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On the Crucial Role of Wind-Wave-Tunnel Studiesto Reveal the Mechanisms of Air-Sea Gas Exchange

Bernd Jähne
IWR and IUP, Heidelberg University

Estimates of air-sea fluxes rely on the knowledge of the gas transfer velocity. Despite more than half a century of field measurements, starting with the GEOSECS program in the 70ies, there are still many open questions. At low wind speeds, no reliable measurements are available, because all available techniques (dual-tracer, eddy covariance and active thermography) are either not suitable for measurements under these conditions or deliver too uncertain results. At high wind speeds beyond 25 m/s, almost no measurements are available. In the intermediate wind range enough reliable data are available. But the data are partly contradictionary. The effect of the many other parameters influencing the transfer velocity besides the wind speed is still uncertain. This includes the effect of the sea state (wave age), bubbles, and surfactants.

In wind-wave tunnels, it is easy to perform systematic studies. But the conditions deviate significantly from those at the open ocean in traditional linear facilities because of the short interaction length between wind. Therefore, only young wind seas can be generated, far away from a wind sea in equilibrium with the wind (“fetch gap”).

In 2021, we started a laboratory program, funded by a Reinhart Koselleck Project of the German Science Foundation. It includes three innovative key elements, which together overcome most disadvantages of previous wind-wave tunnel experiments. Firstly, a large annular facility is used, the Heidelberg Aeolotron. Because of the infinite fetch, wind waves come into equilibrium with the wind as at the ocean. Secondly, two imaging techniques are used to measure transfer velocities locally and instantaneously. Active thermography is used to measure the heat transfer velocity across the aqueous viscous boundary layer and a novel fluorescence technique to image the concentration fields in the mass boundary layer and to estimate the gas transfer velocity. Thirdly, measurements are performed under non-stationary conditions. In this way the whole fetch range can be investigated, when the wind speed is turned on, and decaying wind seas, when the wind speed is lowered.

In this talk first results of these measurements will be shown:

At low wind speeds, a significant overshoot in the transfer velocity occurs at low-fetch wind-wave fields.

The change in the Schmidt number exponent of the transfer velocity from 2/3 to 1/2 is related to

the increasing frequency of microscale wave breaking.

An insoluble monomolecular monolayer of hexadecanol has the same effect as the soluble surfactant TritonX-100 (5 ppm by volume): Wind waves are completely suppressed up to wind speeds of about 8 m/s and the spatial patterns of the concentration field in the boundary layer are the same. In contrast, lowering the surface tension to about 43 mN/m by adding 1-hexanol to the water (2.4 kg/m^3) did not suppress wind waves and transfer velocities at all.