AIRS and IASI Arctic data: CH₄ seasonal cycle and growing amplitude over sea

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Acknowledgments to Frank Muller-Karger (USF) and Ira Leifer (BRI)
1. Methane ($\text{CH}_4$) is a greenhouse gas

2. Arctic is warming

3. $\text{CH}_4$ sources are temperature-dependant

4. SWIR (NIR) sounders, like TROPOMI, need Sun light and have low S/N over water and ice. They are inefficient in the Arctic.

5. Data for TIR sounders (AIRS, IASI, etc) are available 24/7 and year-round for 0-4 km layer, **BUT** require high temperature contrast.

6. We use AIRS v6 L3 (IR only) and NUCAPS IASI L2 from the CLASS NOAA site.

7. Maximum emission of CH4 occurs in winter and this emission depends on ice concentration

   Currently emission from the Arctic seas in models and budgets is counted as **ZERO**!
Validation of IASI and AIRS vs NOAA flights at three sites

RED is for mid-upper troposphere >4 km; slopes ~ 1.0
BLUE is for lower troposphere <4 km; slopes 0.4 – 0.5

Slope = sensitivity: response of retrieval to a unit change in real concentration.
Retrieved changes in CH$_4$ for 0-4 km are underestimated.
Presently CH₄ emission from Arctic seas is estimated as negligible. Example CH₄ emissions from currently available models and inventories.
IASI data (2010-2014) imply flux that is comparable with that from land. West Siberia lowland (WSL) was assumed to emit 22 Tg/yr. WSL CH4 anomaly referenced to N. Atlantic was used to scale the map in flux units: mg/m²/day.

CH₄ emissions from various models and inventories.

IASI and CH4_INV are top-down, others are bottom-up. More information see http://transcom.project.asu.edu/pdf/transcom/T4.methane.protocol_v7.pdf
Methane is emitted from the seabed and dissolves in water. In summer the ocean is highly stratified and dissolved gas cannot reach the atmosphere. Methanotrophic bacteria consume this methane. In November the pycnocline breaks down and methane enters the atmosphere if the surface is not ice-covered. This methane may be detected by TIR instruments only, SWIR sensors are idle in polar night.
"Widespread methane seepage along the continental margin off Svalbard - from Bjørnøya to Kongsfjorden" by Mau et al. (2017)


In summer the pycnocline prevents CH₄ entering sea surface. The flux to atmosphere is close to zero. TIR satellite sensors are able to compare atmospheric methane in summer and in winter.
Monthly mean 0-4 km CH$_4$ in ppb retrieved from IASI data, 2018

FILTER: Thermal Contrast ThC >10° C, ThC = SST – T(600 hPa)

Areas with depths 300-500 m, where hydrates are stable

Homogeneous field of methane between May and August

Anomalies between January and April

Anomalies between October and December
Blue line is Mixed Layer Depth, calculated for the Box #1 from a global ocean circulation model ECCO-2.

“Methane Low Tropospheric anomaly” is a difference in concentration between Box #1 (near Spitsbergen) and boxes #2 (near Iceland). The higher mixing, the higher methane.
Change in ice-free winter sea surface from 2003 to 2018 and change in methane, Nov.-Dec.-Jan. season

Focus domain in Kara Sea

Ice-free fraction, 2003/2004

Ice-free fraction, 2018/2019

Ice-free 2018/19 minus 2003/04

Control domain in Norwegian Sea

Methane 2018/19 minus 2003/04
Change $\text{CH}_4$ amplitude (winter minus summer) over Kara Sea and change in ice-free fraction

Open water fraction for November-April season, Russian shelf

- Percentage of open water increases over time.
- 50% open water is reached in 2020.
- 100% open water is projected around 2050.
Conclusions

1. AIRS v6 and IASI NUCAPS indicate a significant methane anomaly over the Arctic Ocean in a period between November and April. The timings of anomaly and good water column mixing coincide. The pycnocline plays a role of a barrier for methane in summer.

2. The amplitude of CH$_4$ seasonal cycle over the Kara sea grows with years. The most reasonable explanation is increasing ice-free sea surface. Methane growth over other Arctic seas is expected as ice decay there occurs.

3. Progressing ice cover decline, surface warming and methane growth may be in a positive feed-back loop. This effect should be included in modeling the Arctic Amplification.