An initial assessment of microwave imager/sounder MTVZA-GY data from Meteor-M N2 satellite

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An initial assessment of observations from the MTVZA-GY instrument on Meteor-M N2 (Cherny et al, 2010) has been undertaken at SRC Planeta/Roshydromet and ECMWF for evaluation of calibration accuracy. The MTVZA-GY is a microwave imager/sounder instrument similar to the SSMIS instrument on the DMSP F16 to F19 satellites. A two-point calibration technique is used for converting the signals from MTVZA-GY to antenna brightness temperatures. In terms of impact on NWP and scientific assessment both MTVZA-GY and SSMIS could be considered the same genre of instrument. The SSMIS instrument calibration has been extensively studied (e.g. Bell et al, 2008) and an initial focus of the evaluation of MTVZA-GY was to compare how similar its characteristics are to the SSMIS. In this initial assessment it appears likely that the MTVZA-GY has broadly comparable performance to SSMIS. Some results of MTVZA-GY post-launch calibration performed at SRC Planeta are also presented.

Introduction

A brief description of instrument

The MTVZA-GY is a 29-channel microwave imager/sounder with conical scan geometry. The instrument is described on the following WMO Oscar web page: http://www.wmosat.info/oscar/instruments/view/333. It should be noted that the zenith angle is 65°, not 53.3° as reported on Oscar. MTVZA-GY data products include both Temperature Data Record (TDR) and Sensor Data Record (SDR). The TDR product is the calibrated antenna temperatures obtained directly from the sensor antenna measurements of earth's outgoing radiation at the top of the atmosphere while the SDR product is the brightness temperature after applying a beam efficiency and scan position dependent bias correction to the TDR data, see (Weng et al, 2013). The data are supplied in HDF4 format and includes attributes that describe the channel frequencies, channel numbers, etc. It should be noted that there are some differences compared with the expected channel list: there are no channels at 42.0 or 48.0 GHz; at 91.655 GHz there is only V polarisation, not H; some of the bandwidths are different.

Initial ECMWF assessment of the MTVZA-GY data on Meteor-M N2

For this study, the FRTM RTTOV v.11has been used (Sounders et al, 1999), together with ECMWF input data to generate model background brightness temperatures (BTs) for each channel. The observed BTs are then compared with the simulated BTs. RTTOV coefficients were generated from a channel list provided by SRC Planeta. The channel numbering system is different from that used in the RTTOV coefficient file, see Table1.

Table 1.

Channel numbering in MTVZA-GY HDF data sets and RTTOV v11

Channel no in MTVZA-GY data file (HDF)	Channel no in RTTOV coefficient's file	Central frequency and polarisation, GHz	Channel name (atmospheric sounding channels)
1	1	10.6V	
2	2	10.6H	
3	3	18.7V	
4	4	18.7H	
5	5	23.8V	
6	6	23.8H	
7	9	36.7V	
8	10	36.7H	
9	25	91.65V	
10 (unavailable)	26	91.65H	
11	15	52.80V	O1
12	16	53.30V	O2
13	17	53.80V	O3
14	18	54.64V	O4
15	19	55.63V	O5
16	20	57+0.32± 0.1H	O6
17	21	57+0.32± 0.05H	O7
18	22	57+0.32± 0.025H	O8
19	23	57+0.32± 0.01H	O9
20	24	57+0.32± 0.005H	O10
21	29	183.31±1.4	HO3
22	27	183.31±7.0	HO1
23	28	183.31±3.0	HO2
24 (unavailable)	-	-	
25 (unavailable)	-	-	
26	7	31.5V	
27	8	31.5H	
28 (unavailable)	-	-	
29 (unavailable)	-	-	

A sample of data from the MTVZA instrument on Meteor-M N2 (Cherny et al 2010) has been provided to ECMWF for initial evaluation. A ECMWF global model analysis was used, centered on 00Z on 8th July 2015. The MTVZA is a microwave imager sounder instrument similar to the SSMIS instrument on the DMSP F16 to F19 satellites. Both are conically scanning instruments combining dual polarised imaging channels, mostly below 50 GHz with temperature sounding channels at 50-60 GHz and humidity sounding channels at 183 GHz. However they are also some notable differences. MTVZA has dual polarised channels at 10

GHz, which SSMIS does not, and MTVZA has a nadir view angle of 53.3°, giving a normal earth incidence angle of 65°. MTVZA also has no fewer than four window channels between 31 and 48 GHz whereas SSMIS only has 37 GHz. MTVZA does not have the upper stratospheric and lower mesospheric channels found on SSMIS. However in terms of impact on NWP and scientific assessment these differences are not critical, we can consider it to be of the same genre of instrument as SSMIS.

The SSMIS instruments suffered from a number of well documented problems (Bell et al. 2008), including ascending-descending orbit bias differences, areas of high bias due to solar intrusions on the calibration target, and inter-line "stripping". These issues had a major impact on the potential impact of SSMIS, particularly for the temperature sounding channels where high accuracy and stability is needed. At ECMWF only the imaging and water vapour sounding channels from SSMIS have been used. However some centres, notably NRL and the Met Office, have put considerable effort into making use of the temperature sounding channels.

In this initial assessment the aim is simply to see to what extent MTVZA suffers from similar problems to SSMIS. 24 hours of data from 17-18 march 2015 have been compared to short range (up to 12 hour) forecasts from the ECMWF system and biases and regional variations examined.

Results

a. Temperature sounding channels.

This initial set of plots is for MTVZA channels 17-24. These are temperature sounding channels and correspond to channels AMSU-A 6-14. For channel 17, which is the first sounding channel not to "see" the surface we can see large airmass biases. This may be indicative that the assumed bandpass and true bandpass are not the same, however it could also be due to an error in the calibration along the orbit. There is little evidence for this channels of ascending-descending bias differences. Stripping noise is clearly visible. There is a large mean bias – the global mean being around 3.5 K.

Figure 2, for Channel 18, shows similar behaviour to channel 17 with a strong north-south bias gradient. The stripping noise is clearly evident. Unlike channel 17 there is now clear evidence of a difference in bias between ascending and descending orbits. There is a strange cold anomaly in the Southern Indian Ocean, warmer O-Bs over Eastern Russia, which may point to calibration issues (intrusions?) and there are some scan lines that appear very warm.

Figure 3 (for channel 19) shows very different behaviour. The bias is now warmest in the tropics and coldest at the poles. The ascending-descending bias differences and stripping are however similar to the two lower channels. The assessment remains similar for the higher peaking temperature sounding channels (not shown), but the airmass bias patterns change for each channel. This may mean it is more likely the bandpass is wrong for each channel, as we might expect calibration problems to have similar impacts for similar channels.

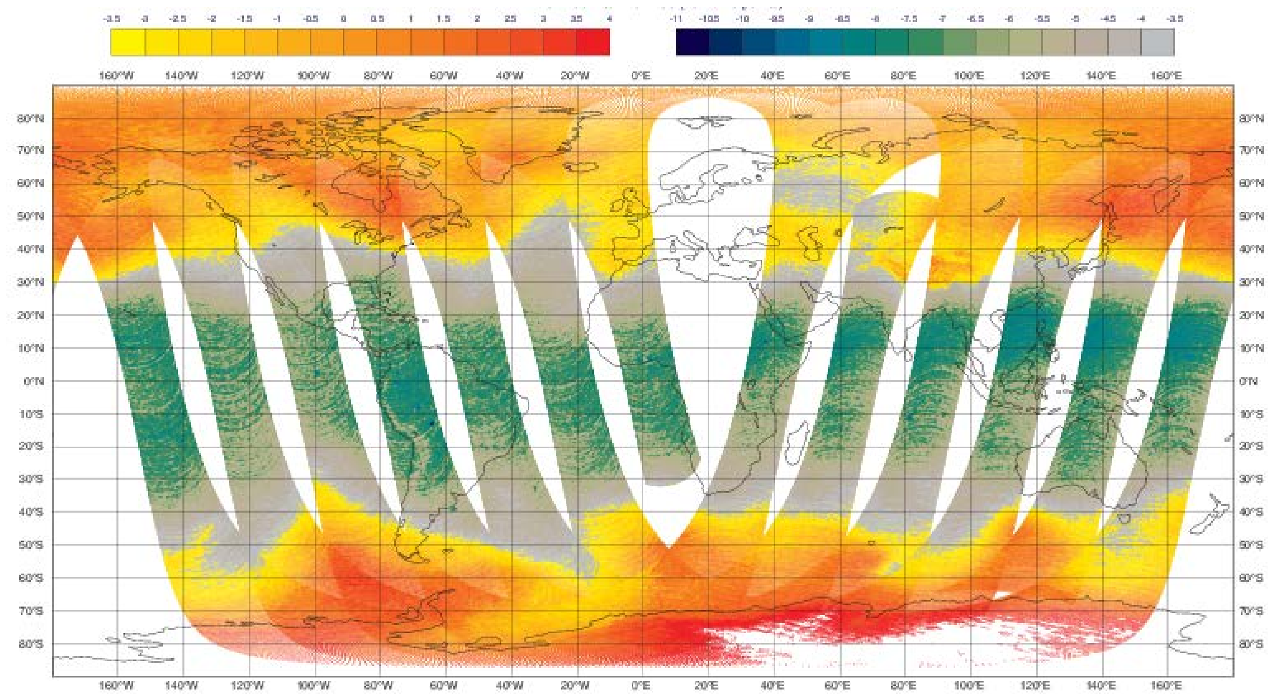


Figure 1: MTVZA-GY channel 17 (similar to AMSU-A Ch.6) Observation minus Background difference from 18 march 2015

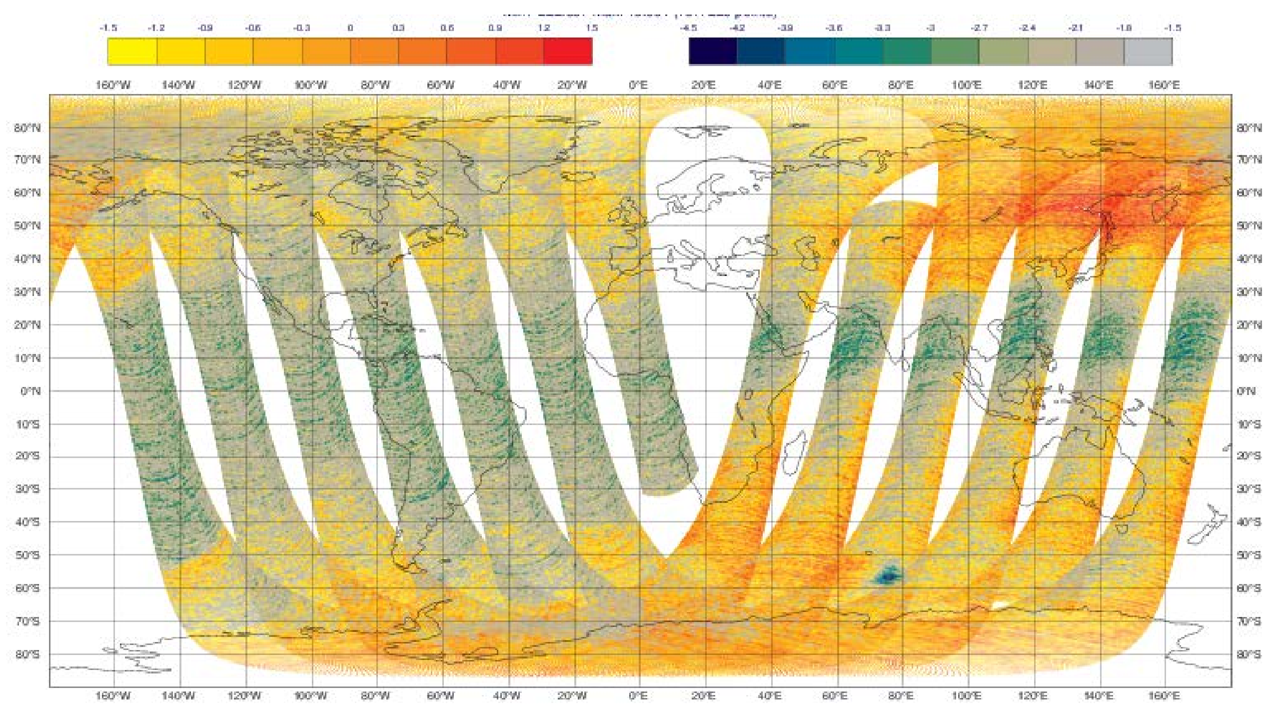


Figure 2: As Figure 1, for Ch.18 (similar to AMSU-A Ch.7/8)

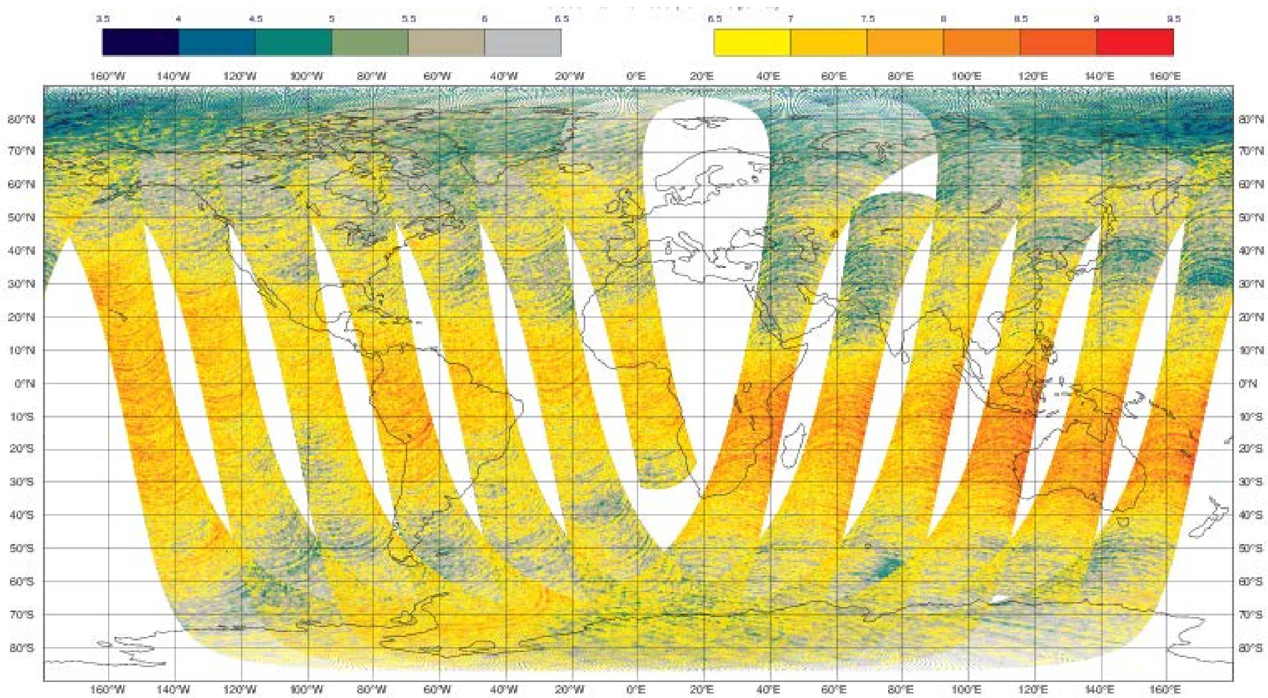


Fig. 3: As Fig. 1 for channel 19 (similar to AMSU-A Ch.8/9).

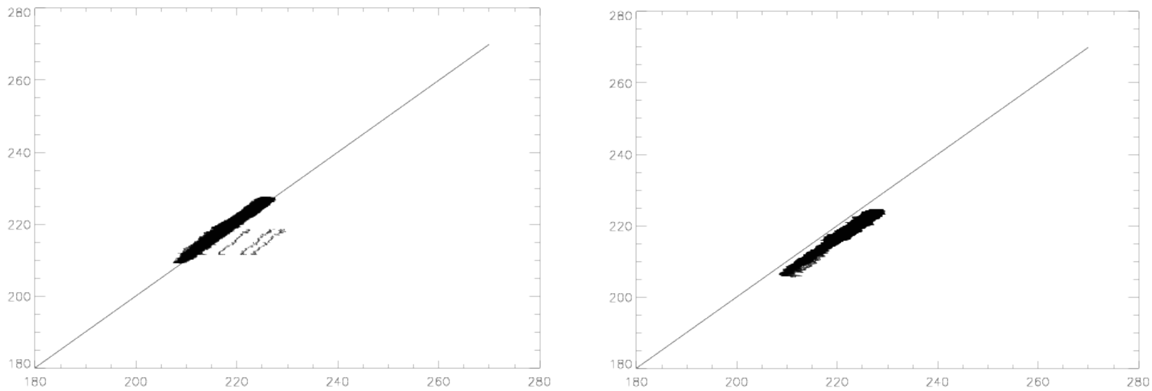


Fig. 4 Background versus observed brightness temperature for channels 18 (left) and 20.

In addition figure 4 plots the background calculated BTs against observed BTs for two of the temperature sounding channels. These do not reveal much more, except some anomalous observations in channel 18, and the sizeable bias in channel 20.

b. Humidity sounding channels

As background errors in humidity correspond to much larger changes in brightness temperature than is the case for temperature sounding channels, many sources of error are always less evident in humidity channels. However the ascending-descending bias difference seen in the temperature sounding channels is also clearly evident in the first humidity channel, with warmer biases in the eastern hemisphere. However other than this the data appears to be good.

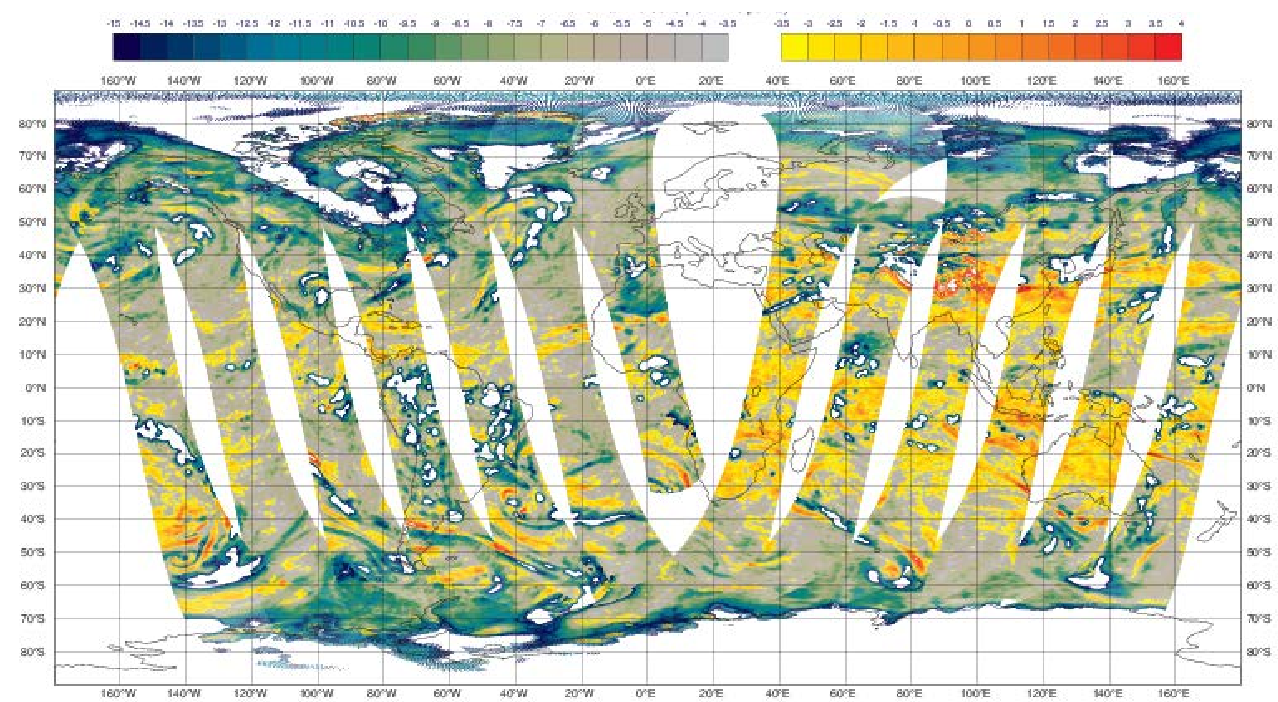


Fig. 4. As Fig. 1 but for channel 27 (similar to MHS-5)

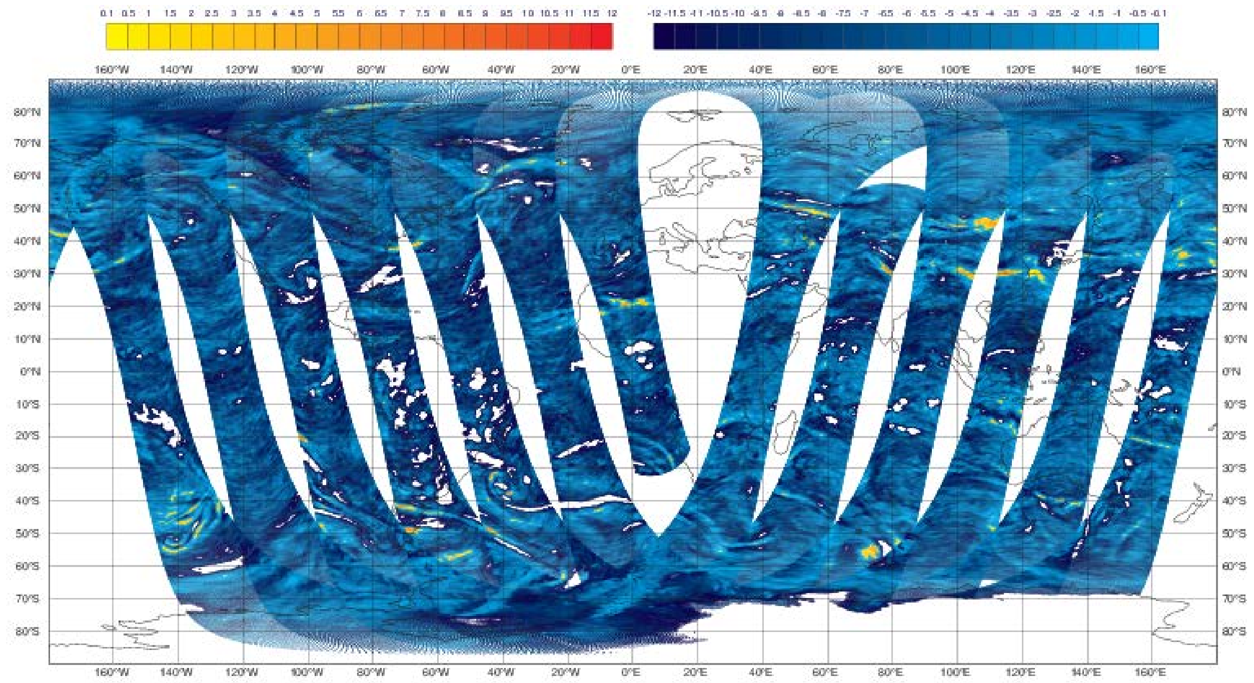


Fig. 5. As Fig. 1 but for channel 28 (similar to MHS-3)

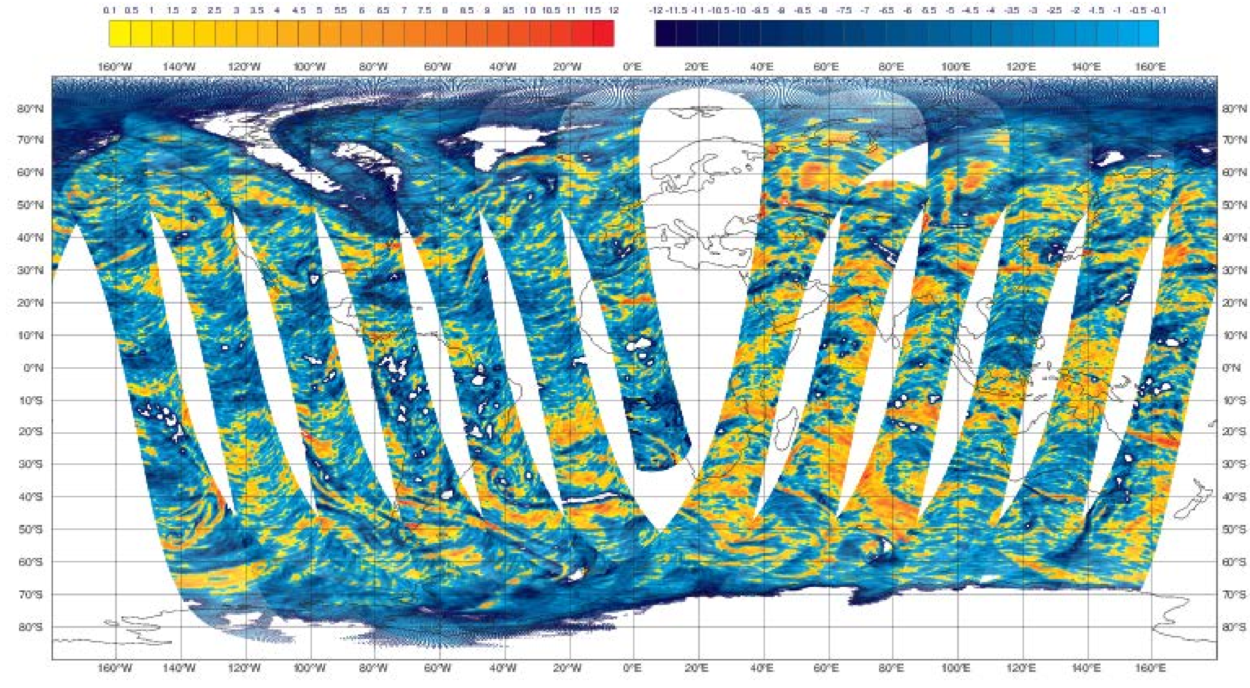


Fig. 6. As Fig. 1 but for channel 29 (similar to MHS-4)

Figures 5 and 6 show the same story for ascending and descending biases as Figure 4, with warmer biases in the descending orbits (in the eastern hemisphere). However what is less obvious from figures 4-6 is that there is also a strong airmass bias variation for the humidity. When we plot background calculated observations against actual observations, as is done in Figure 7, this is much clearer. At warm observed brightness temperature there is generally good agreement, but at cold observed brightness temperature there is very poor agreement.

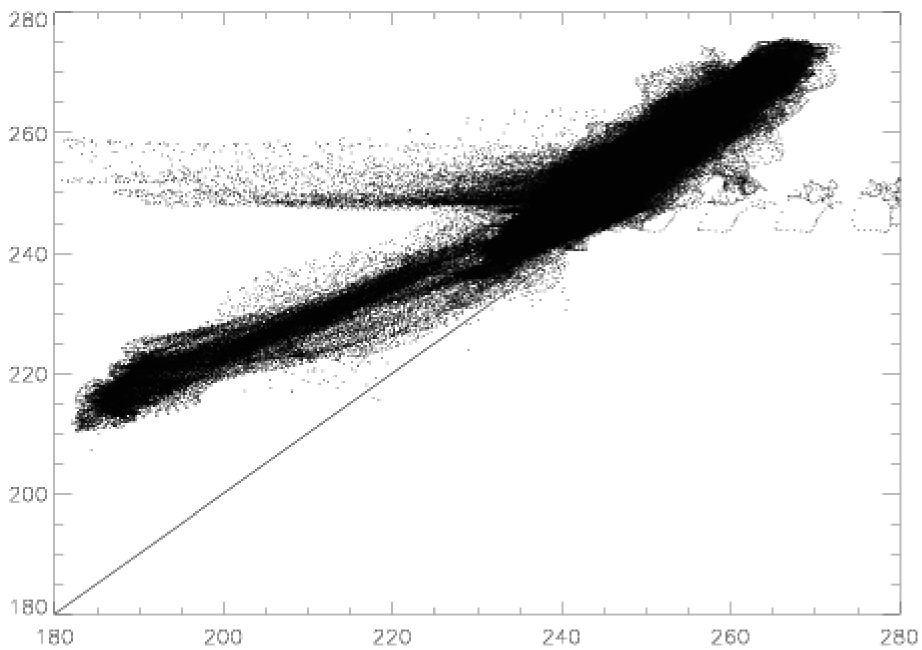


Figure 7: Background BT versus observed BT for channel 28.

c. Imagery channels

Figures 7 and 8 show the 18 GHz vertical and horizontal background departures. Apart from a strange anomaly at the start of the first ascending orbit the data looks OK.

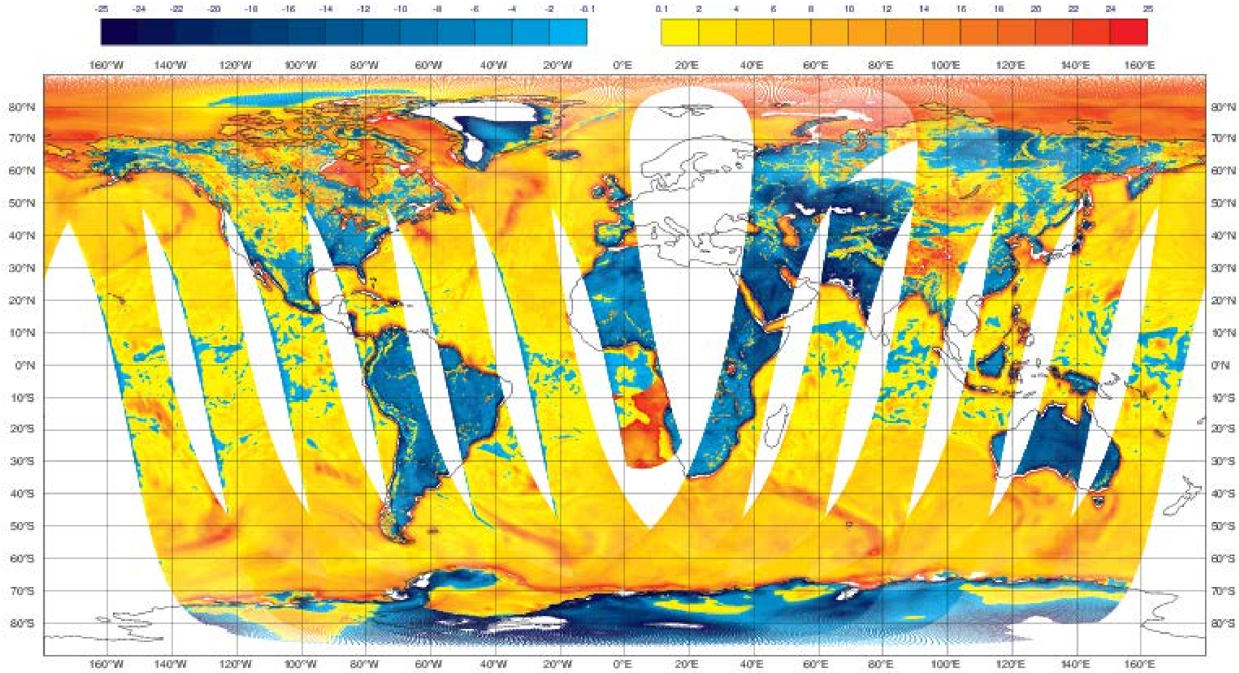


Fig. 7. As Fig. 1 but for channel 3 (18 GHz)

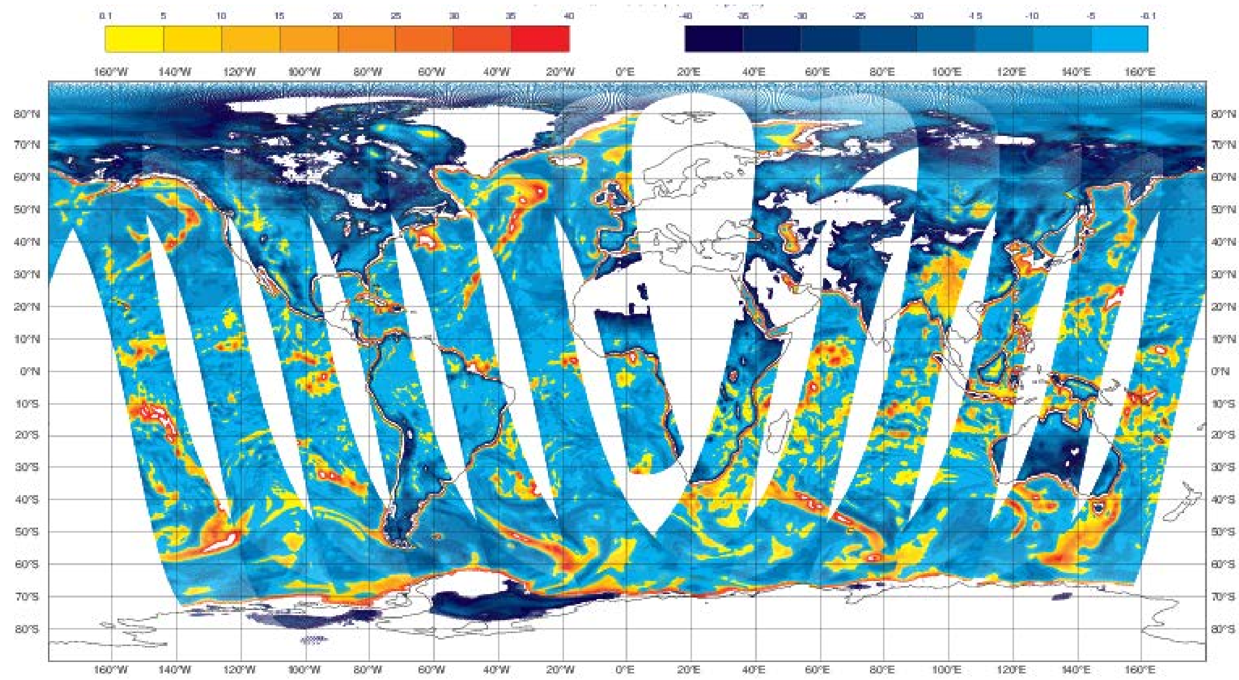


Fig. 8. As Fig. 1 but for channel 4 (18 GHz)

The one standout feature when looking at the imagery channels is the coastline bias, which is more easily seen by showing a small region in more detail. Australia is shown in figure 9. It can clearly be seen that on the north coast there is a strong negative bias (over land) whereas on the south coast there is a strong positive bias (over the ocean). This would suggest that the navigation has a north-south error or there are large side lobes. This also needs to be fully understood.

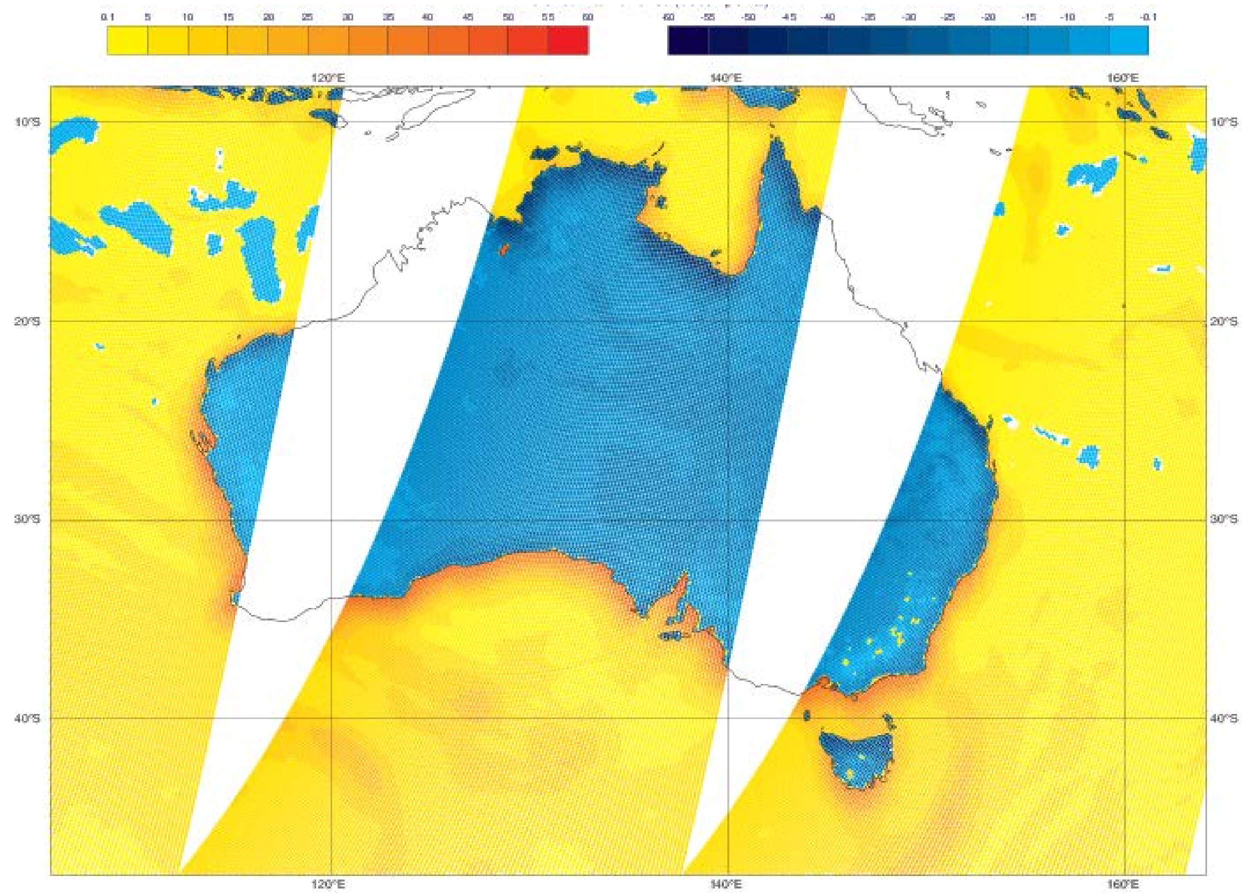


Fig.9. MTVZA-GY channel 4 Observation minus Background difference from 18 march 2015

The MTVZA-GY data assessment in Planeta

Radiation at microwave frequencies emitted from atmospheric constituents allows remote sensing of the atmospheric temperature, and water vapor. Through a two-point calibration equation (Cherny et al, 2010; Weng et al, 2013) the signal from the microwave radiometer can be linked to the brightness temperature. In MTVZA-GY calibration, the biases are expected in radiance measurements as a result of many calibration error sources. For example, biases could come from spacecraft emission, earth-view side lobe effects, etc. It is important to quantify, and correct these biases before their applications in NWP (Bormann et al, 2013).

A powerful approach of monitoring the on-orbit satellite instrument radiometric calibration is to compare satellite-observed radiances with radiative transfer model (RTM)-simulated radiances.

For reference purposes, the channels are grouped into four subtypes corresponding to the lower atmospheric temperature sounding (LTS) channels (channels 11–15), the upper atmospheric sounding (UTS) channels (channels 16–20), the atmospheric water vapor sounding (WVS) channels (channels 21–23), the imaging (IMA) channels (i.e., channels 1–10, and 24-29). We were focused primarily on the atmospheric sounding channels (LTS, UTS, WVS).

The MTVZA-GY absolute post-launch calibration algorithm has been developed and implemented. It is based on a comparison between observed radiances (antenna brightness temperatures-TDR) and RTM-simulated radiances (sensor brightness temperature-SDR) and linear regression.

Here we use our own sensor-channel-based RTM (MWFF), developed by team from Saint-Petersburg State University (Saint-Petersburg, Russia), see (Uspensky et al, 2016). It includes modules that compute the satellite-measured thermal radiation from gaseous absorption, and emission and reflection of radiation by the earth’s surface. The input to the RTM MWFF includes GFS NCEP products such as atmospheric state variables (temperature, water vapor, pressure at 26 layers, and liquid water content) and surface state variables and parameters (surface emissivity and skin temperature, surface wind). To exclude possible precipitating cloud areas we have used the following threshold criteria for LPW from GFS NCEP: LWP<0.05 kg/m^2. Probably for some channels this criteria is way too strong, so as a result there are not many observations left. Water surface emissivities were calculated with FASTEM (RTTOV). For land surface emissivities there was a database used compiled from the AMSR-E data (http://ftp.aer.com/).

A comparison was performed of RTTOV and MWFF simulations. The regression coefficients (a – slope and b – intercept) appears to be pretty close in both cases, see Fig.10.

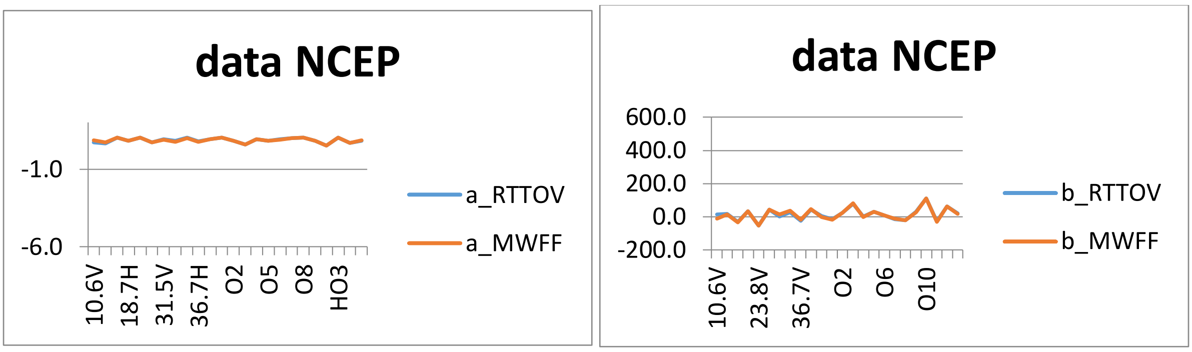
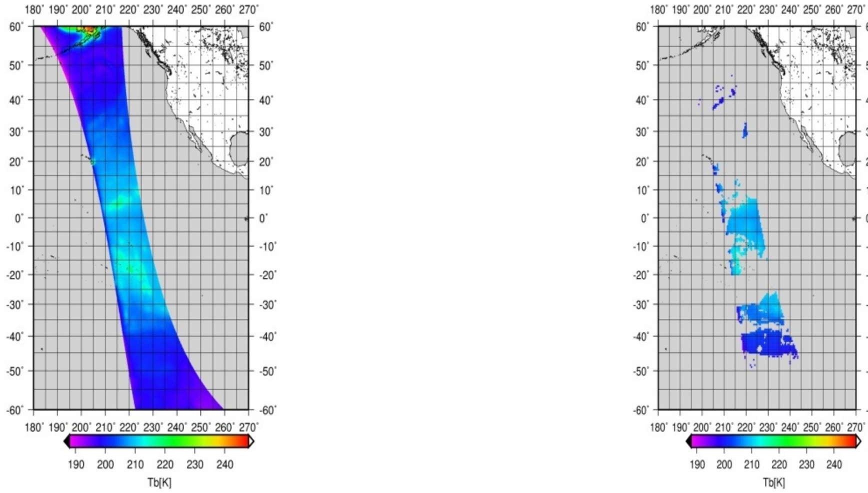


Fig.10. A comparison of regression coefficients calculated using RTTOV and MWFF

Statistical features of the differences between MTVZA-GY observations and RTM MWFF simulations for atmospheric sounding channels were analyzed using all collocated data under clear-sky conditions over ocean within 60 °S–60 °N. An example of dataset used for absolute calibration (06:22 UTC Jan 28 2015) over ocean between 60°S and 60°N in clear-sky, calm conditions is demonstrated at Fig.11.

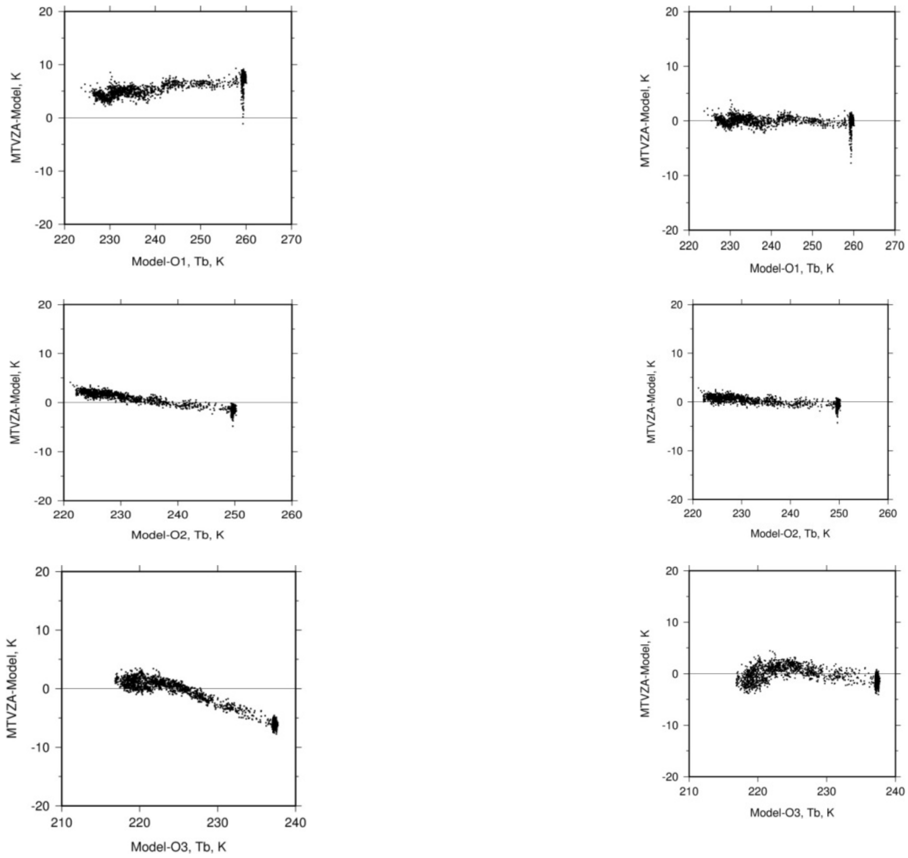


a) Channel 1 (10.6 GHz,V) – an overview;

b) Channel 15 (52.8 GHz,V) – filtered precipitating clouds, surface wind less than 7m/sec

Fig 11. An example of dataset used for absolute calibration (06:22 UTC Jan 28 2015) over ocean between 60°S and 60°N in clear-sky, calm conditions

Scatterplots of brightness temperature differences Observation – Background (O-B) vs brightness temperatures, before and after post-launch calibration applied(data from Jan 26 2015) are shown at Fig.12.



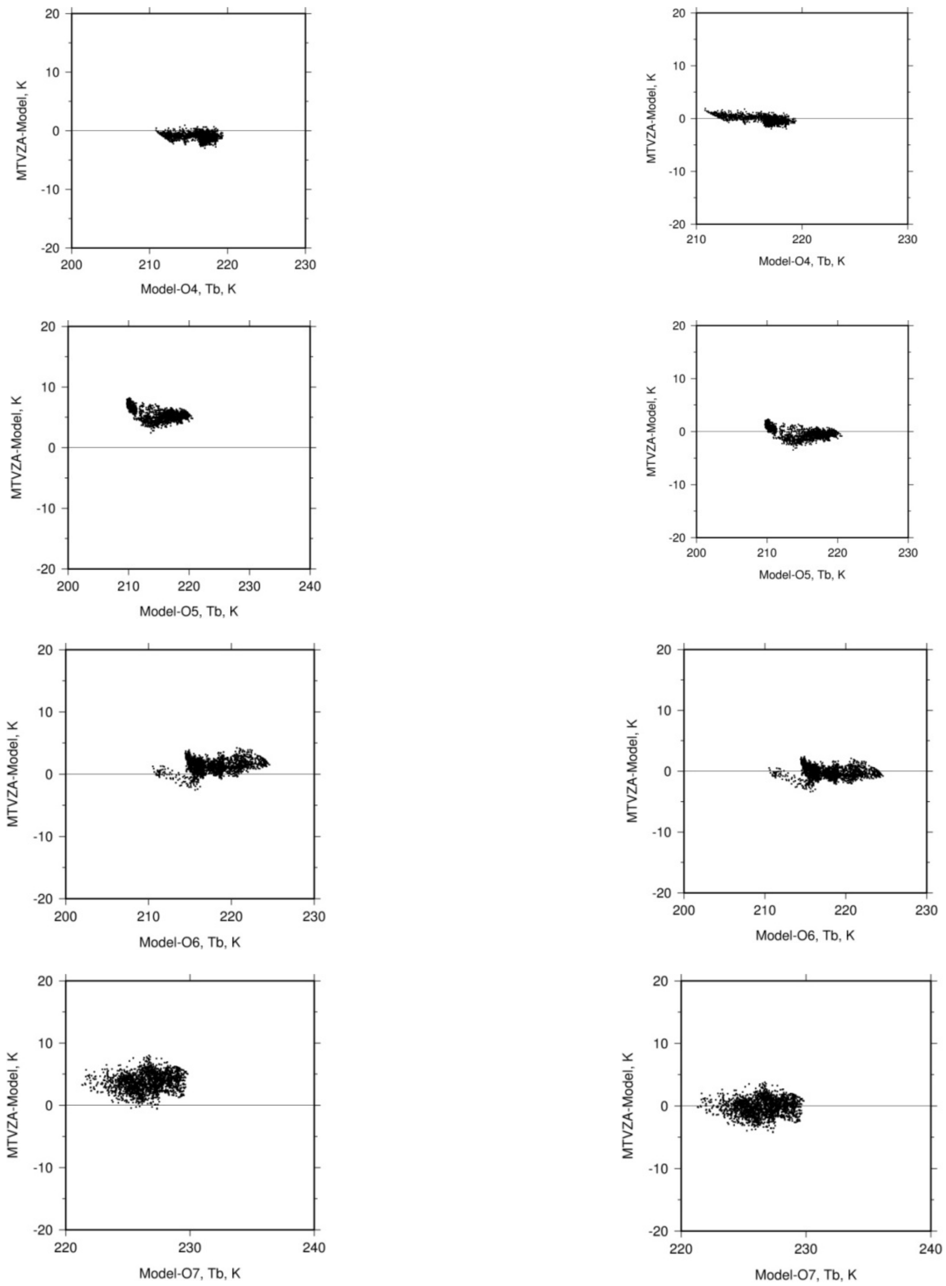


Fig.12. Scatterplots of brightness temperature differences Observation – Background (O-B) vs brightness temperatures for LTS channels, before (left) and after (right) post-launch calibration applied(data from Jan 26 2015)

At Fig.13 the values of biases (Observation minus Background differences) are presented together with standard deviations (std) for all atmospheric sounding channels (LTS, UTS, WVS) before and after post-launch absolute calibration.

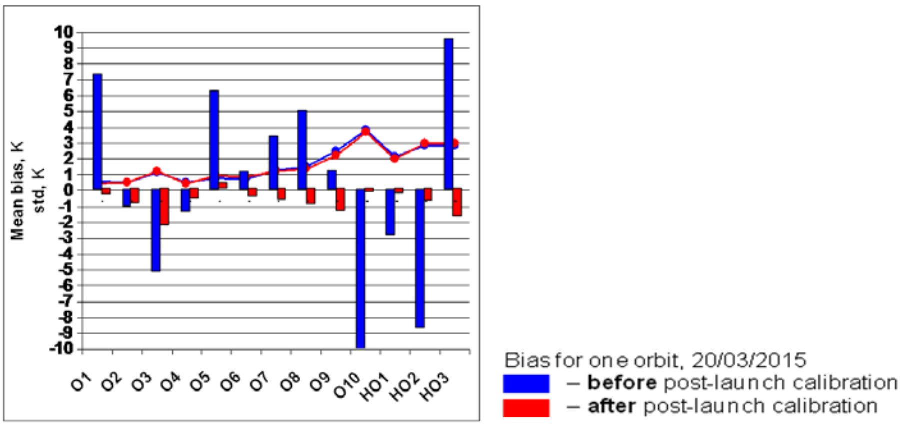
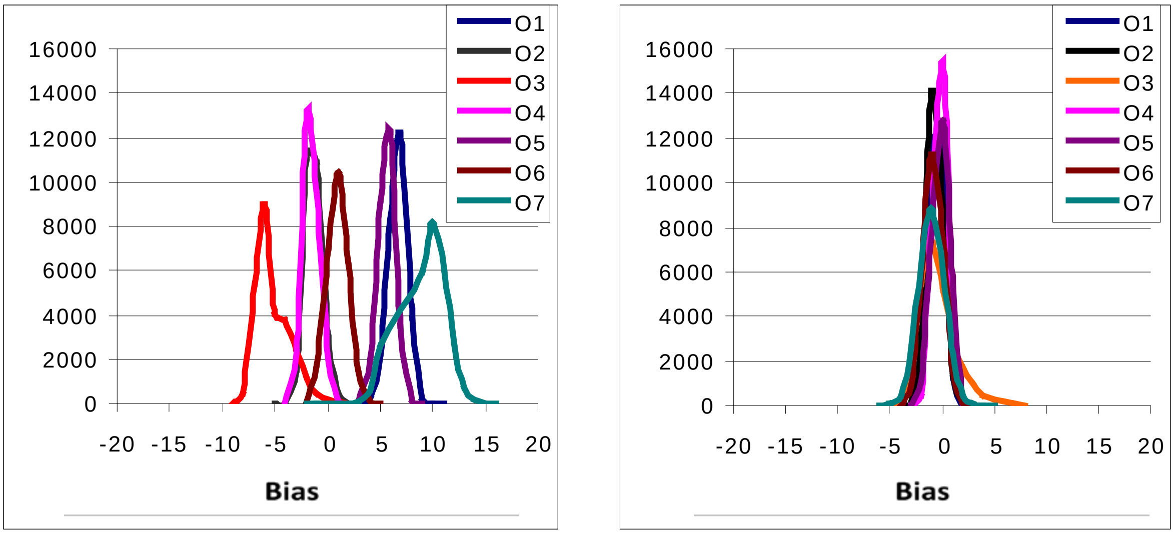


Fig.13. Biases (bar) and std (curve) for one pass, March 20, 2015.

Fig 14 presents frequency distributions of O–B differences before and after the absolute post launch calibration for MTVZA-GY channels 11–15 (O1-O5), 21-23 (HO1-HO3) using all collocated data from two days in June, 2015 under clear-sky conditions over ocean within 60°S–60°N.



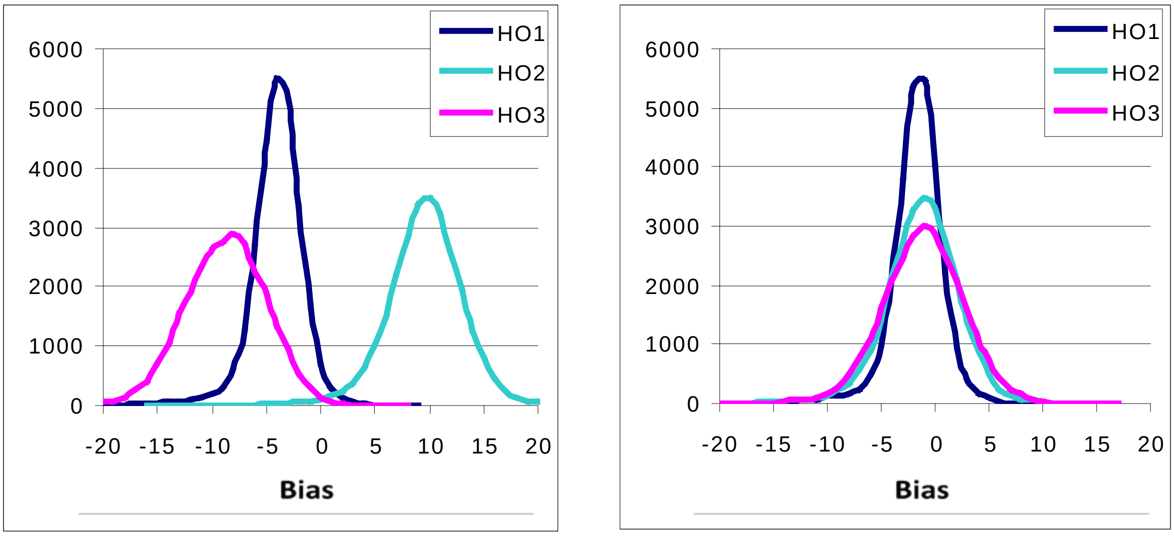
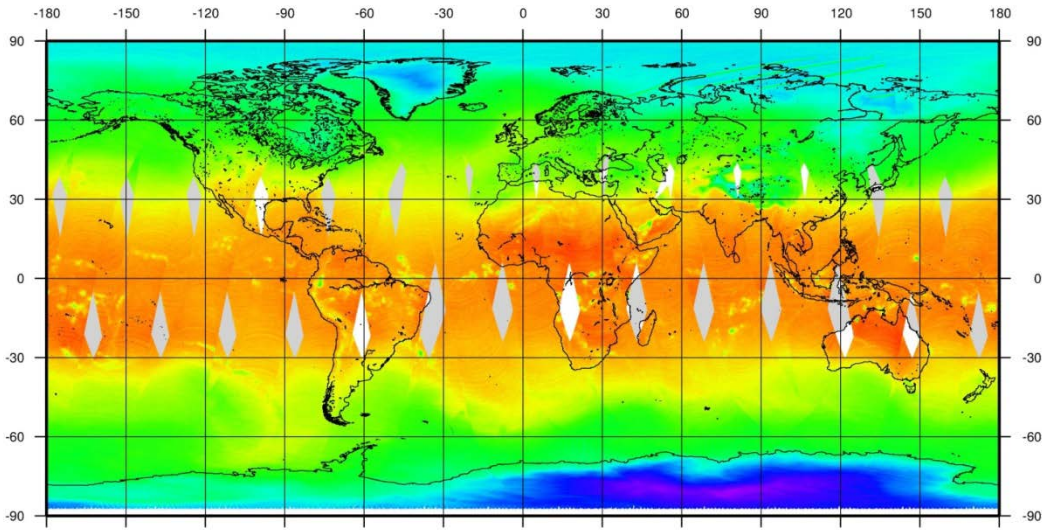


Fig.14. Frequency distributions of (observed – simulated) radiance differences for MTVZA-GY atmospheric sounding channels. Left panel – before, right – after absolute post-launch calibration. Ch O1-O5 – temperature,LTS; Ch HO1-HO3 – humidity sounding,WVS.

It is obvious that for the most channels there are large airmass biases. After the calibration procedures the biases are within limits except for the stratospheric channels (18-20) omitted here. Unfortunately, for these channels it would be useful to have the COSMIC RO data (Zou et al, 2013). As a result, for now the modeled brightness temperatures and calibration coefficients for the mentioned channels may not be reliable. It is necessary to note, that the magnitudes of biases varied with channel number. The error distributions were not of normal Gaussian types. Also, the biases had an asymmetric distribution for some channels. When post-launch absolute calibration was performed, the errors of the MTVZA-GY sensor data record at channels 11-23 became a normal Gaussian distribution.

The results of post-launch calibration applied is shown at Fig.15 for selected LTS channel



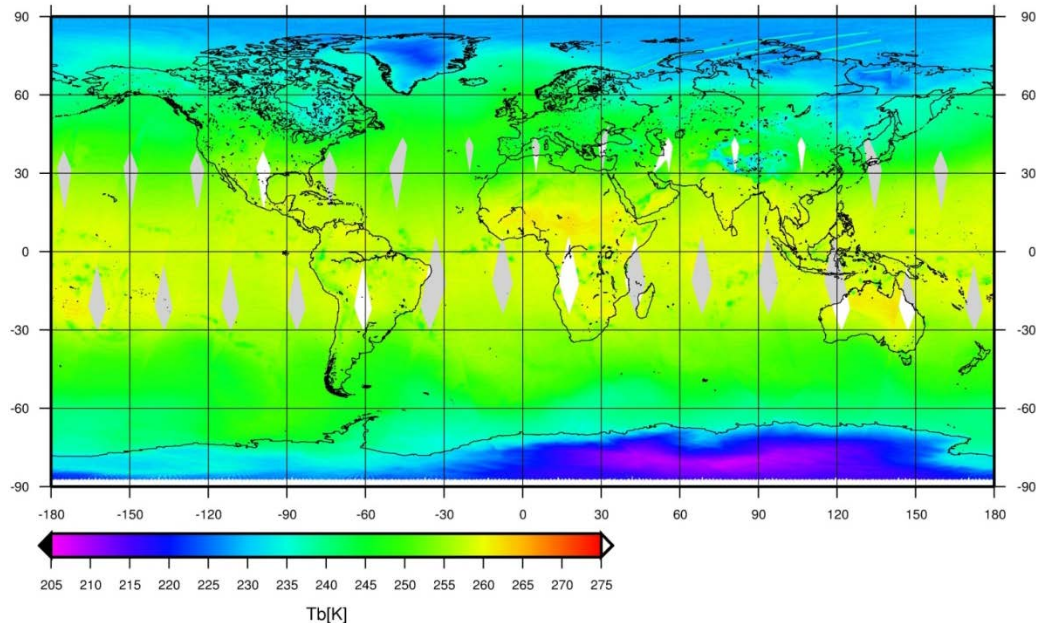


Fig.15.Global distribution of BTs for channel 52.8 GHz, March 22 2015, upper – before, lower – after post-launch calibration applied.

The stripping noise in most channels was also detected, especially for the humidity sounding channels. The team is investigating techniques to mitigate the striping artifacts (Qin et al, 2013).

Conclusions

1).An initial assessment of data from MTVZA-GY has been undertaken at ECMWF. Broadly the results are similar to early results from the SSMIS instruments on DMSP, with a number of issues that are broadly reminiscent of SSMIS. In particular most channels have ascending-descending bias differences, stripping noise and airmass dependent biases. Several channels also have a large global mean bias. These issues would need to be resolved before assimilation trials could begin.

2).At SRC Planeta on-orbit calibration was explored using RTM calculations and GFS NCEP data. MTVZA-GY absolute post-launch calibration algorithm has been developed and implemented. There is a need to refine TDR to SDR conversion (calibration coefficients), especially for upper temperature channels. It would be useful to use the COSMIC RO data.

References

Cherny, I.V, M. L. Mitnik, A.B.Uspensky, A.M.Streltsov, 2010: On-orbit calibration of the “Meteor-M” microwave imager/sounder. Proceedings of IGARSS ,2010,Honolulu,Hawaii, USA,pp.558-561.

Bell, W., B. Candy, N. Atkinson, F. Hilton, N Baker, N. Bormann, G. Kelly, M. Kazumori, W. F. Campbell, S. D. Swadley, 2008: The assimilation of SSMIS radiances in numerical weather prediction models. IEEE Trans. Geoscience and Remote Sensing, 46(4), 884-900.

Bormann N., Fouiloux A. and Bell W.. Evaluation and assimilation of ATMS data in the ECMWF system // J. Geophys. Res. Atmos. 2013. V. 118. doi:10.1002/2013JD020325.

Qin Z., Zou X. and Weng F. Analysis of ATMS Striping Noise from its Earth Scene Observations Using PCA and EEMD Techniques // J. Geophys. Res . Atmos. 2013. V. 118, doi:10.1002/2013JD020399.

Sounders R.W., Matricardi M., Brunel P. An improved fast Radiative transfer model for assimilation of satellite radiance observations // Q.J.R. Meteorol. Soc. 1999. V. 125. P. 1407-1425.

Weng, F., Yang H., Zou X. On Convertibility from Antenna to Sensor Brightness Temperature for Advanced Technology Microwave Sounder (ATMS*) //* IEEE Geosci. Remote Sens. Letter. 2013. V. 10. № 4. P. 771–775. doi: 1109/LGRS.2012.2223193.

Zou X., Lin L. and Weng F. Absolute Calibration of ATMS Upper Level Temperature Sounding Channels Using GPS RO Observations // IEEE Trans. Geosci. Remote Sens. 2013. 52(2), P. 1397-1406.

Uspensky A.B., Kozlov A.A., Kramchaninova E .K. et al. Absolute Calibration of MTVZA-GY atmospheric sounding channels //Issled. Zemli iz kosmosa, 2016, N 3 (in press).