The fate of sediment storehouses of ancient methane in a warming Arctic Ocean

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Outline

• Introduction
  - Methane sources and sinks in the Arctic Ocean
  - Arctic Ocean methane-climate feedback

• State of the science on:
  - Methane hydrates and subsea permafrost in arctic sediment
  - Role of microbes in methane production and consumption
  - Evidence and outlook on the Arctic Ocean methane-climate feedback
Arctic Ocean methane dynamics

- microbes in soils and terrestrial waters
- terrestrial organic matter
- microbes in water column
- marine organic matter
- atmosphere
- microbes in sediments
- gas hydrates
- deep-seated geologic gas reservoirs
- sediment organic matter
- subsea permafrost
- warming

Arctic Ocean methane (dissolved)
Arctic Ocean methane sources

Ruppel and Kessler, 2017
Arctic Ocean methane sinks

Ruppel and Kessler, 2017
Arctic Ocean methane-climate feedback
Uncertainties in this feedback loop

- Global temperature
- Stability of frozen methane sources
- Atmospheric greenhouse gas concentrations
- Methane emission to ocean
- Methane emission to atmosphere

limited by microbial methane consumption in sediments and the water column
“These findings of CH$_4$ emissions from the Arctic sea floor add to our understanding of the atmospheric CH$_4$ budget, but they do not show that Arctic warming has produced a positive feedback in radiative forcing by causing these emissions to increase recently. A newly discovered CH$_4$ source is not necessarily a changing source, much less a source that is changing in response to Arctic warming.”

-Comment by Petrenko et al. (2010) in Science
Hydrate reservoir and its role today

Historical estimate (1988)
Current estimate (2018)
Nominal methane emissions from hydrates to the atm. relative to other sources

Subsea permafrost has been thermally degrading throughout the Holocene

Overduin et al., 2019
Extent of subsea permafrost is *not* to the shelf edge

Brothers et al., 2016
Subsea PF is only found in a limited band of this shelf, in waters <25 m deep.

Ruppel et al., 2016
An image of a seep doesn’t tell the whole story

Westbrook et al., 2009

McGinnis et al., 2006
Methane removal processes are strong in 100-150 m deep waters

Lund Myhre et al., 2016

Graves et al., 2015
How prevalent is *in situ*-produced methane in shelf waters?

Repeta et al., 2016

Lenhart et al., 2016
Are ancient sources of methane being emitted from the Arctic Ocean to the atmosphere?
Study area: Alaskan Beaufort Sea

- Cruise in late Aug. – early Sept. 2015
- Water depth of stations ranged from 2 – 40 m
- Natural abundance $^{14}$C study
$^{14}$C was used to fingerprint the sources of dissolved methane

Sparrow et al., 2018
Samples were collected from 30,000 L SW for each $^{14}\text{C}$-methane sample

Sparrow and Kessler, 2017
300 L of gas was extracted from the water and compressed into a 2 L cylinder.

Sparrow and Kessler, 2017
“Decoupling” of surface and deep waters observed within the shallow shelf waters

Sparrow et al., 2018

Table 1. Calculated fractions of ancient and modern C-sourced CH₄ in each sample.

<table>
<thead>
<tr>
<th>Station</th>
<th>Water depth (m)</th>
<th>Distance offshore (km)</th>
<th>Sample type</th>
<th>Ancient C-sourced CH₄ fraction, $f_a$</th>
<th>Atmospheric-sourced CH₄ fraction, $f_a$</th>
<th>In situ produced CH₄ fraction, $f_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>Lagoon</td>
<td>0.18 ± 0.06</td>
<td>0.47 ± 0.18</td>
<td>0.35 ± 0.25</td>
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<tr>
<td>2</td>
<td>3</td>
<td>2</td>
<td>Lagoon</td>
<td>0.50 ± 0.04</td>
<td>0.23 ± 0.12</td>
<td>0.27 ± 0.17</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
<td>12</td>
<td>Surface</td>
<td>0.25 ± 0.06</td>
<td>0.37 ± 0.18</td>
<td>0.37 ± 0.24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Near-seafloor</td>
<td>0.60 ± 0.04</td>
<td>0.18 ± 0.10</td>
<td>0.22 ± 0.13</td>
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<tr>
<td>4</td>
<td>15</td>
<td>10</td>
<td>Surface</td>
<td>0.39 ± 0.05</td>
<td>0.29 ± 0.15</td>
<td>0.33 ± 0.20</td>
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<tr>
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<td>Near-seafloor</td>
<td>0.45 ± 0.05</td>
<td>0.25 ± 0.14</td>
<td>0.30 ± 0.18</td>
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<tr>
<td>5</td>
<td>13</td>
<td>18</td>
<td>Surface</td>
<td>0.42 ± 0.05</td>
<td>0.27 ± 0.14</td>
<td>0.31 ± 0.19</td>
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<td>Near-seafloor</td>
<td>0.58 ± 0.04</td>
<td>0.19 ± 0.10</td>
<td>0.23 ± 0.14</td>
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<tr>
<td>6</td>
<td>19</td>
<td>27</td>
<td>Surface</td>
<td>0.53 ± 0.04</td>
<td>0.21 ± 0.12</td>
<td>0.26 ± 0.16</td>
</tr>
<tr>
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<td>Near-seafloor</td>
<td>0.83 ± 0.02</td>
<td>0.07 ± 0.04</td>
<td>0.10 ± 0.06</td>
</tr>
<tr>
<td>7</td>
<td>28</td>
<td>48</td>
<td>Surface</td>
<td>0.10 ± 0.03</td>
<td>0.72 ± 0.10</td>
<td>0.18 ± 0.13</td>
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<tr>
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<td>Near-seafloor</td>
<td>0.66 ± 0.02</td>
<td>0.06 ± 0.04</td>
<td>0.08 ± 0.05</td>
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<tr>
<td>8</td>
<td>38</td>
<td>69</td>
<td>Surface</td>
<td>0.07 ± 0.03</td>
<td>0.79 ± 0.07</td>
<td>0.14 ± 0.10</td>
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<td>Near-seafloor</td>
<td>0.61 ± 0.03</td>
<td>0.17 ± 0.10</td>
<td>0.22 ± 0.13</td>
</tr>
</tbody>
</table>
Modern sources of methane dominate in surface waters where depth ≥ 30 m

- Ancient sources are contributing to the dissolved methane pool
- Surface water methane in very shallow waters (<20 m) had significant ancient contributions (25-50%)
- In waters ≥30 m, surface water methane had very little ancient contributions (5-10%)
- Study proves existence of the Arctic Ocean methane-climate feedback, however, it remains undetectable in atmospheric methane data

Sparrow et al., 2018
Thanks!

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