RETRIEVAL OF METHANE AND CARBON OXIDES CONTENT FROM ATMOSPHERIC SPECTRA OF SOLAR RADIATION

Tatyana Yu. Chesnokova[1], Alexey V. Chentsov[1], Nikita V. Rokotyan[2], Vyacheslav I. Zakharov[2,3], A.M. Trifonova-Yakovleva [1]

1 - V.E. Zuev Institute of Atmospheric Optics SB RAS, Tomsk,
2 - Ural Federal University, Yekaterinburg
3 - N.N. Krasovskii Institute of Mathematics and Mechanics UB RAS

Radiative balance of the atmosphere

$$R_a = B^* + F_a - F_\infty$$

B^* is the effective emission of the Earth surface;

F_a is solar radiation absorbed and scattered by the atmosphere;

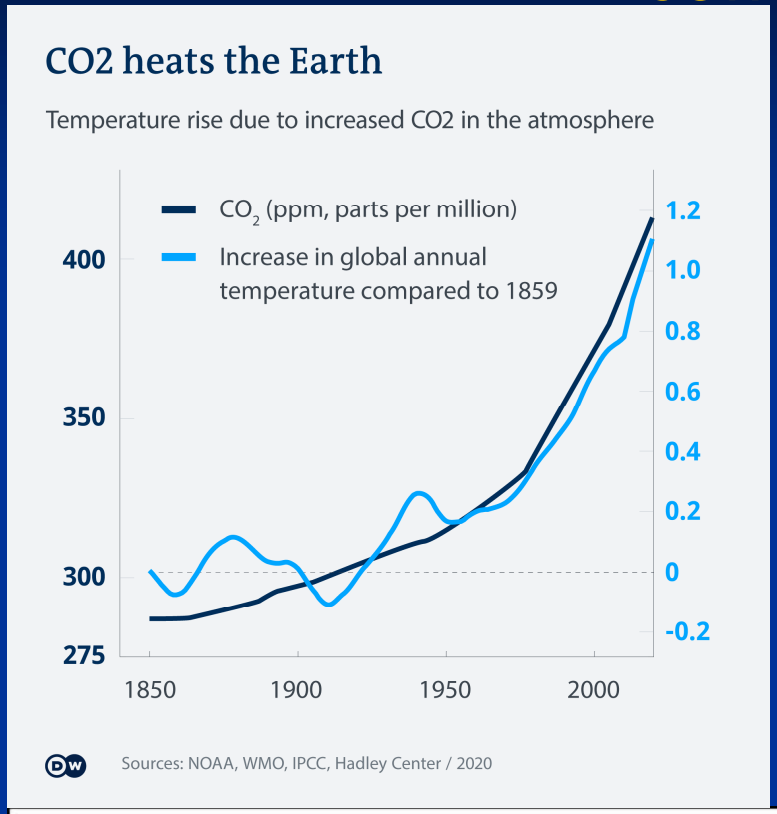
F_∞ is the outcoming emission of the Earth and the atmosphere

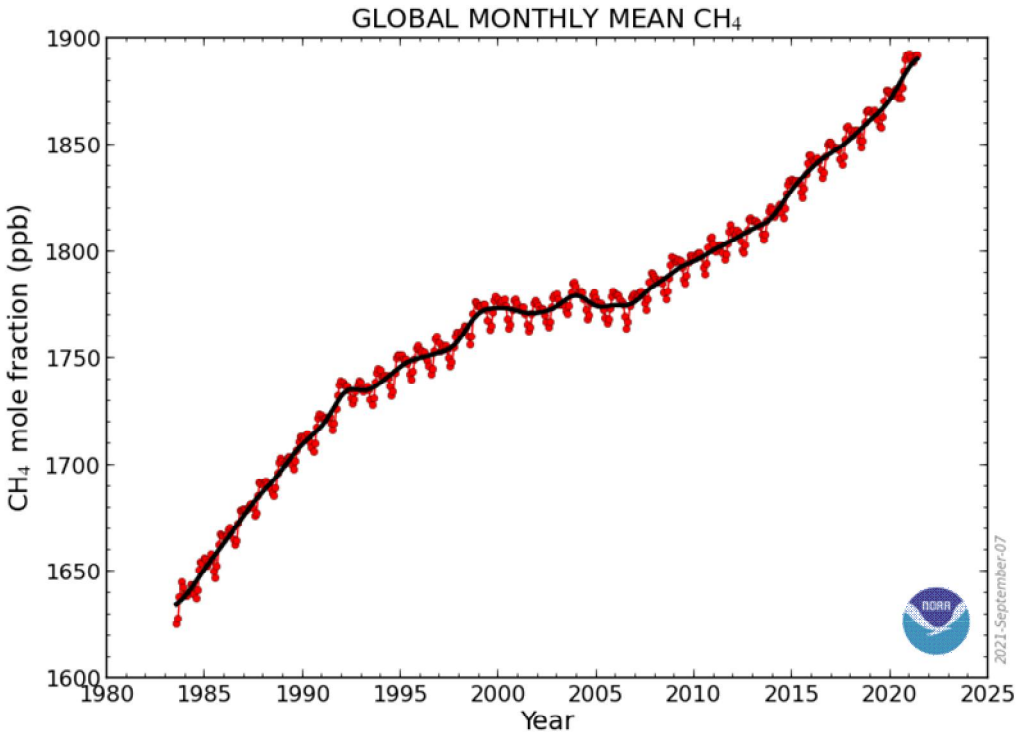
$$\Delta F_\infty = -1\ W/m^2 \rightarrow \Delta t_{surface} = +0{,}6^oK$$

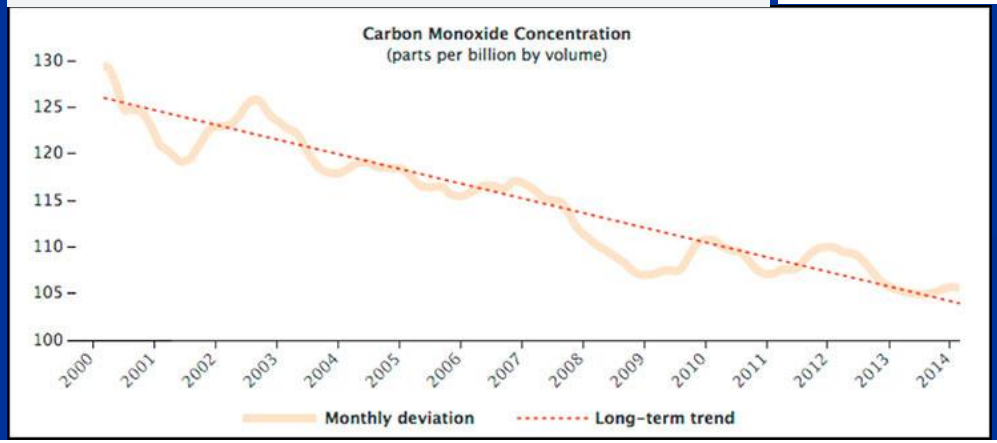
Possible causes of R_a changes

- Solar radiation ΔS=1% (14 W/m^2) $\rightarrow$ $\Delta t_{surface}$= 2^{o}K
- Surface albedo ΔA_S=0,03% $\rightarrow$ $\Delta t_{surface}$= - 0,13^{o}K
- CO_2 doubling $\rightarrow \Delta F_\infty$= +3 W/m^2 $\rightarrow$ $\Delta t_{surface}$= +(3$\pm$1,5)^{o}K;
- Doubling of CH_4, N_20, CFCs $\rightarrow$ ΔF_∞= +2,5 W/m^2 $\rightarrow \Delta t_{surf}$=+ 1^{o}K;
- O_3 decrease by 25% $\rightarrow$ $\Delta t_{surface}$= - 0,25^{o}K

Change in atmospheric CH_4, CO_2 and CO concentrations



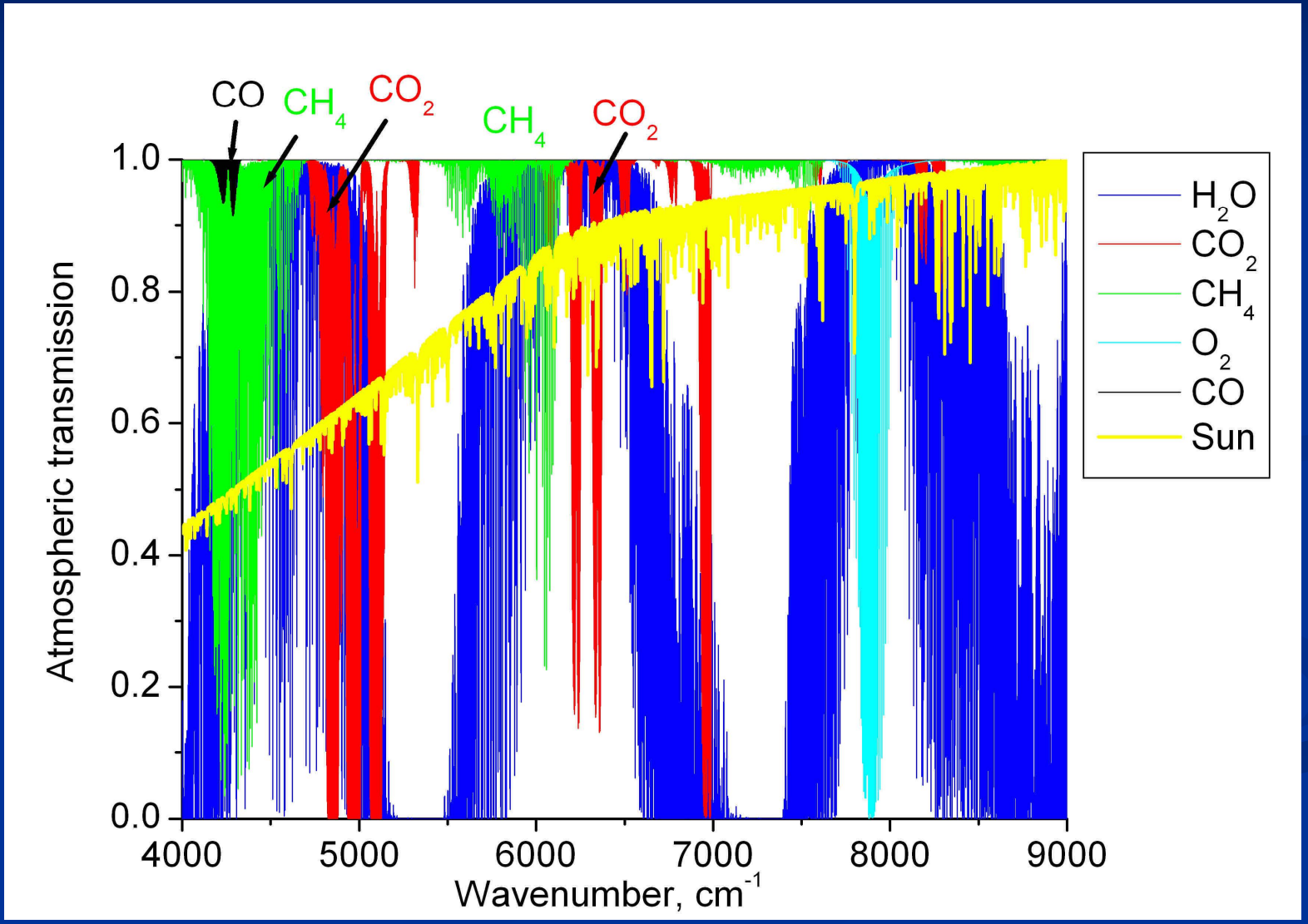




Contribution of CH_4 doubling to radiative forcing = 38% of CO_2 doubling

Atmospheric transmission of main absorbing gases

Meteorological model is mid latitude summer. Vertical path.



Requirements for CO_2 и CH_4 retrieval using SCIAMACHY/ENVISAT and TANSO/GOSAT spectrometers for the climate modeling

Parameter	Req. type	Random error ("precision")		Systematic error ("accuracy")
		Single obs.	1000^2 км^2 monthly	
XCO_2	G	< 1 ppm	< 0.3 ppm	< 0.2 ppm
	B	< 3 ppm (~1%)	< 1.0 ppm	< 0.3 ppm
	T	< 8 ppm	< 1.3 ppm	< 0.5 ppm
XCH_4	G	< 9 ppb	< 3 ppb	< 1 ppb
	B	< 17 ppb (~1%)	< 5 ppb	< 5 ppb
	T	< 34 ppb	< 11 ppb	< 10 ppb

Buchwitz, M., F. Chevallier, P. Bergamaschi, et al.. User Requirements Document for the GHG-CCI project of ESA's Climate Change Initiative, V. 1, 3. 2011.

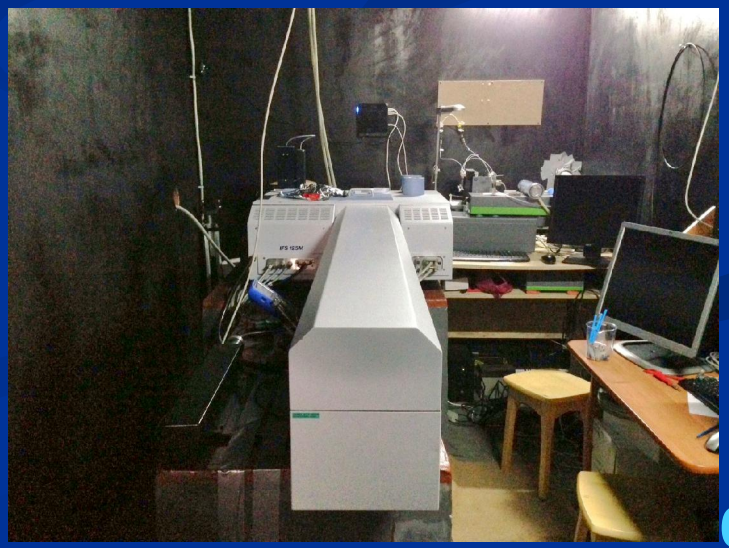
CH_4	**Earth** Very accurate	**Outer planets** ← Between →	**Exoplanets etc** Very complete
Wavelength range (μm)	1.3 – 9	0.6 – 500	0.6 - 9
Temperature range (K)	180 – 350	40 – 200	300 – 3000
Minimum intensity	10^{-26}	10^{-29}	??
Number of lines needed	~0.5 million	10 million	> 1 billion
Pressure broadening species	N_2, O_2, H_2O	H_2, He, N_2	H_2, N_2 ?
Accuracies needed			
Position of line center (cm^{-1})	0.0001	0.001 – 0.100	0.002 - 5
Intensity (%)	0.5 – 3%	2 – 5	10 – 20
Line shape (%)	0.5 – 3 Non-Voigt	2 - 5 Non-Voigt	10 – 20 Voigt

L.Brown et al. JQSRT. 2013. 130. P.201-219

Measurement of atmospheric solar spectra

The atmospheric solar spectra were measured by a ground-based Fourier transform spectrometer in Kourovka observatory (near Yekaterinburg, Russia, 57.038 N, 59.545 E, elevation 300 m, forest area with background atmospheric condition) is made. The spectral resolution is 0.02 cm^{-1}

Atmospheric total content of CO_2, CH_4, CO was retrieved using SFIT4 and GFIT code. The measured spectra were compared with the spectra simulated with taking into account the H_2O, CO_2, N_2O, CH_4, CO, O_3, O_2 absorption and solar lines. Pressure, temperature, and atmospheric gases concentration profiles are taken from the data of NCEP/NCAR reanalysis for Kourovka and local measurements.



Spectroscopic databases of absorption lines of greenhouse gases

Molecule	Number of lines in spectroscopic databases in the 4000-9000 cm^{-1} spectral region							
	HITRAN			GEISA			ATM	
	2008	2012	2016	2011	2015	2020	2012	2019
CO_2	85102	140454	160324	114185	149593	149986	45651	126796
CH_4	90281	165670	175052	90003	138820	146439	64950	80415
CO	2260	2260	2009	6621	6620	6873	1897	2260

HITRAN - https://hitran.org/lbl/

GEISA – *N. Jacquinet-Husson, et al. // JMS. 2016. V.327. P.31–72*

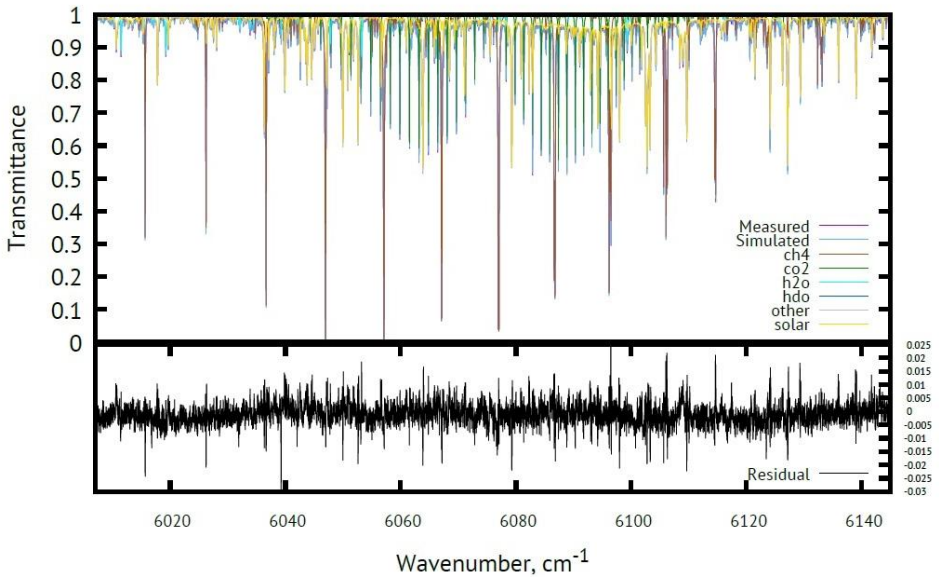
ATM - compilations from G. Toon (JPL)
http://mark4sun.jpl.nasa.gov/toon/linelist/linelist.html

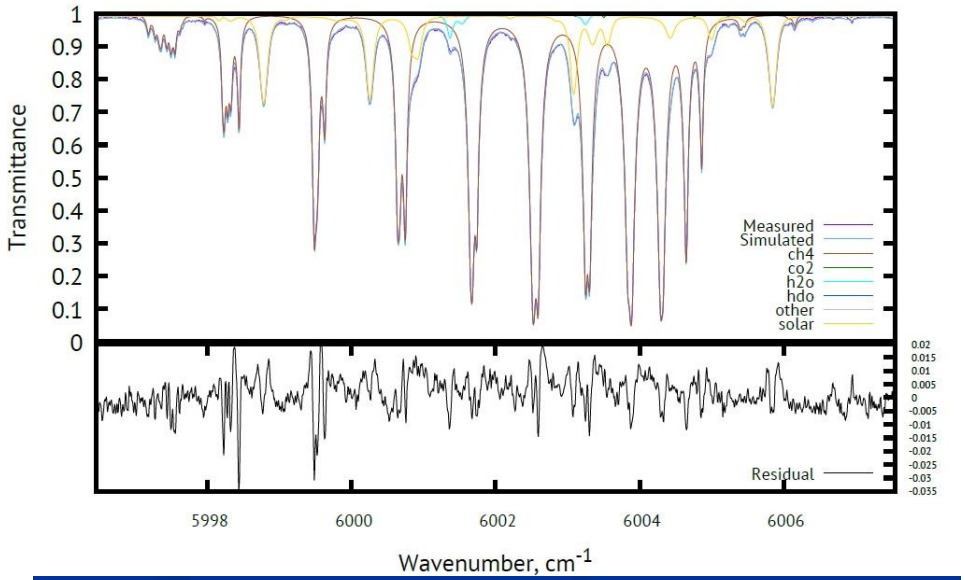
CDSD296 (CO_2) - *S.A. Tashkun, et al. JQSRT. 2015. V.152. P.45–73*

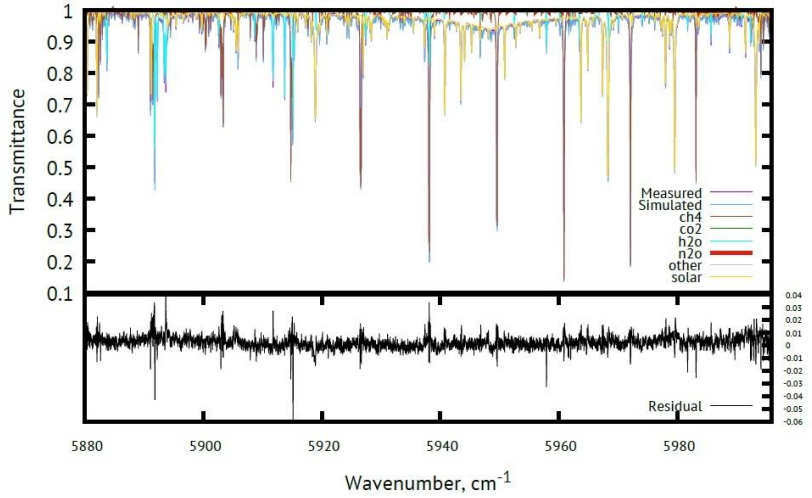
GOSAT2014 **(CH_4)** - *A.V. Nikitin, et al. JQSRT. 2015. V. 154. P. 63–71*

Measured atmospheric solar spectrum and difference between the measured and calculated spectra.

Kourovka, SZA=71,14º

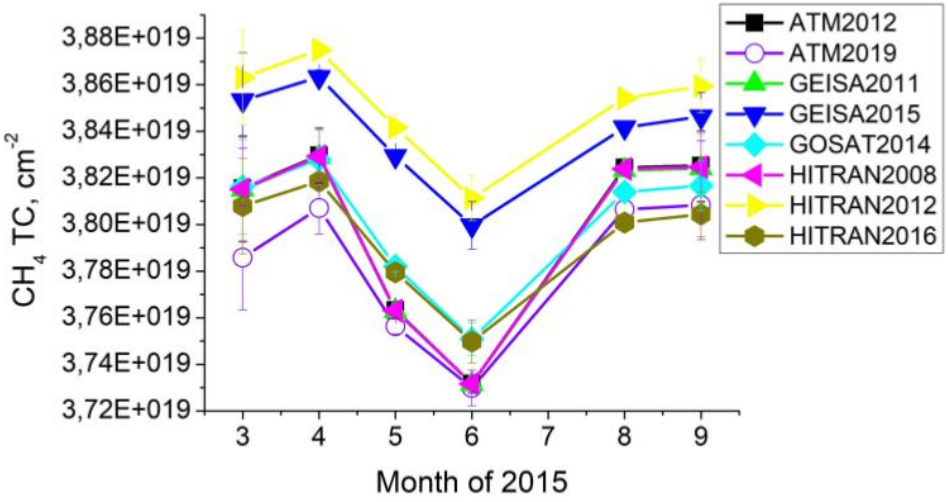


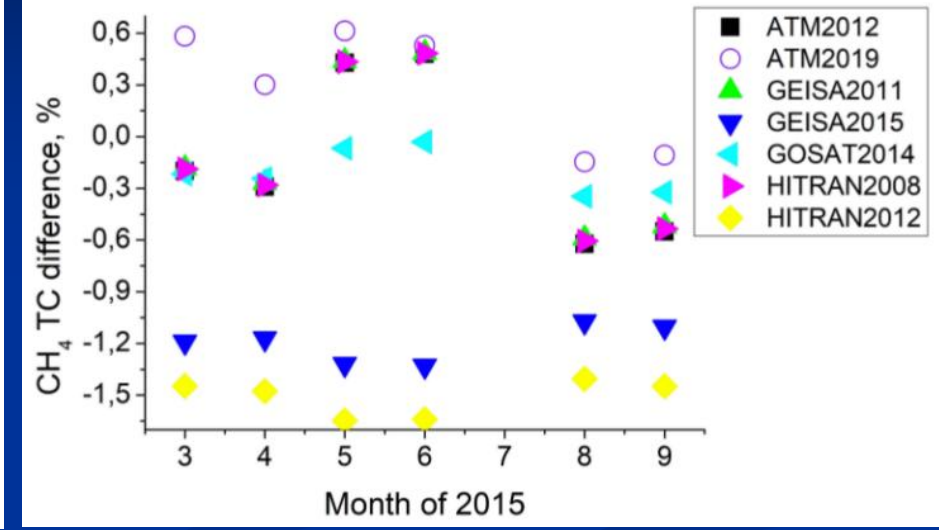




CH_4 TC retrieval

Monthly averaged CH_4 atmospheric total content (TC) retrieved from FTS measured spectra using different spectroscopic databases. Kourovka

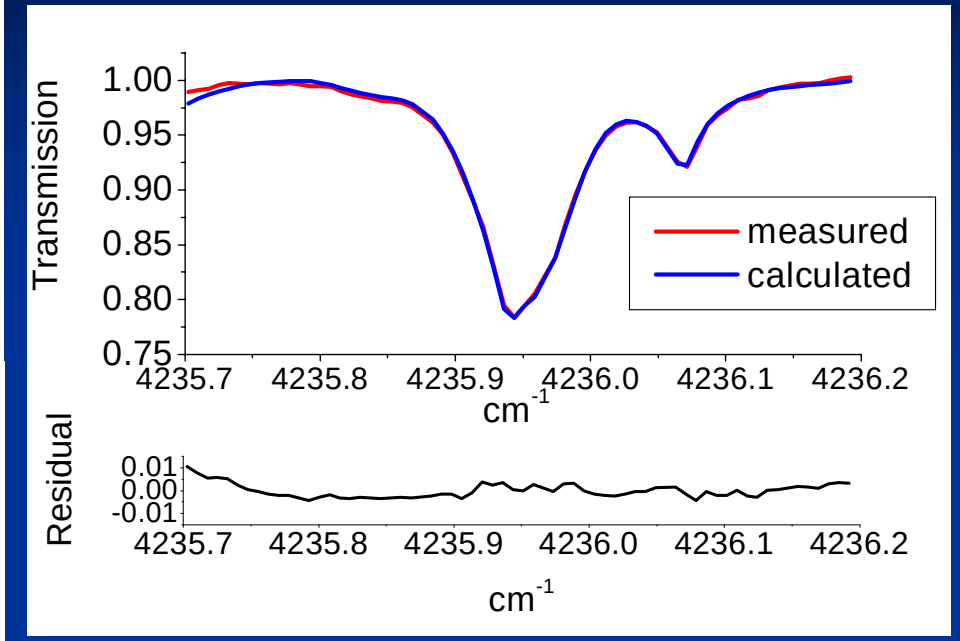


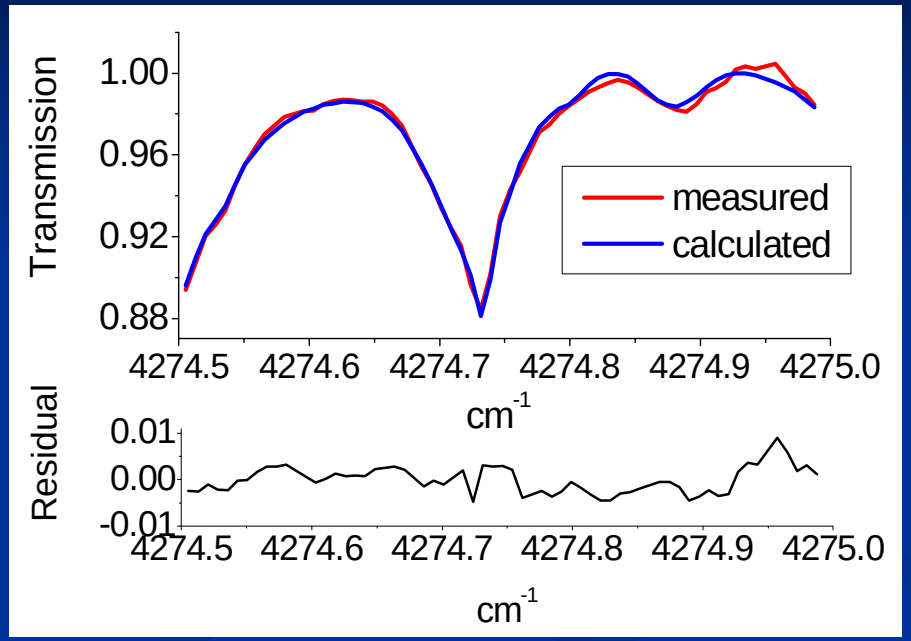


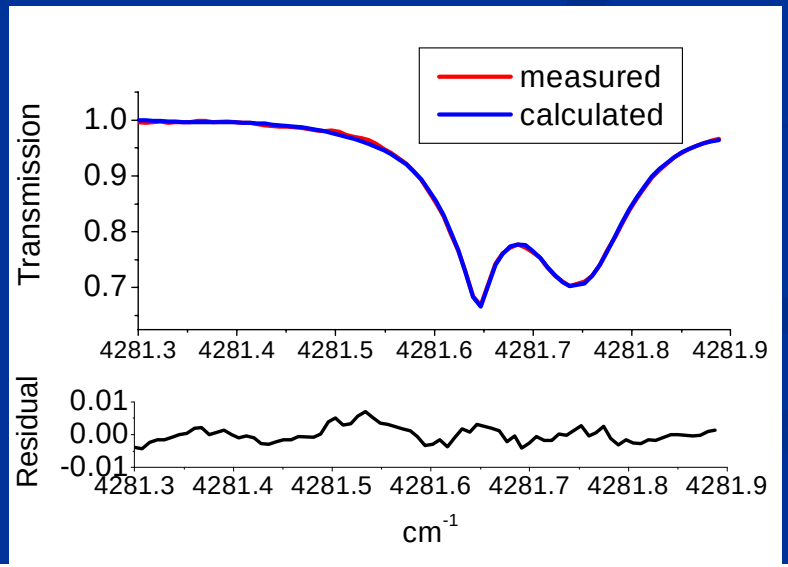
Spectroscopic database	Mean TC, cm^{-2}	RMS, %				χ^2/N			
		5938 cm^{-1}	6002 cm^{-1}	6076 cm^{-1}	mean	5938 cm^{-1}	6002 cm^{-1}	6076 cm^{-1}	mean
ATM12	3.7984E+19	0.54473	0.67045	0.45554	0.55691	0.28079	0.10268	0.19074	0.1914
ATM19	3.7823E+19	0.53408	0.65038	0.44498	0.54315	0.23286	0.13773	0.16509	0.17856
GEISA2011	3.7976E+19	0.54503	0.67049	0.45717	0.55756	0.28118	0.10637	0.18992	0.19249
GEISA2015	3.8389E+19	0.56295	0.76591	0.52847	0.61911	0.22888	0.14621	0.23362	0.2029
GOSAT2014	3.8013E+19	0.53813	0.71574	0.46684	0.57357	0.24003	0.10417	0.1733	0.1725
HITRAN2008	3.7979E+19	0.54424	0.67122	0.45583	0.5571	0.28101	0.10441	0.19039	0.19194
HITRAN2012	3.8508E+19	0.53814	0.81932	0.47677	0.61141	0.25064	0.0989	0.18208	0.17721
HITRAN2016	3.7935E+19	0.56413	0.70721	0.51869	0.59668	0.21802	0.22115	0.27521	0.23813

Chesnokova T.Yu., et al. JQSRT. 2020. V.254.

Measured atmospheric solar spectrum and difference between the measured and calculated spectra. Kourovka

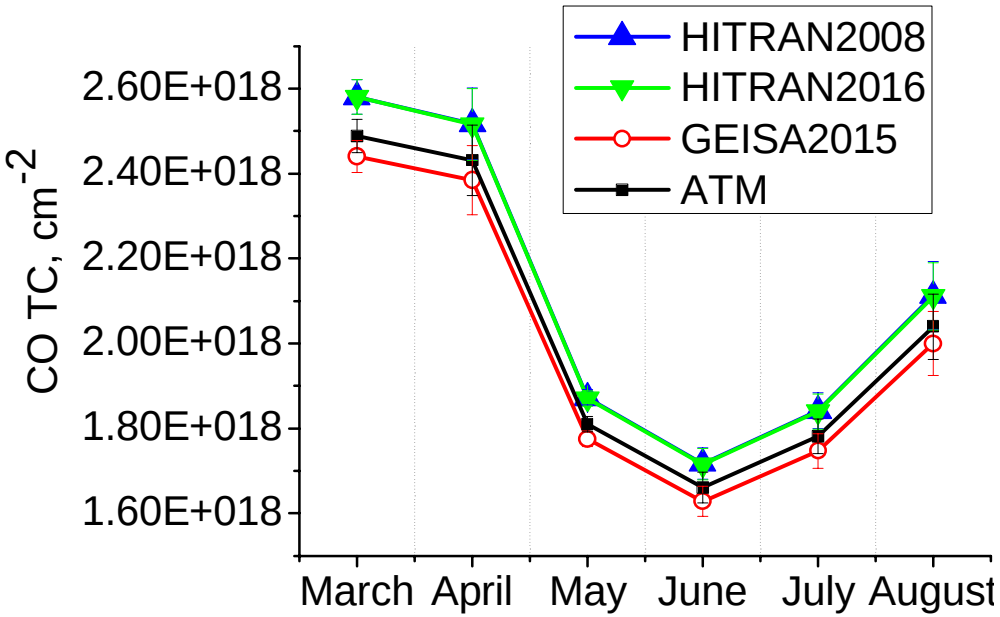


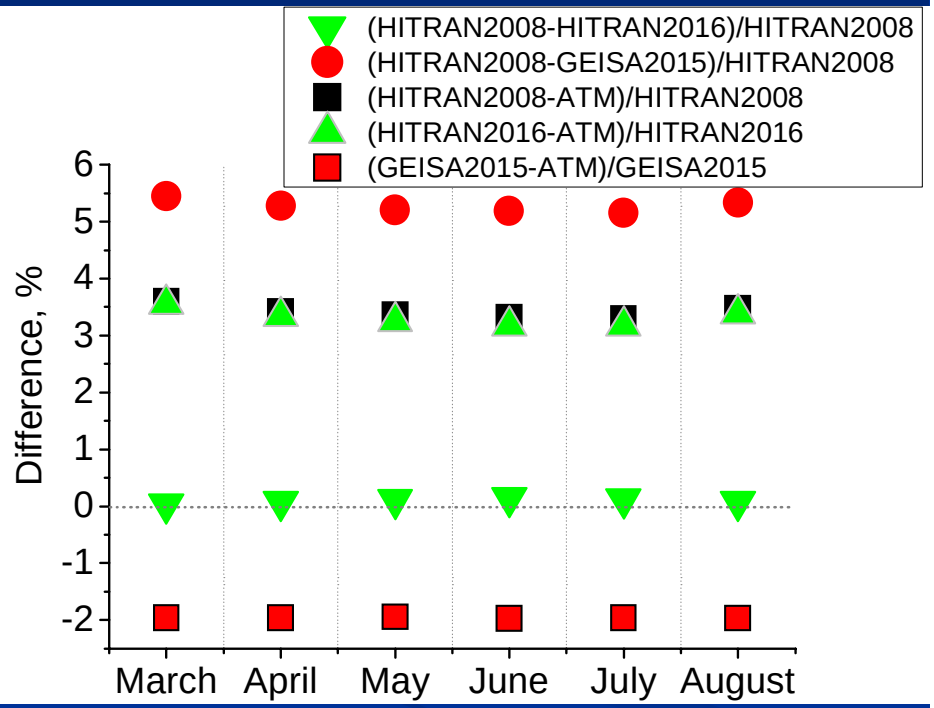




CO TC retrieval

Monthly averaged CO atmospheric total content (TC) retrieved from FTS measured spectra using different spectroscopic databases. Kourovka





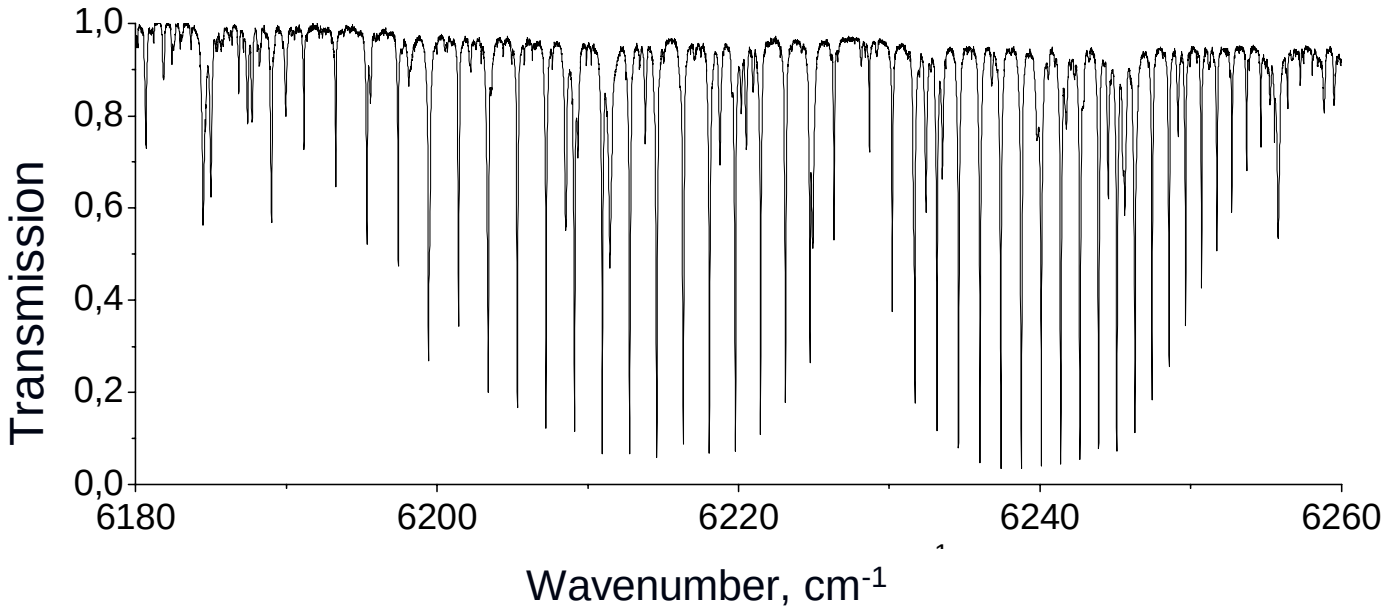
SDB	RMS, %	χ^2
ATM	0,320	0,75
GEISA2015	0,320	0,75
HITRAN2008	0,308	0,69
HITRAN2016	0,305	0,68

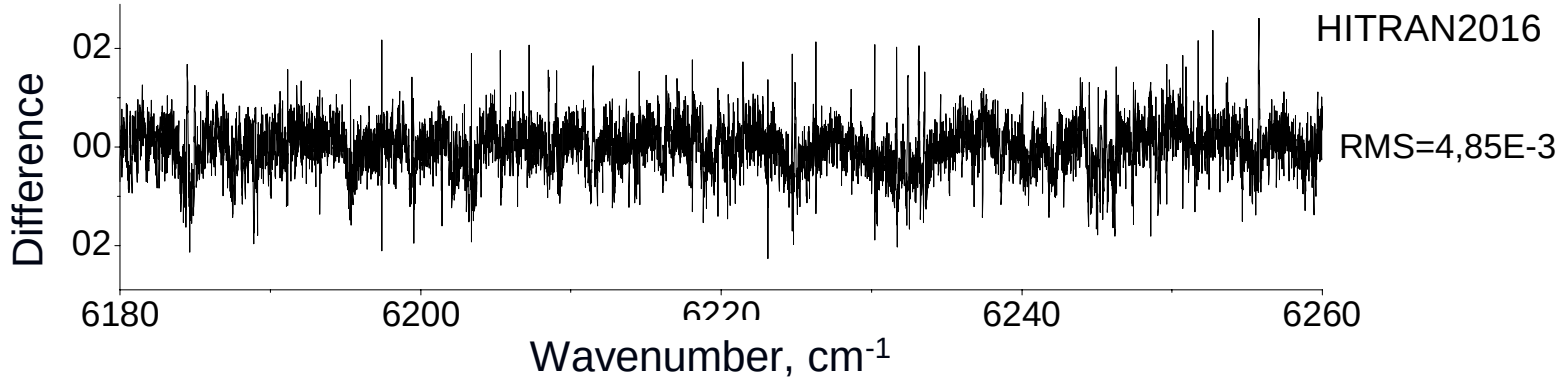
T. Yu. Chesnokova, M. V. Makarova, A. V. Chentsov, Y. V. Voronina, N. V. Rokotyan, V. I. Zakharov, Bavo Langerock // Atmospheric and Oceanic Optics. 2019. V. 32. N4

Measured atmospheric spectrum and difference between the measured and calculated spectra.

Kourovka, 13.08.2015, SZA=49,7º

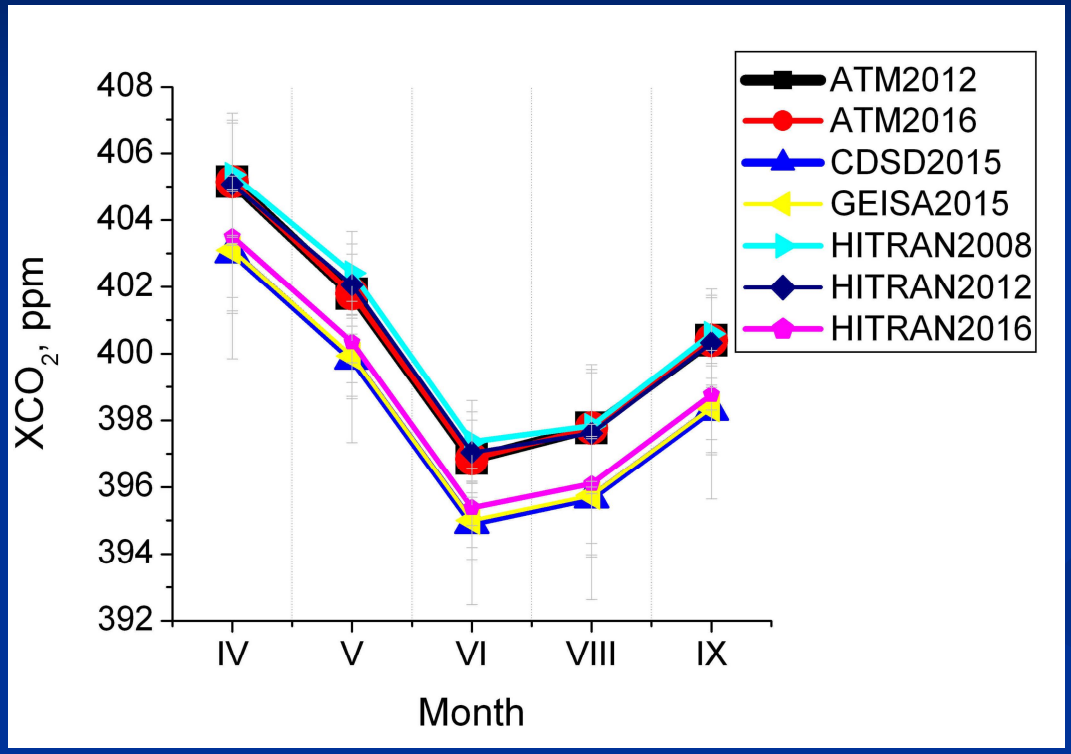
CO_2 TC retrieval

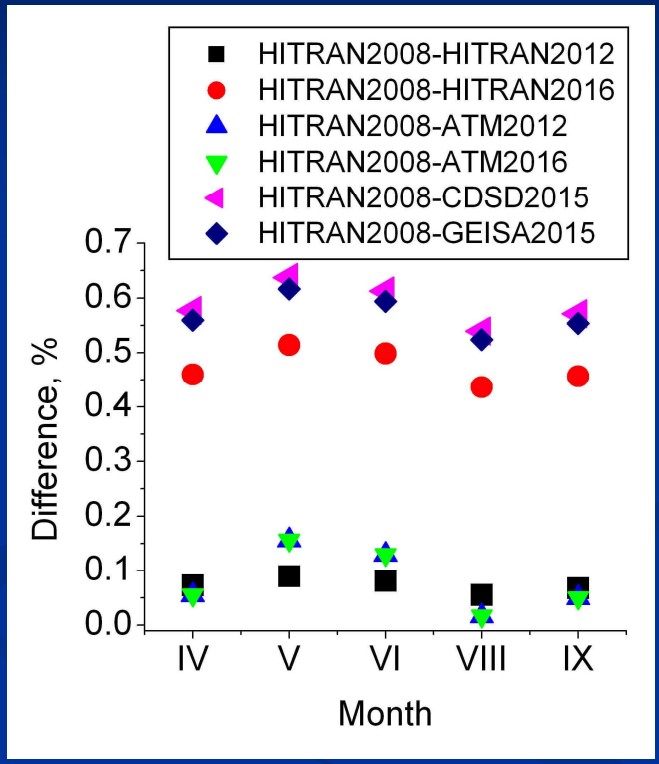




Monthly averaged CO_2 atmospheric total content retrieved from FTS measured spectra using different spectroscopic databases.

Kourovka. 2015

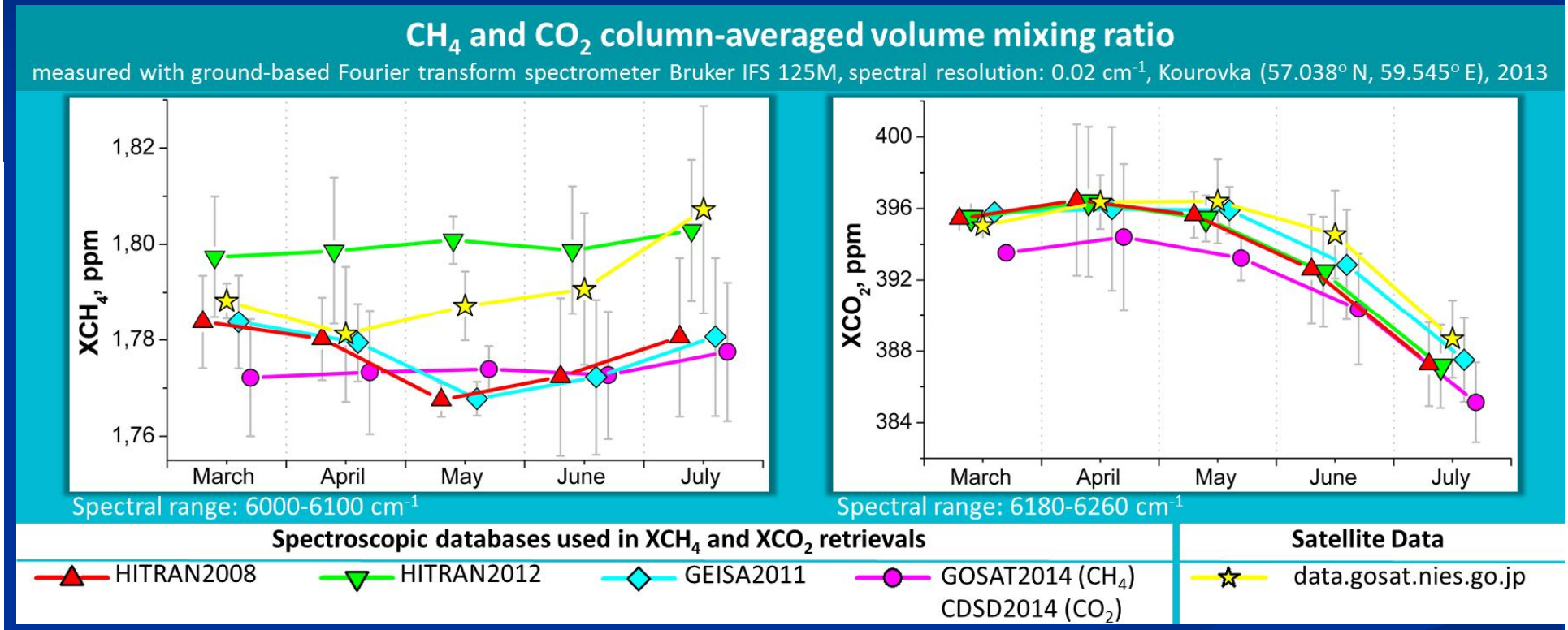




SDB	RMS
HITRAN2008	$4{,}82*10^{-3}$
HITRAN2012	$4{,}82*10^{-3}$
HITRAN2016	$4{,}85*10^{-3}$
GEISA2011	$4{,}83*10^{-3}$
GEISA2015	$4{,}85*10^{-3}$
CDSD2014	$4{,}85*10^{-3}$

Spectral region is 6180-6260 cm^{-1}.

Monthly averaged CH_4 and CO_2 atmospheric total content retrieved from FTS measured spectra using different spectroscopic databases. Kourovka.



T.Yu. Chesnokova, A.V. Chentsov, N.V. Rokotyan, V.I. Zakharov. // Journal of Molecular Spectroscopy. 2016. V.327. P.171-179

Conclusion

- The comparison of the simulated and measured solar absorption spectra in the 5800-6100 cm^{-1} spectral region has shown that the least residual (RMS) and Chi2 were for the simulation with CH_4 line parameters from HITRAN2008, GEISA2011 and ATM. For the CO_2, the residuals were close to each other in the 6180-6260 cm^{-1}. The simulations with HITRAN2016 have minimum RMS in the CO retrieval in the 4227-4235 cm^{-1} region.

- The difference in the atmospheric CH_4 content, retrieved with different spectroscopic databases was 1.7% for monthly averaged values and 4% for individual measurements. For the CO TC results, the difference reaches 5,5%. The difference in the CO_2 atmospheric contents did not exceed 0.6%.

- These differences are comparable with annual trends of CH_4 and CO_2 atmospheric concentration growths, which are ≈0.4-0.6% in 2015-2017(Rakitin et al. ISARD-2019)

Thank you for attention