Ocean Acidification

& its role in a changing climate

Henry Wagner Tre Wilkerson Ryan Larkin Eric Guernsey

WHY OCEANS MATTER

CLIMATE REGULATION

70% Covering 70% of the Earth's surface, the ocean transports heat from the equator to the poles, regulating our climate and weather patterns.

ECONOMY

$282 billion Amount the U.S. ocean economy produces in goods and services. Ocean-dependent businesses employ almost 3 million people.

TRANSPORTATION

76% Percent of all U.S. trade involving some form of marine transportation.

RECREATION

From fishing to boating to kayaking and whale watching, the ocean provides us with so many unique activities.

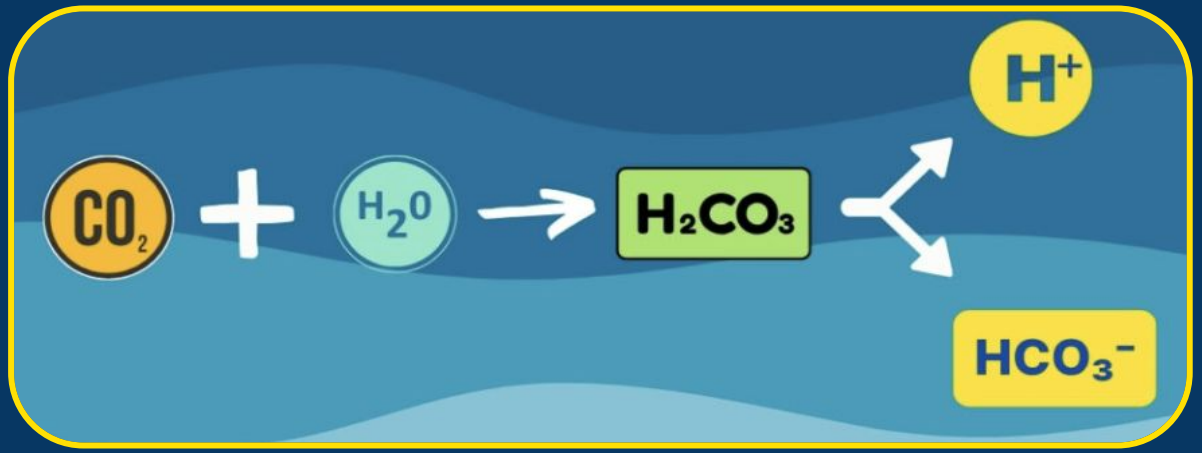
FOOD

The ocean provides much more than just seafood. Ingredients from the sea are found in surprising foods such as peanut butter and soymilk.

MEDICINE

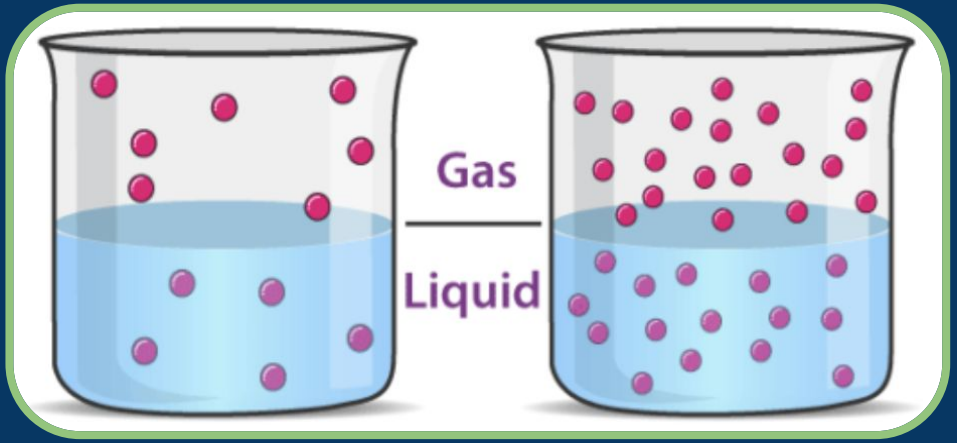
Many medicinal products come from the ocean, including ingredients that help fight cancer, arthritis, Alzheimer's disease, and heart disease.

CO2 in the *Sea*



- Oceans can naturally solvate gaseous CO. Dissolved carbon dioxide + water react to produce carbonic acid (with an acidic hydrogen [pKa ~6.5], which is easily dissociable in water)
- Our oceans exist as a major 'carbon sink'. So, as industries and civilizations continue expanding, more CO2 is emitted, thus more is absorbed by oceans.
- Currently, oceans have taken in ~30% of all human-emitted CO2 (ncei.gov), a massive amount!

THE CHEMISTRY



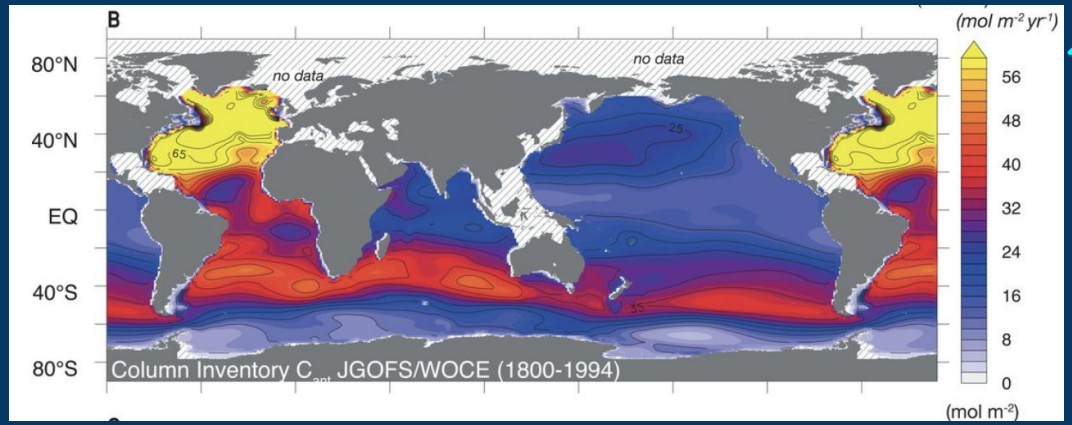
Henry's Law:

As the pressure of a gas over liquid increases,
the amount of gas dissolved in the liquid increases proportionally

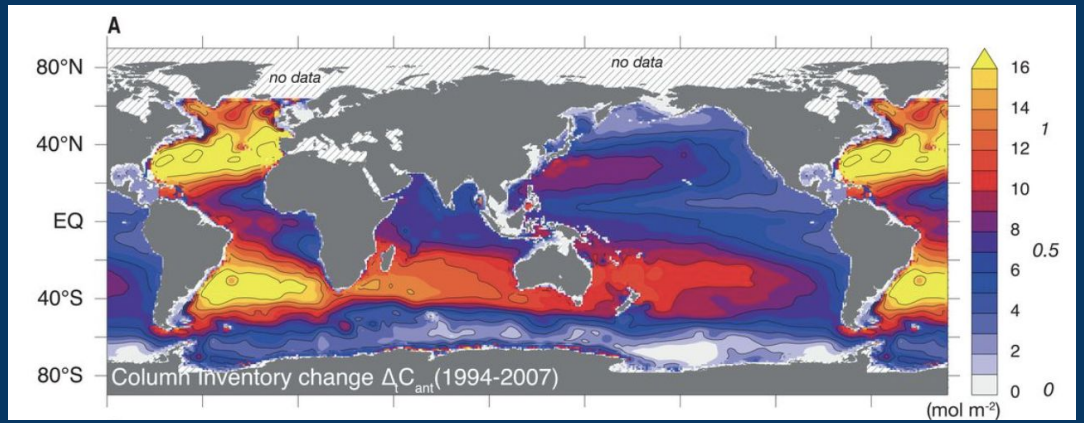
–So, as CO_2 increasingly populates the atmosphere, its fraction of the air pressure above our oceans increases. Thus, the amount of CO_2 dissolving into the oceans rises, and pH lowers.

–It is also important to understand that pH is a logarithmic scale. Ocean water has a natural, slightly alkaline pH (~8.1), which exists right around the acidity tipping point (7). So, small additions of acid can largely influence pH.

–Biological systems are designed to operate within a narrow range of pH, and acidity stresses these systems, threatening marine life and ecosystem wellbeing.



1800 to 1994



1994 to 2007

Extreme

ΔCO2

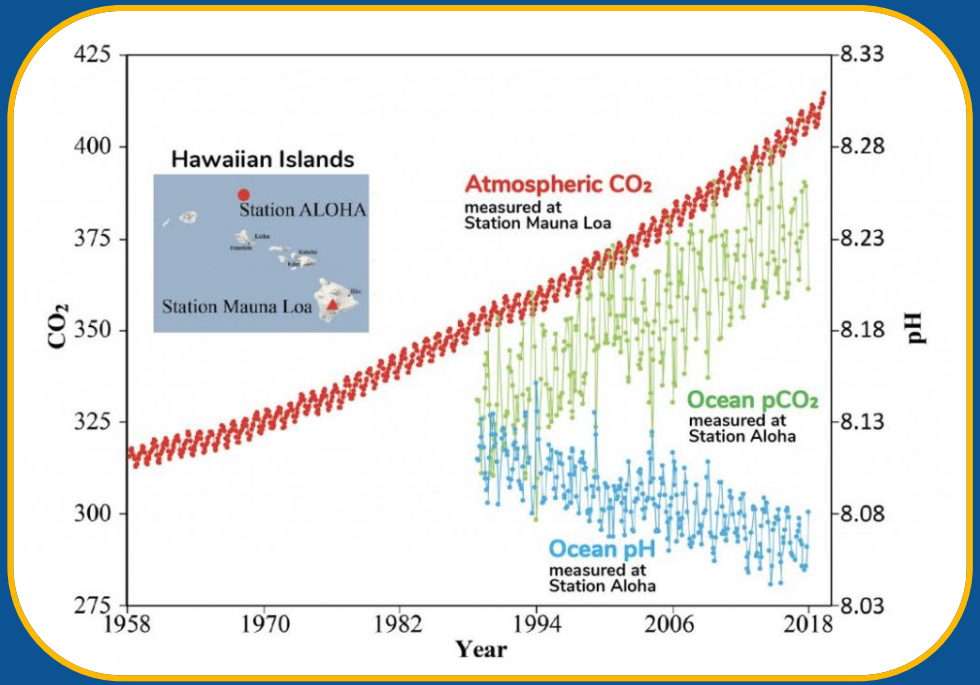
Mild

Locating Extreme Changes

Graphics depict measurement of ΔCO2 Dissolved (anthropogenic) in oceans (0-3000m) (science.org)

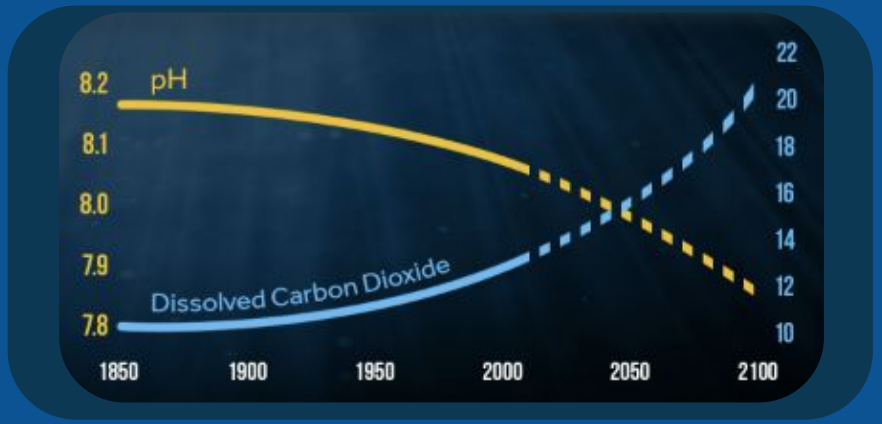
-Notice Non-uniform changes in CO2. Certain areas show consistency in ΔCo2, as in the Northern Atlantic.
-Other areas emerge with extreme changes in recent years (Atlantic coast of South American and Southern coast of Africa.

Aqueous CO2 & pH Over Time



-Data shows a strong upwards trend in dissolved gas, and decreasing of pH
-Notice significant fluctuations within the years. Seasonal water conditions have a large impact on these values…

Study



Heating UP

An important nuance to Henry's Law:

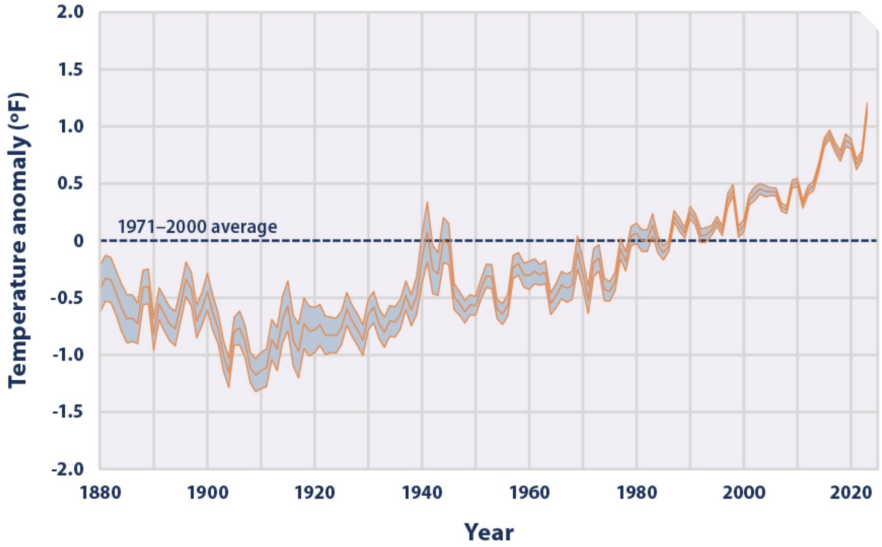
As liquid temperature increases, solubility of gases will decrease. More energy (temperature) in a system means that dissolved gas molecules are more likely to pick up this energy, and escape back into the gas phase.

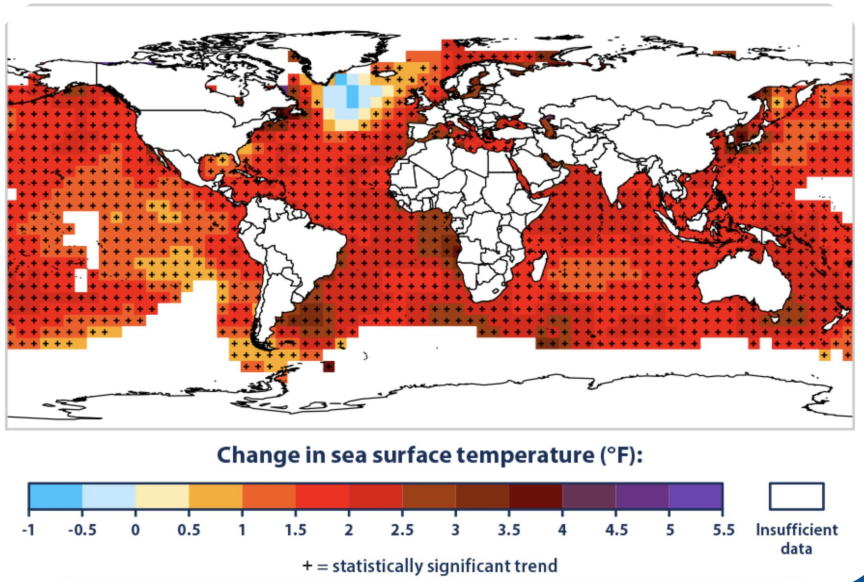
-You may think this is a positive factor, as rising ocean temps make it harder for acidification to propagate. However, it is important to consider that this is simply trading one problem for another. Rather than CO_2 acidifying the ocean, it will be released back into the atmosphere where it adds to GHGs, and drives the greenhouse effect.
-Also, consider that ~30% of all anthropogenic emissions has been solvated into the ocean, so that is **a lot** of potential CO_2 Gas

-By the same principle, warmer water also holds **significantly** less O_2. Unlike CO_2, dissolved oxygen is a fundamental resource for aquatic life. Less O_2 in water may translate to emerging hypoxia zones, where O_2 demand is greater than the supply, and ecosystem equilibrium is thrown off.
-Tropical regions, with preexisting warm waters are the areas most likely to experience immediate and more severe effects. This is a major risk factor, as much of the tropic reefs foster incredible biodiversity that is essential for the wellbeing of our oceans.

The Marine O_2 Squeeze

– In the past few decades, global dissolved oxygen levels have decrease by about 2% (4.8 petamoles, or 4.8 * 10^15 moles)
– It is necessary to consider that this decrease is not evenly distributed. Some areas with more severe warming may lose 5%+ of oxygen, while cooler areas lose 0.5-1%.
- Such a significant change in conditions in certain locations strains marine habitats at both the local and basin scales.





Sea Surface Temperature

Ecological Impacts of Acidification

Coral Reefs and Shellfish

-Reduced calcium carbonate formation
-Severe acidity can dissolve existing coral structures
-25% of all marine life depends on coral reefs for habitat and survival
-500 million people rely on reef ecosystems for food and coastal protection from erosion

Food Web Disruption

-Acidification results in population decline of small animals like clams, oysters, and sea urchins
-Larger predators lose key food sources, creating shortages up the food chain and overall population decline
-Forces species to adapt, migrate to new areas, or face population collapse

Carbon Cycle Impact

As shells and coral bodies form less effectively, the ocean loses its ability to lock carbon away in these structures as a permanent sink, weakening the overall health and stability of marine ecosystems while increasing the amount of carbon in the atmosphere.

Algal Blooming

Nutrient Runoff

-When the level of nutrients such as nitrate and phosphate in our oceans are increased, they fuel large algal blooms

Algal Blooms

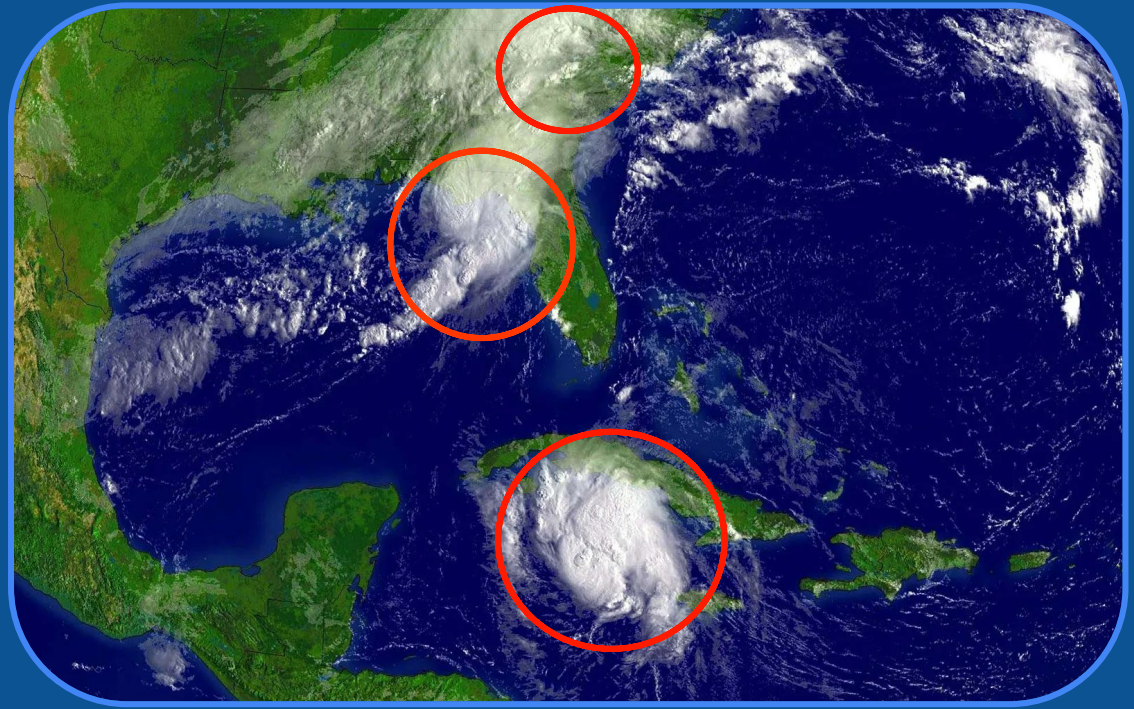
-Algal blooms increase respiration beneath the surface, creating hotspots where major O2 consumption
At the end of blooms, large-scale decomposition produces more Co2, which further decreases pH

-Studies show that many harmful algal species bloom faster and produce more toxins in acidified waters, producing harmful effects

Atmospheric Effects:

-Warmer oceans give rise to greater quantities of water vapor in coastal areas. The atmosphere can hold ~7% more water vapor for every degree of warming.

-These humid regions propagate excessively heavy rainfall, and a much higher risk of frequent, intense tropical storms.



Human-related effects

- The shellfish industry increasing risk of collapse, ruining coastal communities globally, as well as a loss of hundreds of billions of dollars in the world economy

- Will increase risks in safety regarding consumption of anything from the sea, leading to higher health risks and premature deaths worldwide

Large Scale Solutions

OAE: Ocean alkalinity enhancement boosts the oceans ability to remove carbon from the air by increasing alkalinity.

Policy and The Globe:

- Intense international collaboration is a major required steps
- Economic relief to countries affected/unable to emit less emissions

Small scALE Solutions

Seagrass restoration:

- Helps remove CO2 from water
- Strengthens local ecosystems
- Provides shelter to endangered species

Modification of daily life:

- Utilization of carbon friendly transportation
- Joining local conservation efforts to preserve integrity of local coastlines

Works Cited

Natural Centers for Environmental Information. 2022. *Quantifying the Ocean Carbon Sink* https://www.ncei.noaa.gov/news/quantifying-ocean-carbon-sink

Yang, Y., Brockmann, P., Galdino, C., Schindler, U., & Gazeau, F. (2024). An update of data compilation on the biological response to ocean acidification and overview of the OA-ICC Data Portal. *Earth System Science Data*, 16(8), 3771–3780. https://doi.org/10.5194/essd-16-3771-2024

U.S. Environmental Protection Agency, 2025. *Effects of Ocean and Coastal Acidification on Ecosystems*. https://www.epa.gov/ocean-acidification/effects-ocean-and-coastal-acidification-ecosystems

Wolfe, W.H., Martz, T.R., Dickson, A.G. et al. A 37-year record of ocean acidification in the Southern California current. *Commun Earth Environ* 4, 406. https://doi.org/10.1038/s43247-023-01065-0

Project Drawdown, 2024. *Ocean Alkalinity Enhancement*. https://drawdown.org/explorer/deploy-ocean-alkalinity-enhancement

Çelekli, A., & Zariç, Ö. E. (2024). Rising tide of ocean acidification. *Environmental Research and Technology*, 7(4), 605-613. https://doi.org/10.35208/ert.1407588

IERE Team, 2025. *How can we solve ocean acidification?* The institute for Environmental Research and Education How Can We Solve Ocean Acidification? - The Institute for Environmental Research and Education