Surface Driven Energy Transfer in Atmosphere and Ocean

Energy Fluxes at the Air-Sea Interface

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In Short

- Over 80% of the kinetic energy within the ocean originates from the mechanical action of the wind upon the wavy ocean surface. [5]
- Global circulation models can not resolve the energy-flux controlling small scale processes.
- The partitioning of wind energy contributions into the wave growth, wave breaking, and current generation remains poorly understood.
- We intend to develop a true two-phase flow procedure to study the momentum driven energy transfer along the air-sea interface.
- Comparison of simulation data with experimental results is scheduled to investigate various wind-wave conditions - including more complex phenomena such as wave breaking or micro-scale separation.

The transfer of energy by the free-surface waves is important for the coupled atmosphere-ocean system. In this project, we numerically examine the details of the energy transfer mechanisms in the vicinity of the ocean surface using hybrid scale-resolving Cahn-Hilliard-VoF two-phase flow approaches. Different from all previous approaches, the present computational model is not confined to the single air phase using an assumed free surface evolution together with an arbitrarily chosen interface roughness, but a true two-phase flow representation. Efforts are supplemented by analogue experimental two-phase work and jointly aim to identify the physics controlling air-sea energy fluxes and to quantify the mechanical energy budget within the coupled atmospheric and oceanic boundary layers. Related results should finally feed into an improved model of phase-averaged momentum equations, to be used in future general circulation models.

The computational model is based on a finite volume Navier-Stokes procedure [4,6] and consists of the following ingredients:

1. The wind-wave-interaction is modeled by a simplified version of the diffusive interface CH-VoF published in [3]. The CH-VoF approach features a number of theoretical advantages, e.g. with regards to an efficient (natural) interface compression, relevant for computing the dynamic interplay between two virtually immiscible fluid phases.
2. A hybrid RANS/LES (DES) turbulence model has been introduced to the numerical wind-wave tank. The model features optional DDES and IDDES capabilities [2]. Different from the traditional DES approach, the formulation of the turbulent length scale follows from a dynamic free surface distance instead of the (usually steady) wall distance, which required the implementation of an efficient, HPC-capable distance calculation procedure. The latter is also essential for post processing (cf. 4.), and is computed from a PDE-based approach.
3. A numerical wind-wave flume was set up. Related work aims at the reproduction of experimentally observed wave properties under wind forcing. Experimentally observed (averaged) wind-wave conditions are introduced using an implicit forcing of flow properties (velocity, density, turbulence) in an inlet zone extracted from measurements.[1]

   The latter spans approximately a typical wave length from the inlet into the interior and involves both, the air and the water phase. Water phase forcing refers to the linear wave theory. In the air phase, a logarithmic velocity profile is imposed. At the outlet, the grid is sufficiently stretched to obtain a numerical beach and thereby damping the wave field to suppress reflections.
4. A comprehensive post-processing using phase averaged, wave-following coordinates (vertical coordinate ζ, phase ϕ) has been established which is able to connect numerical results with experimental data. The wave coherent velocities play an important role for the investigation of different wave parameters on the energy budget at the air-sea interface. They can be calculated by a triple decomposition:

   $$u(\phi,\zeta) = \langle u\rangle(\zeta) + \tilde{u}(\phi,\zeta) + u'(\phi,\zeta) \qquad (1)$$

   with $\langle u\rangle(\zeta)$, $\tilde{u}(\phi,\zeta)$ and $u'(\phi,\zeta)$ corresponding to the phase independent mean velocity, the wave coherent velocity and the turbulent fluctuation. The wave-following coordinates are completely unlinked from the employed unstructured

[1] wave length, number, amplitude (λ, k, a), wind velocity u_{10} ($10\,\mathrm{m}$ above the free surface), turbulence properties.

spatial/temporal discretization. The procedure supports averaging the data based upon substantial (dynamic) data identification (binning).

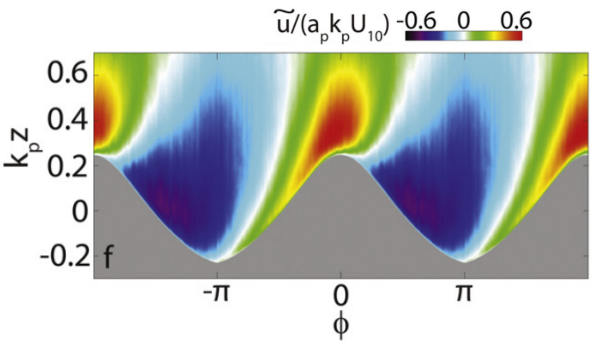

Figure 1: *Experimental results, contour plots of the norm. wave coherent velocity $\tilde{u}$ (cf. [1]).*

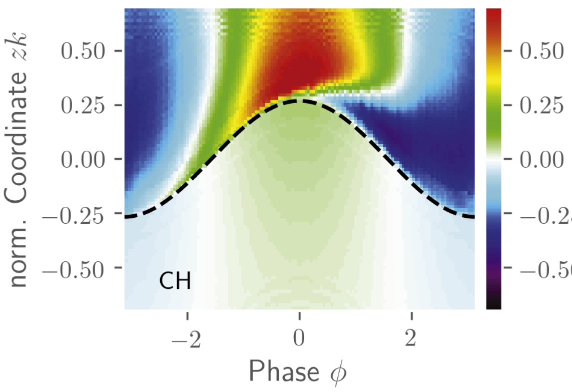

Figure 2: *2D Simulation results, contour plots of the norm. wave coherent velocity $\tilde{u}$ (VoF-CH model).*

First wind-wave computations where performed for a case previously measured in a wind-wave flume, cf. exemplary Figs. (1) and (2). The case was used to assess the predictive performance of mathematical and computational model described above against data published in [1] for a particular wind-wave configuration, i.e. $u_{10} = 16.63\,\mathrm{m/s}$, $\lambda = 0.54\,\mathrm{m}$, $a = 0.023\,\mathrm{m}$, which seems least costly to resolve.

Figures (1) and (2) illustrate the normalized wave coherent velocity $\tilde{u}/(aku_{10})$ contours over the surface elevation. The results of the CH-VoF model are a good approximation to the experimental data, both qualitatively and quantitatively. These 2D simulations are of course not expected to adequately mimic turbulence quantities but served for the various initial studies on the predictive performance of the mean flow properties and the post processing itself, which can be assessed from 2D studies.

In the second stage, the 2nd order moments (e.g. modelled and resolved Reynolds Stresses) from elaborate 3D simulations are compared with the measured data.

Finally, in a later stage, the resources are devoted to study more complex phenomena (e.g. intermittent/microscale separation before the actual breaking and the influence of wave breaking on wind turbulence)

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http://www.tuhh.de/fds
https://www.trr-energytransfers.de/

More Information

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Project Partners

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