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Towards 4D Visualization of Air-Water Gas Transfer

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The exchange of a soluble gases through air-water interface is controlled by a thin 20-200 µm thick mass boundary layer at the top of the water side [Jähne, 1985]. Standard measuring techniques such as eddy covariance and mass balance techniques give no direct insight into exchange mechanisms and turbulence structures within the boundary layer. Laser-induced fluorescence (LIF) techniques have recently made progress for gas exchange study. But they are hard to apply for visualization of air-water gas transfer across the mass boundary layer at a free water surface. Because of necessity of high spatial and temporal resolution in order to resolve the mass boundary layer and fast turbulent processes, visualization of concentration fields are mostly possible in 2 dimensional space only that does not yield the full understanding of the mechanisms of a gas exchange.

Therefore a new modified LIF technique has been developed for the visualization of simplified turbulence structures of the aqueous mass boundary layer [Kräuter et al., 2014]. The technique is based on a system of chemical reactions to feature binary concentration fields. With penetrating through air-water interface, an alkaline tracer gas (in current studies - ammonia) changes a temporal equilibrium of chemical species in the water that defines local $[H^+]$ concentration. A shift in $[H^+]$ concentration, consequently a shift in pH value can be captured with high resolution imaging by the use of fluorescent pH indicator Pyranine (8-hydroxy-1,3,6-trisulfonated pyrene). More importantly, logarithmic dependence of the pH value on $[H^+]$ concentration provides a rapid increase of pH value that insures sharp change in fluorescent component of Pyranine, hence proximate binary fluorescent field.

This contribution reports two pieces of work. Firstly test experiments were performed at the small Benjamin linear wind-wave tunnel in order to verify the technique and to set it up in an optimum way. Secondly, an approach is introduced to reconstruct 3D- image sequences in order to fully capture the spatio-temporal turbulent structures in the mass boundary layer.
In the Benjamin facility a vertical laser beam at 445 nm was focused to excite Pyranine fluorescence. To capture one dimensional profiles with a high resolution of 4.4 µm, tilted sided-placed Basler ace acA2500-14gm cameras with 2.2 µm pixel size were operated in 320 Hz mode.

Experimental 1D concentration profiles at different conditions were analyzed with defining the range of ammonia and Pyranine concentrations as well as initial conditions to maintain in order to gain binary concentration fields. At the different wind speed the experimental profiles were evaluated to estimate the thickness of the mass boundary layer and to detect boundary layer detachments (surface renewal events). The profiles were also compared to simulation profiles for different gas exchange models to verify the case of simplified binary fields and to understand the behavior of fluorescence within the mass boundary layer. An example of time-depth image sequence is presented in Fig.1.

Fig.1: Time sequence of vertical concentration profiles.

Secondly, a trinocular setup was tested for high-resolution 3D-reconstruction of sequences of boundary layer images at the large annular Aeolotron wind-wave facility in Heidelberg. In contrast to the setup of [Kräuter et al., 2014] (abstract submitted to this conference) three low noise CMOS cameras were placed underneath the facility. An example of captured images from cameras placed 25 cm apart from each other is presented in Fig. 2. The next step of presented work will be the reconstruction of captured 2D-projections to 3D space.

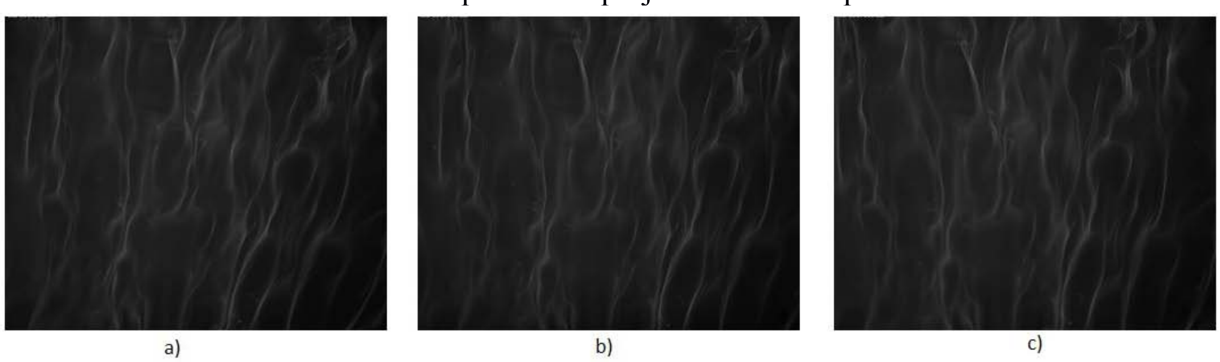

Fig. 2: Images of the water surface (31×37 cm) from a) left, b) middle and c) right cameras.

References

Jähne, B. (1985), Transfer processes across the free water surface, Habilitation thesis, Univ. of Heidelberg, Heidelberg, Germany doi:10.5281/zenodo.12202

Kräuter, C., D. Trofimova, D. Kiefhaber, N. Krah, and B. Jähne (2014), High resolution 2-D fluorescence imaging of the mass boundary layer thickness at free water surfaces, *J. Eur. Opt. Soc., 9,* 14016, doi:10.2971/jeos.2014.14016