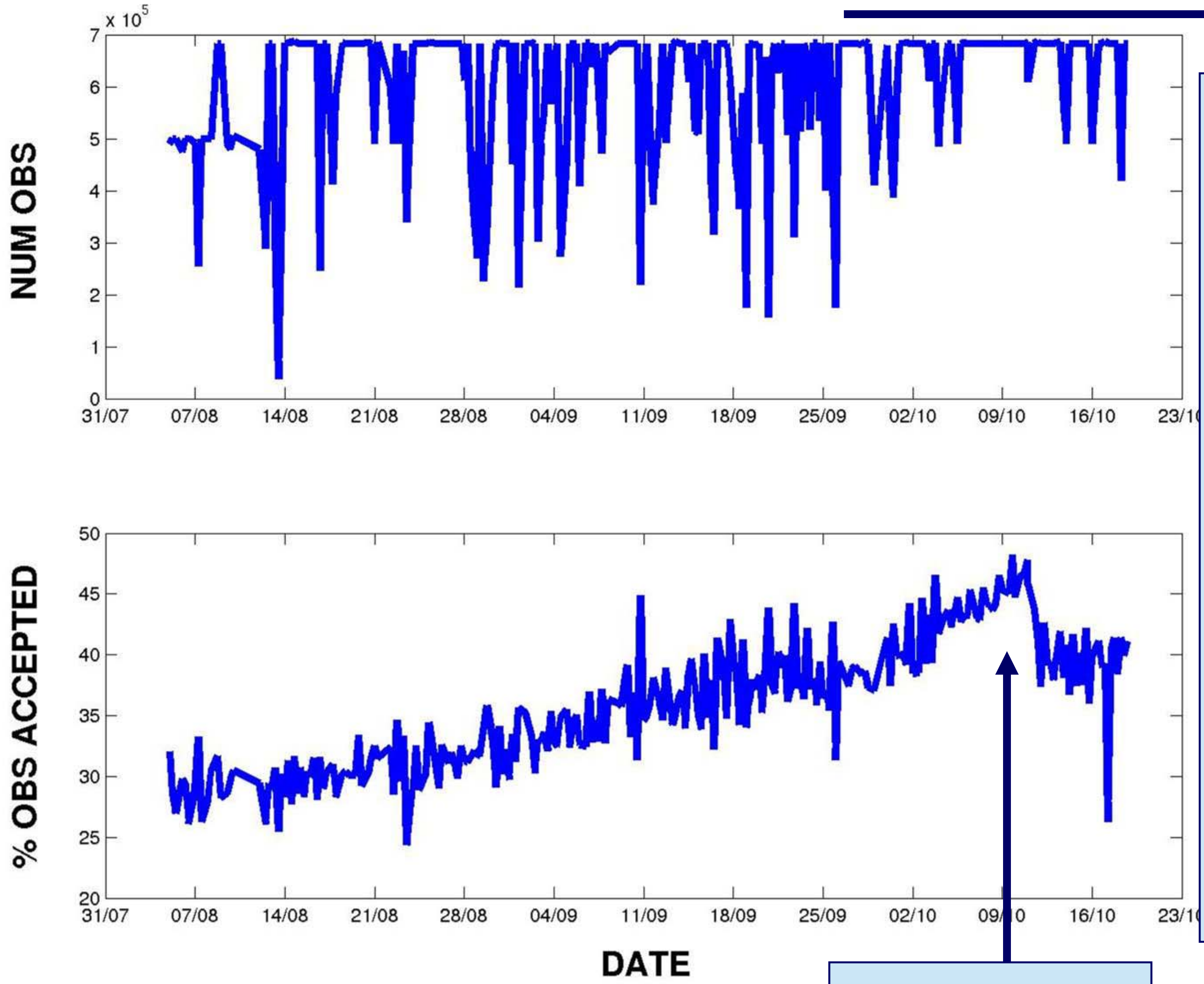
Need to check a_1 and a_2 (fitted) are plausible given thermal properties of main reflector

Performance of reflector emission correction



Monitoring Data from 00,06,12 & 18 Z cycles

Better handling of duplicate orbits



Modified intrusion map

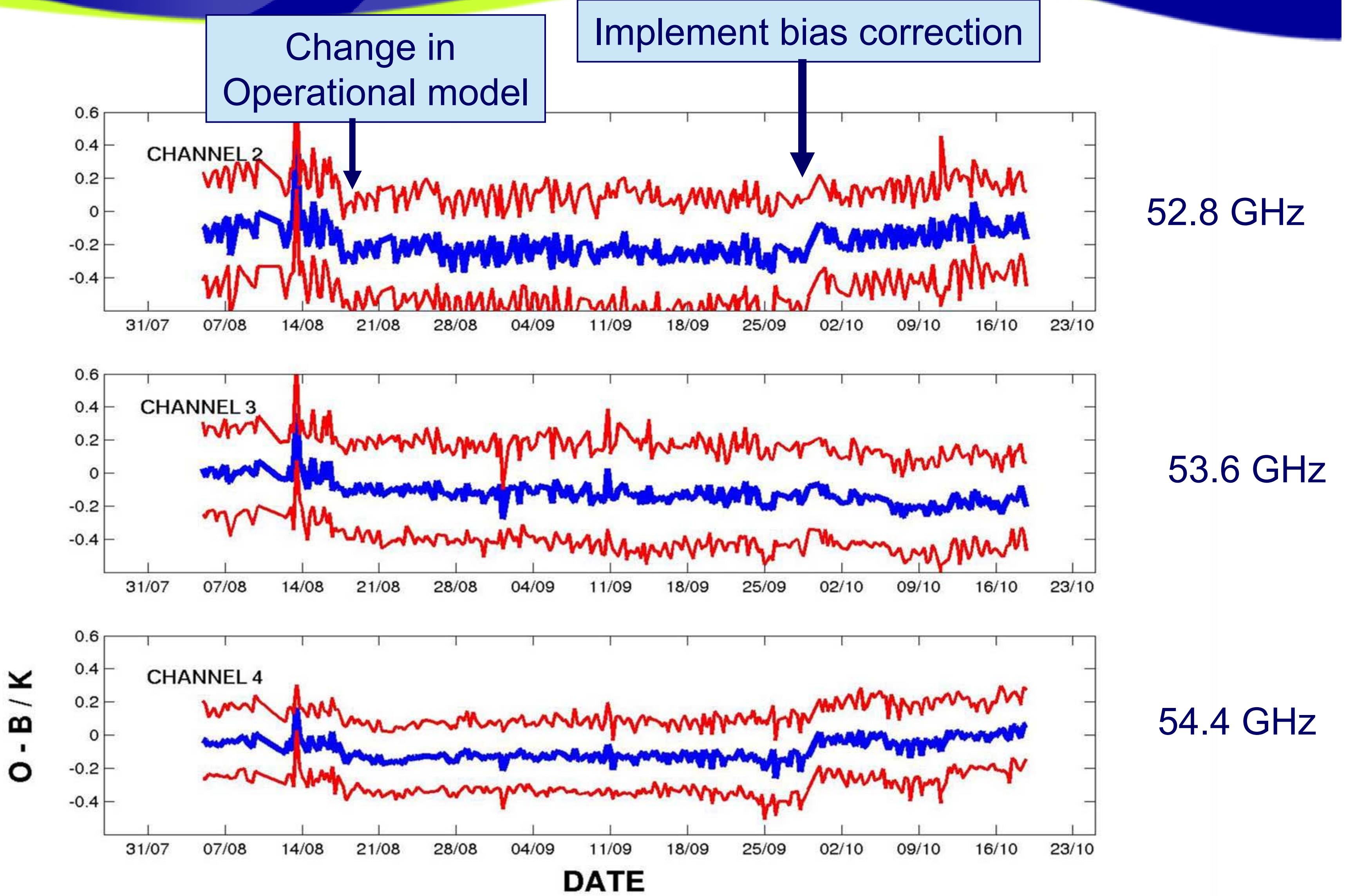
Typically, in 1D Var :

48 % are rain or intrusion flagged
8 % don't converge
2% bad background
<1% fail in rttov, or fail gross O-B check

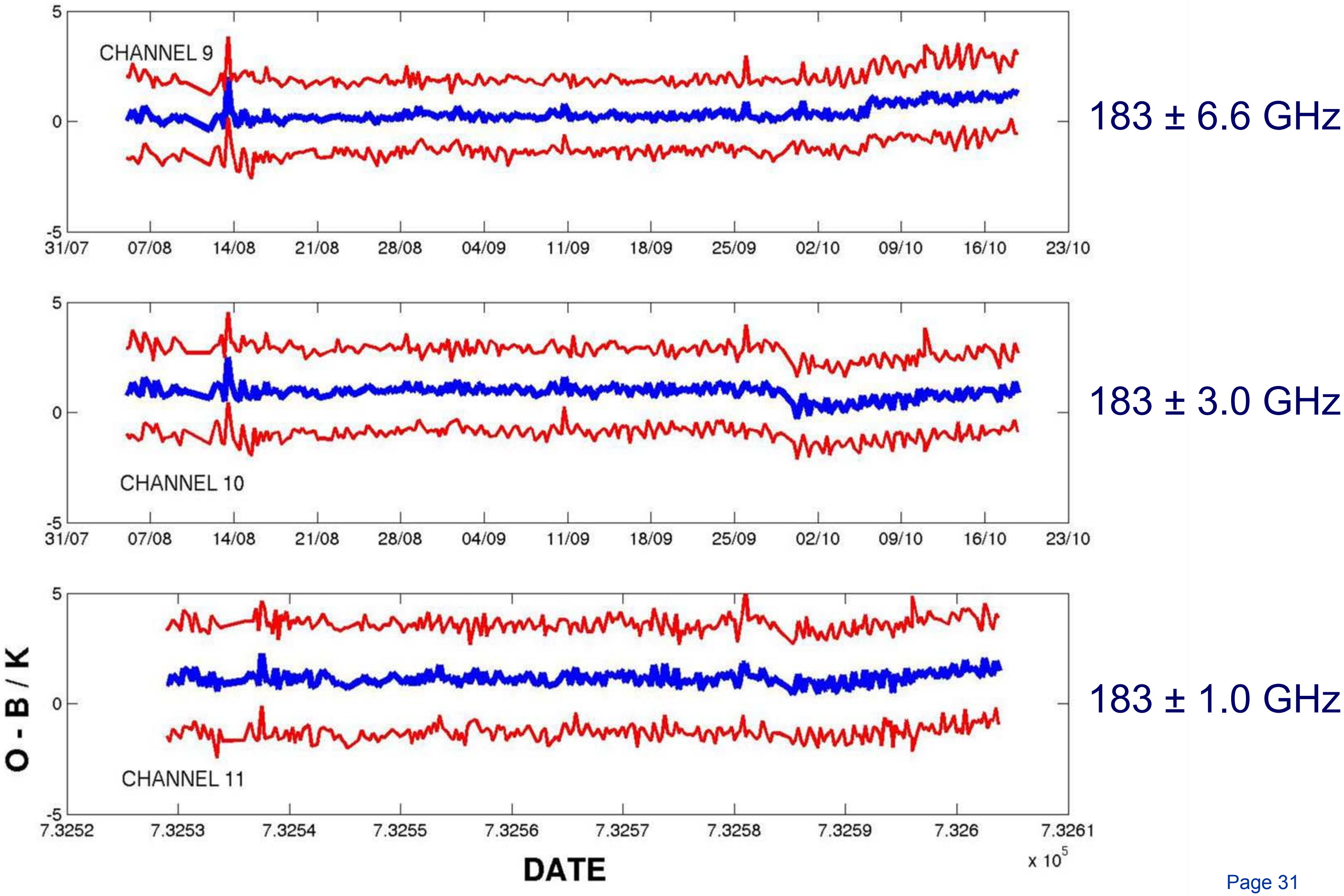
ie 58 % rejected at 1D Var step.

Further rejections in 4D Var based on retr LWP

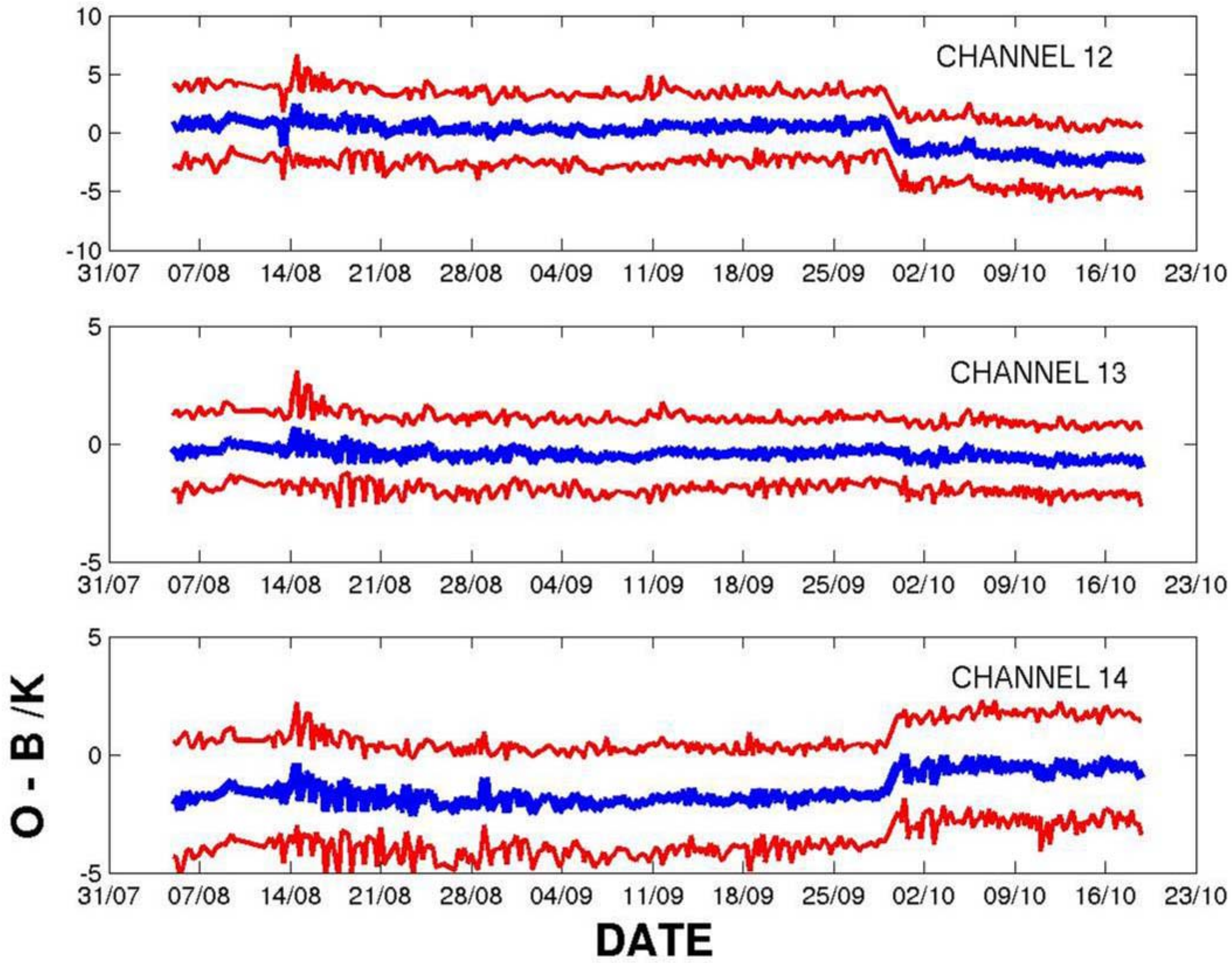
Radiance monitoring: LAS channels 2,3 & 4



Radiance monitoring: IMA channels 9,10 & 11



Radiance monitoring: ENV channels 12,13 & 14



19 GHz (H)

19 GHz (V)

22 GHz (V)

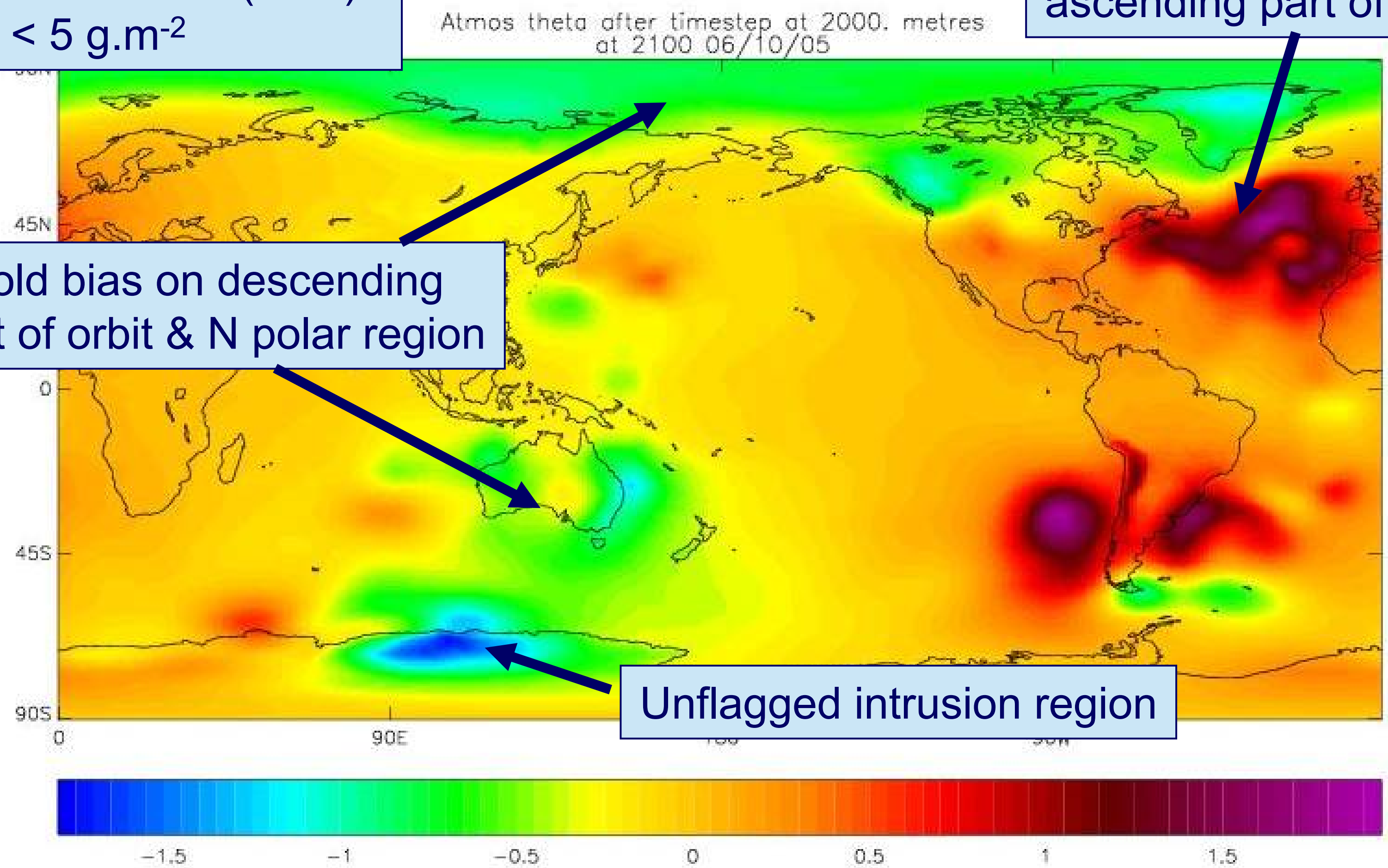
Analysis increments

Channels 2 – 7
Obs errors: 0.25K (2 - 4)
0.5K (5 - 7)
LWP < 5 g.m^{-2}

Warm bias on ascending part of orbit

Cold bias on descending part of orbit & N polar region

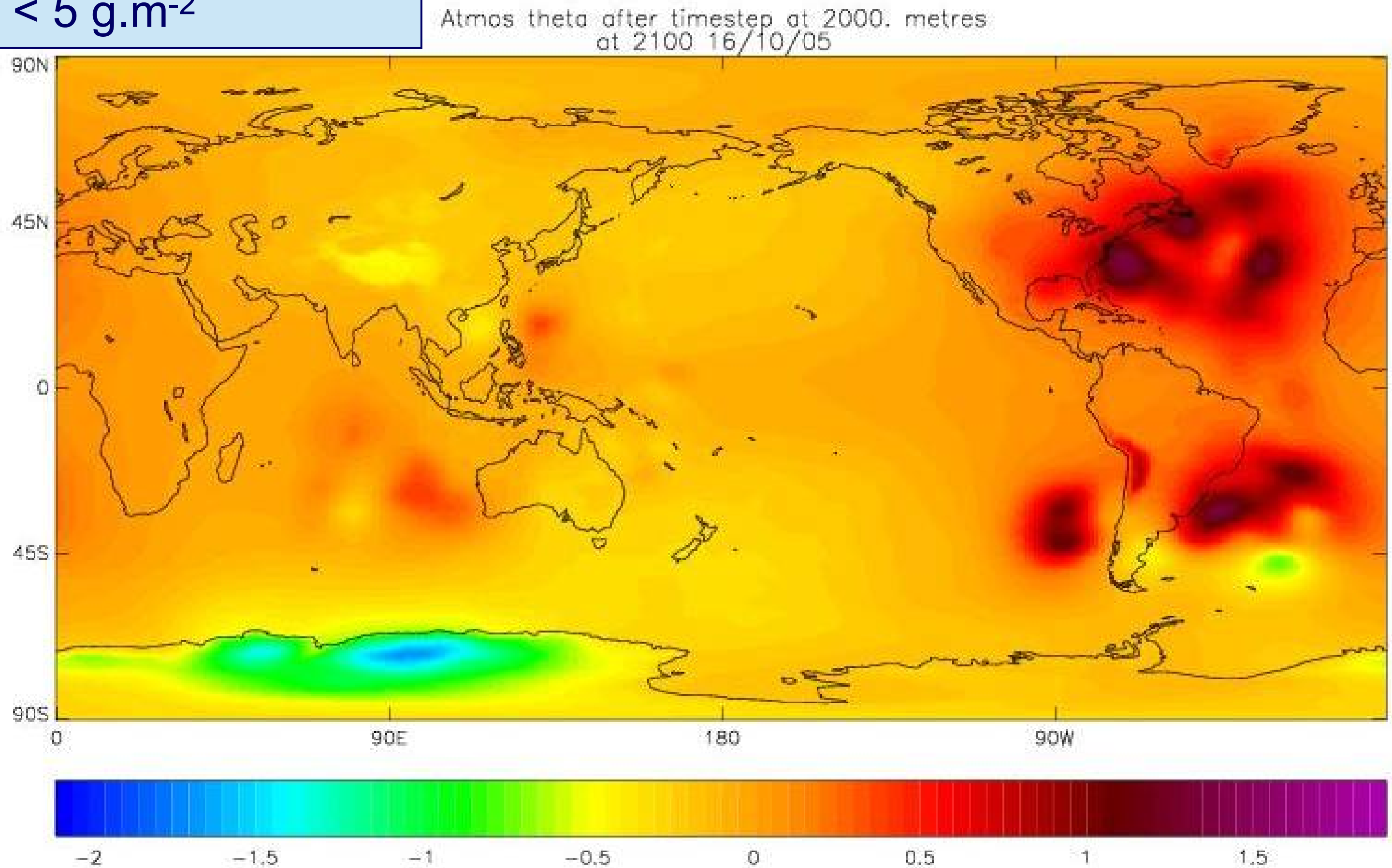
Unflagged intrusion region



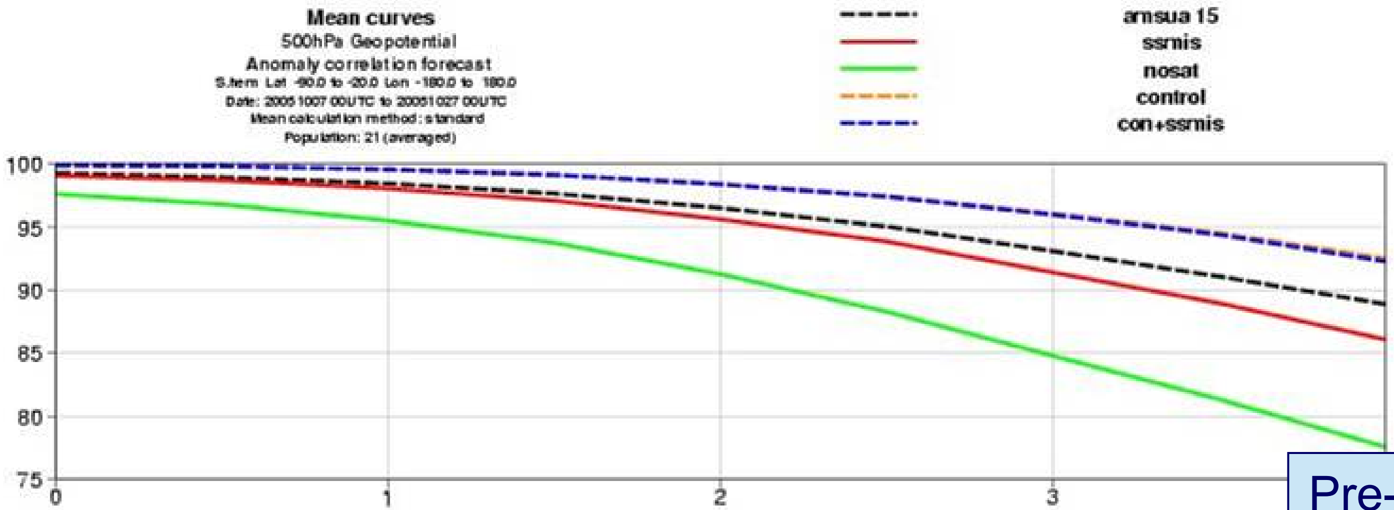
Analysis increments

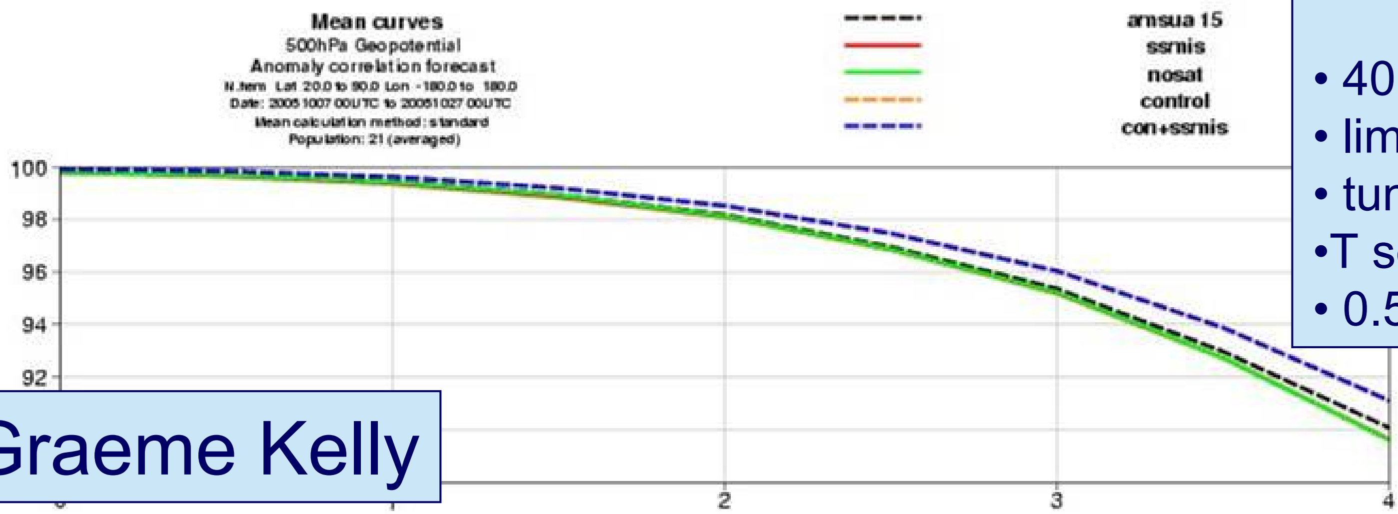
Channels 2 – 4 ONLY
Obs errors: 0.25K (2 - 4)
LWP < 5 $g.m^{-2}$

T_{CORR} = 25K
Adjusted lag



Forecast Impact Studies at ECMWF



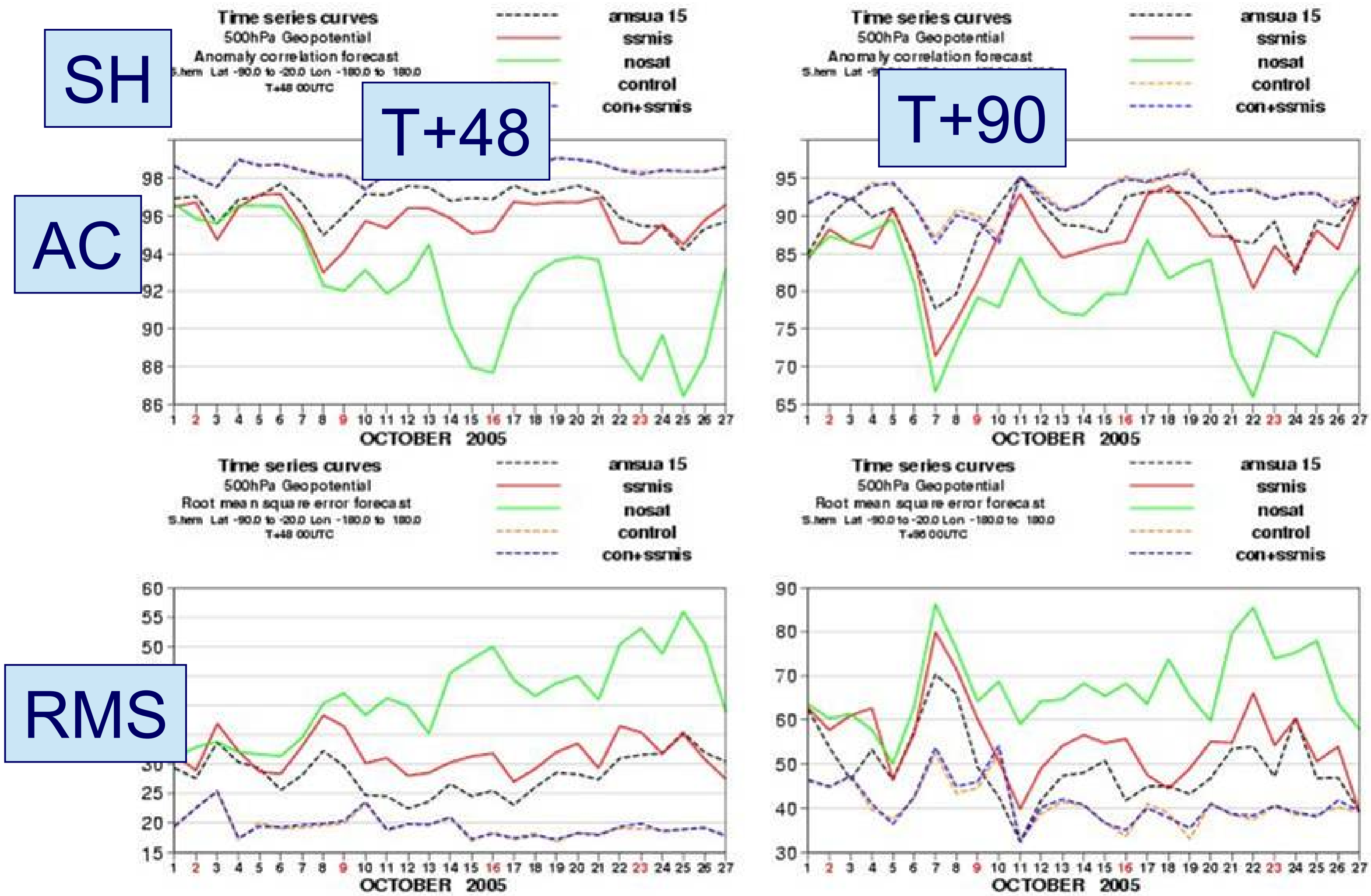


Pre-processed data:

- 40 % flagged
- limited coverage
- tuning ongoing
- T sounding chs only
- 0.5K obs errors

Graeme Kelly

Forecast Impact Studies at ECMWF



Future developments

- Best correction algorithms (from NRL, Met Office and NOAA) will be incorporated in a pre-processor to be run at FNMOC, Monterey to produce a new data stream. Expected early 2006.
- Hardware modifications are in place for F17:
  - Fence to prevent direct solar intrusions
  - Temp sensor re-sited at centre of (back of) reflector (?)
- F17 launch June – Dec 2006

Summary & Conclusions

- In the 2 years since launch a number of important instrument biases in F16 SSMIS have been investigated and are now understood
- Correction algorithms have been developed and the best will be incorporated in a pre-processor to be run at FNMOC
- Baseline forecast studies show the impact of F16 SSMIS to be > 50 % impact of AMSU-A on N-15
- Further improvements expected as coverage is improved, corrections are tuned and more channels are used
- SSMIS should be an important component of NWP DA systems over the next 10 years

Summary & Conclusions (contd)

- Some instrumental biases are not easily dealt with in conventional predictor based schemes, new diagnostics are needed to study these and develop correction algorithms
- Ever more complex radiometry (conical scan, aperture synthesis, imaging interferometric) may pose even more complex bias problems – we need to be flexible in developing solutions
- NWP fields can be very useful in instrument Cal/Val – we should be prepared to contribute to Cal/Val efforts

The End ………………..

…………Thanks.