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Closer together: coupling the wave and ocean models

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Closer together: coupling the wave and ocean models

Øyvind Breivik, Magdalena Alonso-Balmaseda, Jean-Raymond Bidlot, Peter A E M Janssen,Sarah Keeley, Kristian Mogensen

Traditionally, wind-generated surface waves have been treated as a phenomenon somewhat detached from the goings-on of the ocean beneath. That waves affect the marine boundary layer of the atmosphere by modifying the surface roughness has long been known. Consequently, since 1998 ECMWF has been running a coupled forecasting system where the atmospheric component of the Integrated Forecasting System (IFS) communicates with the wave model (WAM) through exchange of the Charnock parameter which determines the roughness of the sea surface (*Janssen*, 2004).

If the wave model is allowed to interact with the atmospheric component, it may be pertinent to ask if it should also be allowed to 'talk' to the ocean model, NEMO. This is the topic of the European Union FP7 project MyWave which started in 2012 and runs until the end of 2014. Waves affect the upper part of the ocean through three distinct mechanisms which are illustrated in Figure 1.

- ***Stress.*** When waves are growing they soak up momentum (and thus energy) which otherwise would have been transferred to the ocean interior. This is shown in the left part of Figure 1 as the difference τ_w between the air-side stress on the water surface (τ_a) and the water-side stress (τ_o).
- ***Turbulent kinetic energy.*** As waves break (right side of Figure 1) they inject turbulent kinetic energy, thus enhancing the mixing, while also feeding momentum into the currents. If there is equilibrium between wind input and dissipation, then the airside stress would be equal to the total water-side stress. However, most of the time waves are not in equilibrium giving differences in air-side and water-side stress of the order of 5–10%, which is not an inconsiderable difference.
- ***Stokes drift.*** Waves set up a current in the down-wave direction known as the Stokes drift. Although this effect decays rapidly with depth, it can be substantial near the surface (~1 m/s). In combination with the earth's rotation it adds an additional veering to the upper-ocean currents known as the Coriolis-Stokes force (see e.g. *Janssen*, 2012; *Belcher et al.*, 2012).

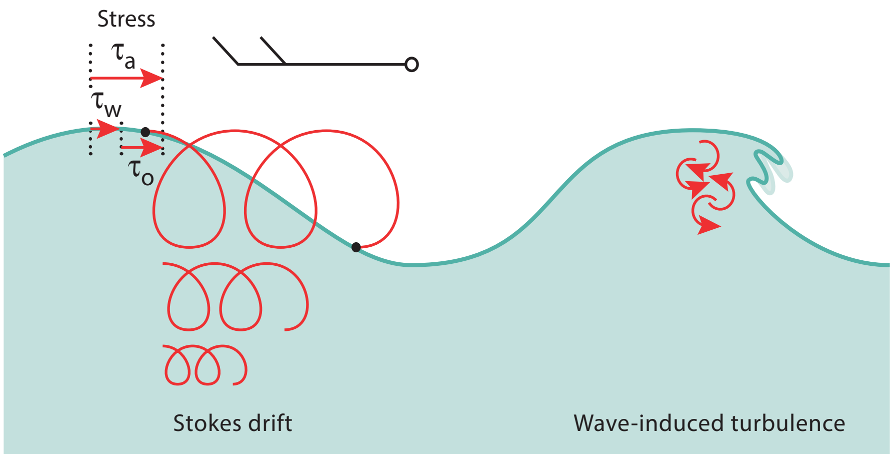

Figure 1 Wave-ocean interaction. As waves grow under the influence of the wind (left), the waves will absorb momentum (τw) which otherwise would have gone into the ocean directly (τo). As waves break (right), turbulent kinetic energy is injected into the ocean mixed layer, significantly enhancing the mixing. The Stokes drift, a Lagrangian effect of waves of finite amplitude, sets up a current in the along-wave direction which decays rapidly with depth. Near the surface it may become substantial (~1 m/s). The Coriolis effect works on the Stokes drift and adds a new term to the momentum equations known as the Coriolis-Stokes force.

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All three of the above mechanisms are already available from WAM, both as operational forecast products (since June 2012) and in the ERA-Interim reanalysis (1979 to present, see *Dee et al.*, 2011).

To test the impact of wave information on the upper ocean we have performed experiments where wave effects are introduced in NEMO. A comparison was made between stand-alone (ocean only) integrations where (a) stress, energy flux and Stokes drift are taken from the ERA-Interim archive and (b) a control run without Stokes drift and with an energy flux based on fully developed wind sea. Therefore, the control run also includes the effect of breaking waves on upper-ocean mixing, but ignores the effect of growing and decaying wind sea on the energy and momentum fluxes (*Craig & Banner*, 1994). The integration covered the thirty-one years from 1979 to 2009.

The sea surface temperature differences are shown in Figure 2. The sea-state dependent mixing gives rise to rather large temperature differences with the biggest deviations found in the summer hemisphere. This is partly due to too vigorous mixing in the control run. Whereas the temperature differences due to modified mixing are quite uniform throughout the extratropics, the differences linked to the Coriolis-Stokes effect are more localized. The pronounced differences found in the Kuroshio and Gulf Stream stem from both Coriolis-Stokes forcing and modifications to the stress. Overall the differences amount to more than 2 K in the extratropics.

In the experiments shown in Figure 2, NEMO is updated with wave fields four times daily. However, in the new coupled model system (see *Mogensen et al.*, 2012) which is now under development, WAM, NEMO and the atmospheric model are tightly integrated. It is expected that this system will allow efficient exchange of a large number of fields at high temporal frequency. Early results with fully coupled runs indicate an impact from the coupling of WAM and NEMO also on the atmosphere. But, no matter how large the wave effects in the end will turn out to be, the tight coupling under development opens up new possibilities for exchange of parameters, not just between the wave model and the ocean model, but also the other way round.

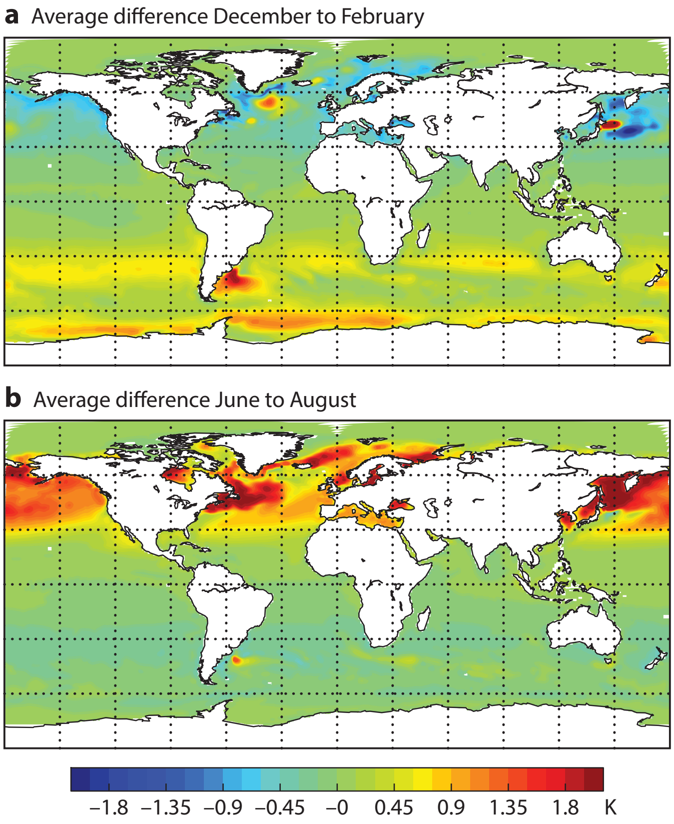

Figure 2 Temperature difference between a control run with energy flux estimated from an average sea state and a run where wave effects are computed from the ERA-Interim WAM model (averaged over the period 1989–2008) for (a) December to February and (b) June to August. The effects are most pronounced in the extratropics of the summer hemisphere, where the difference amounts to more than 2 K. The effect of the Coriolis-Stokes force and the modified momentum flux is most pronounced in the Gulf Stream and Kuroshio currents.

Further reading

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