Gases in Ice

and around

LANL: S. Elliott, E. Hunke, N. Jeffery, M. Maltrud
IARC: C. Deal, M. Jin
LBL: M. Reagan, G. Moridis
LLNL: P. Cameron Smith, D. Bergmann
Others: B. Loose, J. Stefels, M. Levasseur

U.S. DOE SciDAC for Earth System Modeling, Plus Gas Hydrates and IMPACTS methane cycling
OUTLINE: Gases of the Ice Domain

OPENING MONTAGE – volatiles on parade

ECOLOGY first but MINERALOGY close behind

Extreme THERMO and C BUDGETS coming fast

ORGANOSULFUR in ice and surroundings

METHANE BUBBLES below and to the pack

OTHER compounds, issues
CO₂, DMS, O₂, CH₄

Loose et al. 2011
Deboer et al. 2011
Light et al. 2002
Obzhirov et al. 2004
Shakhova et al. 2009
All roads lead to ecodynamics, but...

N, Si, Fe drive:
\[ n\text{CO}_2 + n\text{H}_2\text{O} = (\text{CH}_2\text{O})_n + n\text{O}_2 + \Delta \text{alkalinity} \]
\[ \text{Ca}_2^+ + \text{CO}_3^{2-} = \text{ikaite} + \Delta \text{alkalinity} \]
\[ \text{H}_2\text{O.CO}_2 = \text{H}^+ + \text{HCO}_3^- \]
\[ \text{HCO}_3^- = \text{H}^+ + \text{CO}_3^{2-} \]
Vertical and ice-air transfer
All hypersaline: Pitzer eqs.
Extreme Thermochemistry

Millero et al., several? No, CRREL as usual
Pitzer equations - just Debye-Huckel on steroids
In spring, $\text{CaCO}_3$ trapped within sea ice dissolves. This process consumes $\text{CO}_2$.

Budget of winter and spring processes is a net sink of $\text{CO}_2$. It depends on:

- ratio of $\text{CaCO}_3$ trapped vs $\text{CO}_2$ expelled (?)
- quantity of $\text{CO}_2$ which pass below the pycnocline during the autumn-winter (?)

Rysgaard et al., 2007, Delille et al., in prep.
DMS via CICE: beneath, residual
Major Constituents

O$_2$, photo-radical chemistry
- Biological stress
Nitrogen redox:
- Nitrification, N$_2$O
(Which incidentally…
(Points to rest of N system…
(Reduced gases too, NH$_3$/NH$_4^+$))
Bubble rise for DOE Impacts and Gas Hydrates

{Swap in latest runs, methane trapped below ice…}
Bubbles and Futures

<table>
<thead>
<tr>
<th>Percent CH₄, Atlantic Layer to Arctic Mixed Layer (conservative Kᵥ)</th>
<th>Bubble Rise (vertical from destabilization at 350)</th>
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<tbody>
<tr>
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<td>0 m</td>
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<tr>
<td></td>
<td>(floor up)</td>
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<tr>
<td><strong>Circuit</strong>&lt;br&gt;1,000 km</td>
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<td>&gt;10,000 km</td>
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<td>(GIN mix)</td>
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(a) ads - adsorption<br>des - desorption<br>diff - diffusion<br>conv - convection
...and (ever) more

Organic surface chemistry
Transfer from leads
Halogenates, I₂
By these criteria, rank order for high latitude cycles:

- Ice chlorophyll (surface darkening)
- DMS
- Organics tweak sea-air transfer
- CH$_4$
- Organics tweak aerosol
- Seeding tweaks sea-air transfer
- Open, brine, skeletal C cycles
- Aerosol/ice iron cycle
- Ice nitrogen (NH$_3$/N$_2$O)
- O$_2$ and radical photochemistry

Note: Order 10$^2$ characters – IPCC does same job in 10$^6$. 

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