OZONE LAYER
AND UPPER ATMOSPHERE
RESEARCH
LABORATORY

Tropospheric ozone measurements by the IKFS-2 spectrometer aboard the Meteor-M N2 satellite

Yana Virolainen, Alexander Polyakov, Georgy Nerobelov, Svetlana Akishina, Roeland Van Malderen, Corinne Vigouroux

QOS 2024
15–19 July 2024, Boulder, Colorado

Outline

Aim of the study:

To derive a new tropospheric ozone column (**TroC**) product for two layers: from surface to 400 mbar (~**7 km**) and to 300 mbar (~**9 km**) from **IKFS-2** spectral measurements that can be used for analysis of TrOC variability on global and regional scales in 2015-2022.

Steps:

- ❖ Development of retrieval strategy
- ❖ Validation of TrOCs against reference data
- ❖ Comparison with independent data
- ❖ Preliminary analysis of the IKFS-2 TrOC variability
- ❖ Comparison with regional model

Future plans:

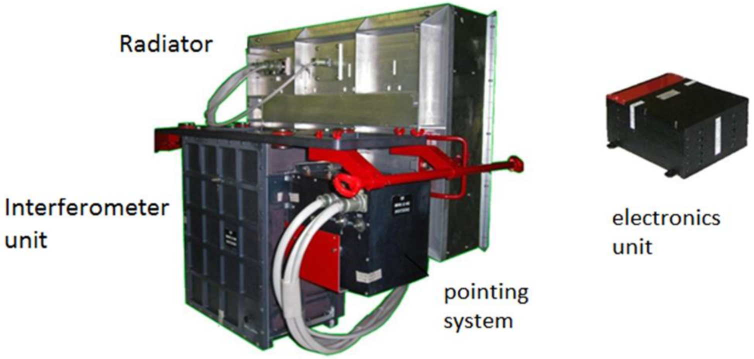
To improve the regional model and to analyze the TrOC spatial and temporal variability in details

IKFS-2 spectrometer

Location: Meteor-M No. 2 satellite, launched in July 2014, solar-synchronized orbit, local Equator Crossing Time of 9:10 for a descending node.

Method: Thermal radiation in 5-15 μm spectral range, spectral resolution of **0.7 cm^{-1}**, horizontal resolution in the nadir viewing mode of **~ 35 km**.

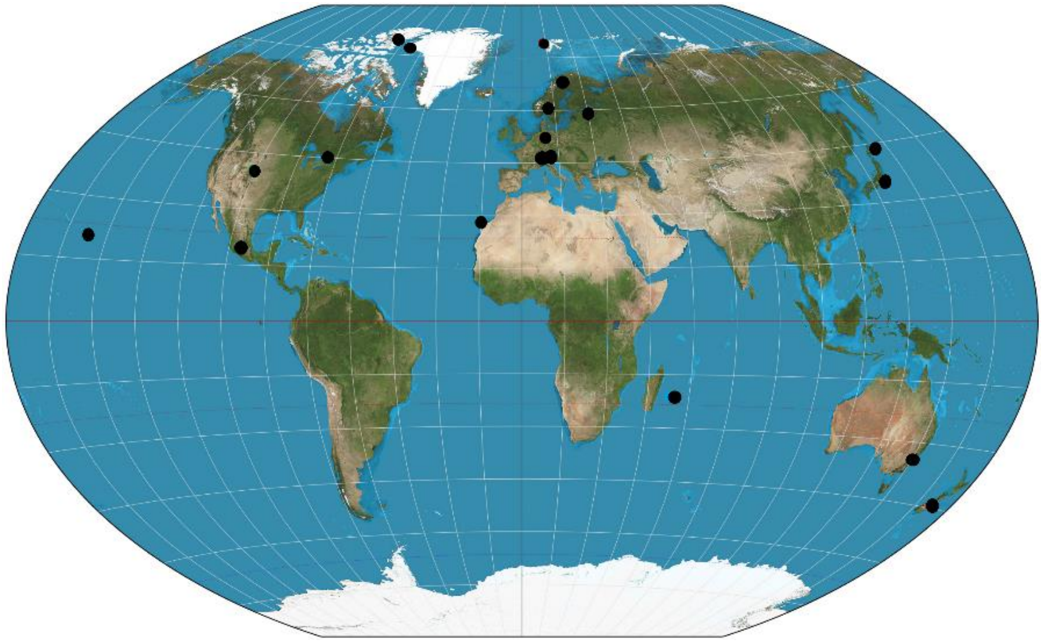
Analysis of measured spectra: Retrieval technique based on the artificial neural network (ANN) algorithm, trained on the ozonesonde data, and the principal components method provides information on TrOCs with **~ 12-15%** retrieval error.



For details of the retrieval technique, see

Akishina_S6_101_2024-07-18_2min.mp4

Ground-based IRWG-NDACC sites



Location of the IRWG-NDACC sites, equipped with Bruker 125 HR spectrometers

Sites with available FTIR data derived using the same retrieval strategy (IRWG2023) are highlighted with yellow color.

Site	Latitude	Longitude	Altitude
Eureka, Canada	80.05° N	86.42° W	610 m
Ny Ålesund, Norway	78.92° N	11.93° E	15 m
Thule Greenland, Denmark	76.53° N	68.74° W	220 m
Kiruna, Sweden	67.84° N	20.41° E	419 m
Harestua, Norway	60.2° N	10.8° E	596 m
St. Petersburg, Russia	59.9° N	29.8° E	20 m
Bremen, Germany	53.1° N	8.8° E	27 m
Zugspitze, Germany	47.42° N	10.98° E	2964 m
Jungfraujoch, Switzerland	46.55° N	7.98° E	3580 m
Toronto - TAO, Canada	43.66° N	79.40° W	174 m
Rikubetsu, Japan	43.46° N	143.77° E	380 m
Boulder CO, USA	39.99° N	105.26° W	1634 m
Tsukuba, Japan	36.05° N	140.13° E	31 m
Izaña Tenerife (Spain)	28.30° N	16.48° W	2367 m
Mauna Loa HI, USA	19.54° N	155.58° W	3397 m
Altzomoni, Mexico	19.12° N	98.66° W	3985 m
Maido Reunion, France	21.1° S	55.4° E	2155 m
Wollongong, Australia	34.41° S	150.88° E	30 m
Lauder, New Zealand	45.04° S	169.68° E	370 m

Validation of IKFS-2 TrOCs against IRWG-NDACC data

Similar ANNs were used to retrieve TrOCs from IKFS-2 spectra for both layers.

Data pairs were selected in accordance with the following criteria:

- Daily averaged FTIR TrOCs, and
- Daily averaged IKFS-2 TrOCs in a circle with 100 km and 200 km radius with a center at station location.

Standard deviation of differences at all 19 sites (different retrieval strategies)

Layer below	Radius of IKFS-2 averages	
	100 km	200 km
300 mbar	3.17 DU	3.24 DU
400 mbar	3.29 DU	3.33 DU

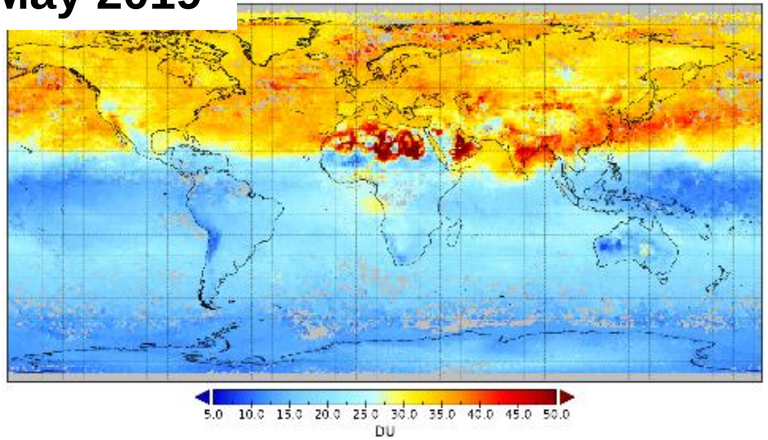
Standard deviation of differences at 11 sites (IRWG2023 retrieval strategies)

Layer below	Radius of IKFS-2 averages	
	100 km	200 km
300 mbar	2.91 DU	2.95 DU
400 mbar	2.87 DU	2.99 DU

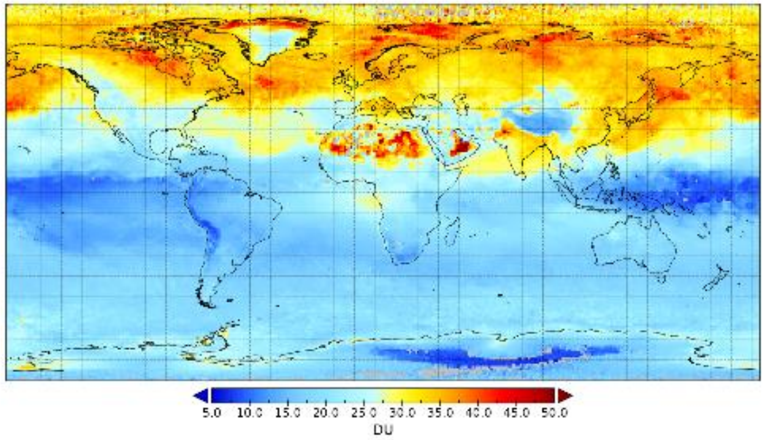
Comparison of IKFS-2 vs. IASI TrOCs

May 2019

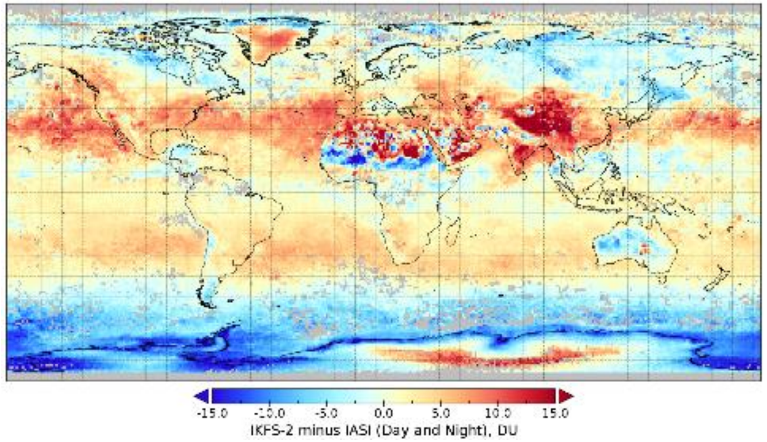
IKFS-2



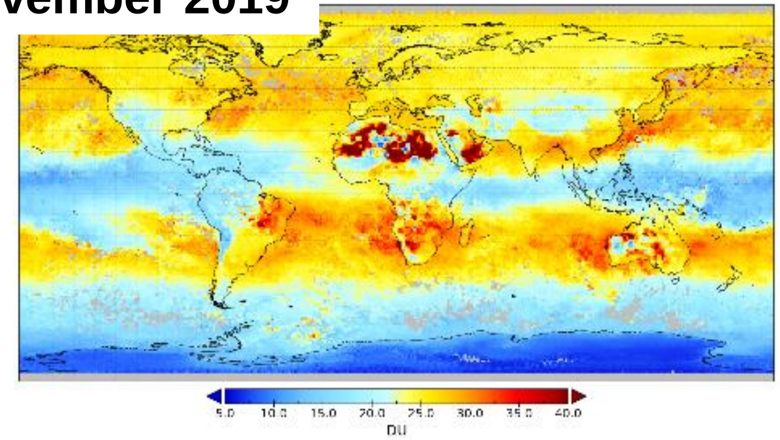
IASI

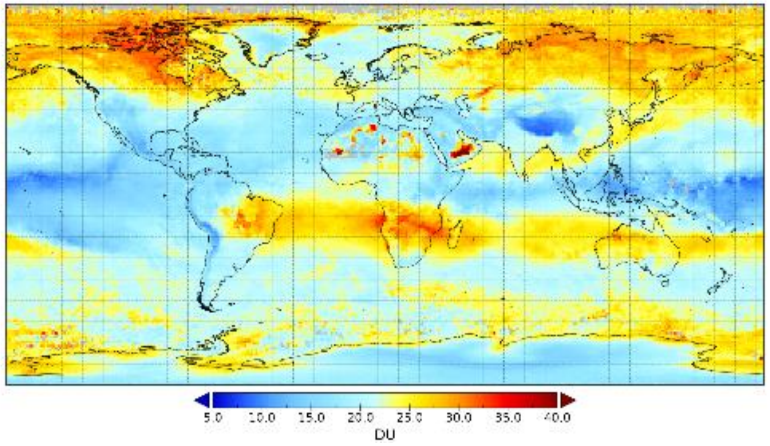


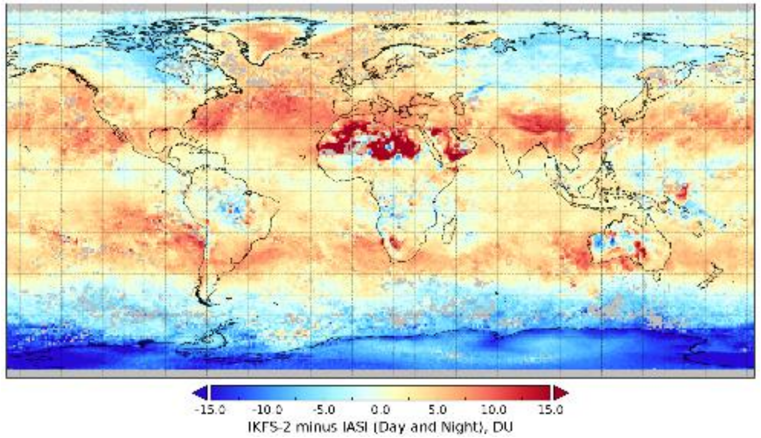
IKFS-2 minus IASI



November 2019



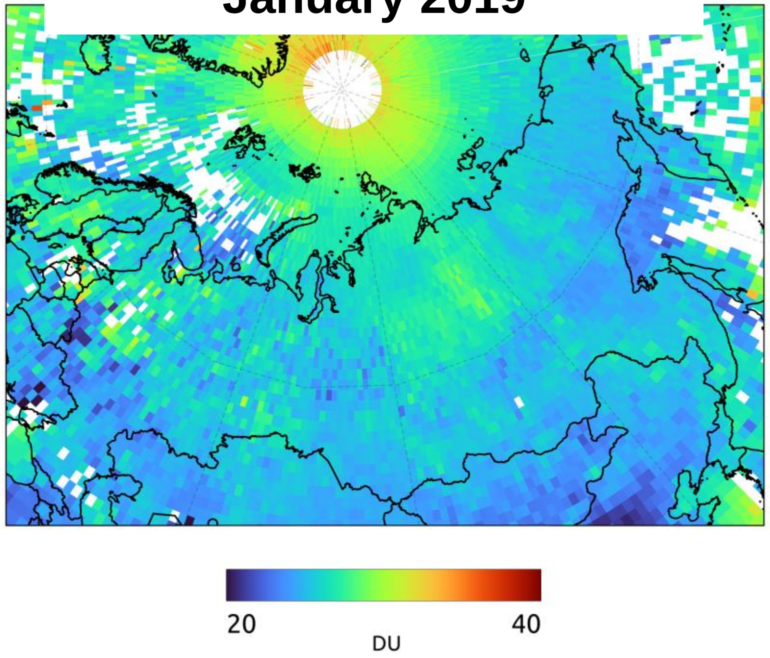




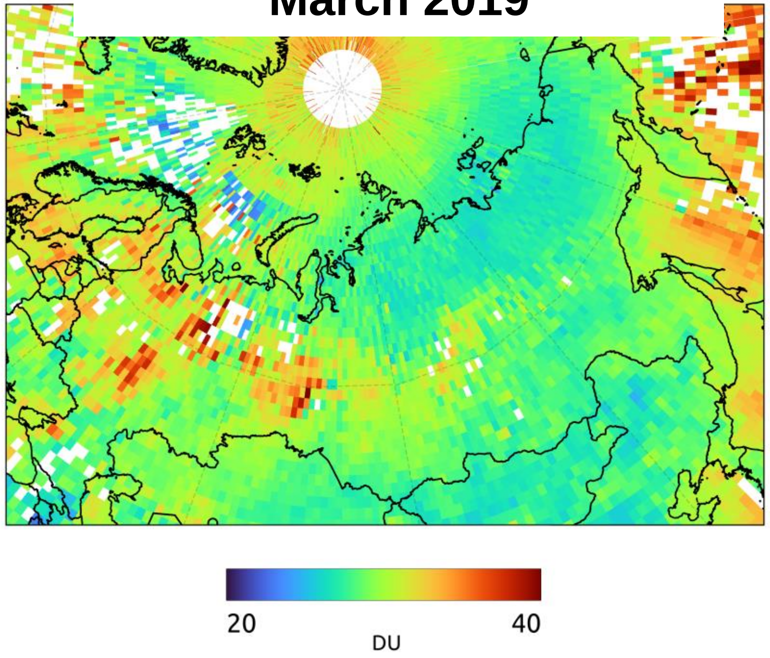
IKFS-2 slightly **overestimates** IASI monthly mean TrOCs (surface – 300 mbar) in **subtropical** latitudes of both hemispheres and **underestimates** IASI TrOCs over **midlatitudes** of **Eurasia** and **high latitudes** of the **Southern Hemisphere**.

Seasonal variability in IKFS-2 TrOCs over Russia and adjacent regions

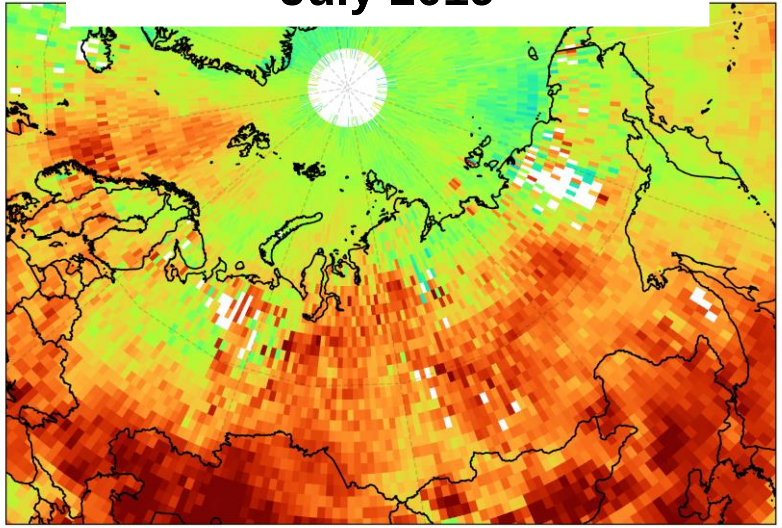
January 2019



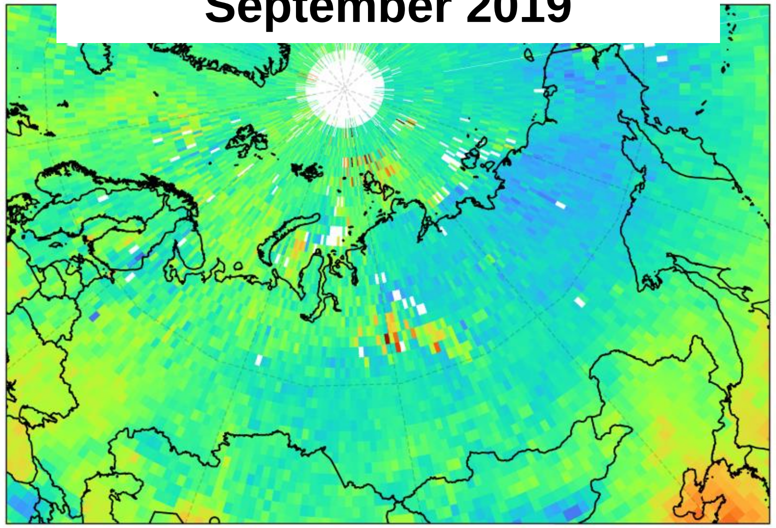
March 2019



July 2019

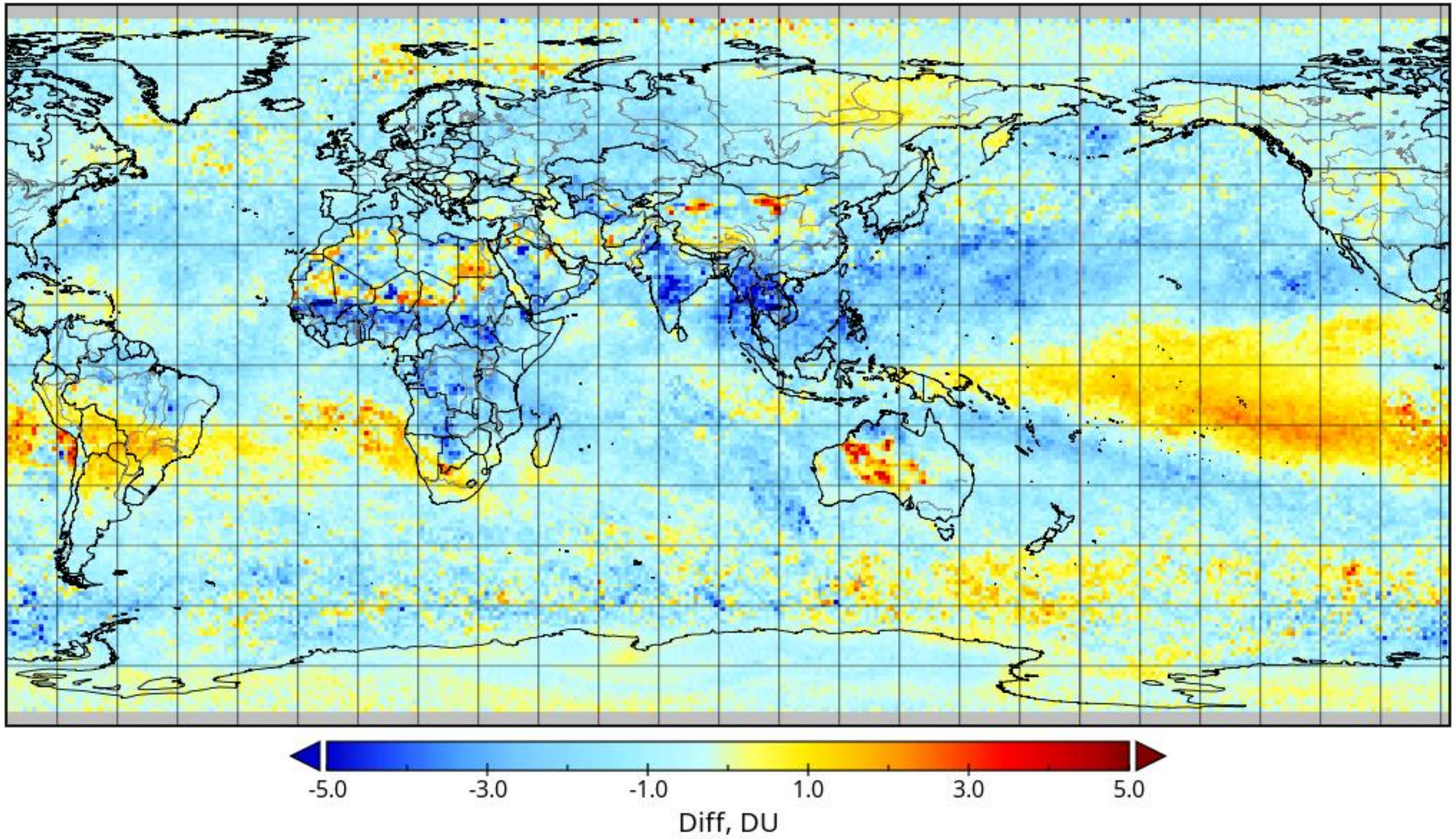


September 2019



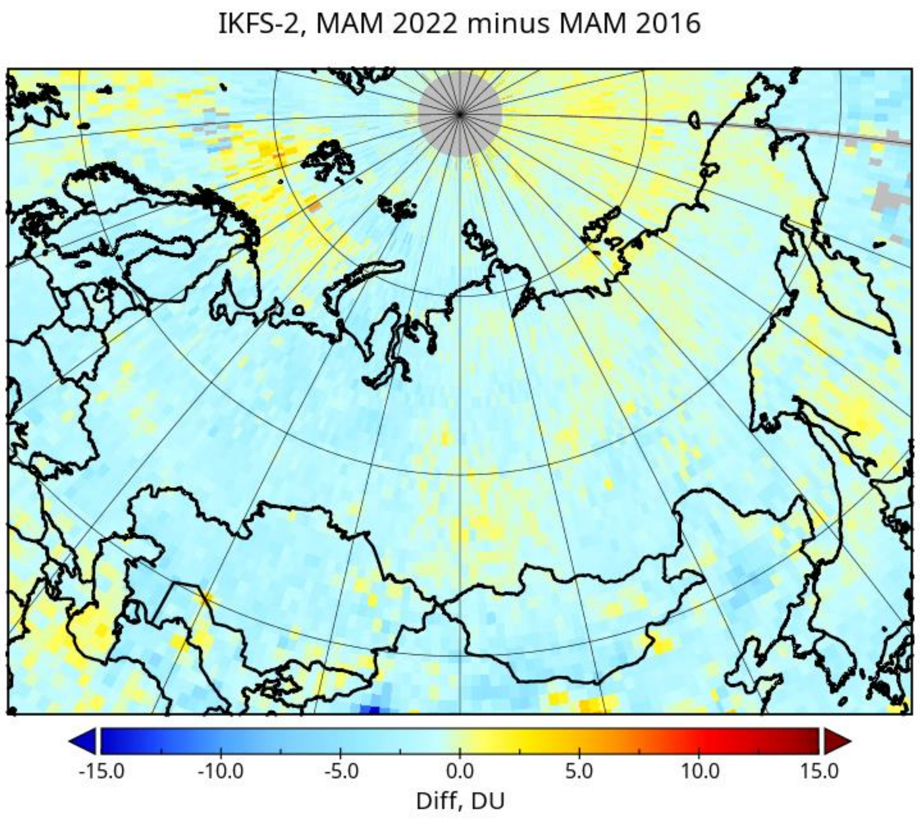
Maximum TrOC values in the surface – 300 mbar layer is observed in higher latitudes **in summer** due to the enforcing ozone production under increased solar illumination and high temperatures. Ozone generation may also be caused by increasing emissions of ozone precursors due to forest fires.

Changes in annually mean TrOCs from 2016 to 2022

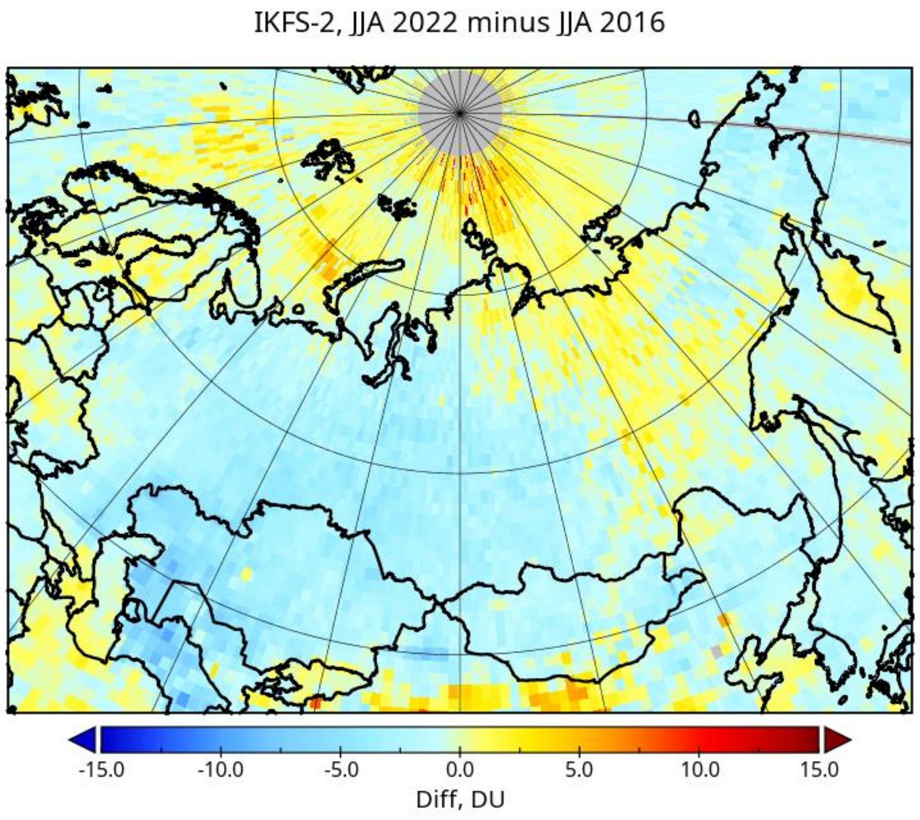


IKFS-2 reveals a slight **increase** in TrOCs in equatorial zone over **Pacific Ocean**, tropical zone of **South America** and Atlantic Ocean **west to South Africa**. A **decrease** in TrOCs is observed in tropical zone of **Southeast Asia**, **Central India**, and **Central Africa**.

Changes in seasonally mean TrOCs over Russia from 2016 to 2022



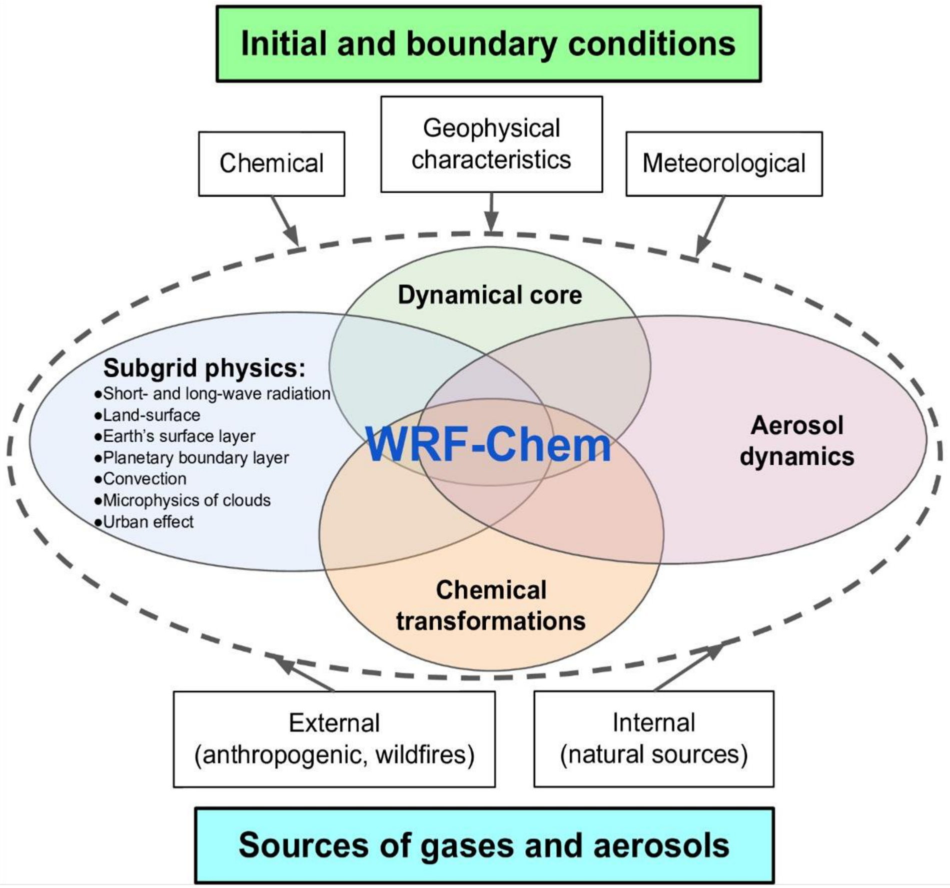
Spring



Summer

IKFS-2 demonstrates a slight **decrease** in TrOCs over the major territory of **Russia** in spring and summer seasons. **In summer**, an **increase** in TrOCs is observed over **Far Eastern Federal District**, namely over **Sakha Republic** and **Kamchatka**, mainly caused by increase in the number, intensity, and duration of forest fires.

Simulation of TrOCs by the WRF-Chem model

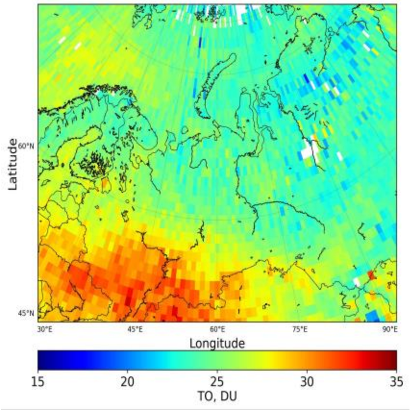


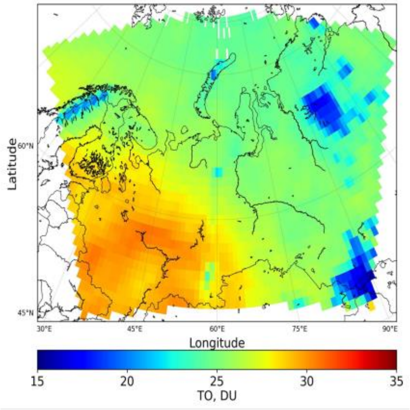
Nerobelov et al.
Atmosphere **2024**, *15*(7), 775

Horizontal extent and resolution		960×960 km², 10 km 4200×3300 km², 30 km
Dynamical, chemical and photochemical time steps		Adaptive time step (~4-6), 5, 10 minutes
Vertical resolution		25 hybrid levels, from the surface up to 50 hPa
Initial and boundary conditions	Meteorology	ERA5 reanalysis, hor.res. 0.25°, up to ~80 km on 137 hybrid levels
	Chemistry	CAM-chem and WACCM data, hor.res. 0.9×1.25°, up to ~45 km on 56 hybrid levels
Emission sources	Anthropogenic emissions	EDGARv5.0 (2015), hor.res. 0.1°, monthly variation
	Biogenic fluxes	Online biogenic model MEGAN, hor.res. ~1 km
	Biomass burning	FINN database v.2.4 and 2.5, hor.res. ~1 km
	Dust and sea salt	Online dust and sea salt emission preprocessors
Chemistry scheme		MOZART
Aerosol scheme		MOSAIC
Simulation period and output frequency		2016-2021 / 2019-2021, 1 h

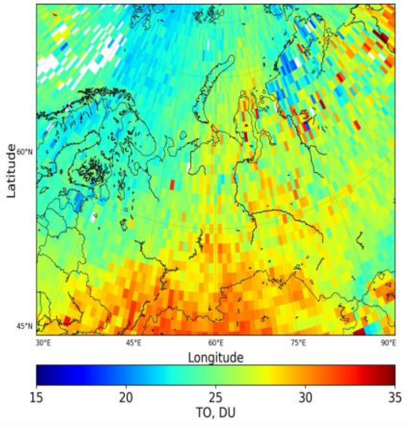
TrOC distribution over Russia and adjacent regions

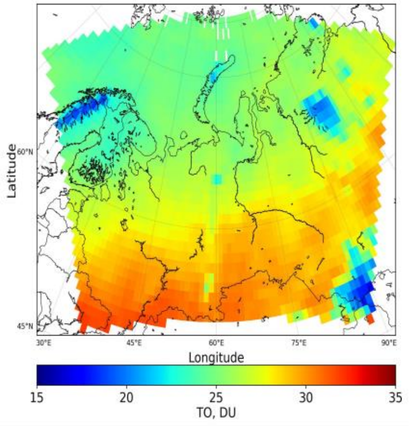
June



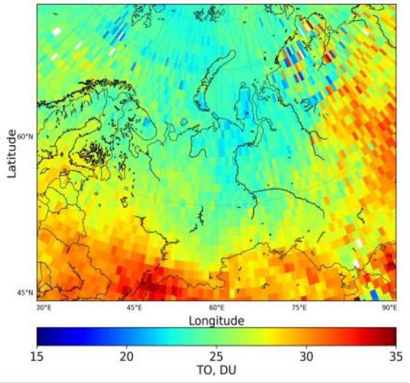


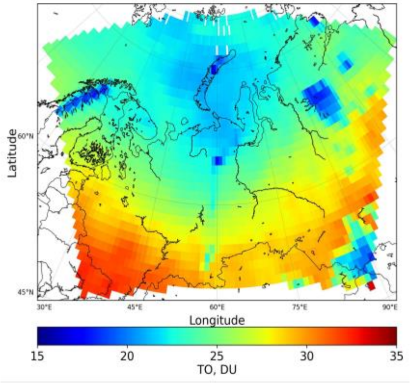
August



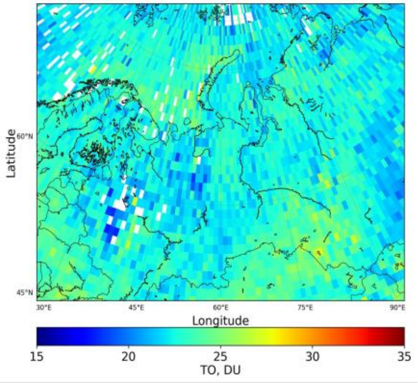


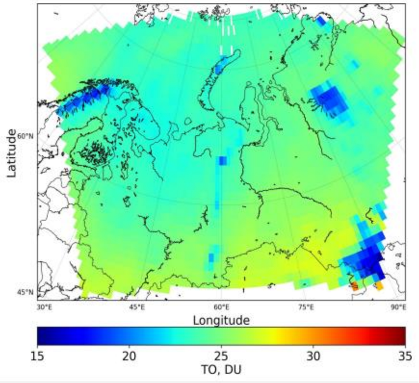
July





September





IKFS-2 **WRF-Chem** **IKFS-2** **WRF-Chem**

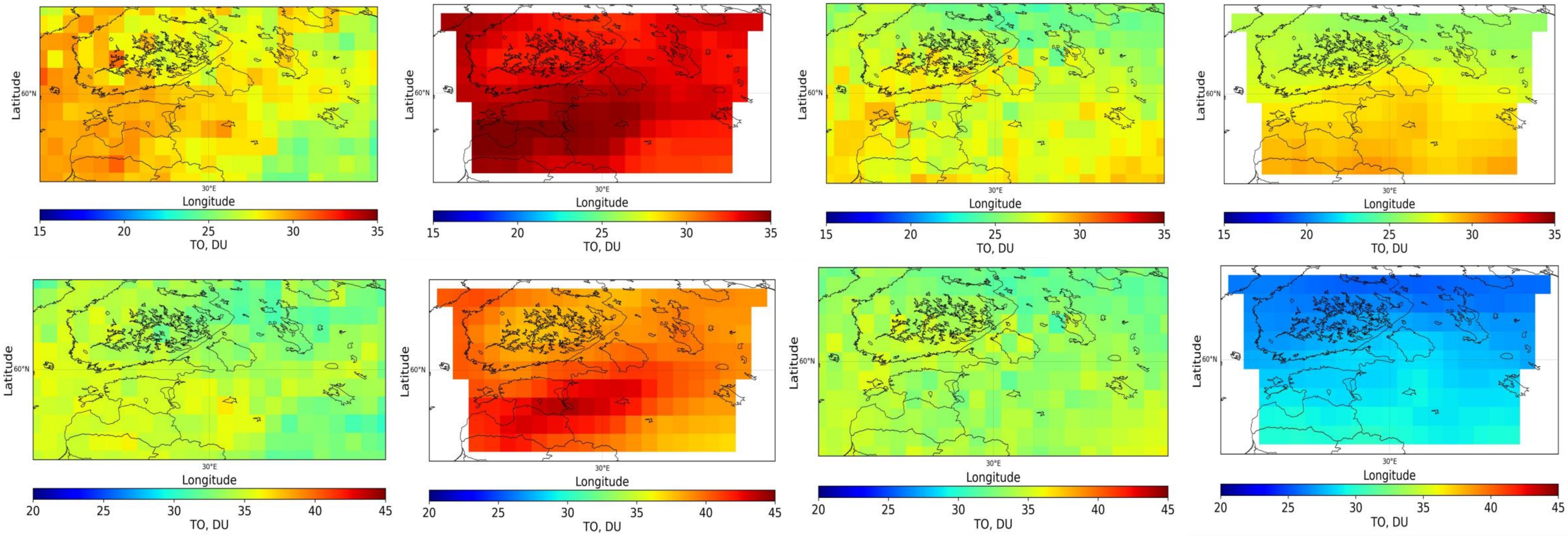
Monthly mean TrOCs (from surface up to 400 mbar) in summer – early fall 2021

Summer 2021 was one of the **hottest** in the last decade characterized by large **forest fires**, especially in Siberia and Far East of Russia in **July** and **August**.

WRF-Chem with 30 km spatial resolution **reproduces well** the increased values of TrOCs observed by IKFS-2.

Validation of WRF-Chem model in the area of the Gulf of Finland

April 2019 **July 2021**



Surf. – 400 mbar

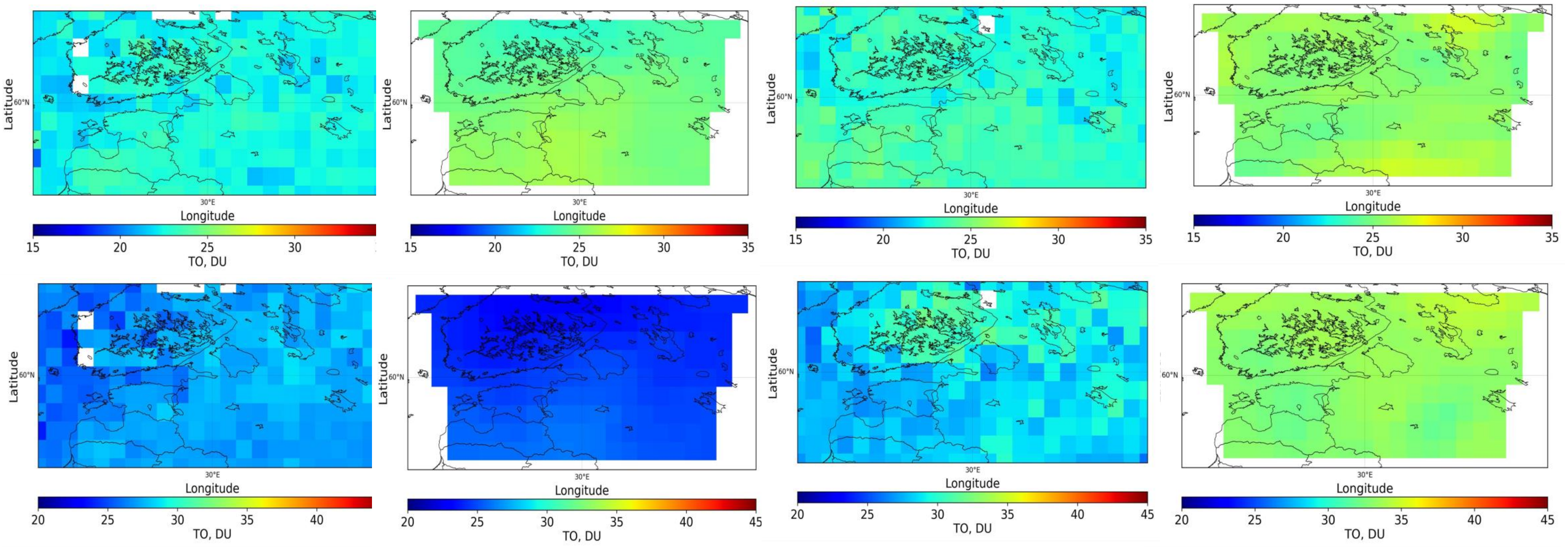
Surf. – 300 mbar

IKFS-2 **WRF-Chem** **IKFS-2** **WRF-Chem**

In spring, the WRF-Chem model with 10 km spatial resolution mainly **overestimates** TrOCs for both layers, correctly reproducing TrOC spatial variations. **In summer**, model **captures well** TrOC distribution for surface – 400 mbar layer and often underestimates TrOCs in surface – 300 mbar layer.

Validation of WRF-Chem model in the area of the Gulf of Finland

October 2021 **February 2019**



Surf. – 400 mbar

Surf. – 300 mbar

IKFS-2 **WRF-Chem** **IKFS-2** **WRF-Chem**

In fall and winter, the WRF-Chem model with 10 km spatial resolution mainly **reproduces well** TrOC variability for both layers, **better** for surface – **400 mbar** layer. For surface – 300 mbar layer, model may slightly underestimate (in fall) or overestimate (in winter) IKFS-2 TrOC measurements.

Conclusions

- IKFS-2 measurements of TrOCs in two layers (up to 400 mbar and up to 300 mbar) in 2015-2022 have been analyzed and compared to independent data.

- The average **standard deviations of differences** between **IKFS-2** and **FTIR** TrOCs over IRWG-NDACC sites for both layers are within **3 DU**. The mean differences depend on altitude and geographical location of a site.

- In general, **IKFS-2** and **IASI** satellite measurements demonstrate nearly **similar** spatial and temporal **variability** in observed TrOCs with **various biases** in different latitudes.

- Both **IKFS-2** and the **WRF-Chem** model **can track variability** in TrOCs, but further improvement of modeling is needed.

- Further research suggests using both IKFS-2 and other data together with model simulations to analyze the reasons of TrOC variability both on a global and regional scale.

ACKNOWLEDGEMENT

❖ SRC “Planeta” for providing access to the IKFS-2 level 1b data

❖ the AERIS data infrastructure for providing access to the IASI data, ULB-LATMOS for the development of the retrieval algorithms, and Eumetsat/AC SAF for O_3 data production

❖ HEGIFTOM working group within the TOAR-II project for providing access to harmonized ozonesonde data, and

❖ IRWG-NDACC PIs for providing access to the FTIR ozone data.

Study was supported by the Russian Science Foundation in the frame of the project No. 23-27-00166, https://rscf.ru/en/project/23-27-00166/ .

For any questions, please, contact me directly:

THANK YOU FOR ATTENTION!