Catlin Arctic Survey 2010
Ocean Acidification

• What are Catlin Arctic Surveys
• Introduction to the issue: Ocean Acidification
• An Ice Base and an Exploration Team
• Sampling and Experiments
  • Observational (Biochemistry, Biology, CO2 flux)
  • Experimental (Mesocosms)
• The next data set: Catlin Arctic Survey 2011
• Longer-term research
Ocean Acidification in the Arctic 2010/2011

• Catlin Group – title sponsor
• Geo Mission
  o Operate Catlin Arctic Survey
  o Environmental sponsorship agency
  o Provide interface for private finance of quality science
• Facilitate science in extreme environments
• Arctic Sea-Ice in ‘difficult’ winter-spring time
  o Ecosystem is ‘coming-to-life’
  o No ships available/disruption to sea-ice ecosystem

www.catlinarcticsurvey.com

www.geomission.co.uk
An International Scientific Collaboration

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• Dr. Lisa Miller
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Mauna Loa Observatory, Hawaii
Monthly Average Carbon Dioxide Concentration
Data from Scripps CO₂ Program  Last updated November 2007

CO₂ Concentration (ppm)

Year

**Ocean Uptake of Atmospheric CO$_2$**

- Increased CO$_2$ is usually buffered by reaction with carbonate
- Recent uptake of CO$_2$ is too rapid for the supply of carbonate
- CO$_2$, H$^+$ (pH), HCO$_3^-$ increasing, CO$_3^{2-}$ decreasing

3 major polymorphs of Calcium carbonate (CaCO$_3$) mineral: Calcite, Aragonite, Mg-Calcite

\[ \Omega = \frac{[Ca^{2+}] [CO_3^{2-}]}{K_{sp}} \]

- $\Omega > 1$ supersaturated with respect to CaCO$_3$
- $\Omega < 1$ undersaturated with respect to CaCO$_3$ (dissolution)
Projections for Ocean Acidification

- CO₂ is ↑ so H⁺ ions are ↑ and pH is ↓
- Already changed by 0.1 pH units - 30% < in acidity
- pH could fall by 0.7 pH units by 2150
- pH has been stable for at least 25 my
Why study Ocean Acidification in the Arctic?

• Polar regions have naturally low $[\text{CO}_3^{2-}]$
  • increased CO$_2$ solubility
  • cold sensitivity of acid-base dissociation coefficients
  • ocean mixing patterns
  • reduction in availability of insoluble CaCO$_3$ species (e.g. aragonite) required by shell-bearing species
• Recent results show areas of aragonite undersaturation in some northern polar seas
• Current CO$_2$ emission rates project surface waters of Arctic Ocean under-saturated for aragonite by 2100
Calcifying Marine Organisms

- Echinoderms
- coralline algae
- coccolithophores
- coral reefs
- foraminifera
- Pteropods
The Bottom of the Food Chain!

Phytoplankton

Zooplankton
Ice Base vs. Explorer Data

- Ice Base: temporal study at one location
- Explorer Data: spatial study covering numerous point locations over a period

Both very important - Need to know what changes are occurring in time (Ice Base) but also need to relate this point to a wider area of the Arctic Ocean (Explorer Data)

Image: L. Edwards

Amundsen Basin

Lomonosov Ridge

Gakkel Ridge

Alpha Ridge

Morris Jesup R.
Expedition from 85° to North Pole
Questions posed by our Ice Base scientists

- What is current state of Arctic Ocean chemistry and biology?
- How do Arctic marine communities respond to changes in ocean chemistry?
- How do individuals respond to ocean acidification – physiology, development, behaviour?
- How does sea-ice affect the flow of CO$_2$ between the atmosphere and the ocean?
Sea-Ice Base off Ellef Ringnes Island
Biochemistry/Chemistry Sampling: 15th March - 15th May

- **IB:** Depths: 0, 3, 5, 10, 20, 50, 200m/Frequency: Every 4 days
- **Ice Coring**
- **ET:** Depths: 0, 10m: Every 3 days

- **Chemistry**
  - Ocean Acidification (DIC/ALK/SAL/PIC)
  - Minerals (DIN/OXY/SIL/PHO)
  - Water Origins (018)

- **Biochemistry**
  - Chlorophyll(CHL)
  - Microbiology, 18S DNA (MIC)
  - Particulate Organic Carbon (POC)
  - Dissolved Organic Carbon (DOC)
Example CTD Profiles
Biology Sampling: 17th March - 30th April

- Depths: 200m to surface
- Plankton Tows
- Frequency:
  - 17th-30th March: 3X every 4 days
  - 1st-15th April: 3X every 2 days
  - 15th-30th April: Every 6 hours!

- 6 types of ‘live’ acidification experiments
- Marine zoo-plankton and phyto-plankton, identification, preservation and return South
CO$_2$ flux through sea ice

• Initially sea ice thought to be a barrier CO$_2$ but:
  – Brine within the ice keep channels open
  – Flux dependent on age of ice (older ice is fresher)

• Most measurements of CO$_2$ flux through sea ice in summer

• Winter/spring period is an interesting time
  – changes in sea ice cover begin
  – biological activity increases

Image: L. Edwards
Eddy Covariance/Dome Experiments
Acidification Experiments

• Real-Time Acidification Experiments
  – Send key Arctic marine-life ‘into the future’
  – Crustaceans/Molluscs/Larvae/Bacteria
  – IPCC Scenarios: Now/Low/High Future

• Studies in the field
  – Shell thickness and anatomy
  – Behavior (swimming)
  – Feeding, Respiration

• Post-event lab analyses
Pteropods

perturbation experiments

Staining of the shell

Incubation at 3 different pH during 10 days

Measurement of the shell growth

Shell size-weight relationship
Bacterial response to pH variations

- Sampling of in situ sea water
- Incubation in 2l bottles at 3 pHs for 10 days

- Effect on the population diversity (genetic diversity)
- Effect on the bacterial abundance
Maintaining tight biochemistry under trying conditions!
Catlin Arctic Survey 2011
Ocean Acidification 2nd Yr.

• Continuing measures of 2010 baseline
• Light and nutrient regimes through the pre-bloom period - primary and secondary production to carbon and nutrient cycling
• Ocean acidification sensitivity experiments on primary production and copepods
• CO2 flux through sea ice during the winter-spring transition period

Image: L. Edwards
Catlin Arctic Surveys – potential models of impacts on fisheries and fish-stocks

**Catlin Arctic Surveys**

- 2009
- 2010
- 2011

**Modeling Predictions**

<table>
<thead>
<tr>
<th>Arctic Ocean Change</th>
<th>North Atlantic Change</th>
<th>North Atlantic Fish Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea-ice effect on Storm Tracks</td>
<td>Circulation ‘lanes’ switch</td>
<td>Nutrient ‘lanes’ switch</td>
</tr>
<tr>
<td>Sea-ice/open water plankton habitats</td>
<td>Plankton migration to/from Arctic</td>
<td>Plankton supply</td>
</tr>
<tr>
<td>Acidification affects plankton health/biodiversity</td>
<td>Plankton migration to/from Arctic</td>
<td>Plankton supply</td>
</tr>
<tr>
<td>Freshening disrupts plankton habitat</td>
<td>Plankton migration to/from Arctic</td>
<td>Plankton supply</td>
</tr>
<tr>
<td>Freshening disturbs water column</td>
<td>Circulation conveyor-belt disrupted</td>
<td>Colder waters</td>
</tr>
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Adult Calanoid copepods were collected from extra zooplankton trawls using a 255 mm plankton nets and counted out into 600 ml culture bottles, each containing 30-50 individuals. Exposures were run for up to two weeks with water changes every day. Measurements of survivorship, feeding behaviour and swimming behaviour were made on site. Samples were preserved for morphometric analysis, biochemical responses and energetic partitioning back at PML and University of Exeter. Nauplii copepod experiments were conducted on 3rd to 11th April and 13th to 20th April. Nauplii were collected using a 53 mm plankton tow and separated out into 9 experimental containers (50 ml falcon tubes) so that each container held 50 individual stage I nauplii. Nauplii were counted for survival and development through stages at the beginning, midway and at the end of the experiment. Surviving individuals at the end were preserved to carry out morphometric analysis back at PML. Seawater carbonate chemistry was manipulated in "header" tanks (25 L) which was then used to fill up the individual experimental bottles holding the copepods. The desired pH conditions were ambient (pH 8.0), yr 2100 scenario (pH 7.7) and yr 2300 scenario (pH 7.4). I've attached a figure for you to include (if you want) detailing the conditions of the experiment seawater. The figures show a) pH conditions in "header" tanks, b) the desired pH vs measured pH during experiment, c) the alkalinity measured in "header" tanks and d) the calculated pCO2 values.
Sample processing – an international collaboration

France

• Measurement of 400 shell linear extensions and size-weight relationships.
• Pteropod shell will be sent to Cambridge for shell structure and composition analyses.
• Bacterial abundance (cytometer) and diversity (DNA analyses) will be measured in Villefranche laboratories.
• Preliminary results expected by the end of the summer.
• Publication of the results planned for the end of the year.

UK/Canada

• Eddy Covariance data
  – Post processing and calibration
  – Combining with seawater DIC and Alkalinity and ice core data
  – Input into models
• Water chemistry and ice core analysis
• Further analysis of biology
  – e.g. Metabolomics and energetics analysis, morphometrics
• Possible preliminary results in September
Importance of CAS Data

• The Arctic is experiencing large changes (ocean and air temperature increases and sea ice cover reduction in extent and thinning)

• Arctic Ocean is considered particularly sensitive to OA changes due to the greater solubility of CO2 in cold waters – impacts likely to occur here first

• Relatively few measurements in the Arctic - Very few in the winter-spring transition period

• Represents a starting point (current state) for future measurements
  – Can’t predict future if we don’t know where we’re starting from
  – Important to build on this (more fieldwork measurements in future to study changes)

• Acidification studies on Key Species of Plankton
  – contribute major source of protein for fish-stocks
  – Vital to transfer of carbon from atmosphere to ocean floor

• Ground truthing for satellite data

• Data inputs for ocean acidification models, to make more reliable predictions

Image: L. Edwards
Using CAS 2010 data

- Modelling flux of CO$_2$ through sea ice
- Many complicated equations calculate sea ice growth and decay and interactions with ocean and atmosphere
- Can be linked to an ocean and atmosphere model and/or run with inputs of data such as satellite data and measurements from the field
- Will use some CAS 2010 measurements of CO$_2$ flux to input to the model and some for comparing with model results to try to understand how CO$_2$ flux through sea ice changes
Temperature (top) and salinity (bottom) showed only subtle changes over the time period, in particular in the surface 10 m. There was an increase in salinity except immediately below the ice surface where salinity decreased and temperature decreased indicating ice melting. Only the surface 20 m was well mixed, below which there is a steep pycnocline.

Heat fluxes changed from $Q_s$ transport into the ice & loss of $Q_L$ from the ice at beginning to small loss of $Q_s$ from the ice & small gain of $Q_L$ into the ice at end. 

$CO_2$ fluxes changed from a small release at the beginning to an uptake at the end of the period; consistent with a reduction in atmospheric $[CO_2]$. Maximum observed $CO_2$ uptake was 64 mg m$^{-2}$ d$^{-1}$. This pattern of flux change occurs at the end of a longer period of air temperature change from about -30 °C to -10 °C.

Sea-ice nutrients were present in low concentrations, suggesting that by late winter any nutrients that had been concentrated during brine formation have been consumed by biological communities in and under the sea ice. Seawater nutrients in the top 10 m were also found in low concentrations for winter-time levels. Nitrate, phosphate and silicate concentrations increased with depth. Chlorophyll levels were detectable but low in the surface 10 m, with a peak concentration found at about 5 m.
Eddy Covariance System

- Measures vertical wind speed and CO₂ concentration
- Infra-red gas analyser to measure CO₂ concentration
- Sound waves used to measure wind speed
- Together with sea-water measurements can be used to estimate flux of CO₂ through sea ice