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Impact of Langmuir circulations on TKE dissipation in the surface layer of the ocean

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Our understanding of the oceanic boundary layer owes a great deal to theories originally developed for the atmospheric boundary layer. The constant shear stress and logarithmic mean velocity profile that are known to exist in the former were initially thought to have equivalents in the latter, although ocean currents are driven by a wind stress. The profile of the TKE dissipation rate that is consistent with a logarithmic mean velocity profile is proportional to z^{-1}. However, observations in the ocean over the last decades, in the WAVES and SWADE campaigns and subsequently, have shown that in the oceanic surface layer the dissipation increases much faster as one approaches the surface. Various theories have been proposed to explain this phenomenon, mostly relying on the transport of TKE injected by breaking waves into the water. Here, a complementary explanation is proposed, where the interaction of turbulence with surface waves and currents leads to an amplification of the TKE, and consequently of its dissipation.

The model developed here is based on Rapid Distortion Theory (RDT), and assumes that turbulence existing initially has a constant shear stress, as in the atmospheric boundary layer, but is subsequently distorted by the joint straining of the wind-induced shear current and the Stokes drift of surface waves over a time of order the eddy turn-over time of the turbulence, after which the flow saturates and further growth is prevented by nonlinear processes. This can be considered a finite-amplitude version of the instability mechanism established by Craik and Leibovich as a source for Langmuir circulations. While the flow evolves to be progressively dominated by streamwise vortices, its TKE grows exponentially, leading to a similarly strong increase of the dissipation rate. Since both currents and the Stokes drift of surface waves decay with depth, this mechanism is most active near the surface, leading to a dissipation variation much faster than proportional to z^{-1}.

The shear stress is partitioned between a component supported by the current and a component supported by the Stokes drift. This leads to weakening of the shear as the turbulent Langmuir number La_t decreases, a fact confirmed by independent data. The dissipation rate normalized with the friction velocity u_* and the wavenumber of the dominant surface waves k_w is found to be a function of depth normalized by k_w, of La_t, and of a dimensionless eddy turn-over time. Since turbulence is likely to originate mostly from wave breaking, the eddy turn-over time is estimated in terms of u_* and k_w. Results from the model are compared with measurements from the WAVES and SWADE campaigns, and more recent datasets. When suitably calibrated, the model is able to predict the magnitude of the dissipation rate better than previous models. The data confirm that depth scales better with k_w^{-1} than with the significant wave height, and that the dissipation rate depends on La_t. Additionally, the model appears to be able to account for shallow water effects in the dissipation profiles.