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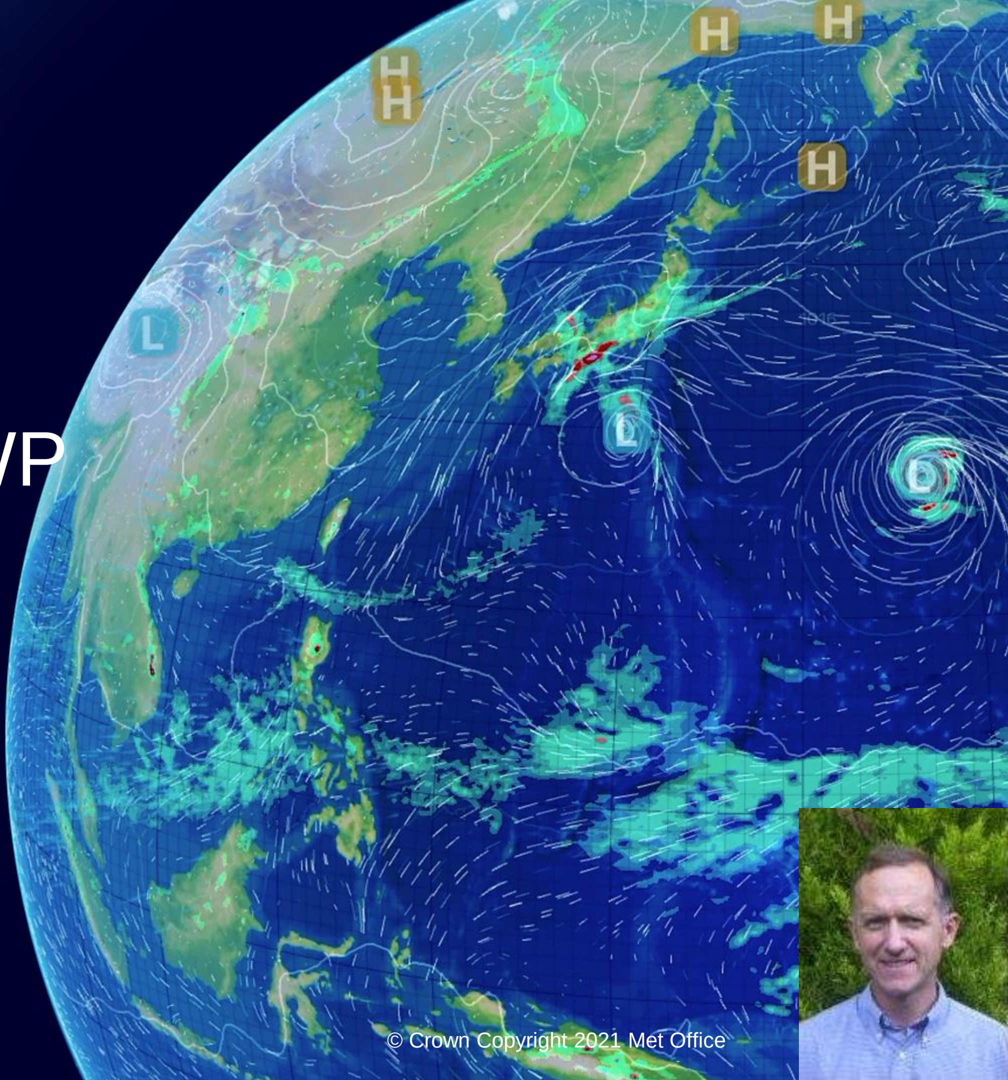
Observation processing and calibration: how to assess errors in level 1 radiances; the role of NWP in cal/val



Nigel Atkinson

ECMWF Annual Seminar 2021

nigel.atkinson@metoffice.gov.uk

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Contents

- Steps to good quality data: satellite instrument life cycle, from specification to reanalysis
- Pre-launch testing
- Some cal/val investigations
- A “rogues gallery” of instrument problems that we have encountered at various stages of this process

Steps towards good quality data

1. Ensure that instrument specifications are appropriate for requirements
2. Procure a well-designed instrument – and understand how it works
3. Pre-launch characterisation
4. Algorithm Theoretical Basis Document (ATBD) and Processing Specifications
5. Produce well-written software for central processing and (if applicable) direct broadcast
6. Commissioning of satellite and instrument, usually including a dedicated cal/val phase
7. Monitor the operational data, using whatever tools are available (including NWP comparisons)
8. Long-term trending
9. Reanalysis

Specifications and user requirements

Usually takes place years or even decades before launch

User requirements drawn from several sources, e.g.

- WMO (rolling review of requirements; gap analyses; etc.)
- Met centres (e.g. EUMETSAT member states and ECMWF)

Aim to produce requirements in a technology-free way

- Not easy! E.g. choice of frequencies and bandwidths inevitably depend on technology

Satellite agency (e.g. ESA for a new design) converts the requirements to a specification

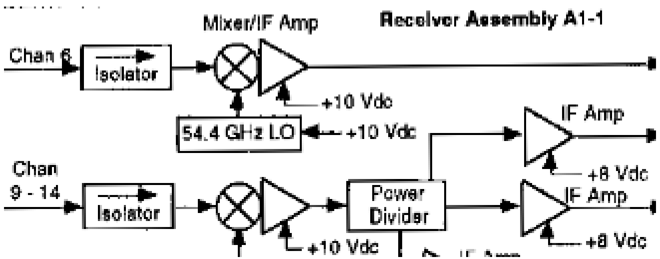
Then the instrument contractor translates those requirements into a realistic design.

- This may be an iterative process
- Science Advisory Groups may play a role (e.g. SAGs exist for EPS-SG instruments)

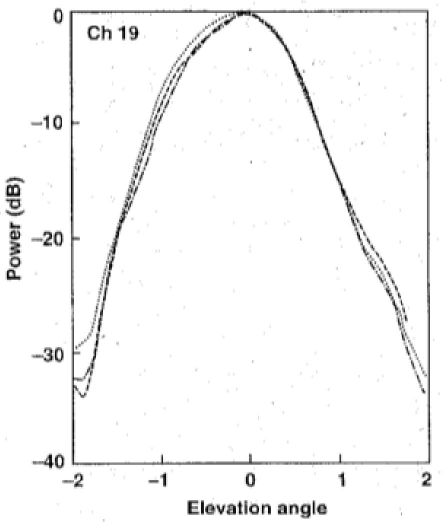
Understand your instrument

Examples:

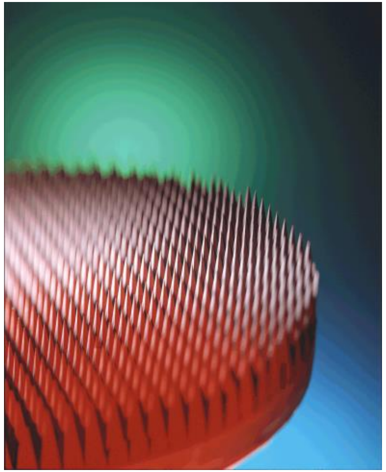
- What is the calibration system? Calibration targets or noise diodes? They may have different error characteristics
- Antenna pattern?
- Receiver configuration (e.g. heterodyne/direct detection)?



How are the channels related?



Beam pattern may not be ideal

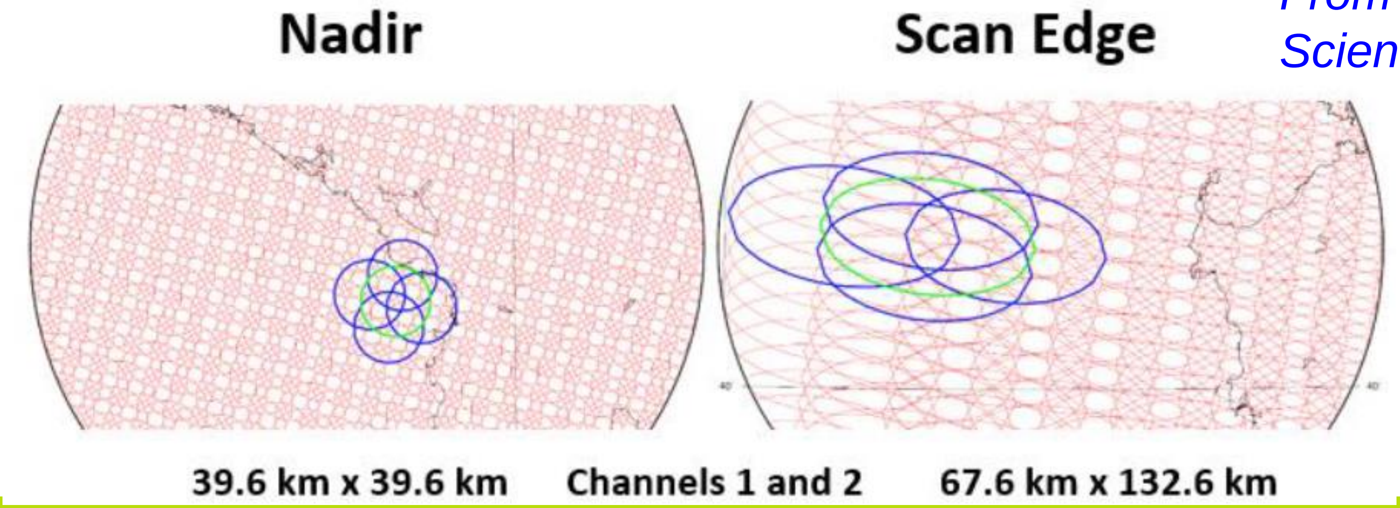


Microwave calibration target

Scan pattern

- In microwave sounders, it's normal for different frequencies to have different beam widths
- You may want to pre-process (e.g. using a package like *AAPP*):
  - to reduce noise in heavily-over-sampled channels
  - To equalise the beam widths

From MWS Science Plan



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Instrument factors affecting bias for microwave radiometers

From MWS Science Plan

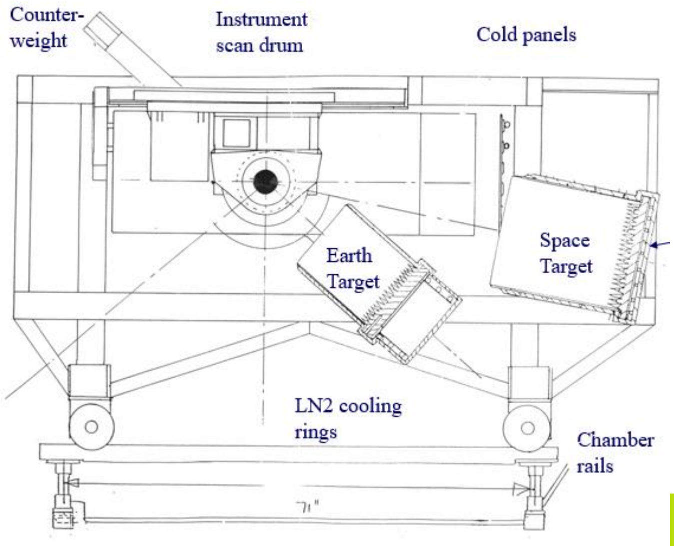
Factor	Bias characteristic	Warm or cold bias, if uncorrected?
Accuracy of thermometry for the warm load, and its thermal uniformity	Bias at warm scene temperatures.	Either
Warm load microwave emissivity and the shielding of the warm load cavity from the space environment	Bias at warm scene temperatures.	Depends on the radiometric temperature of the cavity. Cold if shielding from space is inadequate.
Accuracy of modelling the radiance of the cold space calibration view, including contamination by the Earth limb and the satellite	Bias at cold scene temperatures.	Warm
Accuracy of the antenna pattern correction for Earth views (influence of cold space)	Bias largest at the edge of scan and for warm scene temperatures.	Cold
Knowledge of the nonlinearity for each channel	Bias at mid-range scene temperatures	Either
Accuracy of modelling the antenna reflectivity and the variation of the reflectivity with polarisation	Scan-dependent bias, largest at nadir for cold scene temperatures.	Cold for QV channels, warm for QH channels.
Cross-polarisation sensitivity	Bias for window channels when viewing ocean, symmetric about scan axis. Zero at nadir and 45° scan angle	Depends on scan angle and polarisation
Polarisation twist	Bias for window channels when viewing ocean, asymmetric about scan axis. Zero at nadir.	Either
Oscillator frequency drift	Depends on channel. Varies with time. May be correlated with instrument temperature.	Either
Radio frequency interference	Unpredictable	Either
Cold calibration counts too close to lower limit of ADC range	Large, variable bias at cold scene temperatures.	Warm
Warm calibration counts too close to upper limit of ADC range	Large, variable bias at warm scene temperatures	Cold

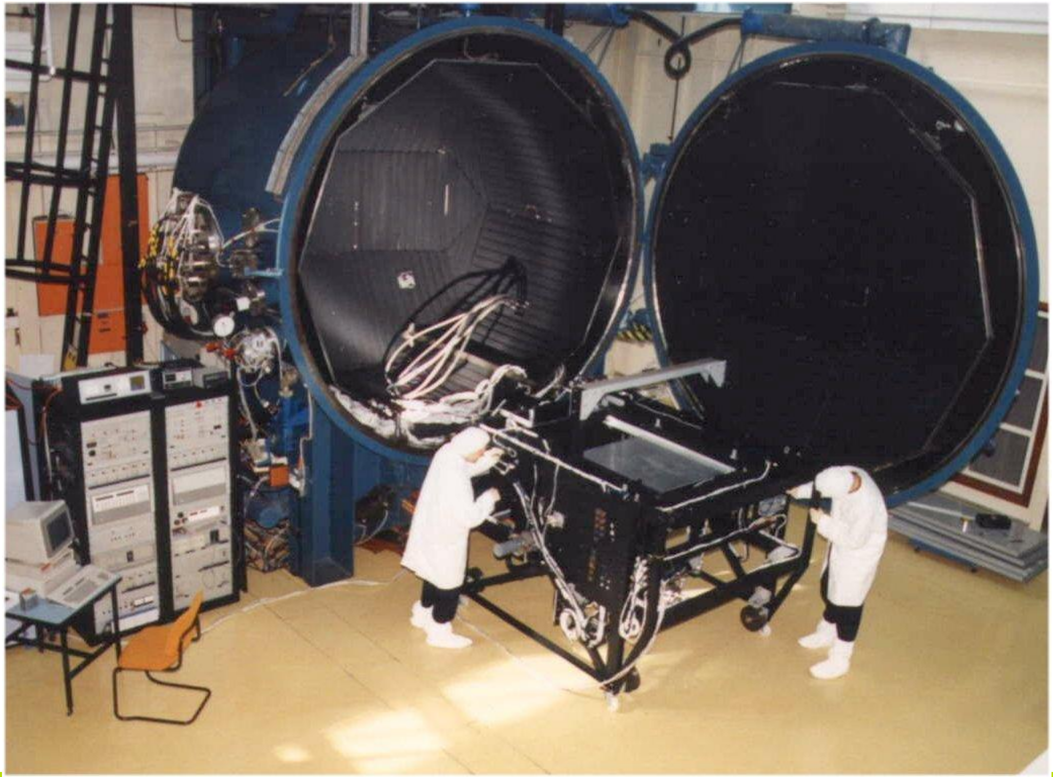
Table 7: Factors influencing radiometric bias

Pre-launch characterisation

Vacuum chamber and rig used for AMSU-B in the 1990s

Earth target could be moved in vacuum – this was a first





Pre-launch characterisation (2)

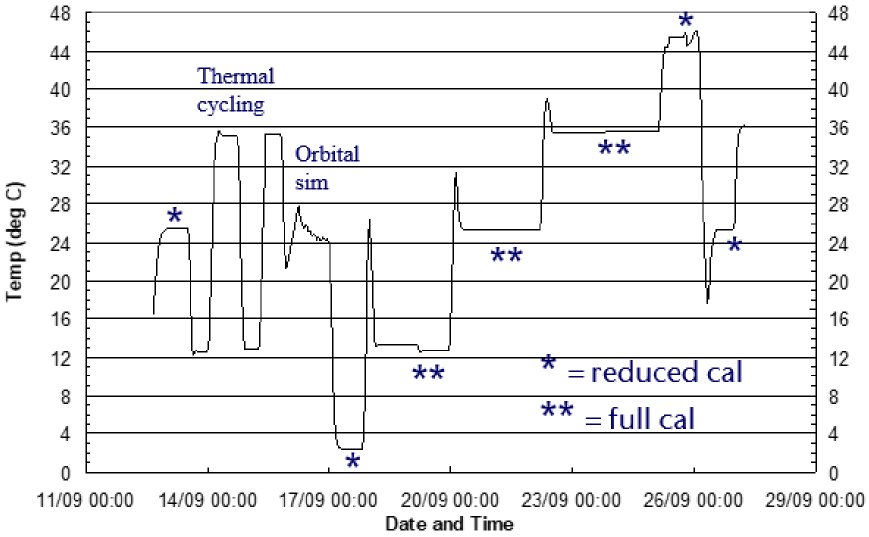
Thermal vacuum tests, with precision calibration targets, are used to measure:

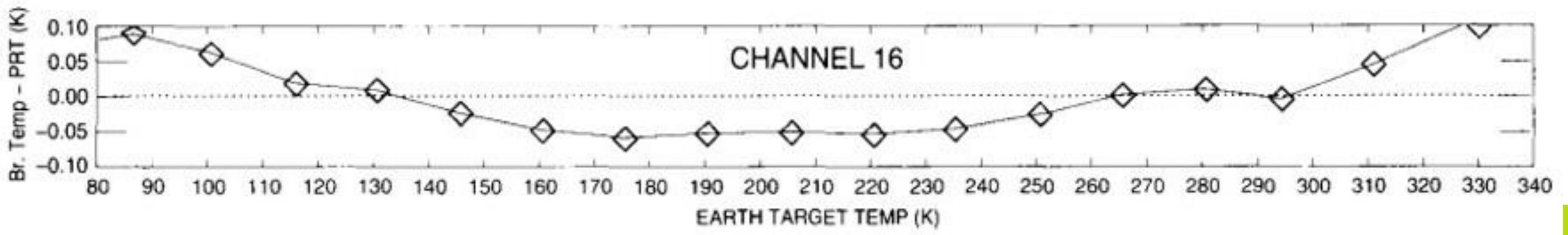
- Channel nonlinearities
- Warm and cold calibration offsets
- Scan dependent biases

- all at several different temperatures

Also:

- Thermal cycling qualifies the instrument, to maximise reliability





Level 1 processors

Typical development sequence (slightly cynical view):

- Scientists write the ATBD, often based on experience with heritage instruments
- They may also generate prototype processors (e.g. in Fortran, Matlab, etc.)
- Produce processing specifications for Industry
- Industry produces operational code (often in a programming language that the scientists are not familiar with!)
- Then somebody realises that the operational code is not suitable for direct broadcast use … need new code for DB use, perhaps based on the prototype processors. Can be a significant effort.
- Finally, the climate community develop their own code for generating climate data records in a consistent way (e.g. FIDUCEO)

Issues:

How to ensure global/local consistency?

How to ensure rapid update of the operational code if something happens?

Access to raw data and ancillary files … see next slide

Example: ATMS

- ATMS raw data (e.g. measured counts when viewing the earth, warm cal and cold cal) are in Raw Data Record (RDR) files
- These are *not* in a format such as hdf5 that is readily readable
- If you know how to do it, it's possible to extract the raw counts, but it's a complicated procedure
- Implicit assumption that users are not interested – not true!
- Much better if this information can be included in the level 1 (this is planned for Metop-SG MWS)

Recommendation from ITSC-18 (in 2012):

Recommendation PSWG-9: ATMS, VIIRS, and CrIS SDR calibration traceability must be improved to allow users to investigate detailed instrument performance.

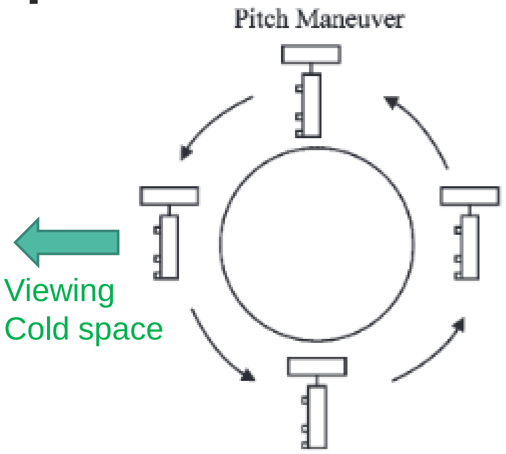
Post-launch activities

Usually a commissioning period of several months:

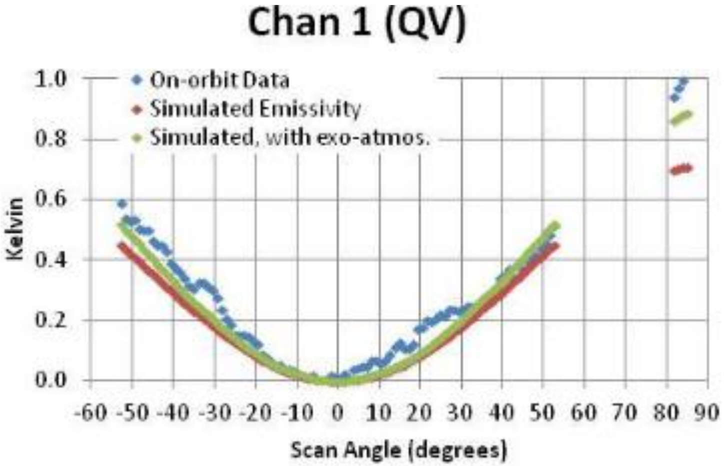
- Outgassing (especially for IR instruments with cooled detectors)
- Power-on
- Setting up channel gains, offsets, etc.
- Selecting space views
- Special tests …

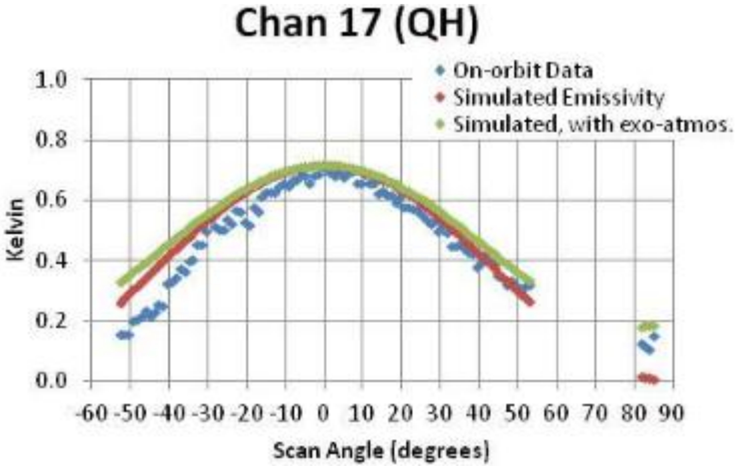
Pitch-over test for S-NPP

- The normal rotation of the satellite is stopped or reversed, so that instruments view cold space
- This tells you about scan dependent biases



(Kleespies 2007)





Scan-dependent bias due to polarisation

Nadir view: E field parallel to plane of reflector (for QV channels)

Reflectivity ≈ 99.8% (for AMSU-B)

can be estimated from the surface electrical conductivity and skin depth

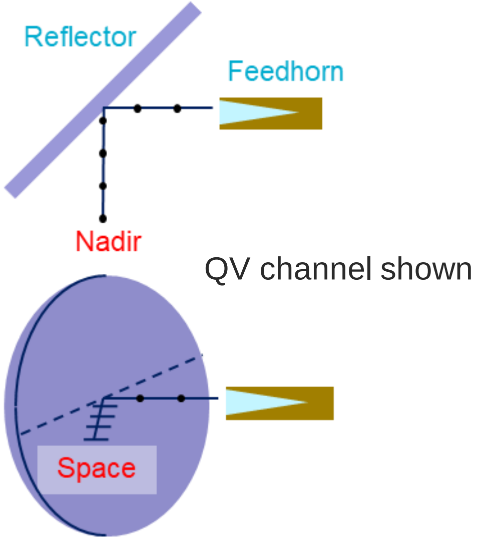
Space view: E field at 45° to plane of reflector

Reflectivity ≈ 99.6%

Result: Bias at nadir (cold scene) = 0.002 × ΔT = 0.4K

A small reflectivity difference leads to measurable change in bias

Effect seen in MSU, AMSU-B, MHS, ATMS, etc.
Larger for ATMS than for AMSU-B



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Changes to ATMS L1 processing

- The original ATMS L1 processor did not include allowance for scan mirror reflectivity
- The scientific work was carried out by NOAA following analysis of the S-NPP pitch-over results. Several papers were written.
- Finally implemented in the L1 processor in 2019 – 8 years after launch of S-NPP!

It's good to make such improvements, but …

NWP centres need to have plenty of notice of changes like this that will affect bias. The ITWG NWP working group is closely involved in coordination.

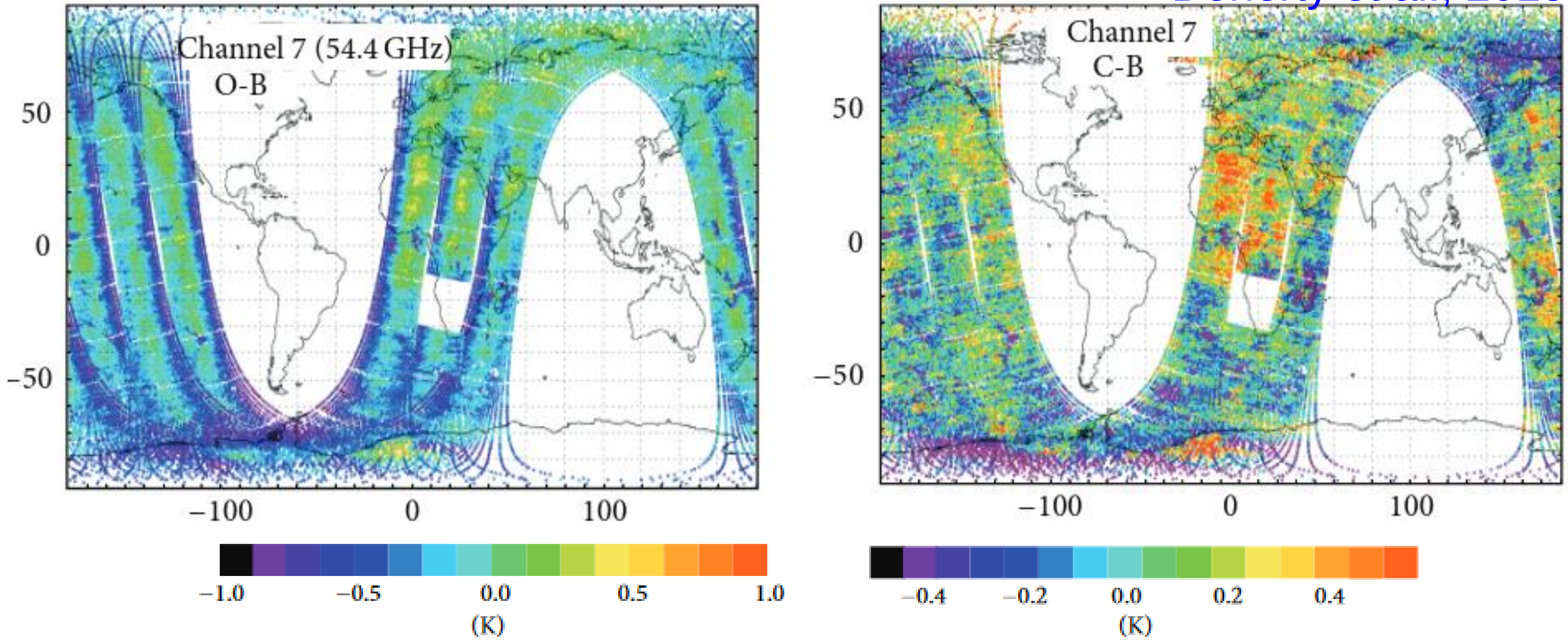
Monitoring techniques used in cal/val

- Simultaneous nadir observation (SNO)
- Comparisons with radiosondes
- Dedicated campaigns with ground truth (aircraft instruments, etc.)
- Comparisons between observed radiances from the instrument and simulated radiances based on forward model (e.g. RTTOV or CRTM) and NWP model fields

NWP models ingest a wide range of observational data (satellite and non-satellites), so are well-placed to assess a test dataset

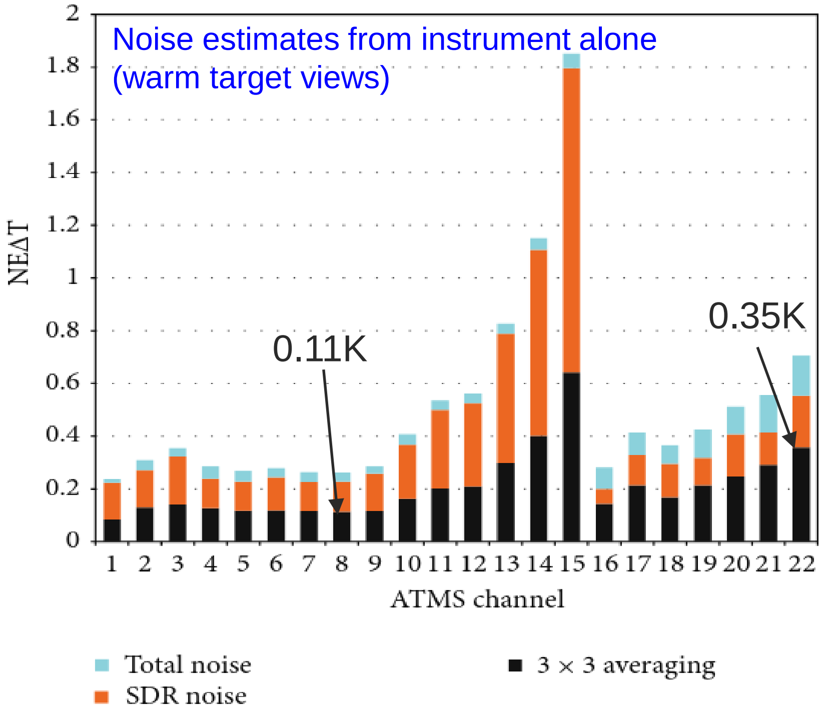
Evaluation of ATMS on Suomi-NPP

Doherty et al., 2015

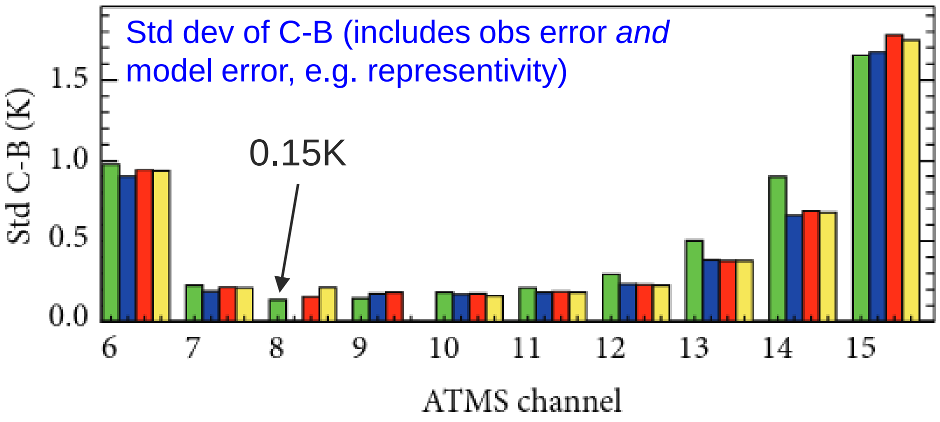


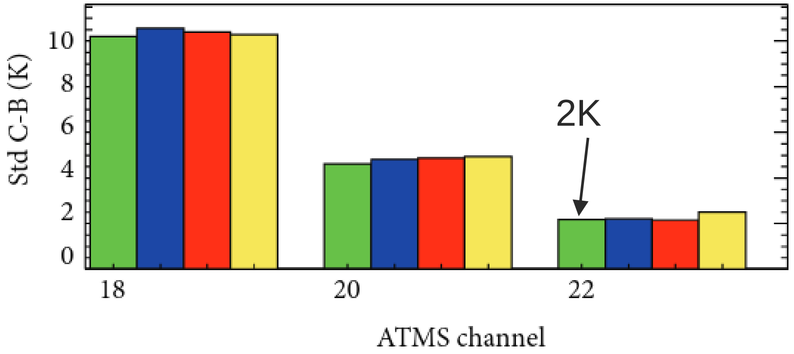
- Structure seen in O-B (cross-scan bias) but largely removed after bias correction
- Some striping seen in C-B (1/f, or “flicker” noise)

ATMS noise estimates



Green = ATMS, blue = Metop, red = N18, ylw = N19





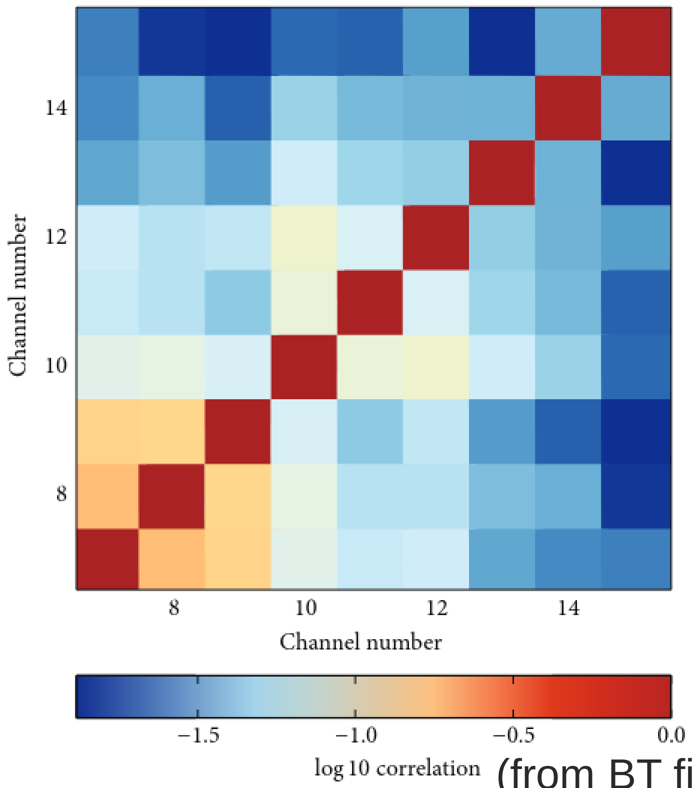
T sounding, background noise ≈ instrument noise

Q sounding: background noise > instrument noise

(but improving over the years)

Are the channels independent?

- Not entirely (for ATMS)
- You can estimate correlations from
  - BT fields
  - Raw counts from calibration views
  - Desroziers diagnostics
- Not surprising: channels 3-15 share a low-noise amplifier (LNA) and channels 3–9 share a mixer and IF amplifiers
- The 183 GHz channels are also correlated
- See earlier comments about receiver design



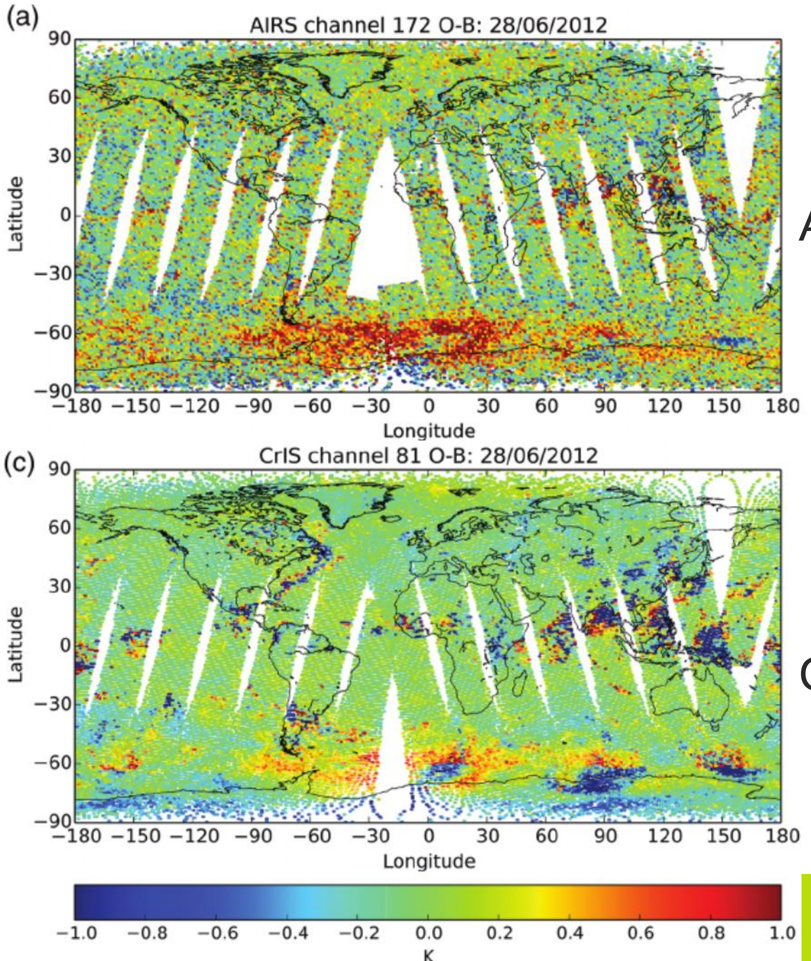
(from BT fields)

Assessment of CrIS on S-NPP

- The reduction in noise, compared with AIRS (and to a lesser extent IASI) was striking

O-B for a lower stratospheric channel

Smith et al., 2015



The SSMIS calibration saga

- SSMIS was the first mw imager that also had sounding channels
- O-B comparisons were done during and after commissioning
- Showed strong geographical features
- A bias std dev of 0.53K is not good
- What is going on?

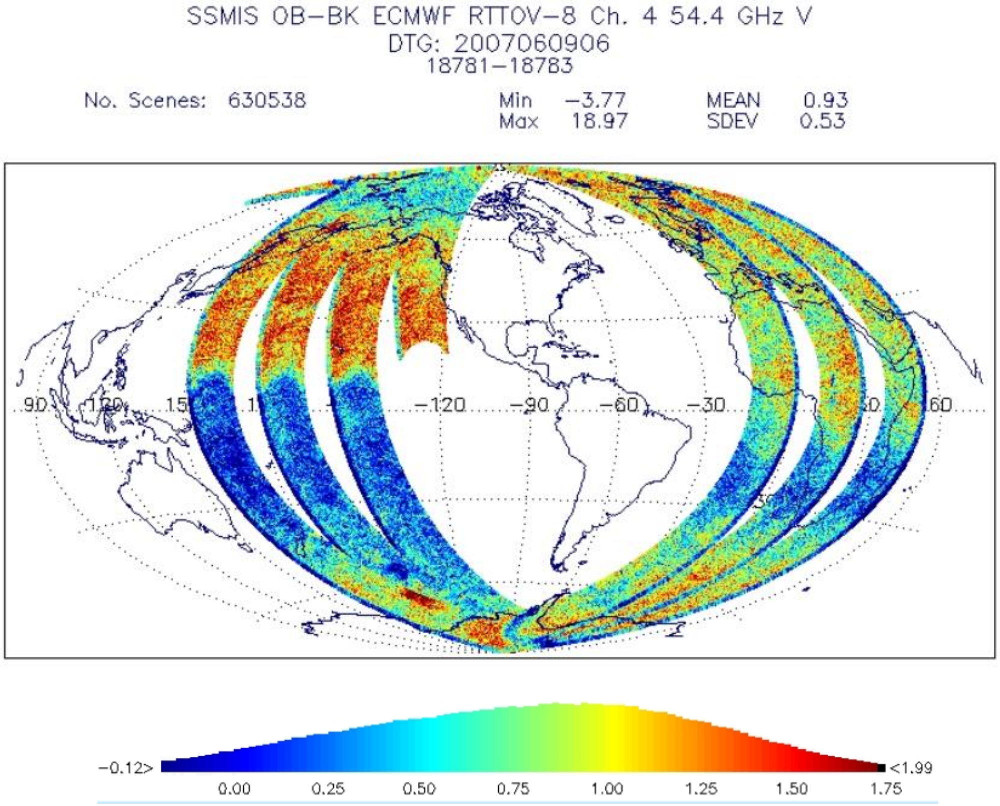


Figure from ITSC-16 (2008) presentation by Bill Bell

SSMIS investigation

Detailed investigation by NRL, Met Office, Aerospace Corp. and others

Main sources of error identified:

- The main reflector is not a perfect reflector and its temperature varies round the orbit
- Sunlight can fall on the warm load (solar intrusion)

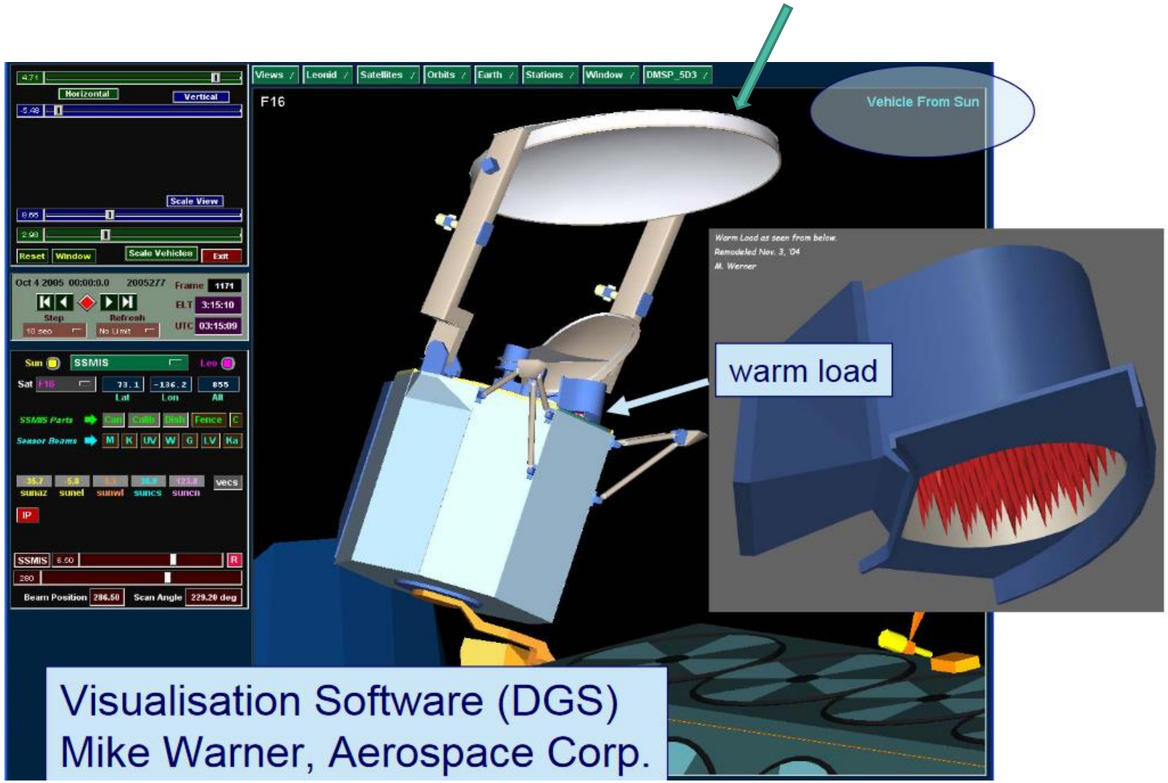
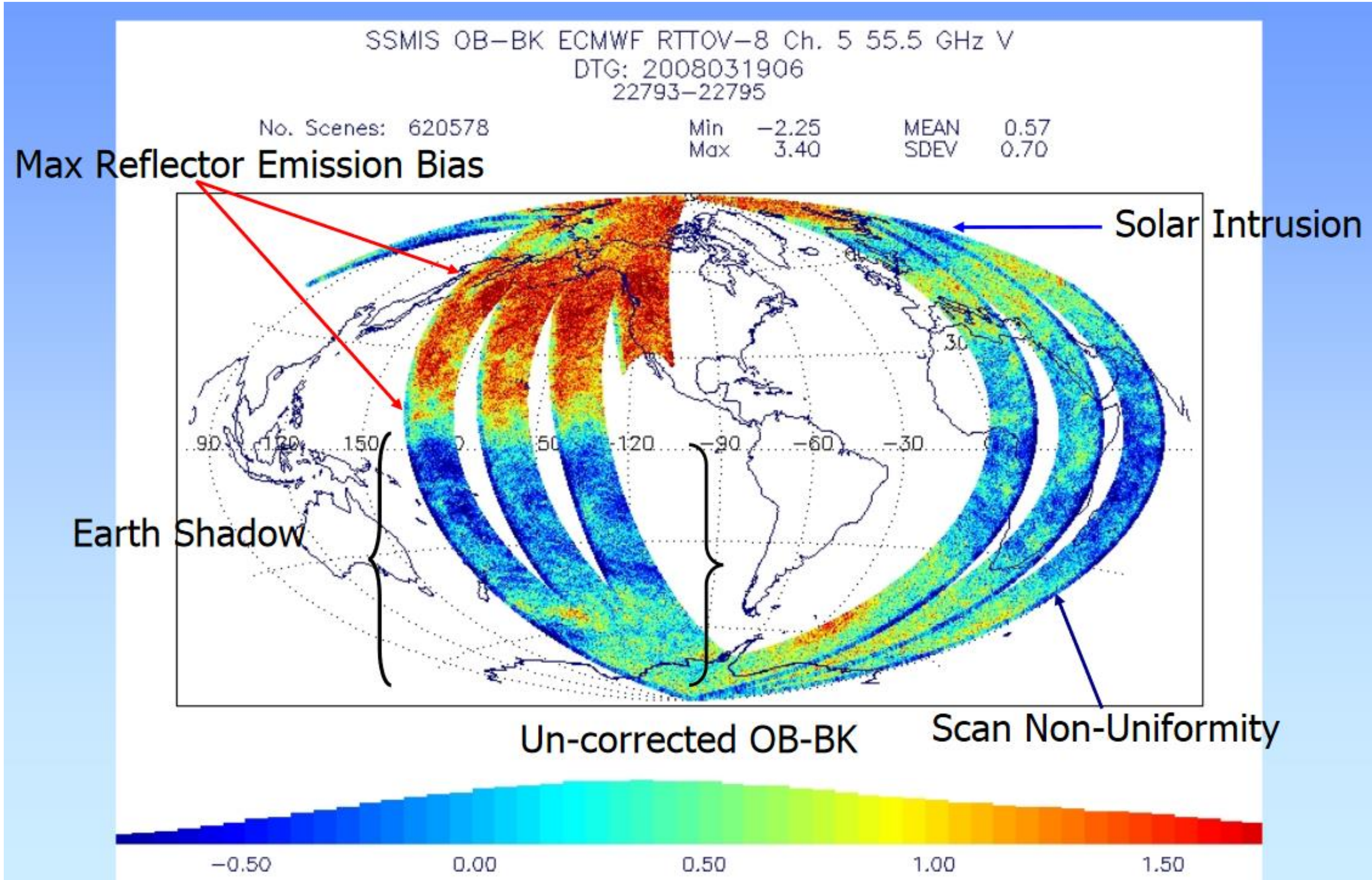


Figure from ITSC-15 (2006) presentation by Bill Campbell (NRL)

Error attribution



Quantifying the errors

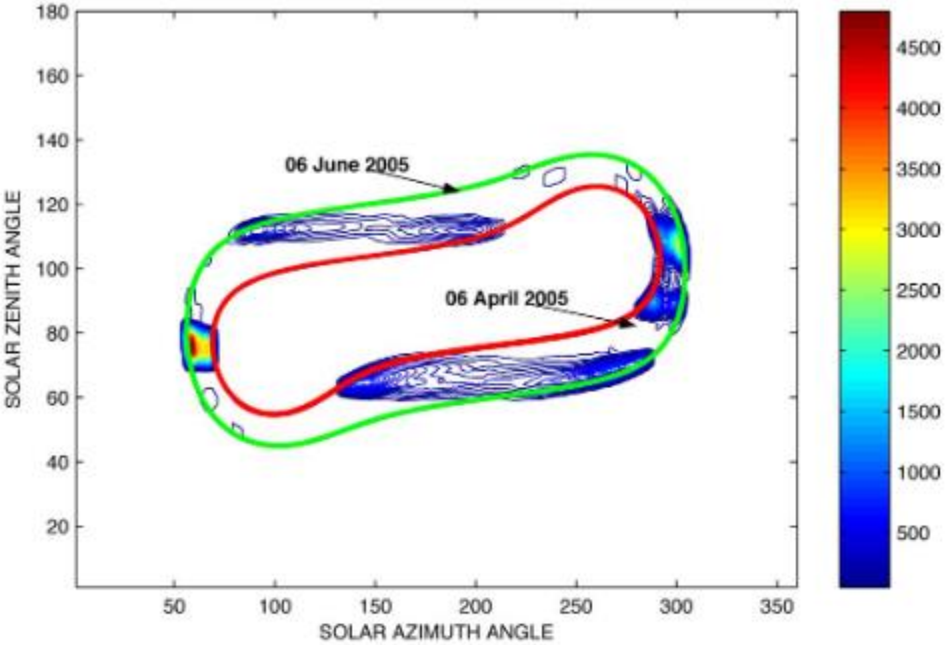


Fig. 4. Solar intrusion map constructed from data obtained between April and June 2005. The red and green lines show the trajectory through the azimuth/zenith space for single SSMIS orbits on April 6 and June 6, 2005, respectively. The color scale (in arbitrary units) is a measure of the intensity of the solar intrusions.

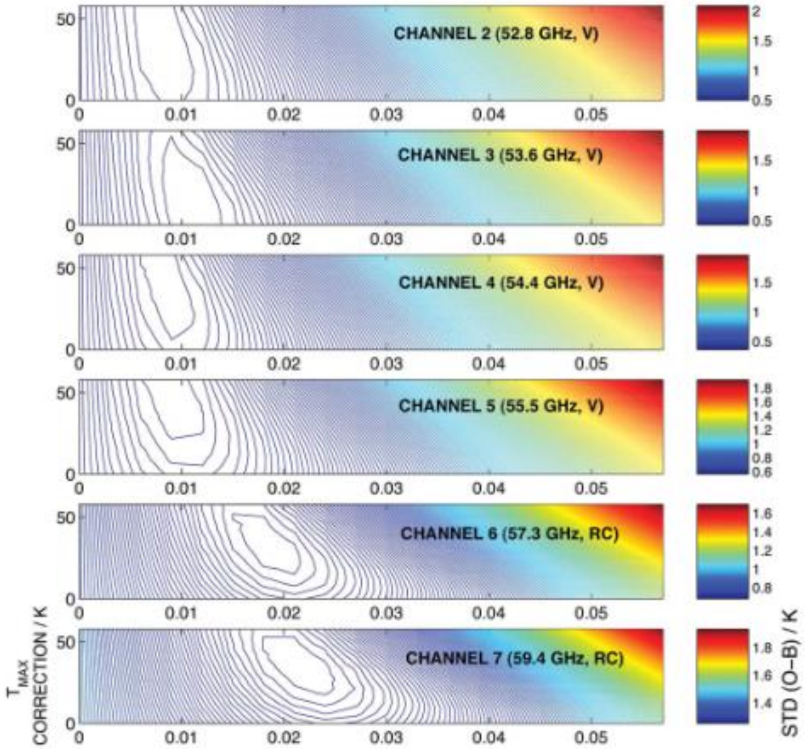


Fig. 5. Fits to innovations as a function of effective emissivity and correction to the reflector temperature for LAS channels 2–7. The statistics were computed for approximately 600 000 observations over a 6-h assimilation window, during June 2005. Similar results were obtained for other periods.

Solar intrusions

Emissivity determination

Met Office

SSMIS data correction

A software package was developed and was run routinely at NRL …

From ITSC-16 presentation (2008)

NRL/Met Office SSMIS
Unified Pre-Processor (UPP) Overview

Unified Pre-Processor designed to mitigate the calibration anomalies uncovered during the SSMIS Cal/Val process and produce corrected SSMIS TDR files suitable for radiance assimilation at both global and regional scales.

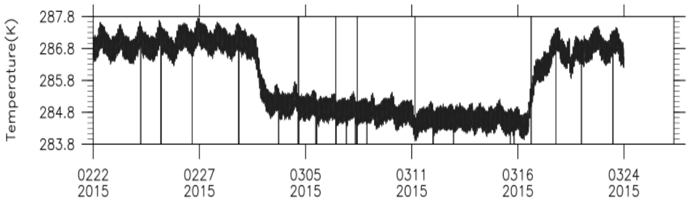
- UPP V1 included
  - Reflector Emission Corrections
  - Warm Load Solar Intrusion detection and flagging (Gain Anomalies)
  - Spatial Averaging to reduce NEΔT to the 0.1 K level
- UPP V2 includes
  - Uses Operational NGES Fourier Filtered Gain Files to Correct Gain Anomalies
  - Produces ASCII and BUFR TDR output files at reduced resolution
  - Performs Scan Non-uniformity corrections

SSMIS summary

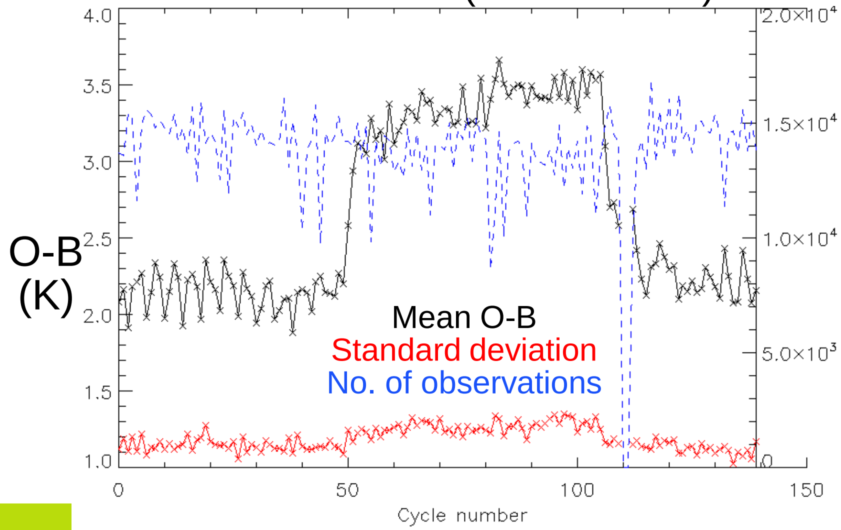
- For more detail, see Bell et al., IEEE Trans. Geosci. Rem. Sens., 2008
- "Observation minus background field differences are reduced from 0.5–0.8 K (at one standard deviation) for uncorrected data to 0.2 K for corrected data"
- Similar approach was adopted for all 4 SSMIS instruments, though they had differences in the details of the errors
- Powerful demonstration of the value of NWP in cal/val – the errors would not have been characterised effectively if we were just relying on comparisons with other instruments

FY-3C MWHS-2 bias issues

Instrument temp on MWHS-2
22/02 – 24/03 2015

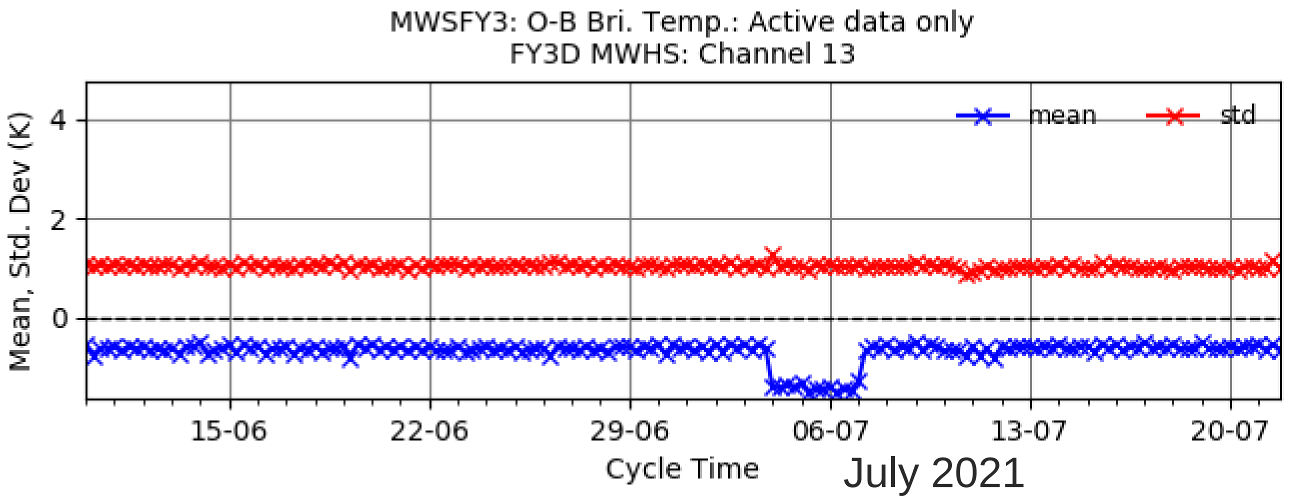


MWHS-2 14 (183±4.5GHz)



- Sharp transitions in O-B seen in ch 3-6, 11-14
- Associated with platform temperature changes while another instrument was turned on/off
- Why? Instrument calibration should be robust with respect to temp changes
- This was never satisfactorily explained

More recent example – FY-3D MWHS-2



July 2021

- The cause of this bias change is not known
- Unfortunately, instrument temperature is not included with the operational data

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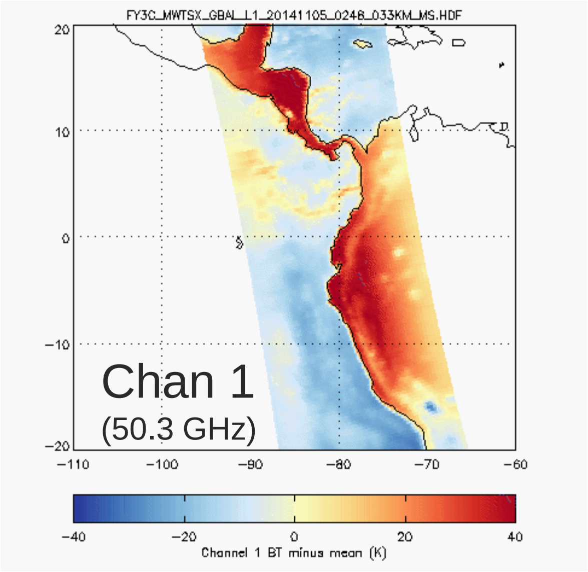
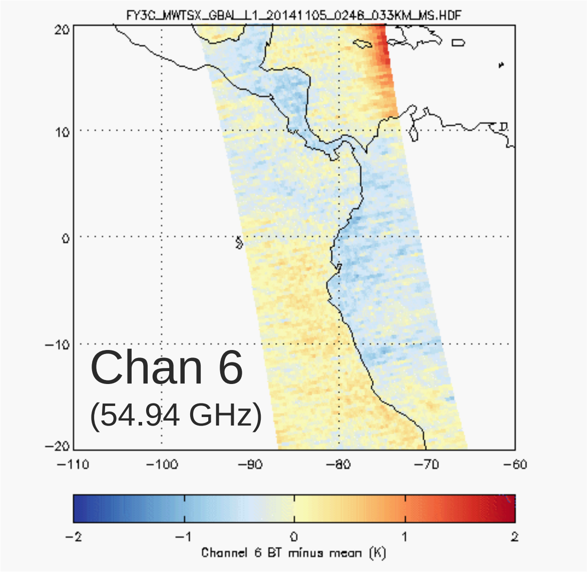
Recommendation

Instrument temperatures, and anything else potentially relevant to bias correction, should always be included in level 1b datasets and in BUFR files distributed to NWP centres

Unexpected land/sea contrast in FY-3C MWTS-2



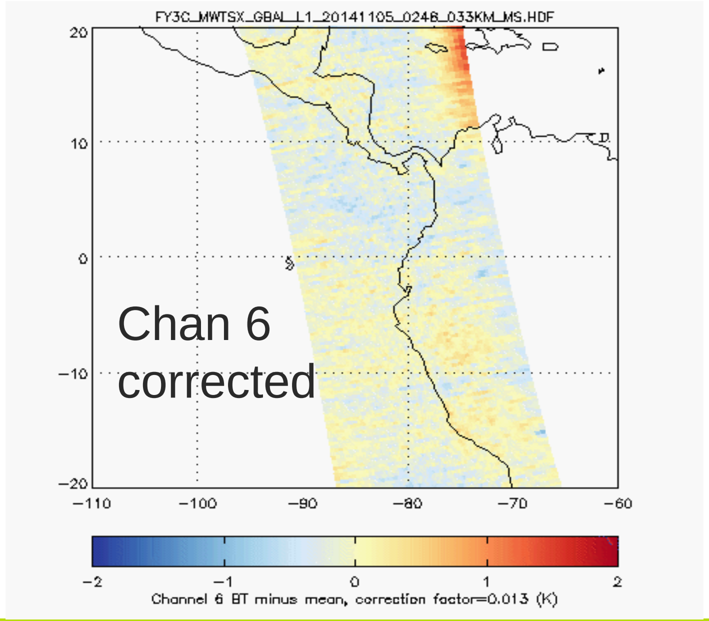


- Channel 1 is surface-sensitive but channel 6 should not be
- In practice we saw BT *depressions* over land for channels 5, 6, 7, 8
- Visible in O-B comparisons and also in the raw BTs
- The cause was unknown

Unexpected land/sea contrast (cont.)

- We postulated inter-channel interference and came up with an empirical correction: $BT_J\,(\text{CORR}) = BT_J + \kappa(BT_1 - BT_J)$
- Values of k from NWP comparisons (O-B over land compared with sea):

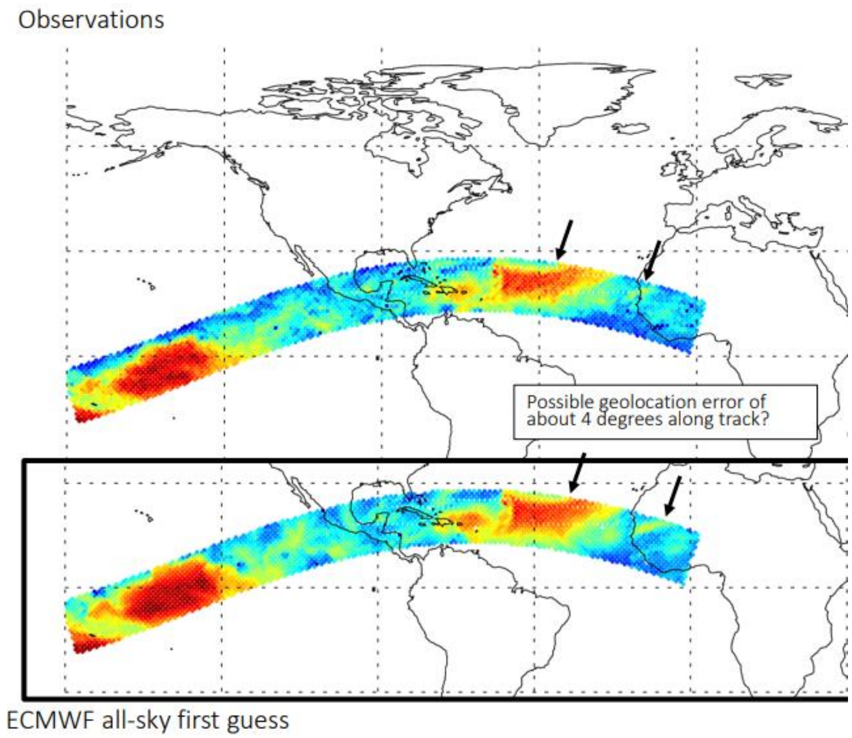
Channel	k
5	0.0169
6	0.0128
7	0.0052
8	0.0034



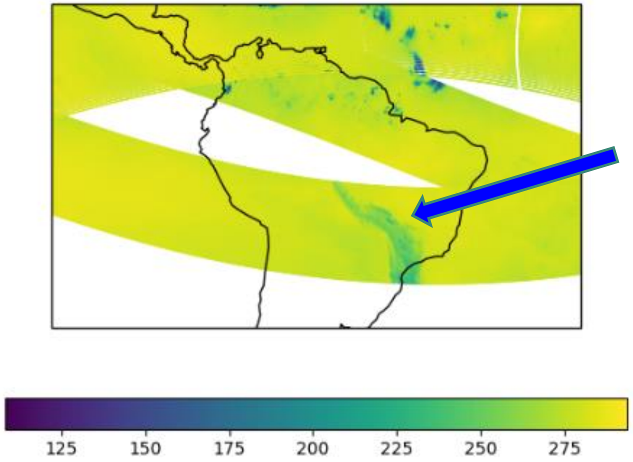
- This was implemented by CMA in their ground segment – though it would have been better to find the root cause
- No such problem with FY-3D MWTS-2!

Geolocation issues - SAPHIR

19th August 2018



3rd August 2020



Andes in the wrong place!

SAPHIR has no clean window channels: 183 ± 11 GHz is the lowest peaking

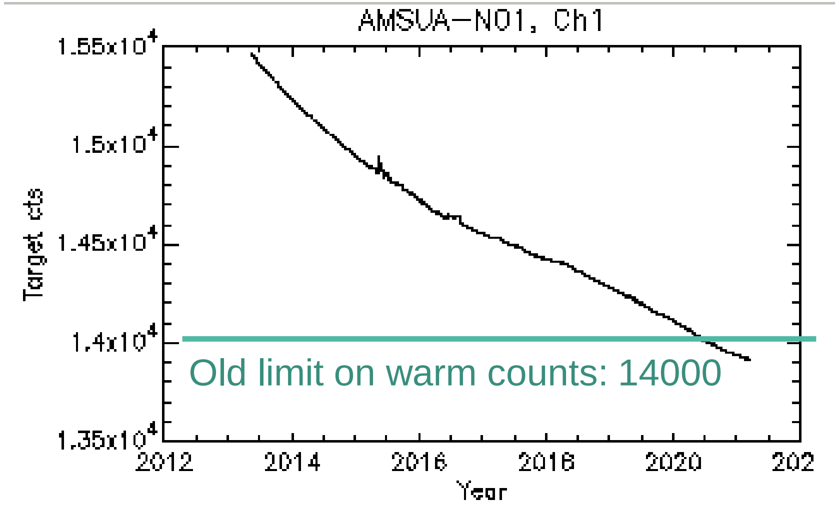
Errors spotted by degradation of NWP fit

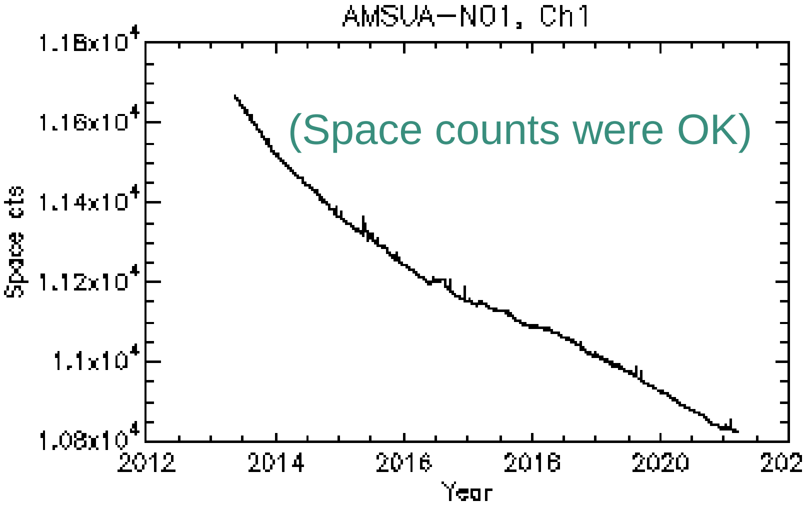
Revealed by plotting obs and fg separately

Typical problems with AMSU and MHS level 1b

- AMSU and MHS data are distributed by NOAA/NESDIS in a very old, but useful, binary format.
- They can be converted to l1c BUFR using AAPP
- The central processor has various limits specified (and so does AAPP):
  - Warm calibration max/min counts
  - Cold (space) calibration max/min counts
  - Maximum difference between readings in the same scan
  - Maximum scan to scan differences
  - etc.
- Channels drift with time, so we sometimes get calibration outages for a particular channel, as NESDIS don’t appear to have routine checking
- NESDIS usually fix them quickly when notified.

Example: Metop-B AMSU channel 1

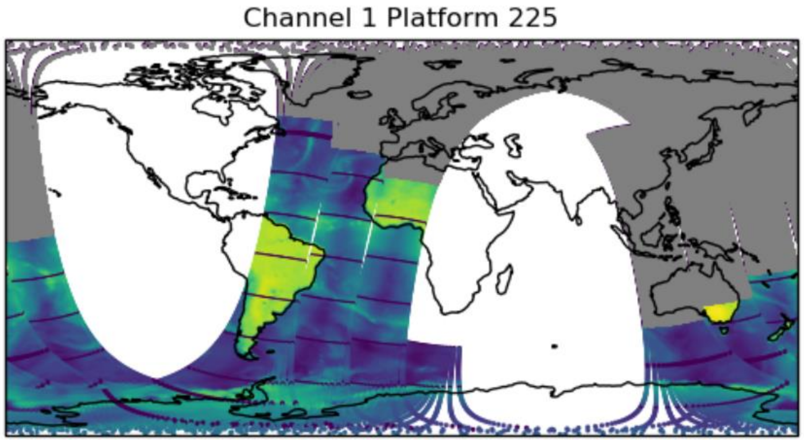


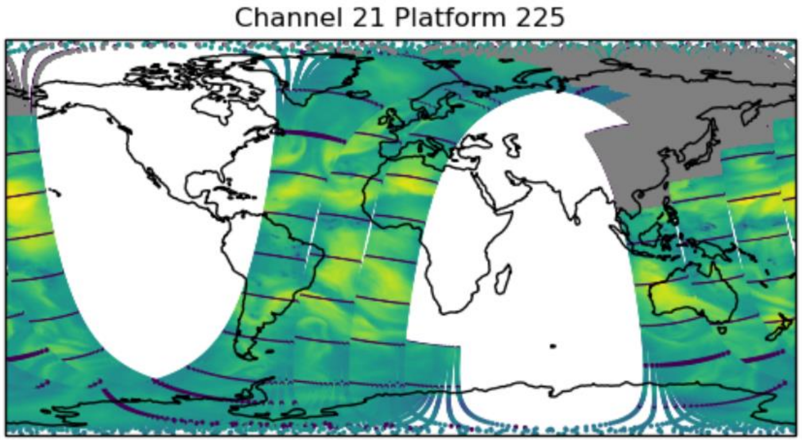


NESDIS lowered to 13000 in July 2020

Similar issue with NOAA-19 MHS June 2021

ATMS 24th Dec 2020

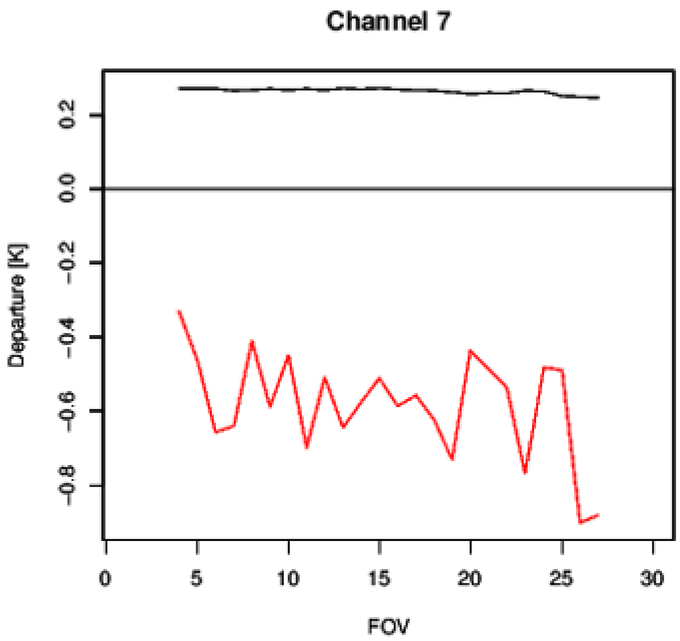




- What caused these data gaps in ATMS?
- Turned out to be the moon close to space view
- Some months it’s more obvious than others
- NOAA correct for lunar contamination in their processing, but we flag it anyway

Cross-scan biases

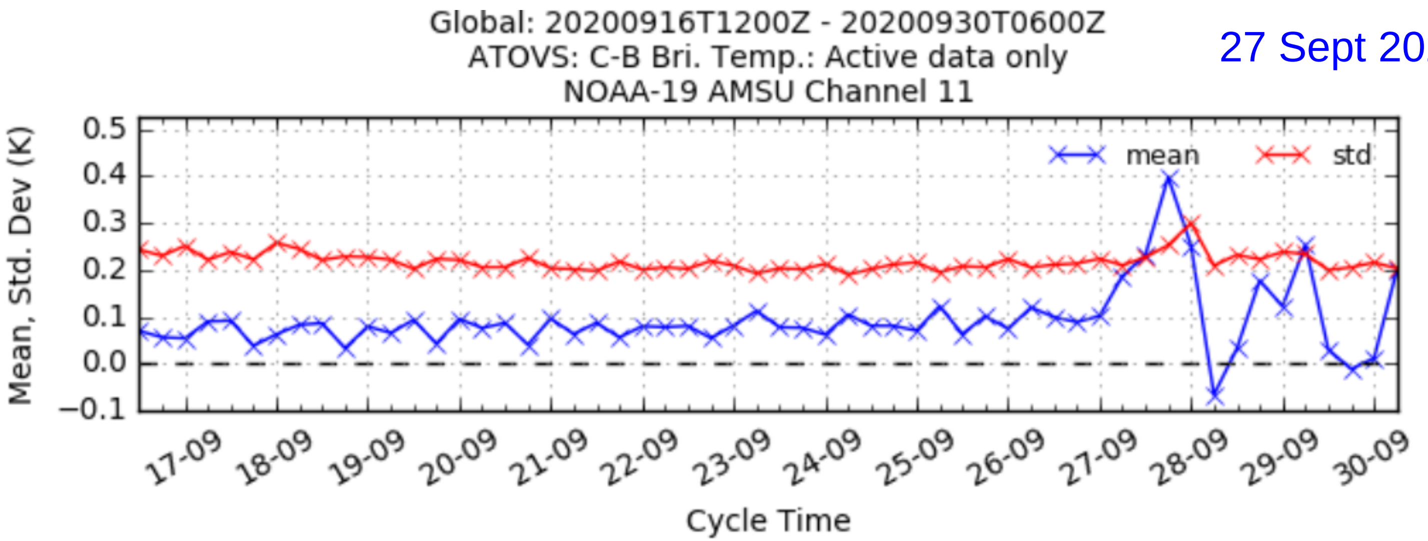
- Bias is often smooth across the scan – but not always
- NOAA-19 AMSU 7 was not
- And the pattern was not always stable
- Suspected some sort of standing wave in the instrument?
- *Beware of this when designing VarBC schemes*



Plot from 2009, ECMWF

A strange problem with NOAA-19 AMSU ch11

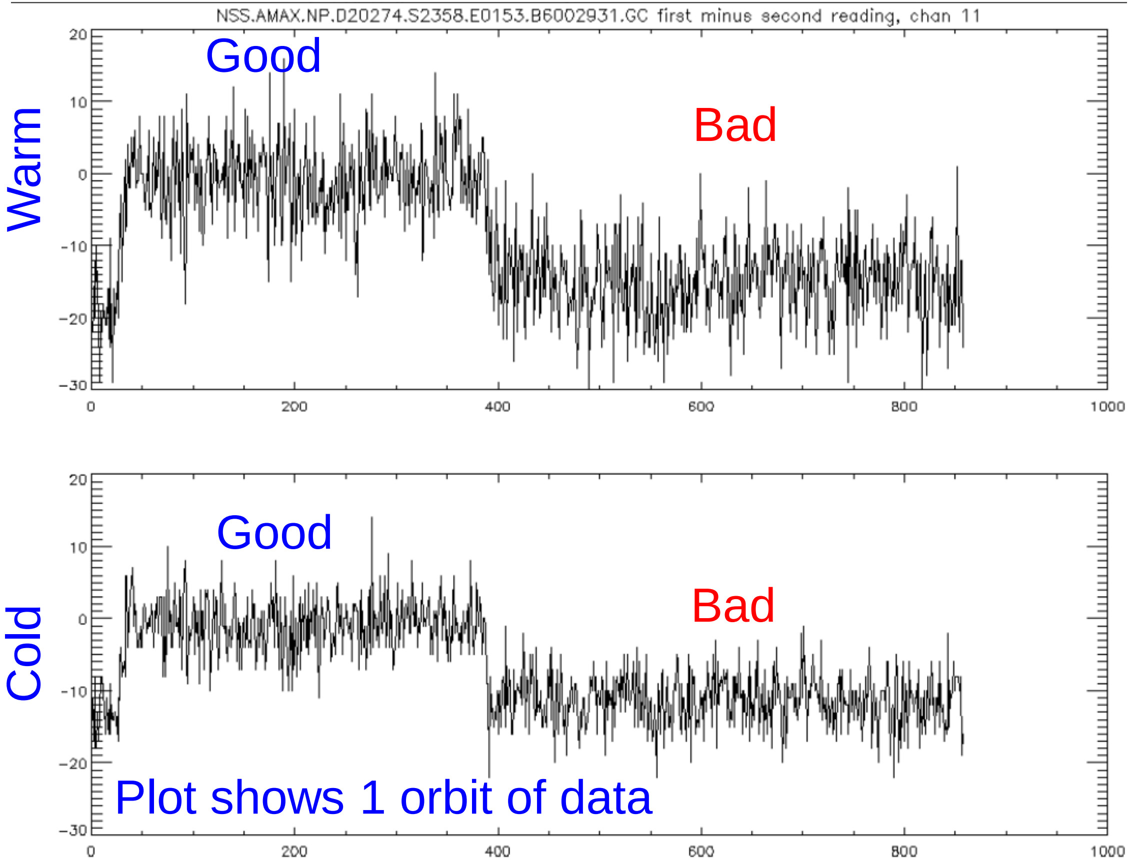
27 Sept 2020



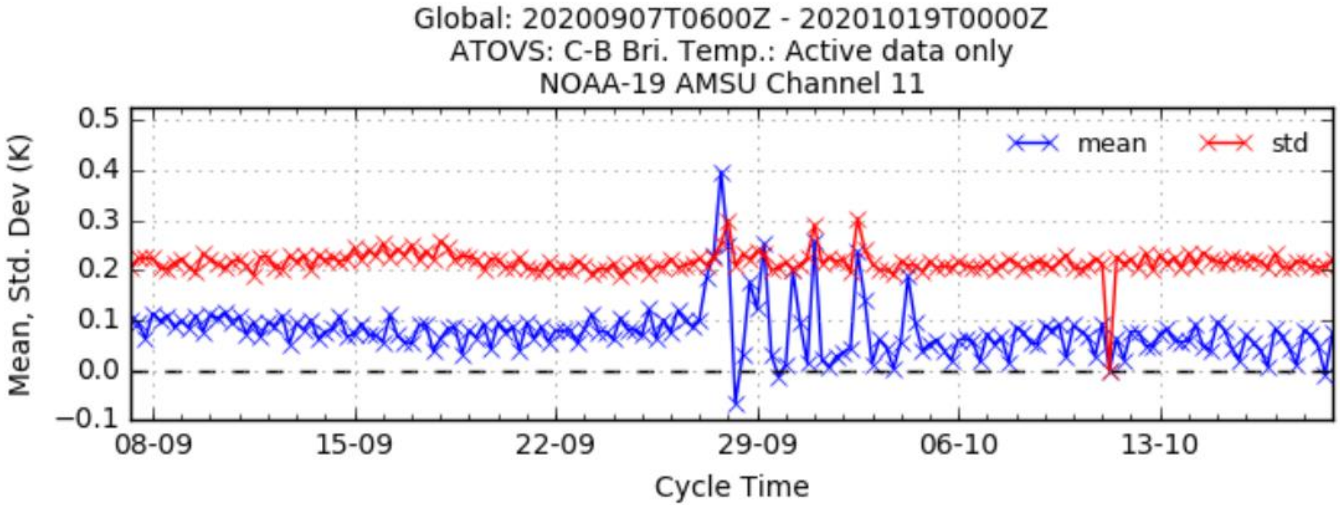
- Why the sudden changes in mean and standard deviation?
- Nothing obvious in the quality flags or in plots on NOAA STAR web site
- We examined the raw counts …

NOAA-19 AMSU ch11 (cont.)

- AMSU has 2 warm cal and 2 cold cal readings per scan
- They should be consistent – but found they are not!
- The first is constant but the second sample (+ earth counts) shows jumps
- 20 counts is about 1K
- Made a local modification to AAPP to try to trap this problem. It helps, but not perfect.

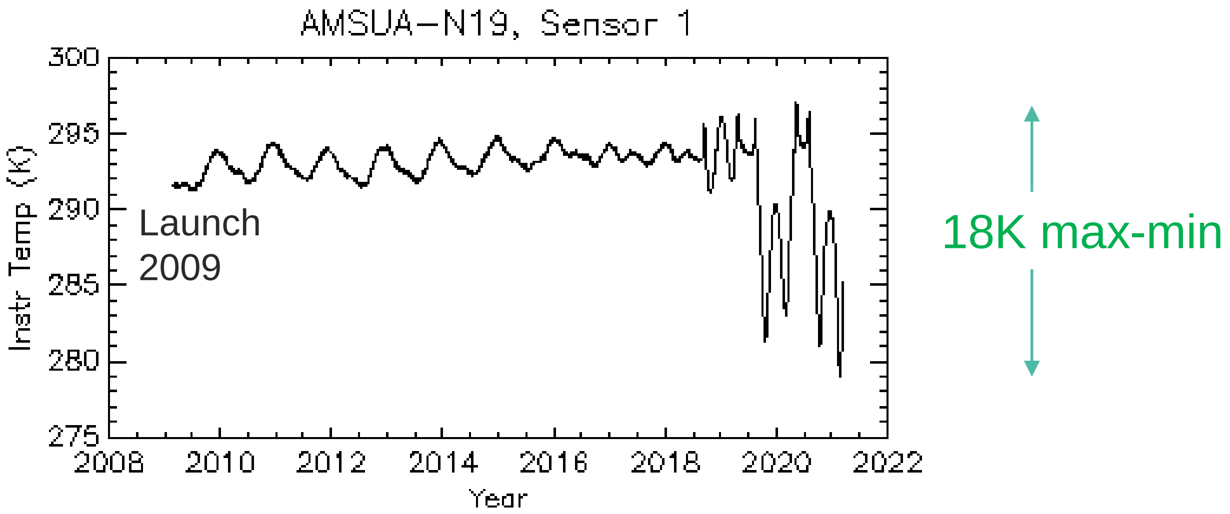


NOAA-19 AMSU (cont.)



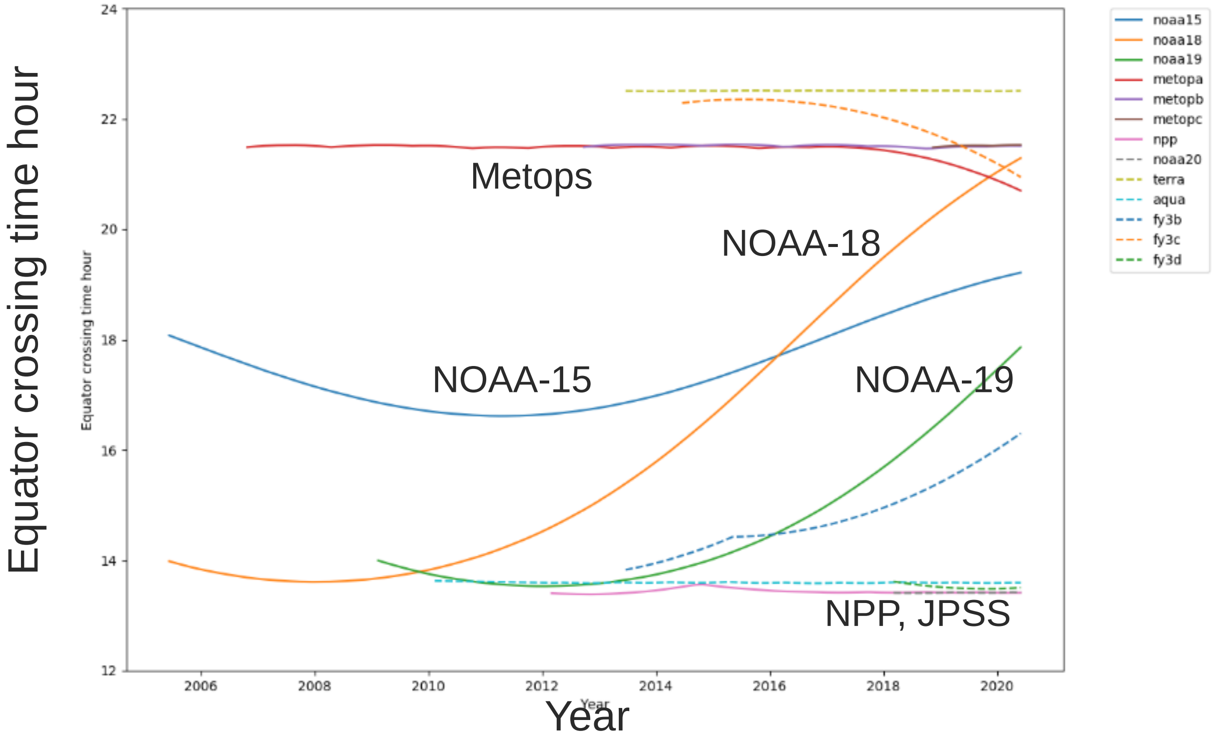
- Eventually the problem went away (as they often do)
- Returned for a few days in Feb 2021
- Seems to happen when the instrument is particularly cold (orbit drifting) … but reason for the anomaly is unclear

NOAA-19 AMSU (cont.)



Note the large temperature variations since 2019, as orbit has drifted

Long-term perspective

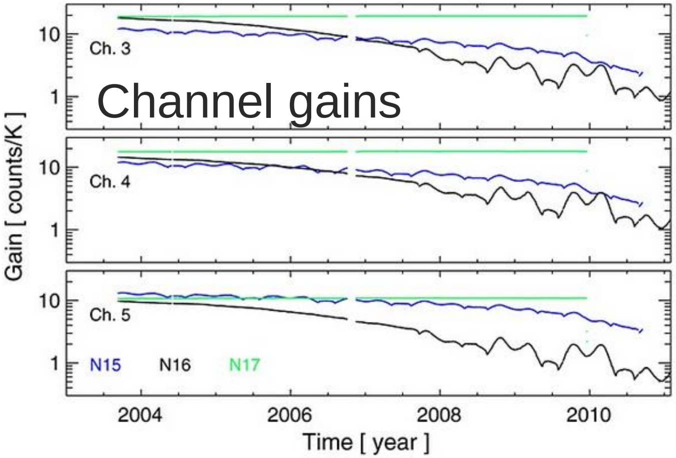


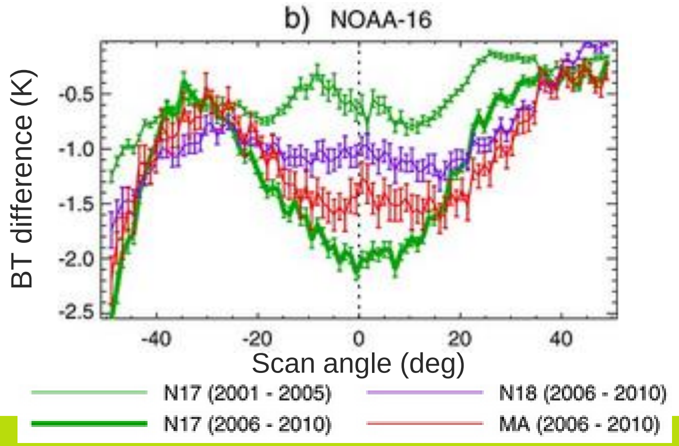
- Instrument characteristics may depend heavily on the solar angles – which can vary with time, particularly for older satellites

Long-term monitoring

- Long-term trending is vital for climate purposes
- John et al., (2013) used all-angle collocations to look at scan biases in AMSU-B
- Even when the data were too noisy to be useful in NWP, it was still useful for understanding biases due to RFI (a known problem with AMSU-B)

We should aim to preserve O-B records for posterity, not just for day-to-day use





Met Office

Useful resources

- NWP SAF monitoring pages (links to several different centres):
  https://nwp-saf.eumetsat.int/site/monitoring/nrt-monitoring/
- NOAA STAR (instrument monitoring for POES, Metop, JPSS)
  https://www.star.nesdis.noaa.gov/icvs/index.php
- ITWG, particularly the NWP Working Group
  http://cimss.ssec.wisc.edu/itwg/index.html
- ECMWF observations data events (2012 to present)
  https://confluence.ecmwf.int/display/FCST/Observations+data+events

NWP SAF Monitoring			
	ECMWF	Met Office	Meteo France
Microwave radiances			
AMSR-2	plots	plots	plots
ATMS	plots	plots	plots
AMSU-A	plots	plots	plots
AMSU-B/MHS	plots		plots
GMI	plots	plots (high freq) plots (low freq)	plots

Monitoring From Other Centres
Environment Canada*
EUMETSAT Metop monitoring
GMAO: • Radiances - coverage • Radiances - time series • Ozone

Extract from NWP SAF page

Conclusions

- Good data quality starts with the specification and design process, and goes right through the instrument life cycle
- When assessing an instrument, try to understand its design
- Access to raw data (e.g. counts) and housekeeping (e.g. temperatures) is important – not just to parameters (like BT) that centres might want to assimilate
- NWP comparisons are an increasingly important part of cal/val and routine monitoring
- Sometimes obscure problems are encountered – these are usually debated on the ITWG NWP mailing list. Problems like these help to make our jobs interesting!

Thank you!

nigel.atkinson@metoffice.gov.uk