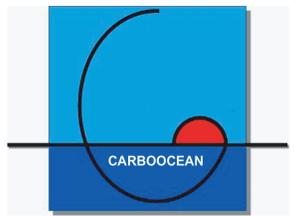


# CARBOCLIM Modelling Results: Ocean Acidification

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**Abstract** Atmospheric CO<sub>2</sub> is increasing and expected to reach double preindustrial levels within the next 50-60 years in response to anthropogenic emissions. About a third of the carbon dioxide released ends up in the ocean. The term "ocean acidification" refers to the decrease in pH of seawater due to the uptake of carbon dioxide. This is expected to have a major impact on calcifying marine organisms, such as corals and some plankton. Here we present results from a simulation with the coupled climate-carbon cycle model CSM1.4-carbon over the industrial period until 2100. Fossil fuel emissions were prescribed according to the SRES-A2 scenario. This work is part of the CSCS CARBOCLIM project.

## Ocean carbonate chemistry

Atmospheric CO<sub>2</sub> enters the ocean by air-sea exchange at the ocean surface, which tends to equilibrate the partial pressure (pCO<sub>2</sub>) across the air-sea interface (Figure 1). Then a series of chemical equilibria determines the partitioning of the components CO<sub>2</sub>, H<sub>2</sub>CO<sub>3</sub>, HCO<sub>3</sub><sup>-</sup> and CO<sub>3</sub><sup>2-</sup>, which are identified together as total dissolved inorganic carbon (DIC). The net chemical reaction that is of interest here is H<sub>2</sub>O + CO<sub>2</sub> + CO<sub>3</sub><sup>2-</sup> ⇌ 2HCO<sub>3</sub><sup>-</sup>. From this it follows that an increase of the uptake of CO<sub>2</sub> by the ocean lowers the concentration of carbonate ions [CO<sub>3</sub><sup>2-</sup>].

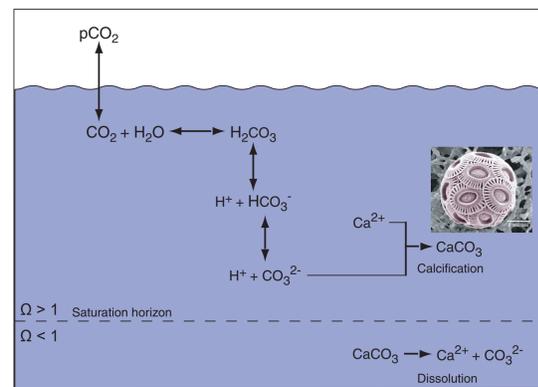


Figure 1: A simplified diagram of the carbonate system in seawater. Ocean uptake of CO<sub>2</sub> changes the carbonate ion [CO<sub>3</sub><sup>2-</sup>] concentration, which has an influence on calcifying marine organisms.

## Impact on calcifying organisms

Marine organisms form calcium carbonate (CaCO<sub>3</sub>) to build their shells or skeletons. CaCO<sub>3</sub> occurs in the form of calcite or in the less stable phase called aragonite. The calcification rate and the dissolution of CaCO<sub>3</sub> is mainly determined by the carbonate saturation state  $\Omega = \frac{[Ca^{2+}][CO_3^{2-}]}{K_{sp}}$ , where K<sub>sp</sub> is the solubility product defined by the equilibrium relationship for the dissolution reaction of the mineral CaCO<sub>3</sub>. At values of Ω less than one waters are undersaturated with respect to CaCO<sub>3</sub> and dissolution will occur, at values larger than one the water is supersaturated.

The decrease of [CO<sub>3</sub><sup>2-</sup>] will lower the saturation state Ω in some regions, making it more difficult for calcifying organisms to build CaCO<sub>3</sub> and their skeletons or shells might start to dissolve [Kleypas et al., 2006].

## Changes in CaCO<sub>3</sub> saturation state from 1820 - 2100 for SRES-A2

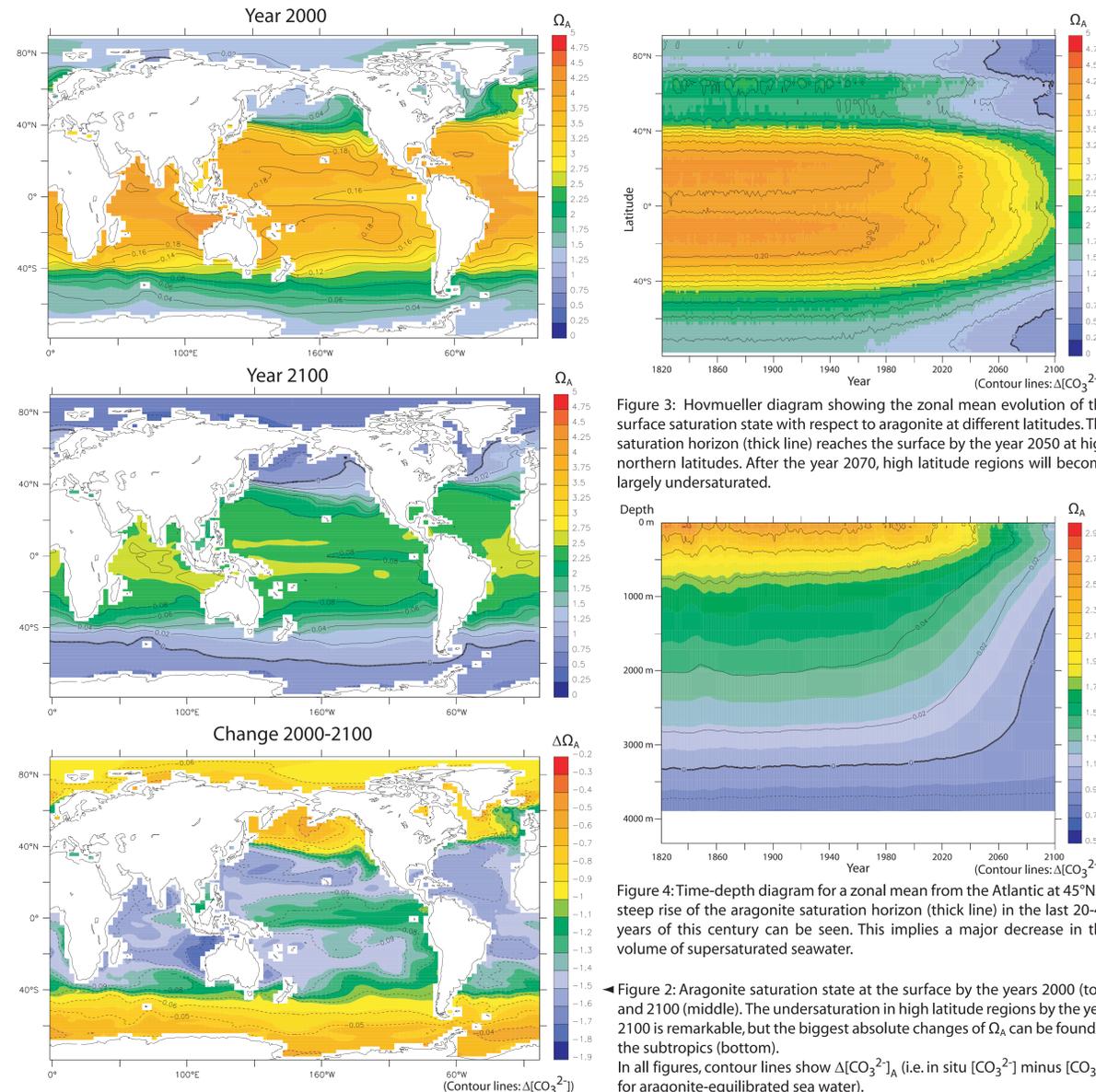


Figure 3: Hovmueller diagram showing the zonal mean evolution of the surface saturation state with respect to aragonite at different latitudes. The saturation horizon (thick line) reaches the surface by the year 2050 at high northern latitudes. After the year 2070, high latitude regions will become largely undersaturated.

Figure 4: Time-depth diagram for a zonal mean from the Atlantic at 45°N. A steep rise of the aragonite saturation horizon (thick line) in the last 20-40 years of this century can be seen. This implies a major decrease in the volume of supersaturated seawater.

Figure 2: Aragonite saturation state at the surface by the years 2000 (top) and 2100 (middle). The undersaturation in high latitude regions by the year 2100 is remarkable, but the biggest absolute changes of Ω<sub>A</sub> can be found in the subtropics (bottom). In all figures, contour lines show Δ[CO<sub>3</sub><sup>2-</sup>]<sub>A</sub> (i.e. in situ [CO<sub>3</sub><sup>2-</sup>] minus [CO<sub>3</sub><sup>2-</sup>] for aragonite-equilibrated sea water).

**Results** It is projected that high latitude waters will first become undersaturated with respect to aragonite by the year 2050 (Figure 3). By the end of this century, large regions in the Southern Ocean and the subarctic Pacific are expected to be undersaturated at the surface (Figure 2). These findings are in agreement with the results from Orr et al. (2005).

A comparison between modelled and data based saturation states Ω<sub>A</sub> shows, that the model matches measurements from GLODAP and WOA01 reasonably well [Key et al. (2004), Conkright et al. (2002)]. However, it slightly underestimates the carbonate concentration at the surface, especially in the North Pacific (Figure 5), whereas the concentrations at depths below 500 m are somewhat too high (Figure 6).

## Comparison with observations

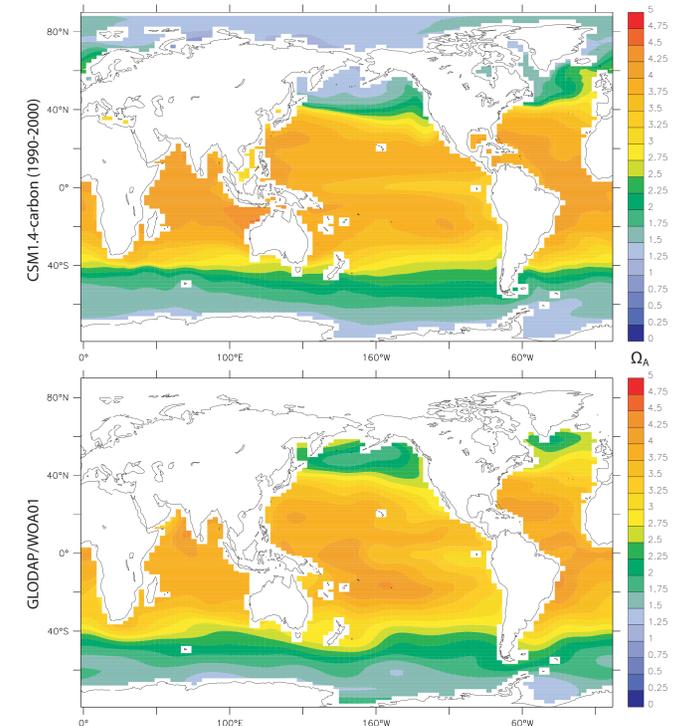


Figure 5: Aragonite saturation state at the surface simulated with CSM1.4-carbon (top) and calculated with measurements from GLODAP/WOA01 (bottom) data.

## References & Contact

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- J.A. Kleypas et al., 2006. Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research, report of a workshop held 18-20 April 2005
- J.C. Orr et al., 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms, Nature, 437, 681-686
- R.M. Key et al. 2004. A global ocean carbon climatology: Results from GLODAP. Global Biogeochemical Cycles, Vol. 18, GB4031
- M.E. Conkright et al., 2002. World Ocean Atlas 2001: Objective Analyses, Data Statistics, and Figures, CD-ROM Documentation. National Oceanographic Data Center, Silver Spring, MD, 17 pp.

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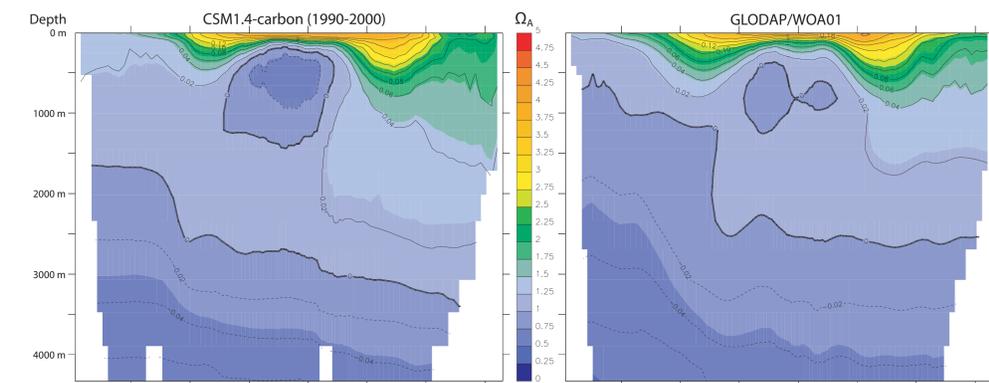


Figure 6: Sections through the Atlantic showing the aragonite saturation state for the CSM1.4-carbon and GLODAP/WOA01 data.