# IRFS-2 instrument onboard Meteor-M N2 satellite: measurements analysis

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## *Abstract*

Fourier-transform spectrometer IRFS-2 is currently being flown onboard the new Russian satellite Meteor-M №2. IRFS-2 measures thermal radiation in 5-15 μm spectral region with the spectral resolution of 0.7 – 1.4 $cm^{-1}$ (after apodization). In order to assess the reliability of the measured spectra, we preliminary calibrated them in comparison with SEVIRI data. Next, we compared IKFS-2 radiance measurements with other hyperspectral instruments IASI-A and –B. The comparison of spectra measured by different instrumentation showed that statistical parameters (mean, SD) for IRFS-2 and IASI-A, -B are mutually close. Furthermore, we described the retrieval algorithms for various parameters including temperature and humidity profiles, total amount of some of the atmospheric gases ($O_3$, $CH_4$ etc.). In the end, we presented the first examples of the retrievals and compared them with independent measurements.

## *Introduction*

IRFS-2 (see Figure 1) was launched onboard the satellite METEOR M №2 in summer 2014. After a period of adjustment and testing, we started receiving and processing the instrument spectra. The present work is a result of joint efforts of the teams of three different institutes: Saint-Petersburg State University, SRC "Planeta" and Keldysh center. SRC "Planeta" is a leading institute of the project, Saint-Petersburg university crew works in a field of inverse problem, and Keldysh Center designed the instrument and codes for the first level data processing.

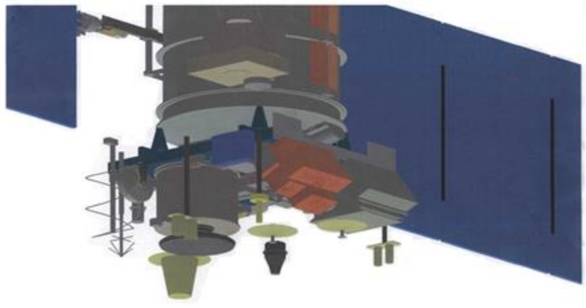

Figure 1. Space borne Infrared Fourier-Transform Spectrometer IRFS-2

Space-borne infrared Fourier-transform spectrometer IRFS-2 measures outgoing infrared radiances and provides data on the atmosphere, land and oceans for application in weather predictions and climate studies. IRFS-2 is one of the key instruments of the Meteor-M N2 satellite. The instrument was developed by Keldysh Research Center together with Krasnogorsky zavod and Bauman State Technical University (Moscow). Table 1 shows the main parameters of the instrument. The spectral region includes 15 µm band of $CO_2$, atmospheric windows and the absorption bands of $H_2O$, $O_3$, and some trace gases.

Table 1. Main instrument characteristics.

| parameter | Requirement |
|---|---|
| Spectral range | 5 – 15 µm (660 – 2000cm$^{-1}$) |
| Unapodized spectral resolution | 0.4cm$^{-1}$ |
| Radiometric calibration error (λ=11–12 µm) | 0.5K |
| Noise Equivalence Spectral Radiance, NESR mW/(m$^2$ sr cm$^{-1}$) | 0.35, λ=6 µm<br>0.15, λ=13 µm<br>0.45, λ=15 µm |
| instantaneous field of view (IFOV)<br>spatial resolution at sub-satellite point | 40 mrad<br>30 km |
| Swath width<br>Spatial step | 1000 – 2500km<br>60 – 110km |
| sampling period | 0.6 s |
| data rate | 580 kb/s |

## *Calibration testing*

Figure 2 shows the results of calibration tests, which were performed at Keldysh center. We compared IRFS-2 spectra with SEVIRI (Meteosat-10) measurements data. The method of comparisons is based on GSICS method of comparisons of SEVIRI and IASI data. Time difference between two types of observations was less than 15 min, the relation for selection zenith angles of measurements was as follows (1):

$$\left|\frac{\cos(ZA_{leo})}{\cos(ZA_{geo})} - 1\right| < 0.01 \qquad (1)$$

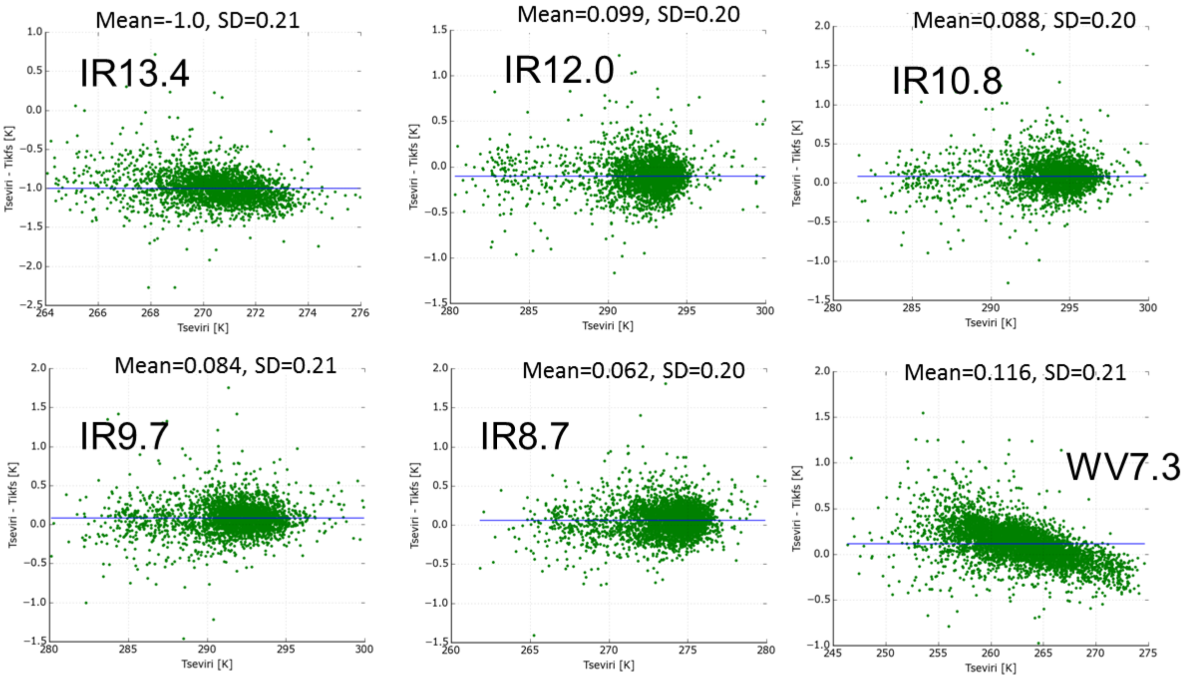


Figure 2. Intercomparison of IRFS-2 and SEVIRI data (Meteosat-10).

The mean difference in integral brightness temperatures is less than 0.1 K for 12.0, 10.8, 9.7, and 8.7 µm spectral channels and totals 1.0 K for 13.4 µm channel, which can be explained by some defects of SEVIRI calibration for this channel, confirmed by GSICS. In the channel 7.3 µm there is some dependence of calibration error on temperature. The reason of this dependence is a non-linearity of IRFS-2 sensor, which is the subject of work of our colleagues at the moment.

The next two figures show the comparisons of IRFS-2 and IASI spectra. Fig. 3 observes the differences between mean spectra of IRFS-2 and two IASI instruments. All spectra were measured at the same period between 6 pm of 5 February and 8 am of 6 February 2015. The orbits of both satellites are close to each other. The differences between measured spectra are small enough: for IASI –A in all spectral channels the difference is smaller than IRFS-2 NESR, for IASI –B the difference is a little bit larger, but relatively small, too.

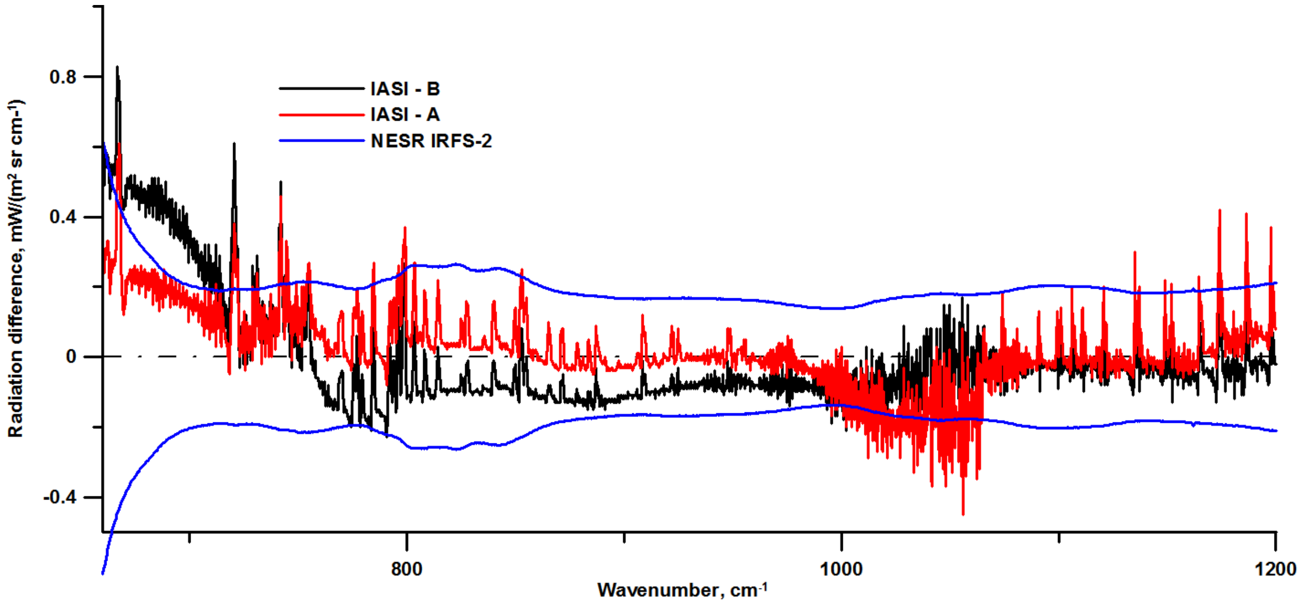


Figure 3. Statistical comparison of outgoing radiation measured by three instruments: IRFS-2, IASI-A, and -B. Differences between mean spectra: IRFS-2 minus IASI. All measurements were performed in clear-sky conditions.

Differences between standard deviations of measured spectra are shown in Figure 4. As we can see, they are close too, but variability of both IASI measured spectra in the region of atmospheric windows is larger than the variability of IRFS measurements. It can be explained by the better spatial resolution of IASI measurements compared to IRFS-2. Owing to the better spatial resolution, IASI can detect much more details of the surface emissivity than IRFS-2.

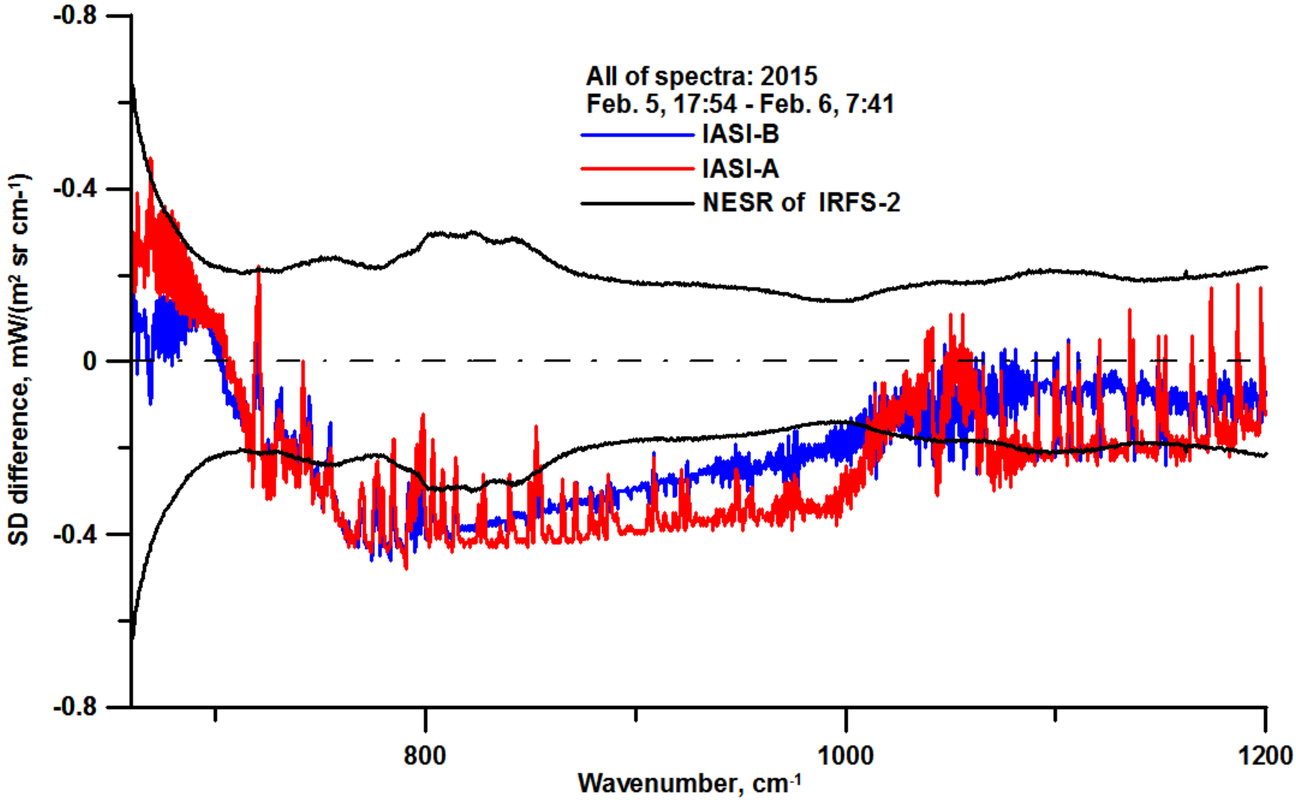


Figure 4. Statistical comparison of outgoing radiation measured by three instruments: IRFS-2, IASI-A, and -B. -B : Difference between SD of radiances: IRFS-2 minus IASI. All measurements were performed in clear-sky conditions.

On the next step of the study, we compared spectra measured by two different instruments in selected coincident pairs. We choose the pairs on July 22-23th, 2015, to compare IRFS-2 and IASI-B measurements. Figure 5 depicts positions of selected measurements.

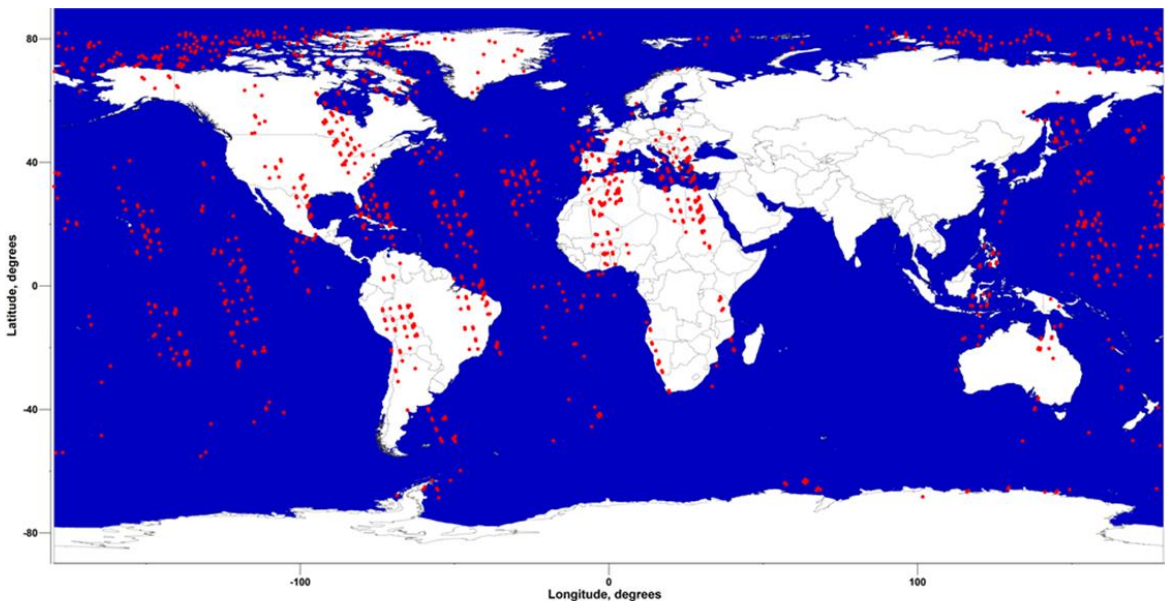


Figure 5. IRFS-2 and IASI-B selected measurements pairs, July 22-23, 2015.

Figure 6 shows the means and RMS differences of IRFS and IASI spectra in CO2 absorption band region. Fig. 6 experiences good agreement of both data, however, the interval of 720-750 $cm^{-1}$ marks some defects of spectral calibration (or, may be, transformation of IASI data to IRFS ILS parameters). The minor increase of RMSD in the same spectral region appears due to the partly transparency of this region.

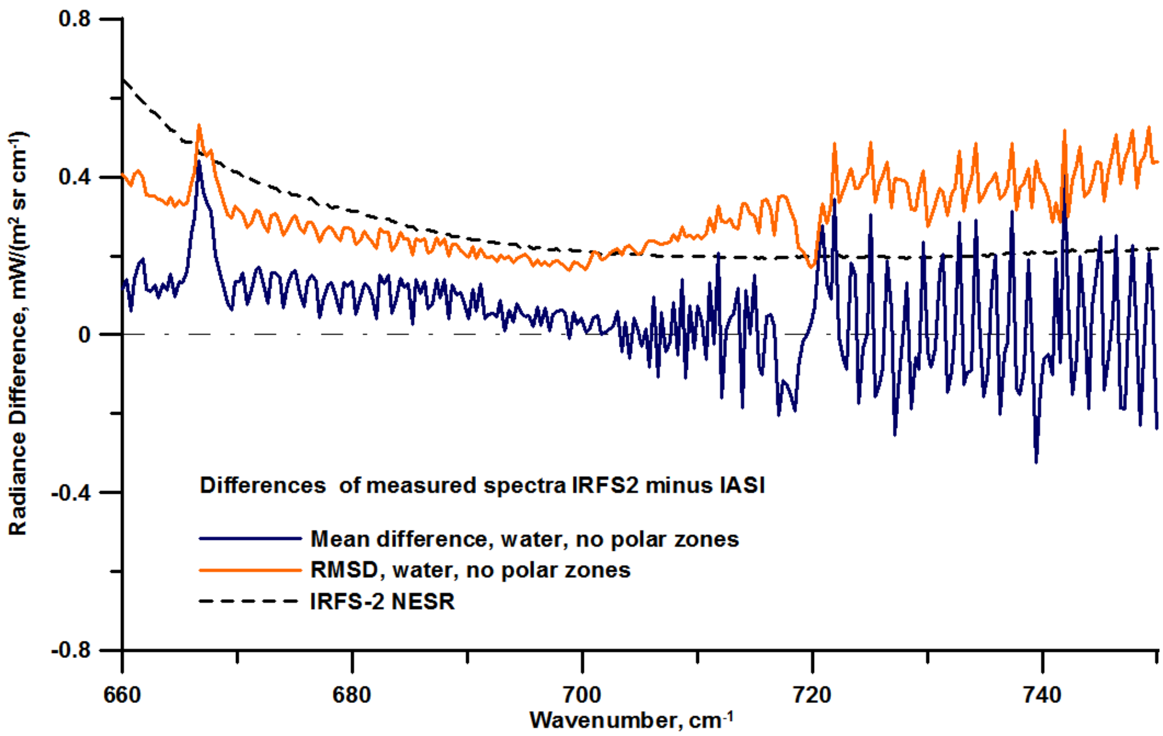


Figure 6. The IRFS-2 and IASI-B coincident measurements, July 22-23, 2015 (612 pairs above water surface, between 65S and 65N). $CO_2$ band spectral region.

Fig.7 depicts the same as Fig. 6, but for atmospheric window. Here we can see the good agreement of mean differences of both instruments and nearly constant RMSD, which accounts for approximately 0.6 mW/($m^2$ sr $cm^{-1}$) The reason of relatively large value of RMSD is the spatial difference of measurement as well as the difference in pixel size and instrumental shape of two instruments.

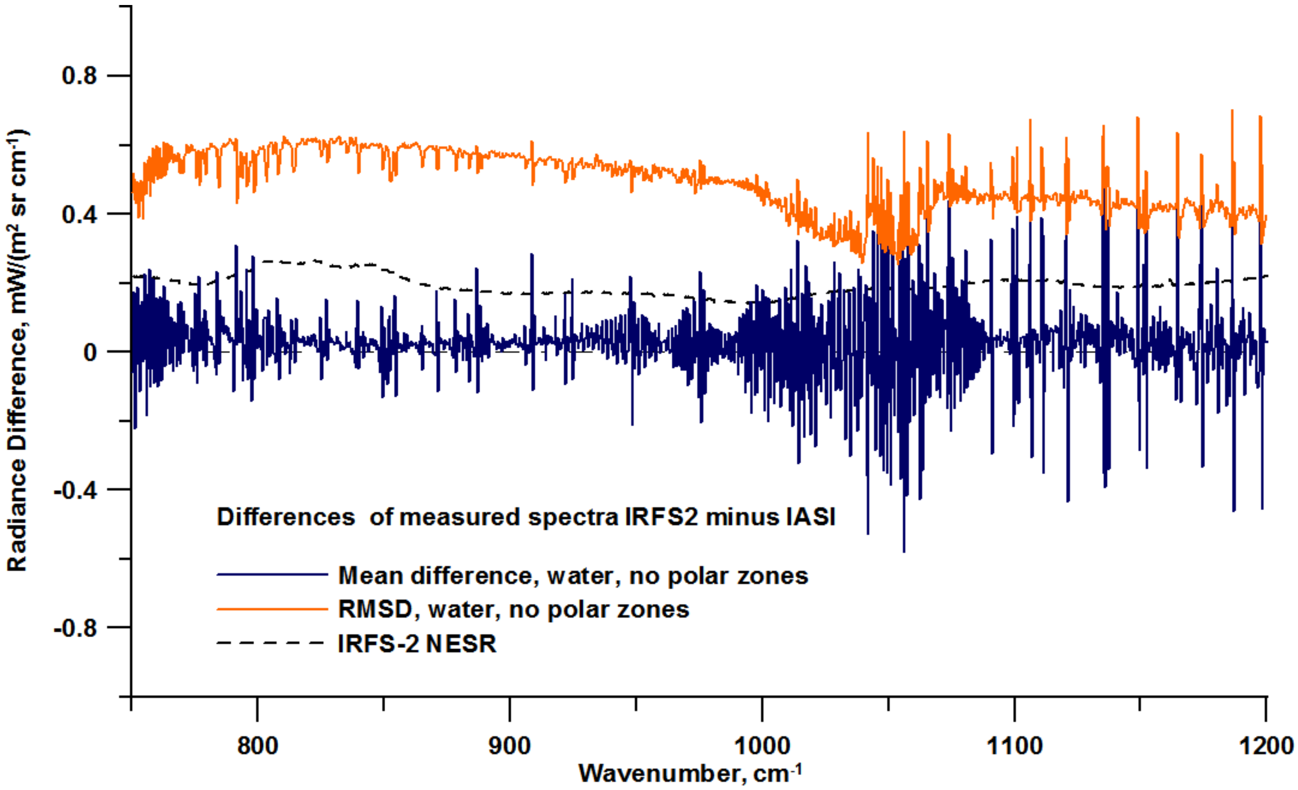


Figure 7. The IRFS-2 and IASI-B coincident measurements, July 22-23, 2015 (612 pairs above water surface, between 65S and 65N). Transparency window spectral region.

Figure 8 shows a desire signal – the variability of the measured radiance – and noise of the measurements.

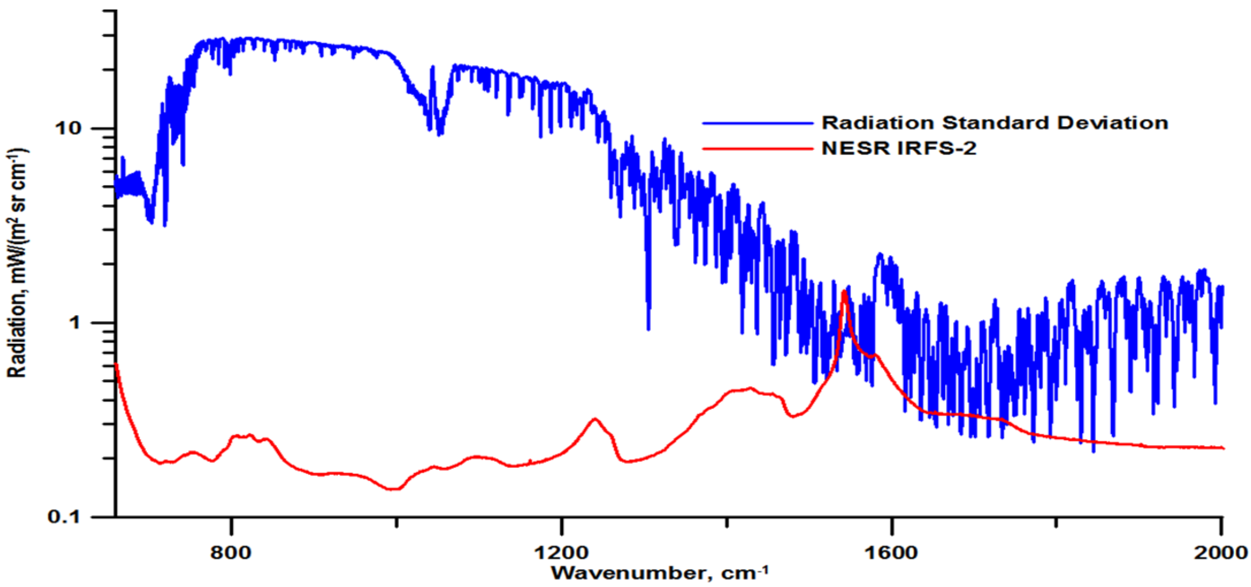


Figure 8. SD spectral radiance and measurement NESR of IRFS-2. Calculated by spectra set: 2015 Feb 05 – Apr 04, total number of the spectra is 1041735

As we can see, in the region of the temperature sounding of atmosphere and surface and ozone band the desire signal is rather more than noise, but, after 1400 cm$^{-1}$ the signal goes down and the noise rises, and after 1600 cm$^{-1}$ they are too close for getting some information from the spectra.

## *Used inversion algorithms and processing results analyze*

Processing code uses 3 main inversion methods: Multiple Linear Regression (MLR), Artificial Neural Networks (ANN), and physical- mathematical iterative method, based on Optimal Estimation (OE).  MLR is used to get first guess, ANN could be used for first guess or for final result, and iteration algorithm based on OE method can improve the solution. It should to mention, the PC approach is used in spectra and profiles spaces. And, before inversion, radiometric correction of spectra is processed, basing on comparisons measured and calculated spectra. Cloud detection is preliminary performed to select only cloudless measurements.
One of the principle features of the remote sensing methods is vertical resolution, or averaging kernels. In Figure 9 the Averaging Kernel of our methods for temperature profile and altitudinal dependence of vertical resolution are shown. As we can see, near surface vertical resolution is close to 1 km, but this one fast rises with altitude raise up to 12 km on 35 km height. It means, that we should use averaging operator to compare our results with other data of high vertical resolution.

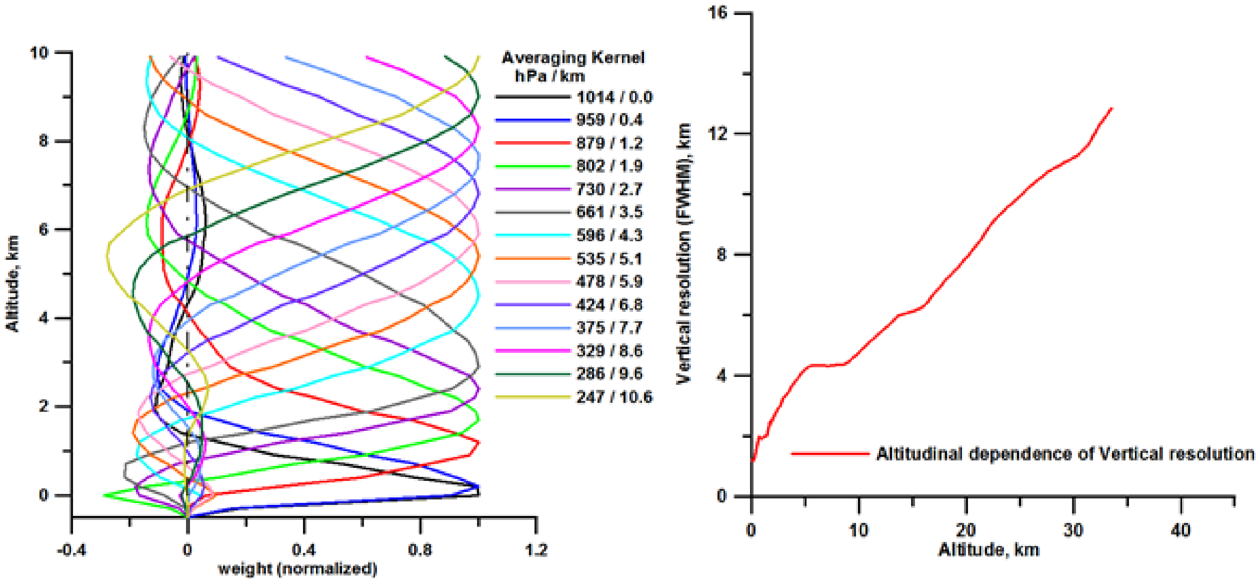


Figure 9. Averaging kernels and vertical resolution of our method in the troposphere temperature profile retrieval.

Figure 10 depicts mean and Root Mean Square Difference (RMSD) of difference between our results and NCEP| GFS data in temperature profiles.

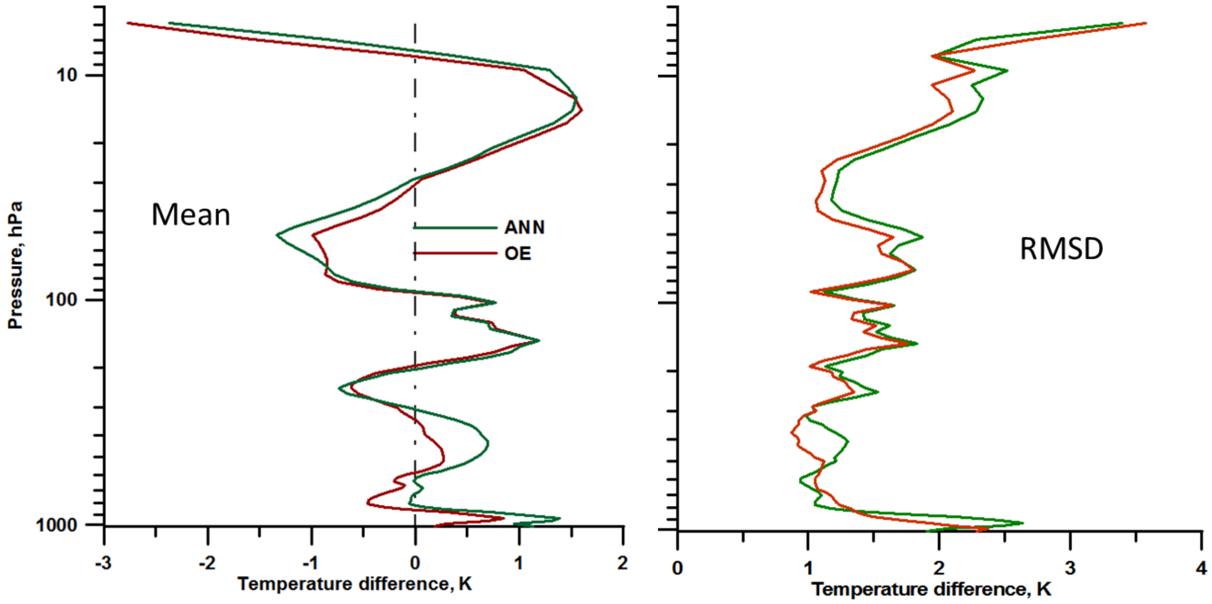


Figure 10. Bias and RMS of temperature profiles : retrieved minus NCEP GFS.

August 20-22, 2015, water surface, latitudes 60S – 60 N, clear sky.

Left part pf Figure 10 shows mean difference between retrieval and NCEP GFS profiles, right part shows RMS of differences. We can see, ANN and OE methods allow getting satisfactory – about 1-2 K - difference between profiles from 800 to 20 hPa, but the difference near surface is bigger.

An analogous dependence for relative humidity are shown in figure 11.

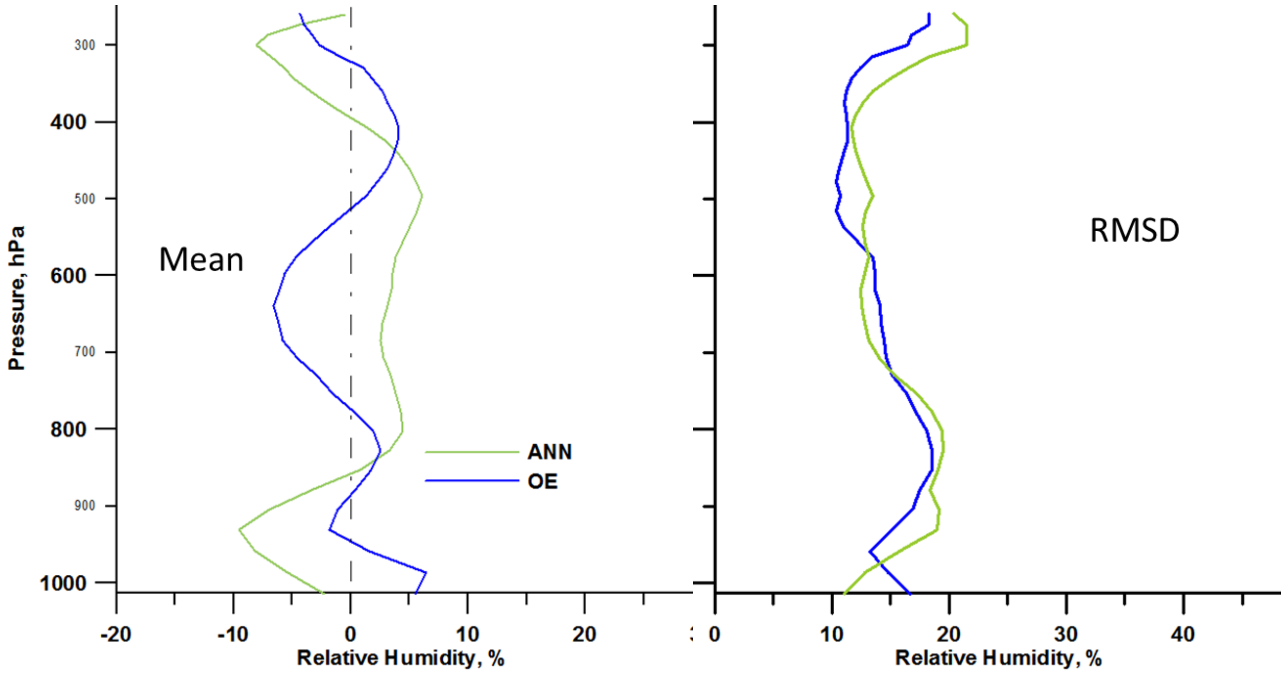


Figure 11. Bias and RMS of Relative Humidity profiles : retrieved minus NCEP GFS. August 20-22, 2015, water surface, latitudes 60S – 60 N, clear sky

Statistics shows, RMS difference between NCEP GFS data and our profiles is 10-20% in whole altitudes.

And, in the end, the figure 12 demonstrates our retrieval of ozone total column in comparison vs OMI data. It is possible to see two fields are similar. But it is only first step, ozone and other trace gases need detail analyzed.

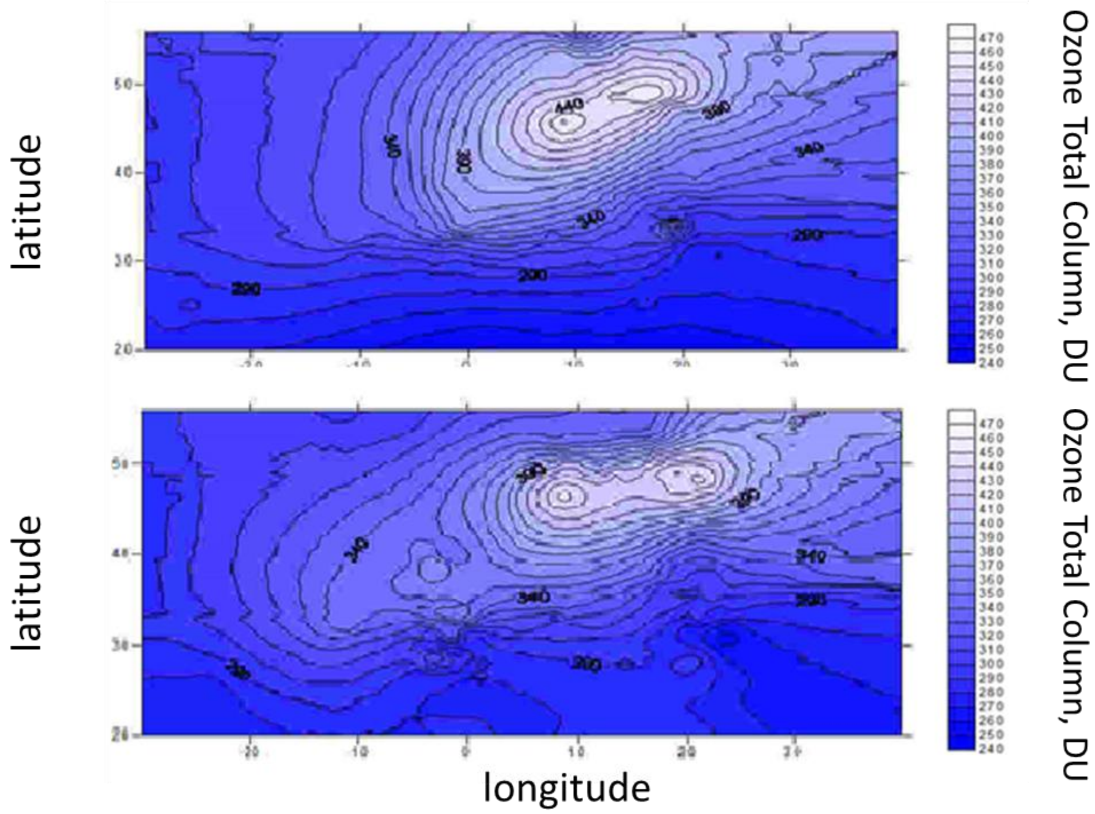


Figure 12. Ozone Total Column. IRFS-2 data (top figure) and OMI data (bottom figure)

## *Summary*

1. IRFS-2 Fourier spectrometer onboard Meteor-M N2 is healthy.

2. Comparisons of IRFS-2 measurements with SEVIRI and IASI data show:

• Variability of IRFS-2 spectrum vs. IASI spectrum variability is relatively close

• Mean difference of IRFS-2 and IASI spectrum in selected measurement pairs is close to zero

• SD difference of IRFS-2 and IASI spectrum in selected measurement pairs is less than NESR in 15um band and less than 0.6 mW/(sr $m^2$ $cm^{-1}$) in atmospheric windows.

3. According to the preliminary estimates, temperature and humidity vertical profiles retrieved by MLR, ANN and physical algorithms give us the RMSE of 1-3K and 10-15% in comparison with the NCEP GFS data.

## *Acknowledgements*

We thank NCEP for possibility of using GFS data; Eva Borbas and other colleagues from CIMSS/SSEC WU for possibility of using data of atmospheric model SeeBor and the global IR land surface emissivity database.

## *Main results of our preliminary researchers were published in these papers:*

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3. Polyakov A. V., Yu. M. Timofeyev, A. B. Uspensky Possibilities for Determining Temperature and Emissivity of the Land Surface from Data of Satellite IR Sounders with High Spectral Resolution (IRFS-2) // Izvestiya, Atmospheric and Oceanic Physics., 2011. **47**, 9. pp. 1092-1096.

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