Cal/Val studies for infrared and microwave sounding data from METEOR-M series satellites

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1 Russian Meteor-M Satellites

Russia is now developing the space-based observation system Meteor-3M including new-generation polar-orbiting meteorological satellites of the Meteor-M type. In July 2014 one of such satellites, Meteor-M N2, was launched on the sun-synchronous orbit with the altitude 830 km, equator crossing time 9:30 a.m., and inclination 98.79°. A constellation of similar satellites in the morning and afternoon orbits with the same payload as the one of Meteor-M N2 are planned to be launched in the near future.

The payload of Meteor-M N2 contains two atmospheric sounders: the hyperspectral infrared sounder IKFS-2 and the microwave imager/sounder MTVZA-GY, see e.g. the WMO OSCAR web site.

2 Post-launch IKFS-2 data cross-calibration and assessment

The hyperspectral IR sounder IKFS-2 is a Fourier-transform spectrometer with the spectral range 5–15 μm and spectral resolution of 0.4–0.7 cm^{-1} (apodised). The spatial resolution is about 30 km. The swath width is 1000 km with 15 pixels in the scan line. The calibration period is 60 scan lines; the ice decontamination frequency is once per a month. IKFS-2 data are not available to direct readout users. Data dumps are now being received in SRC Planeta twice per day. The IKFS-2 instrument status and data quality have been comprehensively investigated during the commissioning phase and exploitation. The performance characteristics (spectral and radiometric calibration, instrumental noise) proved to be consistent with the predetermined specifications.

To monitor the accuracy and stability of IKFS-2 observations radiometric calibration and to evaluate the instrumental noise, a cross-validation procedure of IKFS-2 versus Meteosat-10/SEVIRI was developed by SRC PLANETA and SSC Keldysh Research Centre (Kozlov et al. 2016). SEVIRI can be used as a reference instrument because its radiometric calibration has proven to be stable and accurate. The comparison was performed by matching collocated pixels of the two instruments with similar zenith angles (close to zero) in the Gulf of Guinea (Fig 1, left). The spectrum measured by IKFS-2 was convolved with the spectral response functions of the SEVIRI channels to produce synthetic IKFS-2 observations in SEVIRI pseudo-channels, see Fig.1, right. A similar technique has been proposed by Hewison et al. (2013) in the context of the inter-calibration of SEVIRI infrared channels using Metop/IASI.

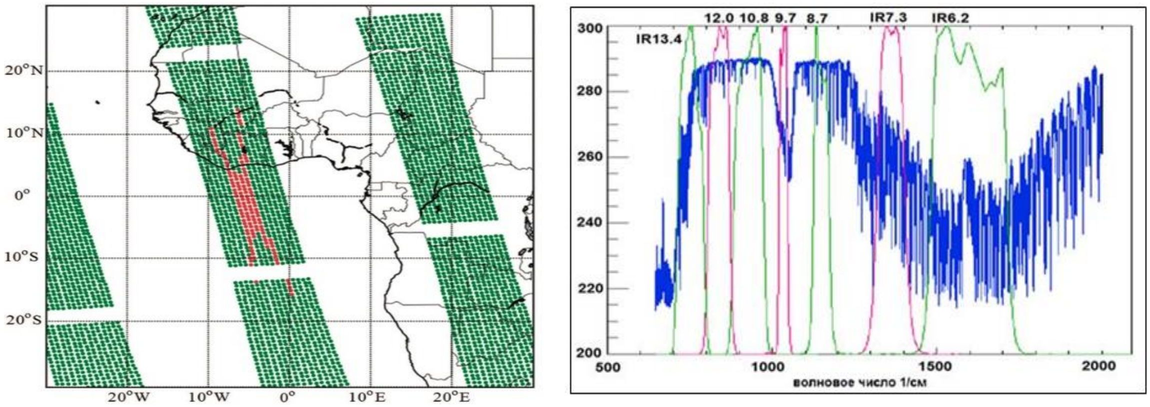

Fig 1. *Left:* IKFS-2 measurements for three consecutive orbits in the IKFS-2-vs-SEVIRI comparison area. *Right:* Spectral response functions for SEVIRI IR channels in the IKFS-2 spectral range.

Results of the IKFS-2 vs Meteosat-10/SEVIRI cross-validation are presented in Table 1. One can see that the results for years 2015 and 2017 are close to each other. The biases between the synthetic IKFS-2 observations in SEVIRI pseudo-channels and SEVIRI observations in channels 7.3, 8.7, 9.7, 10.8, and 12.0 μm are very small and do not exceed 0.1–0.2 K. But in channel 13.4 μm the bias is as large as 1.0–1.2 K. This can be explained by a systematic shift in SEVIRI channel 13.4 μm radiometric calibration, see (GSICS, 2013).

Table 1. IKFS-2 cross-validation vs Meteosat-10/SEVIRI

IKFS – SEVIRI, 2015						
SEVIRI channel	7.3 μm	8.7 μm	9.7 μm	10.8 μm	12.0 μm	13.4 μm
Bias, K	-0.12	0.10	-0.06	-0.1	-0.1	1.0
St. Dev, K	0.07	0.07	0.07	0.07	0.07	0.02
IKFS – SEVIRI, 2017						
SEVIRI channel	7.3 μm	8.7 μm	9.7 μm	10.8 μm	12.0 μm	13.4 μm
Bias, K	-0.10	0.07	-0.2	-0.1	-0.1	1.2
St. Dev, K	0.01	0.01	0.01	0.01	0.01	0.02

3 Post-launch assessment and calibration of MTVZA-GY observations

The MTVZA-GY instrument (where MTVZA is the Russian abbreviation for “module for temperature and humidity sounding of the atmosphere”) is a passive microwave radiometer with the conical scanning regime. It has 29 channels in the 10.6–183.3 GHz frequency range. The viewing angle is 53.3° and the incidence angle with respect to the Earth surface is 65°. A two-point on-board calibration technique is used for converting the measured signals to antenna brightness temperatures T_a, see Cherny et al. (2010). MTVZA-GY data are available to direct readout users. Currently, the MTVZA-GY sensor onboard Meteor-M N2 is down. The next MTVZA-GY sensor is planned to be launched by the end of 2018.

Uspensky et al. (2015) performed an initial assessment of the MTVZA-GY results. By comparing the observed T_a with the reference (simulated) T_b they found significant calibration issues, in particular, large global and air-mass dependent biases in atmospheric sounding channels. To reduce the errors/biases, Uspensky et al. (2015), see also Uspensky et al. (2017), developed and implemented a post-launch calibration algorithm for MTVZA-GY atmospheric sounding channels based on the linear regression

$$T_b = a\, T_a + b, \qquad (1)$$

where T_a is the antenna temperature, T_b is the calibrated brightness temperature, and a and b are the regression coefficients (estimated using least squares from a training sample of the observed T_a's and the collocated reference T_b's). It is essential for this study that the reference brightness temperatures T_b were computed using a fast radiative transfer model similar to RTTOV (Saunders et al.,1999) or directly by RTTOV v.11. NCEP GFS forecasts were used as input to the radiative transfer model together with surface emissivity data. The sea surface emissivities were calculated using RTTOV. The land surface emissivities were specified using the public database “AER Global Gridded AMSR-E Emissivity Atlas” (http://ftp.aer.com/).

Calibrated and bias-corrected MTVZA-GY data were successfully assimilated by Gayfulin et al. (2017) in the meteorological data assimilation system of the HydroMetCentre of Russia. In order to further improve the quality of MTVZA-GY data, Gayfulin et al. (2018) proposed another two calibration techniques. The first one is the generalization of (1) with evolving in time but constant in space coefficients a=a(t) and b=b(t). The second technique presents a more advanced generalization of (1) with evolving both in time and space coefficients $a=a(\alpha,\zeta)$, $b=b(\alpha,\zeta)$, where α and ζ are the solar azimuth and zenith angles. The fields $a(\alpha,\zeta)$ and $b(\alpha;\zeta)$ are defined on a grid in the α-ζ plane. The coefficients $a(\alpha,\zeta)$ and $b(\alpha,\zeta)$ are cyclically updated every 6 hours in a variational scheme using deviations of the antenna temperatures from the reference as observations. For a more detailed description of the new calibration technique see Gayfulin et al. (2018).

Numerical experiments were performed to examine the accuracy of MTZVA-GY data calibrated with the three techniques (designated as the 1st, 2nd, 3rd schemes). Data from three two-week time periods in February, April and June 2017 were examined. Atmospheric temperature channels 15-20 with the center frequencies at 52.8, 53.3, 53.8, 54.64, 55.63, and 57.29±0.32±0.1 GHz (the RTTOV channel numbering is used) as well as humidity channels 27-29 with the center frequencies at 183.31±7.0, 183.31±3.0, and 183.31±1.0 GHz were tested.

Raw observations were subjected to several checks performed to reject single-pixel outliers, data with big departures from the background and with significant dependence on the surface properties, as well as those contaminated by heavily precipitating clouds.

Figure 2 shows the distributions of local biases for channel 18 for an arbitrarily chosen 30h period indicated in the figure caption. The local biases were computed by averaging “observation-minus-background” deviations over the $3^{\circ} \times 3^{\circ}$ grid cells on the globe. The left panel of Fig.2 display the results with the above 2nd calibration scheme and the right panel with the 3rd scheme. One can see how successfully our most sophisticated 3rd scheme removes the local biases, leaving behind, largely, just noise.

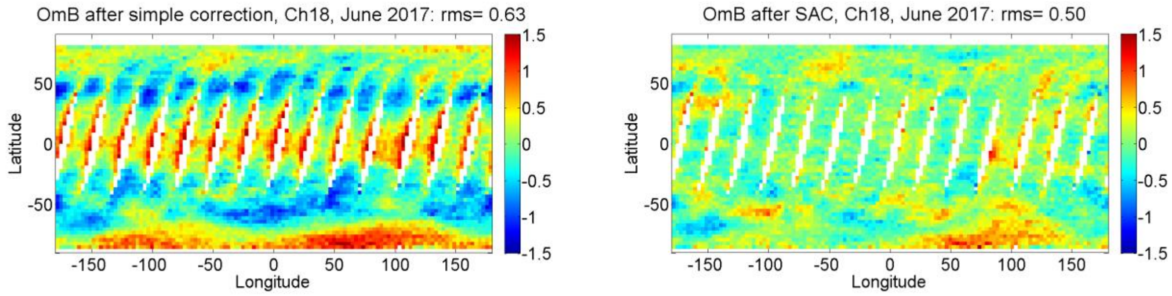

Figure 2. Local biases for observations in channel 18 valid at times from 21h UTC, 12 June 2017 to 3h UTC, 14 June 2017 (descending orbits). *Left:* With the 2nd calibration scheme (with constant in space but updated in time coefficients a and b). *Right:* With the 3rd (solar-angles dependent) calibration scheme.

Table 3 displays the overall calibration results.

Table 2: RMS deviations of calibrated observations from the reference data.

Scheme	Ch15	Ch16	Ch17	Ch18	Ch19	Ch20	Ch27	Ch28	Ch29
1st	0.72	0.85	1.76	0.62	0.71	0.80	2.16	2.21	2.74
2nd	0.67	0.83	1.70	0.62	0.71	0.79	2.00	2.15	2.65
3rd	0.56	0.63	1.04	0.50	0.56	0.62	1.91	2.01	2.38

As it follows from comparing the 1st and 3rd rows in Table 2, the post-launch calibration substantially decreases errors in the MTVZA-GY data. It is worth noting that MTVZA-GY channel 15 appeared to be comparable in accuracy to AMSU-A channel 4 (not shown), whereas MTVZA-GY channel 17 exhibited the worst performance. For the other MTVZA-GY channels, the RMS errors (with the 3rd calibration scheme) were about twice as large as the RMS errors in the similar AMSU-A/MHS channels (not shown).

4 Conclusions

The IKFS-2 vs Meteosat-10/SEVIRI cross-validation has showed good results, confirming stability and high accuracy of the IKFS-2 on-board radiometric calibration.

A new post-launch calibration algorithm for MTVZA-GY atmospheric sounding channels has been proposed. The technique sequentially assimilates observed minus simulated radiance data in a 6h cycle in order to estimate up-to-date calibration coefficients. The calibration coefficients are defined to be functions of the solar azimuth and zenith angles. The calibrated observations are shown to be significantly more accurate as compared with observations that undergo simpler and more traditional calibration techniques.

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