Studies using spectral measurements of satellite atmospheric FTIR sounder IKFS-2

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Outline

1. Instrument

2. Validation of temperature sounding of the atmosphere

- **Method (s)**
- **Spatial/temporal mismatch**
- **Vertical resolution mismatch**
- **Results and conclusion**

3 **Retrieving the total ozone content**

- Method: Details and training (cloudless atmosphere)
- TOC comparison vs. satellite results (OMI, GOME-2), ground-based data by network WOUDC: year 2016, cloudy atmosphere
- Fields of TOC, comparison vs. IASI results in 2016
- conclusion

IKFS-2 instrument specifications

parameter	requirement
spectral range	5-15 μm (660-2000 cm^{-1})
non-apodized spectral resolution	0.4 cm^{-1}
radiometric calibration error (λ=11…12 μm, T=280…300 K), no more than	0.5 K
noise equivalent spectral radiance NESR, [$W \cdot m^{-2}$ $sr^{-1}cm$]	$3.5 \cdot 10^{-4}$, λ = 6 μm $1.5 \cdot 10^{-4}$, λ = 13 μm $4.5 \cdot 10^{-4}$, λ = 15 μm
instantaneous field of view (IFOV) spatial resolution at sub-satellite point	40 mrad 35 km
swath width spatial step	1000…2500 km 60…110 km
sampling period	0.6 s
data rate	580 kb/s
mass	50 kg
power consumption (orbit average)	50 W

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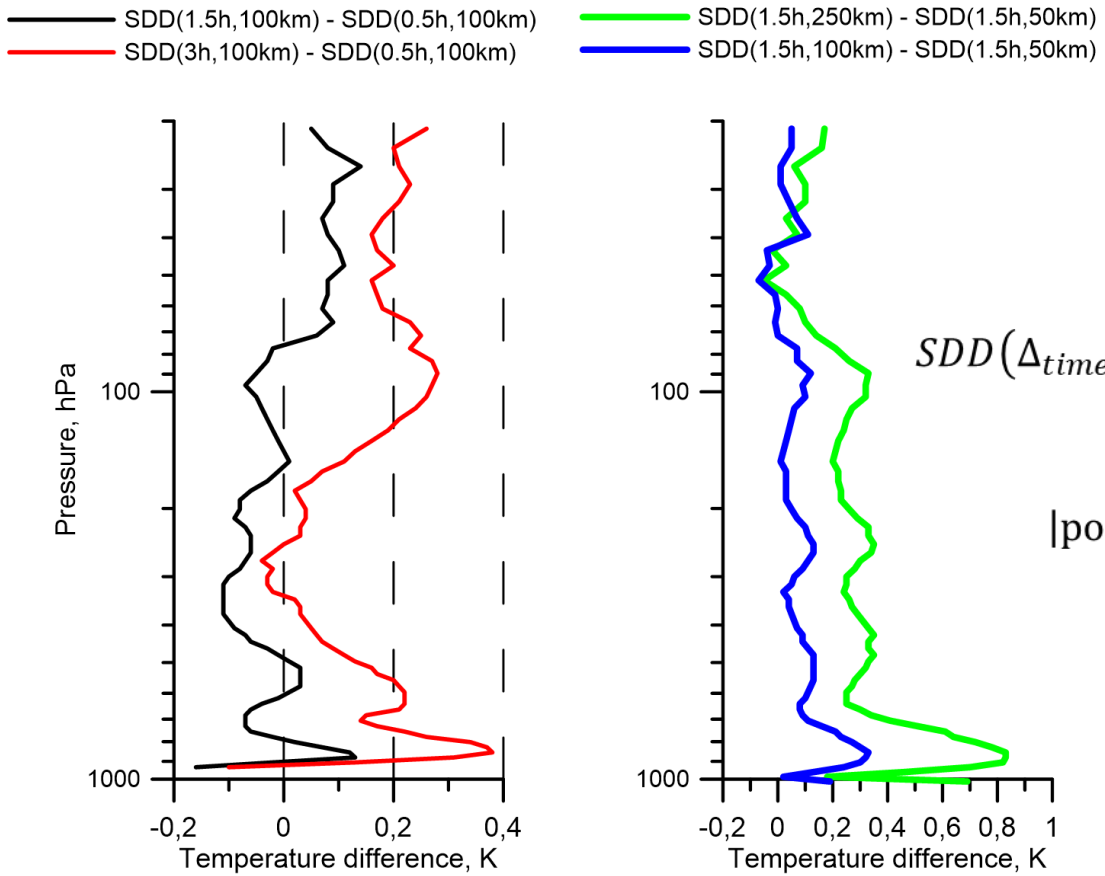
Algorithms for retrieval of the atmospheric and surface parameters from IKFS-2 measurements:

Multiple Linear Regression **(MLR)** for deriving the first guess**,**
Artificial Neural Networks **(ANN),**
Physical inverse algorithm **(PIA) method**

Radiometric correction of the radiation measurements is preliminary performed
Principle Components Analyses of spectra and profiles was used
Selection of cloudless scenes (~30%)

Temporal and spatial discrepancy



Influence of time (left) and spatial (right) discrepancy on Standard Deviation of Difference (SDD) between IKFS-2 and radiosonde temperature profiles.

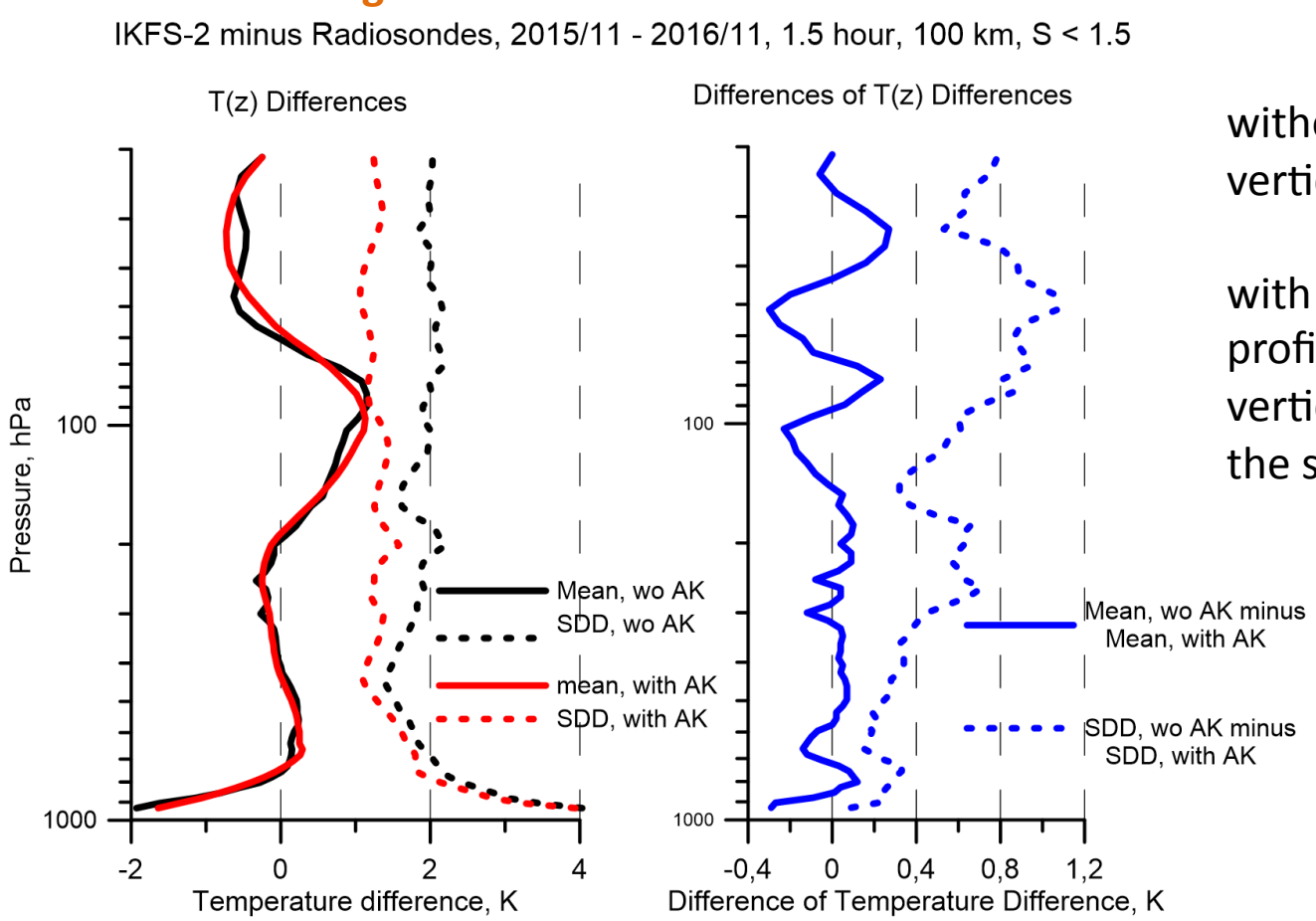
$$SDD(\Delta_{time}, \Delta_{space}) = SD(T_{IKFS-2}(z) - T_{Zonde}(z)),$$

$$|\text{time}_{\text{IKFS\_2}} - \text{time}_{\text{zoned}}| < \Delta_{time} \;\&$$

$$|\text{position}_{\text{IKFS\_2}} - \text{position}_{\text{zoned}}| < \Delta_{space} \;\&$$

Discrepancies were tested:
50, 100, 250 km
0.5, 1, 1.5, 3, 6 hours

Accounting for different vertical resolution



without AK – original vertical resolution

with AK – radiosonde profiles are reformed to vertical resolution of the satellite data

Conclusions (temperature profiles comparison):

- **SDD & RMSD of temperature measured with the help of IKFS-2 and radiosonde ignoring vertical resolution are about 1.5 — 2.1 and 1.5 —2.3 K in the pressure range of 20—600 hPa, and both increase to 4—5 K below 600 hPa. Vertical averaging of the remote method contributes 0.2—1K to this value, and SD & RMSD with its allowance is 1—1.4 and 1 — 1.8 K in the pressure range 20—600 hPa.**

- **At present, determination of the temperature profile by IR spectra is possible in principle only in cloudless cases (~ 30%). The algorithm used in the operational processing allows obtaining a solution in 60 to 95% of cloudless cases, depending on the quality of the results.**

Some details and additional information are shown in the poster 13p.02

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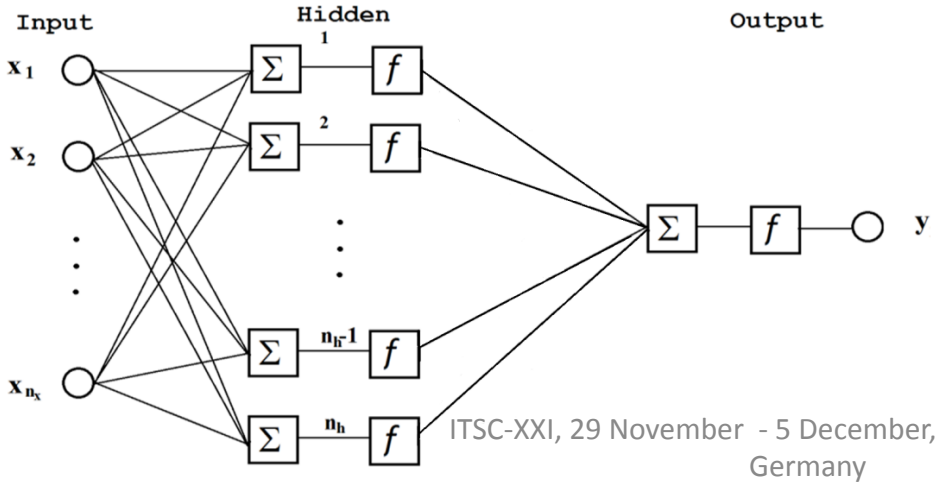
TOC retrieval method

- Artificial neural network - **three-layer perceptron**. Activation function - Hyperbolic tangent for hidden layer, linear or hyperbolic tangent for output layer
- The input parameters are the spectral measurements of the IKFS-2 device: **25 Principle Components (PC) of the whole spectrum + 50 PC of the ozone band** + satellite **zenith angle**
- One outgoing parameter - TOC
- Training set was based on **OMI level 3 data**, ~ 180000 pairs OMI and the IKFS-2 spectra measured for 2 days per month, 2015.
- Pair selection conditions: the same day, distance less then 35km.



$$TOC = f\left(\sum_{i=0}^{70} \omega_i^2 f\left(\sum_{j=0}^{76} \omega_{ij}^1 x_j\right)\right)$$

f – activation function

X_j - one of input parameters

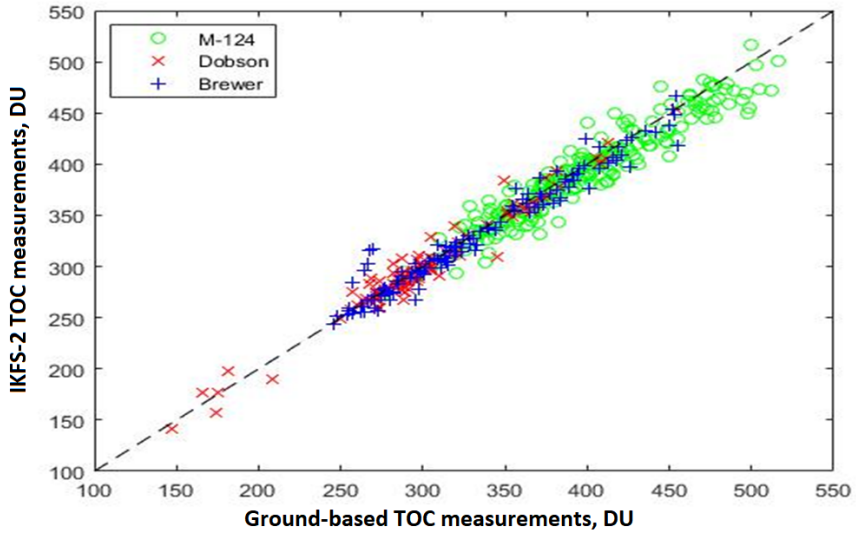
$\omega^1_{i,j}$ and $\omega^2_{i,j}$ - weights

TOC comparison: IKFS-2 (2015)

vs. satellites

Instrument	Bias, %	SD of difference, %	Correlation, R
OMI	0.1	2.8	0.99
GOME-2	0.3	3.9	0.99

vs. ground-based measurements of WOUDC network



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

Cloudy atmosphere: The same method, but training data set contents all the measurements, cloudless and cloudy. Sample size was ~600000.

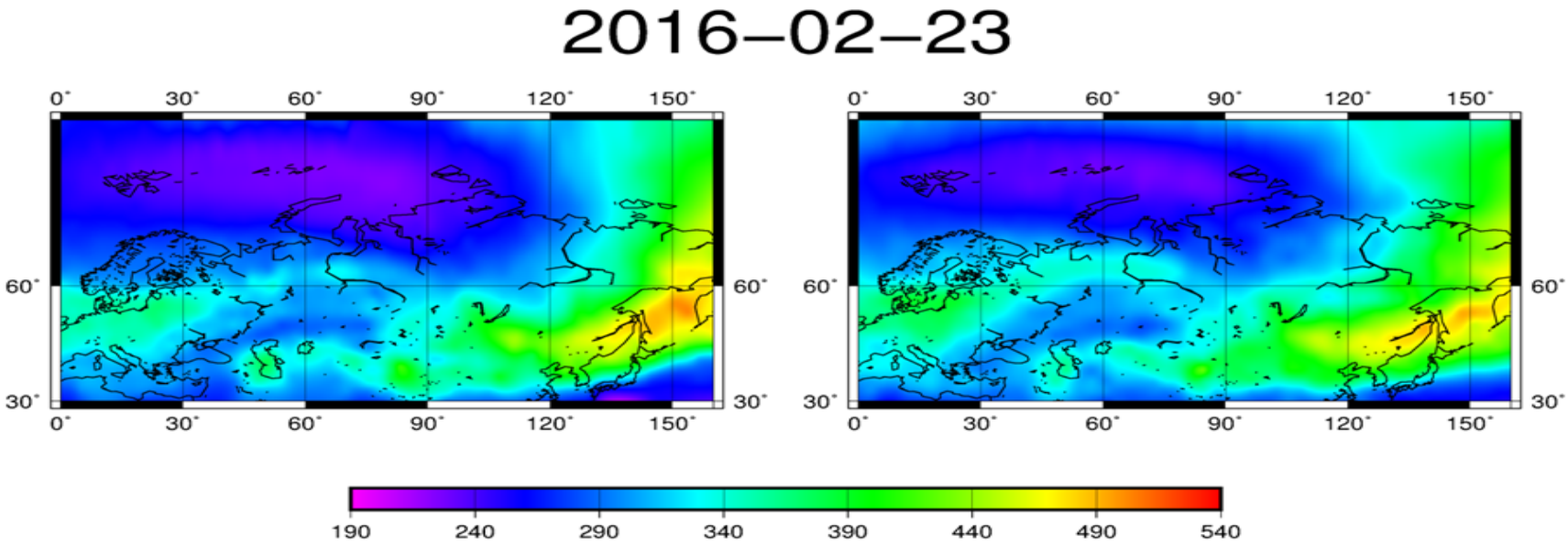
TOC comparisons **2016**: IKFS-2 vs. OMI

	January - February			March - May			June - August			September - November		
	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

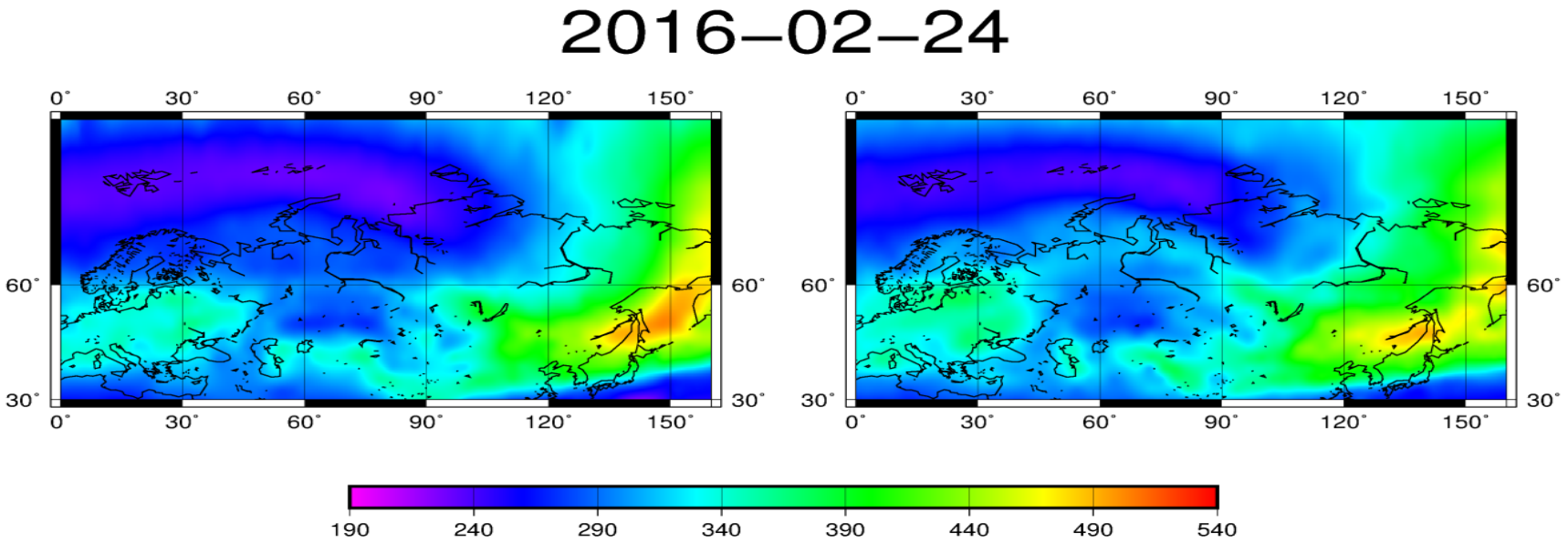
IKFS-2 TOC vs. ground-based measurements data, 2015 & 2016 ys.

	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, Bias
SDD – SD of Difference,
R – correlation
N – measurements number



IASI – left figure , IKFS-2 – right figure, TOC, DU



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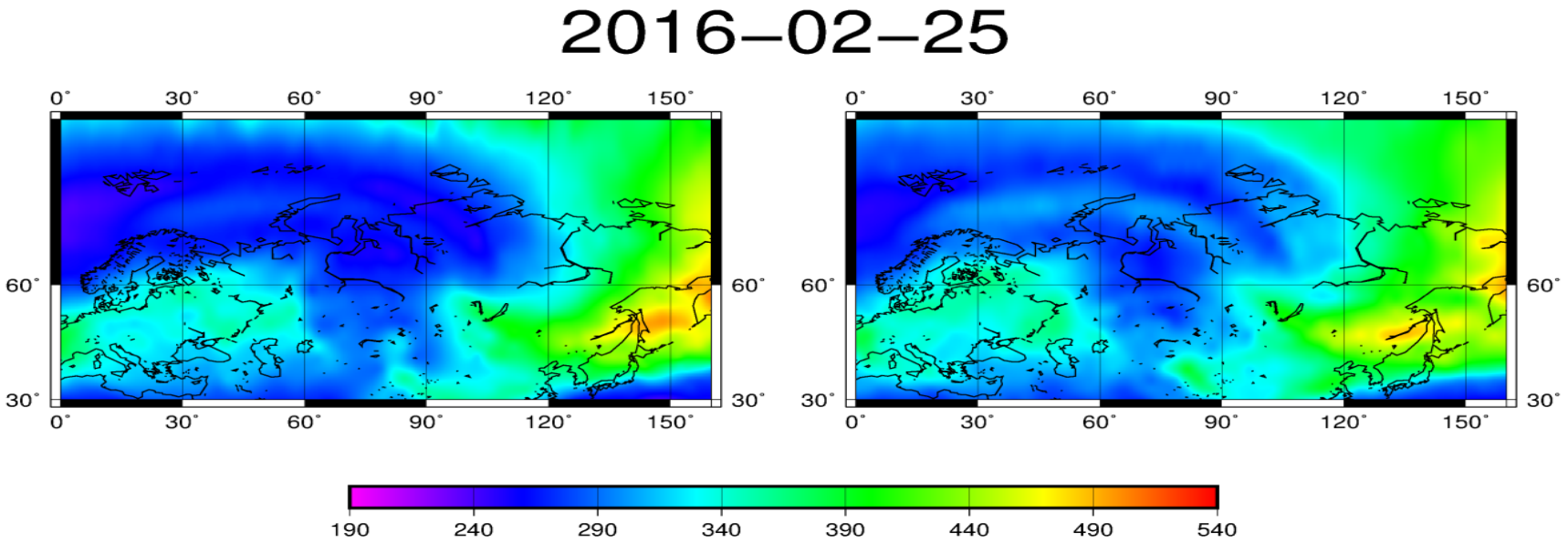

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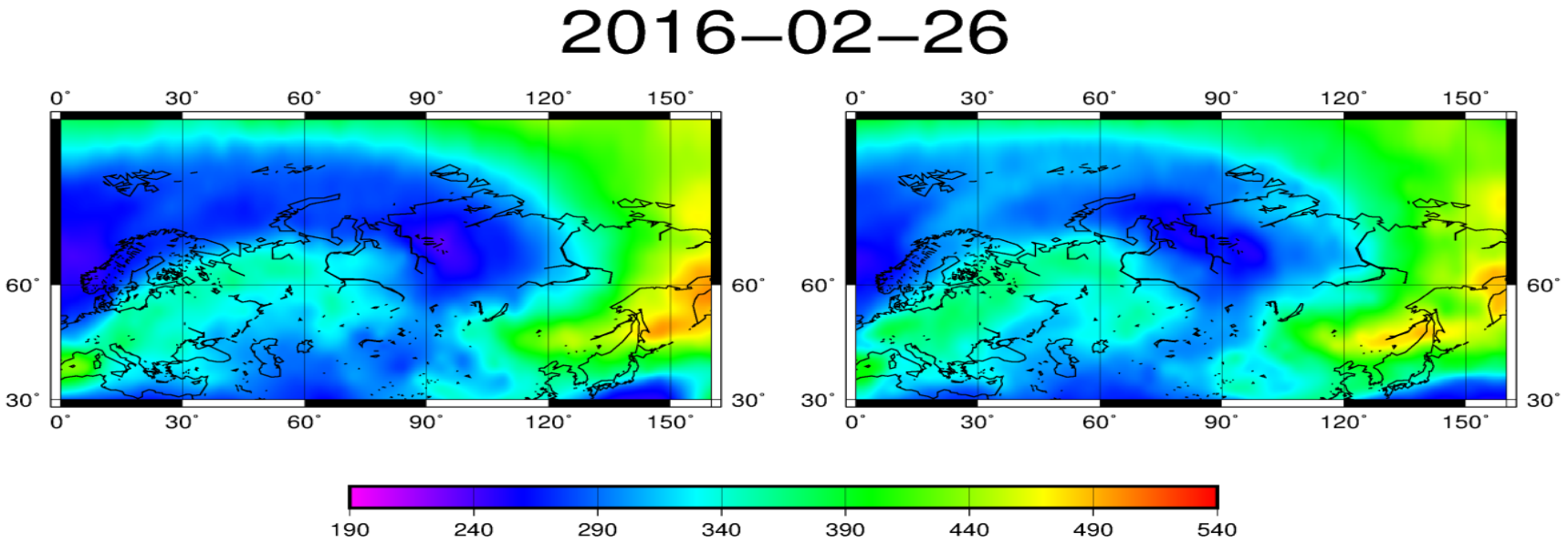

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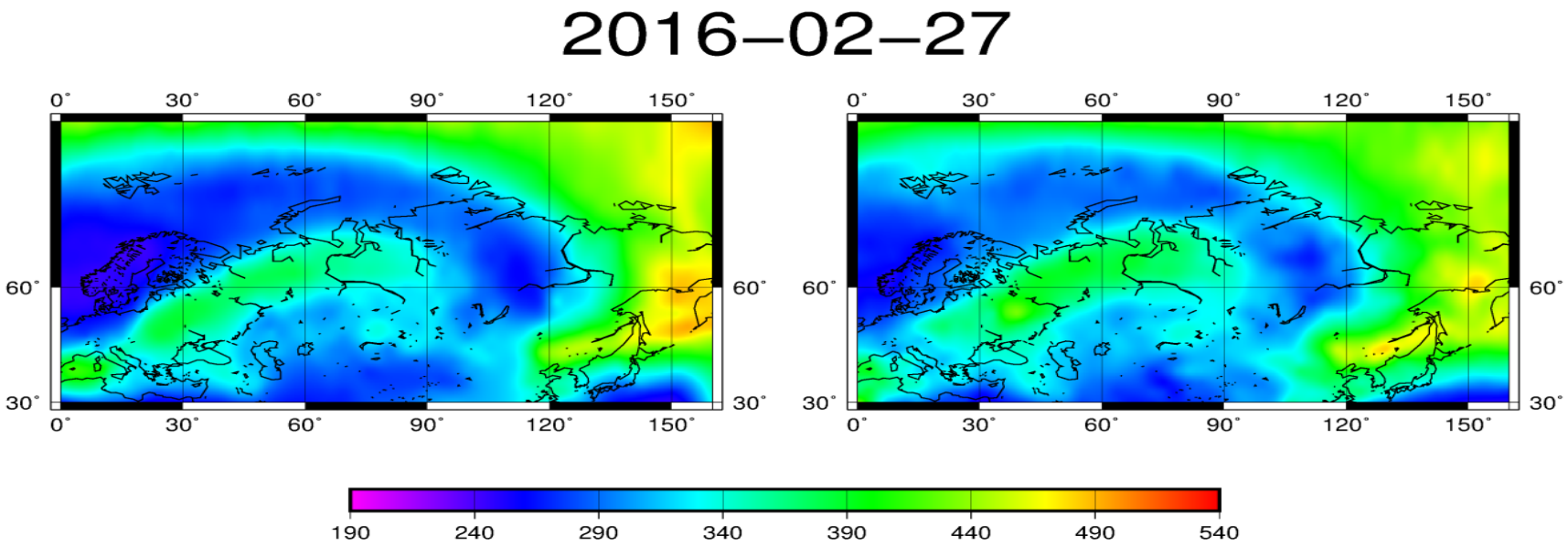


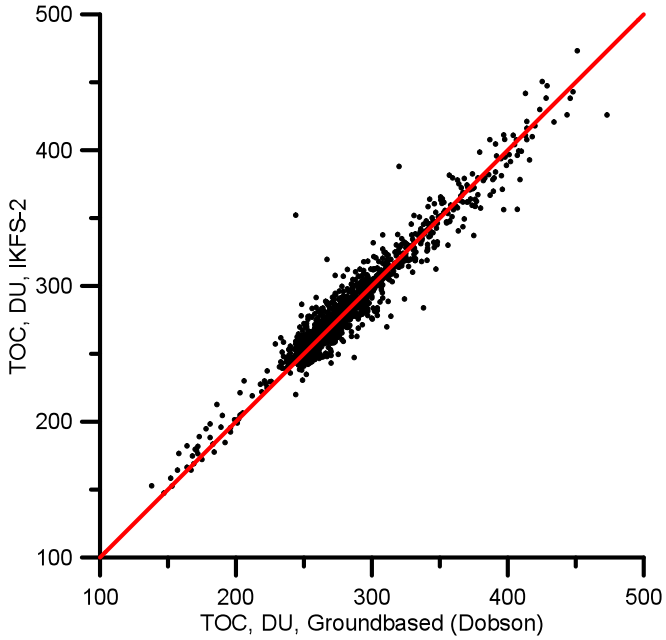
IASI – left figure , IKFS-2 – right figure, TOC, DU

1) **2 years** training data set (to catch QBO)
2) **OMI level 2 TOC** data
3) **Only morning** measurements

First results – ground-based comparisons

Winter October 2015 –April 2016

Instrument / type of measurement		N	MD, %	RMSD,%	R
Dobson		1146	-0.53	4.06	0.97
Brewer		1126	0.90	4.32	0.98
Filter (M-124)	Direct Sun	13	2.51	3.54	0.98
	all	751	0.44	4.87	0.96



Main results and conclusions.

- A technique for determining the TOC from measurements of the spectra of outgoing thermal IR radiation by the IKFS-2 instrument in the presence of clouds is developed. The technique is based on the use of the PC of whole spectrum as well as the ozone band, the application of the ANN method, and the use of TOC measurements by the OMI instrument.

- Comparison with independent satellite and terrestrial measurements has shown that, on average, the IKFS-2 data agree with them no worse than 5% in the sense of RMSD and with bias less 1%.

- The significant dependence of the differences in TOC data on various measurements from latitude and season showed the necessity of analyzing the errors in the training of ANN for individual latitudinal zones and seasons. Especially for polar latitudes and areas of formation of "ozone holes" in Antarctica, where the differences in the data of the IKFS-2 and the results of independent measurements can reach ~ 10%.

Some details and additional information are shown in the poster 8p.05

Thanks to the organizations that provided free access to data:

Ground-based TOC values were obtained from WOUDC – World Ozone and Ultraviolet Radiation Data Centre
OMI ozone data presented on NASA's Goddard Earth Sciences Data and Information Services Center (GES DISC)
NCEP GFS data was obtained from the NOAA website nomads.ncdc.noaa.gov
The radiosonde data is collected and presented on the website of the University of Wyoming weather.uwyo.edu.

We thank T. August (EUMETSAT) for a useful conversations and D. Kozlov (*SSC "Keldysh Research Centre"*) for help in selecting and preparing of IKFS-2 spectra

This work was partially supported by the grant of the RSF 14-17-00096

Thank you for your attention