

OCEANOGRAPHY

Ocean eddies and plankton blooms

Phytoplankton form the base of the marine food web, but their growth in nutrient-depleted surface waters has remained a puzzle. Two complementary studies suggest that ocean eddies help to control phytoplankton growth and distribution in unexpected ways.

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Phytoplankton, microscopic organisms that live in the sunlit layer of the ocean, form the foundation of the marine food web. These tiny plants require sufficient levels of light and nutrients to bloom. Given that surface waters are often depleted in nutrients, and that sunlight penetrates just a few tens of metres down, most of the ocean should be a desert. Winds blowing over the surface, however, drive the upwelling of deep, nutrient-rich waters over parts of the ocean. This upwelling brings nutrients to the sunlit surface zone, and thereby encourages phytoplankton growth. In addition, eddies — ubiquitous swirling currents in the ocean — are thought to support phytoplankton growth in nutrient-poor surface waters by providing time-varying upwelling^{1,2}. Two studies broaden the remit of interactions between eddies and phytoplankton: writing in *Science*, Chelton and colleagues³ suggest that eddies passively advect phytoplankton over much of the ocean; and writing in *Nature Geoscience*, Gruber and colleagues⁴ show that eddies can dampen blooms in upwelling zones.

The oceans are full of eddies. Mesoscale eddies occur on a horizontal scale of tens to a hundred kilometres and form in regions of strong currents. These ocean currents are associated with surfaces of equal density that are strongly tilting rather than flat, as in a still ocean. Potential energy is stored within this density structure, and eddies access this store of potential energy by flattening the density surfaces⁵.

The effect of eddies on phytoplankton growth depends on their environment. The prevailing view is that eddies^{1,2} and finer-scale frontal circulations⁶ sustain phytoplankton growth over nutrient-poor surface waters in the subtropical gyres extending over the mid-latitudes. Eddies and fronts provide intermittent pulses of nutrients to the surface from the nutrient-rich thermocline, that layer of the ocean that separates the upper mixed layer from the deep waters below. This enhancement might be temporary, because repeated transient upwelling events will eventually exhaust the nutrient reservoir in the upper thermocline^{7,8}.

On the other hand, Chelton and colleagues³ suggest that eddies primarily

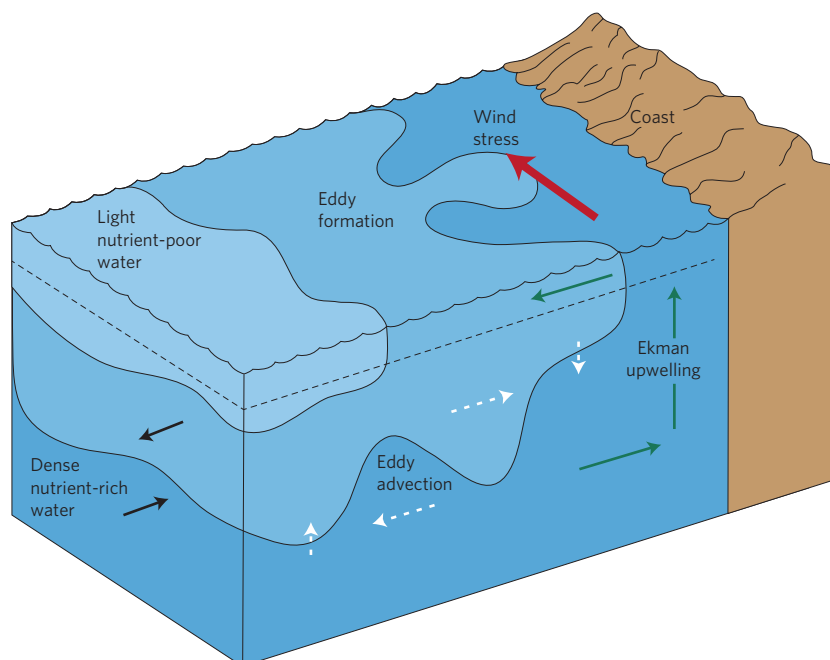


Figure 1 | Ocean eddies in eastern boundary upwelling zones and the waters off Antarctica. Using satellite-based measurements of chlorophyll and eddy kinetic energy, together with model simulations, Gruber and colleagues⁴ show that eddies dampen productivity in eastern boundary upwelling zones (shown here in the Southern Hemisphere, so that west is to the left). A surface wind stress (red arrow) drives upwelling along the coast and the movement of waters offshore (green arrows). Eddies form and provide an opposing circulation (white dashed arrows) to that of the wind. The overall effect of the winds and eddies is to provide a nutrient pathway (black arrows) along density surfaces from the coast to the open ocean. This nutrient transfer might support productivity in adjacent nutrient-poor environments. The findings of Gruber *et al.* might also prove applicable to the upwelling waters off Antarctica, also shown here (now depicted with north to the left).

redistribute chlorophyll. They use satellite measurements of chlorophyll and sea surface height to show that mesoscale eddies generate much of the variability in chlorophyll over the open ocean. Previously, this variability was attributed to the presence of large-scale oceanic waves, called Rossby waves. Chelton *et al.* show that the swirling velocities surrounding the core of the eddies horizontally advect the chlorophyll. Thus, much of the observed chlorophyll variability results from an eddy-induced redistribution, rather than a change in local phytoplankton growth.

In contrast, Gruber *et al.*⁴ investigate the role of mesoscale eddies in the eastern

boundary upwelling systems, some of the most productive environments on the Earth. Winds drive the upwelling of nutrient-rich waters along the eastern boundary of ocean basins (Fig. 1), creating phytoplankton blooms along the coast. Using remotely sensed chlorophyll data and measurements of eddy kinetic energy for the California, Canary, Humboldt and Benguela current systems, Gruber *et al.* find that productivity is reduced whenever there is intense eddy kinetic energy. Model simulations of the California current system confirm this finding and suggest that the local reduction in productivity stems from an eddy-induced transfer of nutrient-rich waters offshore.

Eddies cause the diffusion and advection of nutrients along density surfaces⁹, leading to the advection of thick blobs of less-dense water onshore and thick blobs of dense water offshore (Fig. 1). Together, eddy advection and diffusion transfer nutrients from the local upwelling site to the neighbouring subtropical gyres¹⁰, possibly replenishing nutrients in the upper thermocline.

The findings of Gruber *et al.*, linking eddies and the transport of nutrients offshore, are potentially applicable to the Southern Ocean — the ocean's largest upwelling system and a region of intense eddy activity. Again, the competition between winds and eddies is important. Strong westerly winds around Antarctica drive water northwards in a thin surface layer (Fig. 1, green arrows), resulting in upwelling to the south. Mesoscale eddies again form along the entire current. Together the winds and eddies lead to a northward transport¹¹ of nutrient-rich waters in the upper thermocline.

One way of understanding the different effects of eddies is to think of their life cycle. Initially, eddies provide a vigorous horizontal and vertical transfer of heat and

nutrients as they form in regions of strongly sloping density surfaces. As eddies mature, they move away from their region of origin as coherent features that carry nutrients and heat with them, locally deform their environment, redistribute chlorophyll³ and transport nutrients^{4,10}. Eventually they die, and release their anomalous properties to a new environment.

The studies of Chelton *et al.*³ and Gruber and colleagues⁴ illustrate the myriad effects that eddies can have on phytoplankton. Eddies can stimulate phytoplankton growth in subtropical gyres through time-varying upwelling^{1,2}, although, as noted above, this effect may be short-lived^{7,8}. And, as highlighted by the two new papers^{3,4}, eddies can also dampen phytoplankton growth in eastern boundary upwelling zones and redistribute surface chlorophyll throughout the ocean. Although eddies suppress productivity in eastern boundary upwelling zones, they may raise productivity in the neighbouring subtropical gyres by increasing the nutrient supply to the upper thermocline. The combined wind and eddy transfer of nutrients is probably most important in the Southern Ocean¹¹, enabling a northward

transfer of nutrient-rich waters and, possibly, sustaining high-latitude productivity in the northern basins^{12,13}. □

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