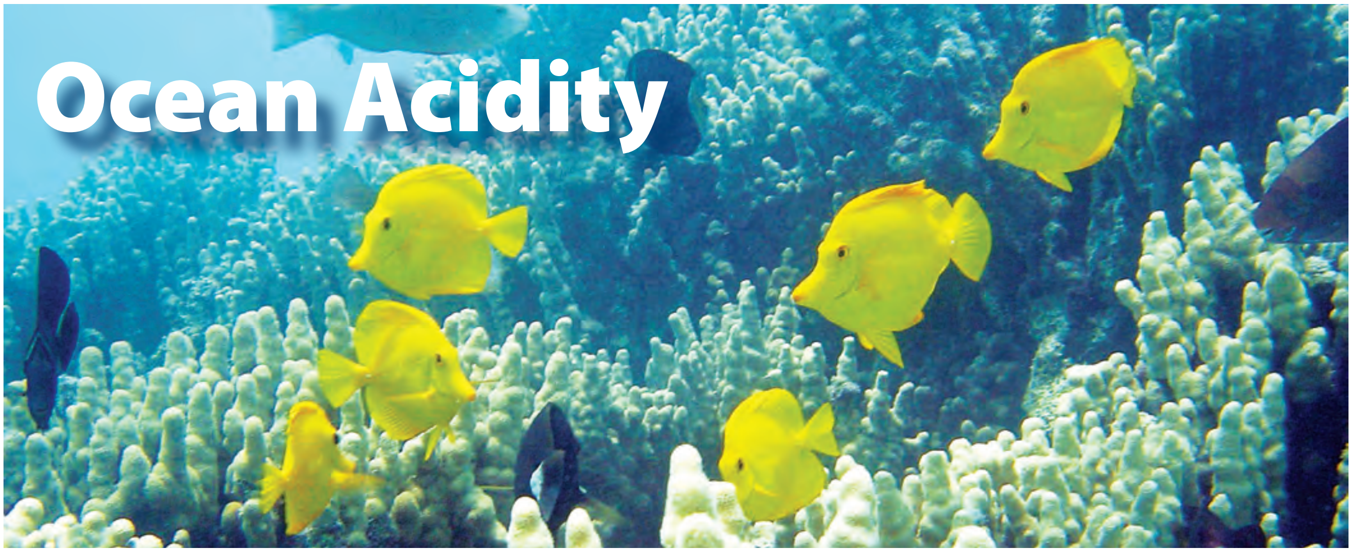


Ocean Acidity

Mankind has released around 500 billion metric tons of carbon into the atmosphere since the Industrial Revolution by burning fossil fuels, producing cement, and changing land use. The oceans have soaked up nearly one-third of these emissions, curbing the effects on global warming. The ocean uptake of CO_2, however, threatens the calcifying ability of corals and other calcium carbonate shell-forming organisms. As CO_2 dissolves in seawater it increases seawater acidity, which decreases the carbonate ion concentration needed for shell building.

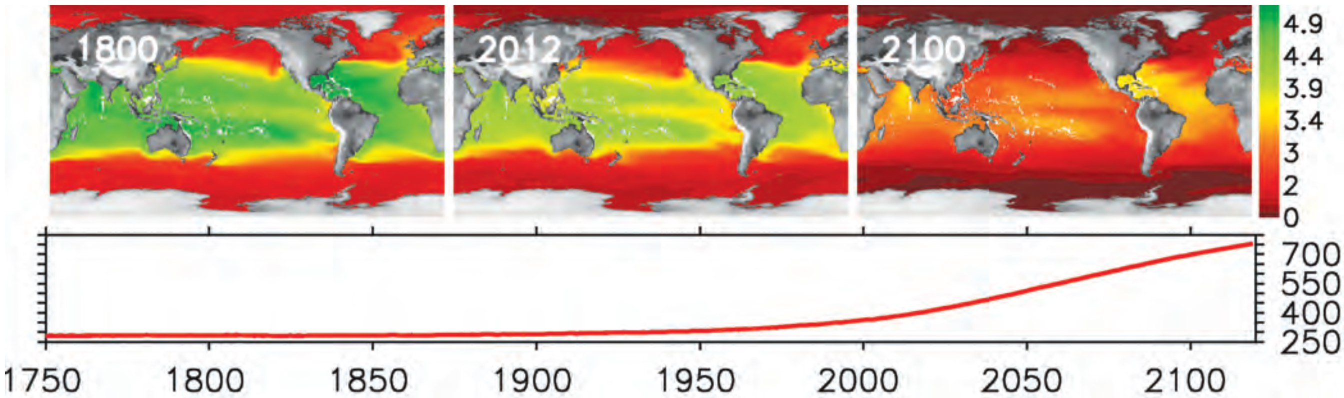
Detecting the man-made CO_2 signal in the ocean has been challenging. Continuous monitoring of ocean chemistry at a few selected stations goes back at most 30 years. The level of seawater pH, furthermore, varies seasonally, annually and regionally, making it difficult to decompose the observed variations into a man-made signal and "natural noise."

IPRC's **Tobias Friedrich** and **Axel Timmermann**, leading a team of climate modelers, marine conservationists, ocean chemists, biologists and ecologists, have developed a method to overcome this difficulty. By using three Earth System models, they have traced the changes in aragonite surface saturation level (a common measure of ocean acidification) 17 thousand years back in time and into the future to the end of this century. They conclude that the surface aragonite saturation levels are currently decreasing at a rate 10–100 times faster than at any time since the Last Glacial Maximum, and that the anthropogenic CO_2 emissions over the last 200 years have pushed ocean acidity far beyond the range that prevailed during those earlier times.

Specifically, their analysis of long-term model simulations conducted with the Max Planck Institute (MPI) Earth System Model yields robust regional signals of decreasing aragonite surface concentrations that compare well with observations over the last 30 years and with proxy indicators going back in time to 800 AD. The carbon-cycle-coupled climate model was driven with the most recent reconstructions of solar and volcanic radiative perturbations, land-use changes, aerosols and orbital variations as well as historical CO_2 and greenhouse gas emissions.

The simulations analyzed by the team showed that for over a thousand years, marine ecosystems have been exposed to aragonite surface saturation levels that varied naturally, like today, on a variety of timescales. Today's observed and modeled levels of surface aragonite saturation, however, have dropped nearly five times below the minimum range existing up until the Industrial Revolution.

For example, if the yearly cycle of aragonite saturation in a region varied between 4.6 and 4.8 units, it varies now between 4.2 and 4.3 units. Based on a recent study by a team of scientists at the Rosenstiel School of Marine and Atmospheric Science in Miami, this drop translates into a 15% decrease in the calcification rates of corals and other aragonite shell-forming organisms. Using this empirical relationship, Friedrich and Timmermann estimate a 60% drop in coral reef calcification by the end of the 21st century; though, to be sure, other factors, such as nutrient and temperature changes, also impact calcification rate.



Upper panel: Simulated surface aragonite saturation. Lower panel: simulated atmospheric CO_2 concentration in parts per million.

"Ecosystems must adapt continually to environmental changes. Adaptation is more likely, though, if the rate of change is slow," explains Friedrich. "The last time that atmospheric temperatures and CO_2 rose rapidly occurred when Earth came out of its last deepfreeze and started to warm 17,000 years ago. Atmospheric CO_2 concentration levels rose from 190 ppmv to 280 ppmv until 11,000 years ago. By simulating this period with two Earth system models, LOVECLIM and MIROC, we could show that aragonite surface saturation had decreased by 0.88 and 0.64 units in LOVECLIM and MIROC respectively during that time. This means that the marine ecosystems had about 6000 years to adjust. Now, for a similar rise in CO_2 to the present level of 392 ppmv and a decrease in aragonite surface saturation of around 0.5 units, ecosystems have had only 100 to 200 years to adapt."

"Any significant drop below the minimum level of aragonite to which the organisms have been exposed to for thousands of years and have successfully adapted will very likely stress them and their associated ecosystems," warns Friedrich.

The study's findings also suggest that ocean acidification will affect calcifying marine ecosystems differently because the variability of aragonite saturation differs by region. This spatial heterogeneity in natural variability together with other local differences, especially in air-sea fluxes, suggests that some regions will be less stressed than others because the greater underlying natural variability of seawater acidity helps to buffer the anthropogenic changes. For example, the Galapagos Islands, located at the center of a strong upwelling region, are exposed to much larger variations in aragonite concentrations than the reefs in the Caribbean and the western Equatorial Pacific, where there is very little natural variability. These two biodiversity hotspots are thus particularly vulnerable to human-induced ocean acidification.

The rate at which aragonite surface concentration decreases in LOVECLIM and MIROC compares well with the rate of decrease recorded over the last 2 to 3 decades at several monitoring sites in the Pacific and the Atlantic. The observed decreases range between 0.09 units per decade for the Canary Islands and the Caribbean to 0.04 for Bermuda. The slowest rate of change in Bermuda already exceeds 32 (56) times the rate estimated in LOVECLIM (MIROC) for the last glacial termination; in the Caribbean, which shows the largest regional trends, the decrease over the last 20 years reaches 78 (138) times the previous rate.

Coral reefs live in places where open-ocean aragonite saturation reaches levels of 3.5 or higher. Such conditions exist today in about 50% of the global ocean – mostly in the tropics. By end of the 21st century, the MPI model simulations project that such levels of aragonite saturation will occur in less than 5% of the ocean. Because aragonite saturation decreases from the equator poleward, the Hawaiian Islands, which sit just on the northern edge of the tropics, could be among the first to feel the impact.

"Our results suggest that severe reductions are likely to occur in coral reef diversity, structural complexity and resilience by the middle of this century," concludes Axel Timmermann.

This story is based on

Friedrich, T., A. Timmermann, A. Abe-Ouchi, N.R. Bates, M.O. Chikamoto, et al., 2012: Detecting regional anthropogenic trends in ocean acidification against natural variability. *Nature Climate Change*, **2**, 167–171.

Animation of ocean acidification is at tinyurl.com/IPRCacid.