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Atmospheric composition study based on ship measurements in the Russian Arctic seas in summer 2019.

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Abstract. We present observation results of methane (CH₄), its isotopic signature ($\delta^{13}\text{C}_{\text{CH}_4}$) and carbon dioxide (CO₂) surface concentrations, made aboard the research vessel (R/V) "Akademik Mstislav Keldysh" in the Russian Arctic seas in summer 2019. The main goal of the study is to determine the possible sources of methane. As a result of the study, localized areas with an increased methane concentration (up to 2092 ppb) in the surface layer are identified. It may be related to the advection of water masses rich in organic matter from the Ob and Yenisei Rivers. In addition, increased methane concentrations (up to 2010 ppb) are observed in the Kara Sea near the Yamal Peninsula, where gas deposits are concentrated, and active methane emissions from wetland ecosystems are noted. We conclude that the average concentration of methane in surface air in the Arctic seas is determined mainly by large-scale transport of air masses

1. Introduction

According to the available data, emissions of greenhouse gases have increased the intensity of global warming over recent decades and the strongest increasing of mean temperature is observed in the Arctic. Methane (CH₄) is the second-most-powerful carbon-based greenhouse gas in the atmosphere behind carbon dioxide (CO₂) [1]. It plays a significant role in the cycles of surface ozone and hydroxyl radicals (OH) [2]. Moreover, in recent years, the increase in methane concentration on the Earth as a whole and in the Northern Hemisphere in particular has accelerated markedly: from 4-9 ppb / year in 2010-2013 up to 12-17 ppb / year in 2015-2016 [3].

The methane concentration in the surface layer of the atmosphere in the high latitudes of the Northern Hemisphere is maximal in comparison with other regions of the planet. The distribution of methane over the Arctic is regulated by the distribution of emissions, atmospheric transport and photochemical processes. The photochemical sink in the case of the Arctic is inefficient, especially in the dark period. Due to these processes methane concentration has clear seasonal distributional. Highest level of CH₄ concentration is in the winter. Starting in January, due to the intensification of photochemical sink, the concentration decreases and returns to its minimum values by summer. In this



study, we analyze the methane concentration in the surface layer of the atmosphere in the summer of 2019 based on ship measurements.

2. Discussion

The measurements were made from aboard the R/V "Akademik Mstislav Keldysh" (76th cruise) from 2nd June to 5th August 2019. The R/V route started from the Arkhangelsk port and gone through White, Barents and Kara seas, special attention was paid to estuaries area of Ob and Enisey rivers. Route map is shown at **Figure 1**.

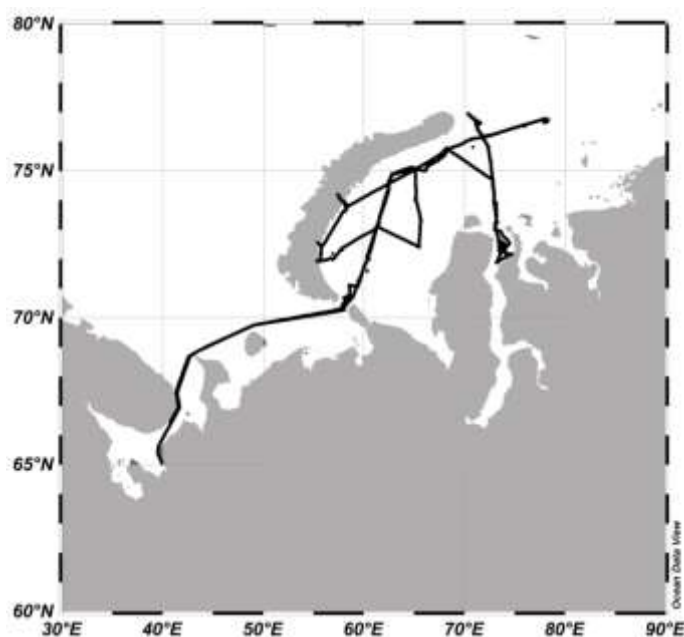


Figure 1. Route of 76th cruise of the R/V “Akademik Mstislav Keldysh”

A Cavity-Ring-Down Spectrometer (CRDS) produced by Picarro Inc., USA (model G2132-i) was used for direct observations of surface air composition: methane, carbon dioxide, water vapor and isotopic signature. Characteristics and installation details are presented in [4, 5]. Obtained data sets have 1-min resolution. Air was sampled from an inlet at the front of the deck at 18.5 meters above sea level. The length of the pipeline was 10 m, and the inner diameter was 3 mm with an air flow rate of about 1,5 litres min⁻¹. Calibration of the G2132-i instrument is described in [5]. Time series of $\delta^{13}\text{C}_{\text{CH}_4}$ and CH_4 are presented on Fig. 2, statistical characteristics are presented on Fig. 3.

Despite the prevailing of high atmospheric pressure field in the study area, a storm conditions was observed in about half the cases, often reaching category of 4-5 (fig.4). Throughout the expedition, the southern direction of the wind dominated (app. 20%), the east and north-east winds are observed significantly rare (totally is about 5% of cases). Thus, most often during the cruise, air masses move from mainland.

In the summer of 2019, abnormal weather conditions developed; an abnormally hot weather was established in Siberia with air temperatures up to 30 °C and above. At this time, the number of forest fires increased, the largest number of which was recorded in the southeast of Eastern Siberia, as well as in the Krasnoyarsk Territory. Microbiological sources have intensified too. In addition, natural gas production areas are an active source. Thus, the transport of air masses from the mainland is a reason to an increase in methane concentration, which is also confirmed by satellite data (fig. 4).

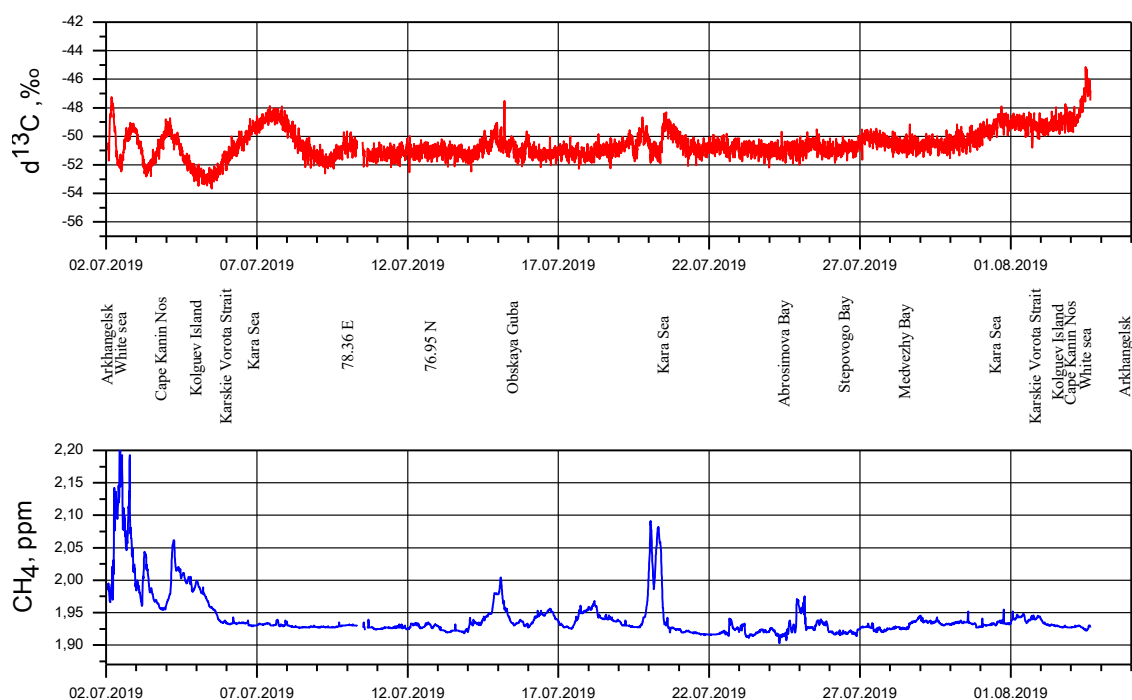


Figure 2. Time series of $\delta^{13}\text{C}_{\text{CH}_4}$ (upper plot) and CH_4 (bottom plot) during 76th cruise of the R/V “Akademik Mstislav Keldysh”.

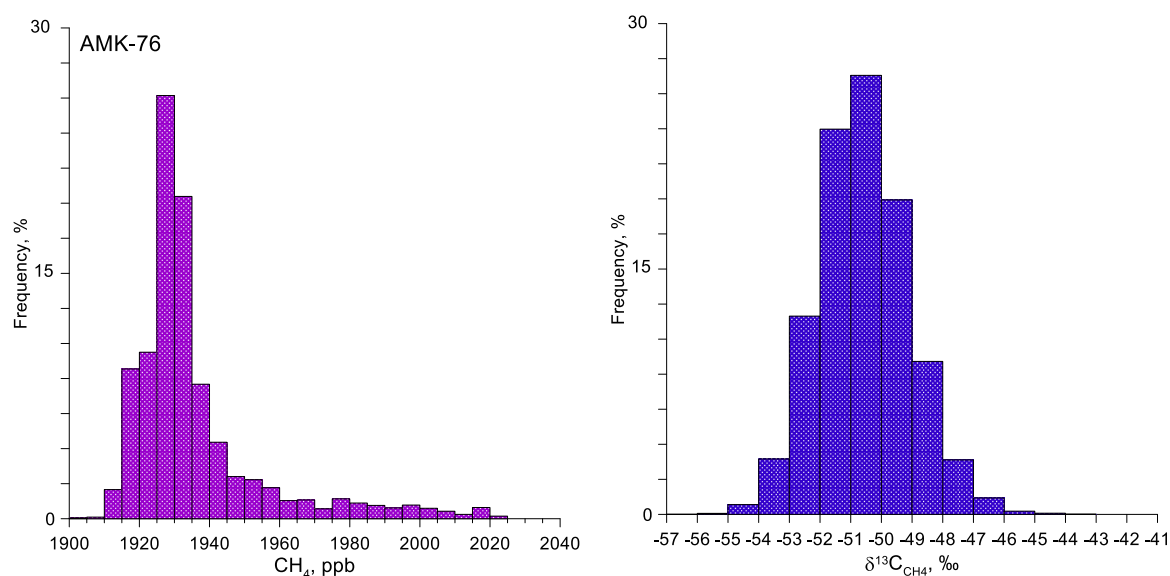


Figure 3. Distributions of the surface concentration and isotopic composition ($\delta^{13}\text{C}_{\text{CH}_4}$) of methane (CH_4) during 76th cruise of the R/V “Akademik Mstislav Keldysh”.

During the cruise, the methane concentration in the surface layer range from 1902 ppb to 2294 ppb. The maximum concentration was observed in the Arkhangelsk port, and is associated with the city and port influence.

Also enhanced methane concentration was observed during passing of the Kara Sea in east direction in the region of Ob Bay. In this case, there was a gradual increase in CH_4 with a maximum of 2005 ppb. It should also be noted that an increase in methane concentration was accompanied by a

decrease in the salinity of surface water (and vice versa), which may indicate the influence of the river flow of the Ob and Yenisei.

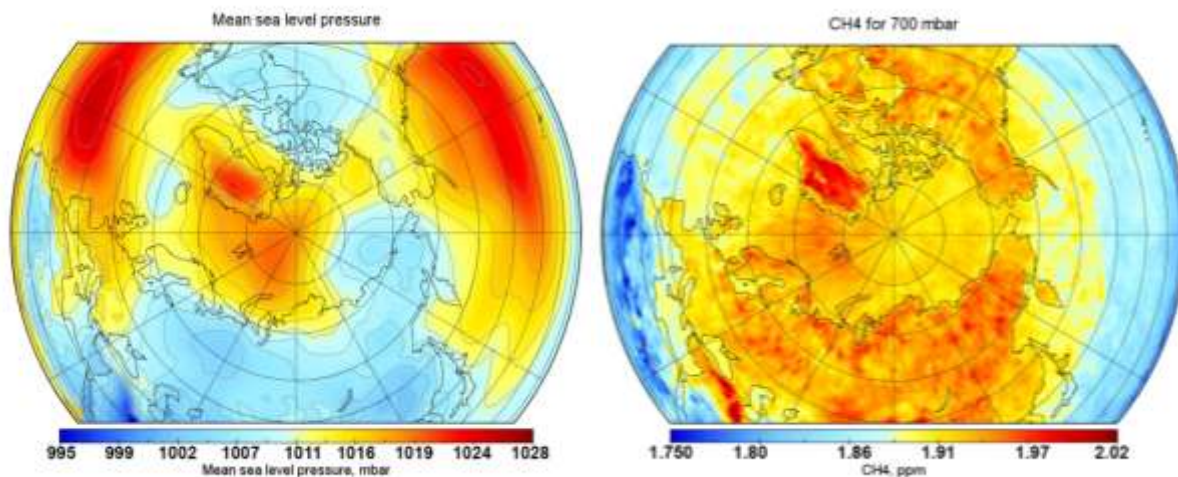


Figure 4. Left plot – mean surface atmospheric pressure (ERA Interim) for July 2019, right plot – mean CH₄ concentration at 700 mbar July 2019 (instrument AIRS [6]).

The maximum values (2092 ppb) of methane in the Kara Sea were recorded west of the Yamal Peninsula on July 20 (Fig. 5). Throughout the time when peak values were noted, the removal of air masses from the mainland was observed. Reduced methane concentrations were generated by advection of air masses from the North Atlantic, with a northwest wind.



Figure 5. Surface concentration of methane (CH₄) on 20 July 2019 and backward trajectory ending at 14:00 UTC on July 20 2019, constructed according to HYSPLIT (<https://www.ready.noaa.gov/>).

It should be noted that the average concentration of methane obtained at the cruise is higher than the global average for this period, while the average concentration of carbon dioxide obtained during the cruise campaign, on the contrary, is lower than the global average for this period.

3. Conclusion

Studies confirm that the spatial distribution of methane concentration in the surface layer above Russian Arctic seas is determined mainly by large-scale air mass transfer processes. In particular, in some areas of the Kara and Barents Seas, methane concentrations increase with the removal of air masses from the mainland, mainly from the gas fields of Yamal and Western Siberia, as well as wetland ecosystems and forest fires. The minimum methane concentration is observed upon advection of air masses from the regions of the North Atlantic.

Localized areas with an increased methane concentration (up to 2092 ppb) in the surface layer were revealed, which is most likely associated with the advection of water masses rich in organic matter from the Ob and Yenisei.

A spread range of $\delta^{13}\text{C}_{\text{CH}_4}$ value indicates mixed characters of methane sources.

Conflict of Interest

The authors declare no conflict of interest.

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