The FY-3C evaluation project: microwave sounder calibration and direct broadcast experiences

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Abstract

Since the launch of FY-3C in September 2013, there has been an international partnership between CMA/NMSC, the Met Office and ECMWF to evaluate the data for use in NWP. The main focus initially was on comparisons of observed brightness temperatures with NWP model simulations: these are reported in other presentations. More recently, a particular effort has been made to understand the details of the calibration process for the sounder instruments (mainly MWTS-2 and MWHS-2); the Met Office and CMA have been working closely together, through visiting scientist missions, to enable this. The paper presents the findings from these investigations, and discusses the relationship between pre-launch measurements of instrument characteristics (e.g. nonlinearity parameters and antenna pattern) and the operational calibration process. It is hoped that by understanding the FY-3C process clearly, and verifying the implementation, the way will be smoothed for a rapid implementation of data from FY-3D when that is launched.

In addition, direct broadcast users around the world have been receiving FY-3C data and processing the data using the direct broadcast package provided by CMA. (The first release of the DB package was during ITSC-19). This covers level 1 processing for the MWTS-2, MWHS-2, IRAS, VIRR and MERSI instruments. In response to an ITSC-19 action from the Products and Software Working Group, the paper describes the characteristics of the data and the experiences at the Met Office (and elsewhere) with using the processing package. The importance of global-local consistency is stressed, noting that regional applications are starting to emerge (e.g. EUMETSAT's EARS-VASS service), and the processing of sounder data from FY-3 is now within the scope of WMO's DBNet programme.

1. Introduction

FY-3C is the third in the Feng Yun 3 series of polar-orbiting satellites, launched and operated by the China Meteorological Administration (CMA), and the first to be designated with "operational" status. The satellite was launched on 23rd September 2013. Since then, evaluation of the sounder data has been carried out through an international partnership comprising CMA/NMSC, ECMWF and the Met Office.

Evaluation of the FY-3C sounder instruments in the context of NWP has been reported by Lu et al. (2015), Lawrence et al., (2015) and Lean et al. (2015). In this paper we address issues related to the calibration of the microwave sounders MWTS-2 and MWHS-2 and their data quality. We also report on experiences in using the direct broadcast software package provided by CMA/NMSC – addressing an action from ITSC-19 Products and Software Working Group – and we provide a general status update on the FY-3C data.

2. Satellite, instrument and processing package status

2.1 Direct broadcast characteristics

After the start of the direct broadcast service from FY-3C, it became apparent that there were several changes compared with FY-3A and FY-3B:

- L-band data rate changed from 4.2 to 3.9 Mbps
- X-band polarisation changed from right-hand circular polarisation (RHCP) to left-hand circular polarisation (LHCP)

Full details can be found in the *FY-3 Satellites to Ground Interface Control Document*, available from the CMA web site http://satellite.cma.gov.cn/PortalSite/Default.aspx (under Documents, Ground system).

The polarisation change is an issue for those ground stations that are designed to operate only with RHCP. Note, however, at the time of writing the X-band transmission from FY-3C is not operating.

2.2 Significant events and current status

A timeline of significant events for the satellite and instruments is shown in **Table 1**, while processing package updates are shown in **Table 2**.

Table 1: Satellite and instrument events

Date	Event
23/9/2013	Launch of FY-3C
31/3/2014	First release of DB package
May 2014	MWTS-2 antenna rate halved due to scan problems
June 2014	Data available via CMA web portal
Sept 2014	Data distributed on EUMETCast in near-real-time
6/1/2015	MWTS-2 processing changes in ground segment
1/2/2015	MWHS-2 processing changes in ground segment
16/3/2015	MWHS-2 antenna correction introduced in ground segment
17/2/2015	Scan anomalies for MWTS-2: global data stopped
31/5/2015	Power supply anomaly: all data stopped
30/7/2015	Resumption of services for MWHS-2, IRAS, MWRI, VIRR, GNOS. Partial resumption of L-band DB.

Table 2: Updates to the Direct Broadcast Processing package

Date	Version	Main Reason	Any problems?
31/3/2014	FY3CL0pp.1.0.0 FY3CL1pp.1.0.0	Initial	-
02/7/2014	FY3CL1pp.1.1.0	Update MWTS-2 scan rate	FY3C_MWHS_QC.XCONF needed modifying – to make the file bigger. Reason not clear.
15/1/2015	FY3CL1pp.1.1.2 with patch 1	Modified MWTS-2 calibration method (nonlinearity; treatment of calibration samples; land/sea sensitivity correction)	Path for new MWTS-2 data files had been hard-coded. Solution at MetO was to modify the binary.
06/2/2015	Patch 2	MWHS-2 bug fixes (wrong cal target, wrong nonlinearity coefs for some channels)	-
27/8/2015	Patch 3	MWHS-2 antenna correction implemented	Delayed: this change was implemented for global data on 16th March.

At the time of writing, L-band direct broadcast is usually only available in parts of Europe, northern Russia and China. For example, coverage of the demonstrational EARS-VASS service, for 5 days in October 2015 is shown in Figure 1.

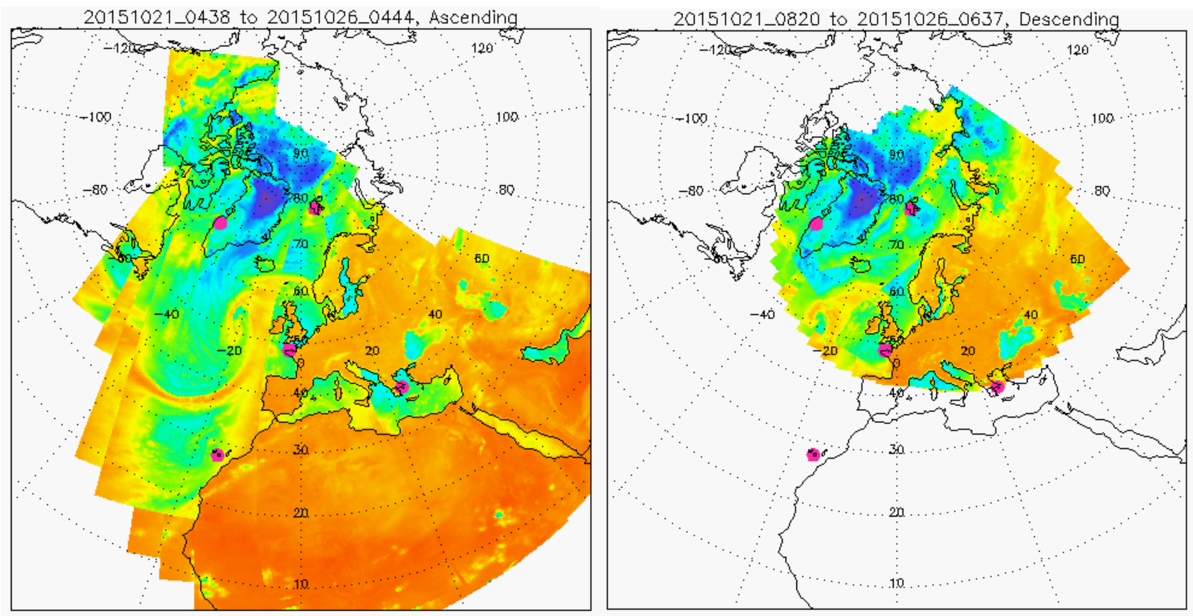

Figure 1: Coverage of demonstrational EARS-VASS service, 21-26 Oct 2015. Left: ascending, right: descending passes. The five reception stations are marked by pink circles. The images show MWHS-2 channel 1 (89 GHz).

3. Calibration method

The calibration method for both MWTS-2 and MWHS-2 follows the approach used for AMSU and MHS, given in Mo (1996) and also detailed in Section 7 of the NOAA KLM Users' Guide.

In brief, the relationship between raw earth counts, C, and calibrated radiance, R, is given by

$$R = R_{BB} + (C - C_{BB})/G + Q$$

where R_{BB} is the radiance of the black body, C_{BB} are the counts for black body view and G is a linear gain computed from the warm view and space (SP) view counts and radiances:

$$G = \frac{C_{BB} - C_{SP}}{R_{BB} - R_{SP}}$$

The quantity Q is a nonlinearity correction. Normally, Q has a quadratic form and is defined to be zero when the scene counts are equal to the space counts and also when the scene counts are equal to the black body view counts:

$$Q = \mu(C - C_{BB})(C - C_{SP})/G^2$$

where the constant μ is determined before launch.

However, in the case of MWTS-2, the form of the nonlinearity correction was changed from a quadratic to a cubic in January 2015. This is discussed further in Section 4.

The following parameters could, in principle, affect the radiometric calibration of the instrument:

1. Nonlinearity parameter and form of the correction
2. Warm target bias (PRT calibration error)
3. Cold space bias (computed from the antenna pattern, due to sidelobes viewing earth or spacecraft)
4. Earth-view antenna correction (due to sidelobes viewing cold space or platform)
5. Assumptions about centre frequencies and bandwidth
6. Smoothing of the calibration view counts (affects overall noise)

Additionally, there is the possibility that the scan mirror reflectivity is not unity, and varies with polarisation, which will introduce a scan-dependent bias (Labrot et al., 2011; Kleespies, 2011; Weng, 2015). This is not considered in the MWTS-2 or MWHS-2 processing.

For this study, the approach taken was to compute the radiance calibration off-line, using "OBC" files from direct broadcast processing, together with pre-launch parameters in the FY3Cl1pp data files. The computed brightness temperatures are then compared with the operational brightness temperatures in the "L1B" files.

4. Evaluation of MWTS-2

The NWP-based evaluation of MWTS-2 (e.g. Lu et al., 2015; Atkinson, 2015) had shown a number of unexpected features in the data, specifically:

1. A cold bias of several K for most channels relative to NWP predictions.
2. Significant “striping”, believed to be due to 1/f (or “flicker”) noise in the receiver.
3. Unexpected land/sea sensitivity for upper tropospheric channels 5,6,7,8. It was hypothesised that this was due to inter-channel interference in the receiver, and an empirical correction was performed using window channel 1. So far, no physical explanation has been found.
4. Erratic bias changes in the data after 6/1/2015, that were not present before that date. This was eventually traced to a bug in the smoothing of the calibration counts (the smoothing was not correctly centred in time).

Taking the first issue, the most likely causes of the significant cold bias were considered to be:

- Inadequate antenna pattern correction of the earth views
- Incorrect nonlinearity parameters (e.g. the data provided by the manufacturer may have been misinterpreted)

To investigate these possibilities, a short study was performed in which the data were processed in three different ways: (i) with the original quadratic nonlinearity correction, (ii) with the later cubic nonlinearity correction, (iii) with the nonlinearity parameter set to zero, but the antenna correction tuned to give zero mean bias, relative to Met Office NWP.

The results for channel 3 (52.8 GHz) are shown in Figure 2 and Figure 3.

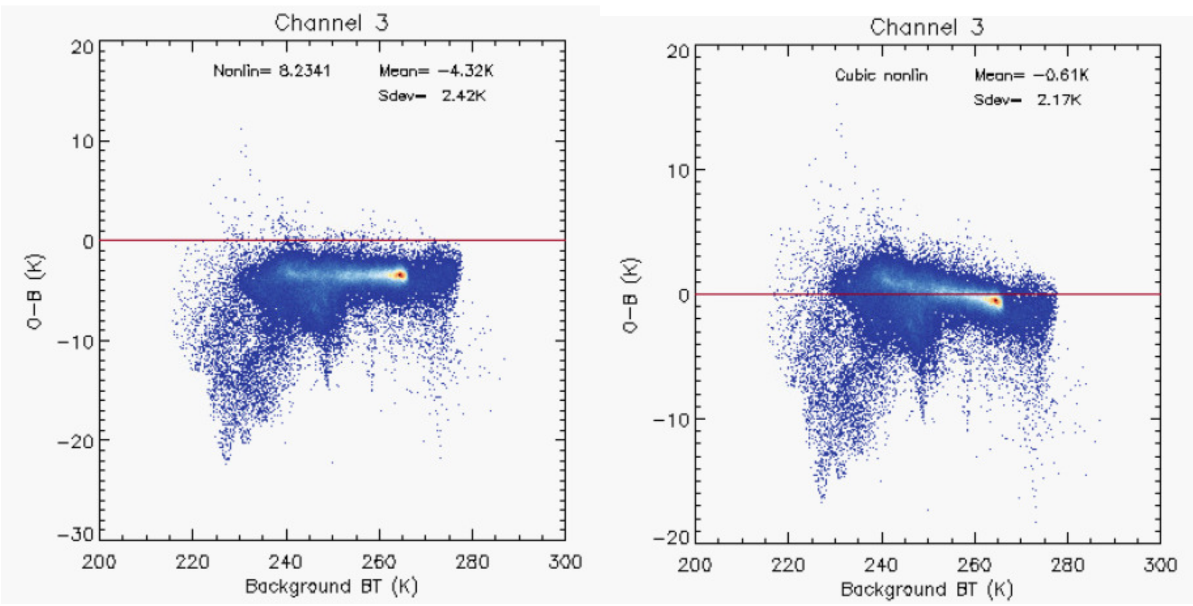

Figure 2: O-B for MWTS-2 channel 3
Left: original quadratic nonlinearity; right: cubic nonlinearity

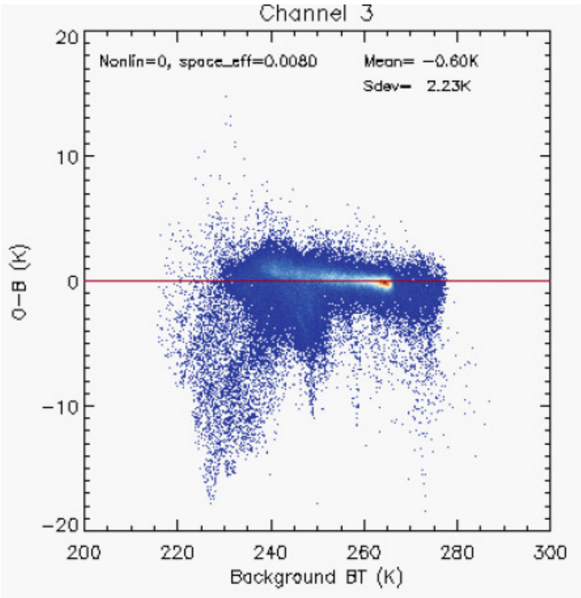

Figure 3: Same data as Figure 2, but nonlinearity set to zero and antenna correction tuned (mean space efficiency set to 0.008)

For channel 3, it appears that the cubic nonlinearity correction has indeed removed the major offset, but has introduced a significant dependence of the bias on brightness temperature. By contrast, increasing the antenna correction and setting the nonlinearity to zero (Figure 3) has removed the bias, with a much smaller BT dependence.

This is just one channel; results for other channels were less conclusive, because of the smaller dynamic range of many channels. However, this result does suggest that the current operational antenna correction is sub-optimal, and should be reviewed. This was also a recommendation of Lu et al. (2015).

Regarding the two different forms of the nonlinearity correction, these are plotted for channel 3 in Figure 4. We note that not only is the cubic correction substantially different from the original, but does not pass through zero at the space counts (having been taken directly from thermal vacuum test chamber results). Again, this should be reviewed.

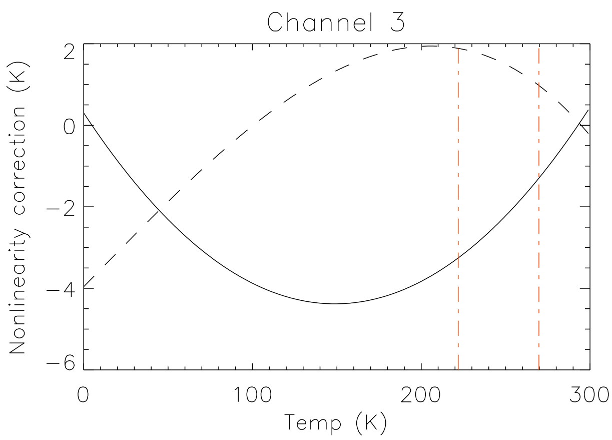

Figure 4: Comparison of nonlinearity corrections
Solid: original quadratic nonlinearity correction; dash: cubic form. The vertical red lines mark the normal brightness temperature range encountered when observing the atmosphere.

A final point to note regarding the MWTS-2 instrument is that the instrument stopped scanning reliably in Feb 2015, and there has been no global data since then. However, the points made above will be relevant to post-launch evaluation of MWTS-2 on FY-3D (which is expected to take place during 2017).

5. Evaluation of MWHS-2

MWHS-2 data are being monitored operationally by CMA, ECMWF and the Met Office, and assimilation trials have taken place. The NWP-based studies have generally shown that the instrument performs well, with acceptable channel noise values (see Lu et al., 2015 for details).

The known issues are:

1. The bias changes unexpectedly when there is a change in platform temperature (e.g. when other instruments are turned on).
2. There is some striping evident, but smaller than MWTS-2 and comparable with MHS and ATMS.

Off-line computation of brightness temperatures (using OBC counts) agrees well with the level 1B brightness temperatures. Also, BTs from the FY3CL1pp package agree well with global BTs (as of 27/8/2015, when the antenna correction was introduced).

Figure 5 shows an example of bias change, in this case associated with a cooling of the instrument (by 2K), and presumably also a cooling of the platform, when MWTS-2 was turned off.

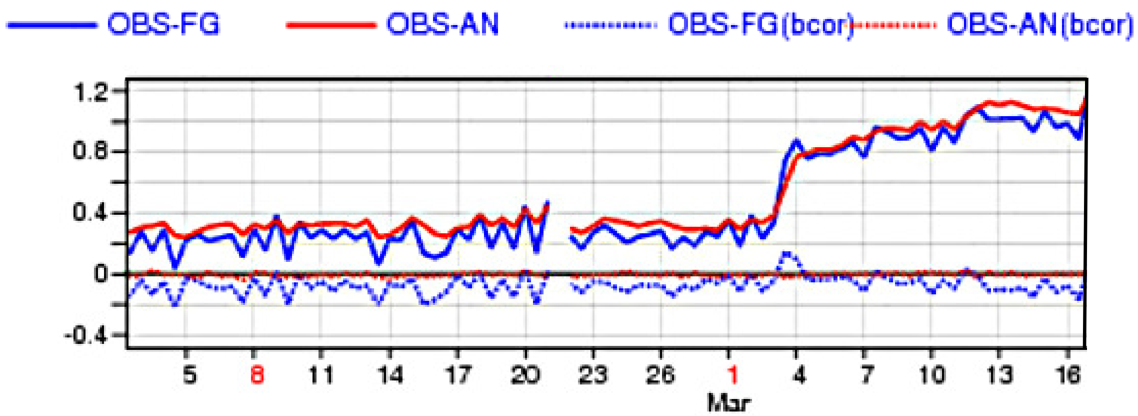

Figure 5: MWHS-2 channel 13 bias changes in early March 2015, from ECMWF monitoring.

The fundamental reasons for the bias change are not clear. One possible explanation could be the temperature dependence of the nonlinearity parameter; however, more detailed analysis showed that this effect would be far too small to explain the observed bias changes. The channels with the largest sensitivity to environment temperature are channel 13-14 (183.31±3 and 183.31±4.5), but a smaller bias change was also observed in the 118 GHz channels. The changes are adequately handled by the ECMWF VarBC system (dotted lines are bias corrected). Also, it has been noted that the bias also depends on the ADC gain setting of the instrument, for reasons that are not fully clear.

6. Conclusions

A detailed evaluation of the calibration process has been carried out for the microwave sounders on FY-3C. MWHS-2 is generally in good shape, though some unexplained bias changes have been observed. The work has led to a better understanding of the MWTS-2 calibration process, and although the instrument is no longer operating, there are valuable lessons to be learnt for the sensor on FY-3D

The direct broadcast packages (FY3CL0pp and FY3CL1pp) have been invaluable for this work, and are now leading to exploitation of these data in regional applications, e.g. through EUMETSAT's EARS-VASS service.

It is hoped that through this cooperative programme, involving CMA/NMSC, ECMWF and the Met Office, rapid progress will be made in the exploitation of data from future satellites in the FY-3 series.

Acknowledgements

The authors would like to gratefully acknowledge the funding and support of the NWPSAF visiting scientist programme for the work of Qifeng Lu. Also, we would like to thank the Climate Science for Service Partnership for funding provided for Katie Lean and Fabien Carminati and the European Union's Horizon 2020 GAIA-CLIM project for supporting William Bell and Nigel Atkinson. Heather Lawrence is funded through the EUMETSAT Fellowship programme. EUMETSAT's efforts regarding the real-time dissemination of FY-3 satellite data are also gratefully acknowledged.

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