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On modelling the influence of wind waves on the turbulent boundary layers above and below the air–water interface

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The exchange of momentum, mechanical and thermal energy, and mass, between the atmosphere and the ocean is mediated by physical processes occurring in laminar and turbulent boundary layers above and below the air-water interface, and at the interface itself. Surface gravity–capillary waves (wind waves) on the interface interact with the mean flow in both boundary layers, via several mechanisms, including the Stokes drift due to non-closed fluid particle paths, the presence of critical layers where the mean flow speed is equal to the phase speed of wave Fourier components, and the injection of momentum into the mean flow in association with wave energy dissipation by wave breaking and other processes. Wave breaking also provides a source of turbulent kinetic energy for mixing.

The magnitudes of the processes mentioned above depend nonlinearly on the wave amplitude and on other variables such as the applied wind stress. However, they may be regarded as being slowly-varying 'mean' quantities of second order in a small parameter such as wave steepness, and thus can be computed using the wave Fourier spectrum and the wave energy input and dissipation terms employed in spectral wave prediction models. Since the flow variables change rapidly in the direction normal to the interface, it is necessary to employ a suitable surface-following coordinate system.

Within the water column, the effect of the waves on the mean flow may be computed directly, via an analytical description of the wave orbital motion. Above the surface it is necessary to invoke an iterative procedure, since equations of the Orr–Sommerfeld type must be integrated numerically for each wave component. We also discuss various methods of parameterizing the turbulent flow variables, and the implications for the air–sea exchange of heat, gas species, and other substances.