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OCB-OA: Physical circulation

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Are all upwelling regions going to be ocean acidification hotspots?

Basic: Some areas of the ocean undergo upwelling, which brings deep water to the surface. Because deep water carries more carbon dioxide than surface waters, it naturally has a lower pH. In some locations, like the west coast of the United States, upwelling water contains some CO_2 from the atmosphere and some from respiration of organic matter falling from the surface ocean. These areas are ocean acidification "hotspots" where pH and saturation state are lower than usual. Not every upwelling site is guaranteed to be a hotspot, though. That depends on local circulation.

Intermediate/Advanced: Upwelling areas are indeed regions of low pH. However, their water chemistry is set primarily by the rise of old deeper water, and not by anthropogenic CO_2-driven ocean acidification. Deep water has naturally lower pH due to respiration of organic matter falling from the surface ocean. In some locations, such as off the west coast of North America (Feely et al. Science 2008), water upwelling from mid-depths contains a great deal of CO_2 from respiration as well as from anthropogenic CO_2, owing to local circulation, so that these locations demonstrate much lower pH and carbonate ion concentrations than are expected from upwelling or atmospheric CO_2 invasion alone (Wootton et al. 2008). Seasonal upwelling happens in many locations worldwide. Upward movement of lower-pH, low-saturation state waters has been reported in the northeast Pacific Ocean (Feely et al. 1988 Marine Chemistry) and the Chukchi Sea in the Arctic Ocean as well (Bates et al 2009 JGR-Oceans)— S. Sundby, K.Y. Børsheim, S. Cooley

If climate change slows ocean circulation, will that change ocean acidification?

Basic: Warming tends to slow down vertical movement of water in the ocean. As a result, less CO_2 will enter the deep ocean with cold, sinking water. At the same time, phytoplankton in the upper ocean will have fewer nutrients to grow, so there will be less carbon-rich material sinking into the deep ocean. Ocean acidification will slow down if climate change slows ocean circulation, but other problems will also come up, like lack of oxygen in the ocean and lower photosynthesis overall.

Intermediate/advanced: If thermohaline ocean circulation slows because climate change increases the temperature of the surface ocean, the water column will become more stratified. This will slow mixing of carbon dioxide down into the upper ocean, although the surface layer will take up a great deal of CO_2. Nutrients also will not be mixed into the upper ocean from below as rapidly, decreasing primary production. This decreases the "biological pump" that carries organic carbon into the deep ocean by way of sinking particles. At the same time, slowing the formation of deep water in high latitudes will decrease the amount of CO_2 that penetrates the deep ocean basins.

(Details can be found in Gruber 2011 Phil. Trans. R. Soc. A (2011) 369, 1980–1996) — S. Sundby, K.Y. Børsheim, S. Cooley

Is ocean acidification the same in the surface and deep oceans?

Basic: OA is happening at a different rate in the surface and deep oceans because of the way CO_2 moves through the ocean. At the surface, the ocean takes up CO_2 directly from the atmosphere. In the rest of the ocean, CO_2 enters the ocean when cold water in contact with the atmosphere sinks into the deep ocean. Then, sinking carbon-rich material from the surface ocean gets digested by deep sea organisms, which exhale CO_2 into the already CO_2 rich deep water.

Intermediate: No. The surface ocean is directly influenced by the entry of anthropogenic CO_2 from the atmosphere. This causes a decrease in marine pH and a subsequent reduction in carbonate ions that are essential for shell building organisms. Ocean acidification is penetrating downward in the ocean from the surface, and most of its impacts are seen in the upper 200-500m of the ocean. Elsewhere, CO_2 accumulates differently. Deep ocean water is "formed" when it cools and sinks in the high latitudes after being in contact with the atmosphere for some time, which sets the basic chemical content of deep water. After that, the deep ocean does not directly interact with the atmosphere. Additional CO_2 accumulation in the deep ocean happens because of the accumulation of respired organic products that have sunk down from the surface (marine snow). Because ocean circulation and mixing are relatively slow (on the order of a thousand years or more) compared to the relatively well-mixed atmosphere, it will take several more generations before we see the penetration of anthropogenic CO_2 spread throughout all of the deep ocean. However, repeat research cruises show that anthropogenic CO_2 is entering the ocean from the surface at the same time as it slowly spreads through the deep ocean. Ultimately OA will decrease the pH of all the water to levels lower than today. —S. Doney, C. Langdon, J. Mathis, R. Feely, S. Cooley

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