Development of Wave-Sea Ice Interactions in the ECMWF Earth System Model

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Abstract

Ocean surface waves drive key upper-ocean processes through Stokes drift, wave-driven turbulent kinetic energy input that enhances vertical mixing, and the modification of surface stress transmitted into the ocean. In the ECMWF Earth System model, these effects are represented via a coupled wave model that provides sea-state-dependent forcing to the ocean component, allowing a more physically consistent representation of upper-ocean momentum and mixing processes.

Building on this coupled wave–ocean framework, an important next frontier lies in the polar regions, where declining sea-ice cover is increasing the exposure of the ocean to surface waves and strengthening two-way wave–sea-ice interactions. These processes are increasingly recognized as important to weather and climate across timescales from short-range forecasting to seasonal prediction. Yet they remain largely unexplored in the context of a fully coupled global Earth System Model, where ocean, atmosphere, sea ice, and waves evolve interactively.

This work focuses on the implementation and repercussions of two-way wave-sea ice interactions within the ECMWF Earth System Model (ESM). Two physical couplings are implemented and explored here. The first is that of wave induced sea ice breakup. Waves can break up the ice through oscillation and flexural failure of the ice. The state of the sea ice (i.e. broken or solid) then defines two clear attenuation regimes, with solid ice attenuating strongly, and broken ice attenuating more weakly. Kousal et al. (2022) implemented this logic within the WAVEWATCH III spectral wave model to form a simple coupled wave-sea ice model (assuming the sea ice takes a binary form of broken or solid), thereby allowing for coupled feedback effects, and showed that such a model can well represent break up of the sea ice as well as wave attenuation in the MIZ. In this work, we build on that of Kousal et al. (2022), except instead of using a simple sea ice model, we use the thermodynamic sea ice model SI3 within the ESM. These are coupled through the aforementioned binary ice breakup field. We also consider the following: the broken ice is able to heal itself based on ice model thermodynamics; the ice breakup field can be advected; this ice breakup translates to a weakening of the internal strength of the sea ice. The second physical coupling we explore is that of wave-radiative stresses, the force that pushes the sea ice in the direction of the propagation of the attenuated waves. Some results will be presented.

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