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The need for a year-round satellite monitoring of atmospheric methane over the Arctic Ocean

Leonid Yurganov, University of Maryland Baltimore County, Baltimore, MD, USA
Correspondence: Yurganov@umbc.edu

Arctic warming has implications for seabed emissions of methane (CH_4), important greenhouse gas. In particular, this gas is “sequestered” beneath subsea permafrost – terrestrial permafrost inundated by rising sea level after the Holocene. Also high amounts of CH_4 that seep from oil/gas fields are locked in the Arctic seabed as methane hydrates. A continuous monitoring of CH_4 emission is desperately necessary for elucidation of its sources, prediction of trends, and assessments of influence on the Arctic and global climate. Methane, ocean stratification parameters (e.g., forming pycnocline and its breakdown), and ice concentration should be included into Essential Arctic Variables (EAVs), that are planned to be discussed at the AOS. In what follows some newly published results on correlations between proposed EAVs will be summarized.

Satellite observations are extremely useful for characterization of global CH_4. Short Wave Infrared (SWIR) instruments TROPOMI and GOSAT require solar radiation reflected from the Earth surface. These sounders are ineffective in the Arctic due to low or no sunlight, low reflectivity from water and ice, and long atmospheric optical path (Leifer et al., 2012). Thermal Infrared (TIR) CH_4 sensors use long-wave outgoing radiation and their data are available globally, day and night. TIR orbital sensors include AIRS/Aqua, IASI/MetOp-A,B,C, CrIS/NPP, CrIS/NOAA-20, and GOSAT/TANSO-TIR. The CH_4 measurements for the Arctic supplied by NASA and NOAA were analyzed by Yurganov et al (2016, 2019).

CH_4 retrievals for AIRS and IASI are publicly available. Yurganov et al. (2016) suggested a filtering technique for the Arctic data and presented data on seasonal, spacial and interannual variability of methane in the layer below 4 km. They concluded, "Seasonal increase in methane has been observed since late October - early November. This can be associated with the beginning of vertical convection in the ocean, caused by the cooling of the surface layers and the simultaneous increase in temperature of the underlying water layers. Bottom layers saturated with methane are brought to the surface" (translated from Russian).

A combination of two conditions are necessary and sufficient for a significant flux of CH_4 from sea to air. First, there should be seabed or seawater CH_4 sources. Second, there should be an effective transport of CH_4 from the sources to the surface seawater layer. A significant emission of CH_4 from

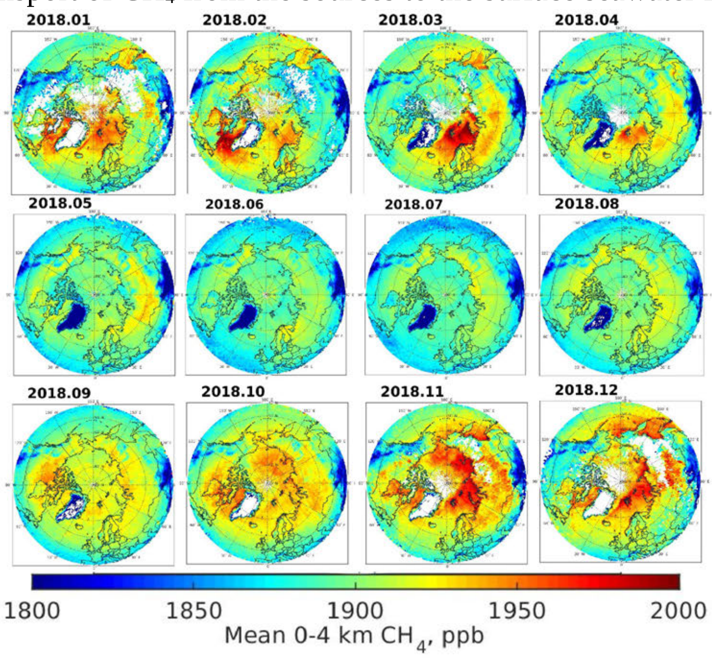

Figure 1 *Monthly mean LT IASI CH4 concentrations in 2018.*

the seafloor to deep water layers around Svalbard and along a path Svalbard -- Bear Isl. has been documented by direct samplings. All these results show negligible CH_4 flux: they were obtained in summer months or in September, i.e., before a breakdown of the pycnocline. Gentz et al. (2014) and Myhre et al. (2016) predict a much higher methane flux in winter, when a transport by an intense turbulent diffusion and convection occurs. Monthly mean maps of IASI Low Tropospheric CH_4 (Figure 1) demonstrate a surprisingly spatially homogeneous CH_4 distribution over the entire Arctic Ocean between May and September (Yurganov et al., 2019). This is in contrast to the heterogeneity observed beginning in October: enhanced methane is observed over Arctic seas. Yurganov et al. (2019) have found a good agreement between methane monthly anomalies measured by AIRS and IASI sounders and Mixed Layer Depth (MLD), Figure 2. On the same graph monthly mean Sea Surface Temperature (SST) are plotted. The variations of SST are found to be out of phase with MLD: in autumn-winter, after breakdown of stratification, cooler and CH_4-richer seawater replaces the summer warmer and fresher seawater.

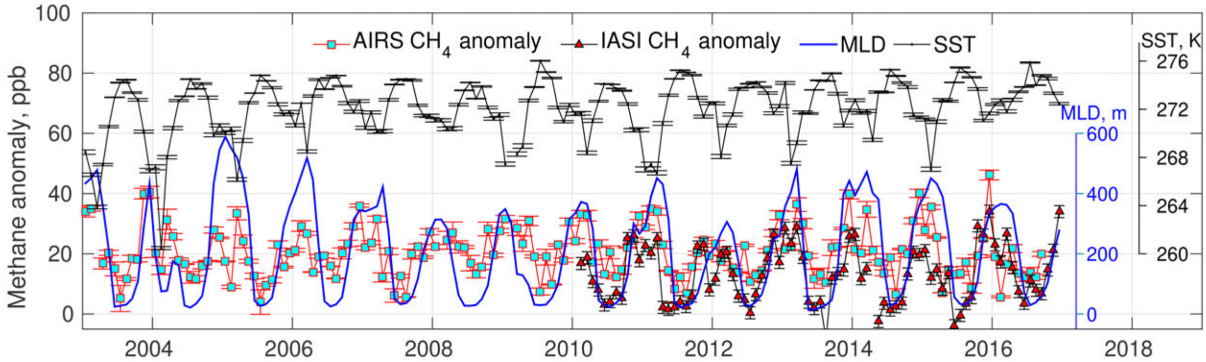

Figure 2 *CH_4 monthly anomalies: LT concentration differences between box to the South West of Svalbard and a box near Iceland according to AIRS and IASI measurements. Blue line is smoothed daily MLD calculated for the box to the South West of Svalbard (accuracy ± 20 m). Also shown are monthly mean SST for the box to the South West of Svalbard.*

Preliminarily, Yurganov et al. (2016) assessed the annual emission of methane from the Arctic Ocean in 2010-2014 as ~ 2/3 of land emission to the North from 60° N. Arctic terrestrial emission is now estimated as 20-30 Tg year^{-1} (AMAP, 2015). Therefore, total marine CH_4 flux from the Arctic can be expected in the range 15-20 Tg CH_4 year^{-1} (without the Sea of Okhotsk and Bering Sea). To our opinion, the Arctic Ocean contribution into the CH_4 global budget should be re-assessed.

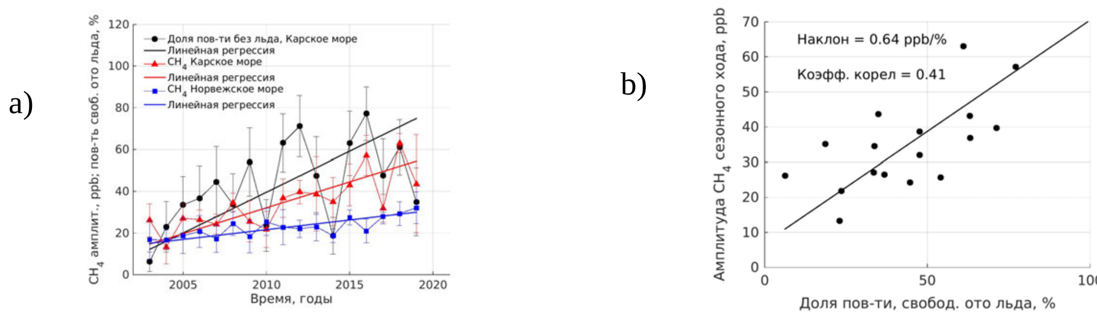

Figure 3. *(a) Methane seasonal cycle amplitude over North Kara Sea (Red) grows with years in compliance with growing percent fraction of the open water (100% - ice concentration) shown in black. Blue is methane amplitude over Norwegian Sea (ice free). (b) Correlation between fraction of water surface (x-axix) and methane amplitude (y-axis).*

Another point is a trend of CH_4 seasonal cycle amplitude (Yurganov, 2020). The amplitude of CH_4 seasonal cycle (SC) was growing for North Kara sea, but almost stable in a control area (near Iceland). This maybe interpreted as a result of changes in methane flux, that should be proportional to the area of the ice-free surface. These data, however, need a careful verification by in situ observations.

Recommendations. The experimental and modeling efforts to quantify CH_4 emission from the Arctic Ocean should be intensified.

1. First, retrieval algorithms, taking into account the Arctic specific conditions should be developed and/or existing retrieval algorithms should be evaluated for the Arctic.
2. Direct in situ measurements of CH_4 emission from the Arctic seas after a breakdown of the pycnocline have to be implemented in conjunction with satellite data.
3. Inverse model efforts for estimating CH_4 emission should take into account satellite data.

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