Heterogeneity of the spatial distribution of CO2 and CH4 concentrations in the atmospheric surface layer over West Siberia: October-November 2018

Arshinov, Mikhail Yu., Belan, Boris, Davydov, Denis, Kozlov, Artem, Fofonov, Alexadr, et al.

Mikhail Yu. Arshinov, Boris D. Belan, Denis K. Davydov, Artem V. Kozlov, Alexadr V. Fofonov, Victoria Arshinova, "Heterogeneity of the spatial distribution of CO2 and CH4 concentrations in the atmospheric surface layer over West Siberia: October-November 2018," Proc. SPIE 11208, 25th International Symposium on Atmospheric and Ocean Optics: Atmospheric Physics, 1120831 (18 December 2019); doi: 10.1117/12.2539205

Event: XXV International Symposium, Atmospheric and Ocean Optics, Atmospheric Physics, 2019, Novosibirsk, Russian Federation

Heterogeneity of the spatial distribution of CO_2 and CH_4 concentrations in the atmospheric surface layer over West Siberia: October-November 2018

Mikhail Yu. Arshinov*[a], Boris D. Belan[a], Denis K. Davydov[a], Artem V. Kozlov[a], Alexadr V. Fofonov[a], Victoria Arshinova[a]

[a]V.E. Zuev Institute of Atmospheric Optics SB RAS (IAO SB RAS), Tomsk, Russia 634055

ABSTRACT

Here, we present the results of a mobile campaign undertaken in late October to early November of 2018 to survey heterogeneity of the spatial distribution of CO_2 and CH_4 concentrations across West Siberia using the Picarro G4301 mobile gas concentration analyzer. The measurements were carried out along the following routes Tomsk–Karasevoe–Tomsk and Tomsk–Omsk–Tobolsk–Noyabrsk–Tobolsk–Chelyabinsk–Omsk–Tomsk. The highest baseline level of carbon dioxide mixing ratio of 431.0±2.2 ppm was observed at the western route segments between Chelyabinsk and Kurgan, and the lowest ones at segments Tomsk – Karasevoye, Demyanskoe – Noyabrsk, and Tobolsk – Yalutorovsk, where average concentrations of CO2 were 410.1±1.1 ppm, 410.7±1.6 ppm, and 411.5±1.5 ppm, respectively. Enhanced methane background (> 2000 ppb) was recorded in the oil and gas production areas, as well as in the vicinity of such large industrial centers as Kurgan and Chelyabinsk.

Keywords: carbon dioxide, methane, spatial distribution, heterogeneity, West Siberia

1. INTRODUCTION

Occupying a vast area of the land surface of the Northern Hemisphere, Siberia plays an important role in the Earth's climate system and its current change. Despite this fact, atmospheric composition observations in this region are still poor or lacking. Carbon dioxide and methane are key atmospheric species which rising concentrations are responsible for a positive radiative forcing. In mid 2000s, V.E. Zuev Institute of Atmospheric Optics SB RAS (IAO SB RAS) under the international collaboration with the National Institute for Environmental Studies (NIES) had deployed a network for greenhouse gas monitoring in Siberia (Japan-Russia Siberian Tall Tower Inland Observation Network – JR-STATION)[1]. JR-STATION covers a significant part of the West Siberian Plain extending between 54.5° and 63.2° north latitude and between 62.3° and 85.0° east longitude. Stations of this network are spaced 300 to 900 km apart. In spite of their instrument suites are operating in a fully automated mode, they should be maintained. For this purpose we usually undertake the road trips to the sites most remote from IAO SB RAS about 4 times a year. During one such road trip we cover a distance of about 7,000 km. With the advent of the Picarro G4301 mobile gas concentration analyzer, we decided to extend our observations using the above analyzer installed in an off-road vehicle during the road trips in order to obtain the data on the GHG distribution across West Siberia with a more detailed spatial resolution.

2. EXPERIMENTAL

The Picarro GasScouter™ G4301 Mobile Gas Concentration Analyzer can measure CO_2 and CH_4 mixing ratios at 1 Hz with a high accuracy: 0.4 ppm and 3 ppb, respectively. The principle of operation of the G4301 is based on the cavity ring-down spectroscopy (CRDS) technique.

The water vapor can significantly affect the measurement accuracy of most trace gas analyzers even such precise as Picarro ones. In particular, errors can be caused by substantial water vapor interference due to the dilution and line-broadening effects when using the CRDS to measure atmospheric CO_2 and CH_4 concentrations[2]. Practically all the Picarro gas concentration analyzers measure H_2O content in the air simultaneously with CO_2, CH_4, N_2O, and CO and have a water vapor correction function. However, multiple investigations stated that correction functions show good results at low levels of water vapor concentrations (<0.2%). Nara et al. recommend the ambient air to be completely or moderately dehumidified before supplying it to the analyzer[2].

*michael@iao.ru; phone +7 3822 492-894; fax +7 3822 492-894; lop.iao.ru/EN

25th International Symposium On Atmospheric and Ocean Optics: Atmospheric Physics, edited by Gennadii G. Matvienko, Oleg A. Romanovskii, Proc. of SPIE Vol. 11208, 1120831
 · doi: 10.1117/12.2539205

Also, the measurement accuracy can be affected by a change in the reflection coefficient of multilayer mirrors depending on the water vapor content in the air sample passing through the optical cavity[3]. In order to reduce interference from the water vapor on accurate measurements of CO_2 and CH_4, as well as to avoid a possible liquid water penetration into the cavity, we used a three-stage drying unit before supplying the ambient air to the analyzer. A schematic diagram of the drying unit is shown in Figure 1a. A gas inlet has been mounted behind a radiator cover of the vehicle (Figure 1b). A GLONASS receiver (Model BU-353) was connected to the G4301 to record the position of a vehicle during the on-road campaign. Just before the road trip and right after it, the G4301 gas analyzer was calibrated against three standard gas mixtures to derive calibration coefficients.

Since it is evident that when driving on the heavy traffic motorways, measurements are highly affected by vehicle emissions, when analyzing the data we derived "background" CO_2 and CH_4 concentrations measured during the trip by retrieving a baseline from the dataset. In cases of traffic jam, to obtain background concentrations, we deviated from the route to the rural area in the direction from which the prevailing wind was blowing.

Mobile on-road measurements of CO_2 and CH_4 using the Picarro G4301 portable gas analyzer were carried out across West Siberia in late October – early November 2018 (Table 1).

(a) (b)

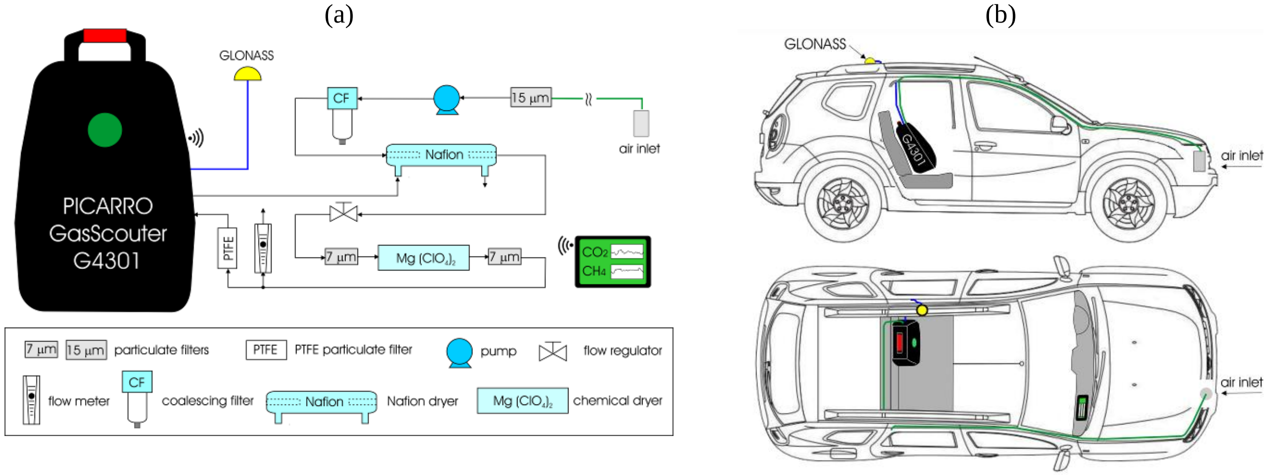

Figure 1. Schematic diagram of the drying unit (a) and the G4301 installation in a vehicle (b).

Table 1. Timeline of the mobile campaign undertaken across West Siberia in late October – early November 2018.

Date	Route segment	Distance (km)	Wind direction*
October 18, 2018	Tomsk–Karasevoe–Tomsk	610	⇨
October 28, 2018	Tomsk–Kalachinsk	848	⇨
October 29, 2018	Kalachinsk–Tobolsk	790	⇨
October 30, 2018	Tobolsk–Surgut	548	⇨
October 31, 2018	Surgut–Noyabrsk	309	⇨
November 1, 2018	Noyabrsk–Surgut	309	⇨
November 2, 2018	Surgut–Tobolsk	548	⇨
November 3, 2018	Tobolsk–Chelyabinsk	703	⇨
November 6, 2018	Chelyabinsk–Vaganovo–Chelyabinsk	212	⇨
November 7, 2018	Chelyabinsk–Abatskoe	648	⇨
November 8, 2018	Abatskoe–Kalachinsk	368	⇨
November 9, 2018	Kalachinsk–Tomsk	848	⇨

* Arrow colors are used to represent the wind direction observed along each route segment in Figure 2a given below.

3. RESULTS AND DISCUSSION

3.1 Heterogeneity of the spatial distribution of CO_2

In Figure 2 the spatial distribution of carbon dioxide concentration obtained during the above mobile campaign is shown. From fig. 2a, it can be seen that the motorways from Novosibirsk to Omsk (40 km north-east of Azovo) and from Omsk to Chelyabinsk have the most high traffic density where enhanced CO_2 concentrations were observed on some sections. High CO_2 mixing ratios were also typical for the road sections located in the vicinity of large settlements.

Despite this fact, the baseline values derived from the raw dataset of the on-road measurements showed a good agreement with the data obtained at observation towers of the JR-STATION network when arriving there for maintaining the measurement system setup (Figure 2b).

Figure 3 shows latitudinal and longitudinal distributions of CO_2 obtained during the mobile campaign. The lowest baseline levels of CO_2 were observed over the route segments from Tomsk to Karasevoe, from Demyanskoe to Noyabrsk, and from Tobolsk to Yalutorovsk (56.7°N, 66.4°E), where average values were : 410.1±1.1 ppm, 410.7±1.6 ppm, and 411.5±1.5 ppm, respectively (Figures 2 and 3). The highest ones (431.0±2.2 ppm) were measured in the western part of the campaign from Chelyabinsk to Kurgan suggesting a strong anthropogenic impact on air masses advected from the west against the background of the absence of photosynthesis during this period.

On the way back, when driving from Chelyabinsk to Tomsk, the measurements were carried out under conditions determined by a cyclone with two systems of fronts, which covered almost the entire territory of West Siberia (Figure 3f). The trough axis was stretching out from the north-east to the south-west. On the route segment from Chelyabinsk to Azovo, we were driving in a warm subtropical air mass. In the vicinity of Kalachinsk (100 km east of Azovo), the vehicle crossed the system of fronts, as a result, the ambient air temperature dropped sharply, and further measurements were carried in the arctic air mass with the winds blown predominantly from the north and north-west. This led a decrease in CO_2 concentration (Figure 3e), and its average baseline value over the route segment from Kalachinsk to Tomsk became 412.7±1.3 ppm.

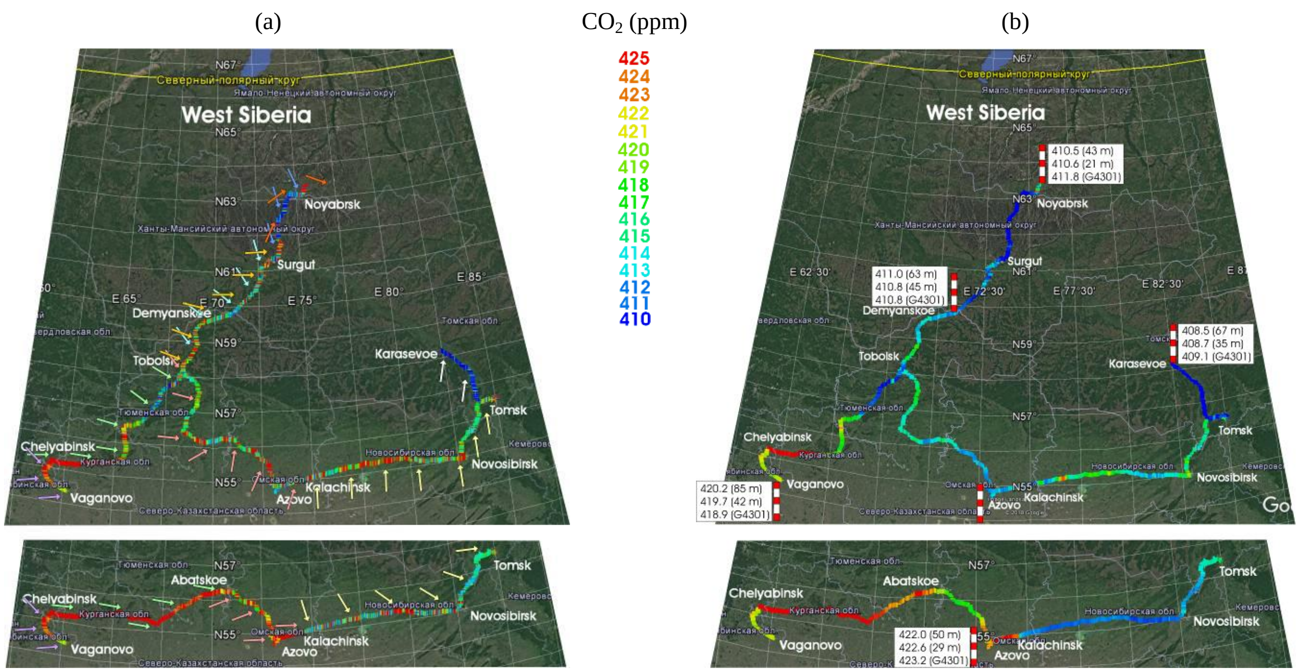

Figure 2. Spatial distribution of CO_2 concentration across West Siberia: raw data (a) and baseline values (b). Arrows at the panel (a) represent the wind direction observed over different road sections. Red-and-white bars at the panel (b) represent observation towers of the JR-STATION network. Lower panels show CO_2 distribution obtained on the way back.

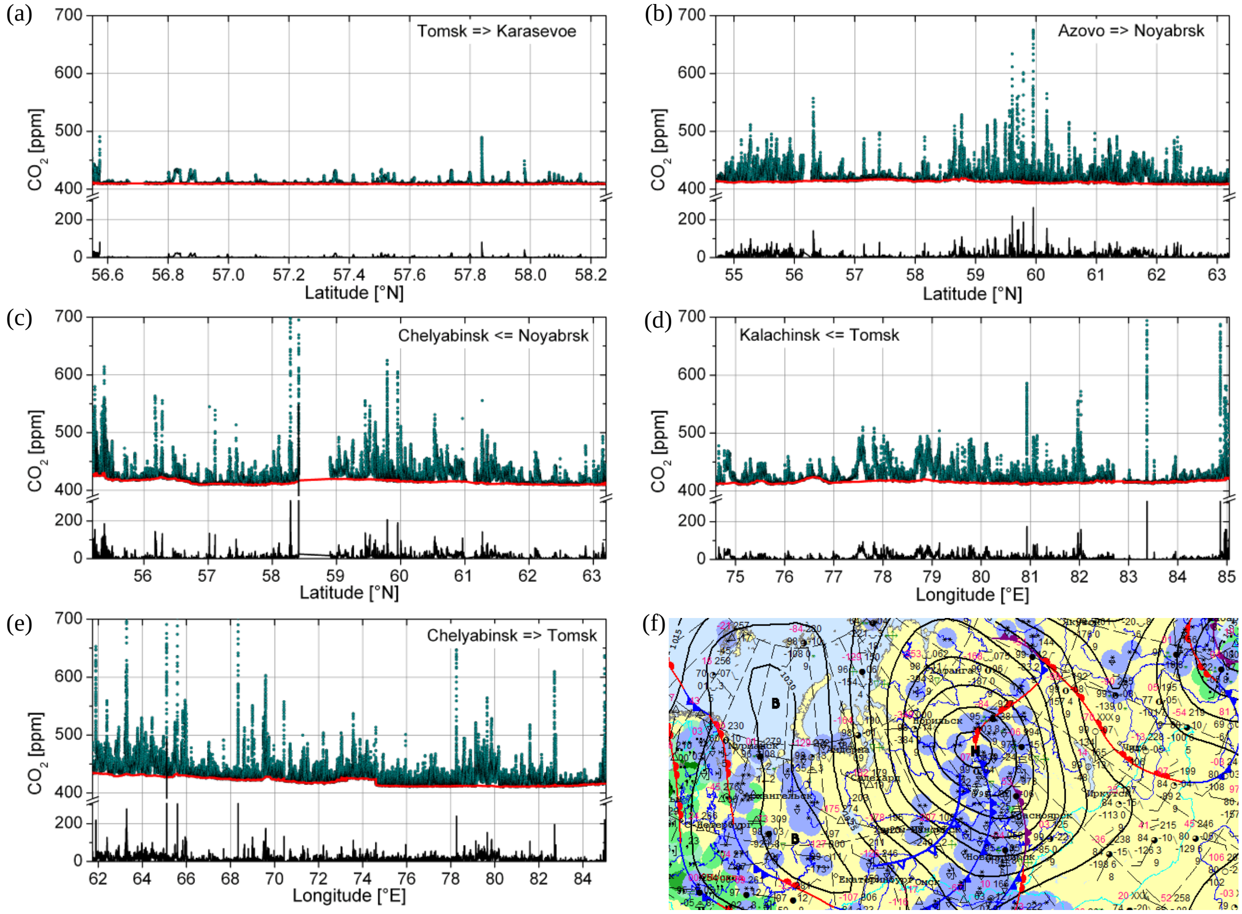

Figure 3. Latitudinal (panels a, b, and c) and longitudinal (panels d and e) distributions of CO_2 across West Siberia: raw data (dark cyan), sectional baselines (red), and excess values (black, $[CO_2]_{excess}=[CO_2]_{raw} - [CO_2]_{baseline}$). Panel (f) – surface weather map (November 9, 2018; 06 UTC)

3.2 Heterogeneity of the spatial distribution of CH_4

The spatial distribution of methane concentration derived from the mobile on-road measurements carried out across West Siberia is shown in Figure 4. It is characterized by a pronounced positive latitudinal gradient of CH4 concentration from the steppe regions in the south to the wetland areas in the north. Unlike the carbon dioxide, the on-road motor vehicle emissions affected the measurements of CH_4 mole fractions less. Highest methane concentrations that significantly exceeded 2000 ppb (Figure 5) were found in oil and gas production areas, near the gas transmission systems, as well as in the vicinity of gas stations selling methane as a motor fuel. In particular, the absolute maximum mole fraction of 4225 ppb CH4 was measured in the immediate vicinity of the natural gas pipeline compressor station located 30 km north-east of Demyanskoe observation tower. The average baseline value of CH4 concentration over the northern route segment between Tobolsk and Noyabrsk was 1987±12 ppb.

In the southern regions, a high level of baseline values of methane, as in the case of carbon dioxide, was observed over a long segment of the route between Chelyabinsk and Kurgan (55.4°N, 65.3°E) that confirms the anthropogenic pollution of the air transported from the west. Also, elevated CH_4 concentrations, but of natural origin, were measured when driving from Tomsk to Kalachinsk through the Chany district of the Novosibirsk region covered with numerous shallow lakes and wetlands (marked by white circle in Figure 4b). After 11 days, on the way back, the lakes and swamps in this area were already covered with ice, and methane emissions from them did not affect the measurements, but the overall baseline level in the area from Kalachinsk to Tomsk increased markedly (1988±17 ppb) due to the air advection from northern regions.

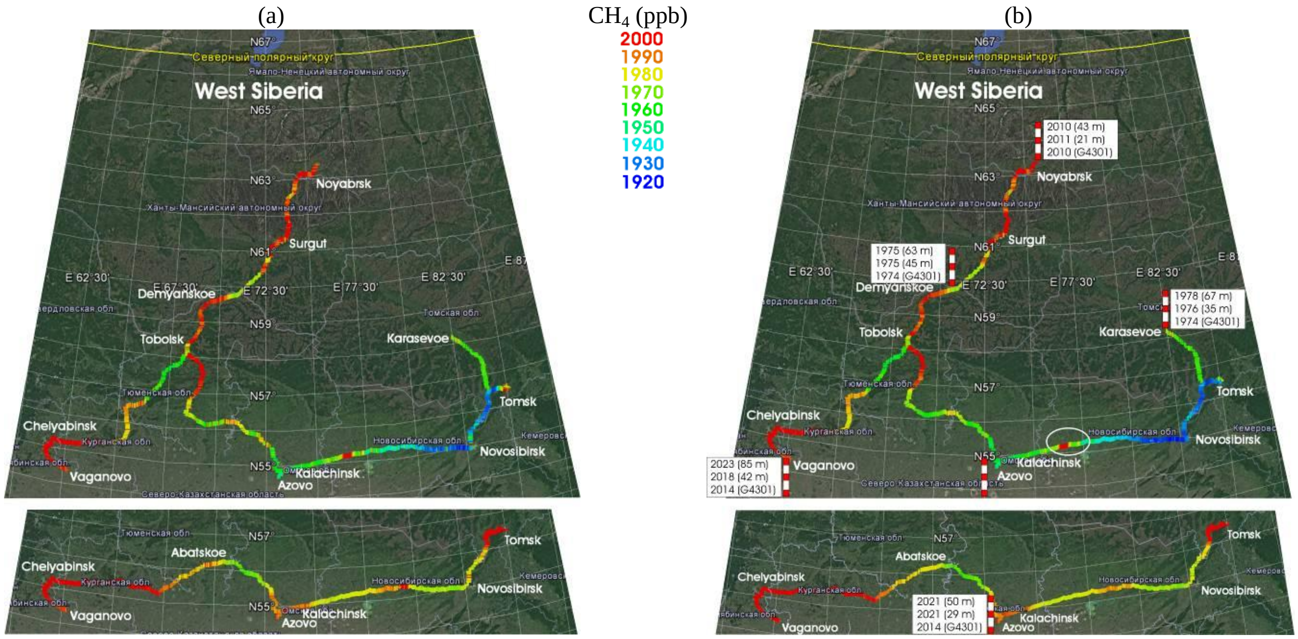

Figure 4. Spatial distribution of CH_4 concentration across West Siberia: raw data (a) and baseline values (b). Red-and-white bars at the panel (b) represent observation towers of the JR-STATION network.

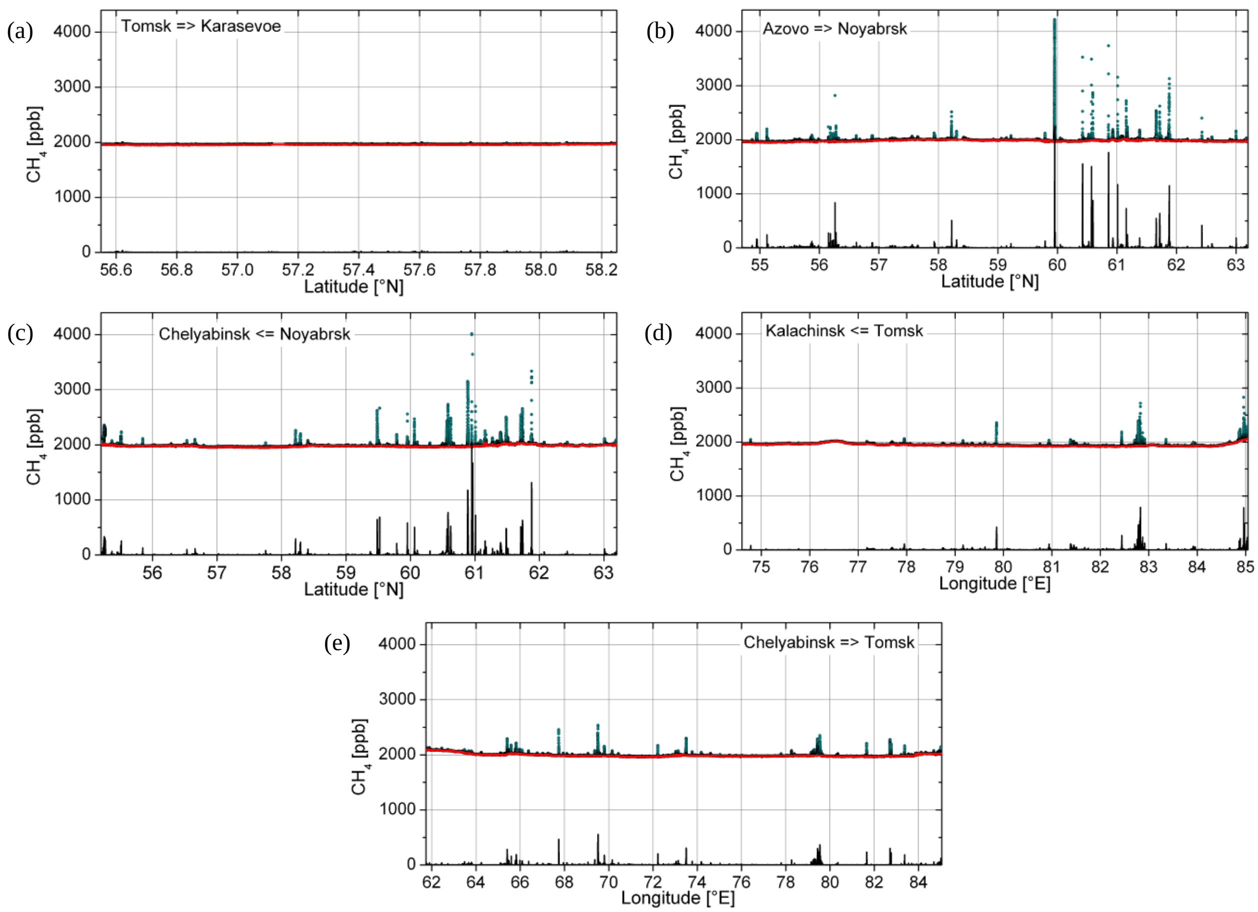

Figure 5. Latitudinal (panels a, b, and c) and longitudinal (panels d and e) distributions of CH_4 across West Siberia: raw data (dark cyan), sectional baselines (red), and excess values (black, $[CH_4]_{excess}$=[$CH_4]_{raw}$ – $[CH_4]_{baseline}$).

4. CONCLUSIONS

The mobile on-road campaign undertaken in West Siberia in late October to early November of 2018 showed that the data obtained with the Picarro G4301 gas concentration analyzer can be useful when analyzing tower data of the JR-STATION network for GHG monitoring.

At the same time, the mobile instrument suite should be augmented with CO analyzer to estimate the traffic emission influence on the tower measurements using the approach proposed by Schmidt et al.[4]

We are planning to continue carrying out mobile on-road measurements to investigate seasonal changes in CO_2 and CH_4 distribution in the study area.

ACKNOWLEDGEMENTS

This work was supported by the Ministry of Science and Higher Education of the Russian Federation under State Contract No 14.613.21.0082 (ID No RFMEFI61317X0082).

REFERENCES

[1] Sasakawa, M., Shimoyama, K., Machida, T., Tsuda, N., Suto, H., Arshinov, M., Davydov, D., Fofonov, A., Krasnov, O., et al., "Continuous measurements of methane from a tower network over Siberia," Tellus B: Chemical and Physical Meteorology 62(5), 403–416 (2010).

[2] Nara, H., Tanimoto, H., Tohjima, Y., Mukai, H., Nojiri, Y., Katsumata, K., Rella, C. W., "Effect of air composition (N_2, O_2, Ar, and H_2O) on CO_2 and CH_4 measurement by wavelength-scanned cavity ring-down spectroscopy: calibration and measurement strategy," Atmospheric Measurement Techniques 5(11), 2689–2701 (2012).

[3] Serdyukov, V. I., Sinitsa, L. N., Lugovskoi, A. A., "Influence of gas humidity on the reflection coefficient of multilayer dielectric mirrors," Applied Optics 55(17), 4763 (2016).

[4] Schmidt, A., Rella, C. W., Göckede, M., Hanson, C., Yang, Z., Law, B. E., "Removing traffic emissions from CO_2 time series measured at a tall tower using mobile measurements and transport modeling," Atmospheric Environment 97, 94–108 (2014).