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Cold seep hibernation in Arctic sediments during cold bottom water temperature

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ARTICLES

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Reduced methane seepage from Arctic sediments during cold bottom-water conditions

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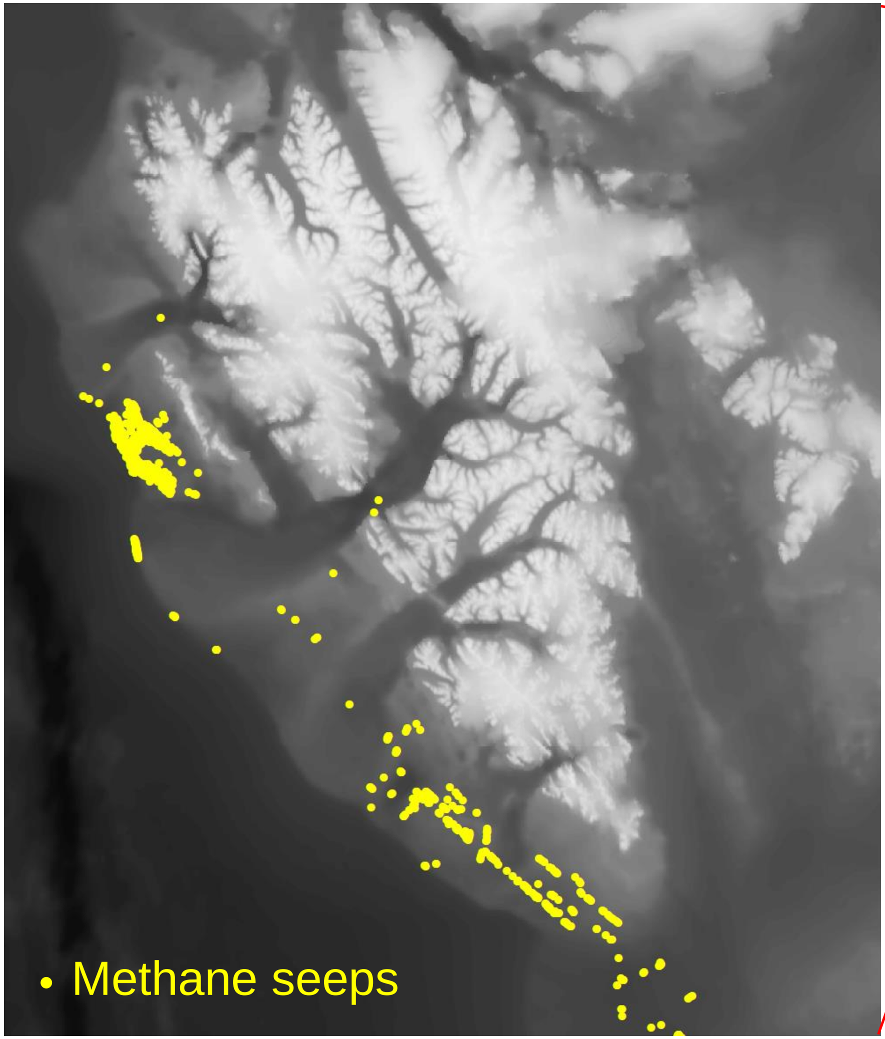
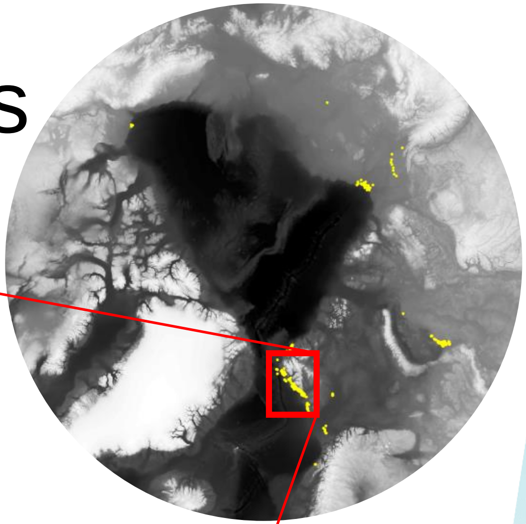
Methane in Arctic marine sediments

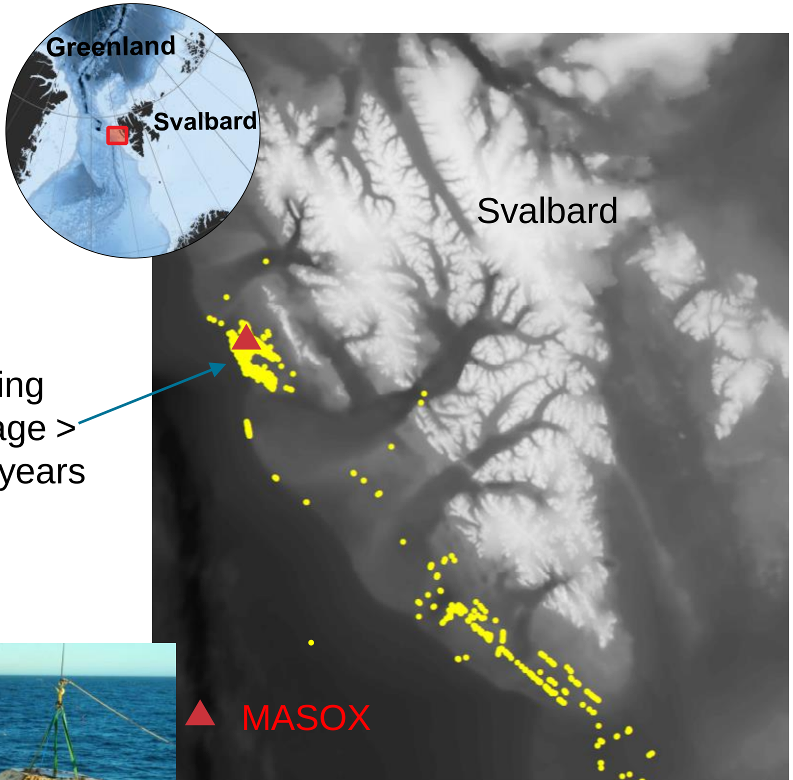
- Methane seeps (called flares) observed around 400 m depth and shallower.

- <u>Study area</u>: offshore Svalbard, where thousand of methane seeps were located.



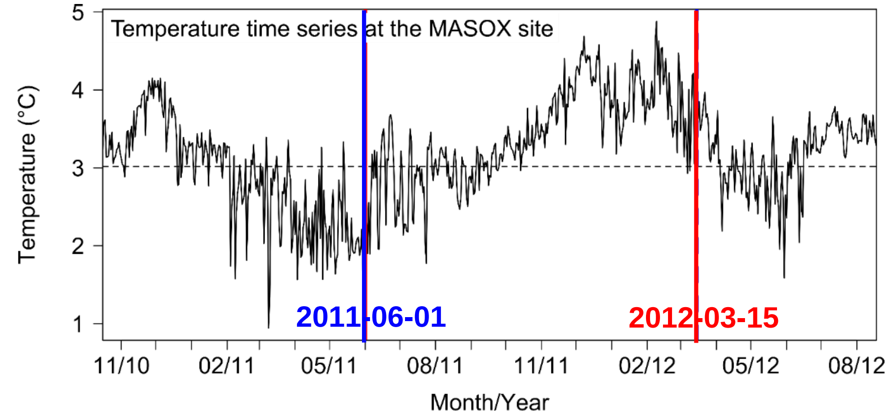


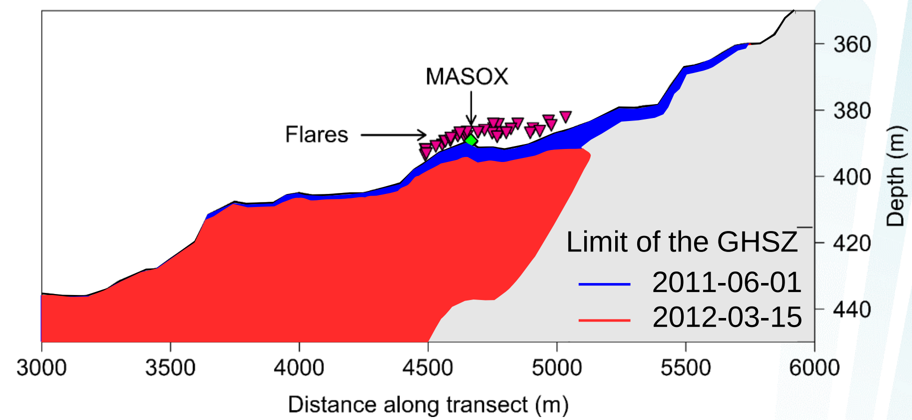
Widespread methane seepages offshore Svalbard



Ongoing seepage > 3000 years

From Berndt et al. 2014





The MASOX seafloor observatory deployed for 2 years in strong seepage cluster ~400 m depth, revealed strong seasonality of bottom water temperature. Modeling of the evolution of the GHSZ, where CH_4 can remain stable instead of diffusing into the water column, showed that (Berndt et al. 2014):

Cold water (June 2011) → gas hydrates are stable up to a 360 meters water depth.

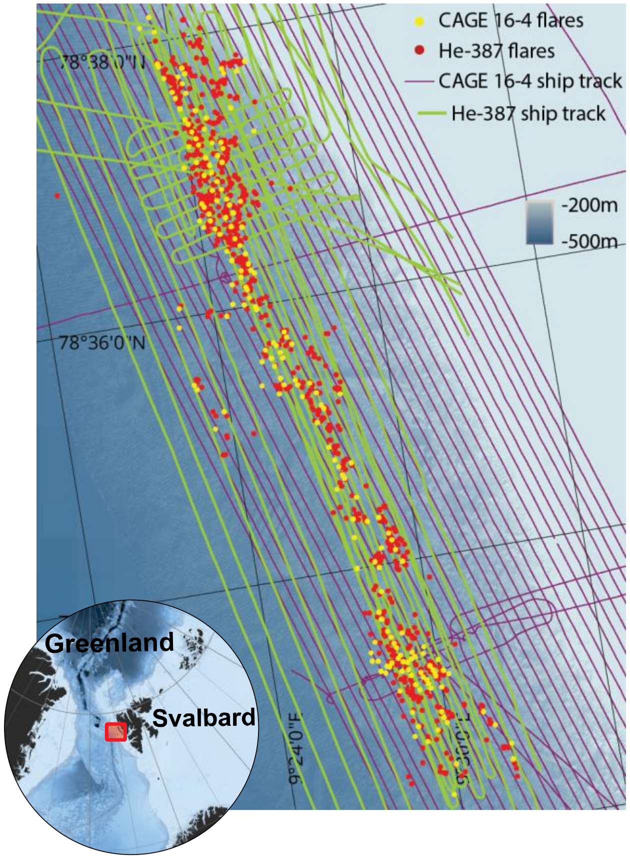
Warm water (March 2012) → gas hydrates disintegrate to a water depth of 410 meters

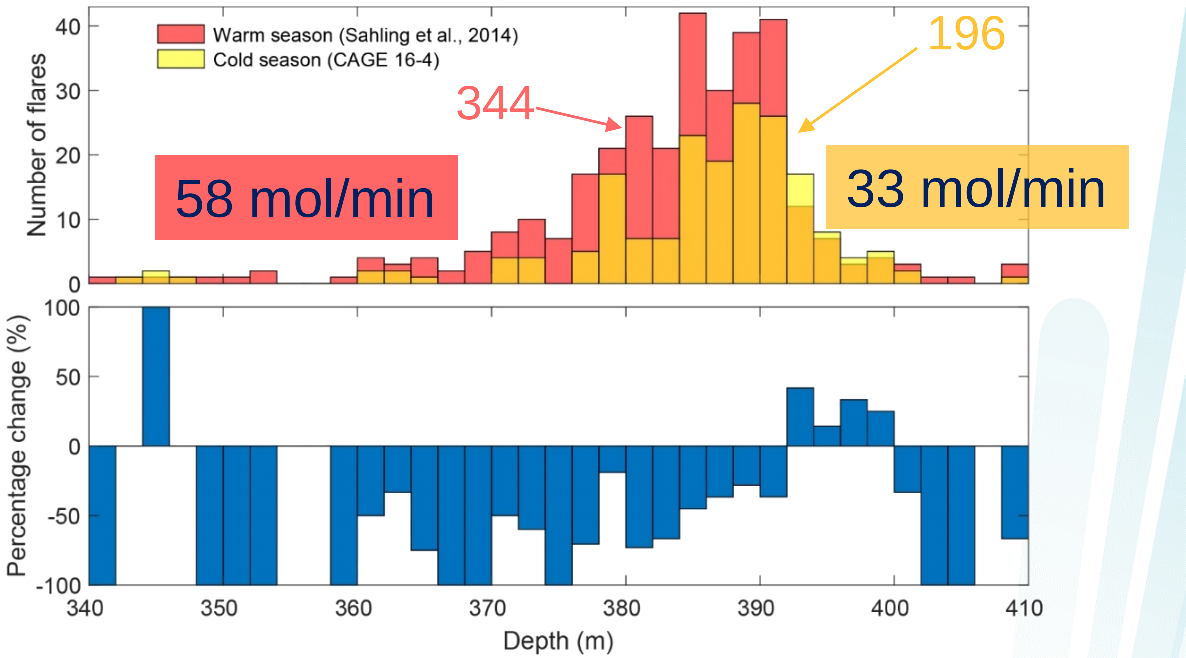
Hypothesis: temperature rise forces CH_4 seep locations to migrate upslope with the deepening GHSZ.

Hydro-acoustic surveys
Seep Density and flow rates: warm vs. cold season

- August 2012 (Sahling et al. 2014)
- Green He-387 ship track
- Red flares and density

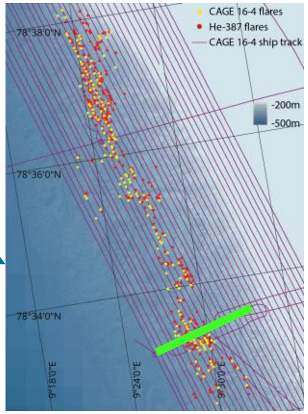
- May 2016 (Ferré et al. 2020)
- Purple CAGE 16-4 ship track
- yellow flares and density





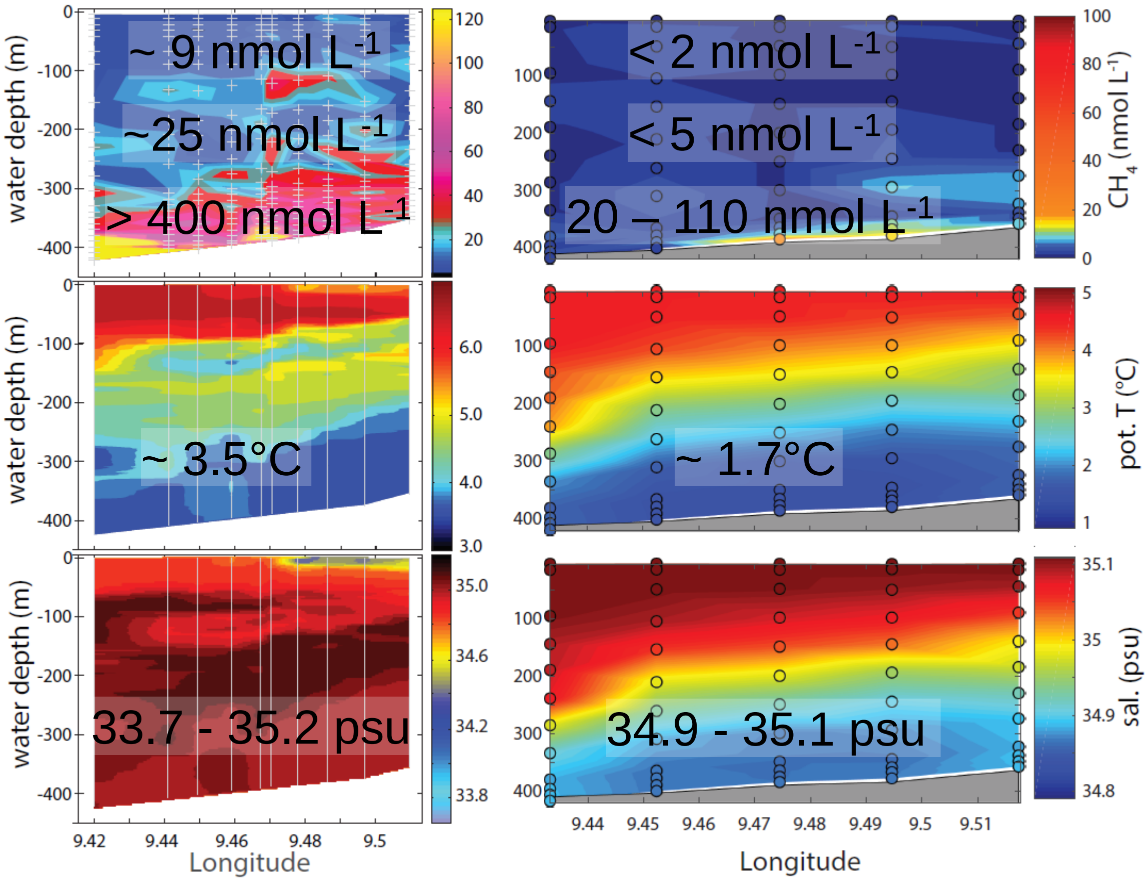
- Twice as much flares in warm (344) than cold season (196) with most flares observed between 360 and 400 m water depth.
- No direct evidence for shoaling of flares position during warm conditions
- Biggest increase during warm condition between 360 and 380m, consistent with a shallowing of the GHSZ limit.
- Flow rates ranging from 2 to 1 900 ml/min
- 43% lower flow rate in cold season compared to summer

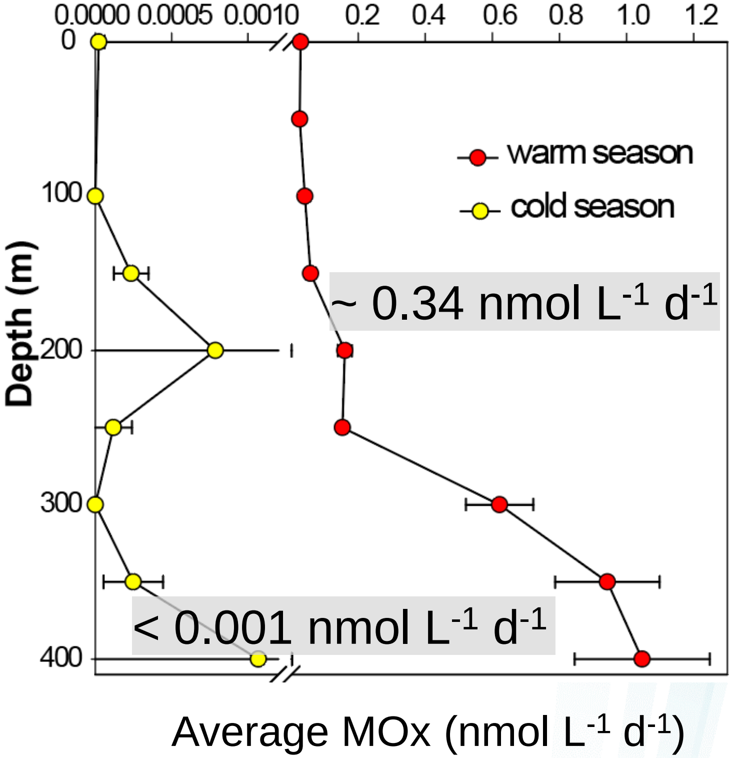
Water column along green transect



Warm season (August 2012) Cold season (May 2016)

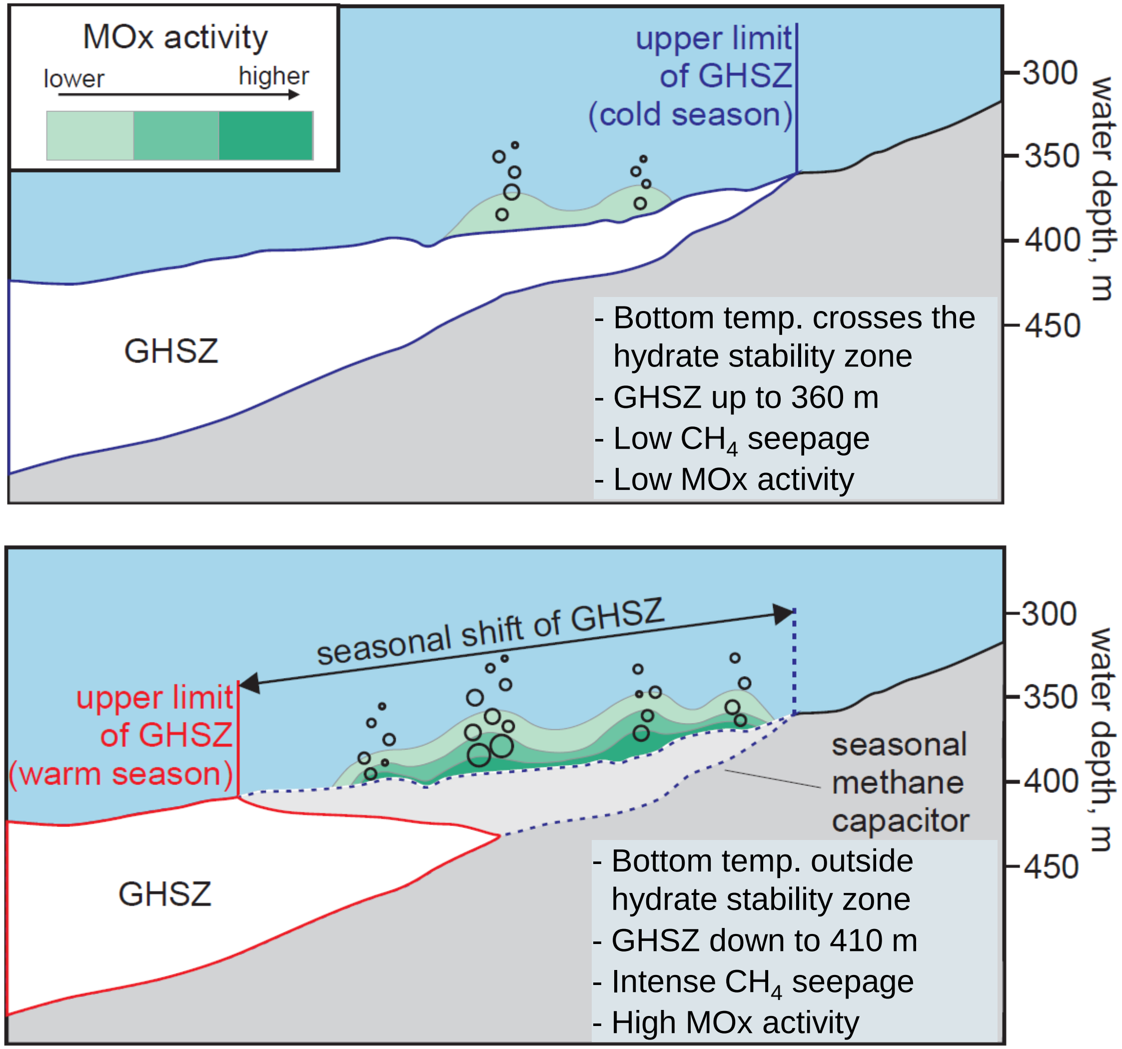
Steinle et al. 2015 *Ferré et al. 2020*

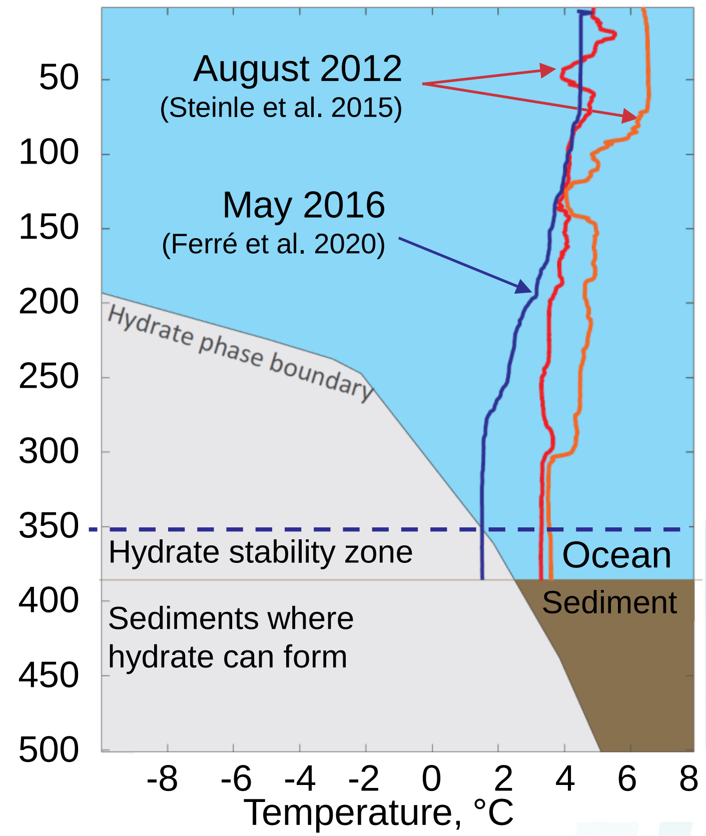




- Note the different scales for each column
- Higher CH_4 concentration in the entire water column in warm season
- Seep-associated aerobic CH_4 oxidation (MOx) rate slows by 2-3 orders of magnitude, meaning that the low CH_4 concentration in the water column is not due to strong consumption of methane by bacteria.

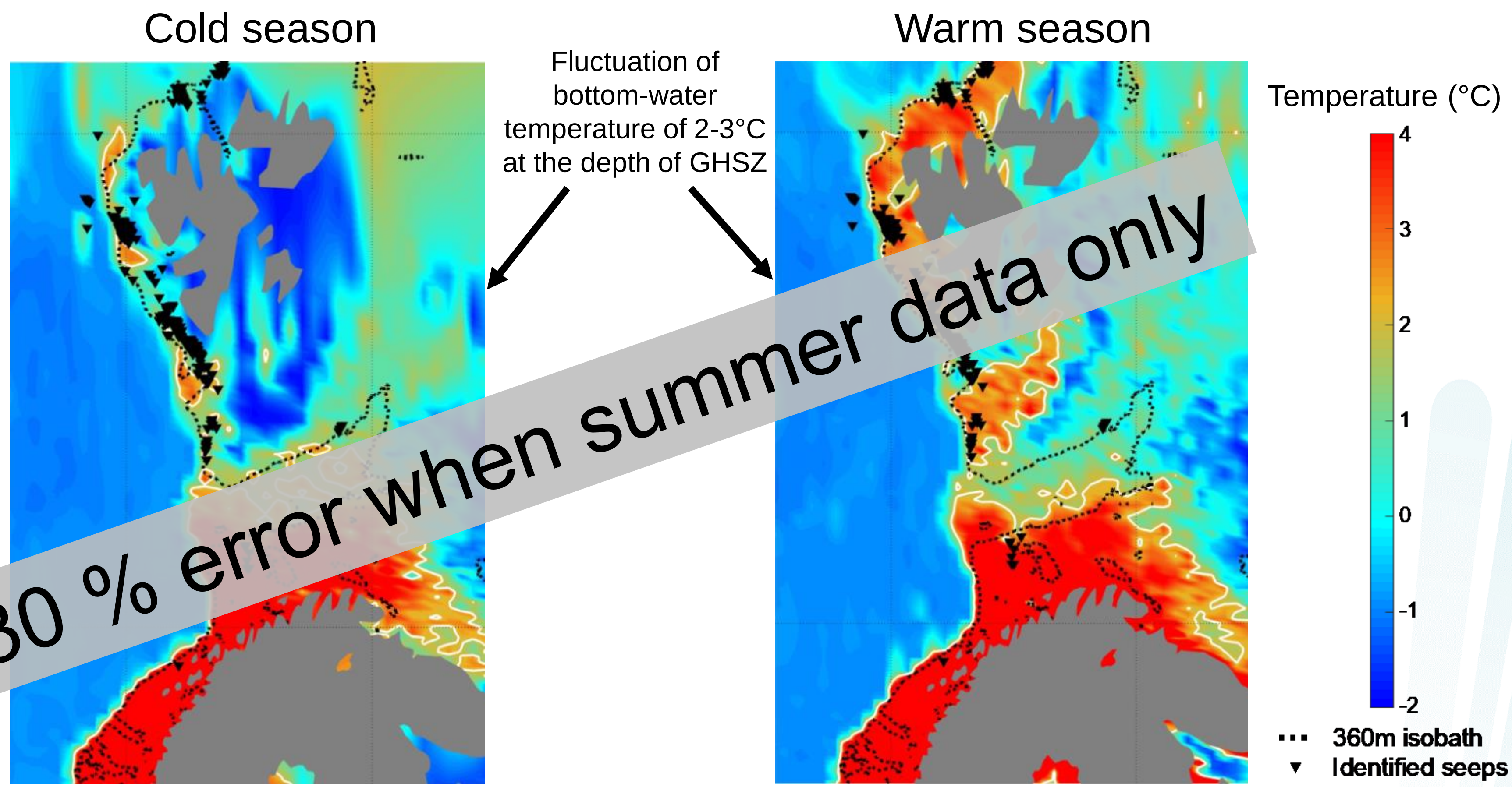
Summary diagram





Consolidation of small hydrate patches in upper sediments during low temperatures, that depletes when hydrates dissociate with higher temperature.

Implications for methane budget?



30 % error when summer data only

Based on summer budgets only : 2 730 mol CH_4 yr^{-1} m^{-1} → 1.75 gigamol CH_4 yr^{-1}

Based on summer and winter budget : 2 140 mol CH_4 yr^{-1} m^{-1} → 1.35 gigamol CH_4 yr^{-1}

Take-home messages

- Methane seepage activity almost halved in cold temperature conditions offshore Svalbard
- Most decrease occurs in the shallower part, consistent with deepening of GHSZ
- High spatial variability in flow rates
- Methane concentration ~80% lower in cold bottom temperature
- Strong reduction of microbial activity in cold water temperature
- Seasonal shift of the GHSZ limit suggests formation of gas hydrates in the upper sediments during the cold season.
- Necessity to account for seasonal cyclicity in future assessments of regional and global CH_4 budget from marine methane seeps
- In a warming Arctic, GHSZ could shift to deeper areas, potentially exposing areas where hydrates are permanently stable at present-day temperature conditions