Technique and results of retrieving the total ozone content using satellite IR measurements from «Meteor-M» No 2

A.V. Polyakov[1] A.S. Garkusha[1], Yu.M. Timofeyev[1], Ya.A. Virolainen[1], A.V. Kukharsky[2], D.A. Kozlov[3]

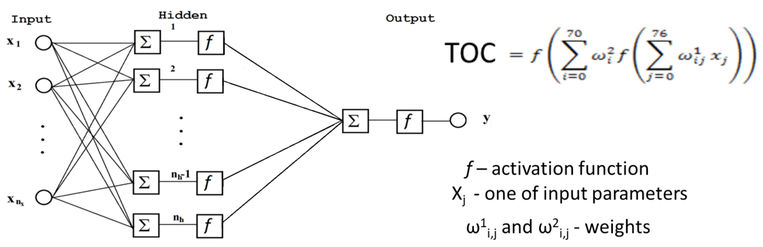
1) Saint Petersburg State University, 2) Scientific Research Center "Planeta" 3) Keldysh Research Center

a.v.polyakov@spbu.ru

Technique for retrieving the total ozone content (TOC) from spectra of outgoing thermal radiation measured by IKFS-2 from aboard the meteorological «Meteor-M» No. 2 satellite not depending on the presence of clouds is developed. Comparison of TOCs retrieved using the developed technique with independent data is performed.

Instrument. IKFS-2 is Russian Fourier –interferometer onboard satellite "Meteor M" No2. Measurement spectral region of the instrument is 660-2000cm^{-1}, spectral resolution after apodization is equal 0.7cm^{-1}

TOC retrieval method



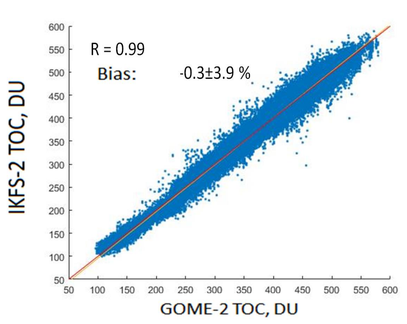
Artificial neural network - three-layer perceptron. Activation function - Hyperbolic tangent for hidden layer, linear for output layer. The input parameters are the spectral measurements of the IKFS-2 device: 25 Principle Components (PC) of the whole spectrum, 50 PCs of the ozone band and satellite zenith angle, 50 neurons in the hidden layer. One outgoing parameter – TOC. Made with MATLAB.

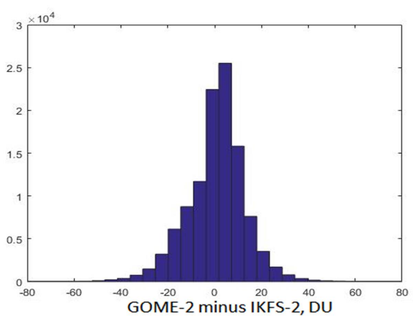
1. Cloudless atmosphere

Training set was based on OMI level 3 data, ~ 180000 pairs OMI and IKFS-2 measurements. Selection conditions: the same day, distance less then 35km. Results are below:

Comparison vs. GOME-2 data

GOME-2: level 3 data - TOC defined on a regular grid 10 x 10. IKFS-2: day measurements (zenith angle of the Sun <90°). Sample size: 111084





TOC comparison: IKFS-2 vs. GOME-2

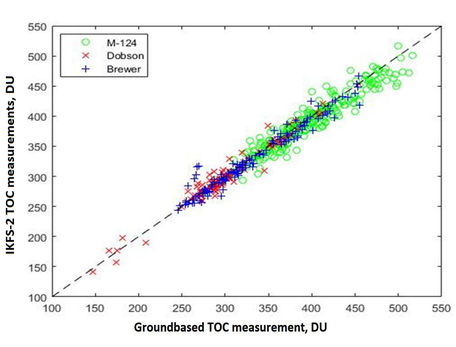
	March-May			June-August			Sept.- Nov.		
	R	Bias	SDD	R	Bias	SD	R	Bias	SDD
90^0 N - 60^0 N	0,94	0,8	3,7	0,96	-1,8	2,3	0,93	-1,3	3,3
60^0 N - 30^0 N	0,95	1,6	3,9	0,97	-1,9	2,1	0,97	-0,2	1,8
30^0 S - 30^0 N	0,86	0,8	4,5	0,99	-2,3	1,3	0,94	-0,7	1,3
30^0 S - 60^0 S	0,87	0,6	5,0	0,90	-5,4	5,1	0,95	-1,9	2,5
60^0 S- 90^0 S	0,86	-1,0	4,8	-	-	-	0,97	-2,0	6,3
All of the latitudes	0,98	0,7	4,0	0,97	-1,9	2,3	0,99	-1,2	3,9

R – correlation, The bias and standard deviation (SDD) are given in percentages

For example, comparison of IASI data vs. GOME-2 data:*
Correlation coefficient: 0.26 ÷ 0.99
Bias: (2.6 ÷ 15.6)%
Standard deviation: (0.8 ÷ 14.0)%, depending on an season and latitude.

**Boynard et al. "Seven years of IASI ozone retrievals from FORLI: validation of independent total column and vertical profile measurement", Atmos. Meas. Tech.., 2016*

TOC comparison: IRFS-2 vs. ground-based measurements of WOUDC network



	Brewer	Dobson	M-124
N	129	111	236
R	0,98	0,98	0,96
Bias, DU	2,3	0,5	6,2
SDD, DU	12,0	9,9	14,5
RMSD DU	12,2	9,8	15,8
Bias, %	0,5	0,1	1,5
SDD, %	3,9	3,5	3,6
RMSD, %	3,9	3,5	3,9

N – number of comparison, RMSD – root mean square of difference

For example, comparison of IASI data with ground measurements with Brewer *:
Correlation coefficient: 0.95 ÷ 0.97
Bias: (3.68 ÷ 4.59)%
Standard deviation: (2.58 ÷ 3.40)%

** Anton et al. "Validation of the MetOp-A total ozone data from GOME-2 and IASI using reference ground-based measurements at the Iberian Peninsula", Remote Sensing of Environment 115 (2011) 1380–1386.*

2. Cloudy atmosphere

The same method, but training data set contents all the measurements, cloudless and cloudy. Sample (2015) size was ~600000.

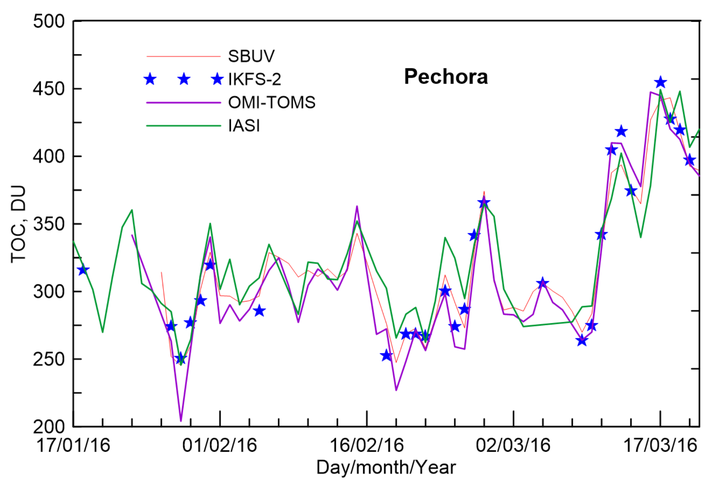
TOC comparisons 2016: IKFS-2 vs. OMI

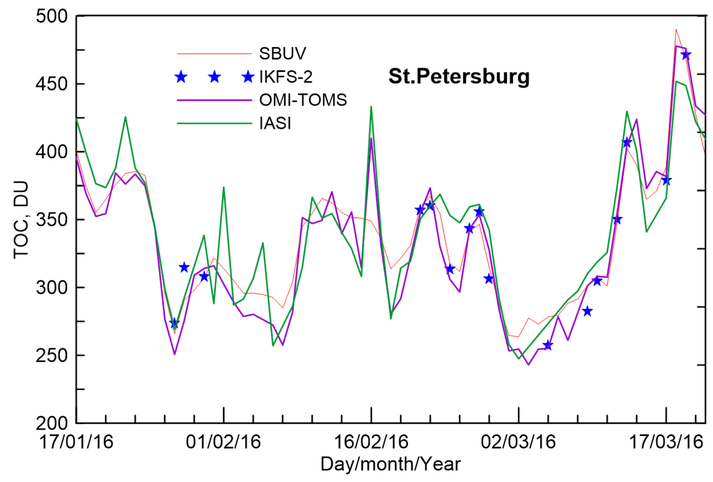
	Jan. – Feb.			March - May			June - August			Sept. – Nov.		
	R	MD (%)	SDD (%)	R	MD (%)	SDD (%)	R	MD (%)	SDD (%)	R	MD (%)	SDD (%)
60 -90 N	0.99	-0.06	3.4	0.94	0.83	3.4	0.90	1.5	3.4	0.84	1.2	4.2
30 -60 N	0.99	0.08	2.9	0.95	0.00	3.5	0.93	0.98	3.0	0.93	-0.68	3.1
30 S-30 N	0.94	-0.14	1.7	0.96	-0.01	1.8	0.93	0.21	2.1	0.86	-0.60	1.9
30 – 60 S	0.90	0.78	2.9	0.93	0.89	4.0	0.91	0.52	4.9	0.97	-0.31	4.2
60 – 90 S	0.75	0.34	3.2	0.79	1.9	6.0	0.91	-0.41	7.6	0.98	3.1	10.9

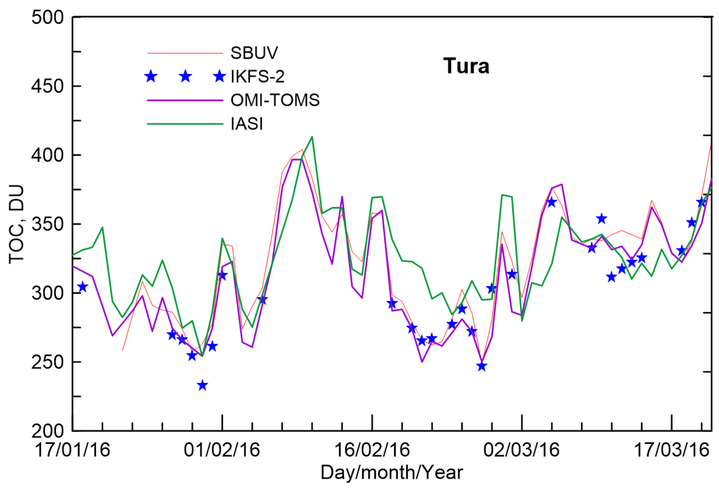
IKFS-2 TOC vs. groundbased measurements data (Dobson, Brewer, M-124), 2015 & 2016 ys.

	2015			2016		
instrument	Dobson	Brewer	M-124	Dobson	Brewer	M-124
N	122	144	74	87	102	7
R	0.97	0.98	0.97	0.95	0.97	0.98
MD (%)	0.03	0.87	1.3	-0.26	1.6	3.8
SDD (%)	3.4	3.9	4.3	4.2	3.8	3.1

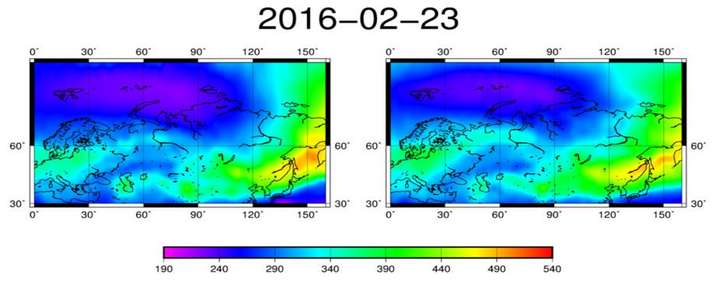
MD – Mean Difference







Examples of measurements of TOC by a few satellite instruments near WOUDC stations.



Example of TOC fields by IKFS-2 and IASI

3. Implementation of the method in the style of an operational code

Artificial neural network - three-layer perceptron. Activation function - **Hyperbolic tangent for both layers**.
The input parameters are the spectral measurements of the IKFS-2 device: 25 PCs of the whole spectrum, 50 PCs of the ozone band (**980 – 1080 cm^{-1}**) and satellite zenith angle, **35 neurons** in the hidden layer.
One outgoing parameter – TOC
Made with **FORTRAN**.
A special sample of measurements of improved quality was prepared (special qualitative measurements of IRFS-2 were selected, and algorithms for spectrometric calibration were improved) for 2 years (to include QBO in its entirety). This sample contains two 12-hour measurement periods per month. Overlaps the period August 2015 - July 2017. Training set was based **on OMI level 2 data. For every IKFS-2 spectra, one OMI measurement was selected by criterion**:

$$(r/\Delta r)^2 + ((t_O - t_I)/\Delta t)^2 \to min$$

$$r < \Delta r \ \ and \ \ |t_O - t_I| < \Delta t, \qquad \Delta r = 300km, \Delta t = 12\ hours$$

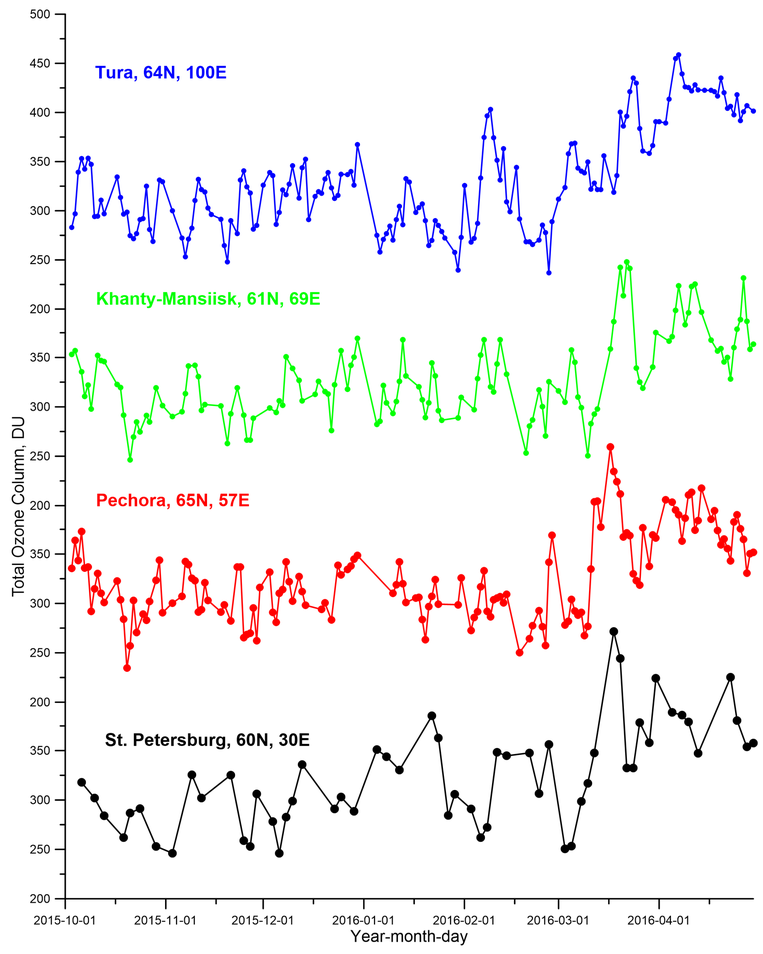
There r is the distance between two measurements,
t_O and t_I are OMI and IKFS $-$ 2 measurement times.

~ 2900000 pairs OMI and IKFS-2 measurements were selected.

Another sample was used for a validation of the retrieval code and for investigations in future. We took all available IKFS-2 measurements from October 2015 to April 2016. There were 334 half-day data files, ~20000000 spectra.
The validation was based on comparison with independent ground-based measurements of WOUDC network and OMI level 3 data.

TOC comparison: IRFS-2 vs. ground-based measurements of WOUDC network

Data set	Sample "2years"				Sample "Winter 2015-16"			
Instrument / type of measurement	N	MD	RMSD	R	N	MD	RMSD	R
Dobson / sun	119	0.22	3.13	0.981	1146	-0.53	4.06	0.967
Dobson / all	192	0.27	4.57	0.960	1820	-0.21	4.48	0.961
Brewer / sun	120	0.58	3.55	0.973	1126	0.90	4.32	0.975
Brewer / all	140	0.99	3.90	0.967	1490	1.58	4.85	0.966
M-124 / sun	3	1.77	4.14	-	13	2.51	3.54	0.978
M-124 /all	114	0.73	4.21	0.937	751	0.44	4.87	0.957



Examples of IKFS-2 TOC above some ground-based stations for analyze in future.

Conclusions: It is shown that differences between TOCs retrieved from IKFS-2 spectral measurements and satellite (OMI device) and ground-based (Dobson, Brewer, M-124) data, as a rule, are 3–5 %. The greatest differences (up to 10 %) are observed over Antarctica in the presence of an ozone hole in the southern polar latitudes. Using the developed technique and IKFS-2 measurements, ozone anomalies over Russia detected earlier by other methods in the first quarter 2016 were registered. In separate days during this period almost 2 times reduction of TOC was observed.

The study was supported by Russian Science Foundation (project 14-17-00096).