Creating Challenges for Middle and High School Science

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We will explore strategies to engage and challenge your students with looming threats to Sustainability

- Human populations continue to increase
- Problems include providing suitable food and water supplies, removing wastes, and creating enjoyable life styles
- Human activities intentionally and unintentionally impact Earth systems
- Economic resources may largely determine what will happen

- Some issues are well known—increase in atmospheric CO2 correlated with increased anthropogenic activities

ANTHROPOSPHERE

Sustainability – Challenges for the Future

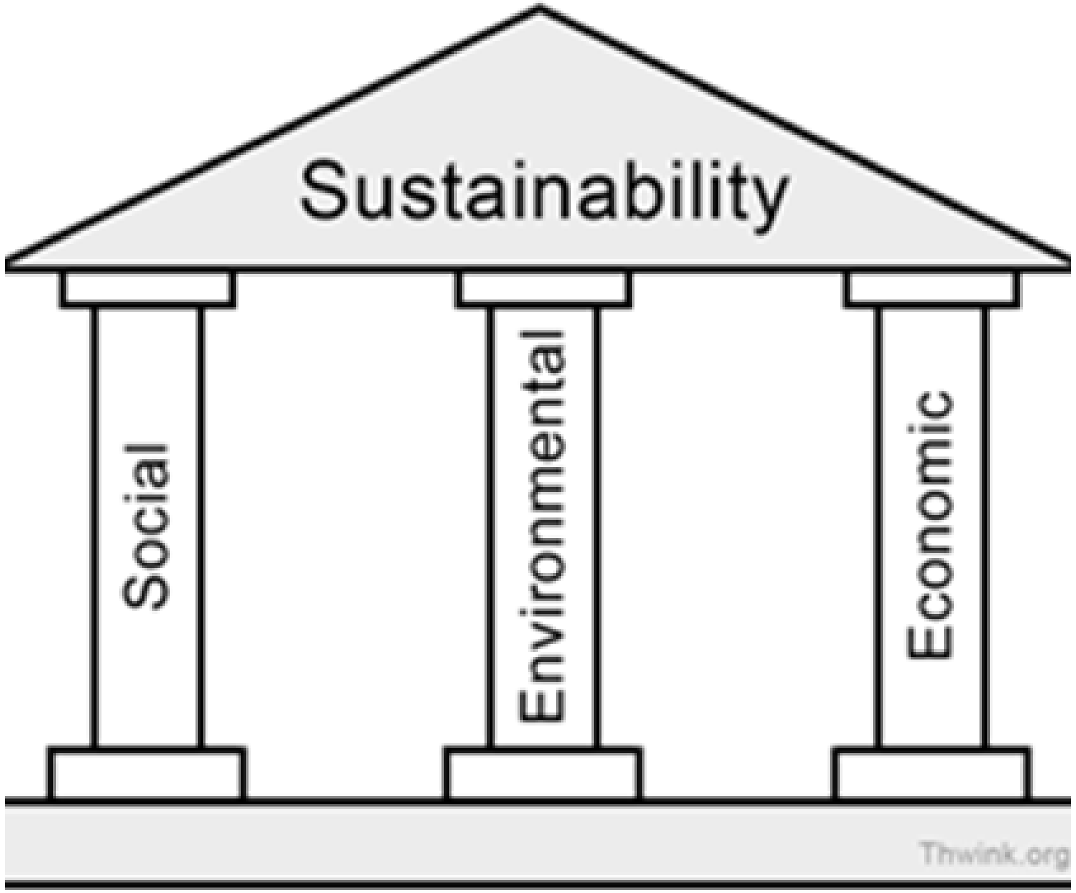
- Ability for natural systems and human needs to remain in balance indefinitely
- Concerns about effects on societies when limits are reached
- “Renewable” resources such as fresh water and timber may become “nonrenewable” when used at a rate faster than they form
- Overuse and pollution weaken natural processes

Sustainability

- "…the process of people maintaining change in a balanced environment, in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations."

  www.globalfootprints.org.

- "Three Pillars: ENVIRONMENTAL—ECONOMIC– SOCIAL



What’s the long-term goal?

- When students **engage in science investigation and engineering design**, they are able to engage deeply with phenomena as they **ask questions, collect and analyze data, generate and utilize evidence, and develop models** to support explanations and solutions.

- Constructing understanding by actively engaging in investigation and design also creates meaningful and memorable learning experiences for all students. These **experiences pique students’ curiosity** and lead to **greater interest and identity in science.**

  https://www.nap.edu/read/25216/chapter/1#vii

“A Framework for K-12 Science Education”

- By the end of grade 8. ***Human activities have significantly altered the biosphere***, sometimes damaging or destroying natural habitats and causing the extinction of many other species. But changes to Earth’s environments can have ***different impacts (negative and positive) for different living things***. Typically, as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise.
- By the end of grade 12. The ***sustainability of human societies*** and the biodiversity that supports them ***requires responsible management of natural resources***. Scientists and engineers can make major contributions—for example, by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. ***When the source of an environmental problem is understood*** and international agreement can be reached, human activities can be regulated to mitigate global impacts (e.g., acid rain and the ozone hole near Antarctica).

https://www.nap.edu/read/13165/chapter/11#196

What's the educational importance?
Selected PEs

HS-ESS3-6. **Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.** [Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from a human activity is how an increase in atmospheric carbon dioxide results in an increase in photosynthetic biomass on land and **an increase in ocean acidification, with resulting impacts on sea organism health and marine populations**.

HS-ESS3-4. **Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.*** [Clarification Statement: Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).]

Is Sustainability even achievable?

- “…the **possibility that human societies will achieve environmental sustainability has been, and continues to be, questioned**—in light of environmental degradation, climate change, overconsumption, population growth and societies' pursuit of unlimited economic growth in a closed system.”

  --worldwatch.org

  THERE ARE MANY CHALLENGES THAT STUDENTS CAN EXPLORE TO LEARN HOW TO CREATE A SUSTAINABLE WORLD.

  TODAY WE FOCUS ON ONE: **OCEAN ACIDIFICATION**.

Discussion Stop 1

- 2 minutes:

- Discuss what are some other Sustainability issues you have included in your teaching, and why you chose these.

What's Ocean Acidification?

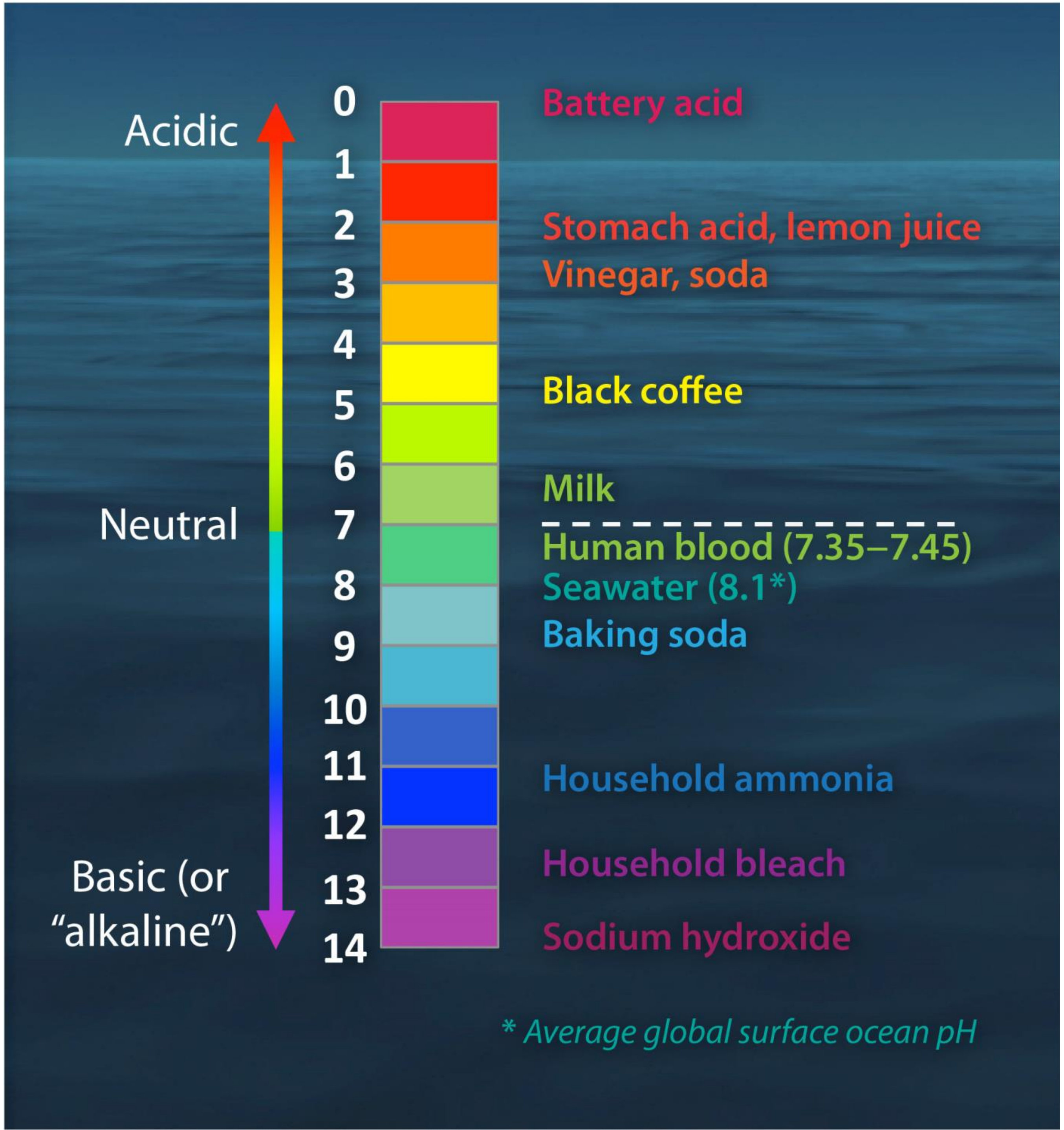
Major challenge, but less well known than global warming because it occurs out of sight beneath the ocean surface

Refers to **a decrease in the pH of the ocean** over an extended period of time caused primarily by uptake of carbon dioxide (CO_2) from the atmosphere.

Threat to many environmental factors, especially affecting plankton, corals, mollusks, and other marine organisms

pH

- Measure of the **acidity** or **baseness (alkalinity)** of a solution
- term derived from German “power of Hydrogen”
- generally defined as the “negative logarithm of the hydrogen ion concentration”
- Acidic: less than 7 Basic: higher than 7 Neutral 7.0



Remember that pH is a logarithmic scale.

Each step is an increase of 10 over the number below it.

So even a slight increase or decrease can mean a significant % change that can impact ecosystems.

https://www.pmel.noaa.gov/co2/files/phfig2-revised.jpg

Why should we be concerned about ocean acidification?

- **Ocean as a Lab: Ocean Acidification** https://oceantoday.noaa.gov/oceanasalab_oceanacid/

  (3:50 min.)

  We will look at examples of data later in this program.

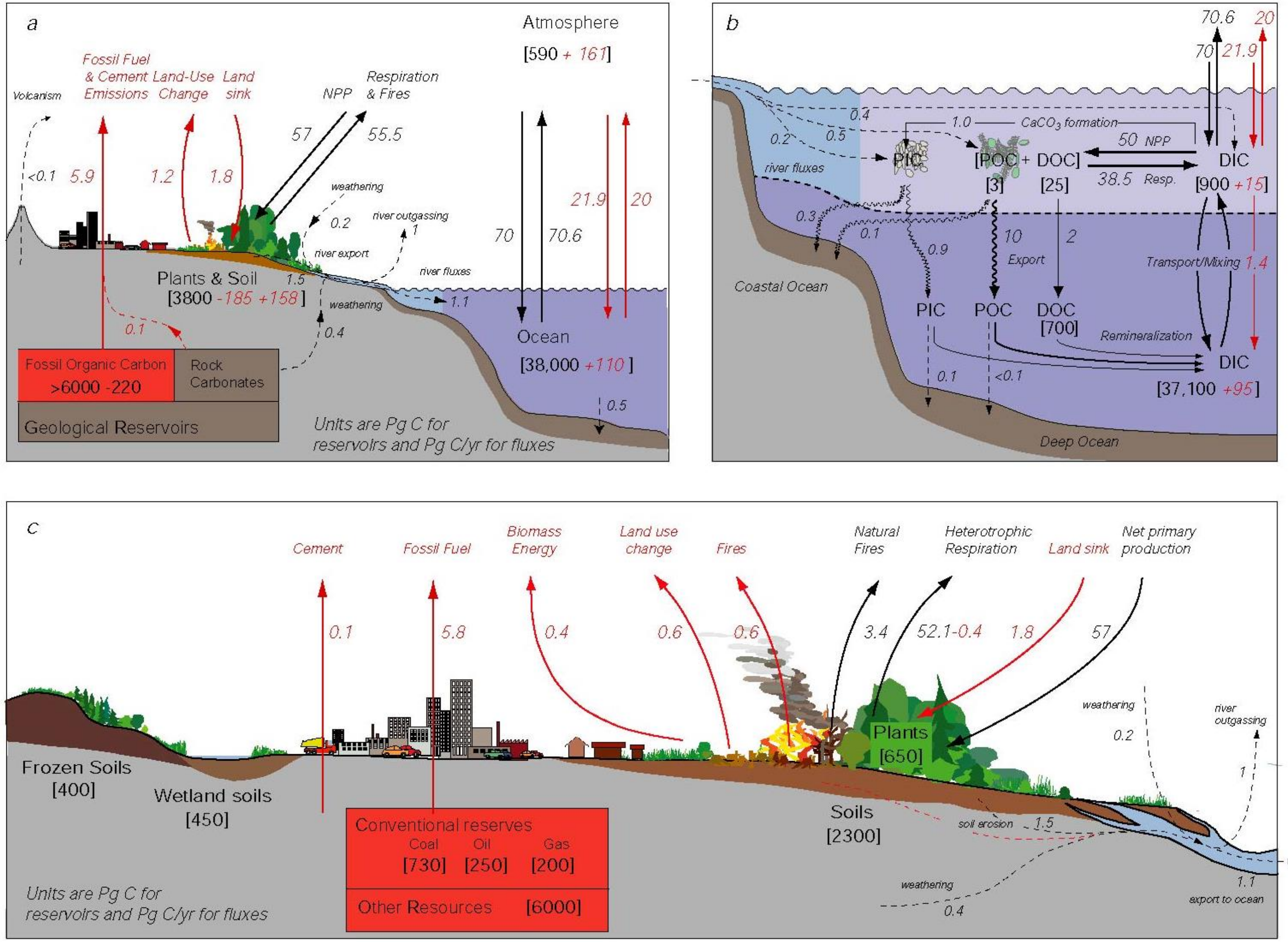
Discussion 2

- 2 minutes

- How might you want to incorporate videos into your teaching?

HMH

CO_2 movements and Ocean Acidification Are Parts of the Global Carbon Cycle

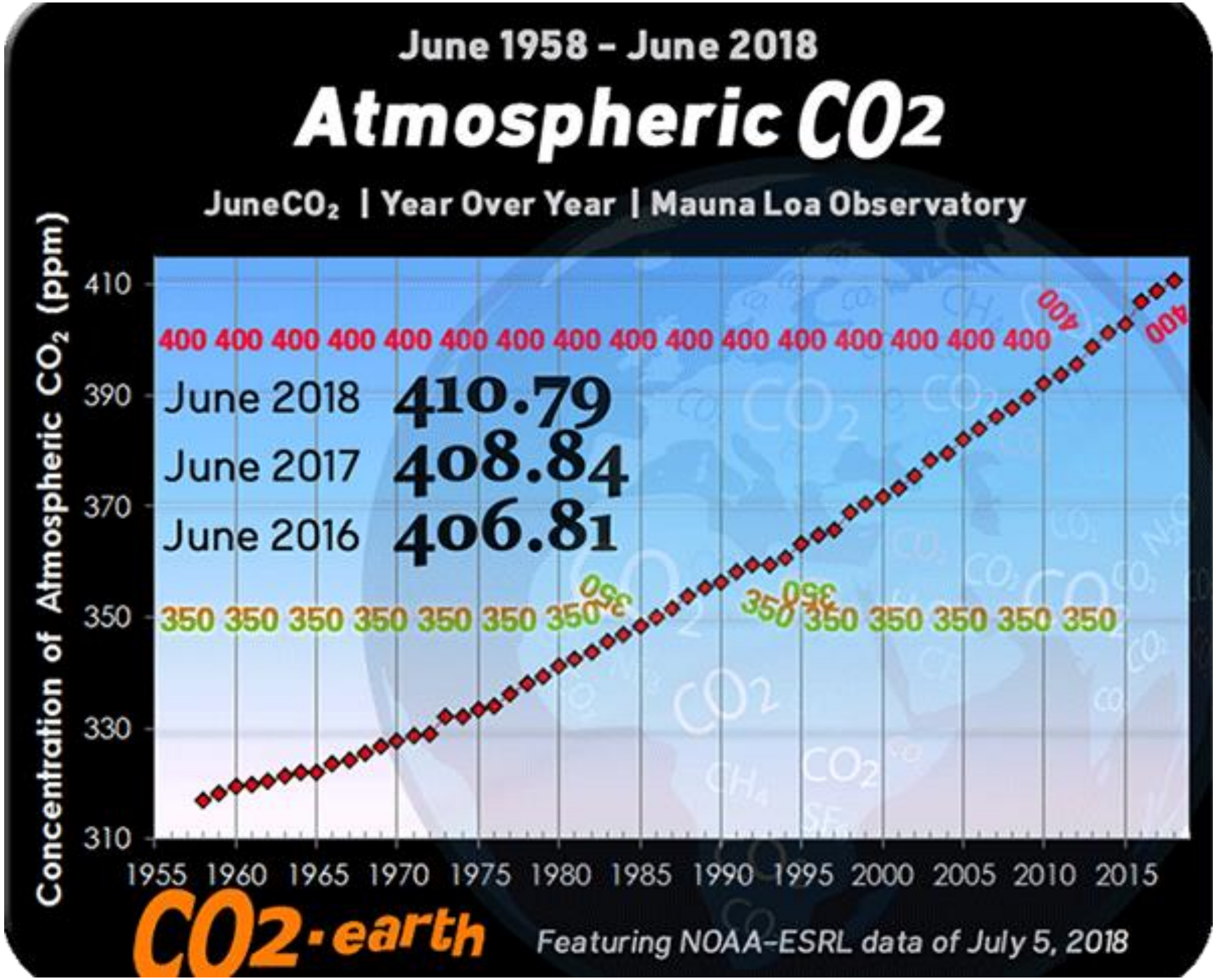


Takahashi, E2C

Atmosphere CO_2—the Keeling Curve

- Continuous upward pattern with seasonal variation since first measured during the IGY (1958)

https://www.co2.earth/

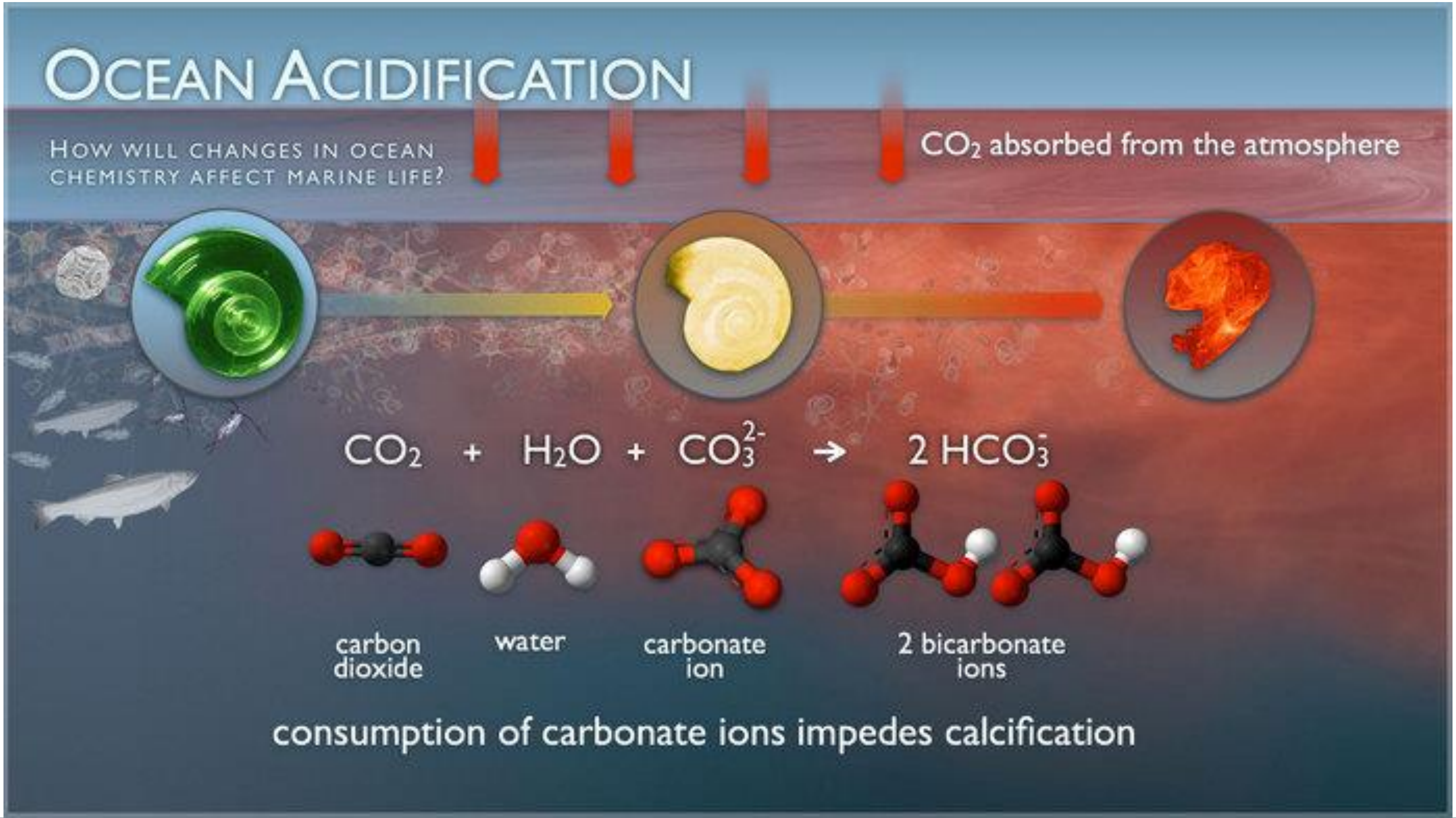


What happens in ocean acidification?

- Taro Takahashi (LDEO) began studying ocean CO_2 at the same time

- Ocean absorbs about 30% of CO_2 released into the atmosphere
- Levels of dissolved CO_2 (p CO_2) have increased
- Triggers series of chemical reactions that increase H^+ ions and reduce carbonate (CO_3^{-2}) ions

https://oceanservice.noaa.gov/facts/acidification.html



https://www.pmel.noaa.gov/co2/story/Ocean+Acidification

More about the series of chemical reactions

Dissolving CO_2 in seawater increases the hydrogen ion (H^+) concentration in the ocean, and thus decreases ocean pH, as follows:

$$CO_{2\ (aq)} + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+ \rightleftharpoons CO_3^{2-} + 2\ H^+$$

https://en.wikipedia.org/wiki/Ocean_acidification#Acidification

Impacts on oceanic calcifying organisms

Decreased pH will have negative consequences for:

- Coccolithophores, corals, forams, echinoderms, crustaceans, mollusks

- As pH falls, [CO_3^{-2}] ions required for saturation increases, so waters become undersaturated, and structures made of $CaCO_3$ become vulnerable to dissolution.

- Research results have not been consistent or definitive

Ocean acidification and global ecology

- Negative impact on calcifying animals, such as mollusks, corals, and certain plankton
- Certain fish's ability to detect predators is decreased in more acidic waters. When these organisms are at risk, entire food webs may also be at risk.
- Many economies are dependent on fish and shellfish and people worldwide rely on food from the ocean as their primary source of protein.

Discussion stop 3

- 3 minutes
- How might you incorporate these findings in biology, chemistry, or environmental science courses?

HMH

Measuring CO_2 precisely in all reservoirs and fluxes becomes critical for understanding the Earth System

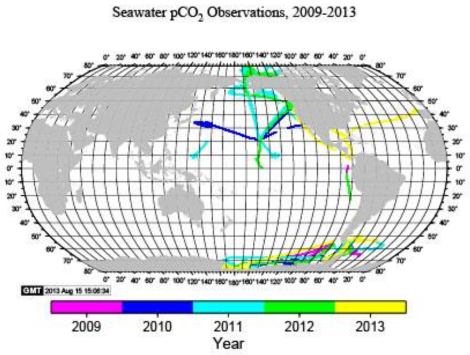
- Many instruments are available to monitor CO_2 under a wide variety of conditions
- Deployment of instruments and collection of samples provide many challenges

pCO_2

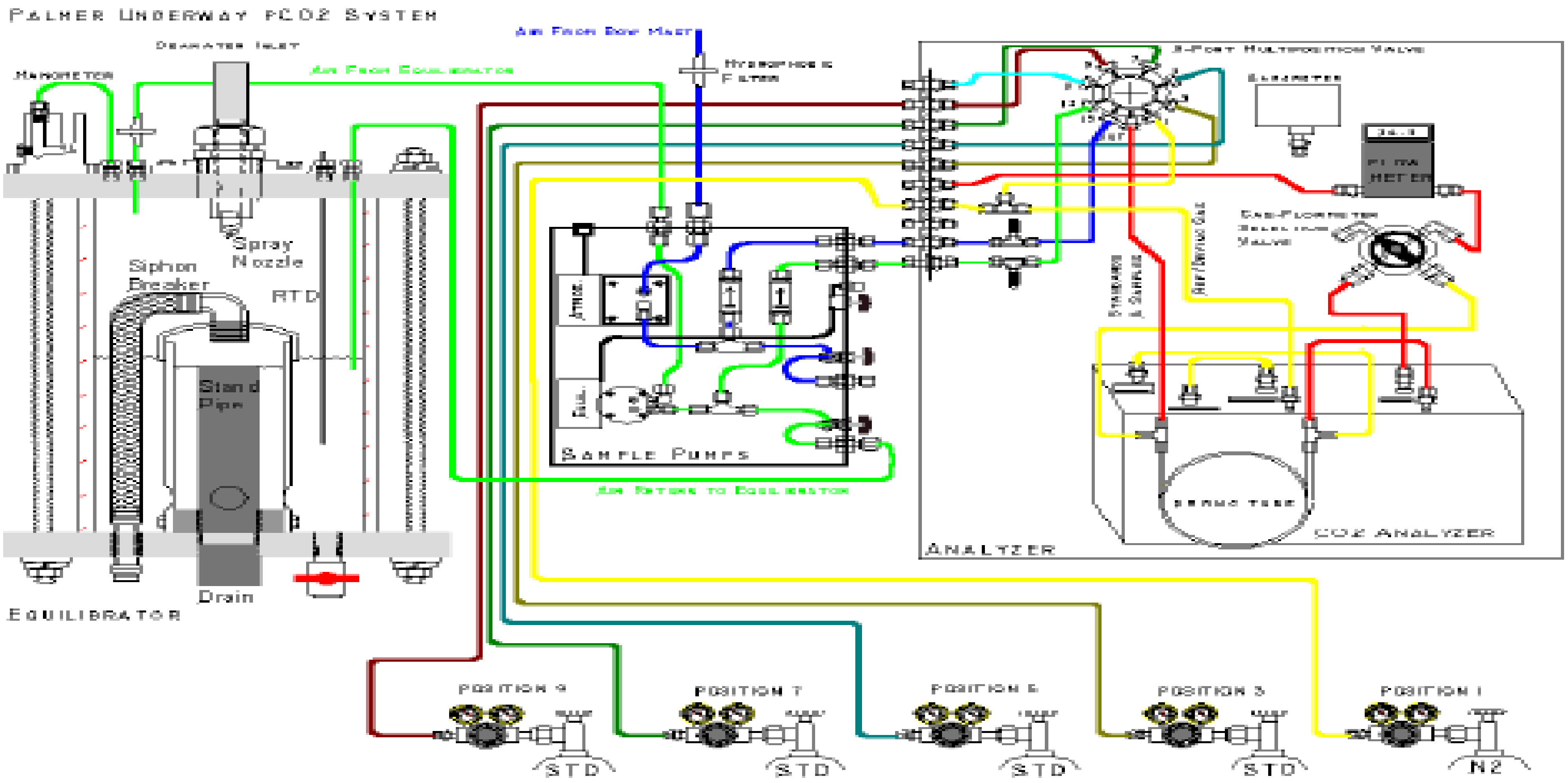
One standard of measurement in chemical oceanography is referred to as "pCO_2"

http://www.ldeo.columbia.edu/res/pi/CO2/carbondioxide/pages/pCO2data.html

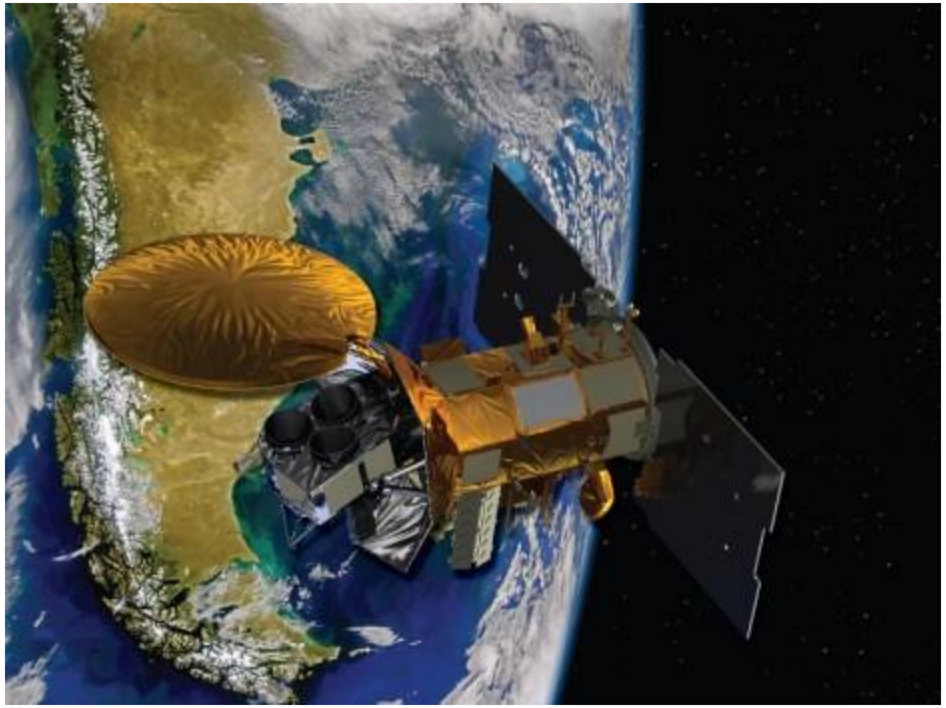
Measurements are routinely collected aboard many NOAA, Navy, Coast Guard, and other research vessels.



In-site measurements at sea are not easy, but we have many years of records



Satellite measurements



- Global observations of CO_2 in the atmosphere and surface waters
- Air-sea flux measurements

https://earthobservatory.nasa.gov/blogs/fromthefield/2012/09/11/measuring-salinity-from-space/

Another important measurement is the saturation state, known as Ω. This is a measure of the potential for the mineral to form or to dissolve

For calcium carbonate this is described by the following equation:

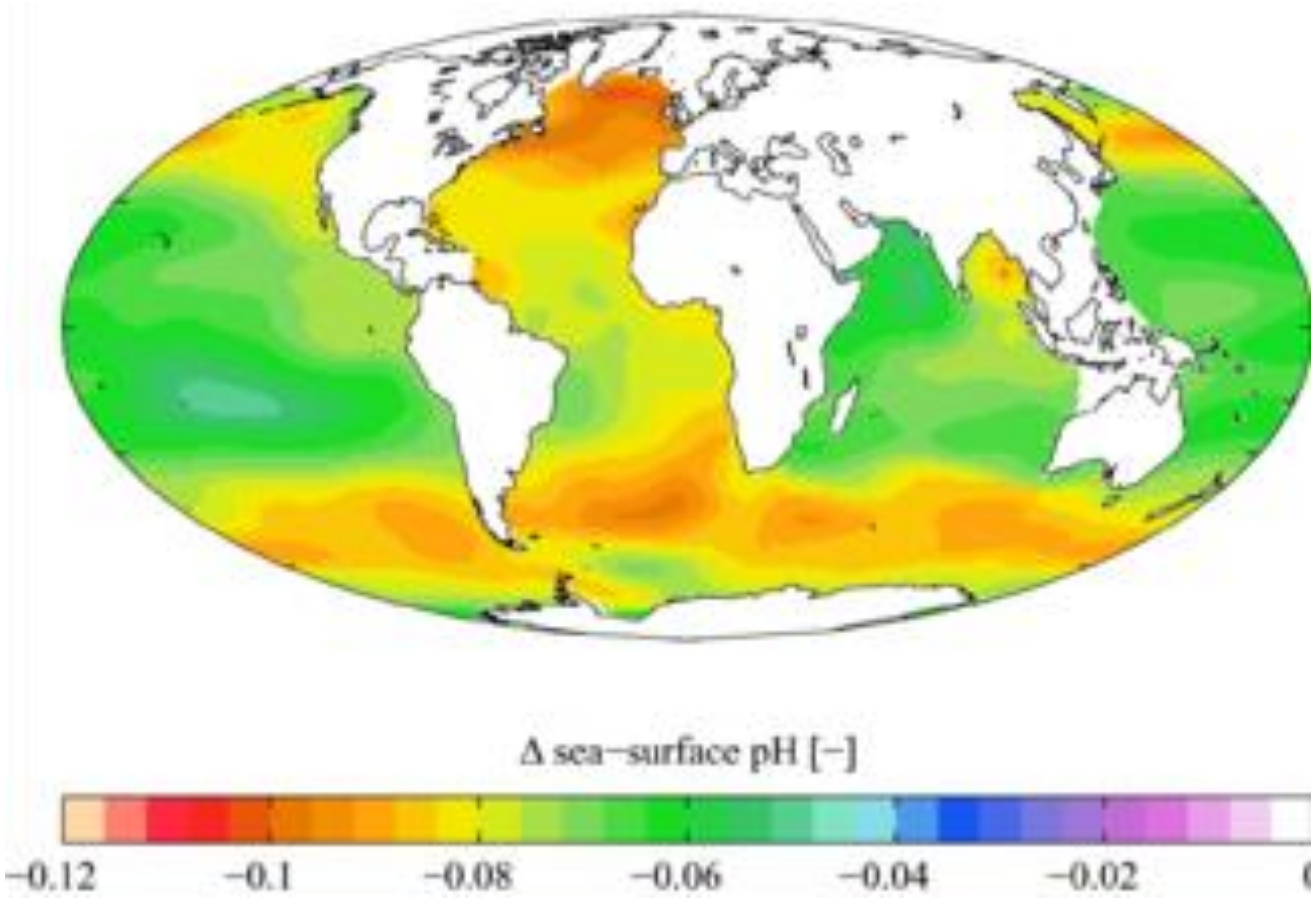
$$\Omega = [Ca^{2+}][CO^{2-}_3] / K_{sp}$$

Ω is the product of the concentrations of the reacting ions that form the mineral (Ca^{2+} and CO^{2-}_3), divided by the product of the concentrations of those ions at equilibrium (K_{sp}), that is, when the mineral is neither forming nor dissolving.

https://en.wikipedia.org/wiki/Ocean_acidification

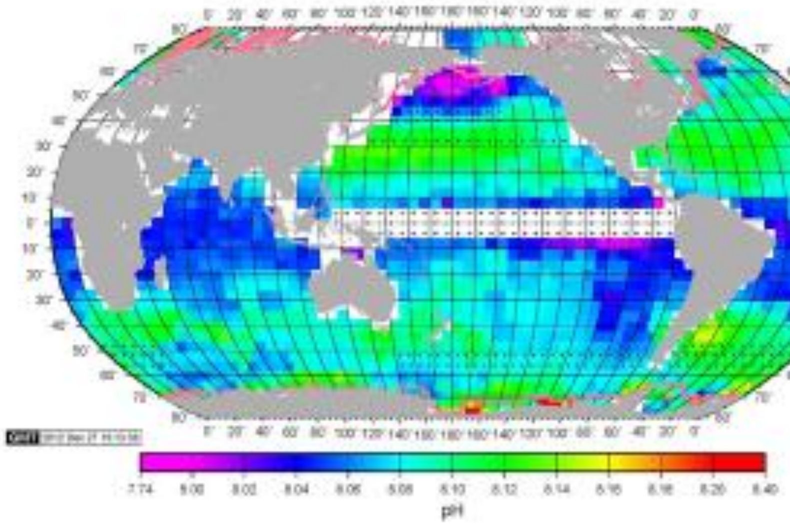
What data can students use to learn about ocean acidification?

- **Color-coded maps**
- Estimated change in sea water pH caused by human-created CO_2 between the 1700s and the 1990s, from the Global Ocean Data Analysis Project (GLODAP) and the World Ocean Atlas
- Decrease from 8.25 to 8.14—30% increase in H^+



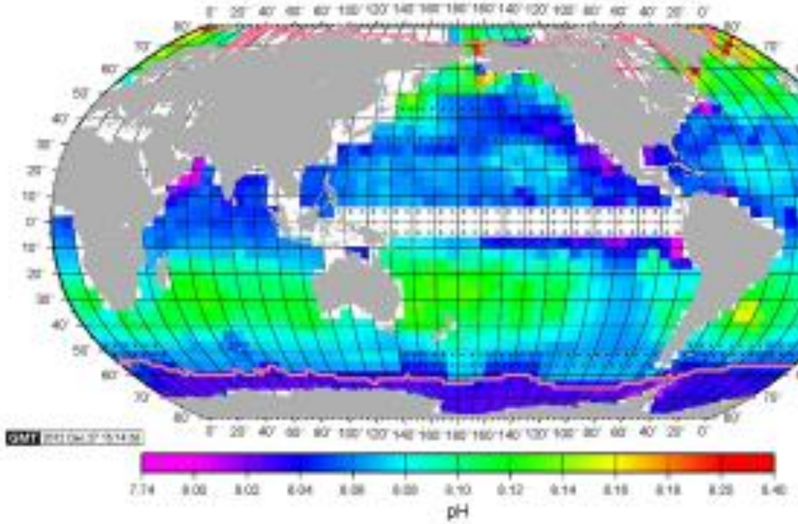
Climatological mean distribution of pH in global surface ocean water
(Takahashi et al., Marine Chem., 164, 95-125, 2014)

(A)
Calculated pH for
February, 2005



Global range of pH = 7.9 to 8.2
(1.3×10^{-8} to 6.3×10^{-9} mol H^{+}/liter),
varying by a factor of 2 in the H^{+}
concentration.)

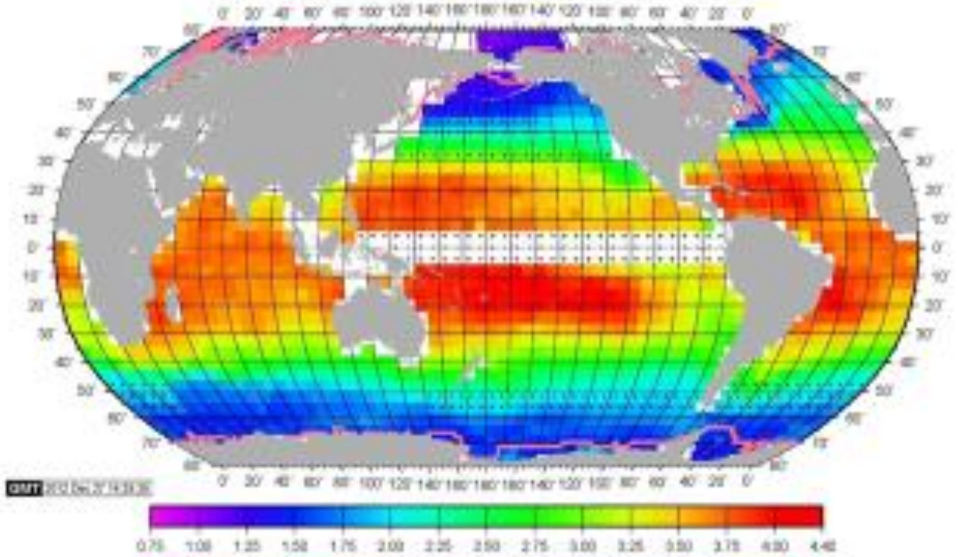
(B)
Calculated pH for
August, 2005



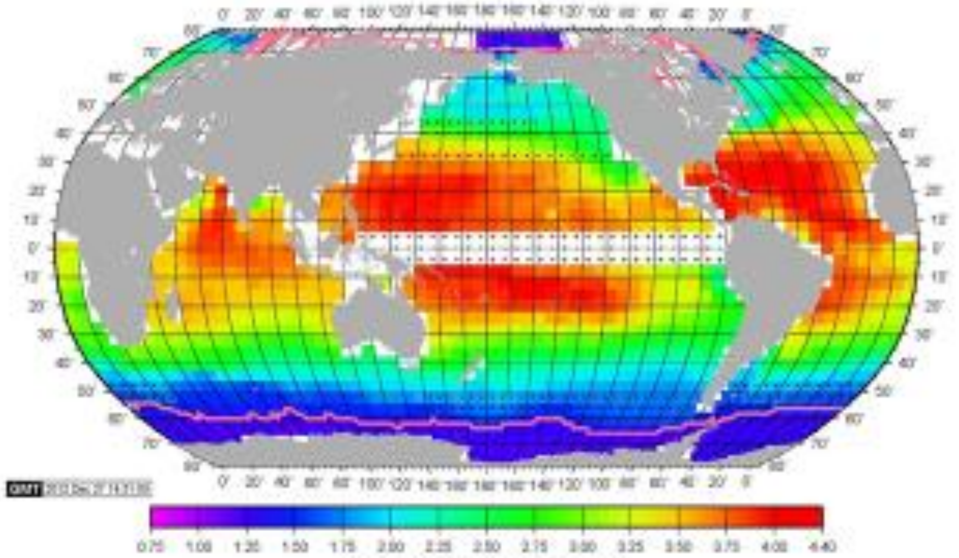
Temperate oceans =
8.05 in warmer months and
8.15 in colder months

Seasonally changes by about 25%
In the H^{+} ion concentration.

A) February, 2005



B) August, 2005



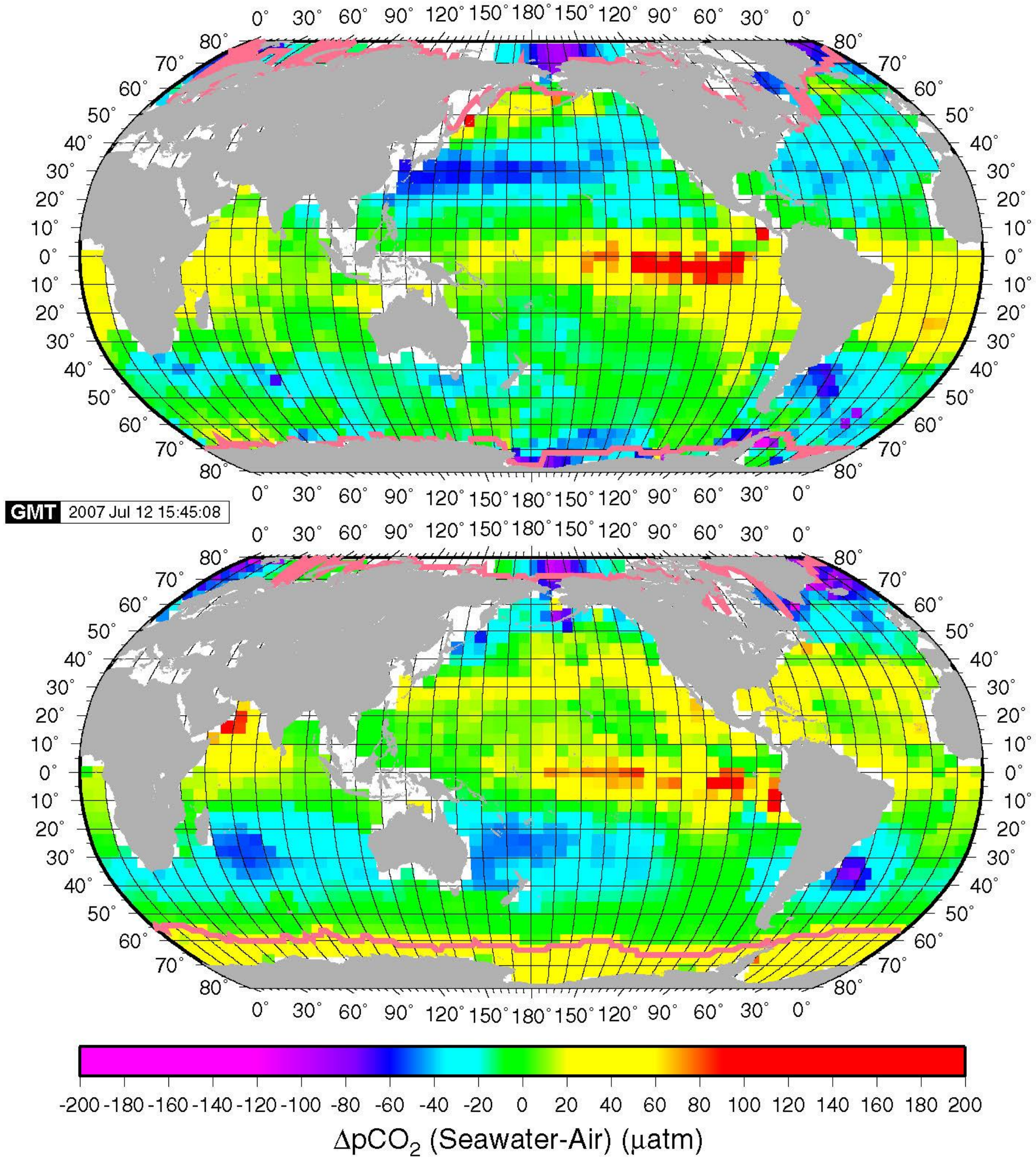
Climatological Mean Distribution of the Degree of Saturation of CaCO3 (aragonite)
Takahashi et al. (2013)

Many corals are made of mineral aragonite (CaCO3). Surface ocean water is commonly supersaturated with respect to this mineral, and hence provide favorable environment for coral growths.
The degree of saturation is expressed in the OMEGA scale: $\Omega = 1$ is at saturation, $\Omega > 1$ is supersaturation , and $\Omega < 1$ is undersaturation (or dissolution).

Today's surface ocean waters are supersaturated with CaCO3 (aragonite) up to 440 %. Only a small portion of the Arctic Ocean is undersaturated with aragonite.

$\Omega = (Ca^{++})\,(CO3^{=})\ /\ Ksp$
and
Ksp is called Solubility product
$= (Ca^{++})\,(CO3^{=})$ at saturation

CLIMATOLOGICAL MEAN SEA-AIR pCO_2 DIFFERENCES



FEBRUARY, 2000

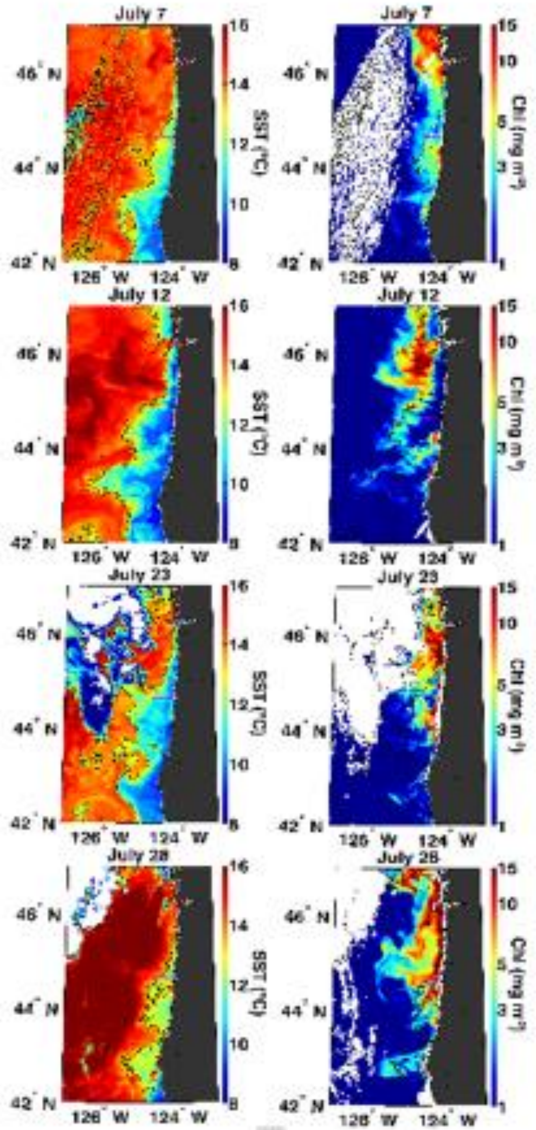
AUGUST, 2000

Wind
to
South

Wind
to
South

Wind
to
South

Wind
to
North



OREGON COAST UPWELLING
JULY, 2008

Upwelling of deep waters started on July 8, driven by the southward winds.
The upwelled waters are colder (blue) and are rich in nutrients and respired CO2 (hence more acidic).

Before the plankton were in full blooms, the wind direction changed to northward on July 26, and the upwelled waters were covered up by the warm (red) waters. The failed plankton blooms caused the waters in oyster hatcheries to be more acidic causing oyster death.

CO2 Concentrations in Deep Oceans

Comparative data from in-situ measurements

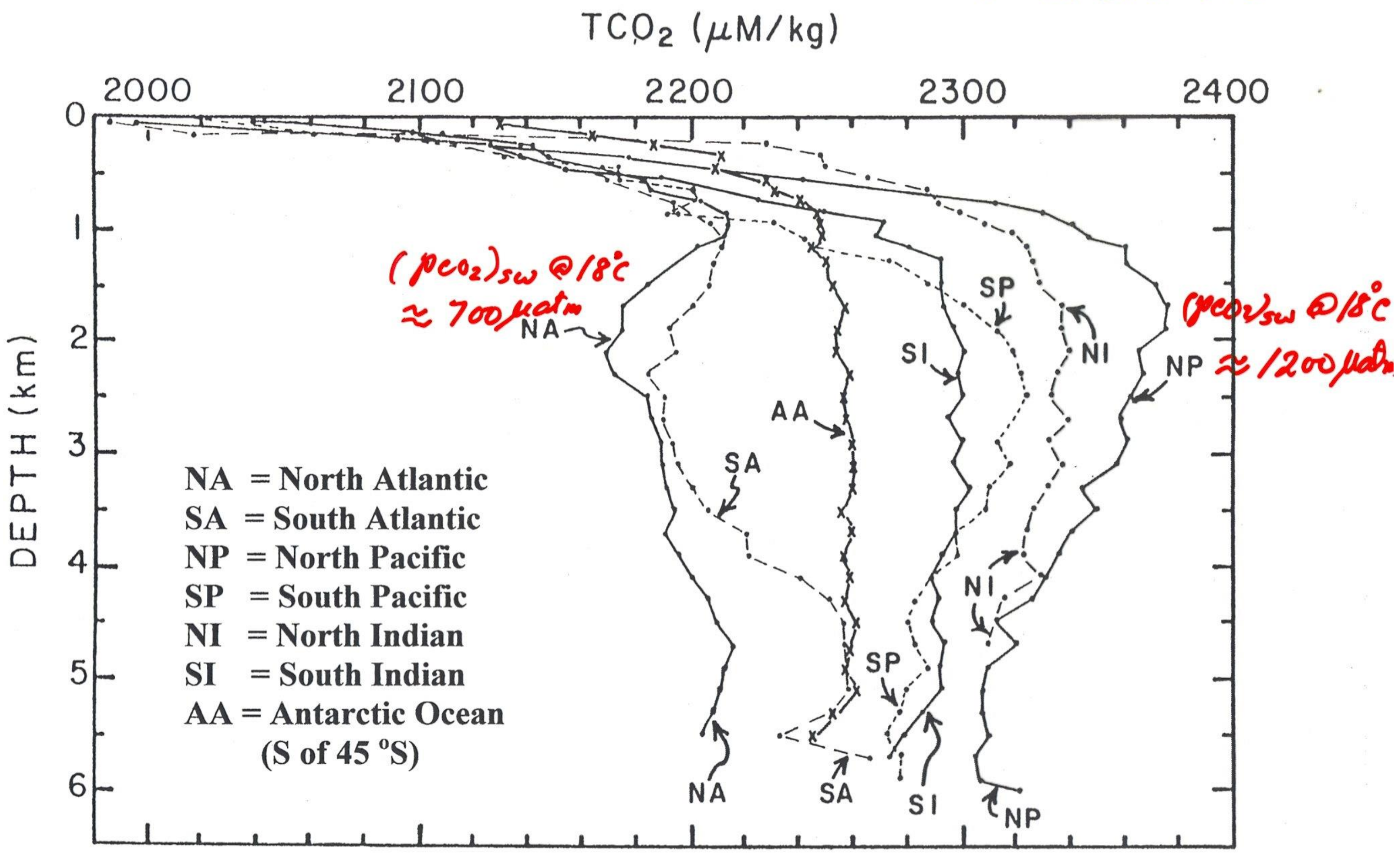
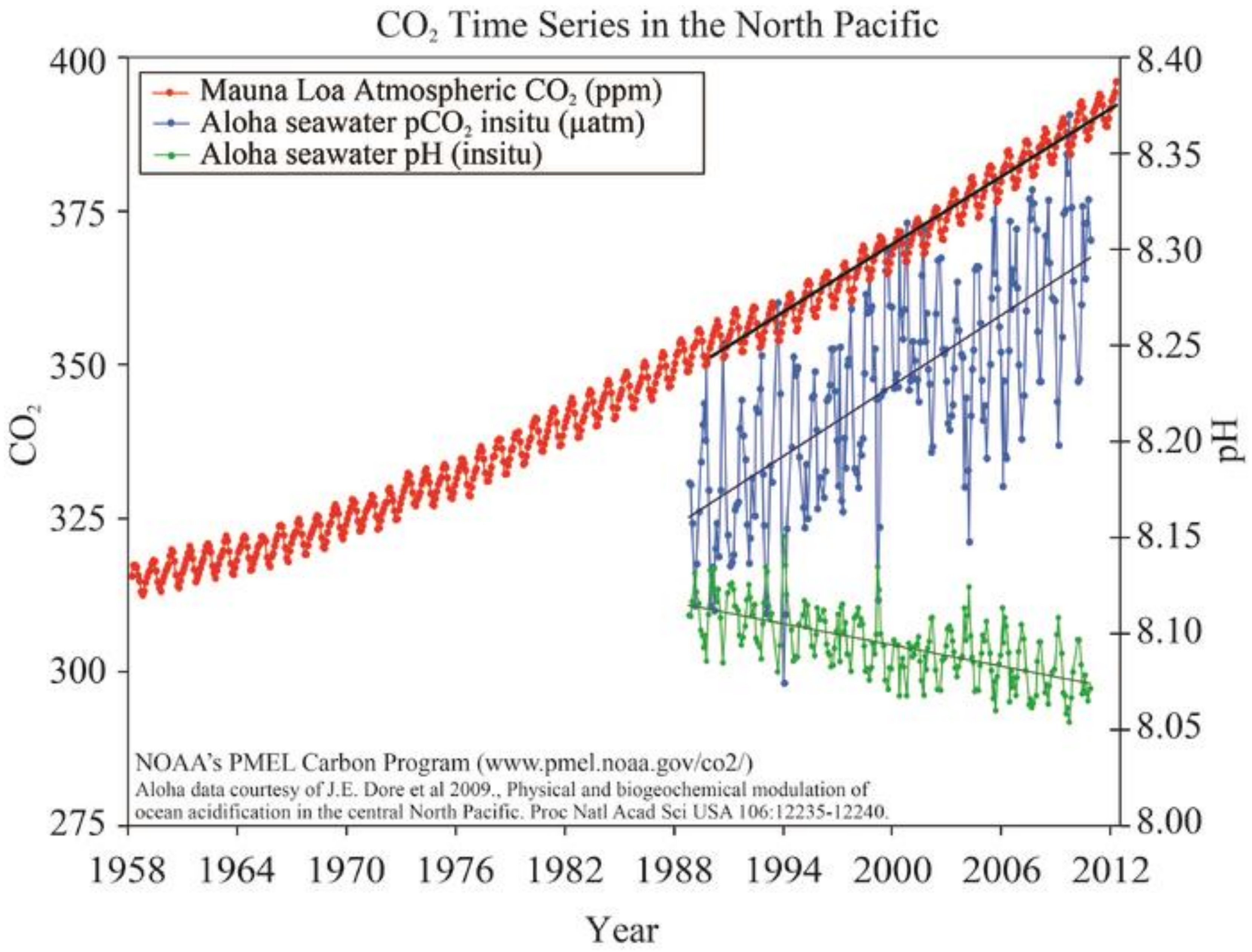
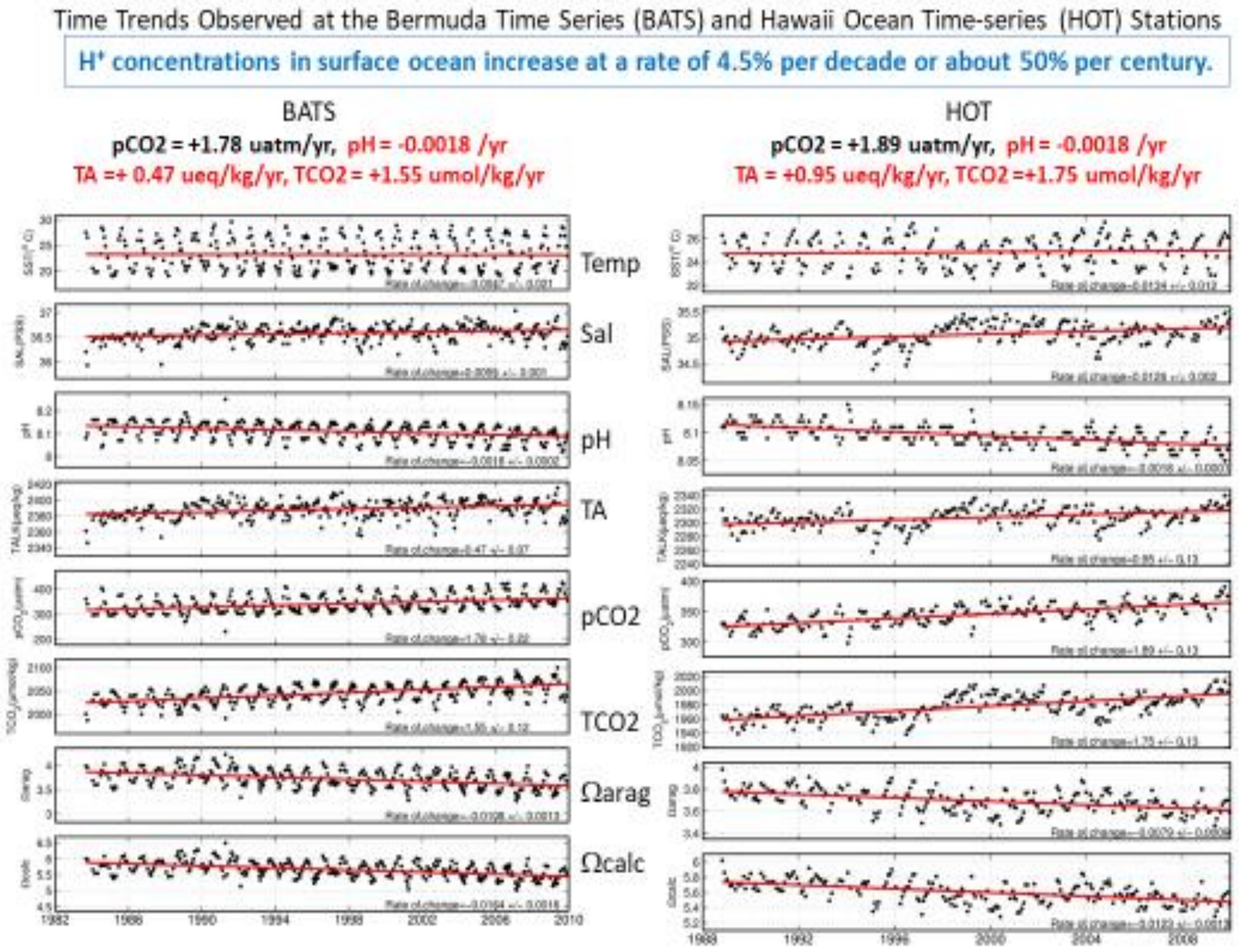


Figure 2: The mean vertical distribution of (a) the alkalinity and (b) the total CO_2 concentration in the seven regions of the world oceans. NA = North Atlantic, SA = South Atlantic, NP = North Pacific, SP = South Pacific, NI = North Indian, SI = South Indian, and AA = Antarctic

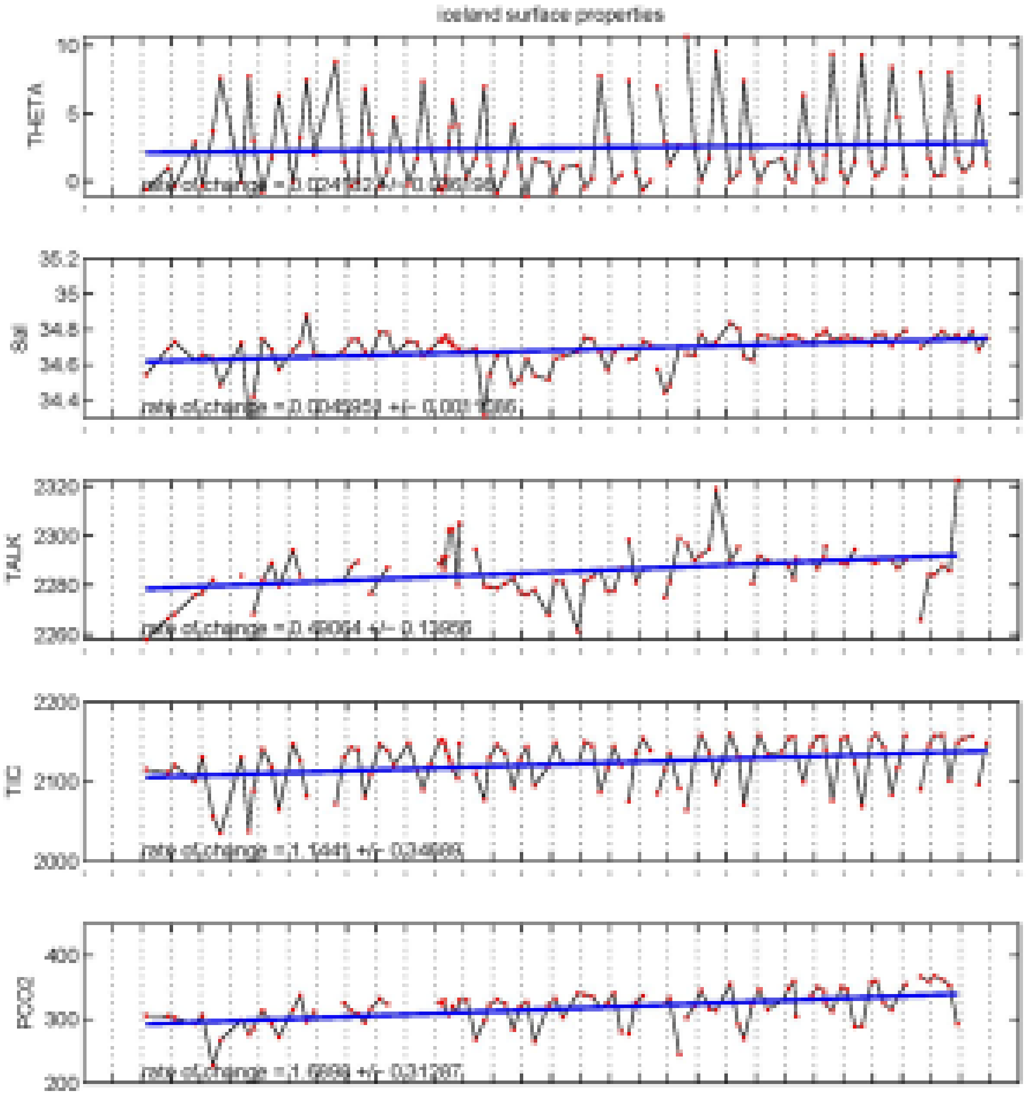


https://pmel.noaa.gov/co2/file/CO2+time+series

“Small-multiple” time series comparisons



Iceland Sea and Vicinity
Time-series, 1985-2013



Annual Rate of change

0.024 °C
±0.036

0.0046 PSS
±0.001

0.49 ueq/kg
± 0.14

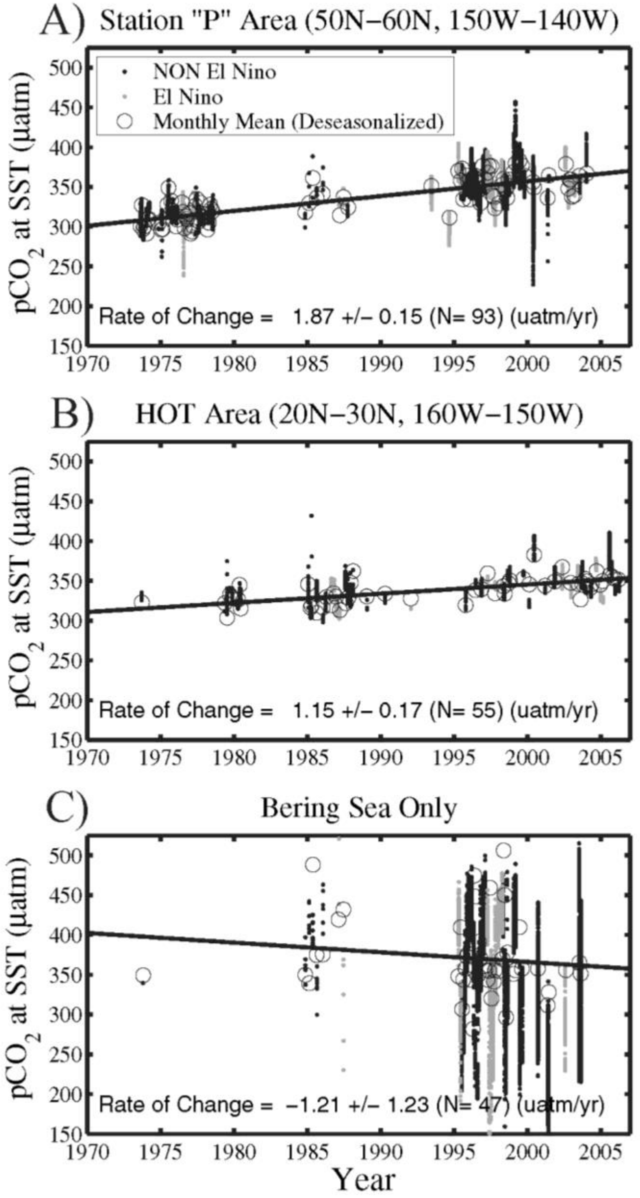
1.14 umol/kg
±0.35

1.69 uatm
±0.31

68°N and 12.7°W

Olafsson and Takahashi,
(in preparation)

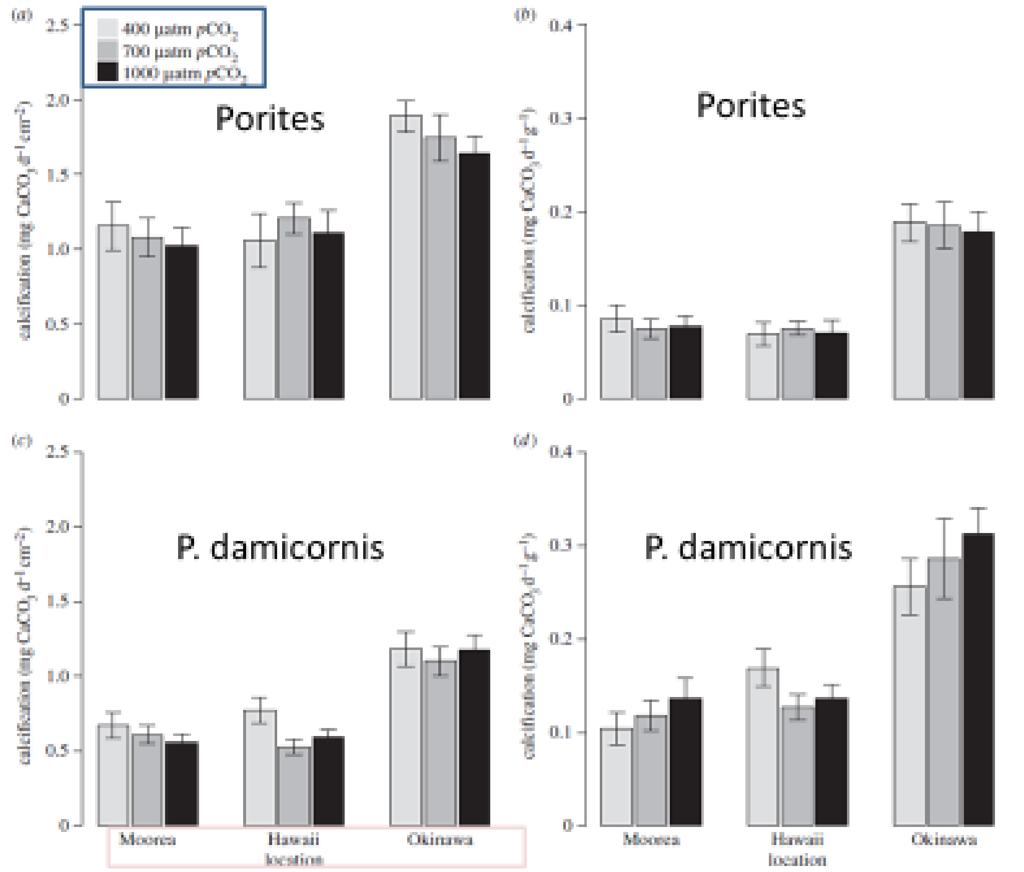
Change in pCO2 of Surface Ocean Water in the Pacific Ocean



Takahashi et al.
(DSR, 2008)

Comparative ecological studies

RESPONSE OF CORALS TO ACIDIFICATION (Three Pacific reef samples)



igure 2. Calcification of the corals massive *Porites* spp. and *P. damicornis* maintained in three pCO_2 levels (400, 700 and 1000 µatm) in Moorea, Okinawa and lawaii, respectively. The first row represents: (*a*) the area-normalized calcification and (*b*) the biomass-normalized calcification of massive *Porites* spp. The second ow shows: (*c*) the area-normalized calcification and (*d*) the biomass-normalized calcification of *P. damicornis*. The bars correspond to the mean calcification and the ertical error bars show the s.e. in the measurement of calcification ($n = 12$).

Comeau et al. (2014). Pacific-wide contrast highlights resistance of reef calcifiers to ocean acidification. Proc. Roy. Soc. B 281, 2014.1339.

Moorea, Equatorial Pacific;
Hawaii, N. Central tropical Pacific;
Okinawa, W. Sub-tropical Pacific

Discussion stop 4

10 minutes

Choose one or two of the examples and discussion

- Why did you select these data formats?
- What do you see in these data?
- What skills would you teach students to be able to interpret these data?
- How might you encourage student research using these data?

HMH

Selected lab activities to explore Ocean Acidification

- **Ocean Acidification in a Cup**
  Exploratorium Science Snacks

  https://www.exploratorium.edu/snacks/ocean-acidification-in-cup

We'll use this 4-part set of videos to examine a simple hands-on classroom activity

Candle Ocean Acidification Demo

Materials

Two wide, shallow glass dishes

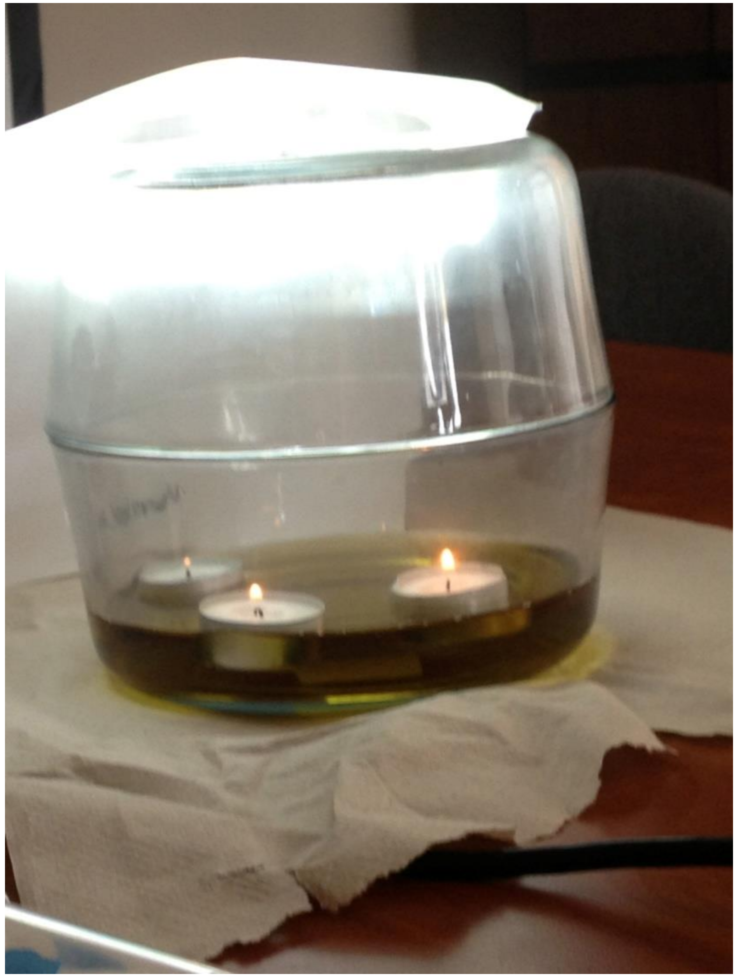
Tea Candles (3)

Match/Lighter

pH Indicator Dye

Distilled Water or Tap Water

[See next slide for directions]



Scripps Classroom Connection

Scripps Classroom Connection OA Activity

This demonstration models the process of ocean acidification on the global scale.

Procedure:

1. Tell students that the water represents the ocean. Why DI Water? (Answer: you will see a pH change because it's not a buffer).
2. Add a 10-15 drops of pH indicator dye
3. Float candles in the water. The candles represent countries burning fossil fuels. (You can make them USA, China, and everyone else.)
4. Light the candles and quickly put the other dish on top of the dish with water. You've essentially created an entire atmosphere by doing so.
5. Ask questions to have students explain the observed changes over time.
    a. Candles should burn out once the oxygen is used up
    b. Color of water should change but only in the upper layer because that's where gas exchange takes place.

Selected other classroom activity guides

- "Lesson 3: Ocean Acidification"

  Teachers Guide
  NOAA National Marine Fisheries Service
  https://www.st.nmfs.noaa.gov/Assets/Nemo/documents/lessons/Lesson_3/Lesson_3-Teacher's_Guide.pdf

- WHOI Ocean Carbon and Biogeochemistry Program "Ocean Acidification lab/ outreach kit"
  https://web.whoi.edu/ocb/wp-content/uploads/sites/43/2017/01/OCB-OA_labkit102609.pdf

Discussion stop 5

5 minutes

- How might you incorporate these activities into your curriculum?
- What questions might your students have or develop for further investigations?

Science and Engineering Practices

- Asking Questions and Defining Problems. ...
- Developing and Using Models. ...
- Planning and Carrying Out Investigations. ...
- Analyzing and Interpreting Data. ...
- Using Mathematics and Computational Thinking. ...
- Constructing Explanations and Designing Solutions. ...
- Engaging in Argument from Evidence.

Let’s continue to find ways to challenge our students

- Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities, as well as to changes in human activities. Thus science and engineering will be essential both to understanding the possible impacts of global climate change and to informing decisions about how to slow its rate and consequences—for humanity as well as for the rest of the planet.

(Grade band endpoint for ESS3)

So, for us as classroom teachers…

- What should we teach about CO_2 and ocean acidification?
- When should we teach it?
- How should we teach it?
- Where can we get the necessary information?
- How good are the data and the deductions?

Selected suggestions to learn more about Sustainability and Ocean Acidification

- What Is Sustainability and Why Is It Important? https://www.environmentalscience.org/sustainability
- The Earth Institute (EI), Columbia University – Mission https://www.earth.columbia.edu/articles/view/1791
- EI "Climate—Hard Science, Promising Solutions" https://www.earth.columbia.edu/articles/view/2124
- Environmental Sustainability https://www.thwink.org/sustain/glossary/EnvironmentalSustainability.htm
- Ocean Acidification: The Other Carbon Dioxide Problem https://www.pmel.noaa.gov/co2/story/Ocean+Acidification
- Ocean Acidification (WHOI) https://www.whoi.edu/OCB-OA/page.do?pid=112076
- What You Need to Know About Ocean Acidification https://www.nrdc.org/stories/what-you-need-know-about-ocean-acidification?gclid=EAIaIQobChMIheGfyq2K4wIVCP_jBx0ssg3OEAAYASAAEgJrOPD_BwE

HMH Resources and Blogs to Learn More

- HMH Science Dimensions: Earth and Space Science
  https://www.hmhco.com/programs/hmh-science-dimensions

- Integrating Science with Engineering and Tech in the Classroom

https://www.hmhco.com/blog/integrating-science-with-engineering-and-tech-in-the-classroom

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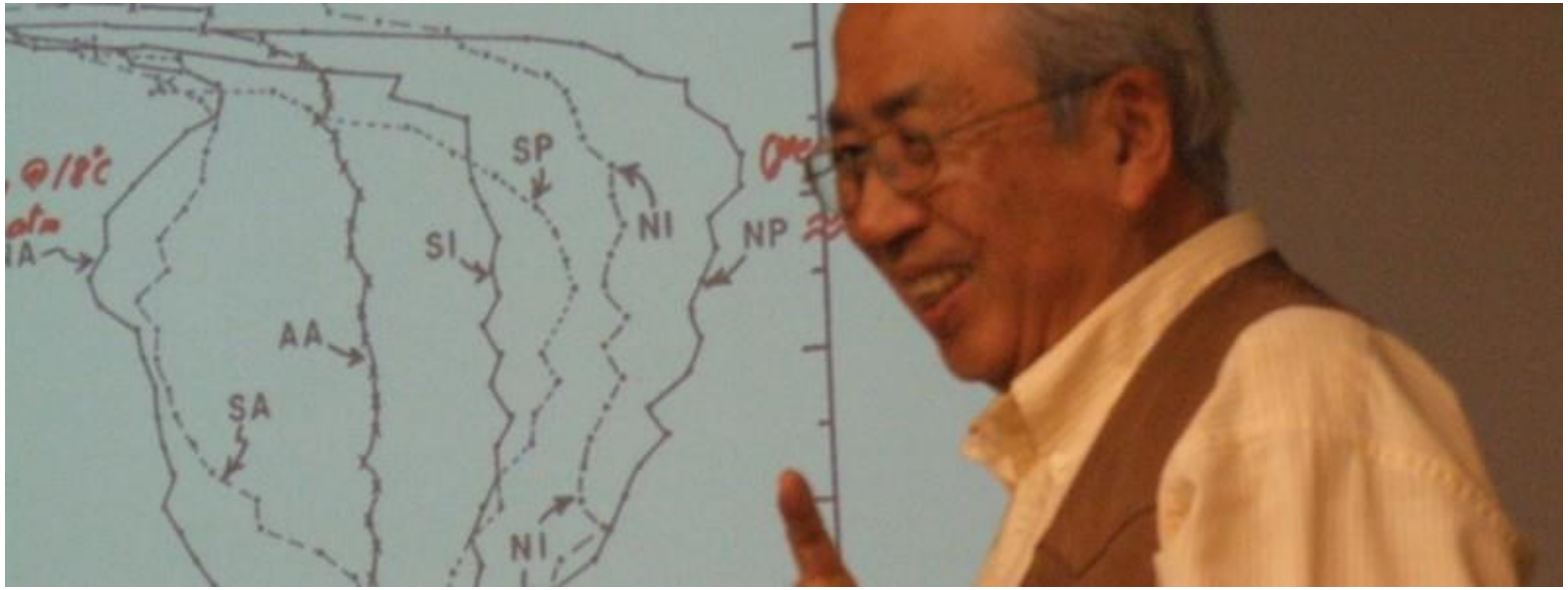
Earth2Class Workshops with Dr. Taro Takahashi

“Ocean Acidification: Recent Progress in Environmental Sensitivity Studies” (11/13)

“Ocean Acidification and Its Effects on Marine Life” (3/15)



TAKAHASHI -- SUMMARY AND CONCLUSIONS from E2C Workshop

1) The anthropogenic emissions of CO_2 are rapidly increasing at the fastest rate anticipated by IPCC (3.4% per year) as a result of increases in “per capita carbon production rates” and human population. 2008 is an exception due to the economic recession.
2) While the carbon emissions from the Developed Countries increased only modestly, those from Developing Countries (China and India) increased very rapidly. The Developing Countries exported manufactured goods as they increased “Carbon emissions”.
3) The carbon cycle in the modern world is broadly understood in the decadal scale, but not in the annual scale satisfactorily.
4) The ocean CO_2 sinks may be weakening for the past decades, while the land biota sink appears to be holding steady.
5) Unless the CO_2 emissions are reduced substantially, the atmospheric CO_2 concentrations would double the pre-industrial level by 2030. The presumed “tipping point” for the global warming of 4°F may be exceeded then.