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Air-sea fluxes of momentum and mass in the presence of wind waves

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An air-sea interaction model (ASIM) is developed including the effect of wind waves on momentum and mass transfer. This includes the derivation of profiles of dissipation rate, flow speed and concentration from a certain height to a certain depth. Simplified assumptions on the turbulent closure, skin – bulk matching and the spectral wave model allow for an analytic treatment. Particular emphasis was put on the inclusion of primary (gravity) waves and secondary (capillary-gravity) waves. The model was tuned to match wall-flow theory and data on wave height and slope. Growing waves reduce the air-side turbulent stress and lead to an increasing drag coefficient. In the sea, breaking waves inject turbulent kinetic energy and accelerate the transfer. Cross-reference with data on wave-related momentum and energy flux, dissipation rate and transfer velocity was sufficient. The evaluation of ASIM allowed for the analytical calculation of bulk formulae for the wind-dependent gas transfer velocity including information on the air-side momentum transfer (drag coefficient) and the sea-side gas transfer (Dalton number). The following regimes have been identified: the smooth waveless regime with a transfer velocity proportional to $(wind) \times (diffusion)^{2/3}$, the primary wave regime with a wind speed dependence proportional to $(wind)^{1/4} \times (diffusion)^{1/2}/(waveage)^{1/4}$ and the secondary wave regime including a more-than-linear wind speed dependence like $(wind)^{15/8} \times (diffusion)^{1/2} \times (waveage)^{5/8}$. These findings complete the current understanding of air-sea interaction for medium winds between 2 and 20 m s^{-1}.