

Ocean convergence and the dispersion of flotsam

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Floating oil, plastics, and marine organisms are continually redistributed by ocean surface currents. Prediction of their resulting distribution on the surface is a fundamental, long-standing, and practically important problem. The dominant paradigm is dispersion within the dynamical context of a nondivergent flow: objects initially close together will on average spread apart but the area of surface patches of material does not change. Although this paradigm is likely valid at mesoscales, larger than 100 km in horizontal scale, recent theoretical studies of submesoscales (less than ~10 km) predict strong surface convergences and downwelling associated with horizontal density fronts and cyclonic vortices. Here we show that such structures can dramatically concentrate floating material. More than half of an array of ~200 surface drifters covering ~20 × 20 km² converged into a 60 × 60 m region within a week, a factor of more than 10⁵ decrease in area, before slowly dispersing. As predicted, the convergence occurred at density fronts and with cyclonic vorticity. A zipperlike structure may play an important role. Cyclonic vorticity and vertical velocity reached 0.001 s⁻¹ and 0.01 ms⁻¹, respectively, which is much larger than usually inferred. This suggests a paradigm in which nearby objects form submesoscale clusters, and these clusters then spread apart. Together, these effects set both the overall extent and the finescale texture of a patch of floating material. Material concentrated at submesoscale convergences can create unique communities of organisms, amplify impacts of toxic material, and create opportunities to more efficiently recover such material.

ocean | submesoscale | dispersion | eddy | vertical velocity

Oil, plastics, and other flotsam floating on the surface of the ocean, as well as buoyant marine plants and animals, are continually redistributed by ocean surface currents. The distribution of such material shows variations on a wide range of scales (1–4) (Fig. 1) often showing long streaks of high concentration on scales of kilometers or smaller that sometimes wrap into spirals. The impacts of pollutants and the rates and types of biological processes depend on the concentration of the material. The understanding and prediction of such concentrations is thus of practical importance and interdisciplinary interest.

Classical models of dispersion build on the kinetic theory of gases to treat the spread of a patch of material as a random process governed by scale-dependent horizontal diffusion (5, 6). However, such models only predict the average concentration and, because they can only spread material not concentrate it into streaks, cannot explain much of the small-scale structure illustrated in Fig. 1.

Dynamically, such models usually assume the surface currents to be nondivergent, with zero vertical velocity, and with motion thus confined entirely to the horizontal plane. These assumptions are approximately valid for mesoscale oceanic motions with horizontal scales larger than 100 km and timescales longer than

many days. Quantitatively, the magnitudes of surface divergence δ and vertical vorticity ζ are much smaller than the Coriolis frequency f . Much recent research has focused on understanding smaller and more rapidly evolving submesoscale motions with horizontal scales of roughly 0.1–10 km (7) for which these assumptions fail. Submesoscale motions are predicted to have significant vertical velocities (8) within structures with $|\zeta/f| \geq 1$ and $|\delta/f| \geq 1$. The resulting exchanges between the surface and the interior can be important both dynamically and for ocean productivity and carbon export (9, 10).

Here, we focus on how surface convergence zones that feed such downward velocities can trap and concentrate floating materials (11) (Fig. 2), a process not included in traditional dispersion models. We describe a surprisingly strong example of such downwelling and convergence, identify the submesoscale structures responsible, and use these to both test theoretical predictions and to explain the distributions seen in Fig. 1.

Observations

Measurements were made in February 2016 in the northern Gulf of Mexico near the site of the Deepwater Horizon oil spill ([Supporting](#)

Significance

Ocean currents move material released on the ocean surface away from the release point and, over time, spread it over an increasingly large area. However, observations also show high concentrations of the material even after significant spreading. This work examines a mechanism for creating such concentrations: downwelling of water at the boundaries of different water masses concentrates floating material at this boundary. Hundreds of satellite-tracked drifters were released near the site of the 2010 Deepwater Horizon oil spill. Surprisingly, most of these gathered into a single cluster less than 100 m in size, dramatically demonstrating the strength of this mechanism.

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Data deposition: Data are publicly available through the Gulf of Mexico Research Initiative Information & Data Cooperative (GRIIDC) at <https://data.gulfresearchinitiative.org> (dois: 10.7266/N7HQ3WZR, 10.7266/N7KW5DH7, 10.7266/N7W0940J, 10.7266/N7H130FC, 10.7266/N7S75DRP, 10.7266/N7610XQ6).

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