Royal Netherlands Institute for Sea Research

Temporal water column dynamics control microbial methane oxidation above an active cold seep (Doggerbank, North Sea)

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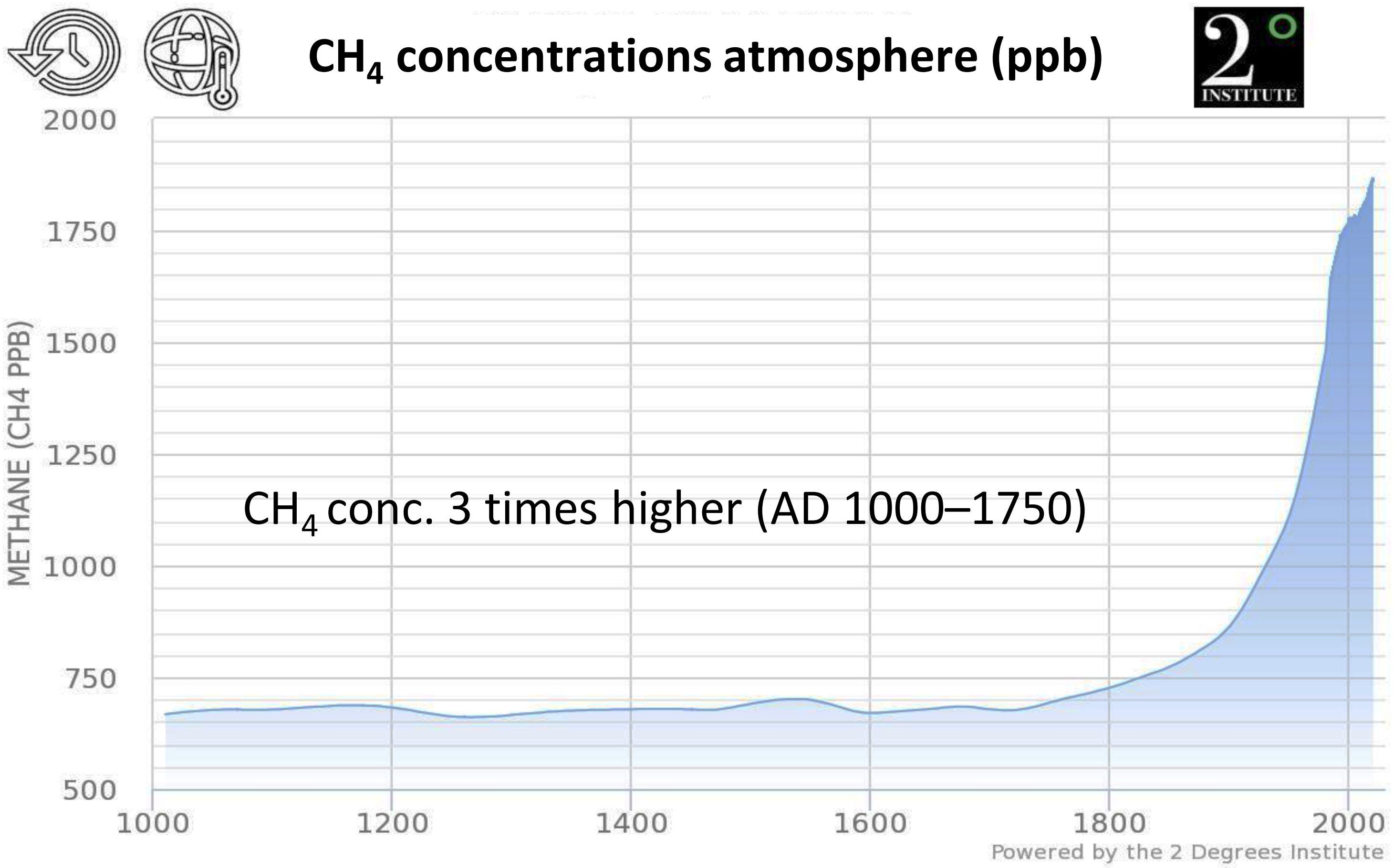
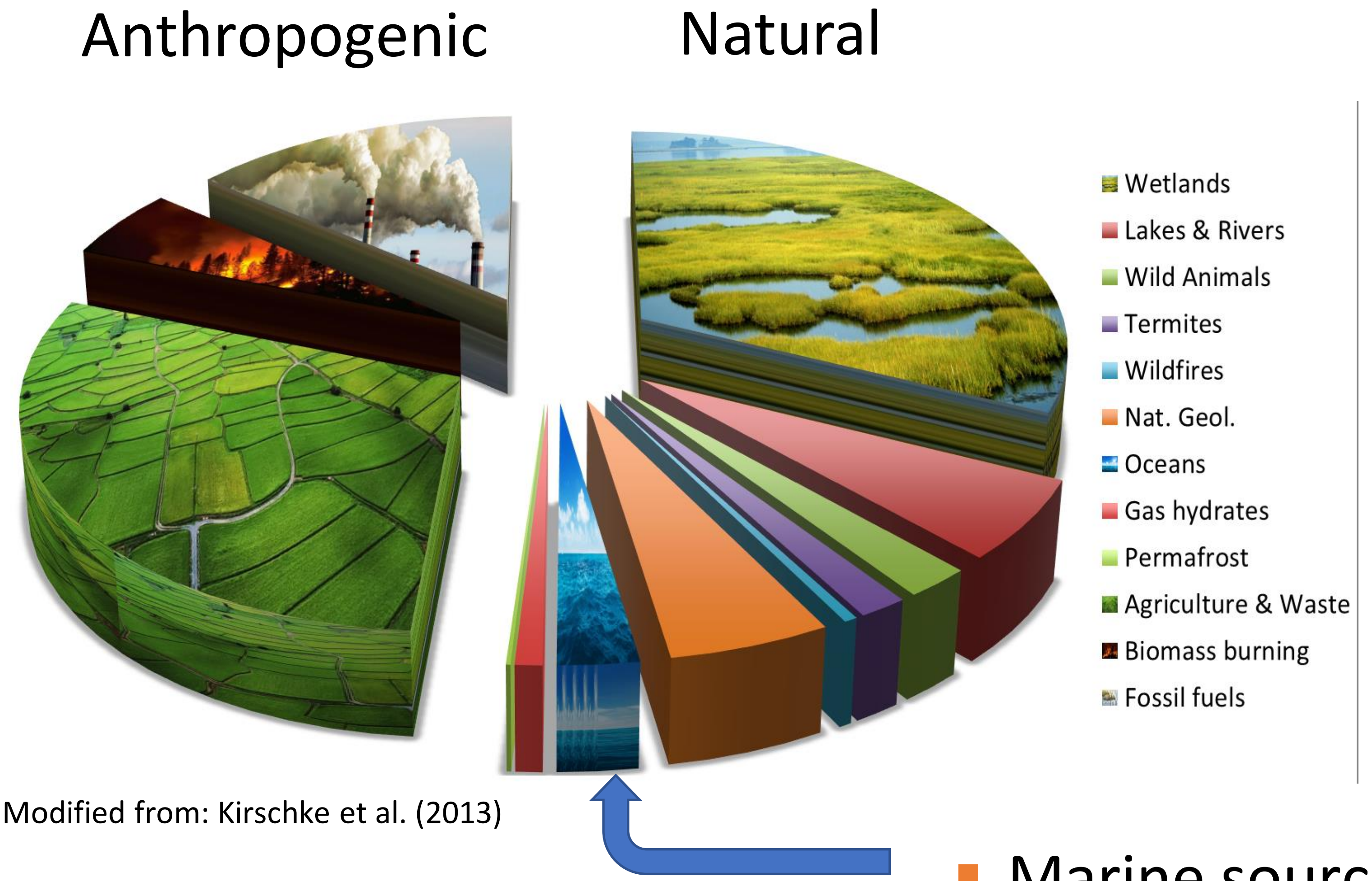
Royal NIOZ is part of NWO-I, in cooperation with Utrecht University

Role of Methane in our climate

- Methane (CH_4) is an important greenhouse gas (GHG)
- Accounts for ~17% of global greenhouse effect
- Warming potential for CH_4 ~25 x CO_2 over period of 100 years
- Lifetime atmosphere 12 years



Major CH_4 sources



Modified from: Kirschke et al. (2013)

- Anthropogenic sources:~200 - 331 Tg yr^{-1}
- Natural sources:~100-230 Tg yr^{-1}
- Marine sources 5-50 Tg yr^{-1} ???

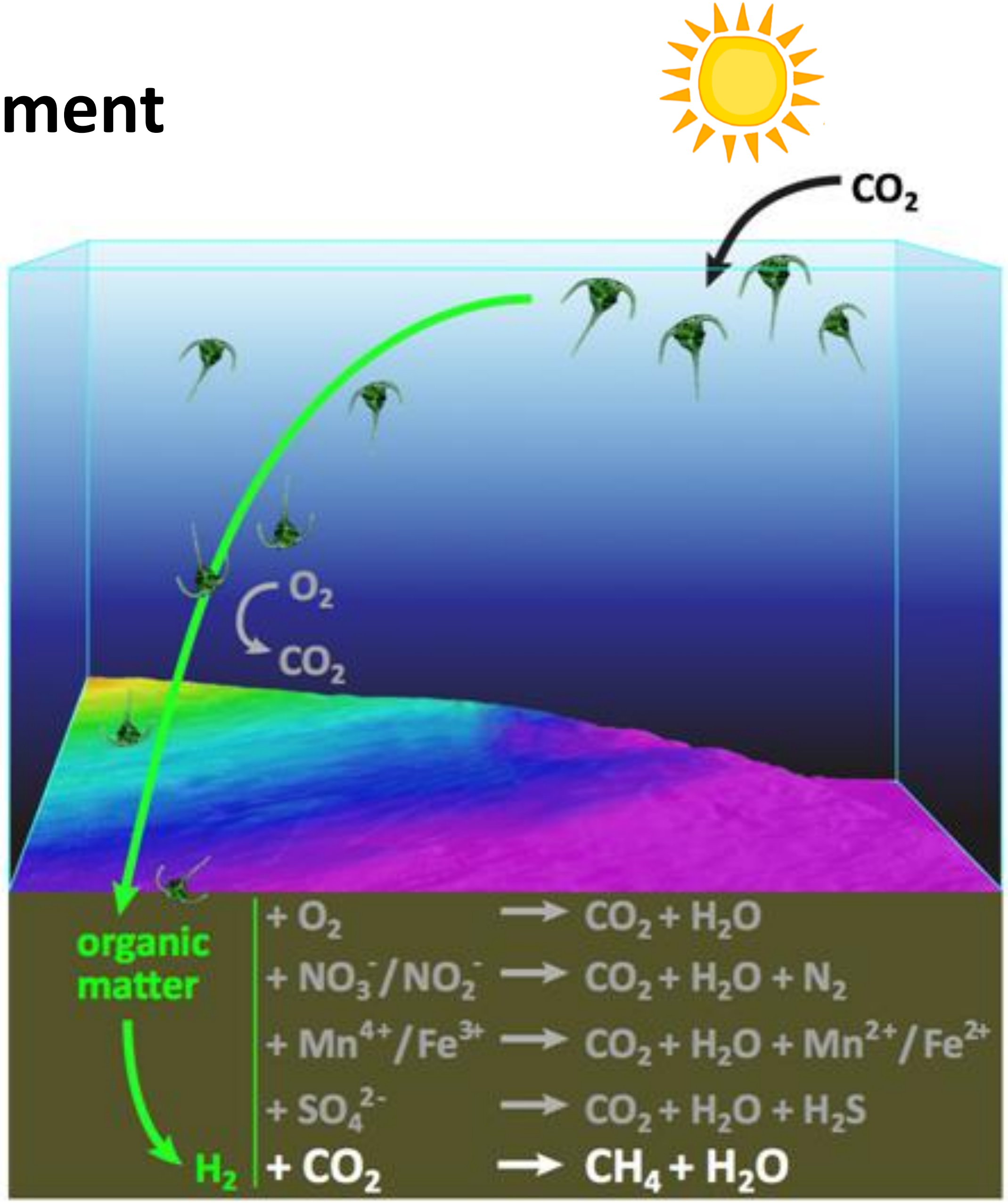
Source of methane marine environment

Organic matter produced in euphotic zone

Sinking of dead organic matter

Organic matter is oxidized in sediments by various electron acceptors

Final OM degradation: microbial methanogenesis → Methane production



Modified from : James et al. (2016)

Major sink environment

1. Microbial methane filter

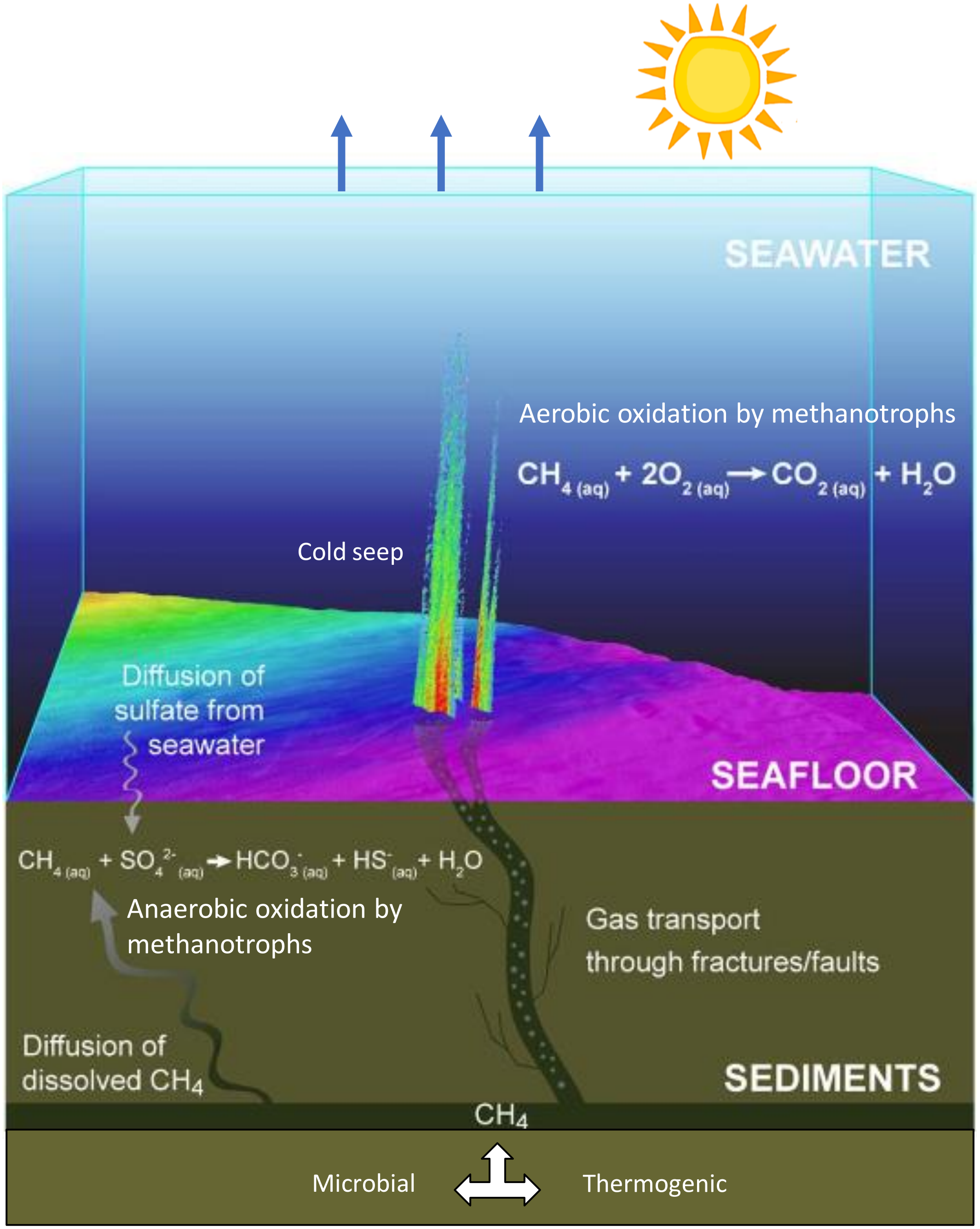
- Highly efficient
- Majority CH_4 does not reach atmosphere
- **Aerobic oxidation acts as a final sink before methane reaching atmosphere → Focus research project**

2. Coastal waters/Shelf seas

- Source of CH_4 to the atmosphere → because of shallow depth: little time for microbial CH_4 consumption
- Dynamic systems → Strong tidal and seasonal currents

3. Would there be a spatiotemporal effect?

- Test efficiency of the methane oxidation filter
- Test distribution of methanotrophs in water column



Modified from: James et al. (2016)

Overarching questions research project

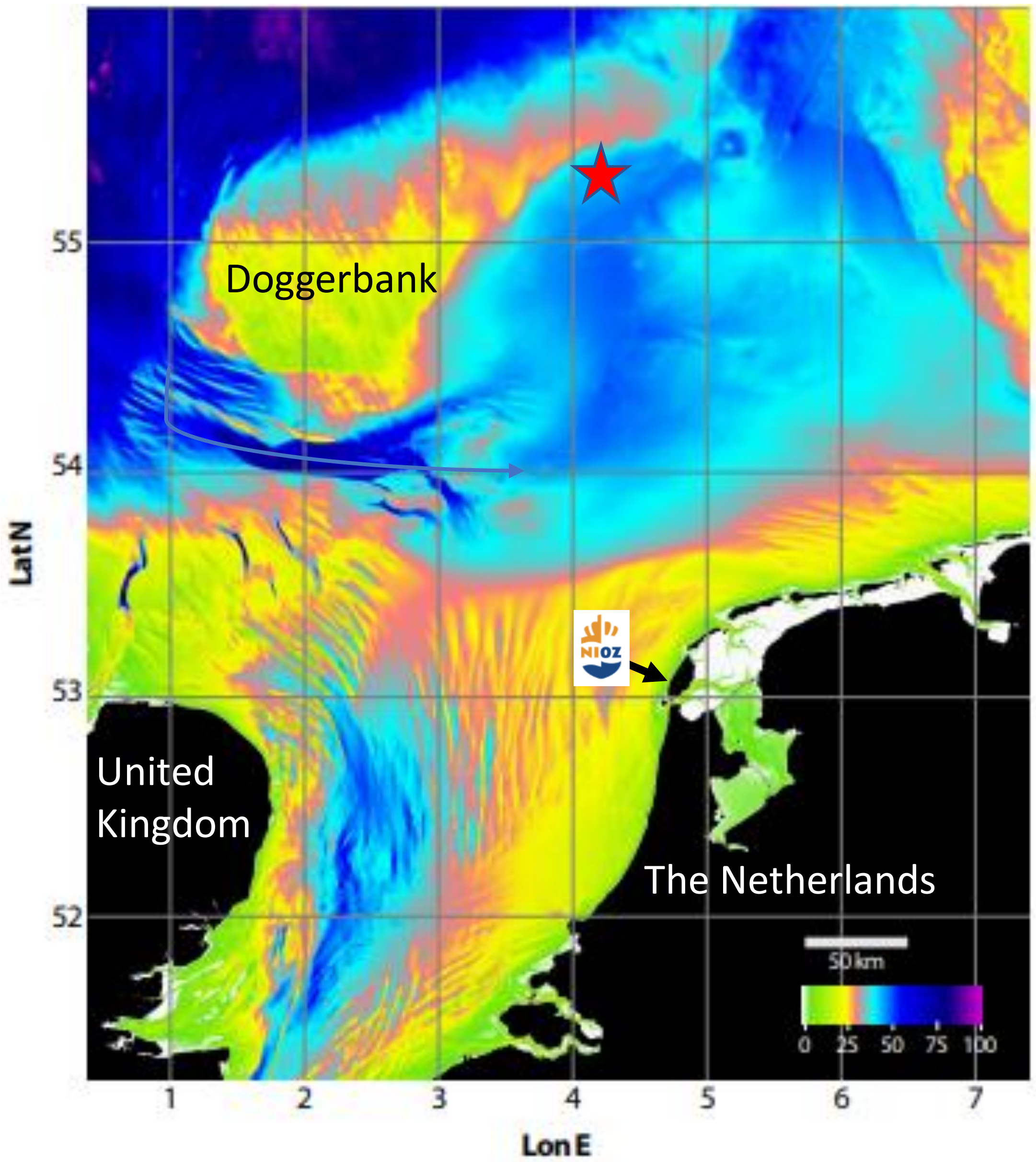
How efficient is the aerobic microbial CH_4 filter at shallow water depth?

Which factors effect the efficiency?

Study site in Southern North Sea

- Shelf sea (max ~75m deep)
- Dynamic sea
  - Tides
  - Seasons
    - Summer stratification
    - Winter mixed water column
- Doggerbank cold seep area ★

Bathymetry map southern North Sea

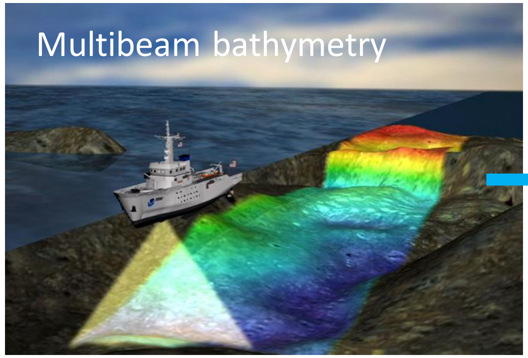


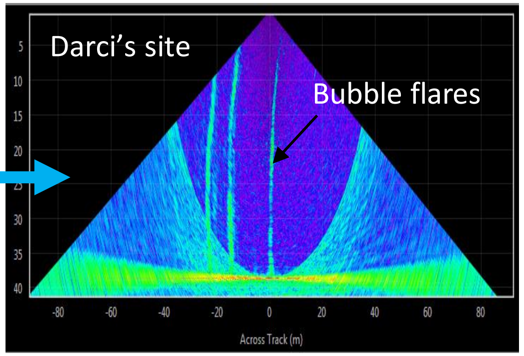
Methods and location Darci’s site

Doggerbank seep area

Times series experiment

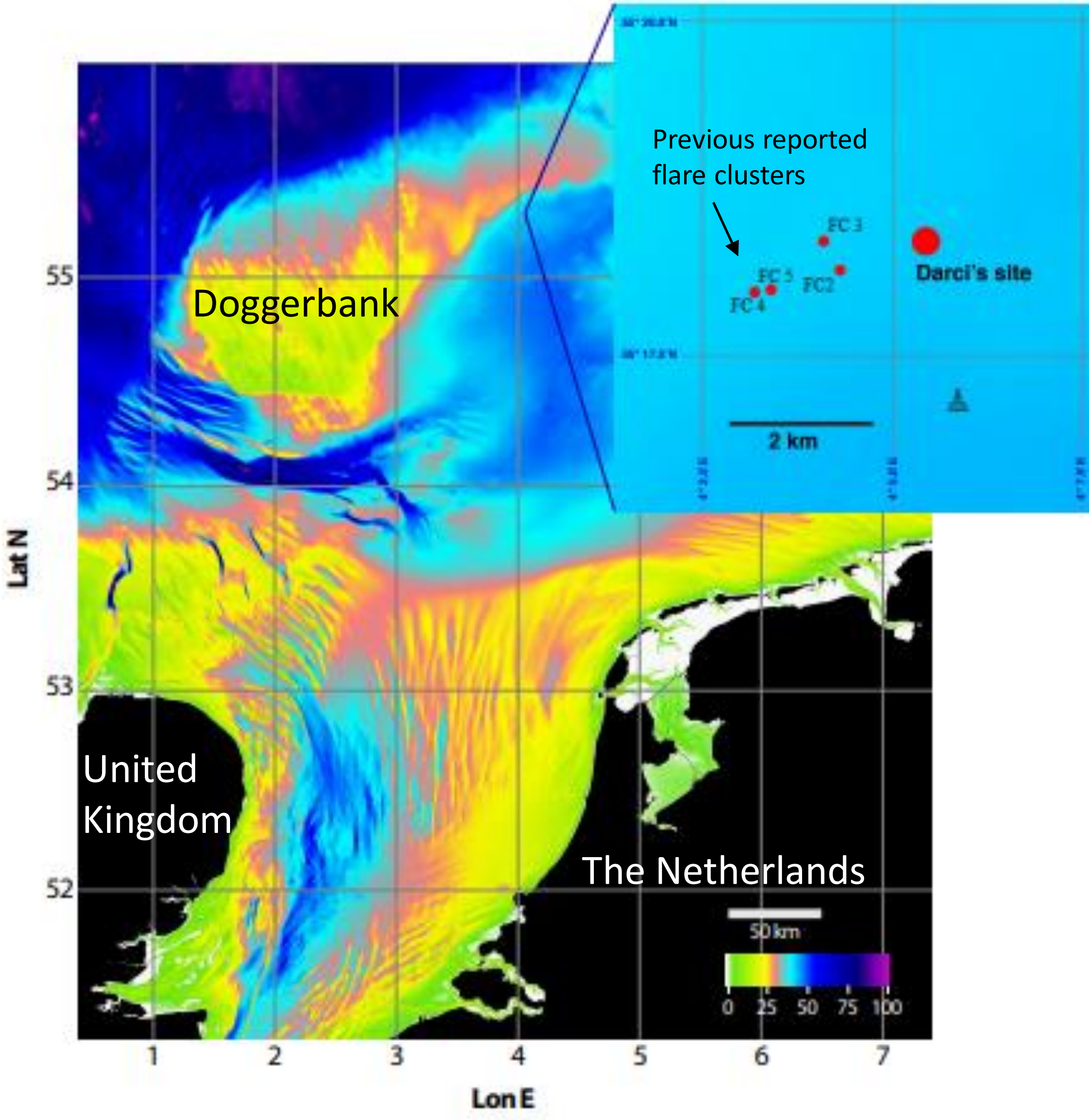
- Summer 2018 (PE-439) and Autumn 2019 (PE-462) R/V Pelagia
- Find cold seep (bubbles) using multibeam bathymetry
- Stay above cold seep for 2 continues days (Darci’s site)





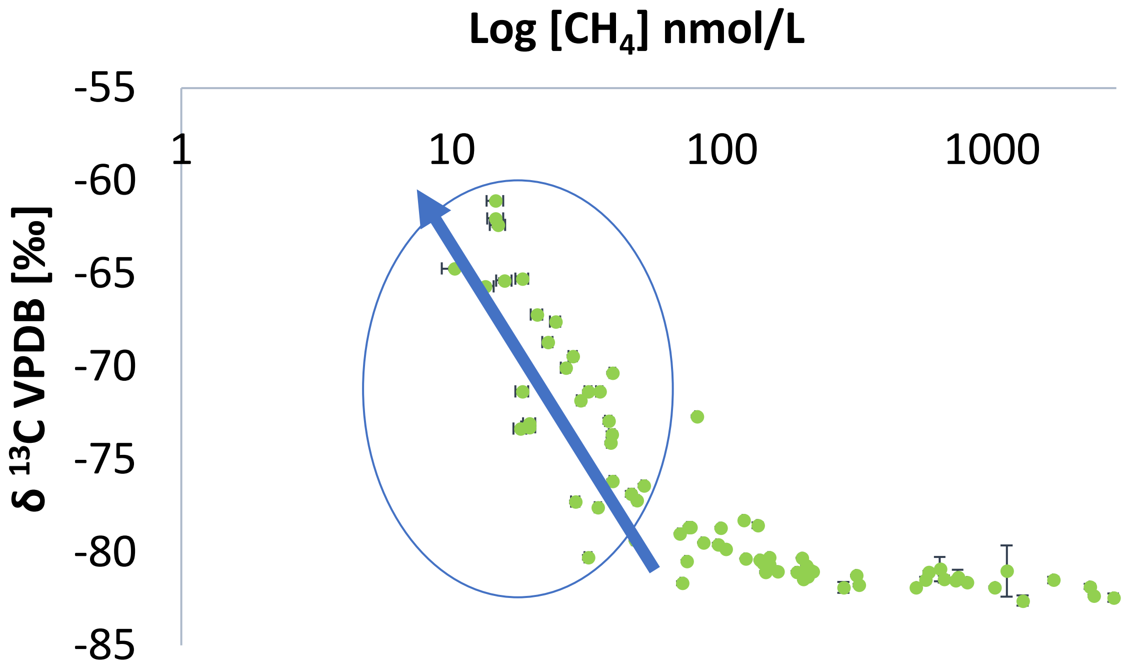
Sample <u>each 2 hours </u>in water column for

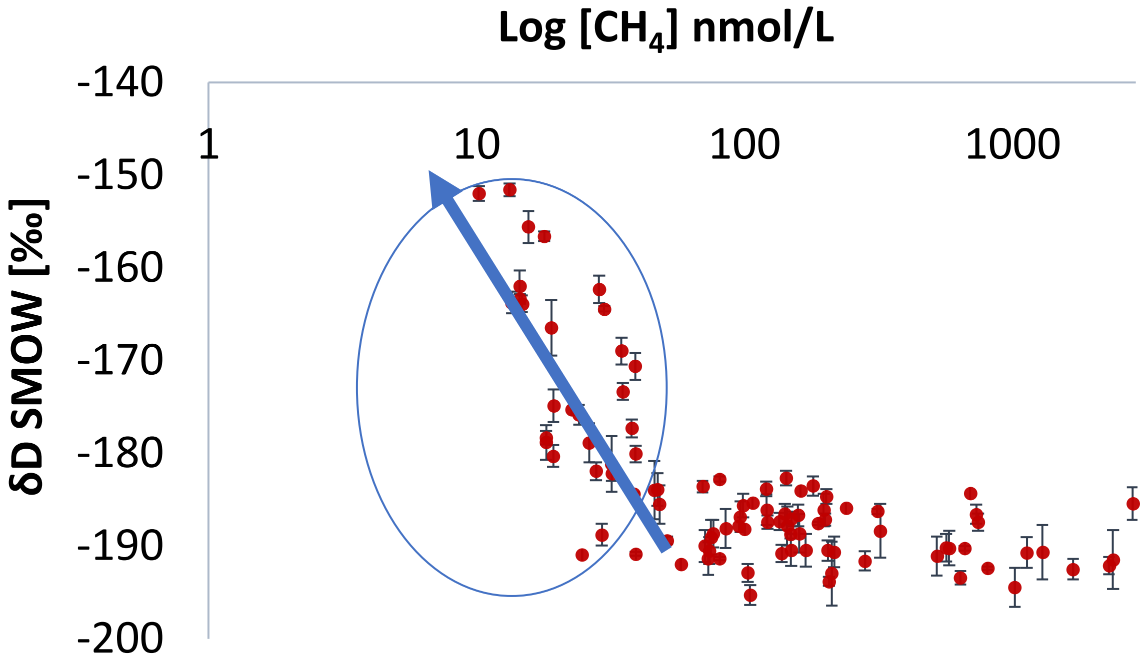
- Stable isotopes composition
- Methane oxidation rates (MOx)
- Methane concentrations
- Atmospheric methane measurements



Results : Isotopic signature shows microbial methane oxidation

Summer (PE-439)





- Our stable carbon ($\delta^{13}C$) and hydrogen (δD) isotopic analysis of dissolved CH_4 at Darci's site show values of -60 ‰ to -90‰ and -160‰ to -200‰ respectively, indicating a microbial origin of CH_4
- Methane oxidation by methanotrophs occurs as towards lower concentrations of CH_4 isotopic signals becomes less depleted (by methanotrophs preferred $C^{12}CH_4$ is consumed)

With the result showed in the previous slide we can raise the following question:

What is the rate of CH_4 oxidation above Darci’s site (cold seep)?

Method→ Rate of methane oxidation (MOx)

- 3 days incubation using radioisotopic labelling (C^3H_4)

MOx: $C^3H_4 + 2\ O_2 \leftrightarrows CO_2 + 2\ {}^3H_2O$

- Analyse water activity and total activity using wet scintillation counting

$$\text{MOx rate} = \frac{{}^3H_2O}{{}^3H_2O + C^3H_4} \times \frac{1}{t} \times [CH_4]$$

Where: t = incubation time
$[CH_4]$ = methane concentration water column

Results Summer (PE-439)

- Highly stratified waters → Figure 1
- High MOx found above stratified barrier → Figure 2
- Seep (CH_4) activity oscillates → Figure 3

Figure 2

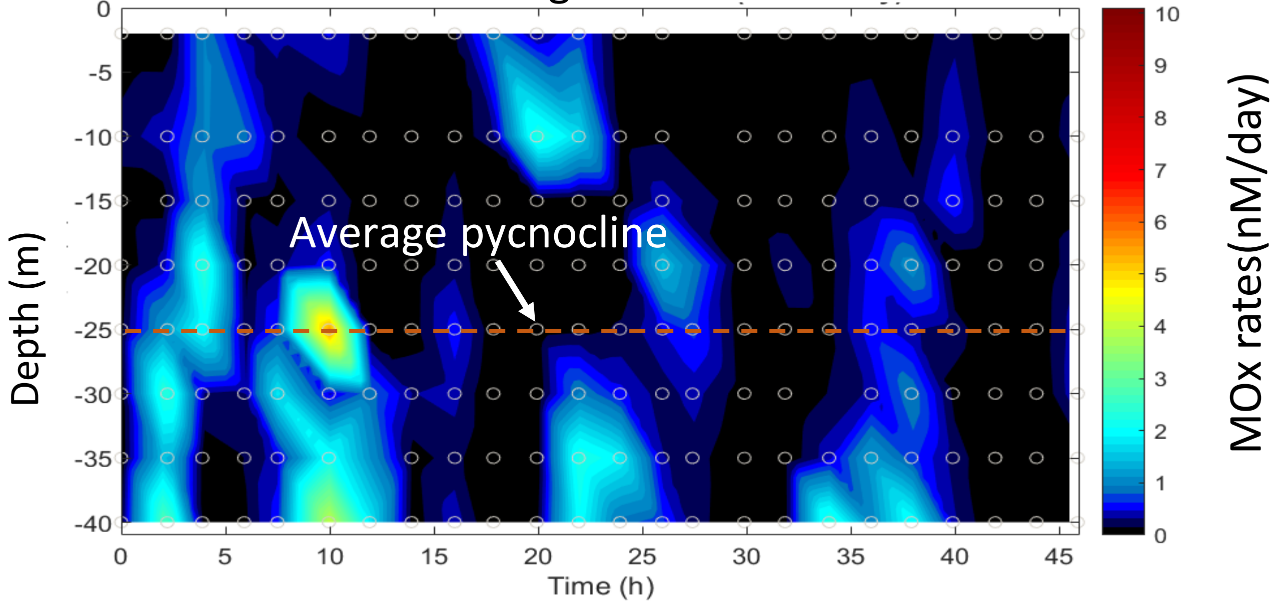


Figure 1

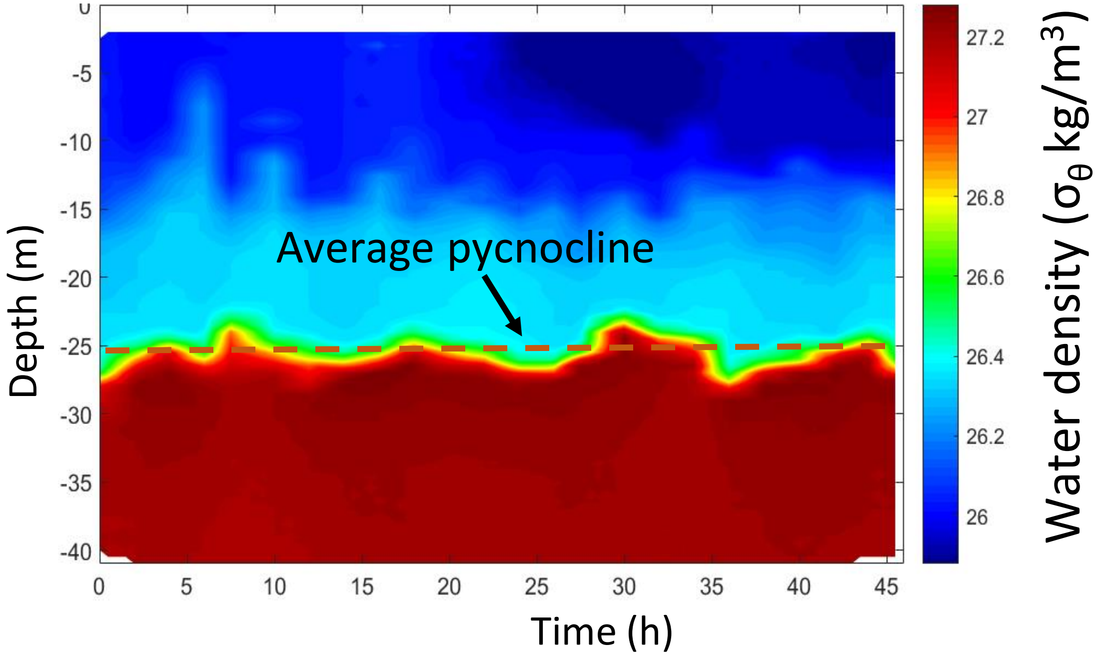
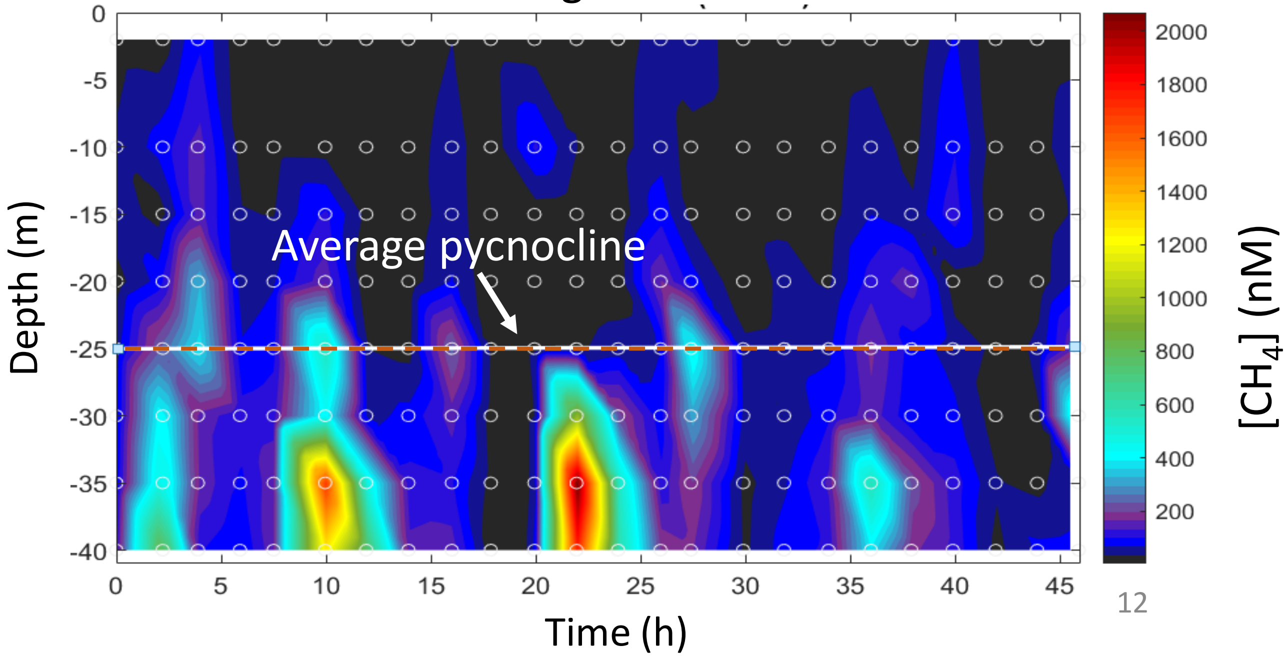


Figure 3



Results Summer (PE-439)

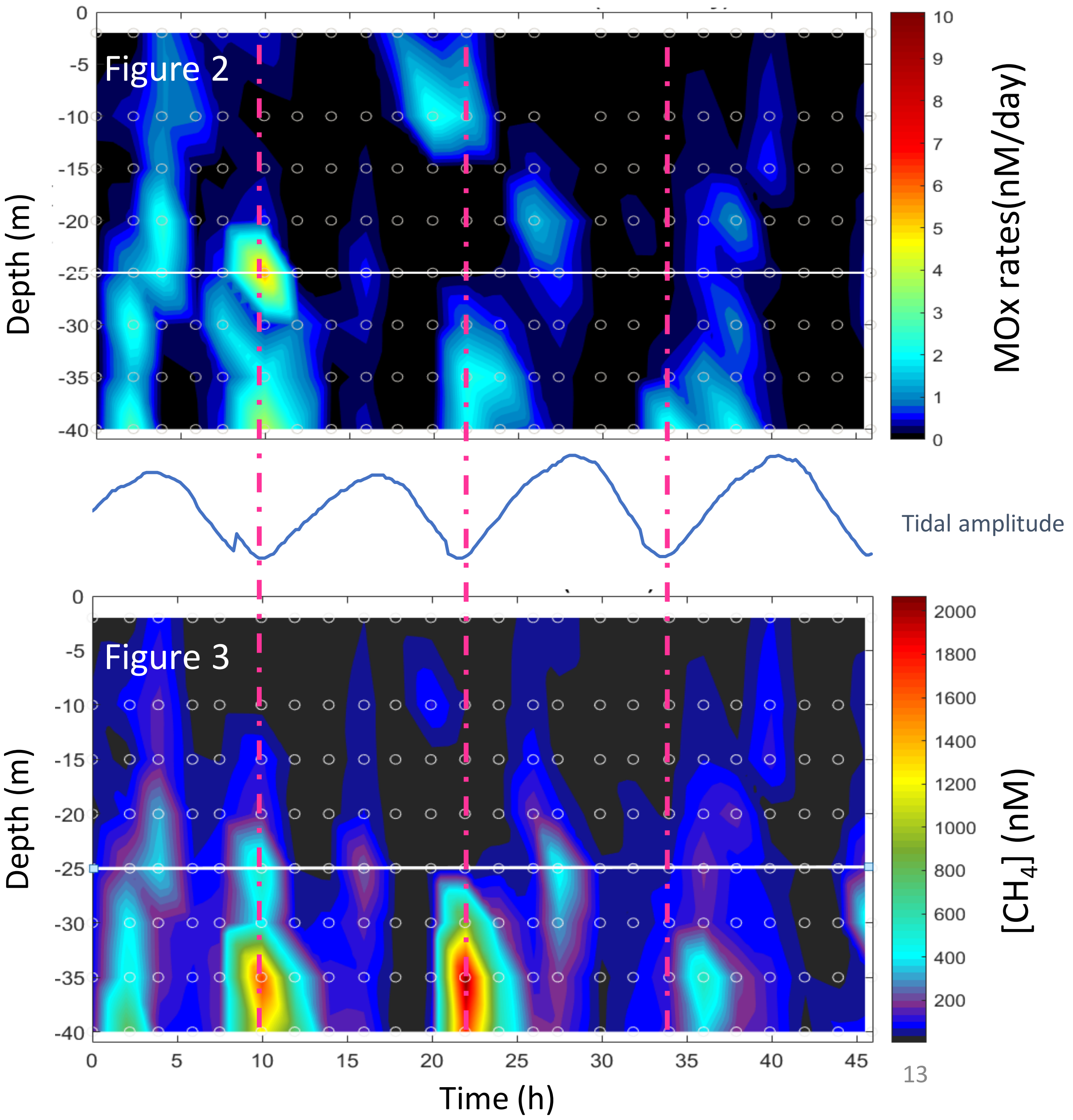
Same figures as previous slide

Figure 2

- Highest MOx up to 5,6 nM/Day were found in bottom waters But high MOx rates 2.2 nM/day were also found in near-surface waters at times of elevated seep activity
- Due to stratification it should be difficult for methanotrophs to travel to surface waters. This implies that methanotrophs were transported upwards through the stratified barrier possibly dragging along with rising bubbles.

Figure 3

- Stratification retained methane in bottom waters compared to upper waters. Still high surface concentrations up to 100nM were found → Atmosphere-water equil. $[CH_4]$ = approx. 2-4 nM → Suggesting high flux towards atmosphere
- Observed oscillations in seep activity were linked to local tidal cycle → temporal effect



Results Autumn (PE-462)

- Mixed waters (no stratification) → Figure 1
- Little activity microbial filter (low MOx) → Figure 2
- Seep (CH_4) activity oscillates and follows a 12.4 hour tidal pattern → Figure 3

Figure 2

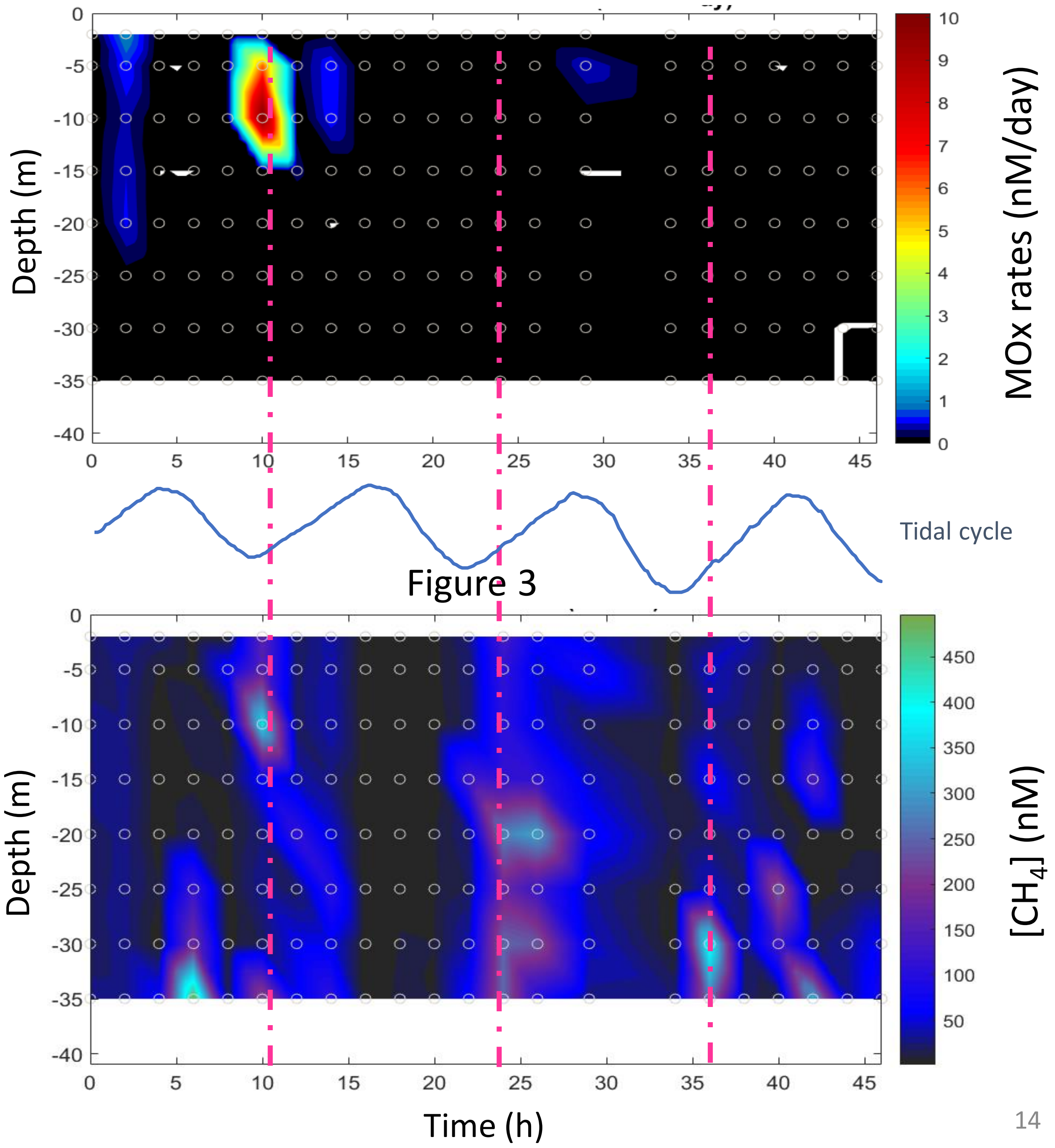
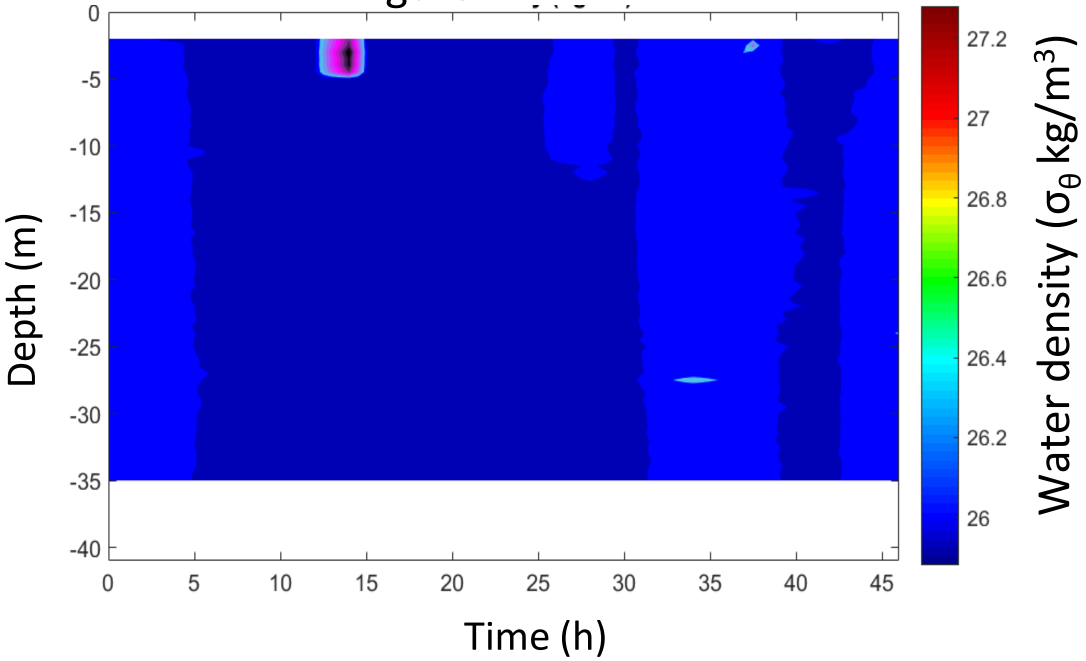


Figure 1



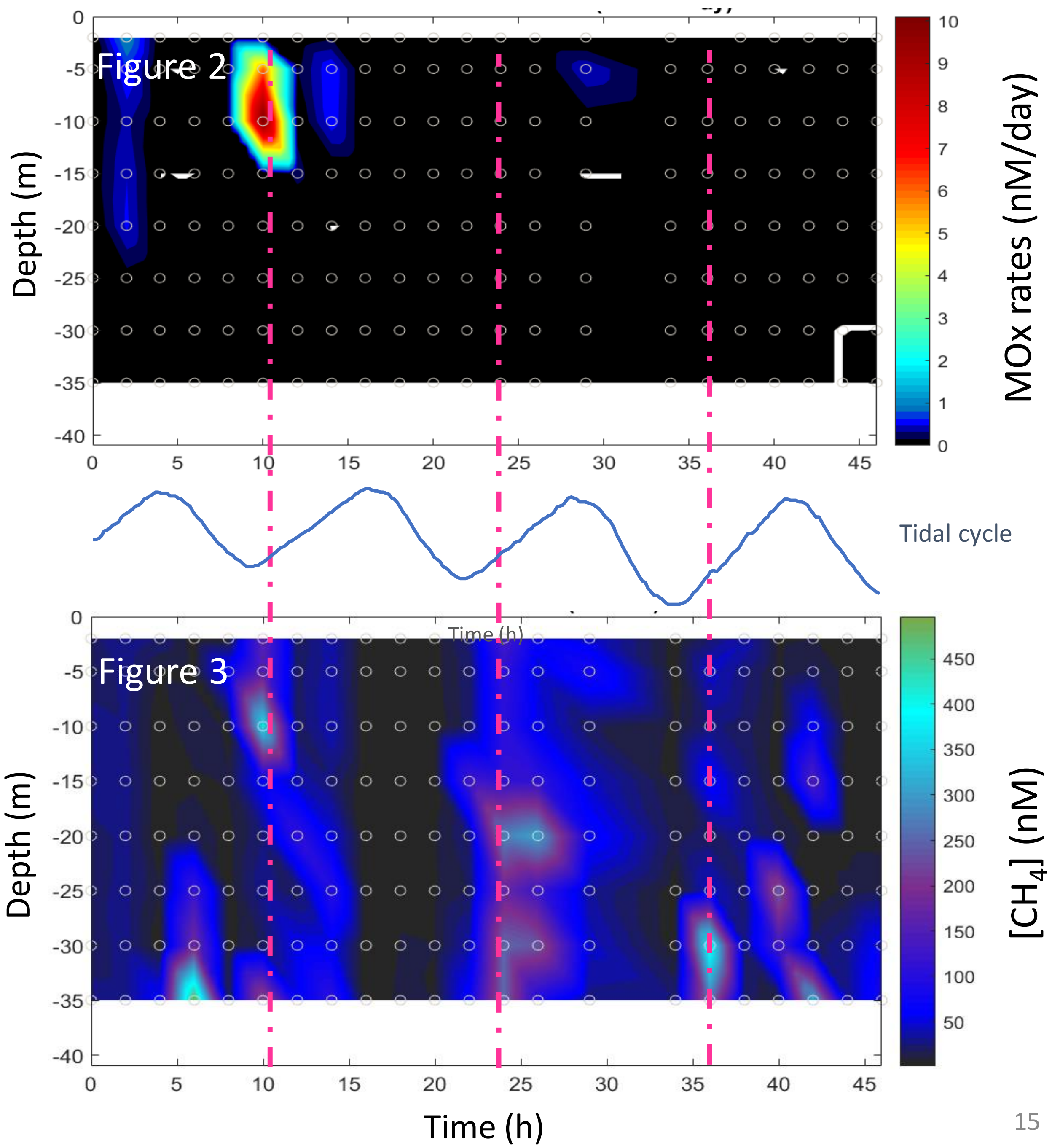
Results Autumn (PE-462)

Figure 2

- Activity microbial filter is much lower compare to summer → seasonal effect
- Heavy weather conditions during cruise might have caused strong watermass movement dragging community away from seep area

Figure 3

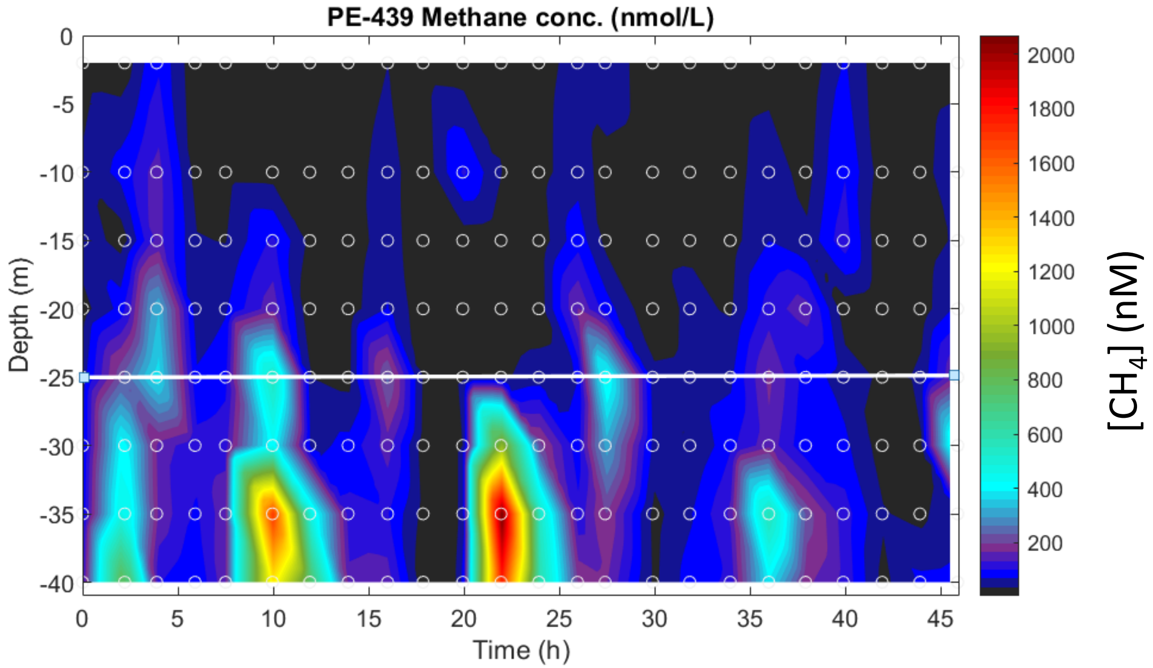
- Methane concentrations clearly distributed throughout the water column due to lack of a stratified barrier.
- Lack of barrier caused higher concentrations in surface waters suggesting higher flux towards atmosphere.



Discussion Methane concentrations : Summer vs. Autumn

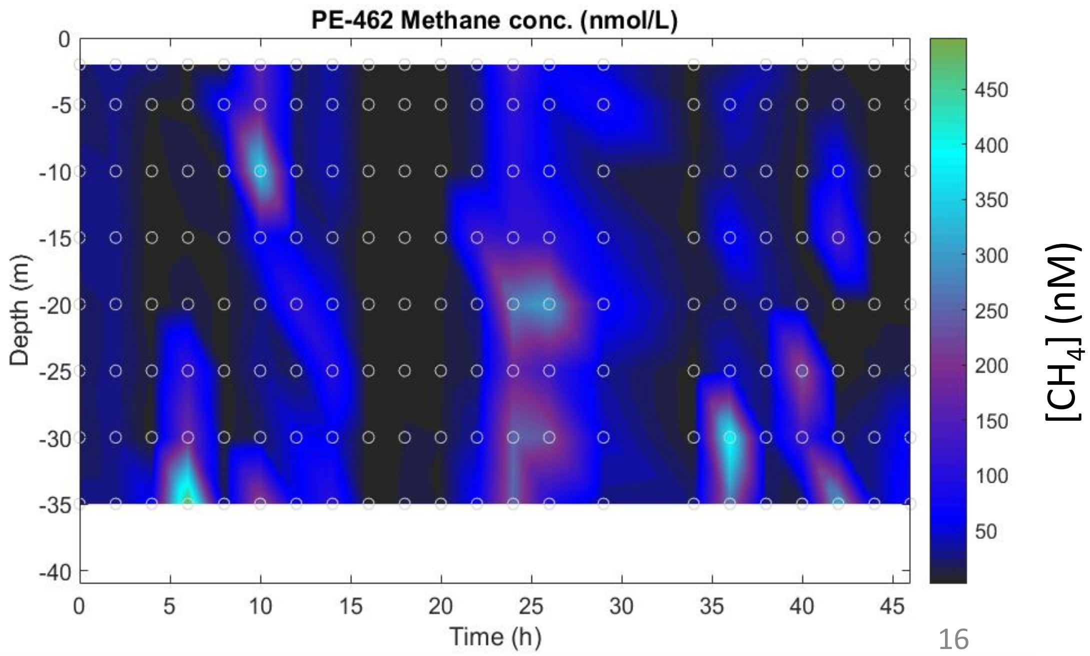
Summer

- Stratified conditions (25m pycnocline)
- ~12h periodicity at falling/low tide
- Average Methane concentrations complete time-series: 139nM with maximum of 2082 nmol/L



Autumn

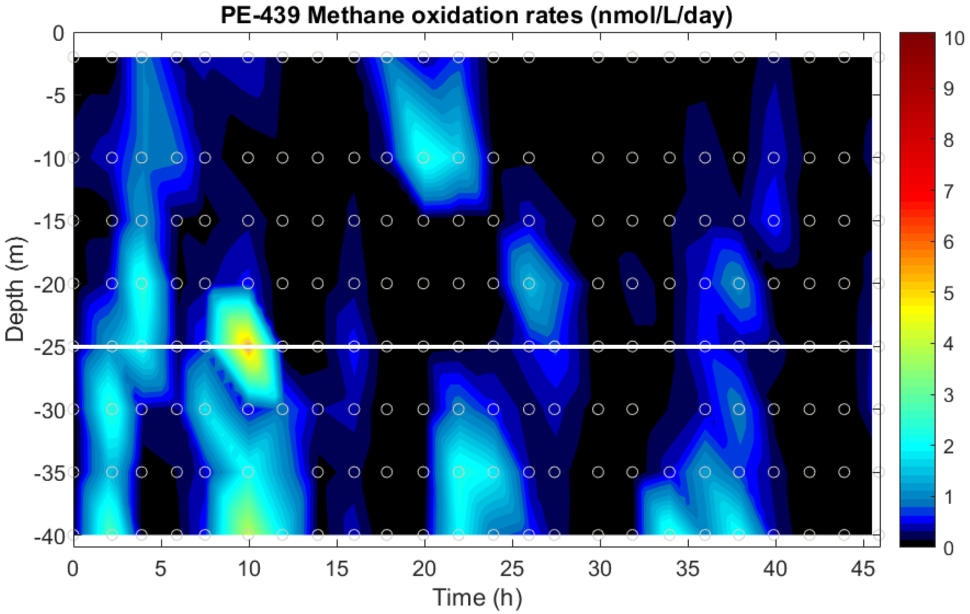
- Mixed water column
- ~12h periodicity at falling/low tide
- Average Methane concentrations complete time-series: 52nM with maximum conc.of 497 nmol/L



Discussion MOx: Seasonal activity microbial filter

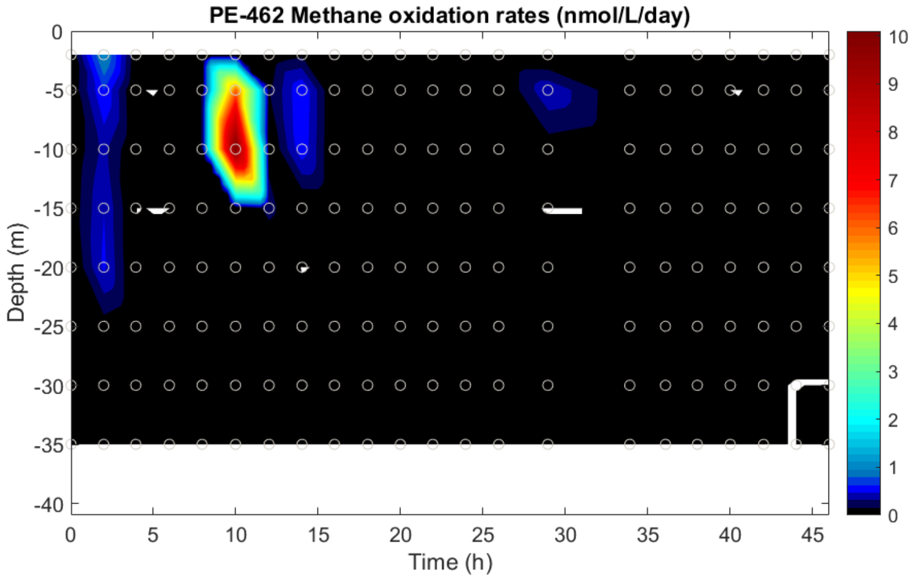
Methane Oxidation (MOx) summer

- Active community microbial community of methanotrophs
- High MOx with elevated seep activity
- Maximum rates were 5.7 nmol/L/day at 25m water depth
- 2.4 nmol/L/day at 10m → Transportation methanotrophs through pycnocline most likely by bubble jet

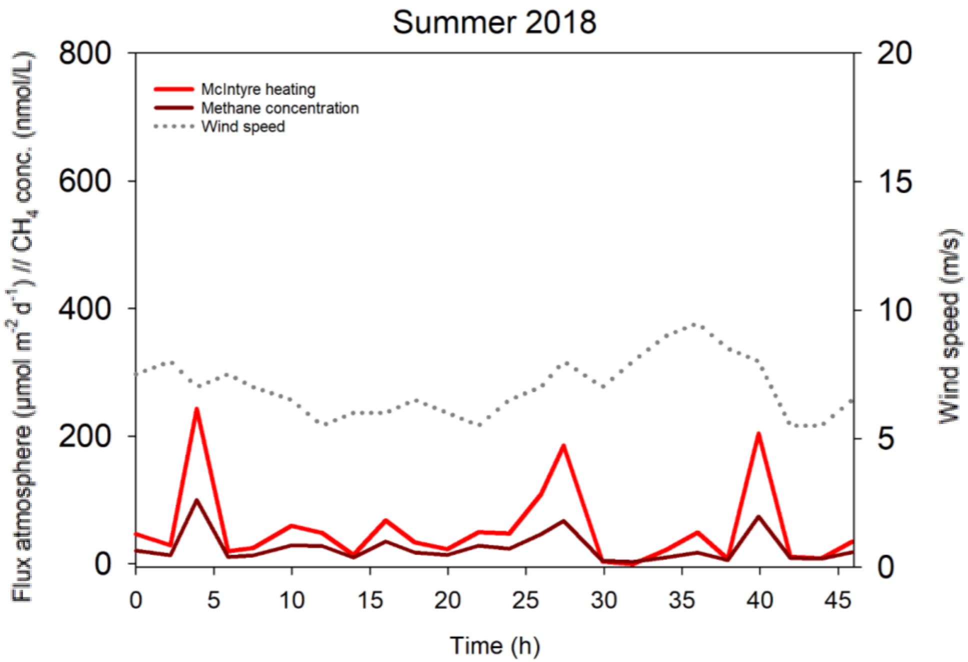


Methane Oxidation (MOx) autumn

- Much less active microbial community of methanotrophs
  - Strong winds possible cause and/or methanotroph abundance
- Low MOx even with elevated Methane concentrations
- Maximum rate of 10.2 nmol/L/day at 10m water depth

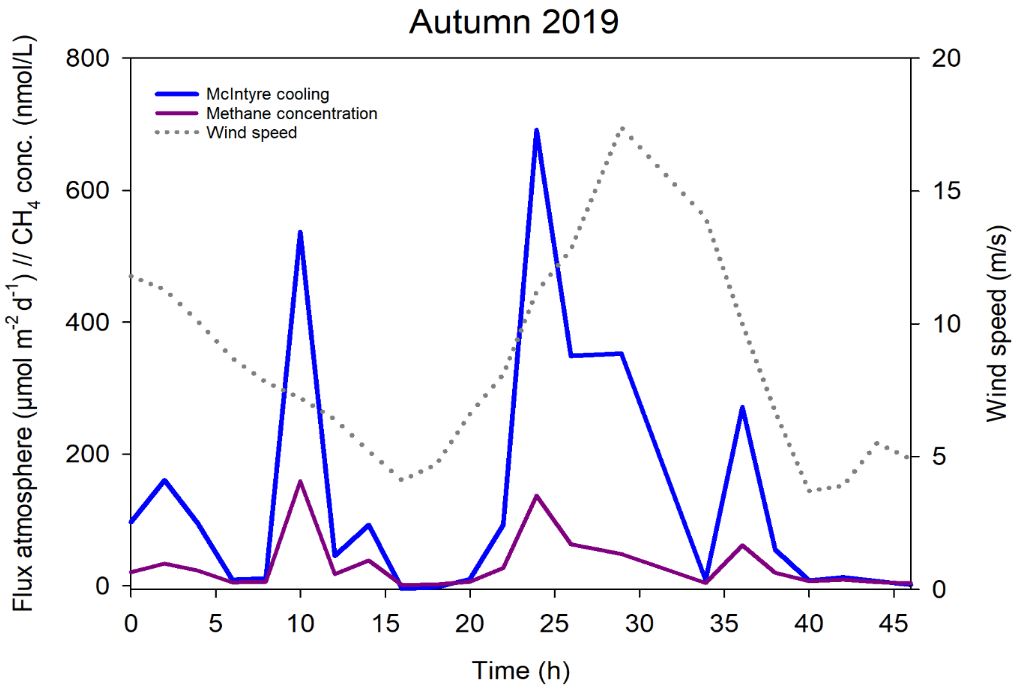


Discussion : CH_4 flux towards the atmosphere



	Wind speed (m/s)	[CH_4] at 2m (nM)	Flux (μmol m^{-2} d^{-1})	Flux (mg m^{-2} d^{-1})
Maximum	9.5	100.13	242.85	3.89
Minimum	5.5	3.18	3.18	0,06
Average	7	25.39	71,24	0.90

- Flux calculated using McInytre et al. (2010) computation for heating system
- Wind relative stable throughout time-series
- Flux highest after elevated seep activity



	Wind speed (m/s)	[CH4] at 2m (nM)	Flux (μmol m^{-2} d^{-1})	Flux (mg m^{-2} d^{-1})
Maximum	19	159.02	559.14	8.95
Minimum	3	1.57	-4.84	-0,08
Average	8	32.12	127.41	2.04

- Flux calculated using McIntyre et al. (2010) computation for cooling system
- Higher flux towards atmosphere caused by higher methane concentrations in surface waters and higher wind speeds

Conclusions

1. How efficient is the aerobic microbial CH_4 filter at shallow water depth?

- Substantial amount of methane retained in water column: more in summer compared to winter
- Efficiency of aerobic microbial filter in summer better than autumn
- Summer stratification and calmer waters seem to allow communities to grow for longer period and thereby improving the efficiency of the microbial filter. Need to obtain extra community data to make full statement (working on this)

2. Which factors effect the efficiency?

- A small difference in hydrostatic pressure, because of tides, led to a change in seep activity and indicates the importance of sampling above cold seeps over longer time periods to avoid under or overestimation of dissolved CH_4 concentrations and MOx.
- Strong seasonal influence caused by stratification effects as CH_4 concentrations and methanotrophs were retained below the pycnocline → Large bursts of bubbles might drag methanotrophs through barrier leading high CH_4 concentrations and MOx in surface waters

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Thank you for your interest!

Special thanks to:

Crew and scientists of PE-439 and PE-462 and technical staff NIOZ

Questions?