Ocean Acidification in the Arctic: A summary from current observations.

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Ocean acidification is normally discussed in terms of global average responses – the global surface ocean pH has decreased by 0.1 unit since the industrial revolution; the global surface ocean pH is expected to continue to decrease by a further 0.3 units by the end of the 21st Century (Feely et al. 2004). However, just like temperature and global warming, we know that ocean pH differs regionally (Fig. 1), and in many locations there is also a seasonal cycle. For example, in the temperate and sub-polar regions of the North Atlantic and North Pacific, there are long-term records that the pH varies on a seasonal cycle (Bellerby et al. 2005; Wootton et al. 2008; Olafsson et al. 2009) because of changes in physical ocean properties, such as temperature and salinity, but also because of the biological processes. Microscopic plants (phytoplankton) photosynthesis in the spring and summer and take up CO_2 from the ocean thereby causing a slight increase in pH, but in winter when few plants grow, respiring organisms have a more significant affect on the pH by releasing CO_2 back into the ocean (Fig. 2; Findlay et al. 2008; Litt et al. 2010). Ocean pH change is buffered by the ions that are present in seawater (collectively known as alkalinity). A particularly important ion is carbonate ion. Carbonate ion can join with hydrogen ions to form bicarbonate ions, and in this way, over long periods of time, these ions regulate ocean pH. However when CO_2 is added to the ocean very rapidly, as is happening now, the concentration of carbonate ions is not able to keep up and so is also reduced.

The carbonate ion concentration is important for determining the saturation states of calcium carbonate ($CaCO_3$) minerals such as calcite and aragonite. These minerals are important for contributing to the carbon cycle but are also important components of many marine organisms' shells and skeletons. When there is a lower concentration of carbonate ions then the $CaCO_3$ saturations state is also going to be relatively lower. If the $CaCO_3$ saturation state falls below 1 (becomes undersaturated) then the minerals are more likely to dissolve. In the Arctic Ocean the alkalinity level is already lower than many other oceans. So the Arctic is unlikely to be able to buffer as much change in pH as other regions might.

To date most data and information about the carbon cycle and ocean acidification in the Arctic Ocean has come from fieldwork carried out in the late spring, summer or early autumn months. There are very few datasets of the wintertime pH conditions and particularly few studies have looked at how the biological processes influence the carbon cycle in late winter and early spring when light levels increase enough to stimulate phytoplankton growth. The Arctic Ocean is further complicated by sea ice, which may act to slow or stop gas exchange between the atmosphere and the ocean; sea ice also affects ocean mixing, temperature and salinity regimes, as well as the marine organisms that are present in the ocean.

Observations of the spring and summertime carbon system, including measurements of pH and the important $CaCO_3$ saturation states, have shown that the Arctic Ocean already appears to have quite low levels of both pH and $CaCO_3$ saturation states, compared to the global averages (Fig. 3). Because much of this data has come from summer research cruises (using research ships) the areas studied tend to be where there is less ice cover and where phytoplankton have already started to consume CO_2 and increase the pH level.

Our research, with the Catlin Arctic Survey in 2010 and 2011, has involved measuring the carbon system in the seawater under the sea ice in the Arctic Ocean during the late winter and early spring period. Although we are still finalising the data, we found levels of pH and carbonate ions are low in the seawater underneath the ice, but can be significantly influenced by both biological and physical processes. The sea ice itself had a pH of about 7.3 at this time of year, which is unsurprising because brine (salt) will have drained out of the sea ice when the sea ice was forming and this process will have removed much of the dissolved inorganic carbon and the alkalinity from the sea ice. Micro-organisms that live in the sea ice are continually respiring and releasing CO_2 as well, so there is a build up of CO_2 gas in the sea ice which lowers the pH.

We were also looking at how different pH levels might affect a type of zooplankton (microscopic animals) called Copepods. Copepods are quite hardy creatures as they are able to thrive in many different environmental conditions. They are able to migrate hundreds of meters vertically through the water column every day. We found that they were not significantly impacted by the changes in pH that we exposed them to in terms of their ability to survive, grow and develop. This is perhaps not surprising as the pH levels that we measured through the water column ranged from about 7.7 at 200 m to 8.0 at the surface. These natural pH levels are equivalent to what are considered the global average conditions for now (pH 8.1) ;and are predicted for the future (pH 7.7); and are the levels that we exposed the Copepods to. Additionally we must remember that there is a seasonal variability in pH. Therefore not only will the pH conditions change depending on where the organisms are living but it will also change depending on the time of year.

Marine organisms that live in these naturally variable environments will only be exposed to these low pH conditions for certain periods of their lives. They are likely to have adaptive mechanisms in their behaviour or physiology that allow them to survive these relatively short periods of stress. Understanding what these mechanism are will allow us to understand how and why some organisms may be more vulnerable than other organisms. So we are still looking deeper into the physiology of these copepods in order to understand if there are subtle changes in their energy budgets and life-history. Another important point to remember is that ocean acidification is acting to shift the range of these naturally variable systems. For example, a seasonal cycle of pH in surface waters could have a pH range from 7.7 to 8.3 (giving an average of pH 8.0). This whole range will shift as the oceans become more acidic. These surface water in the future might therefore experience pH levels from 7.4 to 8.0 (average 7.70). The marine organisms living in these conditions are therefore experiencing periods when the pH level is 7.4.

In the Arctic Ocean it is likely that the loss of sea ice due to global warming will also alter how the carbon cycle works, and how the ocean acidifies. More open water will potentially allow more CO_2 to be added to the Arctic Ocean because the waters are cold and can hold more CO_2. Also, the open waters will expose the phytoplankton to more light; giving them longer periods to photosynthesis and increasing the drawdown of CO_2 from the atmosphere as the phytoplankton use up CO_2 in the surface waters to make organic matter. What’s more, changes in water density from the melting sea ice could also affect how carbon is cycled in the ocean; by changing the rate at which carbon is removed from the surface waters.

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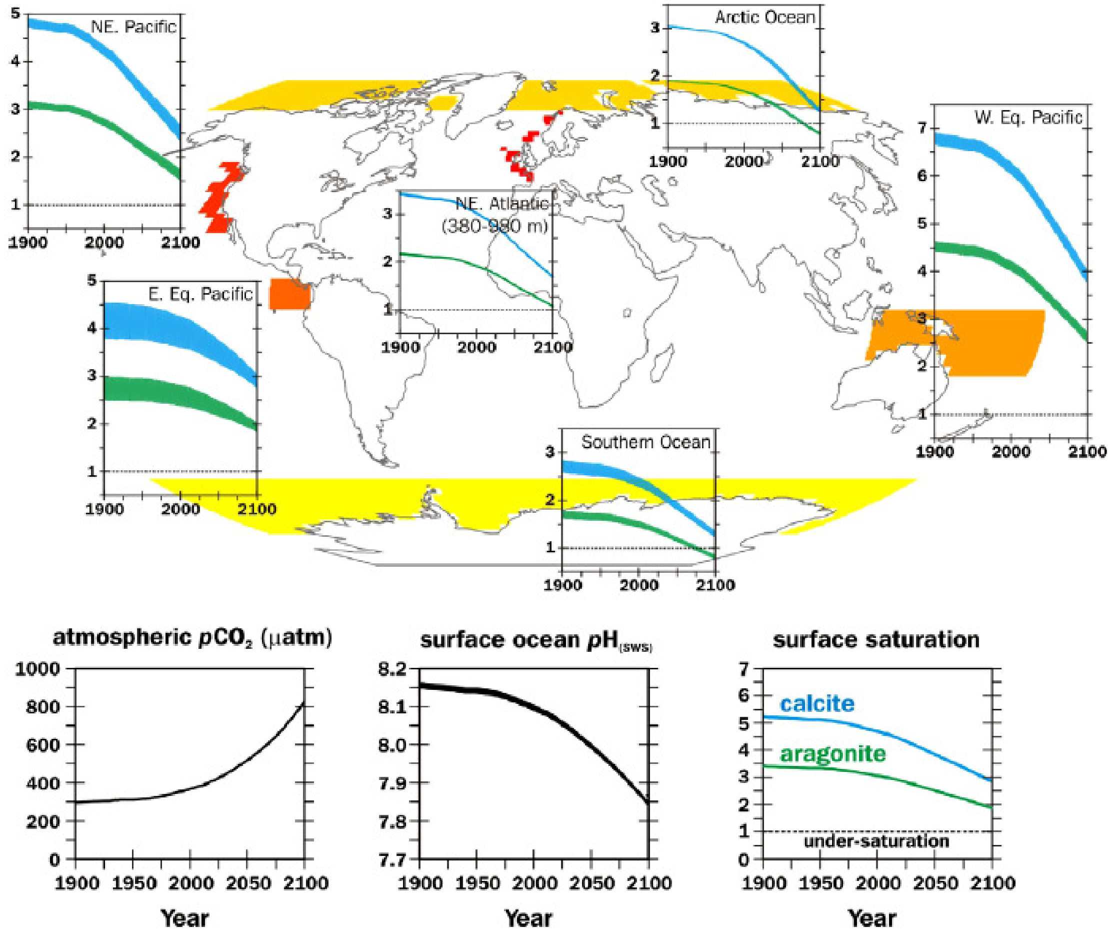

Figure 1: Projected regional changes in ocean chemistry compared to global-scale surface ocean changes. The transient simulation of climate and carbonate chemistry was performed with the UVic Earth System Climate Model using observed historical boundary conditions to 2006 and the SRES A2 scenario to 2100 (Eby et al., 2009). For each of the six illustrative high risk marine ecosystems (Arctic Ocean, Southern Ocean, NE Pacific margin, intermediate depth NE Atlantic (500–1500 m), western equatorial Pacific, eastern equatorial Pacific), the blue shaded band indicates the annual range in ocean saturation state with respect to aragonite, while the green shaded band indicates the range for calcite saturation. Area average surface ocean conditions are calculated for all regions with the exception of the NE Atlantic where area average benthic conditions between 380 and 980 m have been used. The thickness of the line indicates the seasonal range, with the threshold of undersaturated environmental conditions marked as a horizontal dash line. The varying evolution in the magnitude of the seasonal range between different regions is due to the complex interplay between changes in stratification, ocean circulation, and sea-ice extent, and distorted due to the non-linear nature of the saturation scale. The corresponding regions from which the annual ranges are calculated are shown shaded. Global ocean surface averages (bottom three panals) are shown, from left to right: CO$_2$ partial pressure, pH$_{(SWS)}$ and calcite and aragonite saturation state (Figure taken from Turley et al. 2010).

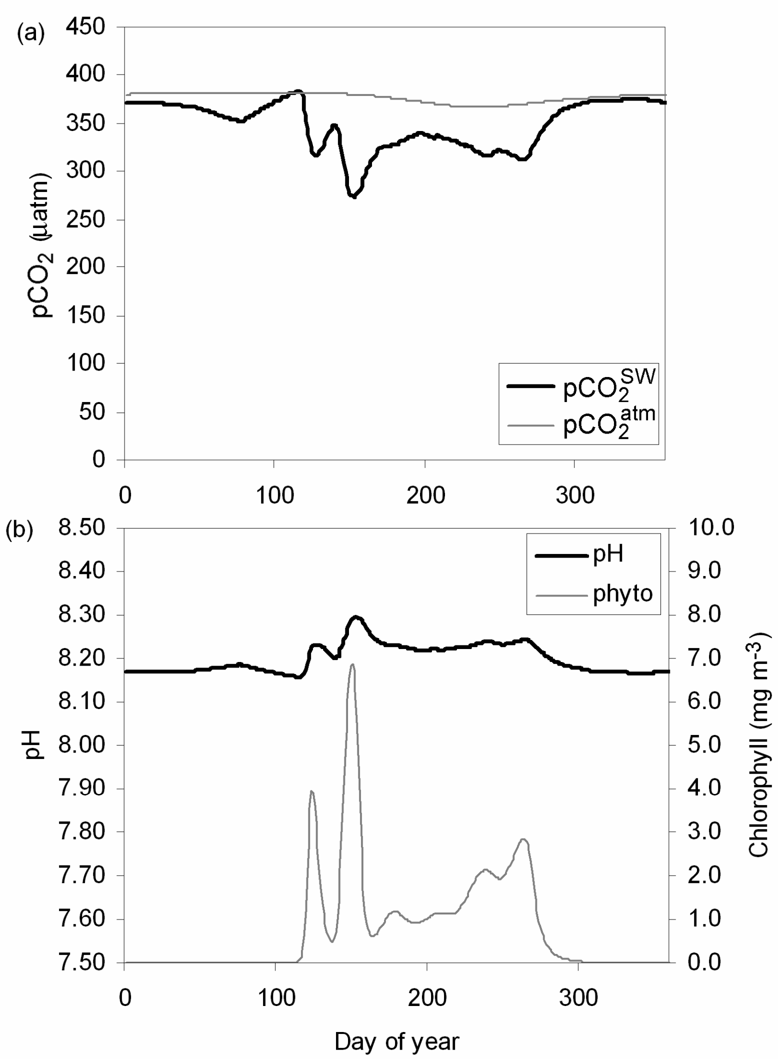

Figure 2: A modelled seasonal cycle of (a) pCO_2 in the atmosphere (pCO_2^{atm}) and in the surface ocean (pCO_2^{SW}) and (b) pH and chlorophyll (a proxy for phytoplankton) parameterised and validated using observational data from Ocean Weather Station Mike in the Norwegian Sea (66 ºN, 02 ºE) (see Findlay et al. 2008).

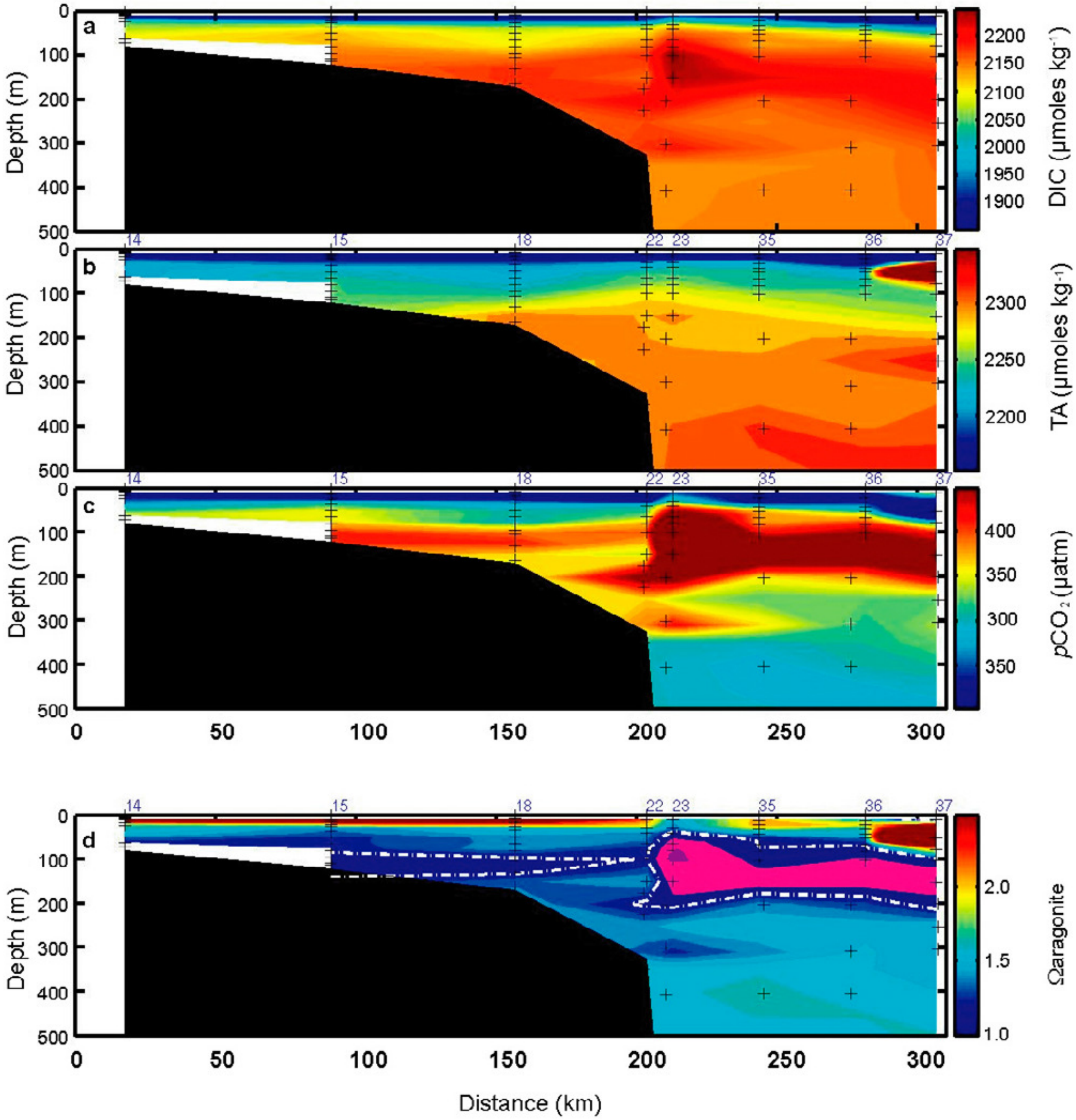

Figure 3: Representative section of (a) DIC, (b) TA, (c) pCO2, and (d) $\Omega_{\text{aragonite}}$ across the Chukchi Sea shelf into the deep Canada Basin of the Arctic Ocean at Barrow Canyon for summer 2002. Note that the pink color represents regions of aragonite under saturation (Figure taken from Bates et al. 2009).