Biogeochemical controls on Arctic Ocean Acidification

Dr. Melissa Chierici
Senior Scientist
Institute of Marine Research
Norway
What is Ocean Acidification?
Effects of Ocean Acidification on organisms
Arctic Ocean is particularly vulnerable!
Observations
Climate change ↔ Ocean Acidification
Unknowns
On-going projects
Atmospheric Carbon Dioxide concentration shows a dramatic and fast increase from 280 till ca 390 ppm in a century. Rate: +1.7 ppm/year
The ocean has taken up about 50% of anthropogenic CO$_2$

- Increased oceanic CO$_2$ concentration
- Decrease in pH (-30%) and carbonate ion concentration [CO$_3^{2-}$]

$\Delta p$H: -0.1 per century
Time serie data >20 year shows changes in ocean CO$_2$ system

- Time serie data from 1984 to 2008 shows increase pCO$_2$ and decrease in pH and CO$_3^{2-}$ (i.e. CaCO$_3$ saturation, $\Omega$)

Surface water changes
Twice as fast pH decrease than predicted

- pCO$_2$: +2.1 ppm/year
- pH: -0.002 /year
- $\Omega$Ar: -0.007 /year
Ocean Acidification may affect the whole marine ecosystem

$[\text{CO}_3^{2-}]$: Calcification (shells, skeleton... Juveniles, larvae

pH:
- Ion exchange/transport
- Enzyme activity
- Protein functioning
- Nitrification
- Behaviour/signal substances

Inside organisms Molecular level

Bio-availability of micro-nutrients (Fe, Mn, Cu...)
Arctic Ocean is vulnerable

<table>
<thead>
<tr>
<th>&quot;HERITAGE&quot;</th>
<th>ENVIRONMENT</th>
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<tbody>
<tr>
<td>Lots of CO₂ $\rightarrow$ Low carbonate and pH</td>
<td>Increased CO₂</td>
</tr>
<tr>
<td>Lots of sea-ice</td>
<td>Freezing/melting</td>
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<tr>
<td>Freshwater</td>
<td>Freshening</td>
</tr>
<tr>
<td>Permafrost</td>
<td>Thawing</td>
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<tr>
<td>Methane hydrates</td>
<td>Mobilization/Warmer bottom water</td>
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</tbody>
</table>
Polar oceans will become undersaturated ($\Omega<1$) first (blue).

Arctic Ocean: 2030 (undersaturated at $pCO_2$ atm of 450 ppm)

Antarctic: Year 2050

$\Omega = [CO_3^{2-}]_{sw}/[CO_3^{2-}]_{sat}$

$\Omega < 1$ undersaturated, $CaCO_3$ dissolves

$\Omega > 1$ supersaturated

Coral reefs need $\Omega=3.5-4$

Model prediction, Steinacher et al., 2009

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Undersaturation of aragonite ($\Omega_{\text{Ar}}<1$) in the Arctic summer 2005

Aragonite-undersaturated waters on the freshwater-influenced shelves of the western Arctic Ocean in summer 2005, substantially sooner than predicted by recent dynamic models by 2030.
Seasonal variability of $\Omega$ in upper <60 m

Chierici et al., 2011, JGR-Oceans

Primary production
Ice melt

Primary production
Ice melt

$\Omega_{Ar}$

$\Omega_{Ca}$

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Chierici et al., 2011, JGR-Oceans
Summary of major drivers of monthly change in $\Omega Ar$

**Biological processes** contributed most to the change: 50%

Physical mixing = S+ sea-ice melt: ~20%

Temperature played a minor role: ~10%
Coupling between Climate Change and OA

- Increased freshwater addition (melt water, precipitation and river runoff)
  → Enhance OA
  → increase organic matter to ocean
  → Enhance OA

- Warming (surface): → less CO$_2$ solubility
  → Limit OA

But at bottom:

- Thawing of permafrost → more organic matter
  → Enhance OA

and

- Release of Methane hydrates
  → Enhance OA

River discharge

Projected change in permafrost boundary

Lind&Ingvaldsen, 2011

ACIA, 2004
Unknowns

• Will primary production increase in a sea-ice free Arctic?
• Role of sea-ice? Will less summer sea-ice lead to more CO$_2$ uptake?
• What is the role of brine and CaCO$_3$ formation in sea-ice relative to an open Arctic (i.e. facilitate direct uptake)?
• Natural variability of CO$_2$ system (i.e. OA state)?
• Will warming lead to release of methane?
ON-GOING PROJECTS

Ocean Acidification Flagship, Fram centre, Tromsø, Norway
Leadership: Nalan Koç (NPI) and Melissa Chierici (IMR)

WP1: Establishing the Current Status of OA in the Norwegian Arctic – OA\textsuperscript{STATE}
The Role of Sea Ice on CO\textsubscript{2} exchange and CaCO\textsubscript{3} saturation - SICCA

WP2: Impact of OA on Arctic organisms

WP3: Socio-economic impact of OA

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TUSEN TAKK!

Arigatou Gozaimasu

Norwegian Embassy  Innovation Norway  NFR