Microwave Remote Sensing Techniques

i) Nadir Atmospheric Sounding for Numerical Weather Prediction

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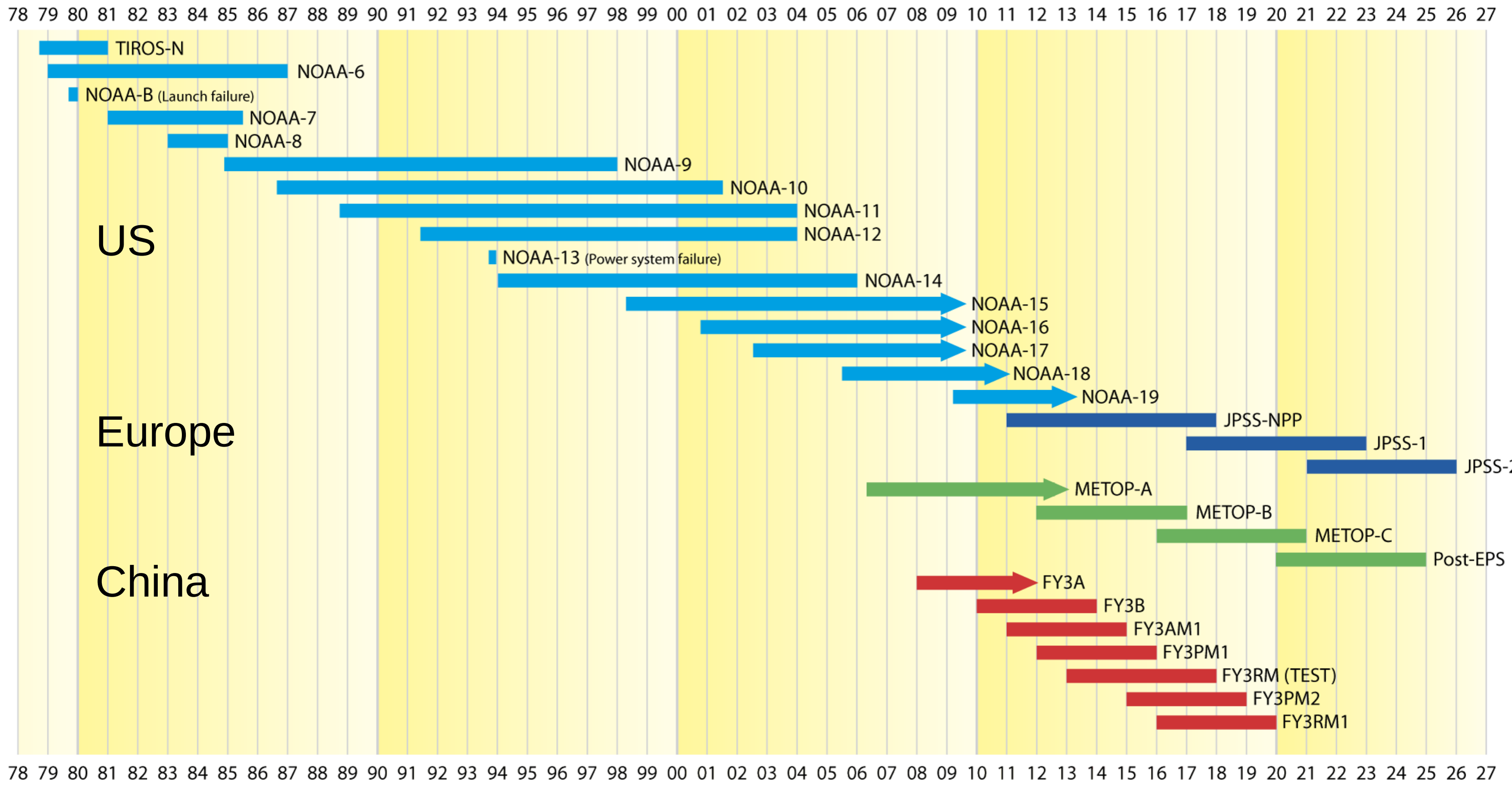
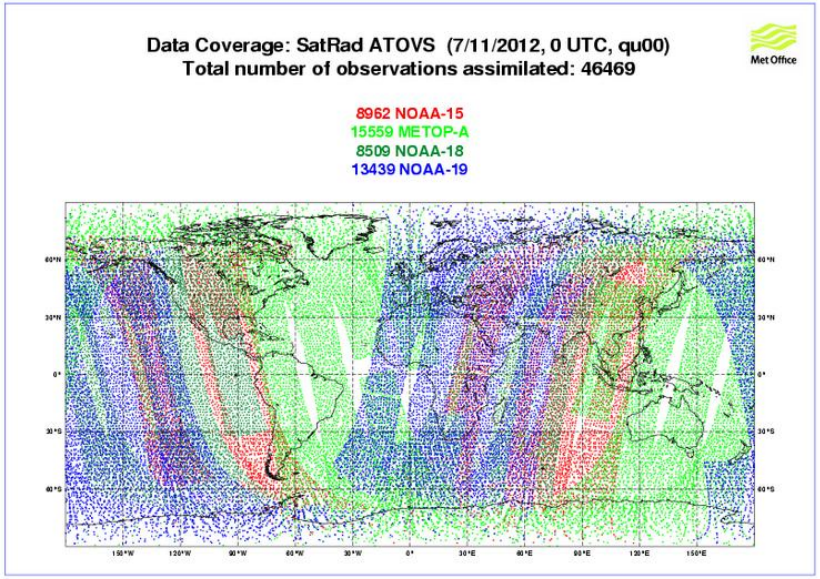
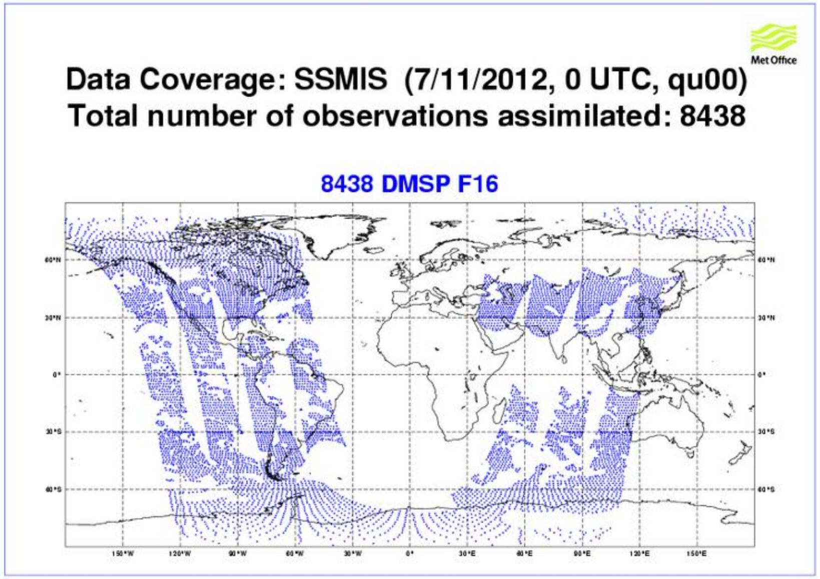
Background
Operational Sounding Satellites: 1978 - 2020



- The use of MW sounding data in NWP data in assimilation systems is mature
- MW sounding data also used in climate and atmospheric reanalysis
- Missions specified, designed & launched in the next decade will serve NWP to 2030 and beyond

Background:
Passive MW data in the Met Office global model





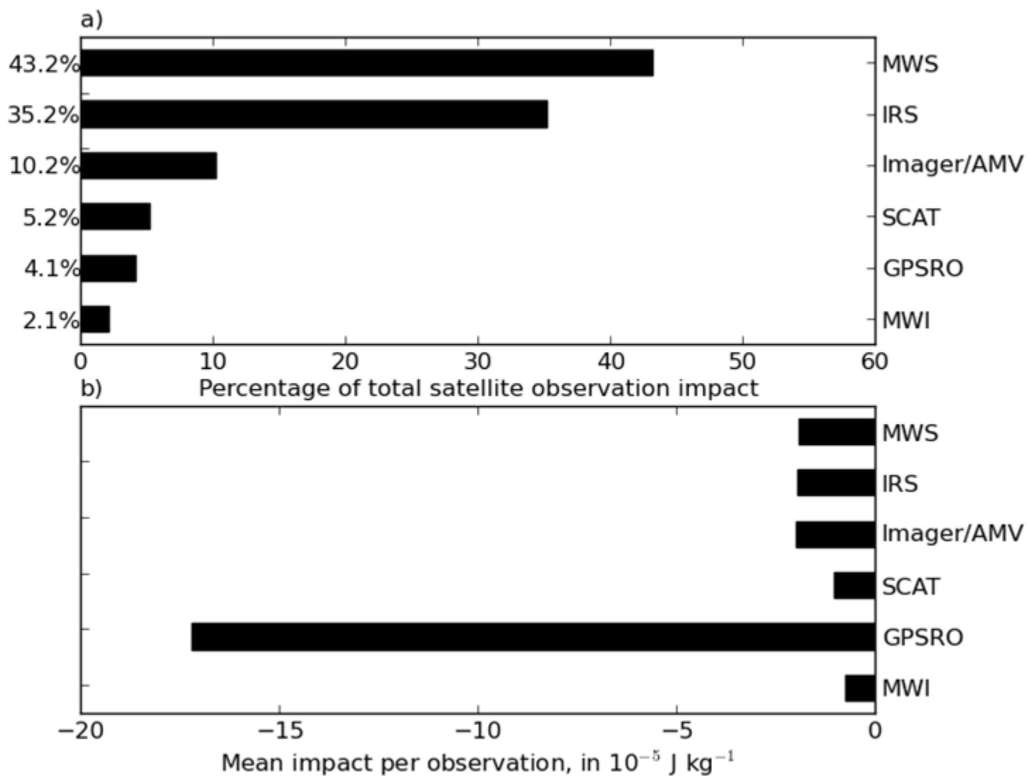
ATOVS suite :

- AMSU-A (x-track T sounder)
- AMSU -B / MHS
  (x-track humidity sounder)
- HIRS (IR sounder)

SSMIS :

- conical imager sounder, combines:
  - Lower atm T & humidity sounding
  - Imager channels (TCWV information)
  - Mesospheric T sounding

Background:
How important is MWS data in NWP data assimilation systems ?

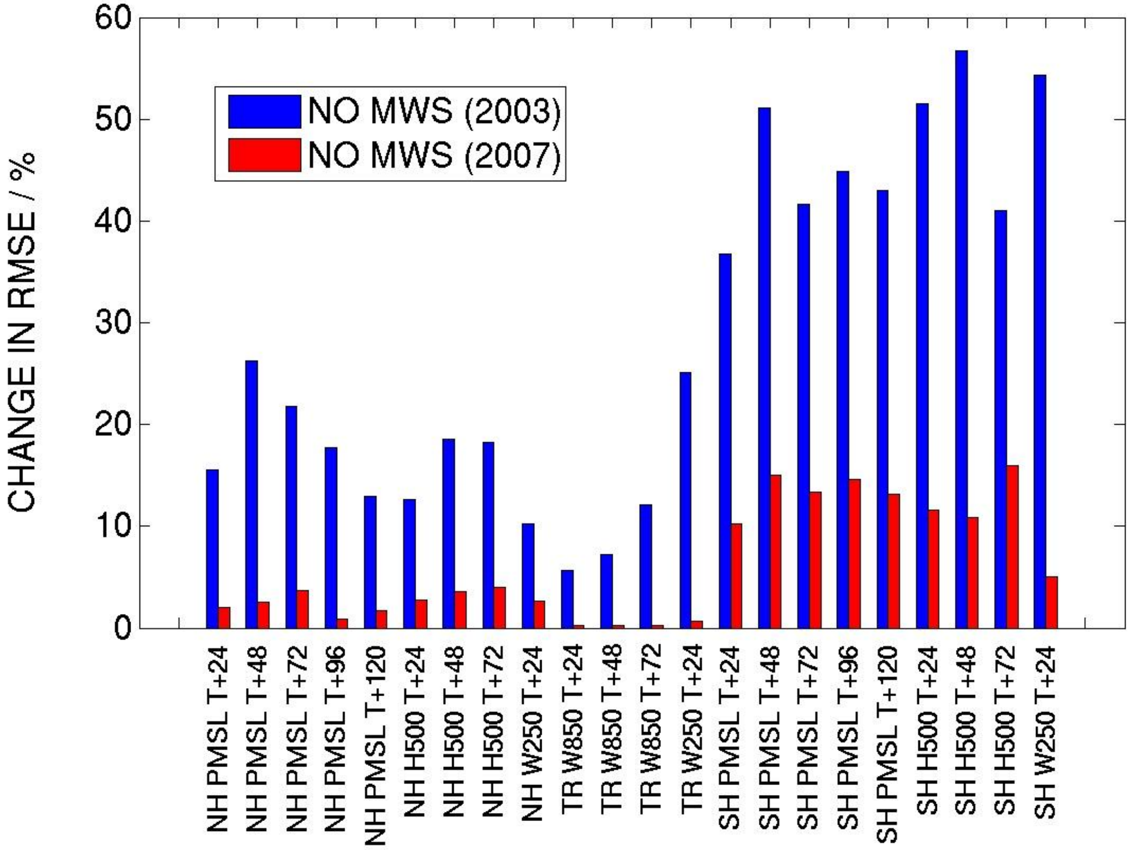


Microwave sounding data
taken as a system -
is currently the most important
In global NWP

per observation MWS data
Matches that of almost
all other satellite data – except
GPSRO (v. high vertical resolution)

Results from Joo, Eyre and Marriott (subm. Monthly Weather Review, 2012)
based on '*Forecast Sensitivity to Observations*' – an adjoint based technique
for assessing the relative contribution of observing systems to forecast accuracy

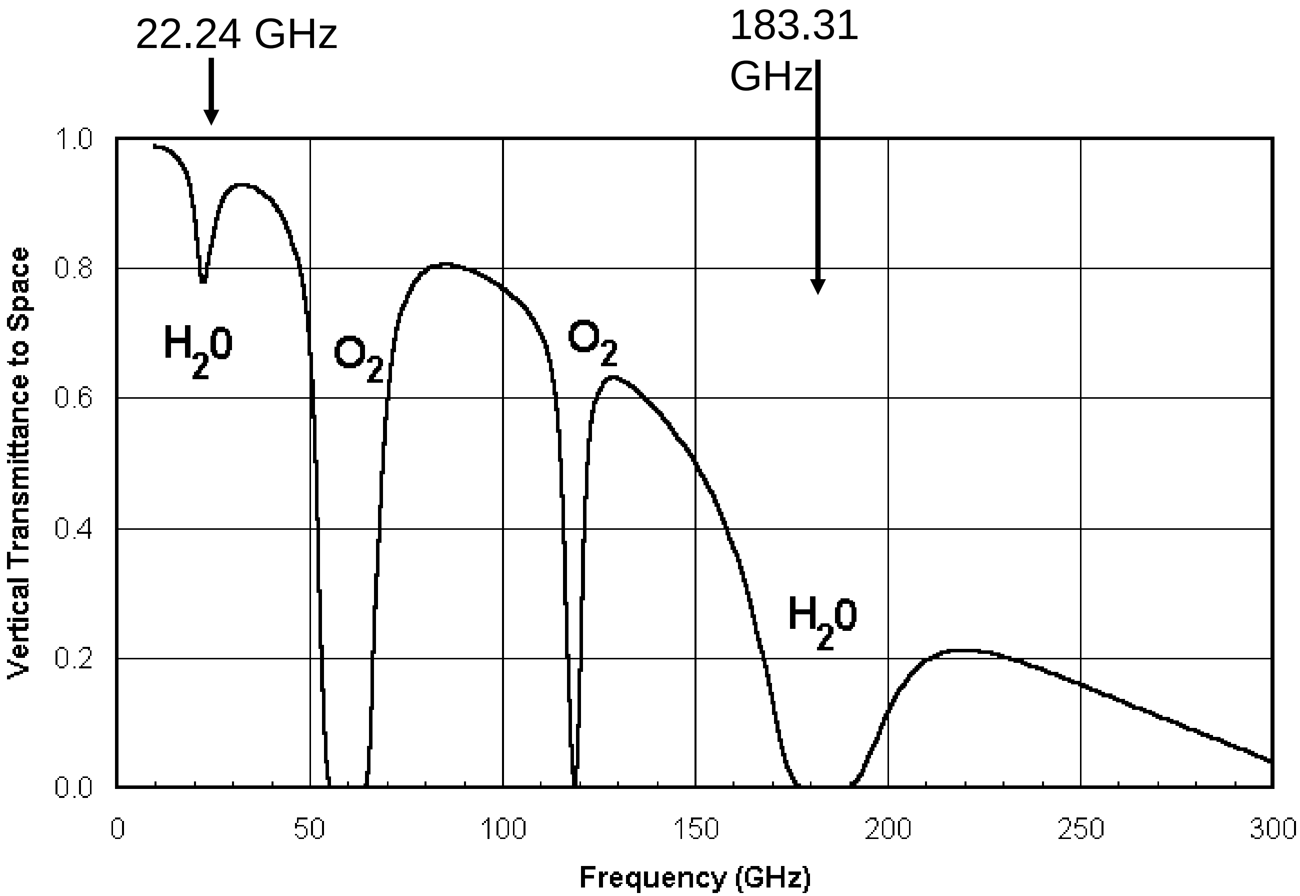
Background: Impact of microwave sounder data in NWP
Observing system experiments.



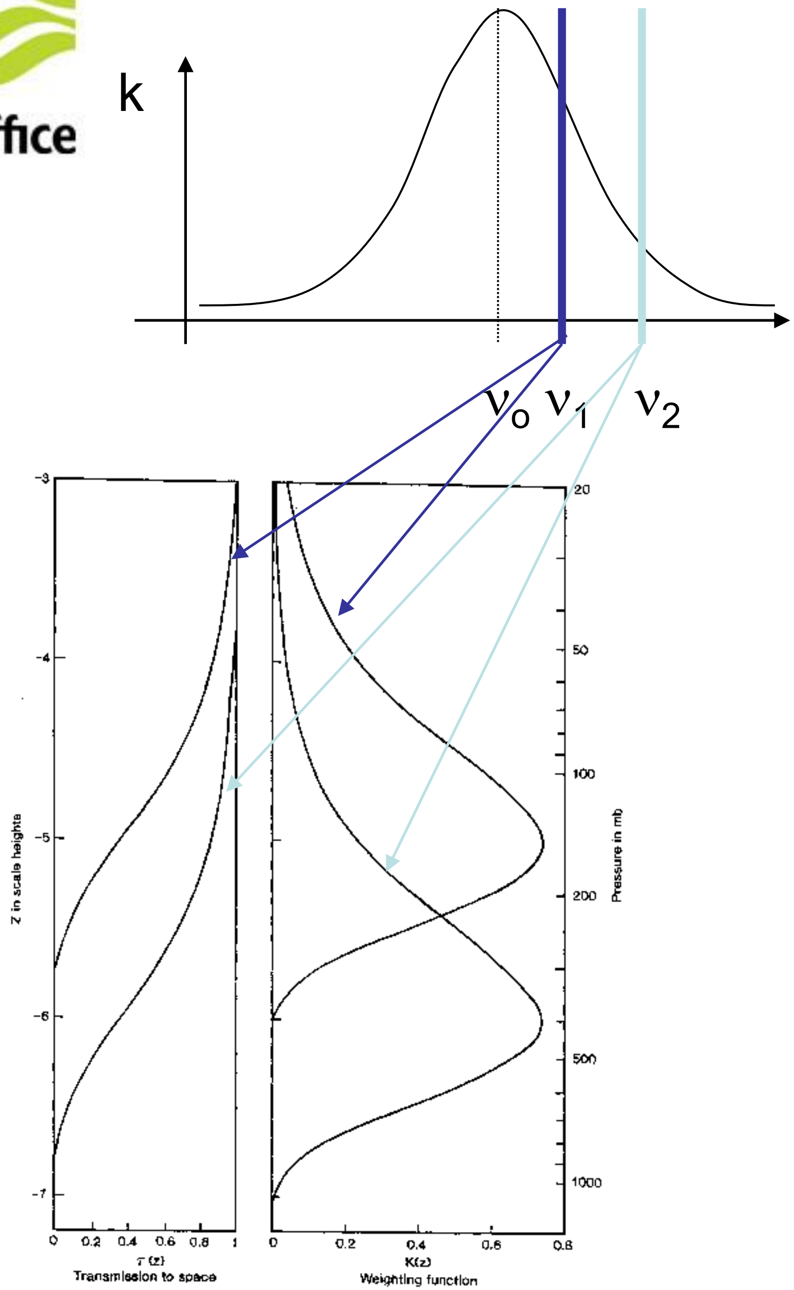
Outline

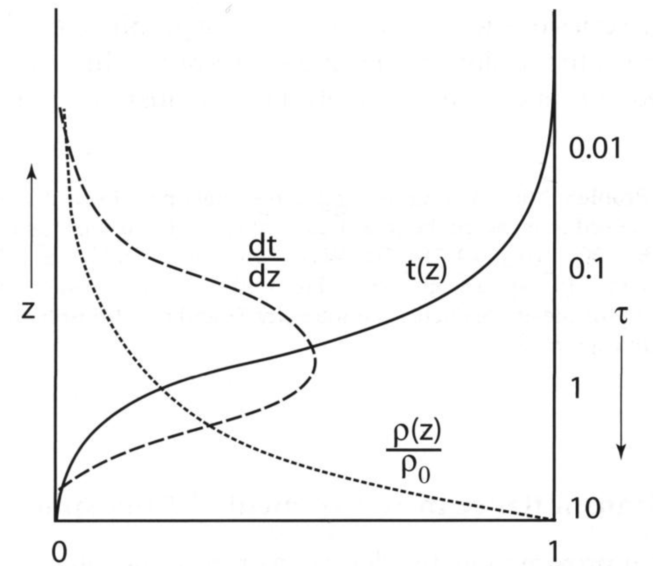
- MW spectrum / channel selection
- Viewing Geometry
- Data Assimilation
- Radiometric Performance Requirements
  - NEΔT & Bias
- Case Studies
  1. Passband uncertainties / non-linearity in FY3A MWTS
  2. Passband Shifts / drifts and Uncertainties in AMSU-A / MSU
  3. Reflector Emission and calibration anomalies in SSMIS
- Summary

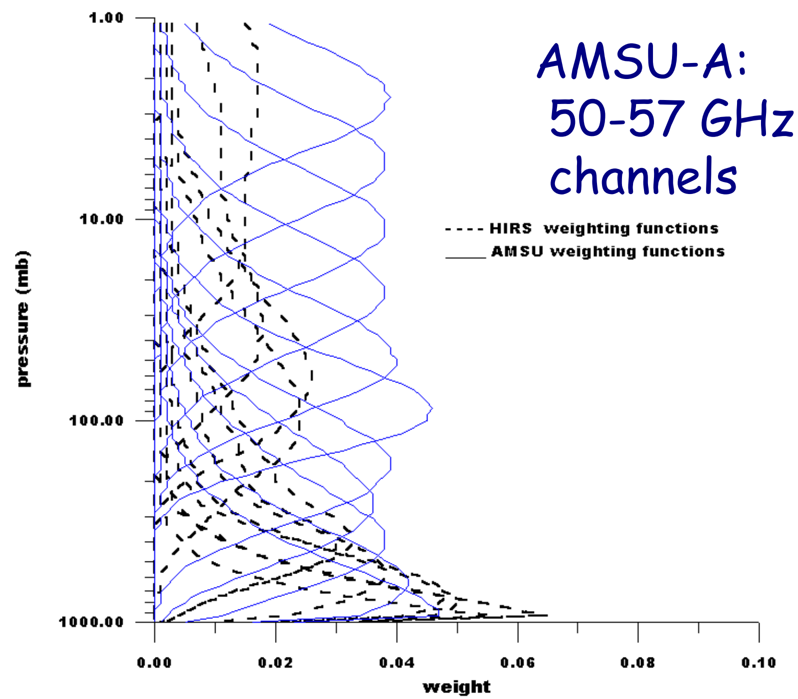
Key absorbing gases in the Microwave



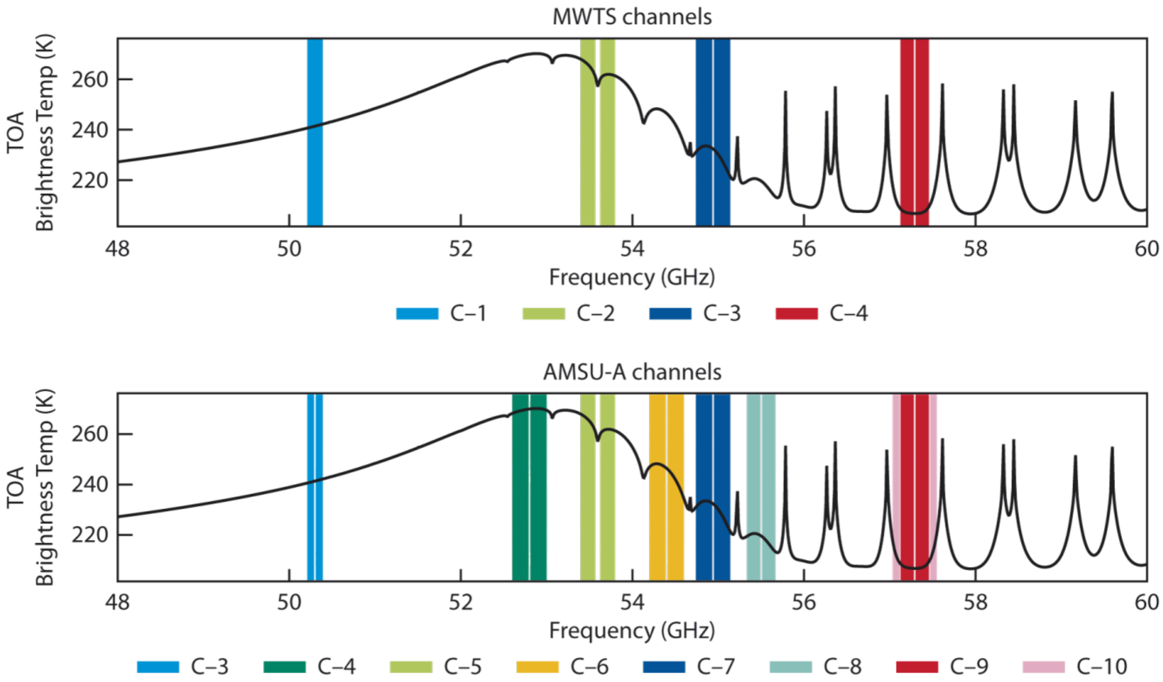
Weighting functions







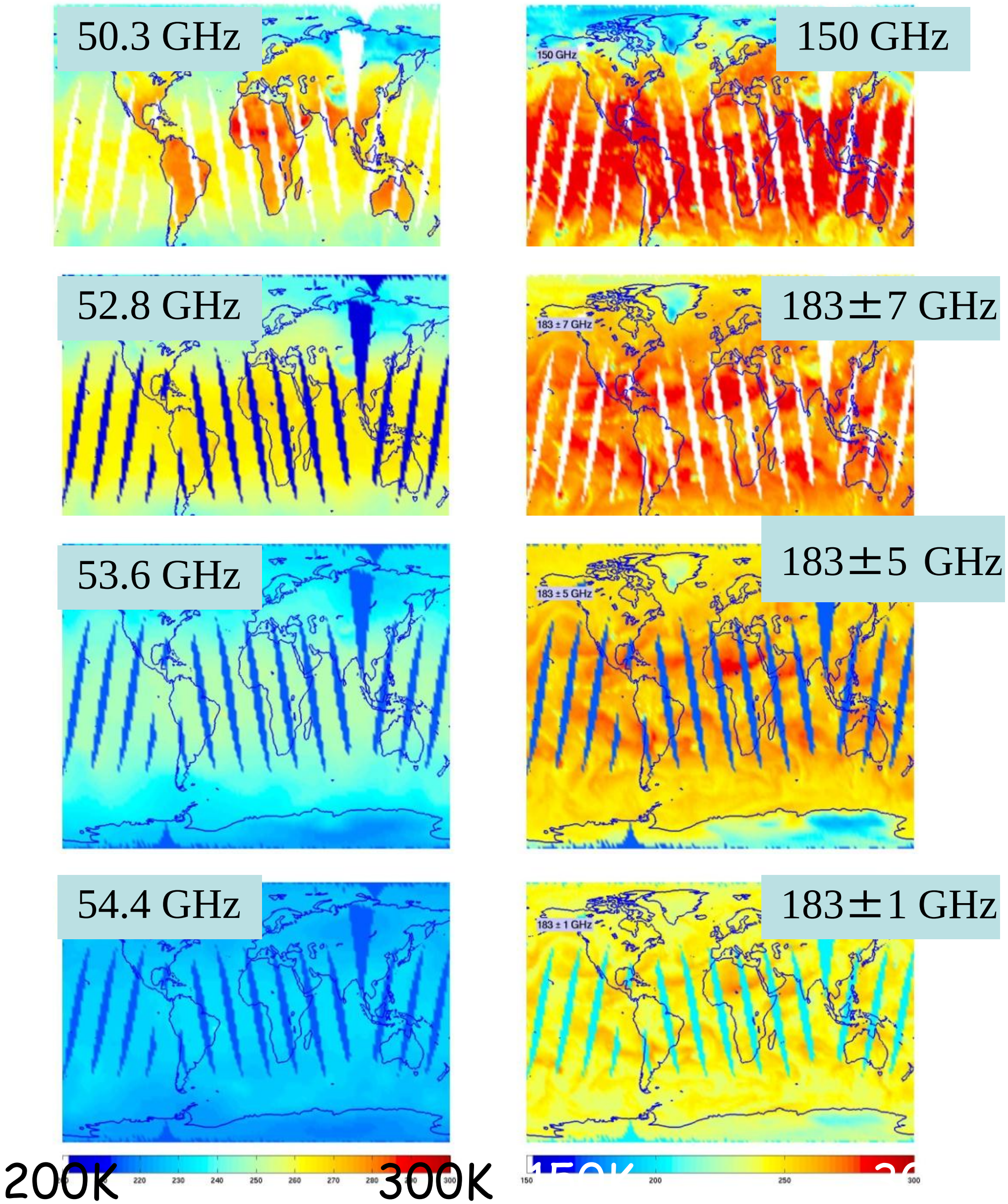
Temperature Sounding 50 - 60 GHz



Microwave sounding data:
some examples of measured radiances

Met Office

Brightness Temperature measurements obtained over ~12 hours by (F-16 SSMIS)



Microwave imagery data:
some examples of measured radiances

Met Office

Measurements
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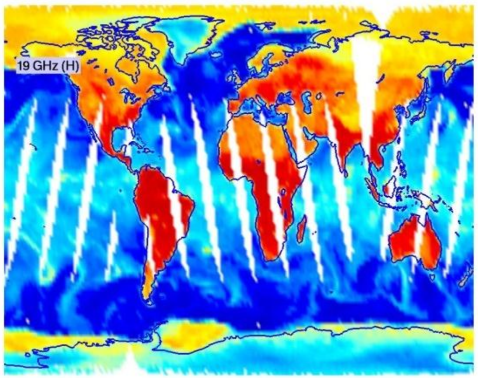
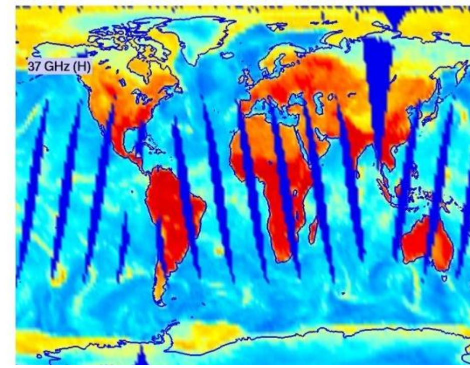
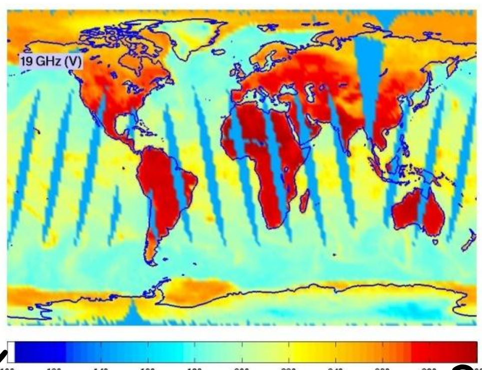
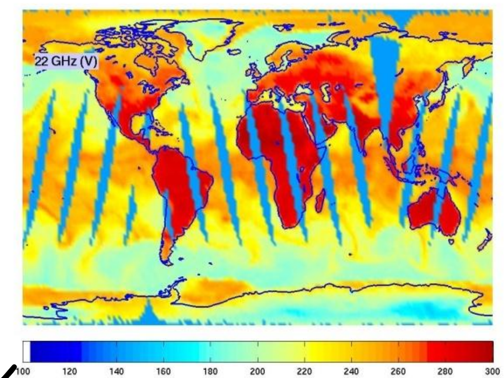
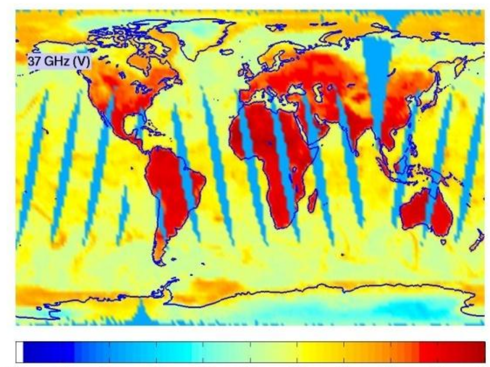






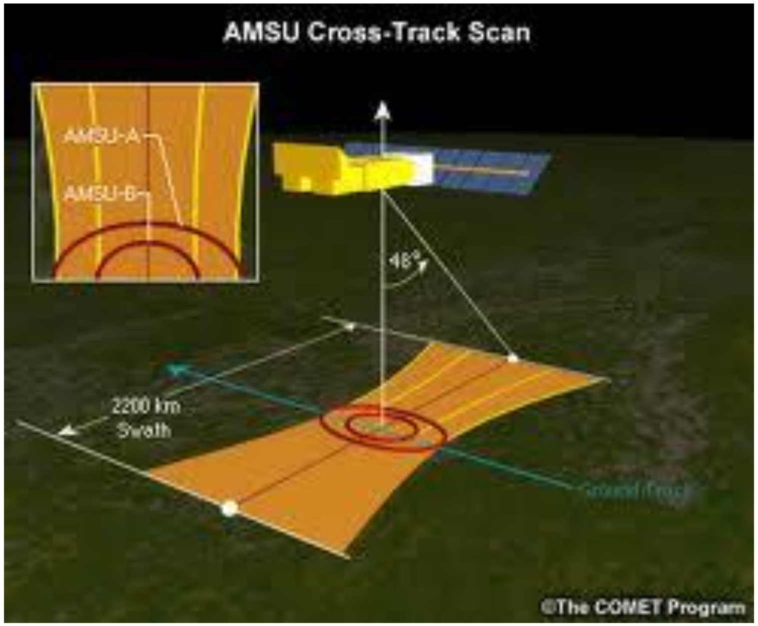


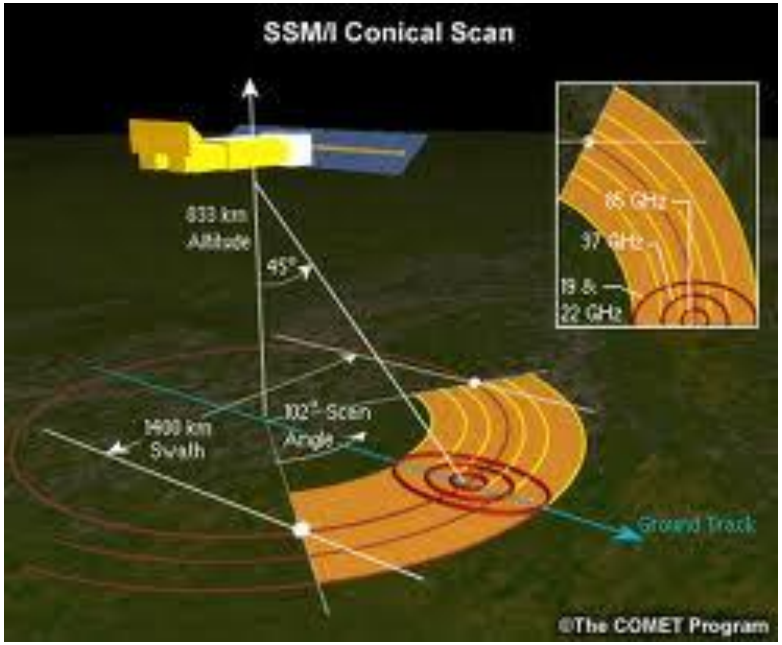


100K 300K

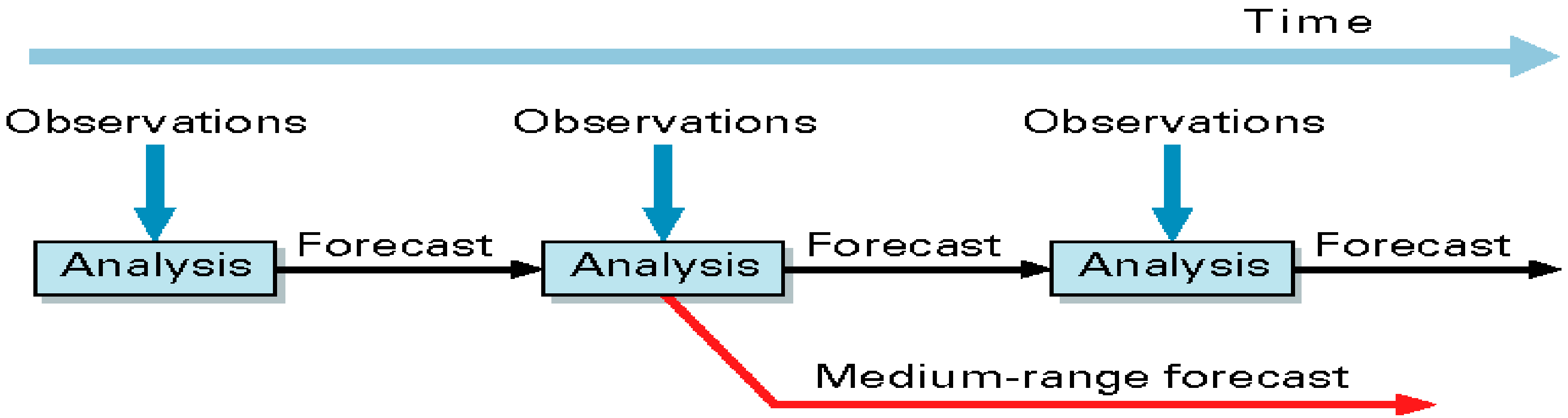
19 GHz (V pol) 22 GHz (V pol) 37 GHz (V pol)

Conical and cross track scan geometries



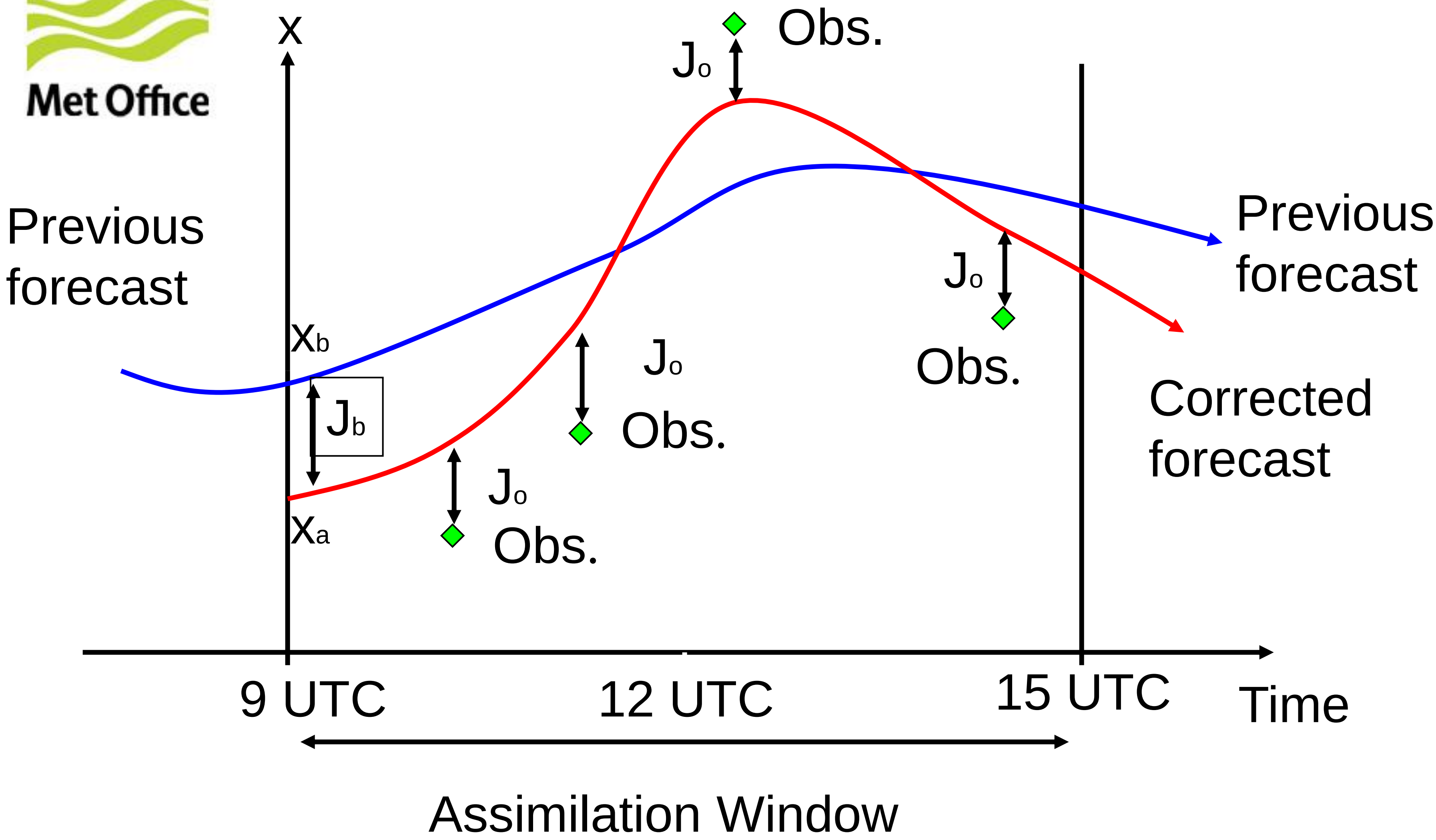


Data assimilation system (4D-Var)



- The observations are used to correct errors in the short forecast from the previous analysis time.
- Every 12 hours we assimilate 4 – 8,000,000 observations to correct the 100,000,000 variables that define the model's virtual atmosphere.
- This is done by a careful 4-dimensional interpolation in space and time of the available observations; this operation takes as much computer power as the 10-day forecast.

4-Dimensional Variational Assimilation



Minimise a cost function **J** that is the sum of :
Observation cost (**J_o**) – representing mistift to observations &
Background cost (**J_B**) – representing misfit to a background state (from previous forecast)

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Data Assimilation – Radiances

Transfer of information between radiances and control variables

Control Variable / state vector	Forecast model	State at time i	Radiative transfer	Radiance observations

$$\mathbf{x}_0 \longrightarrow M_i \longrightarrow \mathbf{x}_i \longrightarrow H_i \longrightarrow \mathbf{y}_i$$

$$\frac{\partial J}{\partial \mathbf{x_0}} \longleftarrow \mathbf{M_i^T} \longleftarrow \frac{\partial J}{\partial \mathbf{x}_i} \longleftarrow \mathbf{H_i^T} \longleftarrow \frac{\partial J}{\partial \mathbf{y}_i}$$

Wind and mass, humidity	Dynamics, moist physics	Wind and mass, humidity, clouds and rain	Clear, cloud and rain including scattering	Clear, cloud and rain

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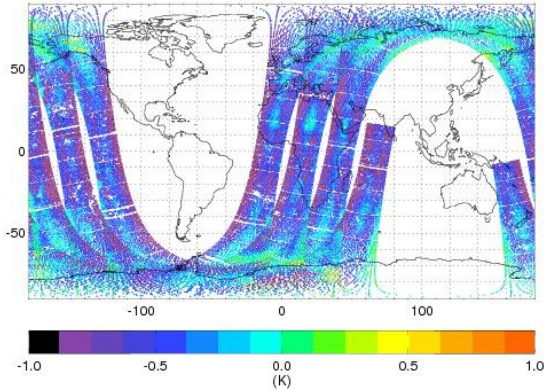
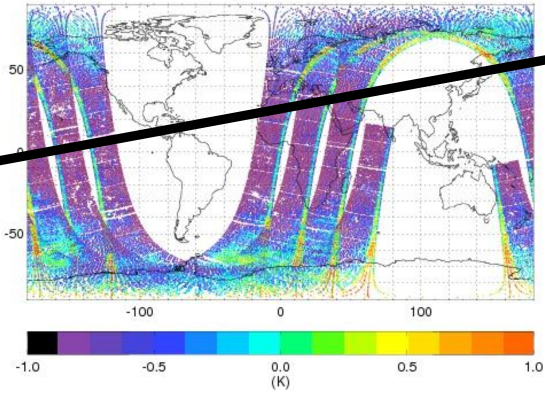
How large are the errors we are trying to correct ? e.g. for temperature sounding channels

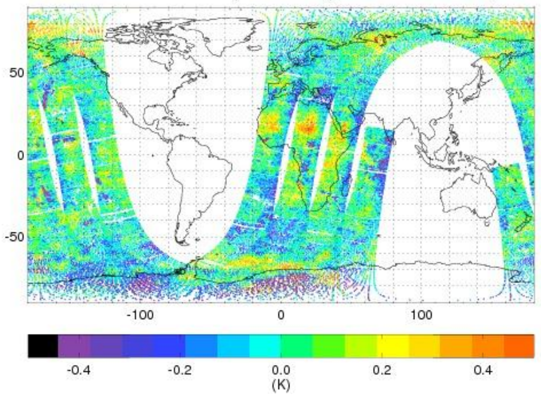
NOAA19 ch6, O-B, 08/11 QU00



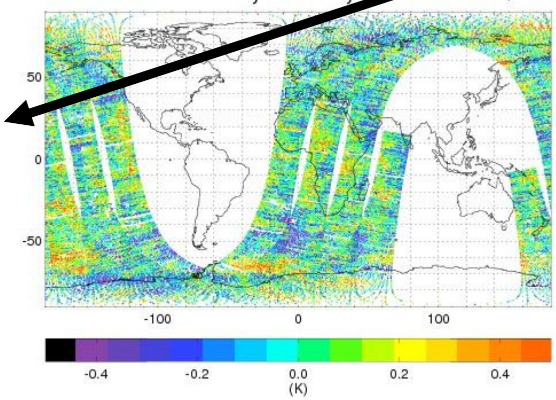
NOAA19 ch7, O-B, 08/11 QU00



NOAA19 ch6, C-B, 08/11 QU00



NOAA19 ch7, C-B, 08/11 QU00



prior to bias correction: large scale biases of ~0.5K (peak-peak)

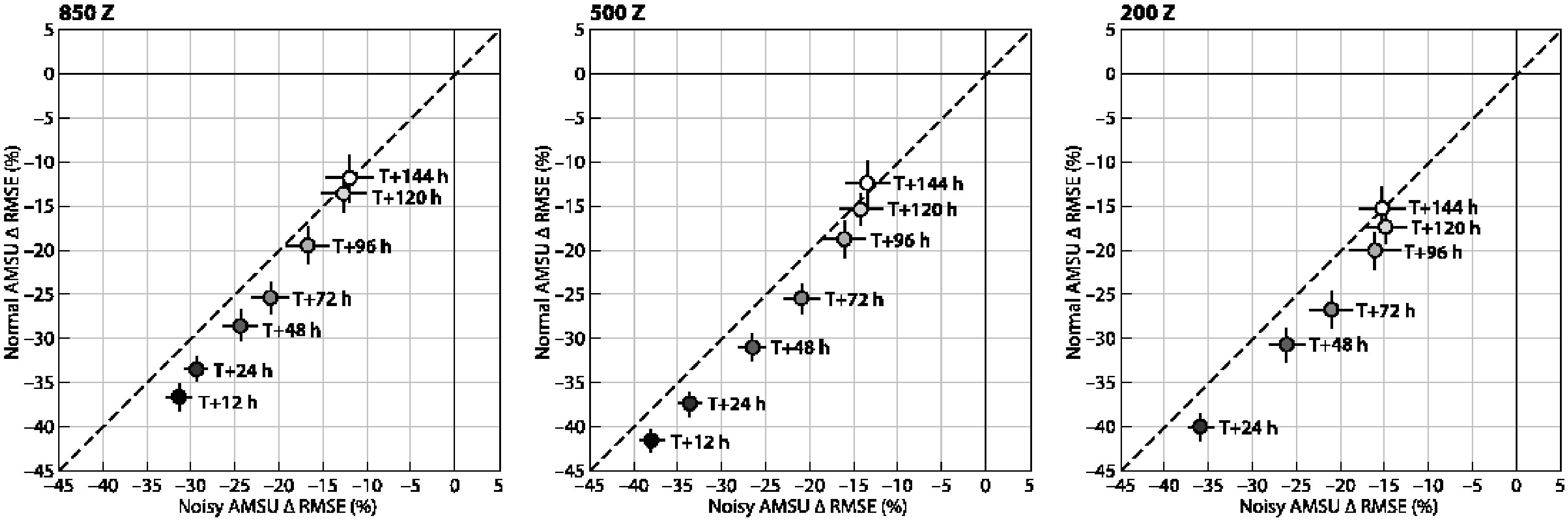
after bias correction: geophysical signals : ~ 50-100 mK (stdev)

NEΔT ~ 100 -200 mK

- Radiometric performance specifications (noise and bias) are demanding - for temperature sounders

- Errors in forecast fields for humidity are larger (1-2K in T_B) – therefore specifications are less demanding

The importance of low NEΔT for temperature sounding channels



Perform experiments in which synthetic noise is added to real AMSU-A data (taking noise from 0.15K → 0.25K)

SH forecasts degraded (by ~10%) by noisy data,
relative to the impact of normal AMSU.

Impacts are largest for mass related fields (T, Z, PMSL)

CASE 1:
Passband Uncertainties and Radiometer non-linearities in China's FY-3A MWTS Instrument

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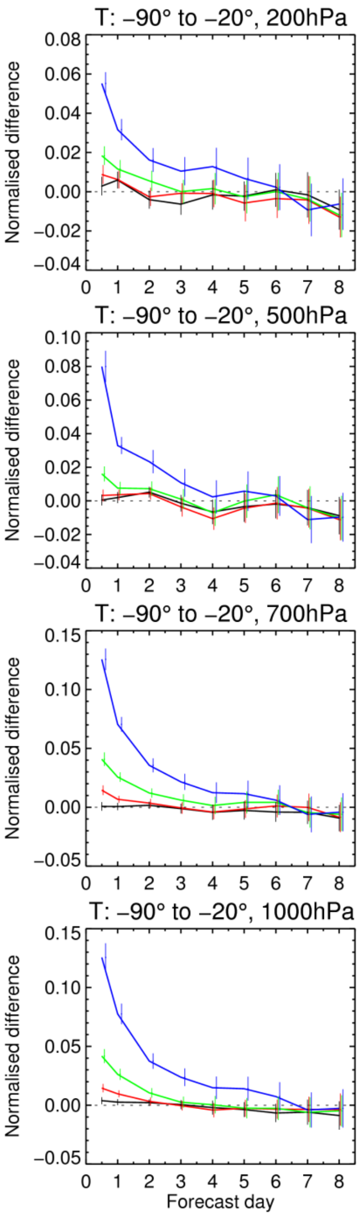
LO Frequency Drift Specification for MW sounders



<u>Approach:</u>

Parametrise errors in T_B resulting from shifts in passband

- Run a series of observing system experiments in which brightness temperature errors are added to real AMSU-A observations for various shifts:

  20 MHz
  10 MHz
  5.0 MHz
  1.5 MHz

- Verify forecasts

↓

<u>NWP requirements</u>: 5 MHz or better, or analyses and forecasts degraded.

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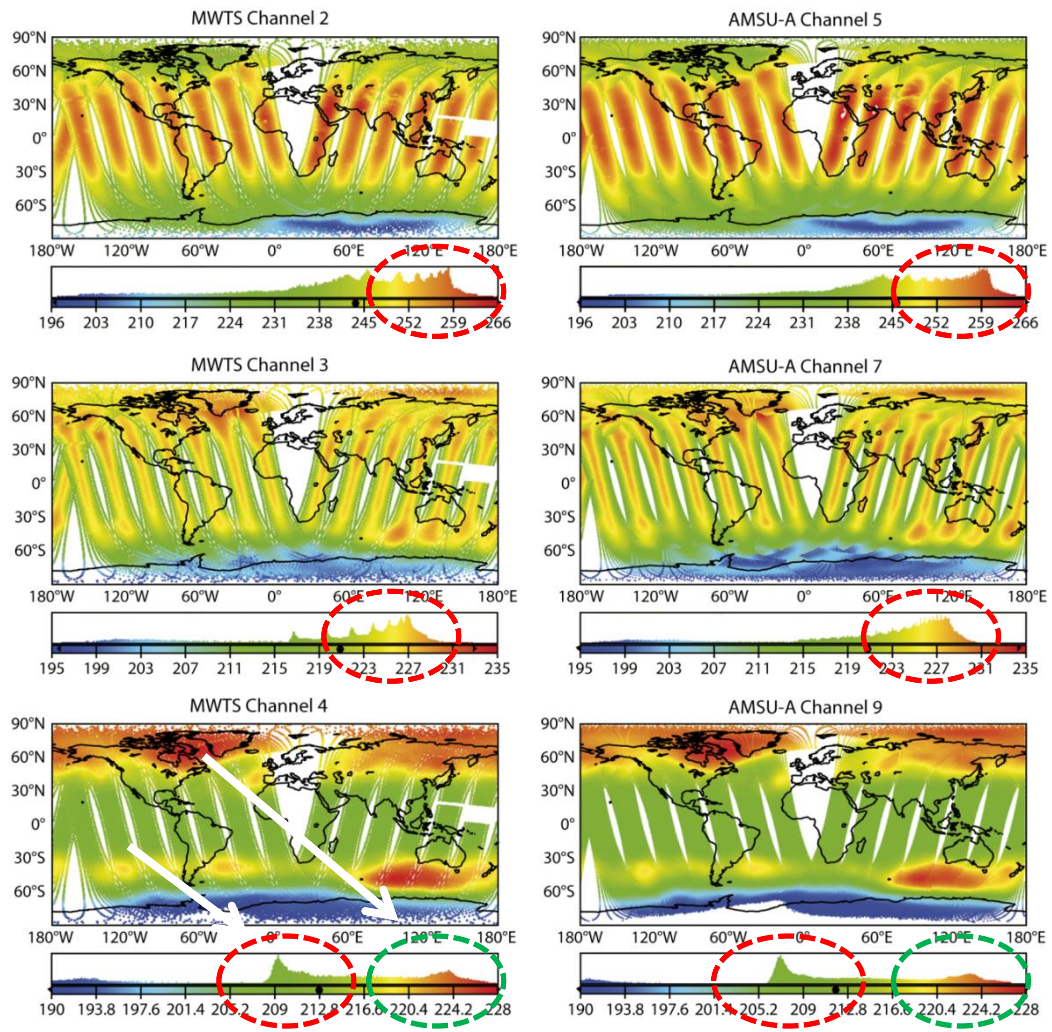
MWS Biases - CASE 1 FY-3A MWTS

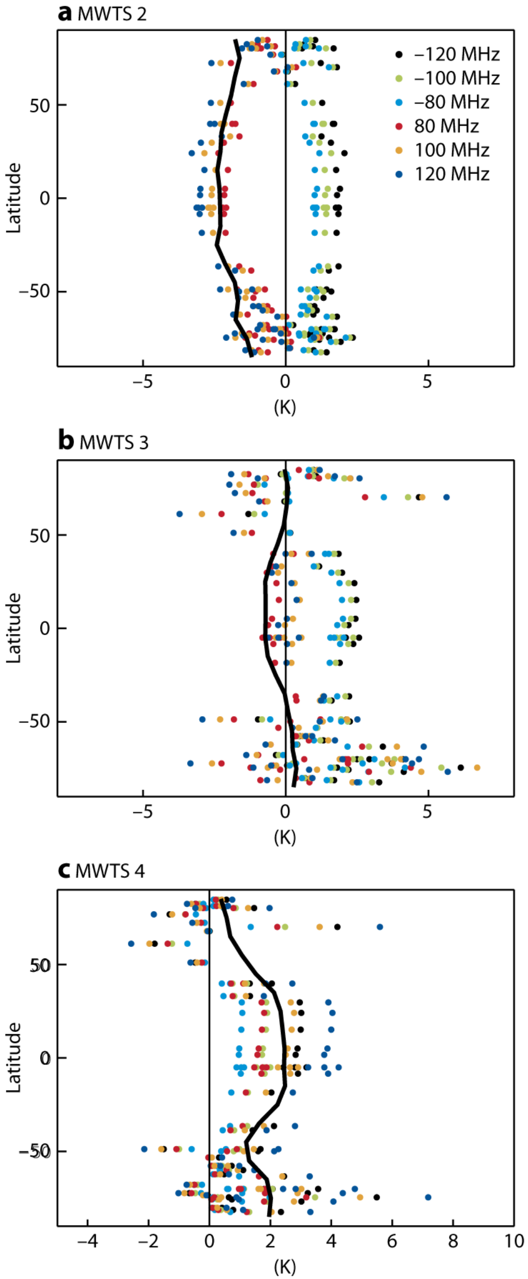
Comparison of MWTS and AMSU-A Brightness Temperatures

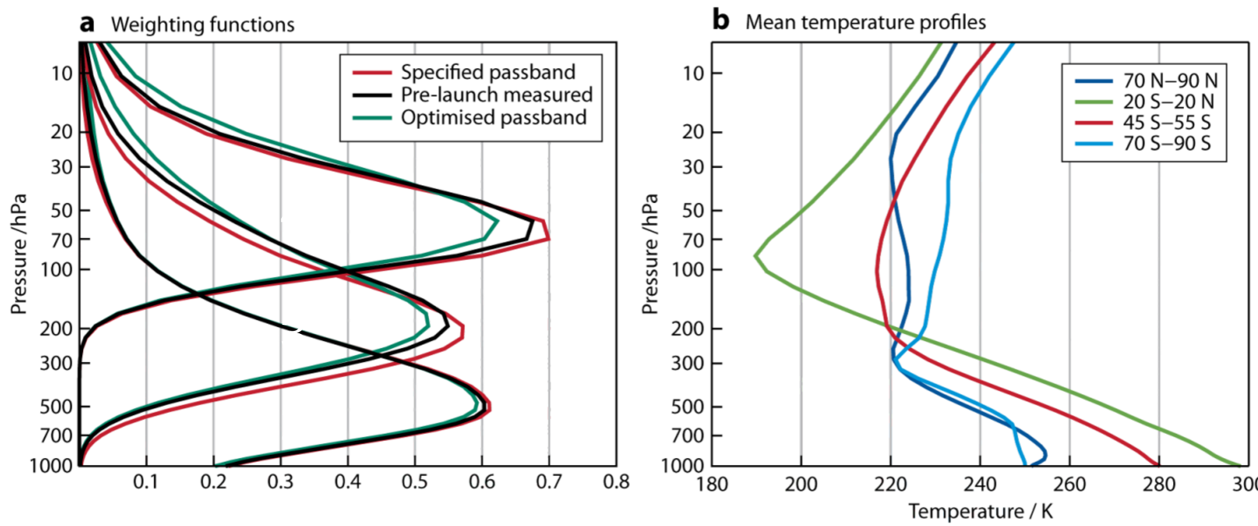


- Recent studies (2009) had shown that LO shifts / drifts / uncertainties > 5 MHz would adversely affect NWP analyses and forecasts

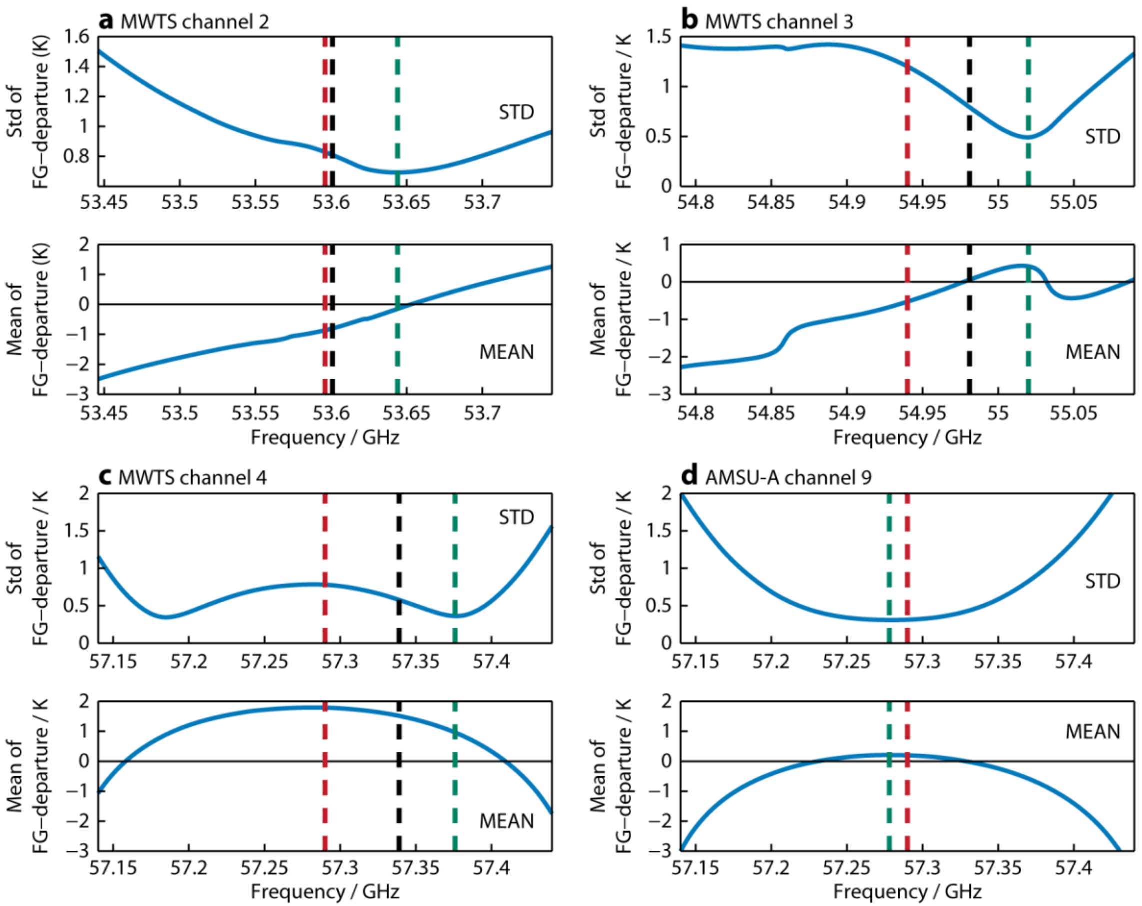
Latitude dependent biases *could* be explained by channel frequency drift

CASE 1: FY-3A MWTS
State dependence of frequency drift errors : lapse rate dependence





CASE 1:
Optimisation of FY-3A MWTS Pass Band Centre Frequency Estimates



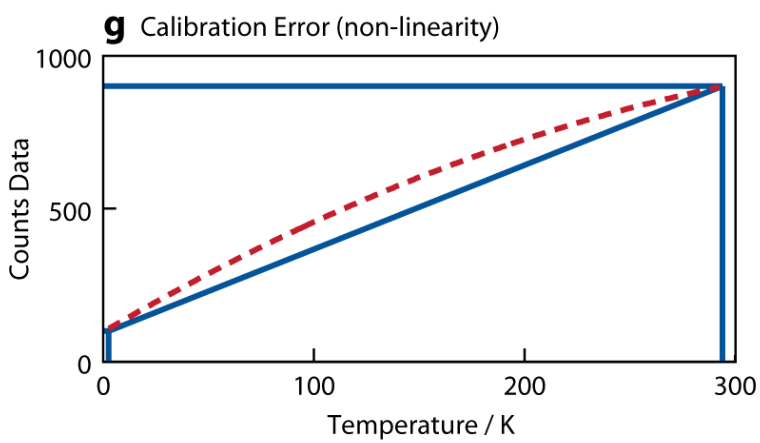
Pass band centres:

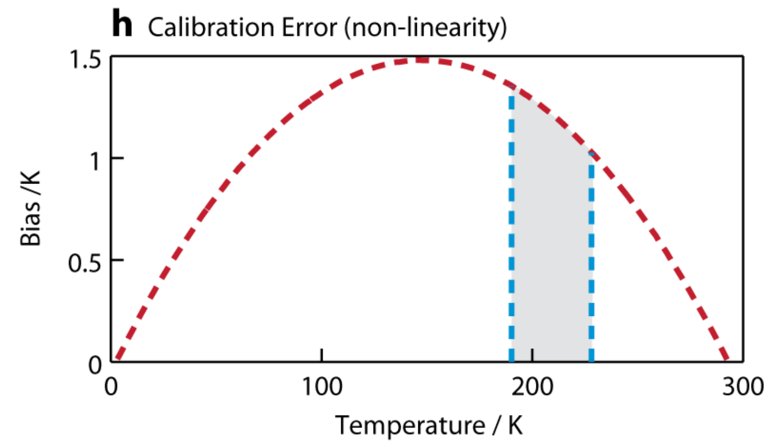
design spec.
measured
optimised

- Use line-by-line RT modelling to analyse pass band errors

- Analysed errors are large 30-55 MHz relative to pre-launch measurements

MWTS Radiometer Non-linearity

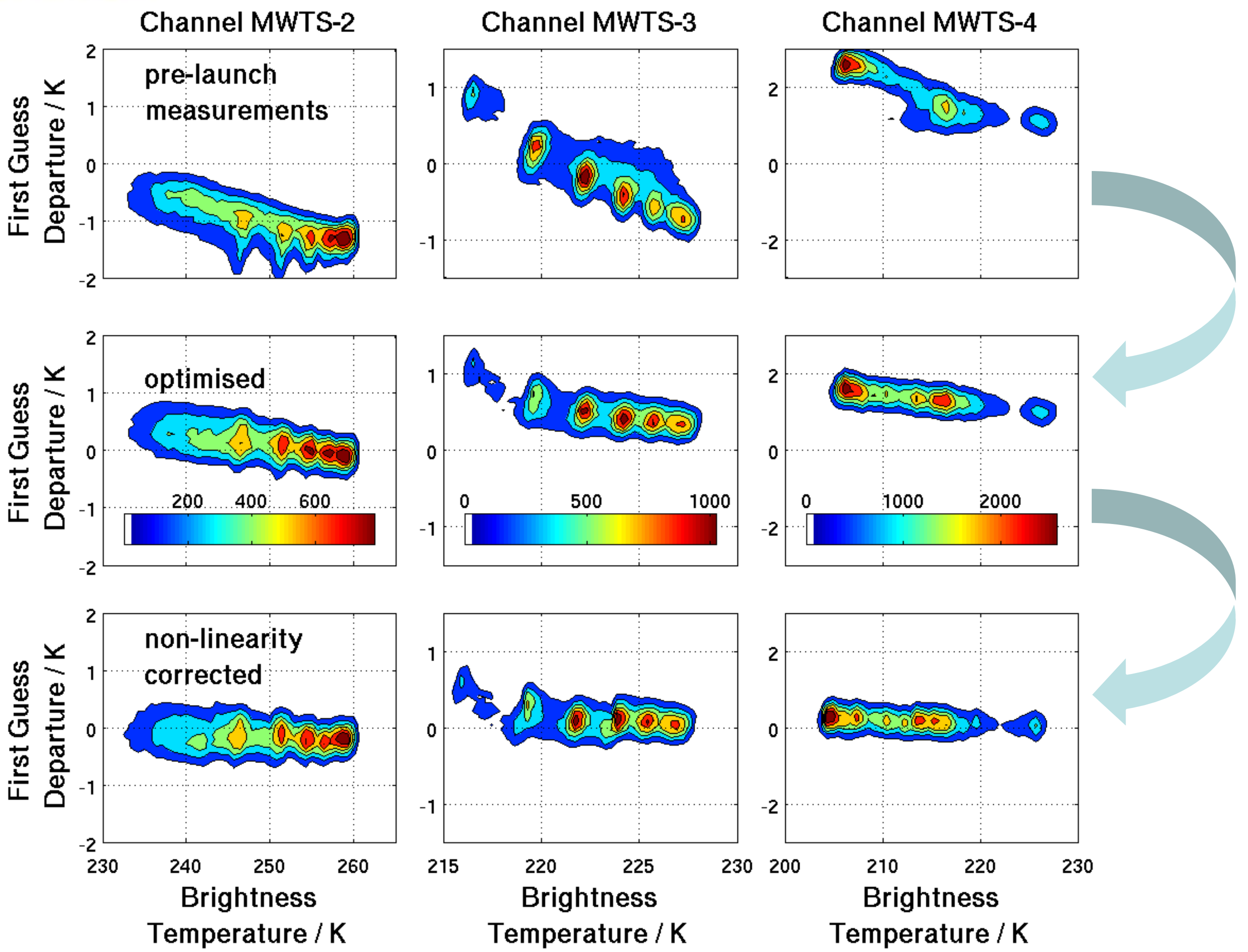




In general the response of a MW radiometer will be slightly non-linear wrt the measured scene temperature.

If perfect linearity is assumed between the 2 calibration points (cold space and a warm target) then an error (bias) results

MWTS Radiometer Non-linearity

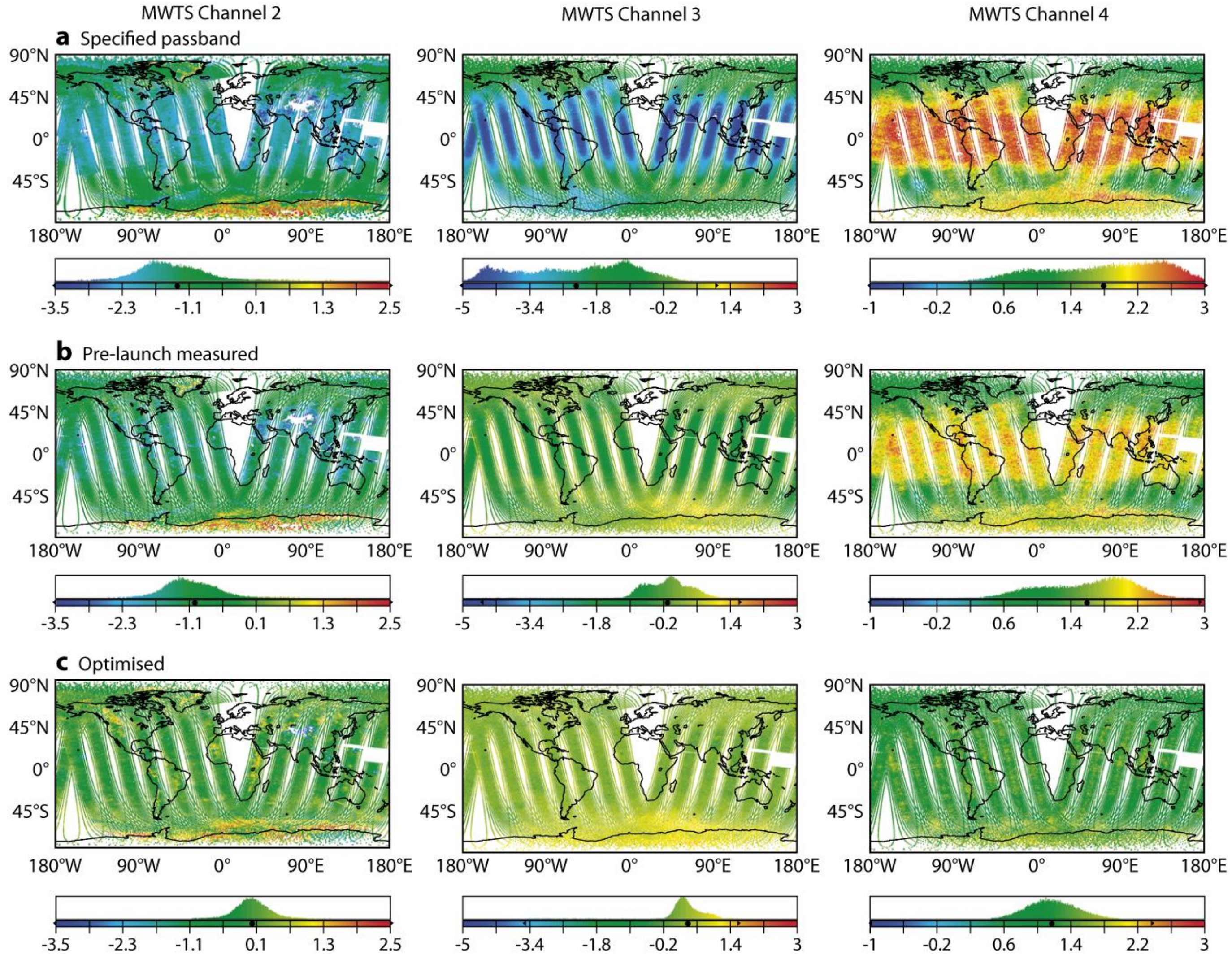


Adjust passband: variance reduced

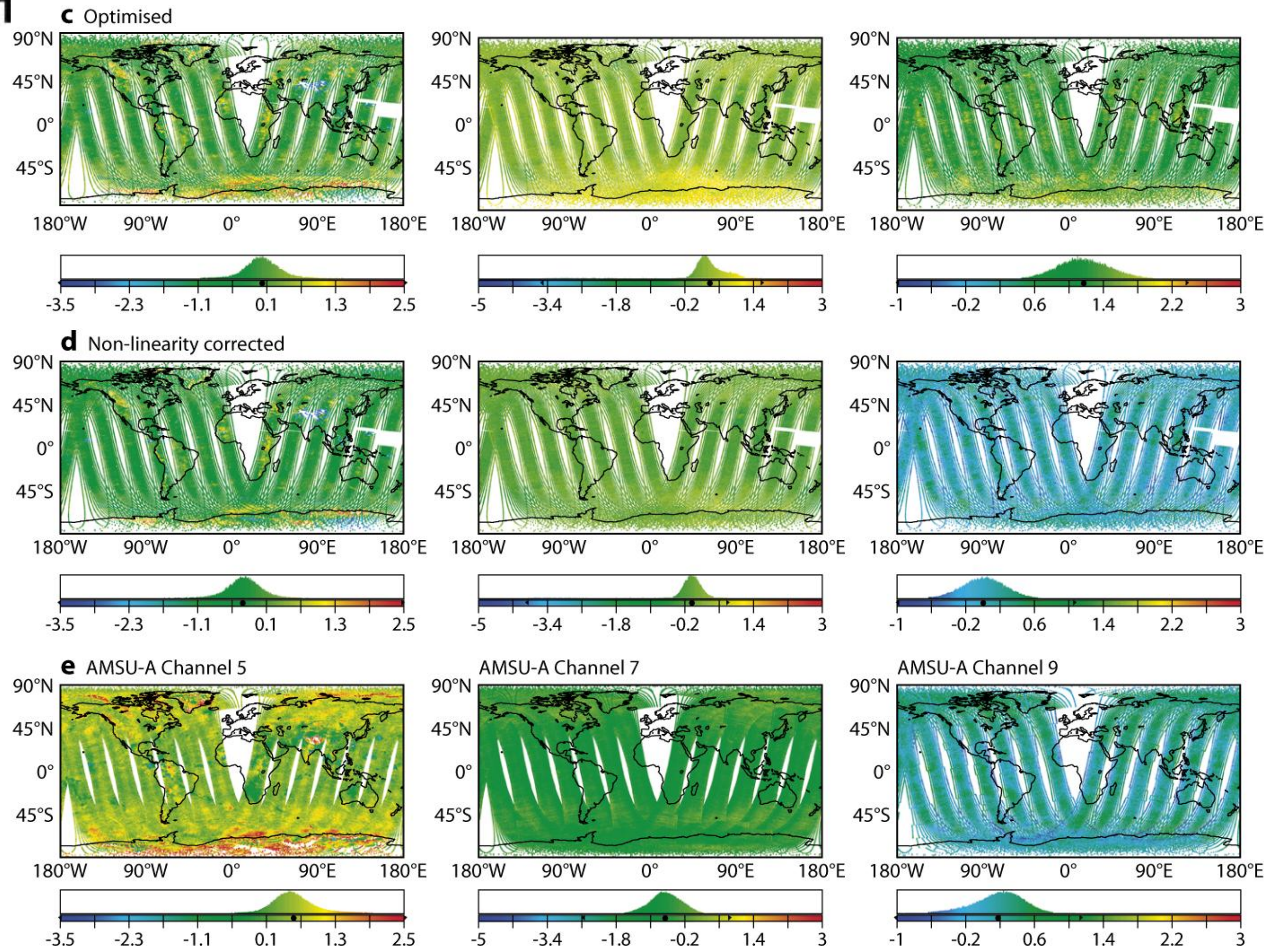
Corrected for non-linearity: leaves locally unbiased data

Improved FY-3A MWTS Data Quality

First Guess Departures / K

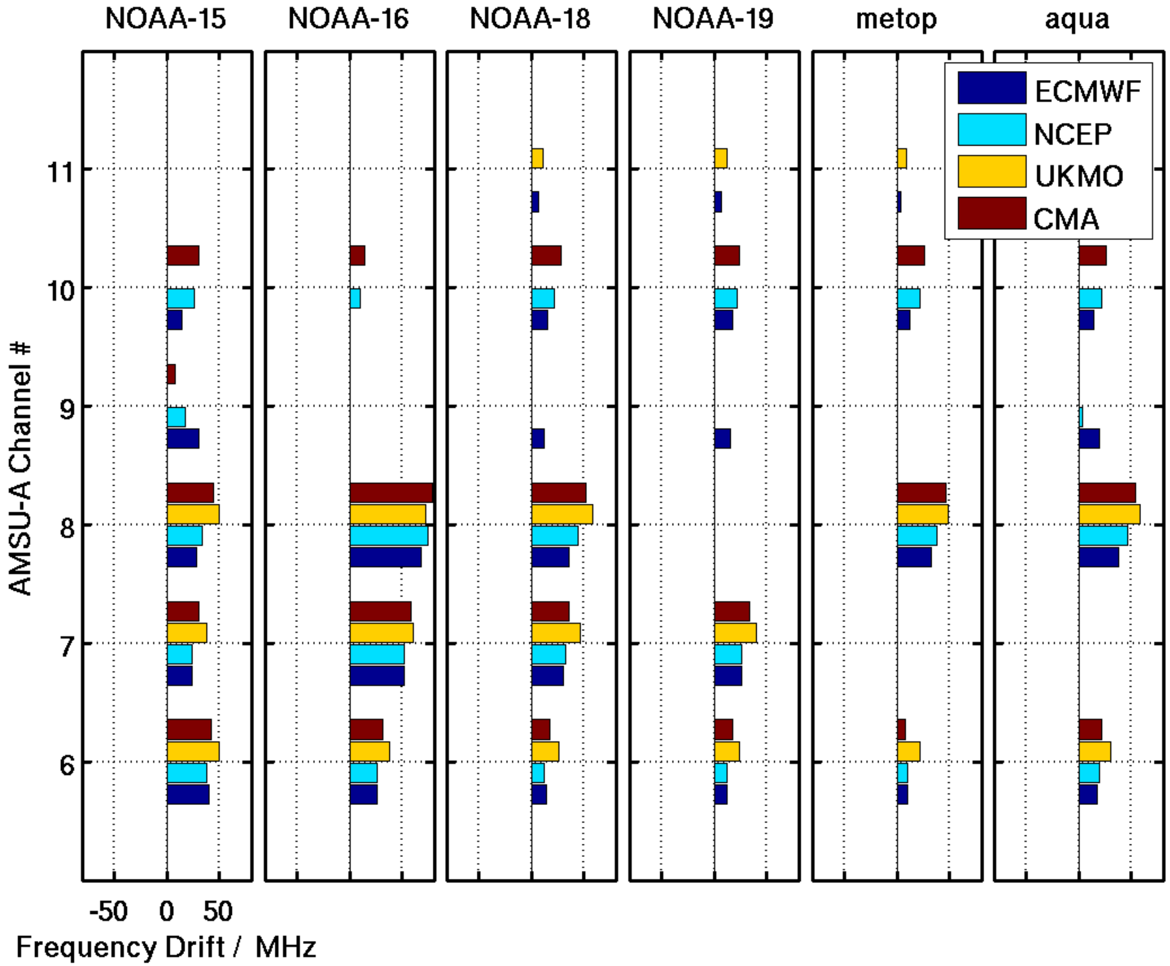


Improved MWTS Data Quality



CASE 2:
Passband Drifts , Shifts and Uncertainties in AMSUA / MSU

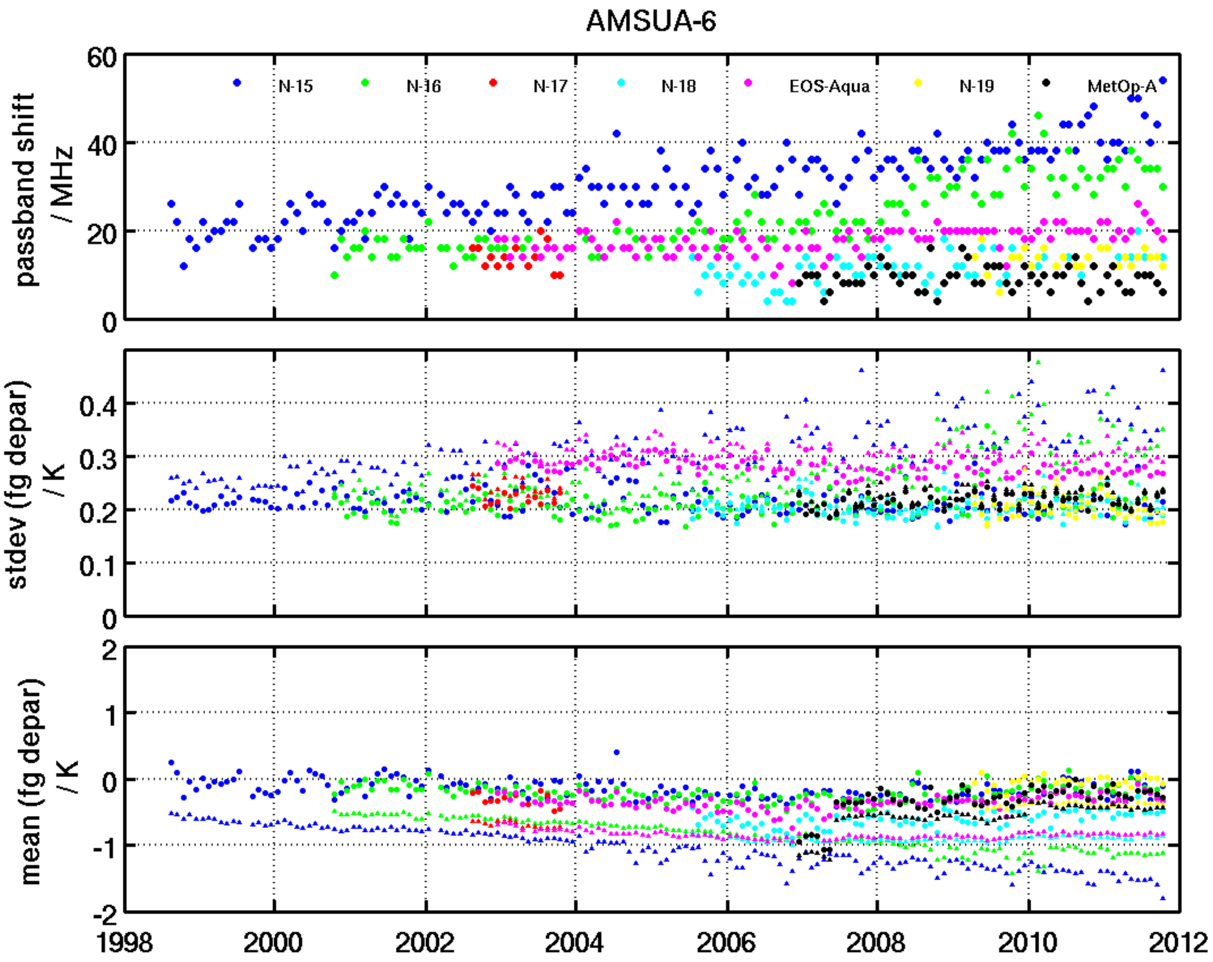
CASE 2: AMSU-A Passband Shifts and Drifts
Analysed Frequency Shifts for AMSU-A:



Similar results obtained From 4 NWP models (ECMWF, UKMO, NCEP, CMA)

Small positive bias (+10MHz) in UKMO results possibly due to error in level calculations.

CASE 2: Analysed Frequency Shifts for AMSU-A : Time Dependence (Channel 6)

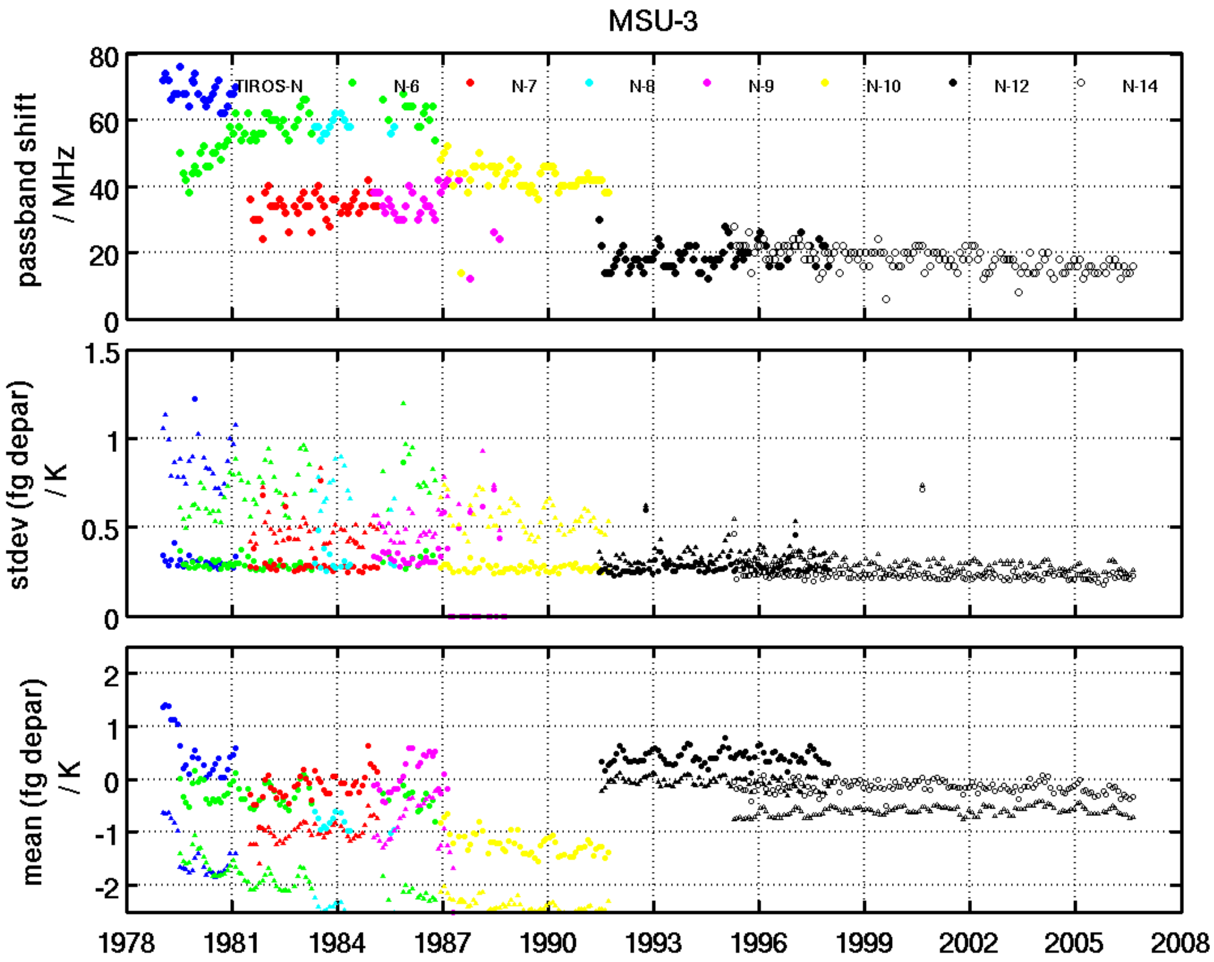


Drifts (NOAA-15 & NOAA-16) and offsets evident

Most recent satellites (NOAA-19 and metop) show smallest shifts

NOAA-15 analysed drift (41MHz in 2011) consistent with SNO derived shift of 36 MHz

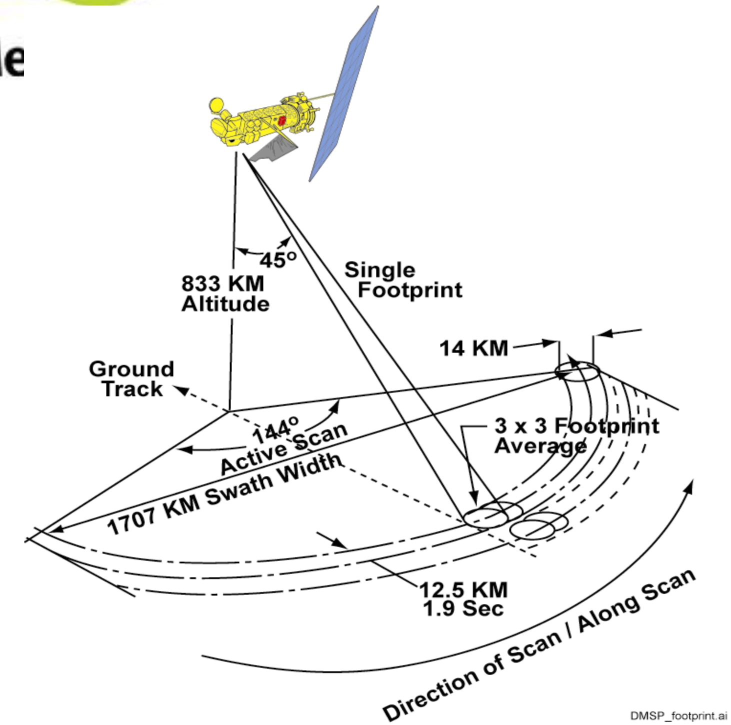
CASE 2: Analysed Frequency Shifts for MSU : Time Dependence (Channel 3)

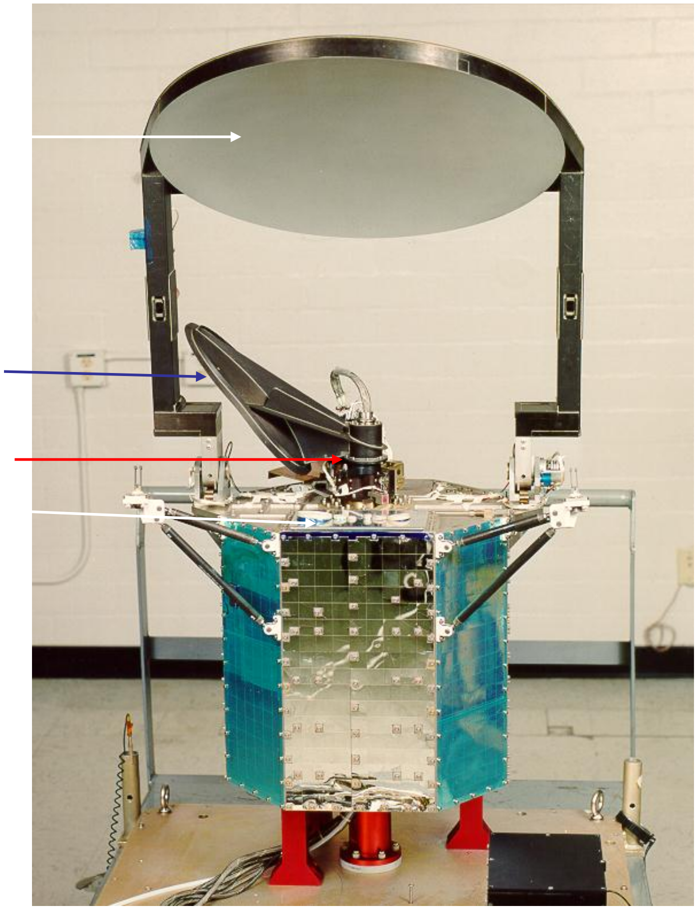


Large offsets for all satellites, earlier satellites worse

Accounting for passband shifts significantly improves fg departure statistics (mean and standard deviation) – see following slides.

CASE 3: SSMIS – A conical microwave sounder





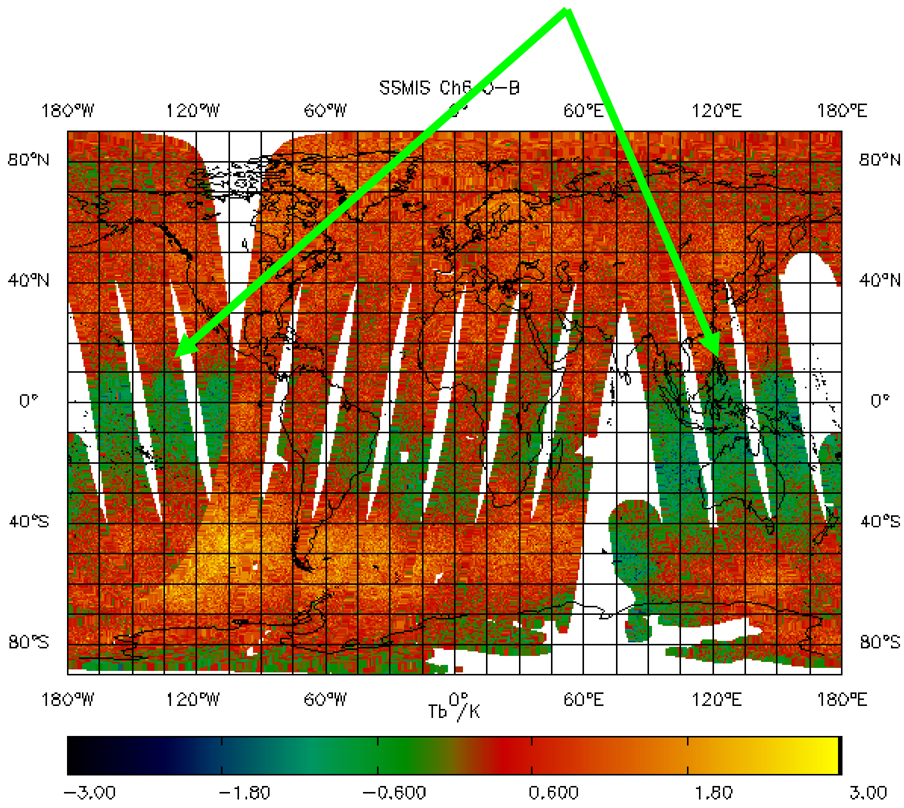
F16 launched October 2003
F17 launched November 2006
F18 launched October 2009
F19 & F20 : 2012 – 2015

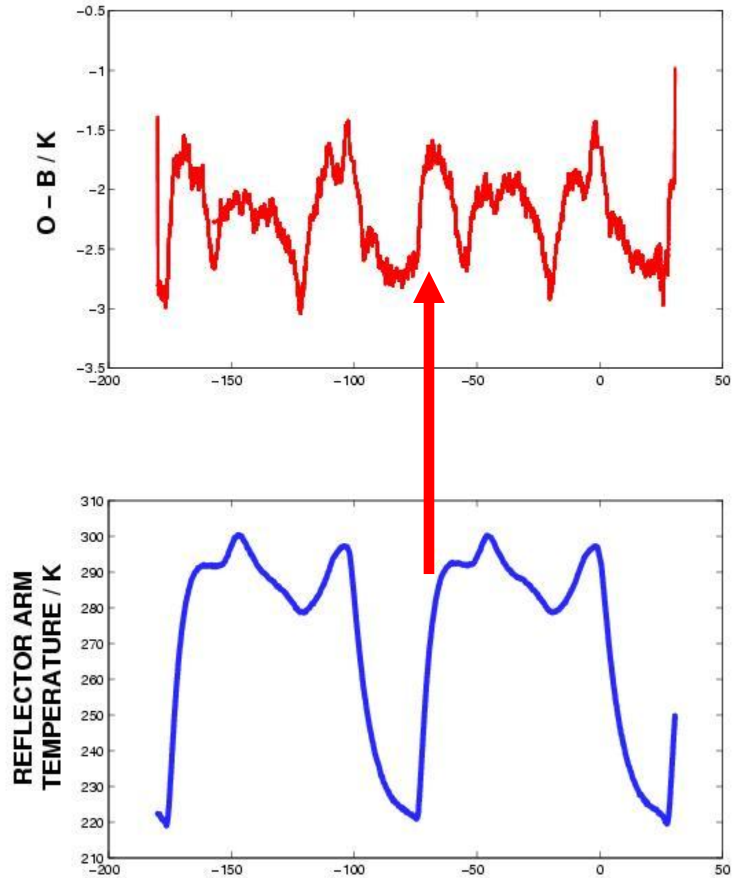
Special Sensor Microwave Imager/Sounder (SSMIS)

CASE 3: SSMIS – A conical microwave sounder
Reflector Emission

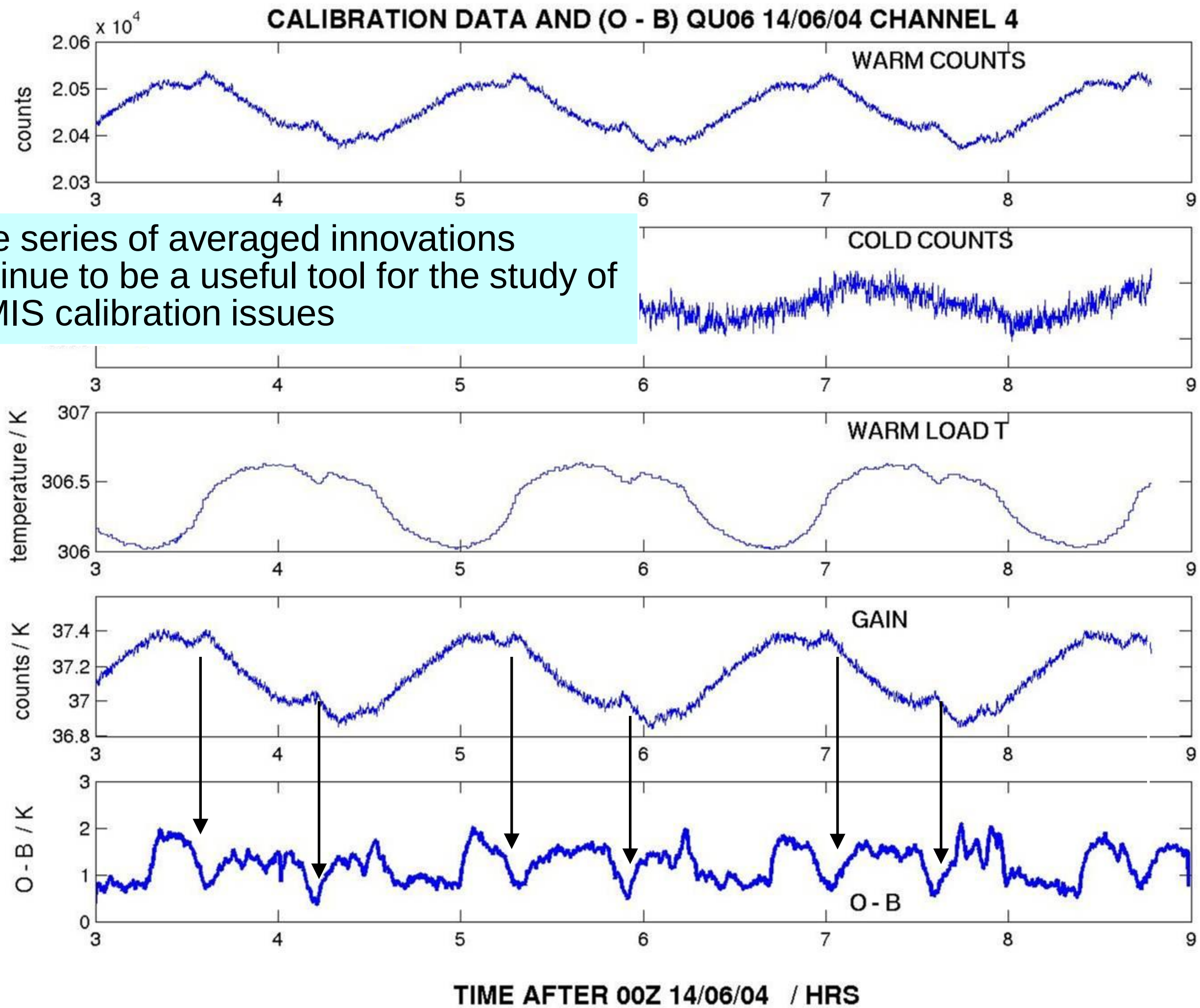
Met Office

Problems in ascending node
not evident in descending node





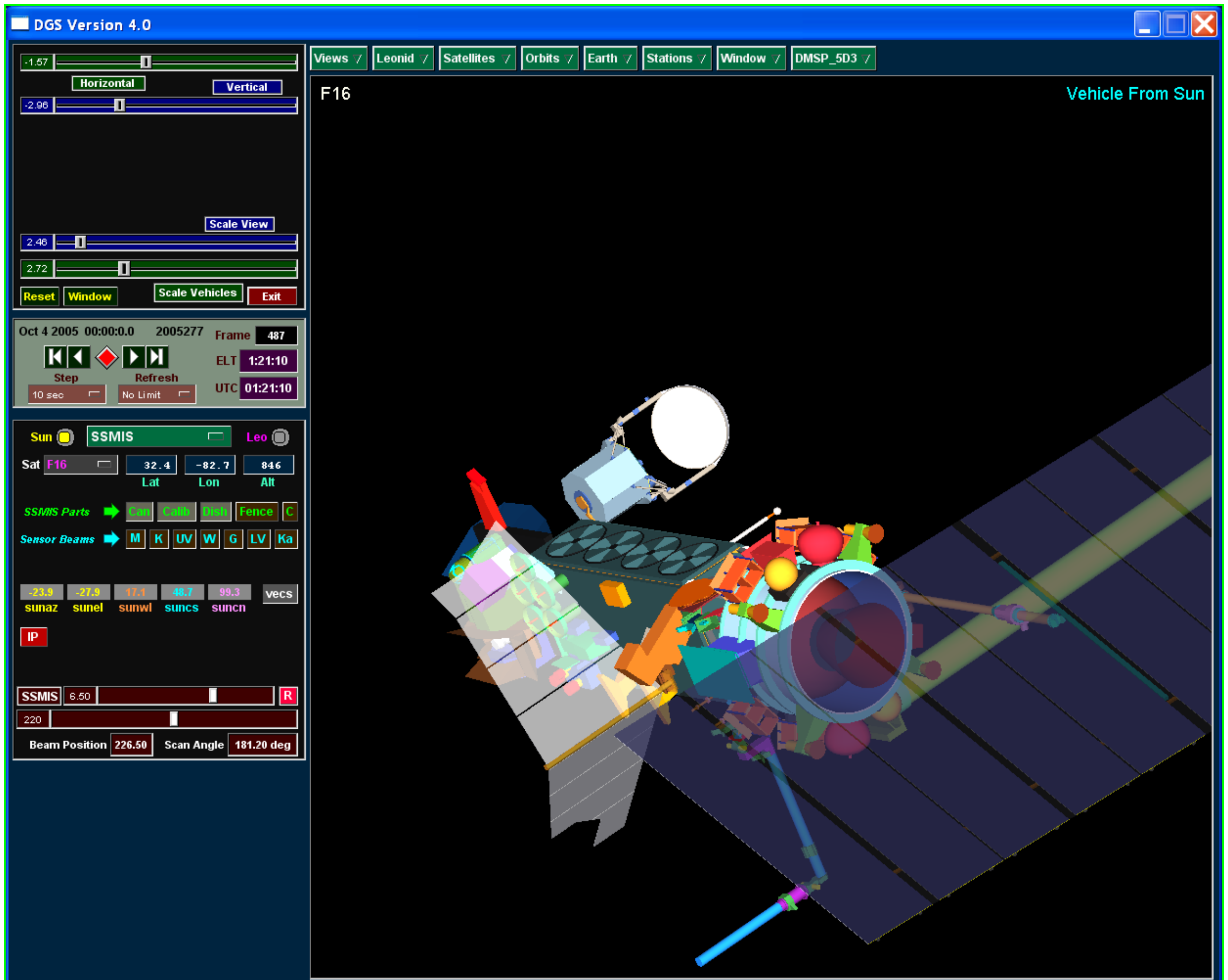
CASE 3: SSMIS – A conical microwave sounder
Warm load solar intrusions



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

Met Office

CASE 3: SSMIS – A conical microwave sounder Emergence from Earth Shadow



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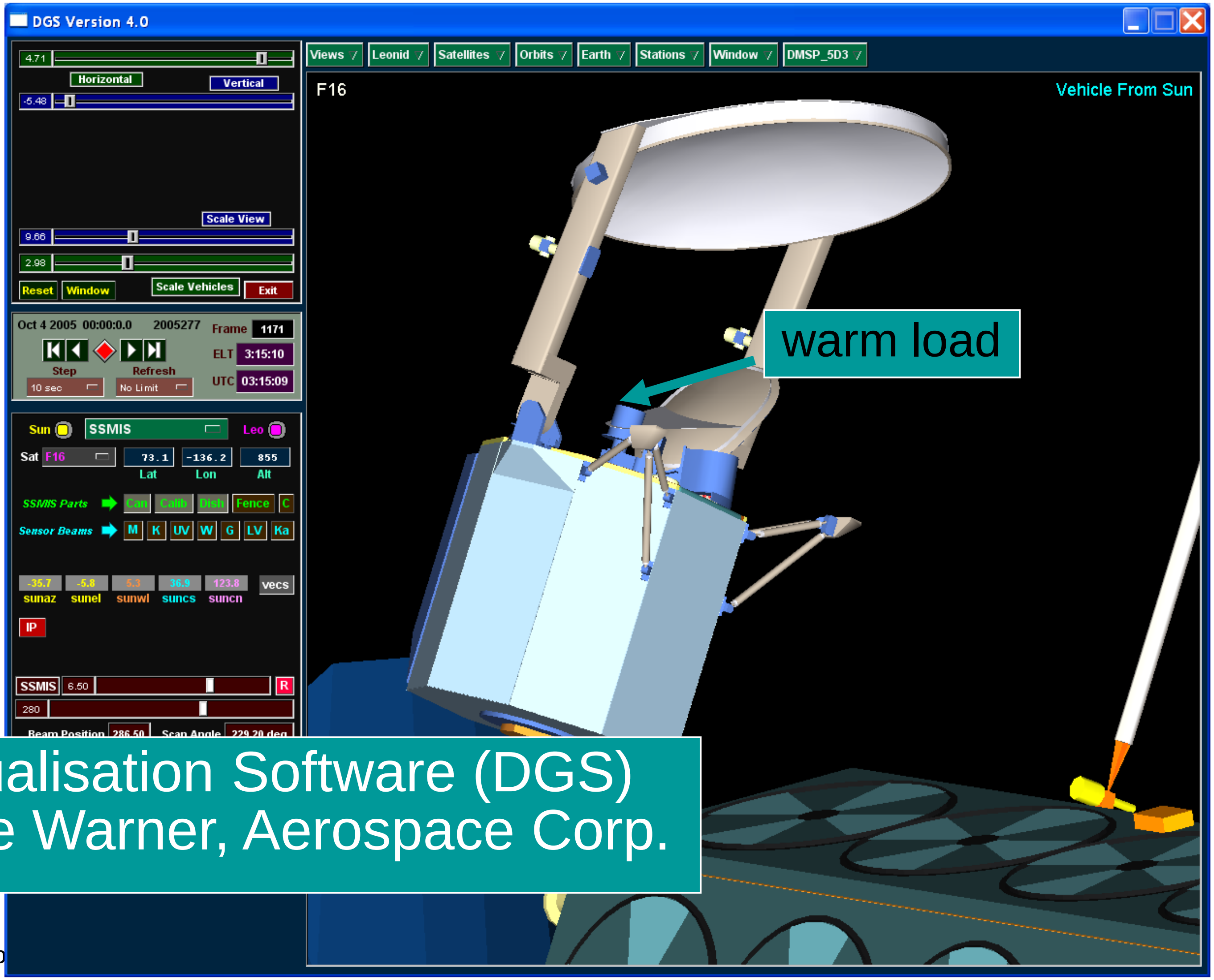
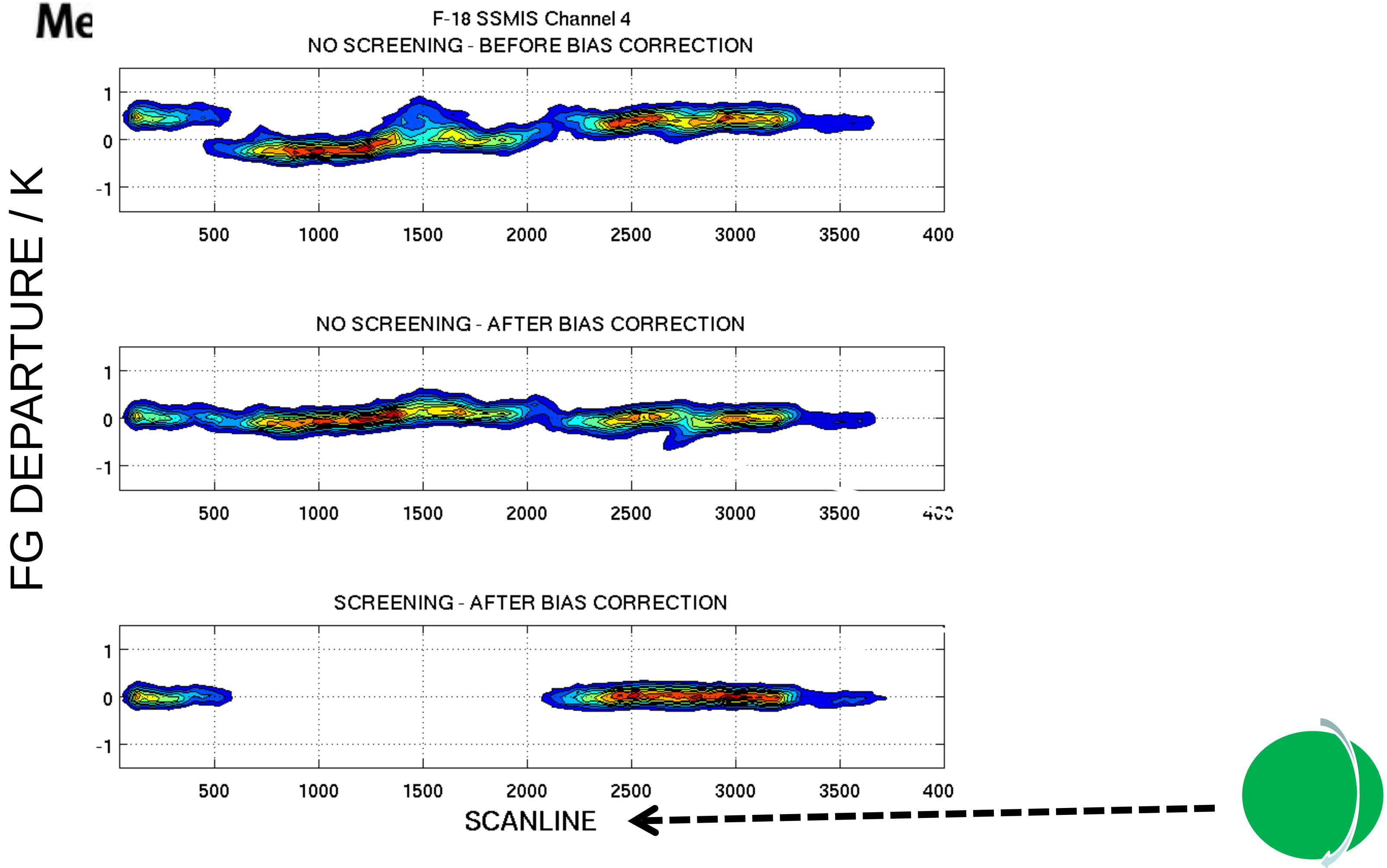


Visualisation Software (DGS)
Mike Warner, Aerospace Corp.

CASE 3: SSMIS – A conical microwave sounder
ASC / DESC bias in latest SSMIS (F18)



Summary

- Microwave Sounding Data (50-60GHz, 183GHz): has been, is , and will continue to be very important for NWP, Climate and Reanalysis.
- The radiometry, especially for temperature sounding instruments, is very demanding & most instruments to date are subject to complex biases
  - NWP have developed bias correction schemes, subject of ongoing research;
  - The biases present an ongoing challenge for climate and reanalysis applications;
  - Can the next generation of instruments (EPS-SG) eliminate these biases ?