Ocean Acidification

Science Partnership

NSF

California Science Project

CALIFORNIA STATE UNIVERSITY EAST BAY

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Ocean acidification is a process where the pH of the Earth's oceans is decreasing (becoming more acidic) as the CO_2 levels in the atmosphere increase.

CO_2 is readily soluble in water and ~30-40% of the anthropogenic CO_2 released into the atmosphere dissolves into the oceans and other water bodies.

CO_2 reacts with water molecules for form carbonic acid

pH is a measure of how acid or basic a substance is where

$$pH = -\log_{10}(a_{H^+})$$

Note that water is a weak acid and a weak base and may dissociate where

$$H_2O \leftrightarrow H^+ + OH^-$$

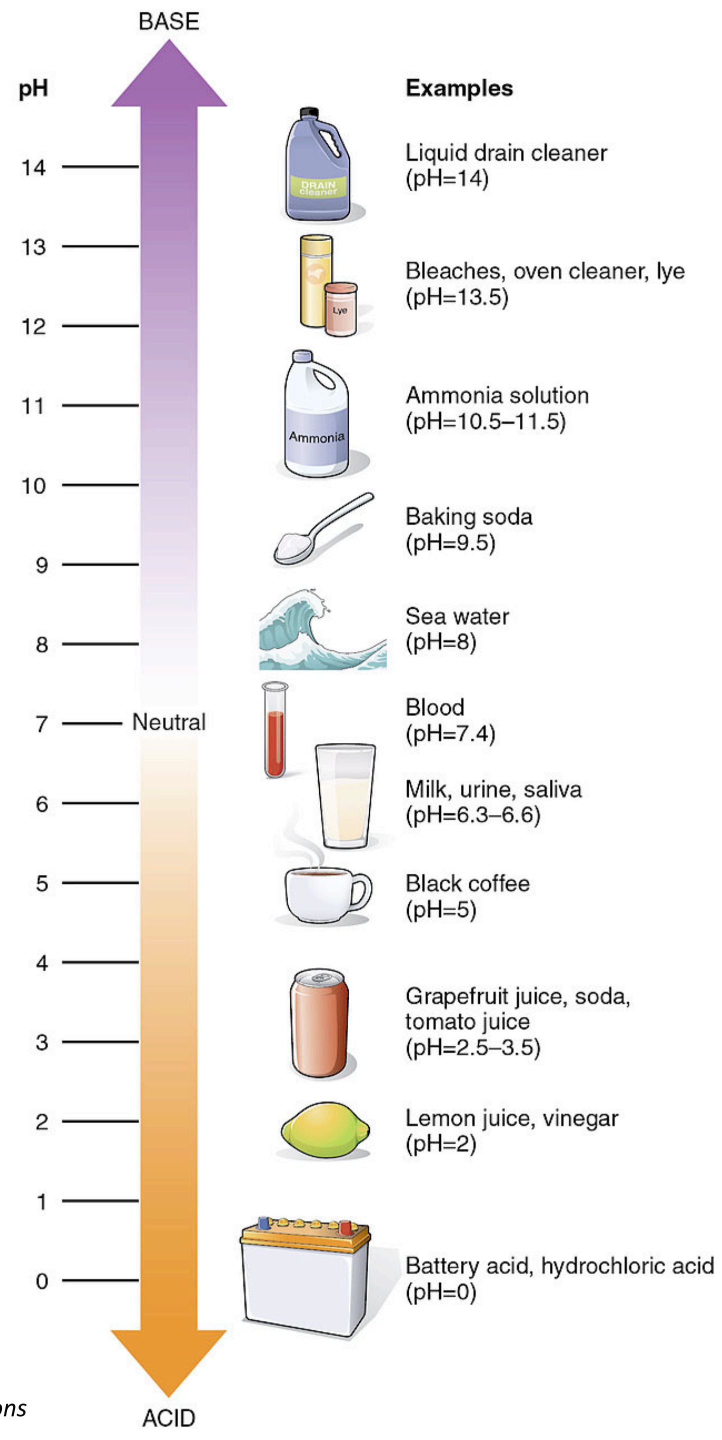
The lower the value of the pH, the higher the concentration of H^+ and the more acidic the solution.

Neutral solutions have a pH of 7.

For acidic solutions, pH < 7

For basic solutions, pH > 7

Seawater is naturally basic with a pH of ~8.

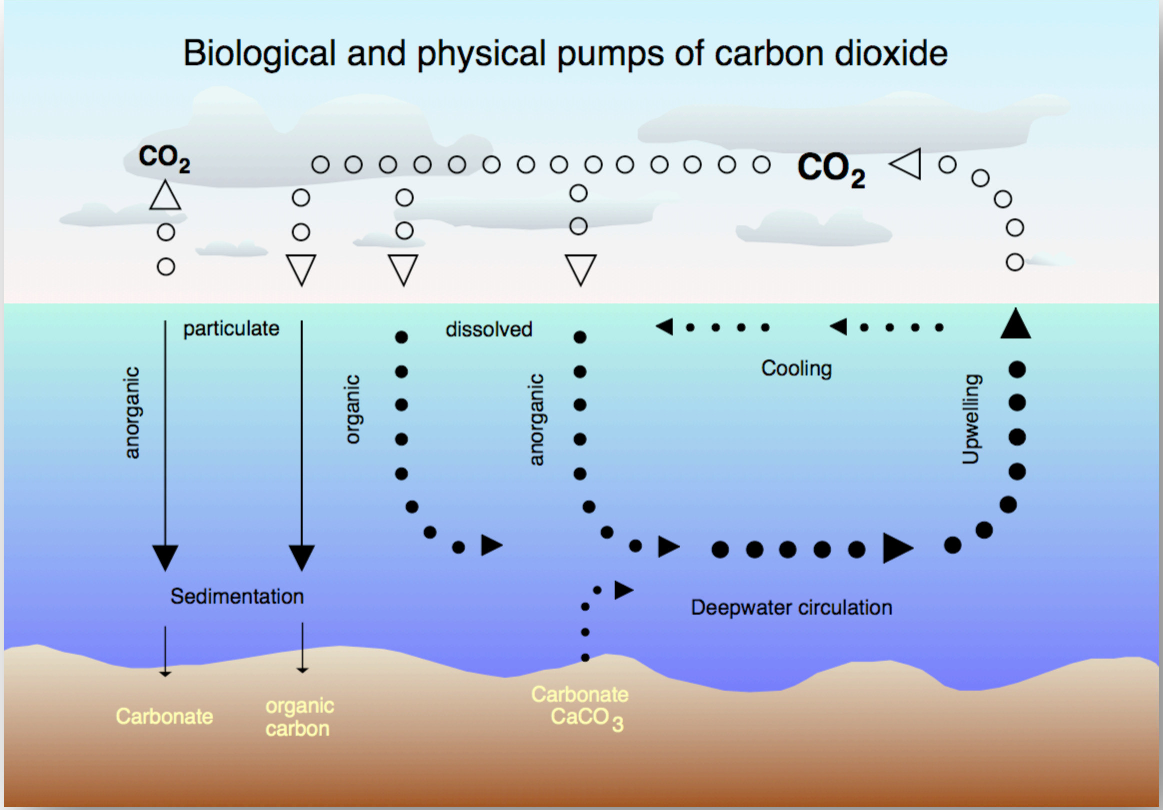


Carbon Cycle

The amount of carbon contained in the oceans is only second to the amount of carbon stored in the lithosphere. Carbon in the world's ocean consists of two types:

- Organic (derived from the biosphere)
- Inorganic (containing no C-H or C-C bonds)

Although carbon can be exchanged between these two different forms, inorganic carbon is the primary agent responsible for ocean acidification.
CO_2 is readily exchanged between the atmosphere and ocean.



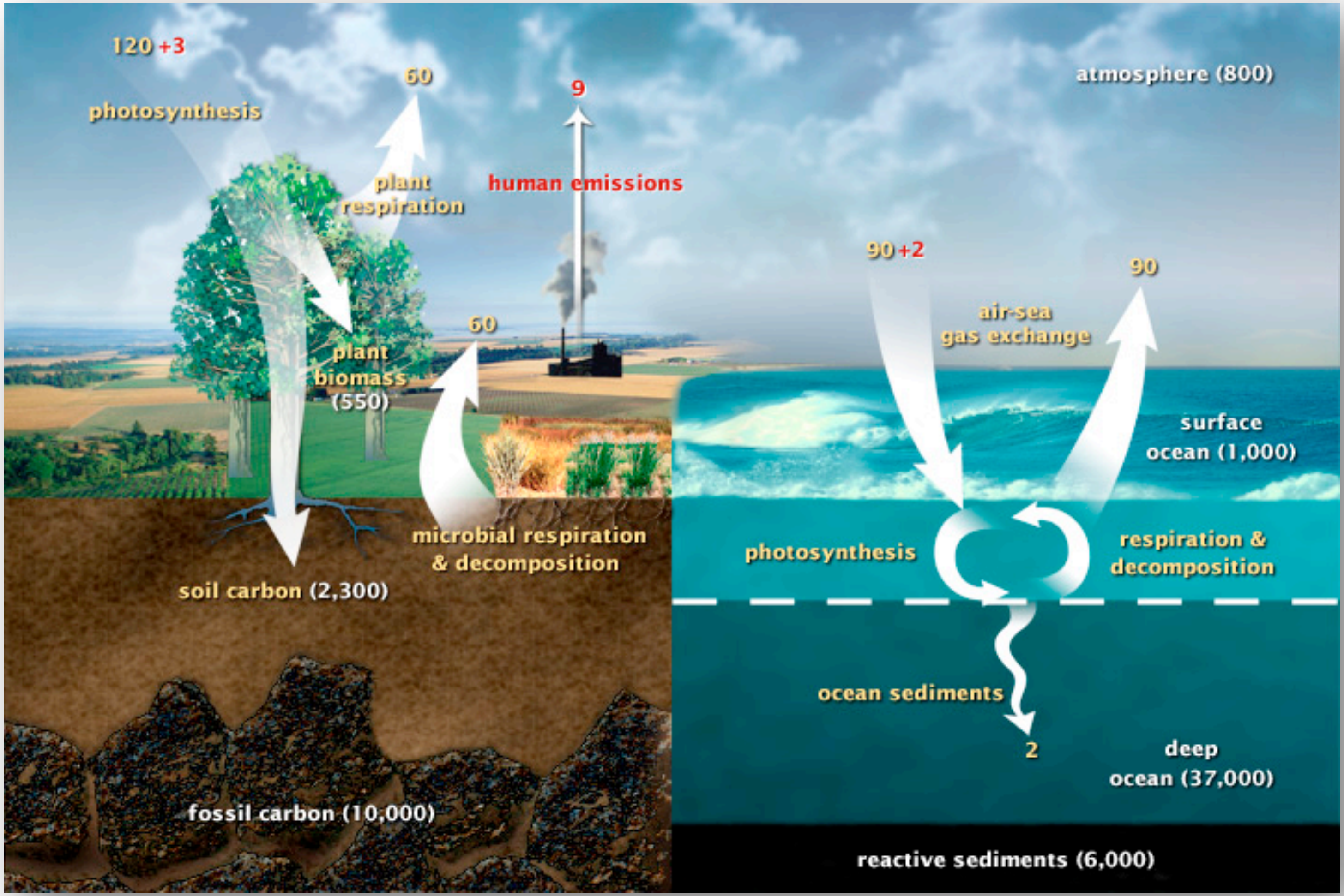
Wikimedia User: Hgrobe

Inorganic carbon exchange between the ocean and atmosphere is a control on pH in the ocean. The diagram shows the movement of carbon between land, atmosphere, and oceans.

Yellow numbers are natural fluxes.

Red are human contributions (gigatons/year).

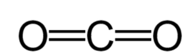
White numbers indicate stored carbon.



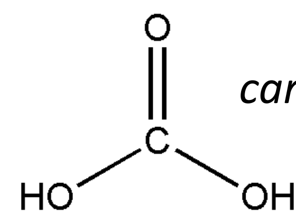
Source: U.S. DOE, Biological and Environmental Research Information System.

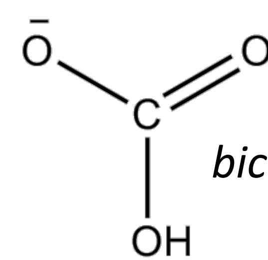
When CO_2 enters the ocean, it participates in a series of reactions:

Dissolution of CO_2:

CO_2 (atmospheric) $\rightleftharpoons$ CO_2 (dissolved)  *carbon dioxide*

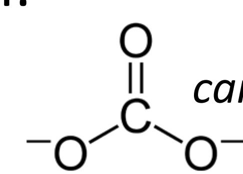
Conversion of CO_2 to carbonic acid:

CO_2 (dissolved) + $H_2O \rightleftharpoons H_2CO_3$  *carbonic acid*

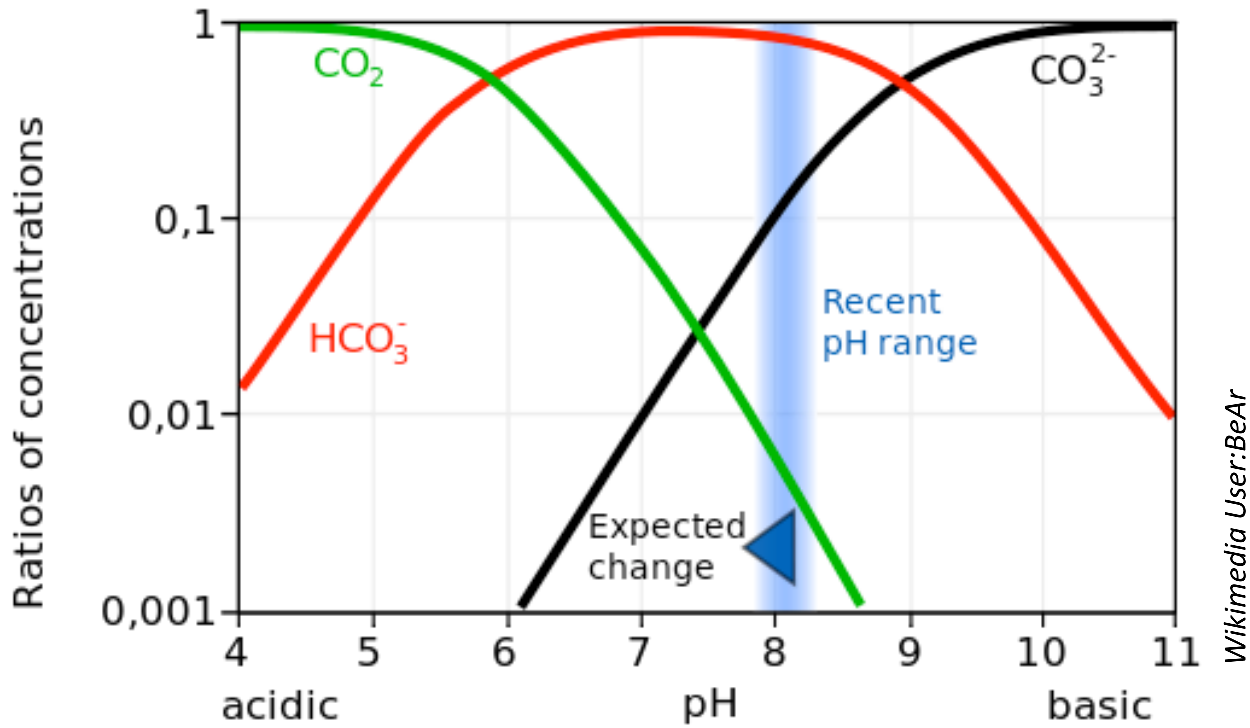
First ionization of carbonic acid to form bicarbonate: 

$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$(bicarbonate ion) *bicarbonate ion*

Second ionization to form carbonate ion:

$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$(carbonate ion)  *carbonate ion*

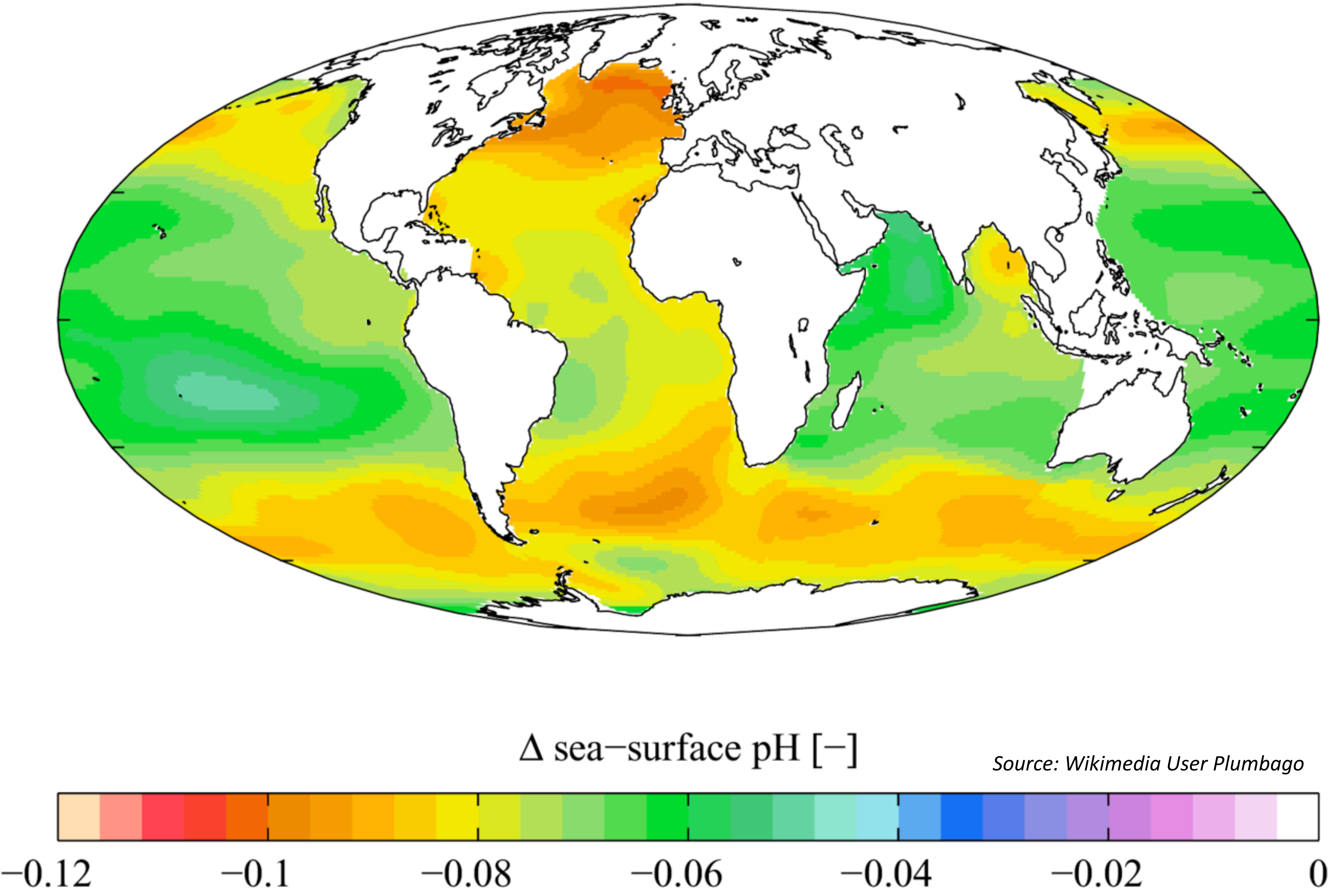
This figure shows the speciation of inorganic carbon species as a function of pH. It is clear from this diagram that bicarbonate (HCO_3^-) dominates in the oceans.



As additional CO_2 is added to the oceans, bicarbonate and carbonate ions are produced. This increases the H ions (acidity) in solution in the ocean's waters.

To maintain chemical equilibrium, carbonate is converted to bicarbonate. Thus, the dissolution of $CaCO_3$ (calcite and aragonite) contained in the shells of organisms favored.

This figure shows the estimated change in pH of seawater from the 1700s to the 1990s



Source: Wikimedia User Plumbago

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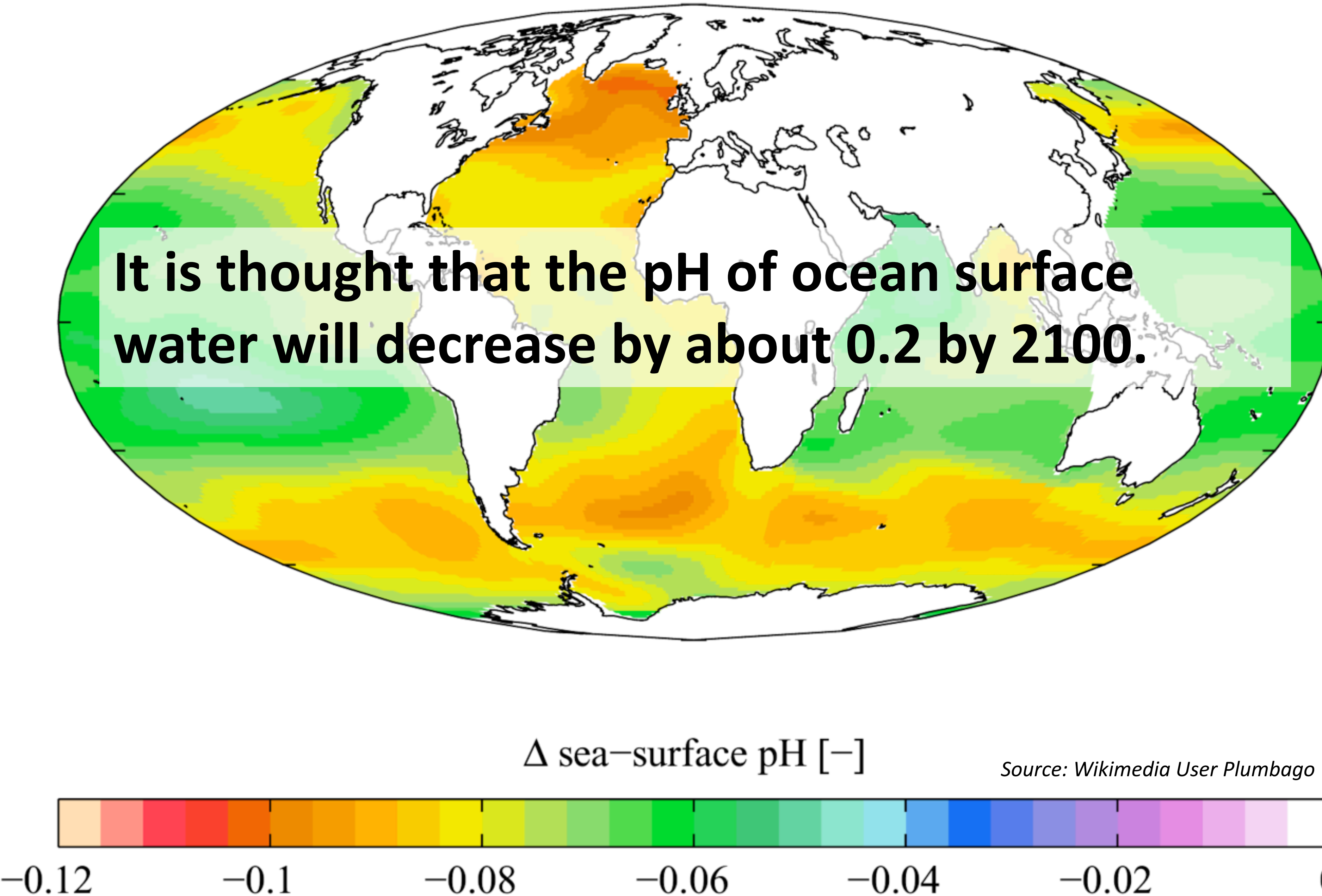


It is thought that the pH of ocean surface water will decrease by about 0.2 by 2100.

Source: Wikimedia User Plumbago

$$pH = -\log_{10}(a_{H^+})$$

- Calculate the increase in the amount of H^+ (acidity) if the pH decreases from 8.0 to 7.8.

  The activity, *a*, is a measure of the "effective concentration" of H^+ ions that are available for chemical reactions – as concentration it would be in units such as (moles H^+/liter seawater) but **don't worry about units**. Remember that $x = \log y$ and $y = 10^x$

- How does the value of the increase in the concentration of H^+ ions related to value of pH?

- What is surprising about your results?

$$pH = -\log_{10}(a_{H^+})$$

At pH = 8:

$a = 10^{-8} = 1.00 \times 10^{-8}$

At pH = 7.8:

$a = 10^{-7.8} = 1.58 \times 10^{-8}$

The increase in the activity of H+ is

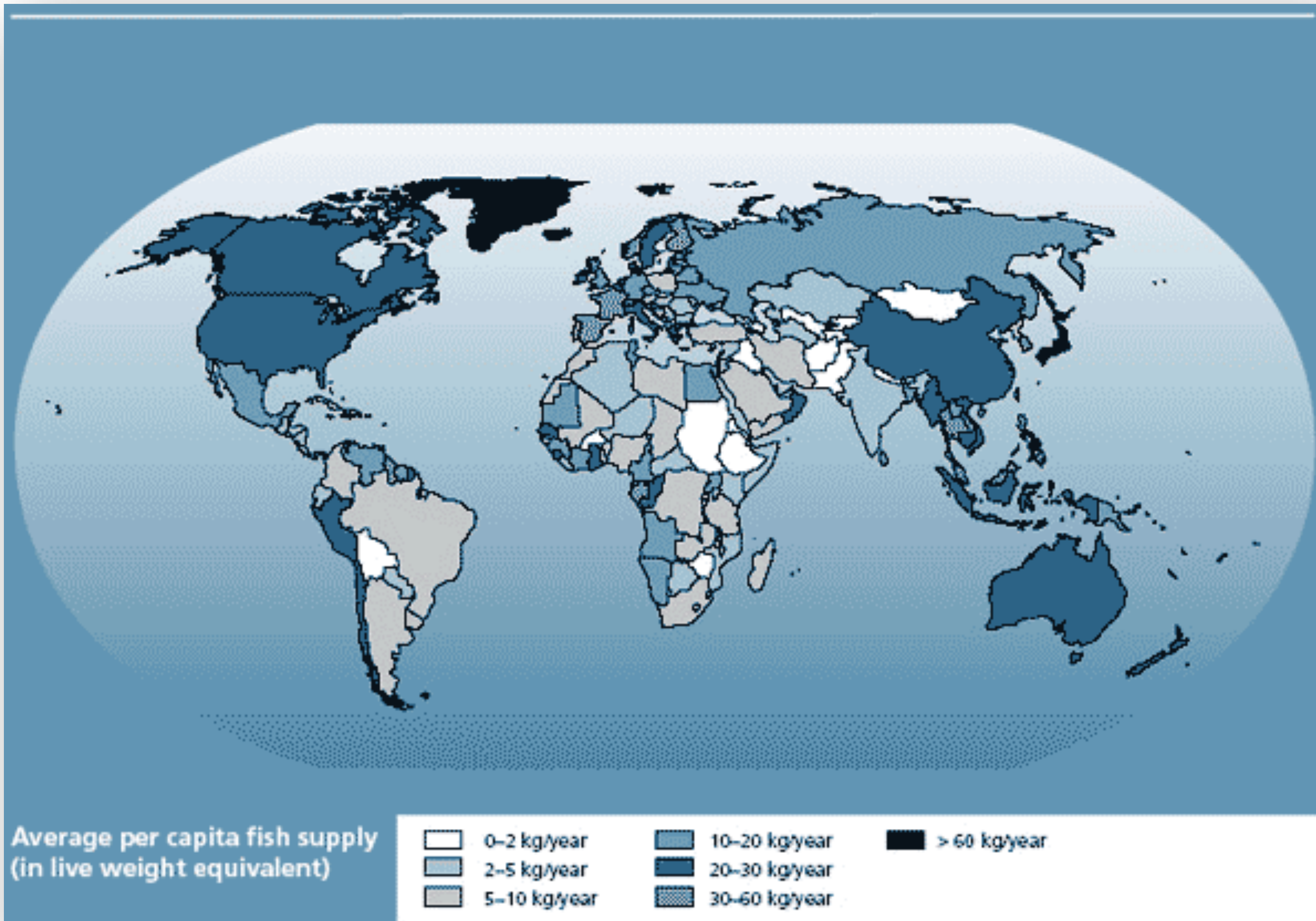
$1.58 \times 10^{-8} - 1 \times 10^{-8} = 0.58 \times 10^{-8}$

The %increase in the amount of H^+ in ocean water is

$$\left(\frac{0.58 \times 10^{-8}}{1 \times 10^{-8}}\right) \times 100 = 58\%$$

This is a significant increase in H^+ for what seems to be a small change in pH

Ocean acidification will affect marine ecosystems. In particular, ocean acidification will have a dramatic affect on the health and survivability of marine calcifying organisms. Many organisms that form carbonate shells (such as foraminifera, coccoliths, echinoderms, etc.) form the base of marine food webs.



Food and Agriculture Organization of the United Nations

Increasing ocean acidification is expected to lead to a decline in commercial fisheries.

World apparent per capita fish consumption has increased from 9.9 kg in the 1960's to 16.4 kg in 2005.