

# Wintertime Methane Emission From the Barents and Kara Seas and Sea of Okhotsk: Satellite Evidence.

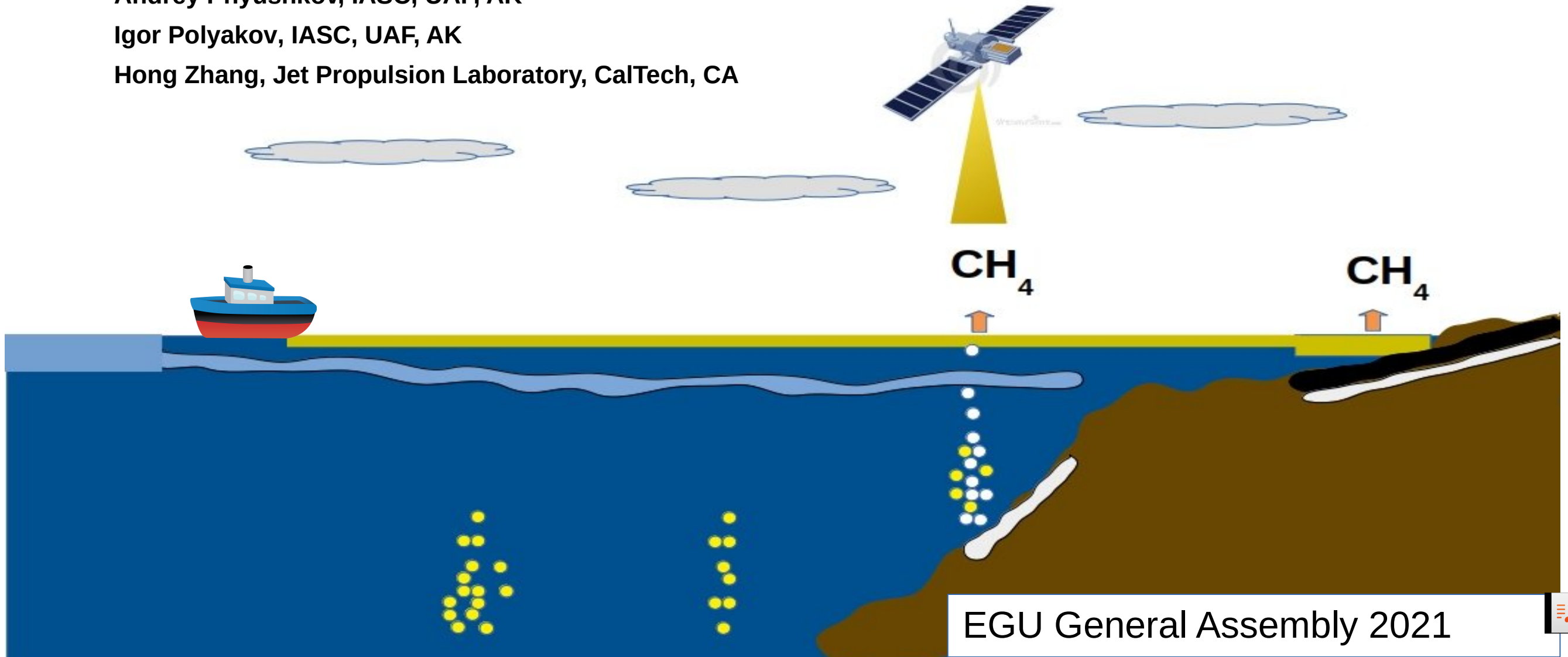
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## OUTLINE

**Methods.**

**Necessary information about methane sources.**

**Available data on dissolved methane from direct measurements.**

**Satellite results.**

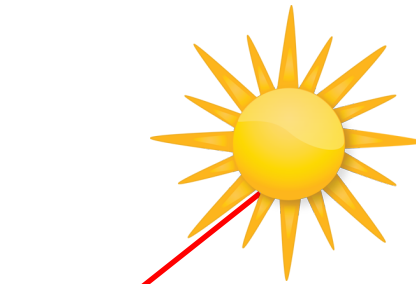
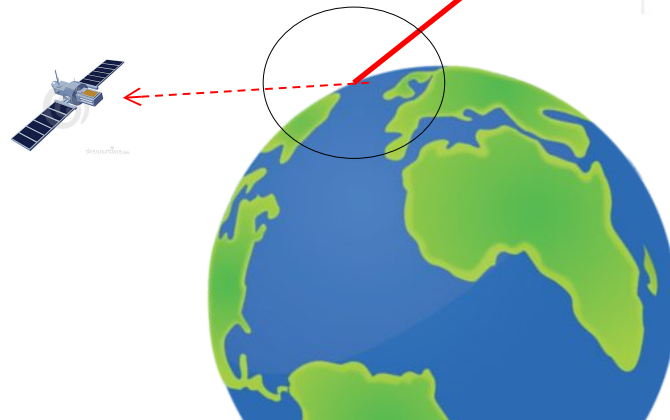
[Yurganov et al., “Ocean stratification and sea-ice cover in Barents and Kara seas modulate sea-air methane flux: satellite data”, (2021), submitted to APS].



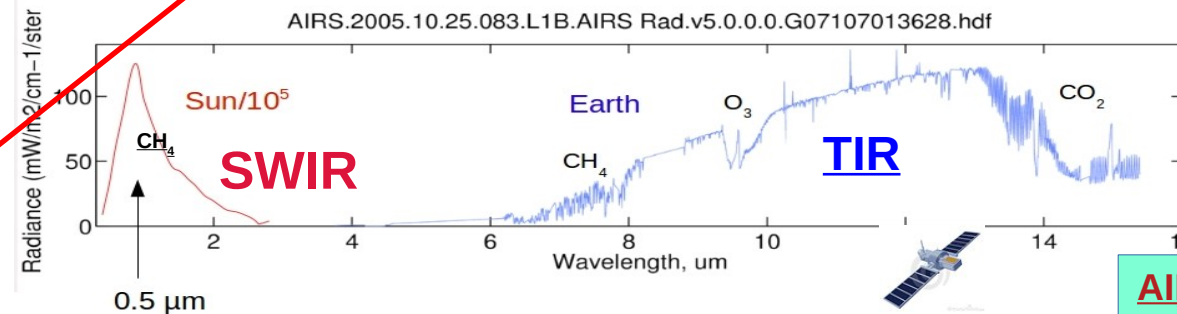
# Satellites measure radiation: incoming Solar (Short-Wave IR, SWIR ) or outgoing Earth Thermal IR (TIR)

OMI, SCIAMACHY, OMPS,  
TROPOMI, OCO, etc

**SWIR sensors have problems in the Arctic: low angles, low reflectivity, polar night.**



Schematic distribution of energy in spectra of the Sun and the Earth



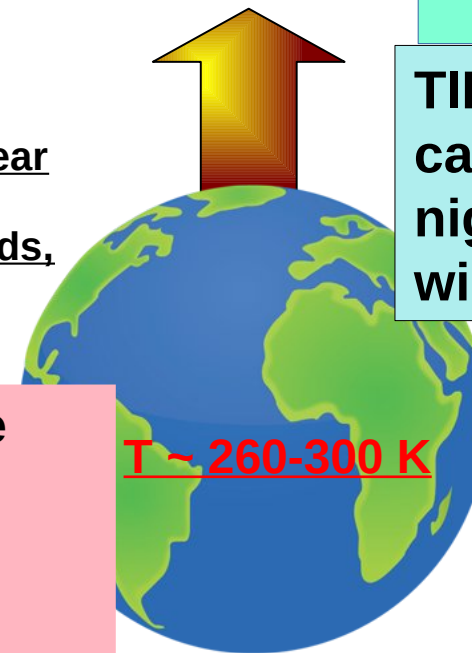
AIRS, IASI, CrIS, etc

**TIR sensors are capable to work day & night, summer & winter, sea & land**

Solar radiance has a maximum near  $\lambda \sim 0.5 \mu\text{m}$  (500 nm), and it is attenuated by scattering, clouds, aerosol, gases, etc

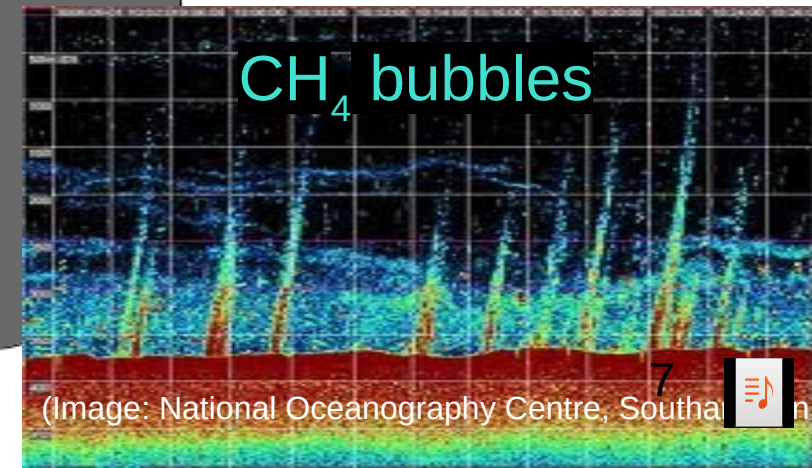
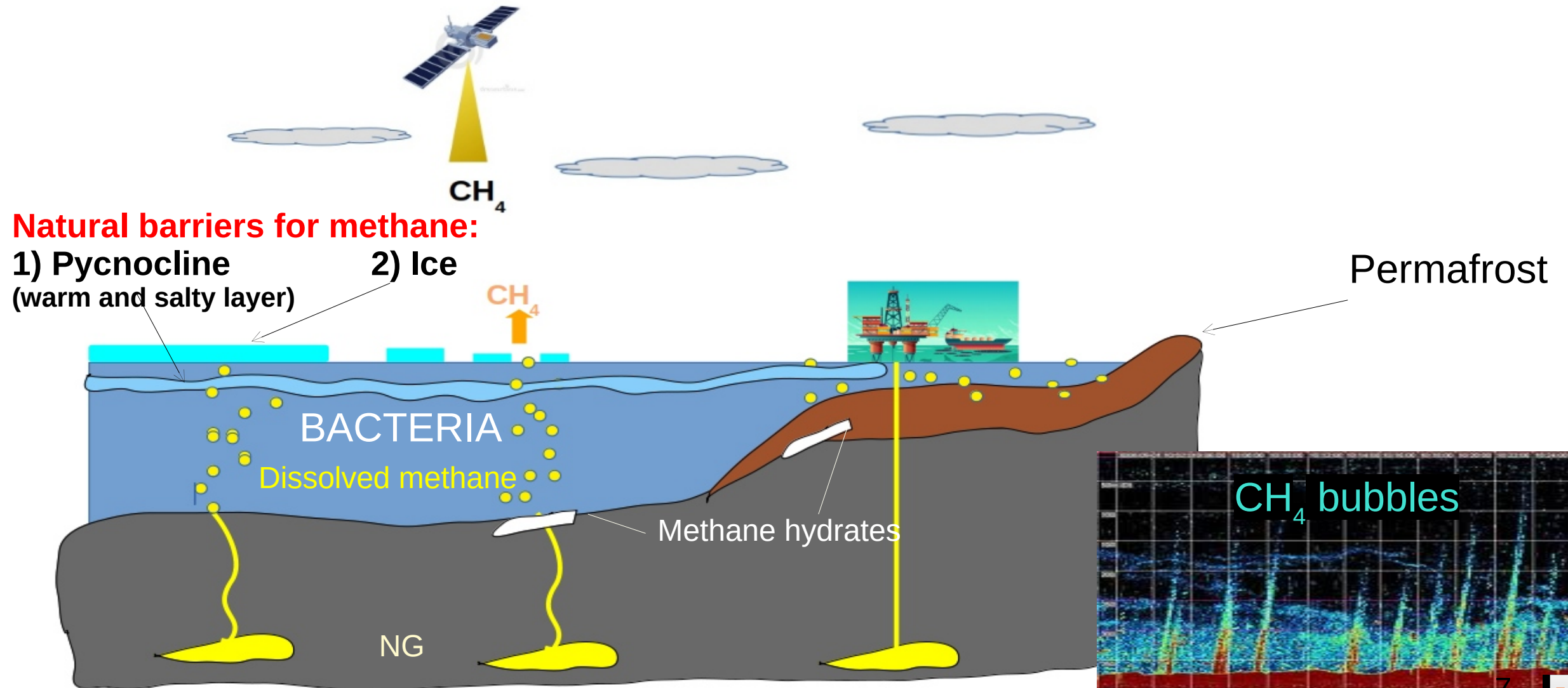
**SWIR is unusable in the Arctic. TIR can be used over water or thin ice. Though, sensitivity to low troposphere is reduced, their data are underestimated and a correction is necessary.**

**$T \sim 260-300 \text{ K}$**



## Arctic methane in Barents/Kara seas: sources, sinks and transport.

Methane is emitted from the seabed and rapidly dissolves in water. In summer the ocean is highly stratified and dissolved gas can not reach the atmosphere. Methanotrophic bacteria consume 90% of this methane. In November the pycnocline breaks down and methane can enter the atmosphere. Sea ice is another barrier for methane in winter.



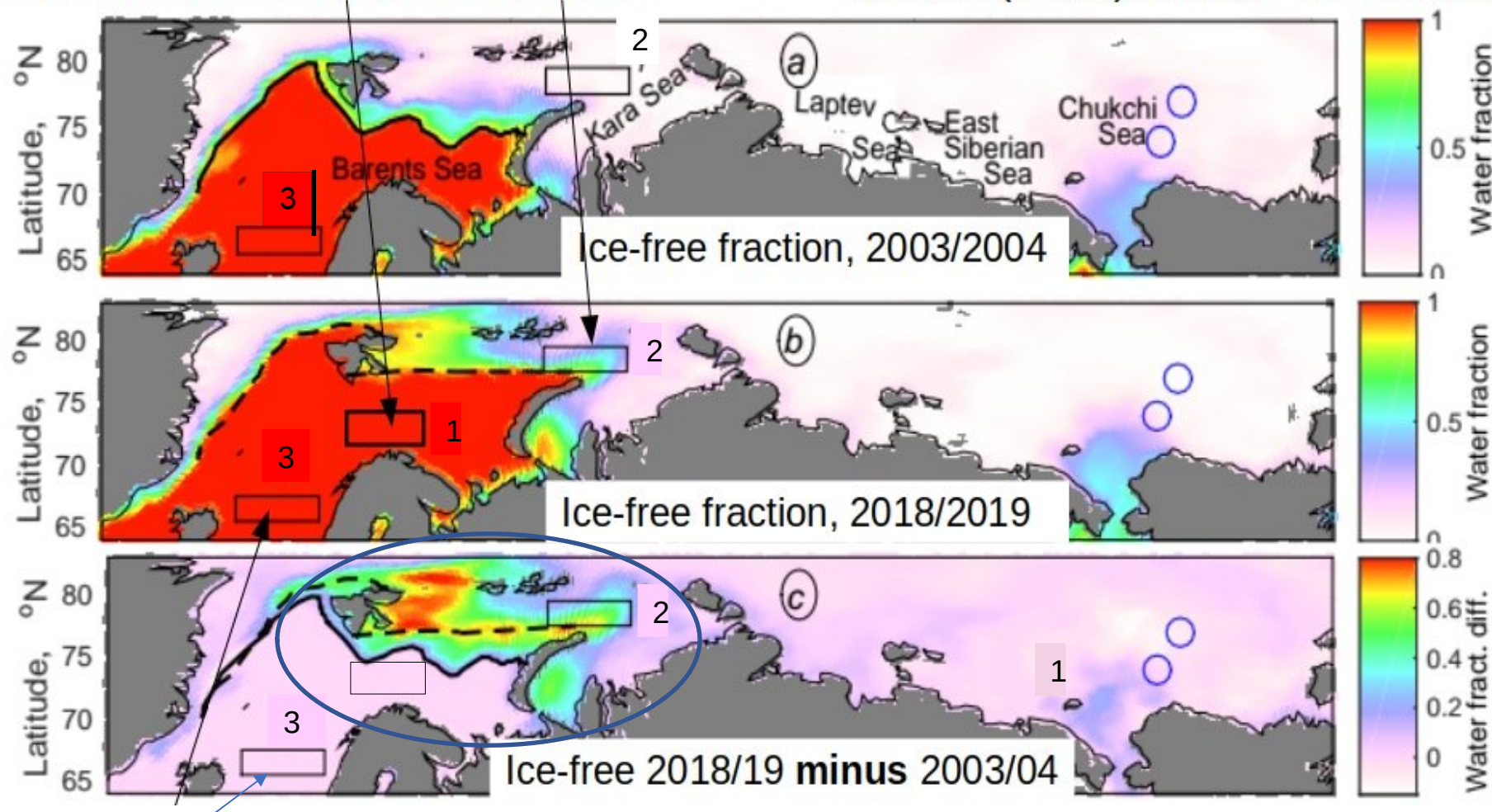
## Geography. Arctic sea ice in early winter.

Change in ice-free **winter** sea surface from 2003 to 2018

November-December-January season

Focus domains in Barents and Kara

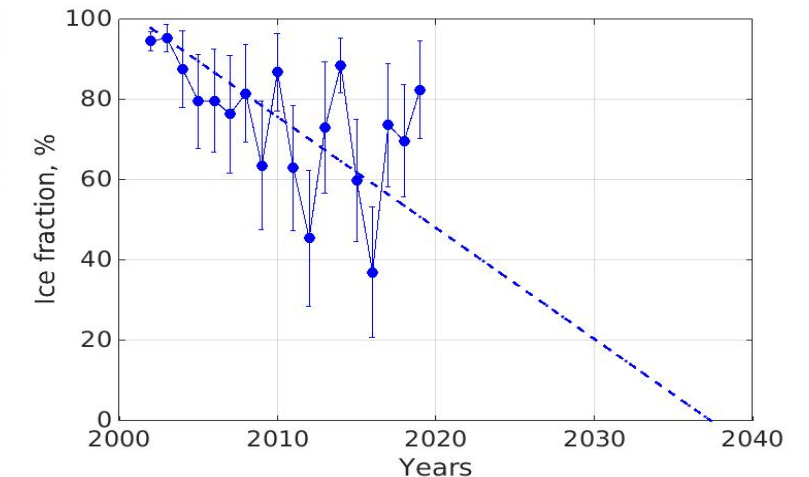
Ice-free (Water) fraction = 1 – ice fraction



Control domain in Norwegian Sea

[Yurganov, 2020]

**Ice fraction  
(concentration).  
Box #2, Kara Sea**

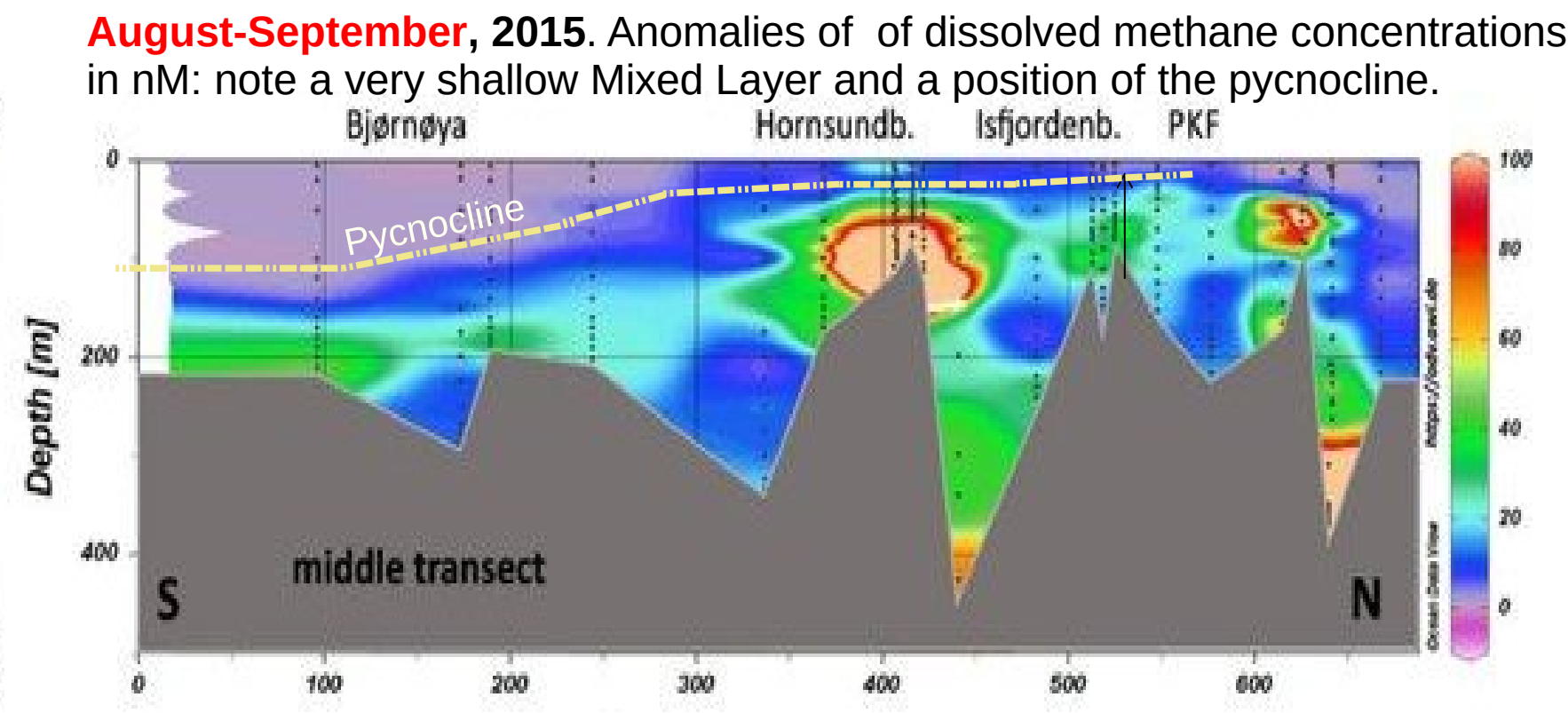


The winter-time ice in the northern Barents and Kara seas (BKS) unprecedentedly declined since 2002. Central/southern Barents Sea is free of ice year round permanently.

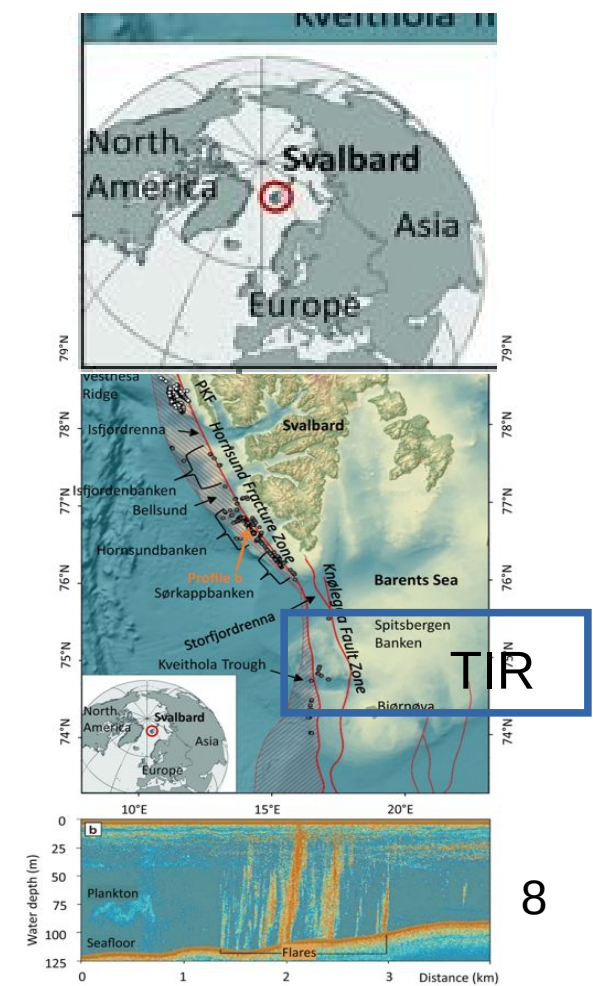


# Available direct samplings of dissolved methane

There are lots of measurements of dissolved methane, all of them are carried out in summer. This is an example: *“Widespread methane seepage along the continental margin off Svalbard - from Bjørnøya to Kongsfjorden”* by Mau et al. (2017)



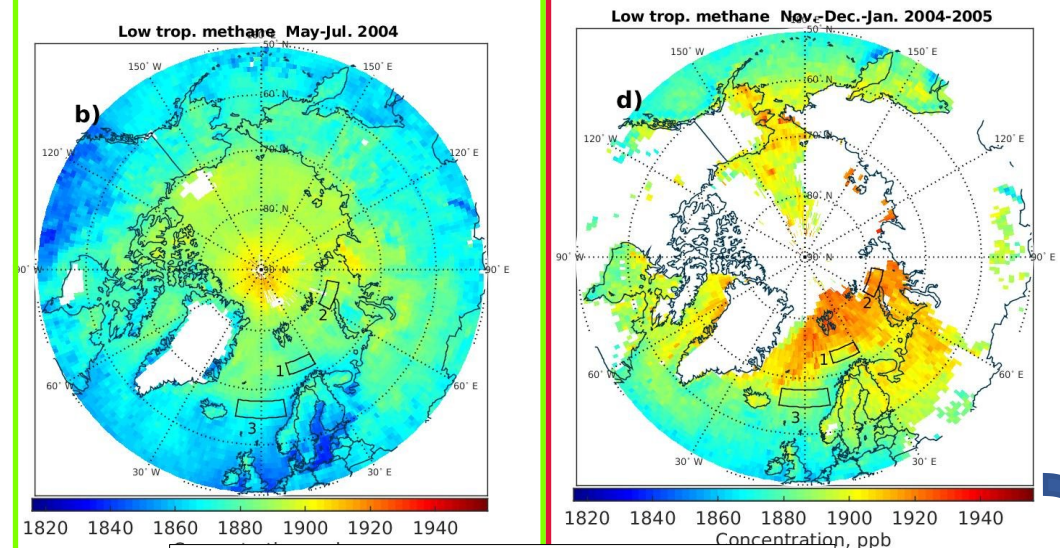
In summer the pycnocline prevents CH<sub>4</sub> entering sea surface. The flux to atmosphere is close to zero. TIR satellite sensors are able to compare atmospheric methane in summer and in winter.



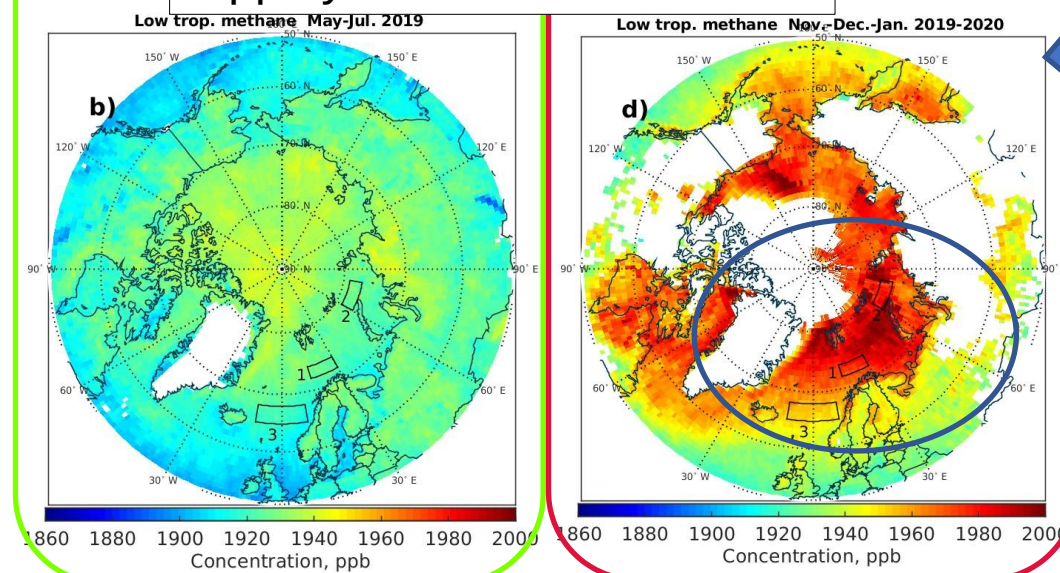
AIRS CH<sub>4</sub> 0-4 km concentrations for  
two seasons, observed 15 years apart:  
in 2004 and 2019

Summer (May-Jul)

Winter (Nov-Jan)



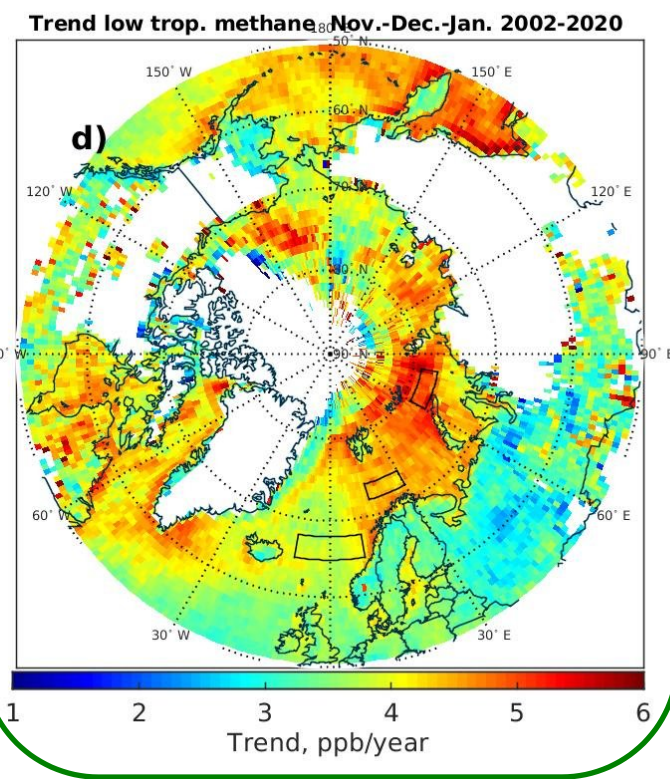
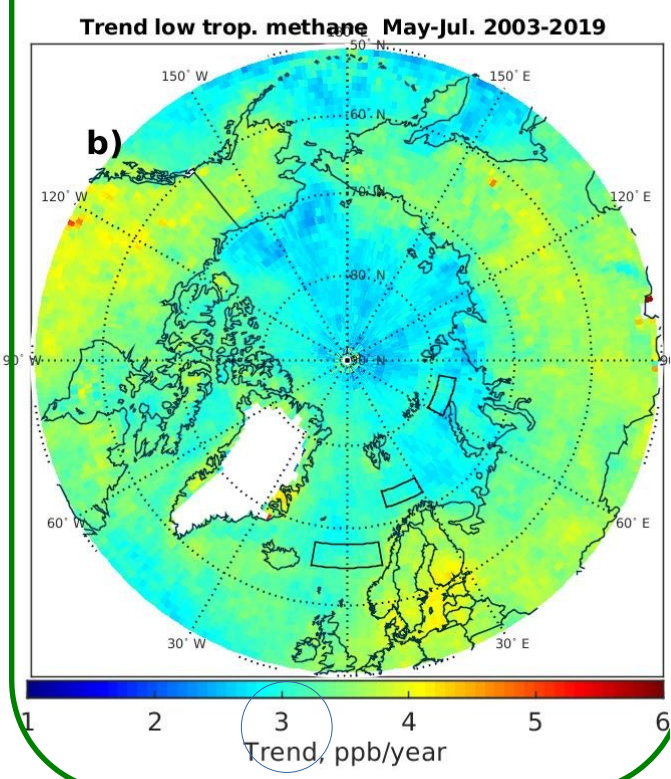
3 ppb/year trend accounted



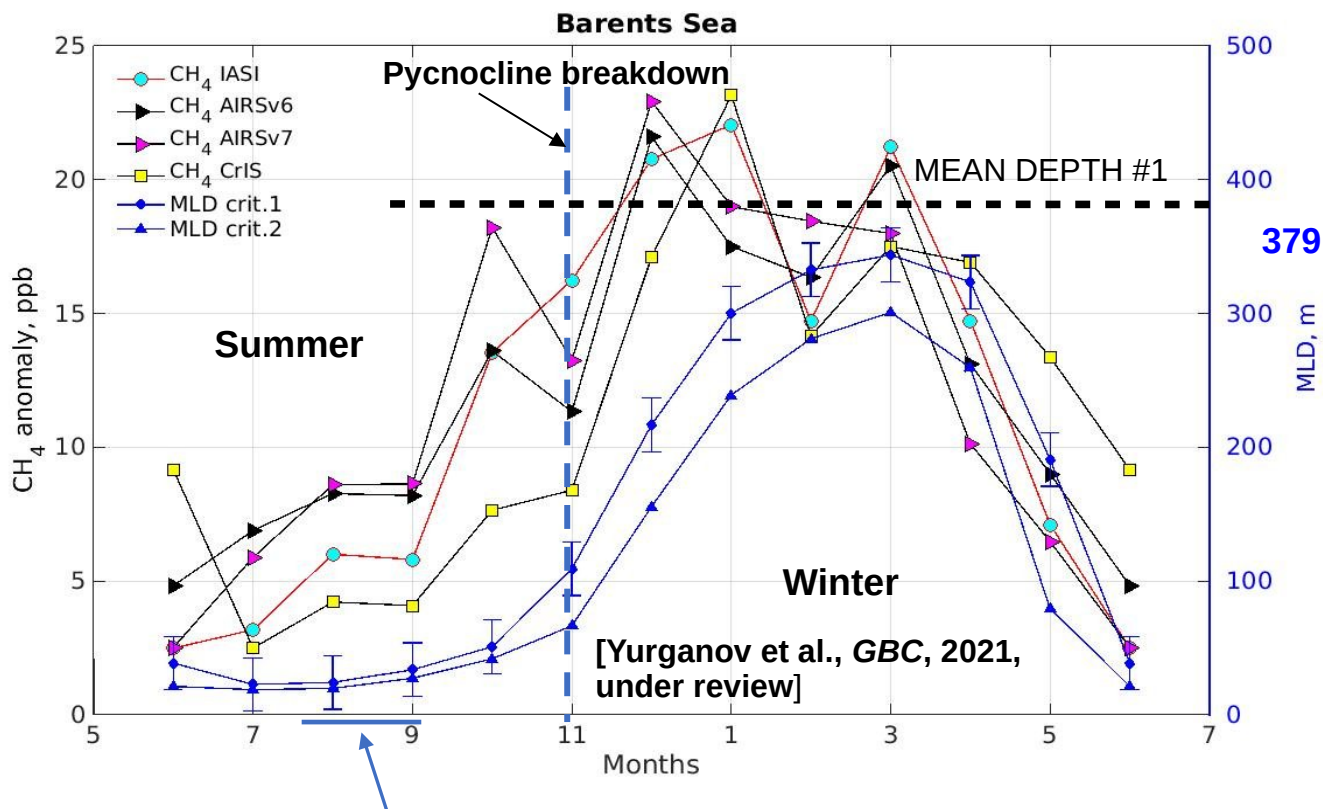
CH<sub>4</sub> linear trends for 2003-2020  
in ppb/year

Summer (May-Jul)

Winter (Nov-Jan)

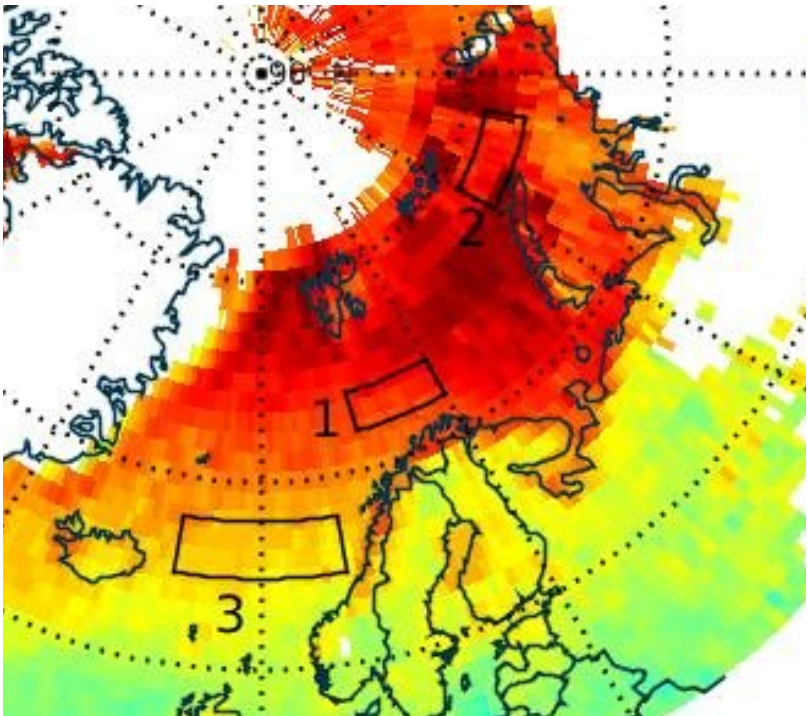
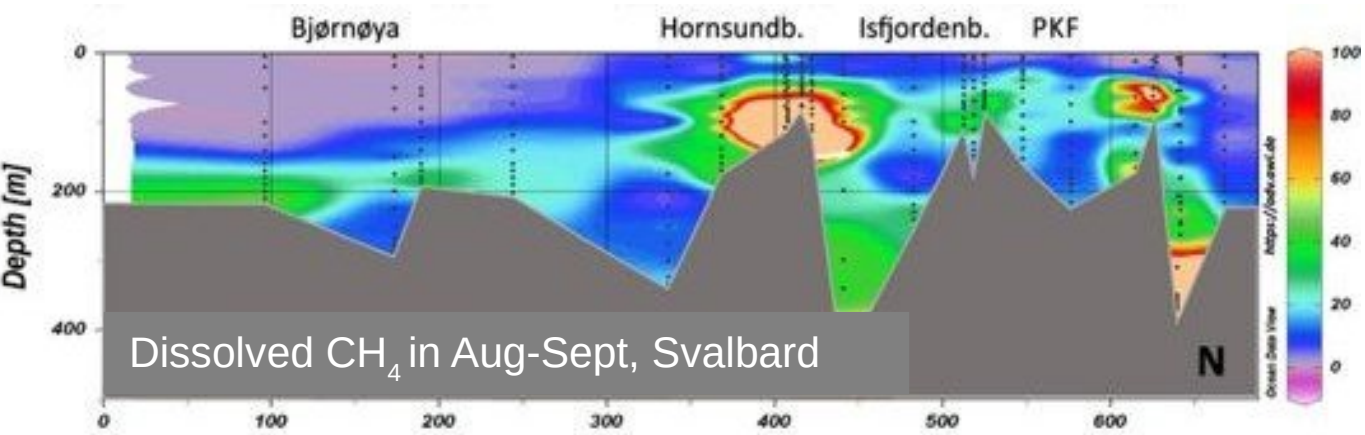


# Methane over Barents Sea, retrieved from 3 sounders and averaged for 2015-2020. Comparison with Mixed Layer Depth.



MLD was calculated from ECCO global circulation model

Monthly mean Box 1 CH<sub>4</sub> excess over deep ocean Box 3. The boxes are located in ice-free areas of the Barents and Norwegian Seas. Mixed Layer Depth is for Box 1.

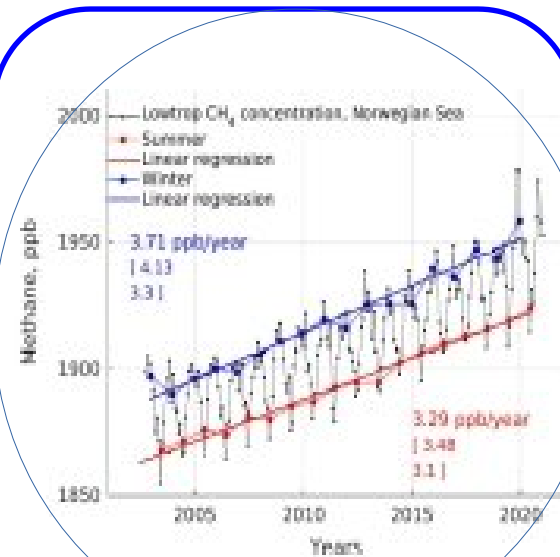


CH<sub>4</sub> anomaly and MLD both maximize in winter

# Methane trend in 3 boxes: two open water and one discontinuous ice, AIRS: 2002 – 2020, IASI: 2010-2020

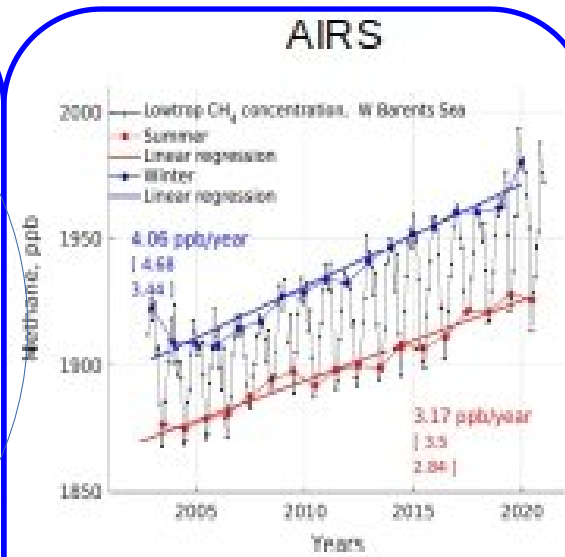
Water surface

Norweg. Sea



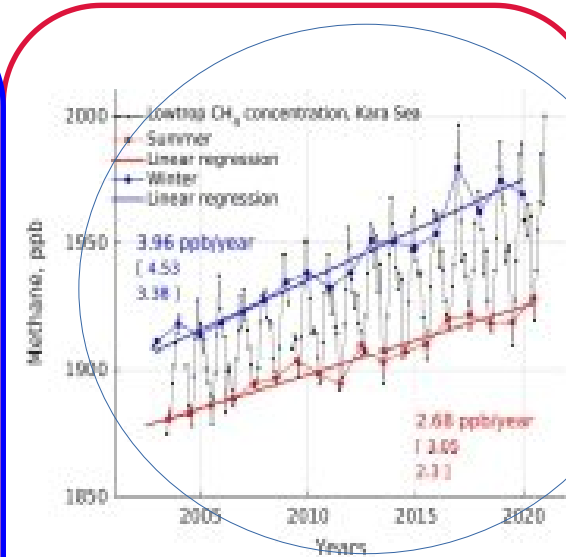
Water surface

Barents Sea

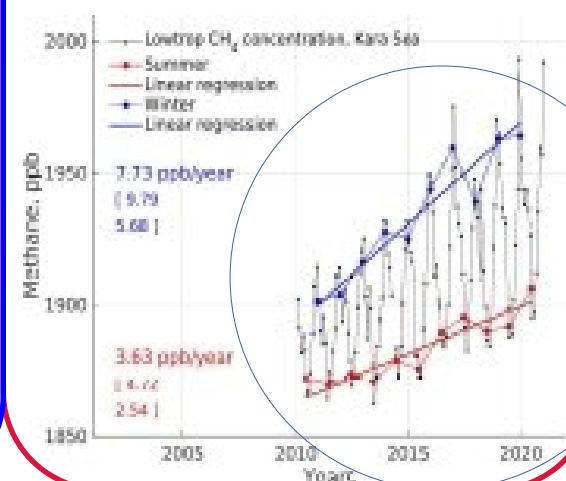
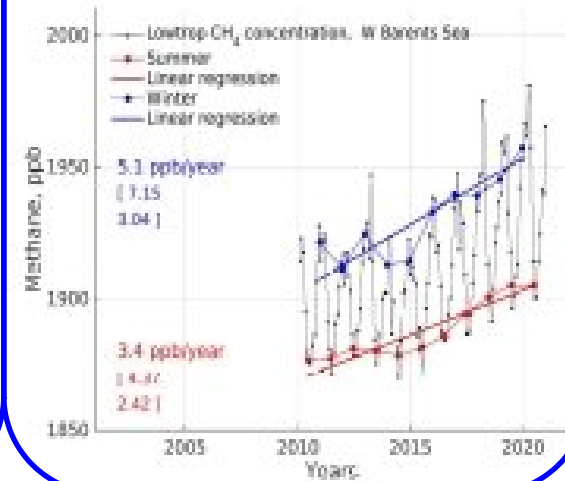
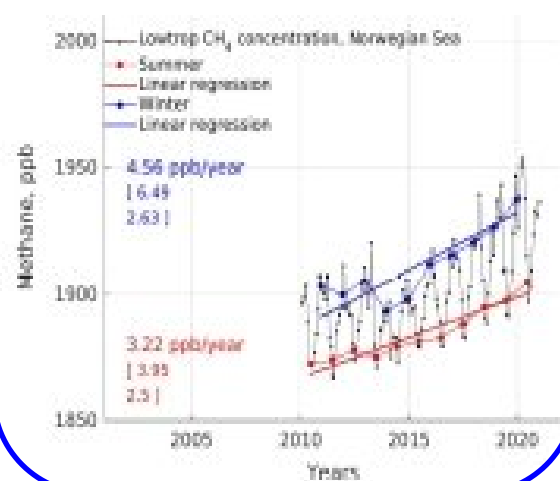


Ice surface

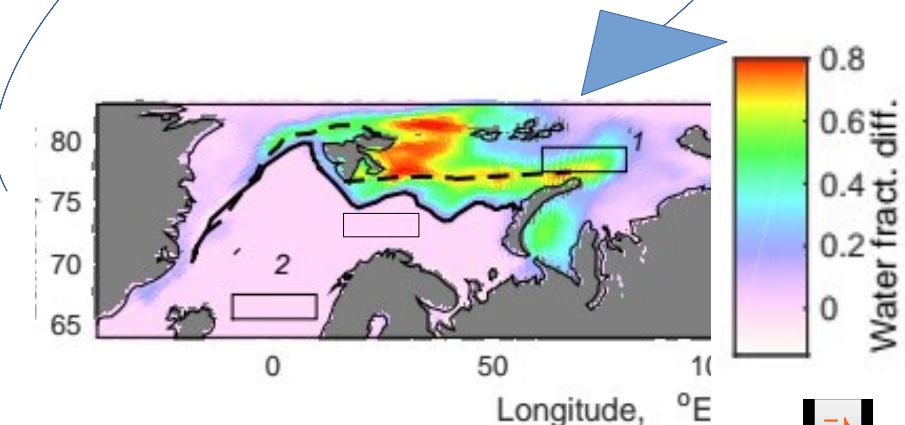
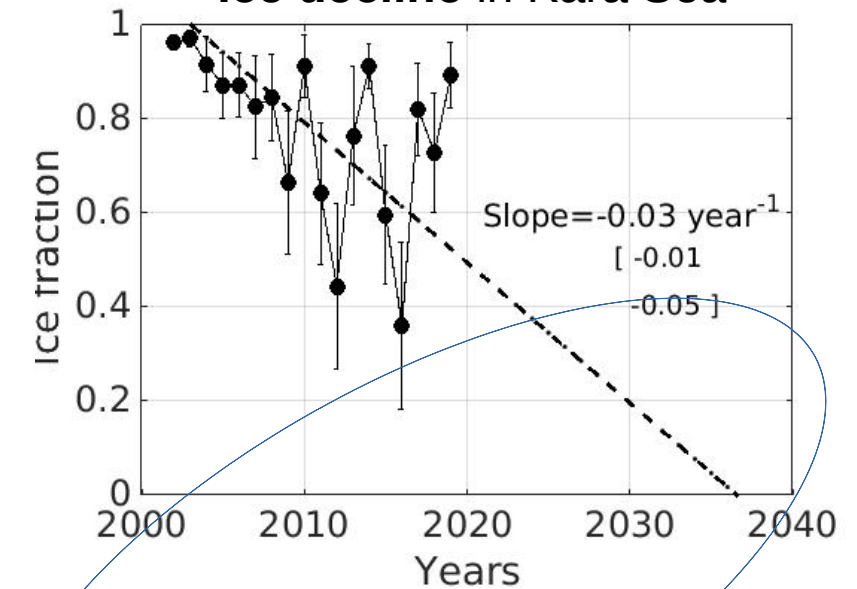
Kara Sea



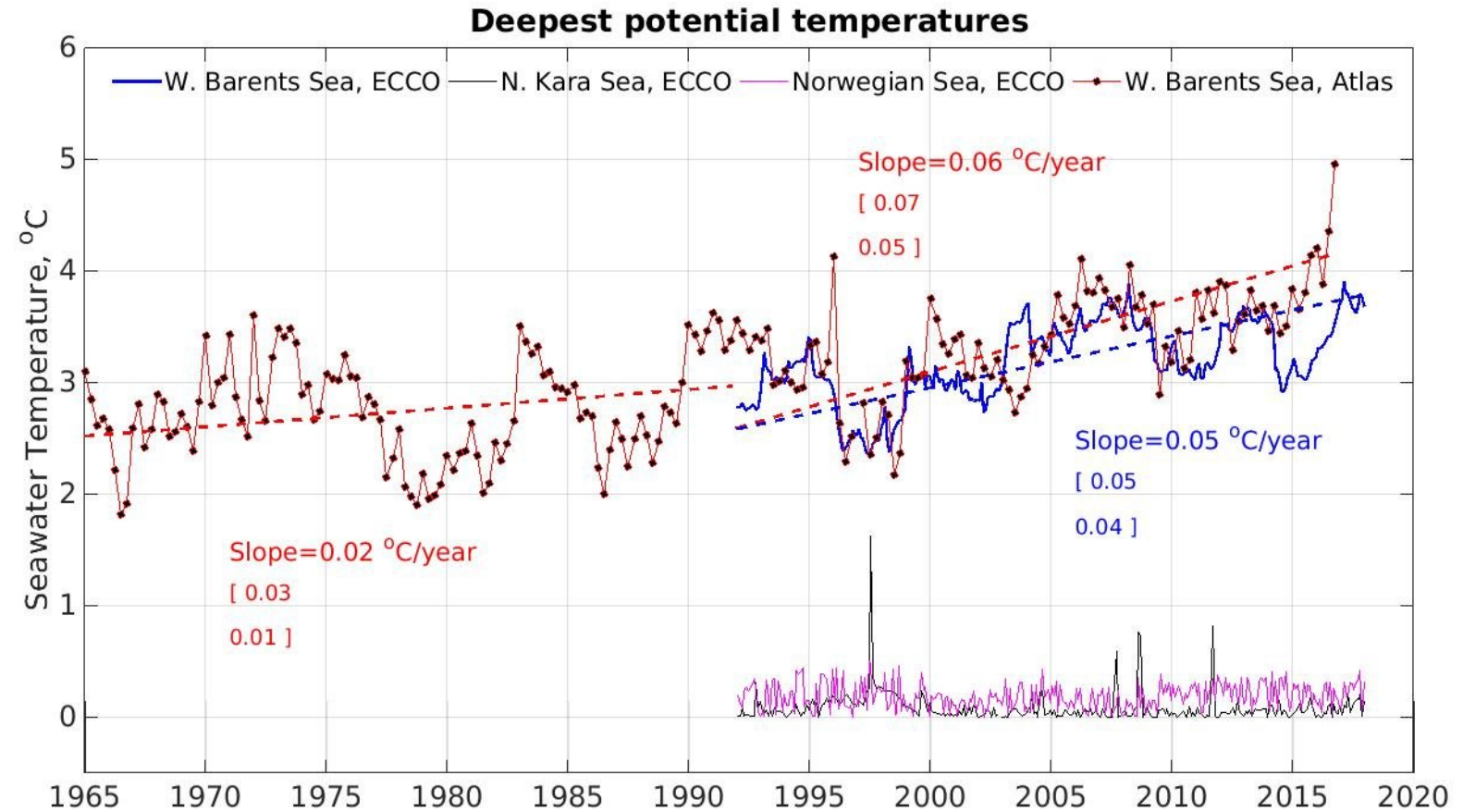
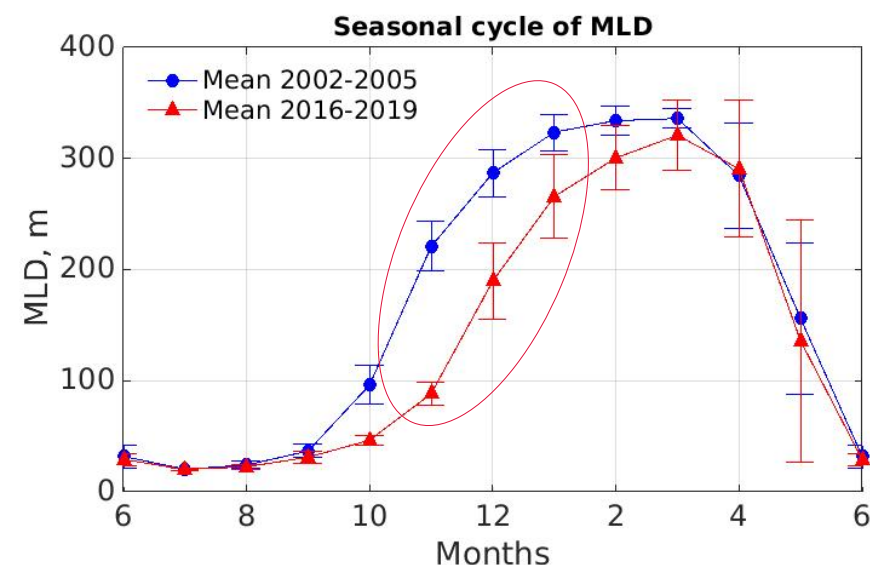
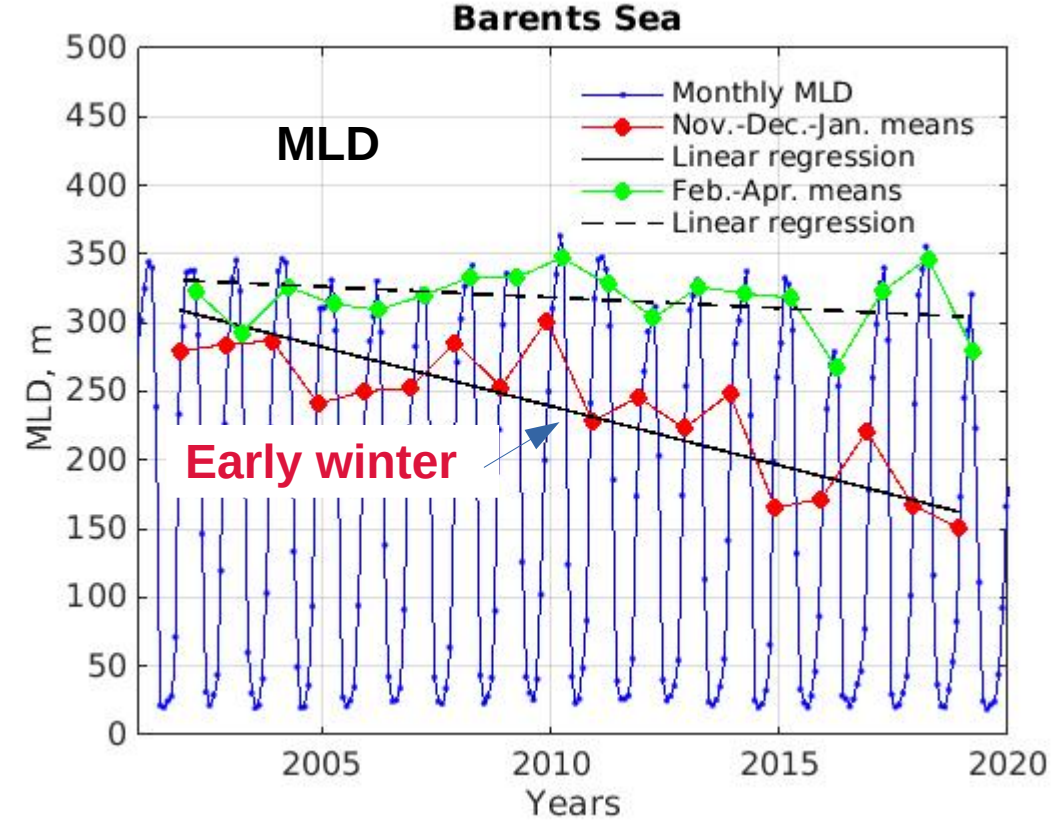
IASI



Ice decline in Kara Sea

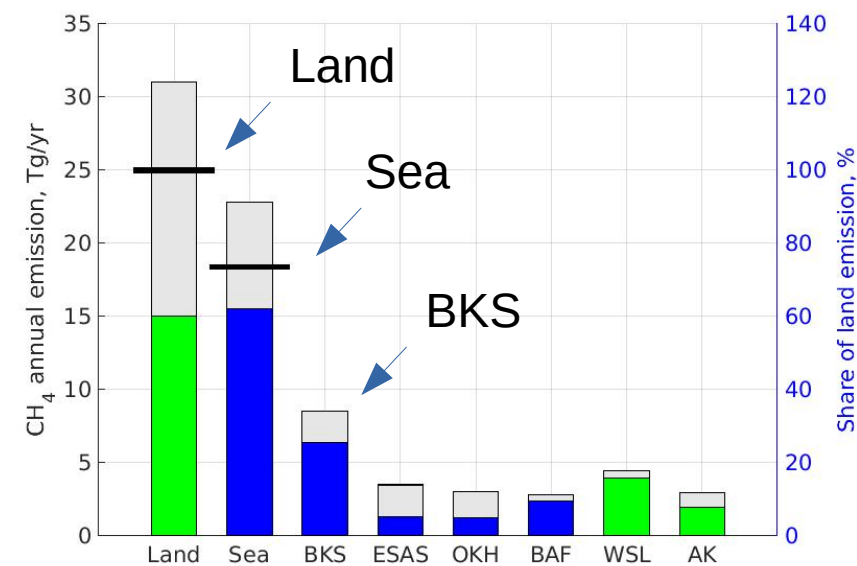
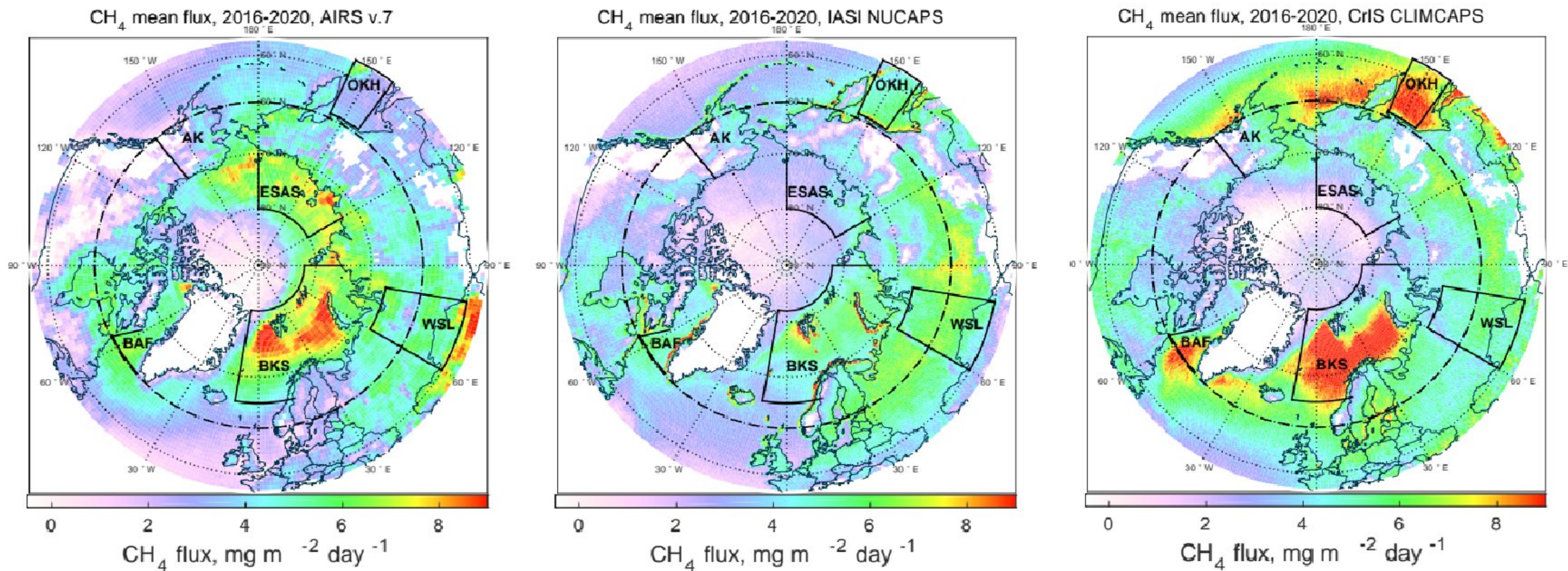


# Trends in mixing intensity (MLD) and near-bottom temperature in Barents Sea



**Mixing intensity (MLD) diminished and near-bottom temperature increased during last 20 years. These effects impact methane emission in different directions.**

# ESTIMATES OF ANNUAL METHANE EMISSION FROM THE ARCTIC IN 2016-2020



**Preliminarily, we estimate total methane emission from the Arctic seas as ~ 2/3 of emission from the Arctic land. Barents/Kara seas contribute up to half to the marine emission.**

## So, what do we have in the bottom line?

- 1) Most of methane emission from BKS **occurs in winter** after the breakdown of the pycnocline.
- 2) **Does the winter flux grow with years?** In the **northern Kara Sea (and the northern Barents Sea)** the methane **seasonal amplitude did increase** since the beginning of the century. **A decline of sea ice cover** is the most likely explanation of that.
- 3) The  $\text{CH}_4$  amplitude in the **Barents Sea** increased just slightly. The temperature of seawater increased, but mixing of water column weakened. It may be speculated that **a growth of methane sources was offset by a lengthening of the stratification period**.
- 4) The Arctic Ocean is responsible for **~2/3 of the land emission** and the Barents/Kara area is the main player.

