3

Ocean Acidification

One of the most disturbing discoveries in climate science of the past 20 years is the effect that increased absorption of human-generated CO_2 is having on the subtle chemistry of Earth's ocean. Our previous calculations hinted that most of the CO_2 introduced into our atmosphere by fossil fuel burning was ending up elsewhere. Much of this "missing" CO_2 is being absorbed into the ocean. This is an excellent application of acid-base chemistry and can be characterized through the following reactions:

$$CO_2(g) + H_2O \rightleftharpoons H_2CO_3\,(aq) \quad (4)$$

$$H_2CO_2(aq) \rightleftharpoons H^+ + HCO_3^-(aq) \quad (5)$$

$$HCO_3^-(aq) \rightleftharpoons H^+ + CO_3^{2-}(aq) \quad (6)$$

The ocean buffers atmospheric CO_2 through the nimble dance between concentrations of carbonic acid (H_2CO_3) and the bicarbonate and carbonate ions (HCO_3^-, CO_3^{2-}). As CO_2 is absorbed into the ocean the buffering action of the ocean does some subtle things. Increased production of carbonic acid is accompanied by an increase in "acidity" (the number of hydronium ions (H^+)) and decrease in pH of the oceans. This in turn causes a shift between the equilibrium of bicarbonate and carbonate ion concentration. Why does this matter? Marine organisms such as corals and mollusks secrete $CaCO_3$ in several different forms, and much of the base of the aquatic food chain is critically dependent on carbonate ion concentration. As the pH of the ocean drops, so too does the carbonate ion concentration, and the solid shells of certain marine organisms become soluble in water. **Figure 3** enables to explore how changing ocean pH can be related to carbon usage as expressed in atmospheric CO_2 concentration. To quantify this, consider the change in ocean pH since the Industrial Revolution. The pre-industrial revolution pH was 8,2 while today the ocean pH is 8,1. That doesn't sound like much of a change! But let's calculate how much the actual hydronium ion content ("acidity") of the ocean has changed.

By definition a pH of 8,2 is given by

$$ph = -\log_{10}[H^+] \quad (7)$$

So the hydronium ion concentration (pre-industrial) was

$$10^{-8.2} = 6{,}31 \cdot 10^{-9}\ mol \cdot l^{-1} \quad (8)$$

A pH of 8,1 corresponds to an H^+ concentration of $7{,}94 \cdot 10^{-9}\ mol \cdot l^{-1}$. This represents an increase of 25% in the acidity of the ocean. This is already (along with temperature effects) wreaking havoc on a wide variety of marine organisms including plankton and those found in coral reefs. Currently Earth's ocean is more acidic than any time in the past 20 million years [2, 3, 4]! This will only worsen over the next century and the results could be catastrophic unless addressed now.

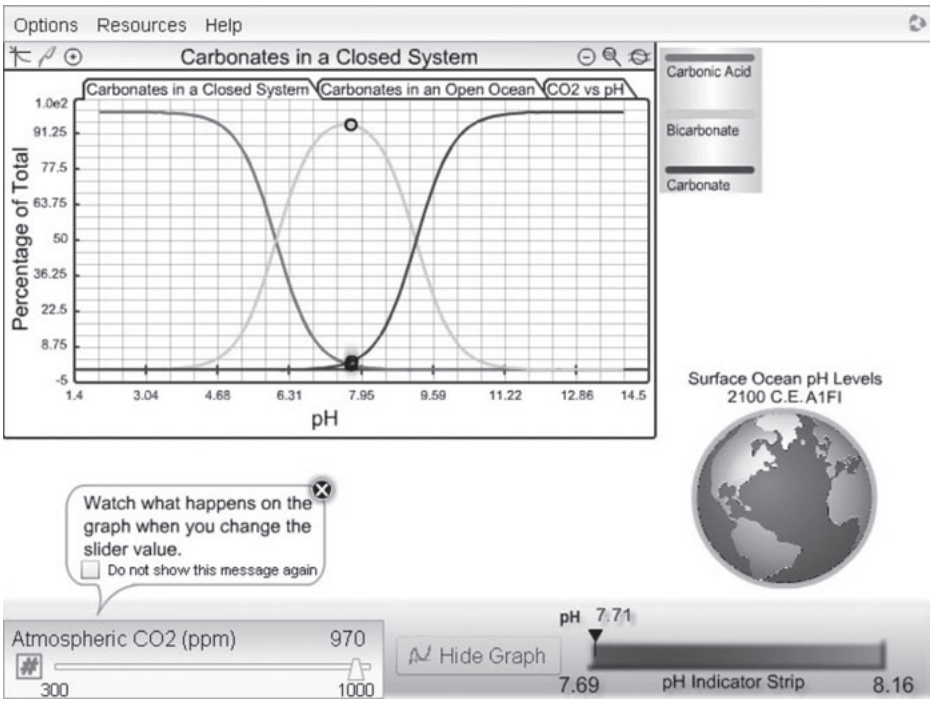

Figure 3 I An applet that enables student's to explore the relationship between atmospheric CO_2 concentration and ocean chemistry (from Visualizing and Understanding the Science of Climate Change).