Universität Heidelberg
Zukunft. Seit 1386.

Heidelberg Collaboratory for Image Processing
Speyerer Straße 4, D-69115 Heidelberg
hci.iwr.uni-heidelberg.de

Heidelberg Collaboratory for Image Processing

Institute of Environmental Physics
Im Neuenheimer Feld 229, D-69120 Heidelberg
www.iup.uni-heidelberg.de

High resolution 2-D fluorescence imaging of gas transfer

C. Kräuter[1),2)], D. Trofimova [1),2)], L. Nagel[1),2)], and B. Jähne[1),2)]

1) *Institute of Environmental Physics, University of Heidelberg, Germany*
2) *Heidelberg Collaboratory for Image Processing, Univ. Heidelberg, Germany*

Measurement principles

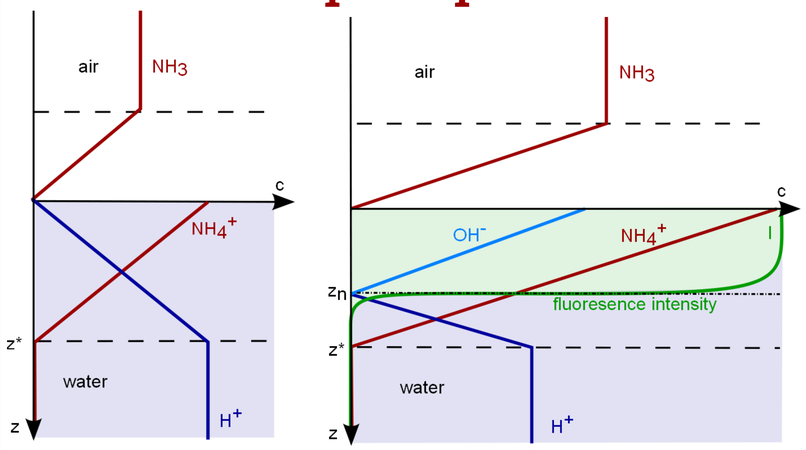

Fig 1: Schematic steady state concentration profiles in air and water over depth.

Transformation of a concentration gradient into a gradient in pH/fluorescence [1]:

- Invasion of ammonia (alkaline tracer) from air to water:
  → Solved and dissociated in slightly acid water (pH = 4)

$$NH_3 + H_3O^+ \rightleftharpoons NH_4^+ + H_2O$$

  → Equal opposite fluxes of hydrogen and ammonium
- Increase of air side ammonia concentration:
  →pH value reaches 7 at the surface
  → Formation of an alkaline layer
  → Visualization by a fluorescent pH indicator

Experimental set-up

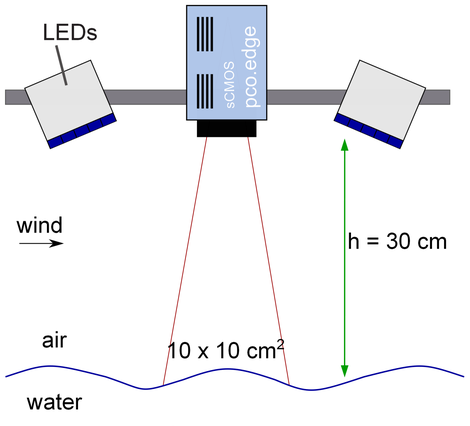

Fig 2: Sketch of the set-up containing a sCMOS camera and blue high power LEDs.

Wind-wave tank:

- Length ≈ 4 m
- Width ≈ 1 m
- Depth ≈ 3 cm
- Water volume ≈ 22 l
- Air volume ≈ 300 l

Optical set-up:

- 50 blue high-power LEDs
- high-resolution (0.1 mm), high-speed (100 ms) sCMOS camera

Components

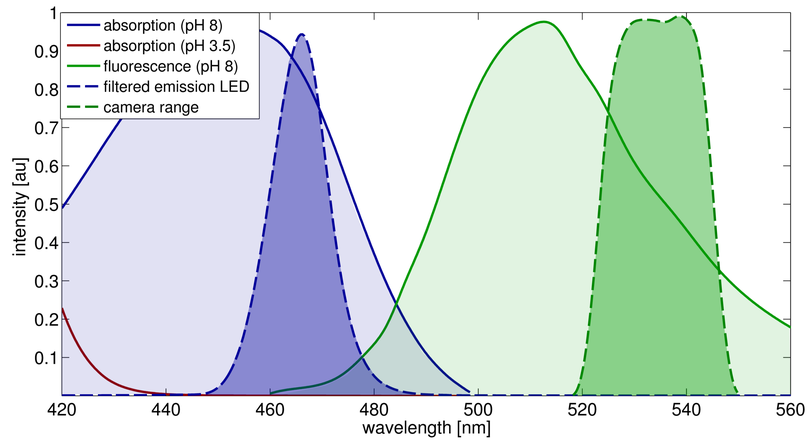

Fig 3: Absorption and emission spectra of Pyranine and filtered LED spectra and camera sensitivity window.

- Indicator (Pyranine [2]):
  → pH dependent fluorescent dye with $pK_s \approx 7.3$
- Light source (wavelength ≈ 430- 540 nm) and Fluorescence:
  → To reduce acid fluorescence; filtered below 440 nm
  → To reduce direct reflections; filtered above 490 nm and camera sensitivity range is filtered by an additional band pass filter

Simulations

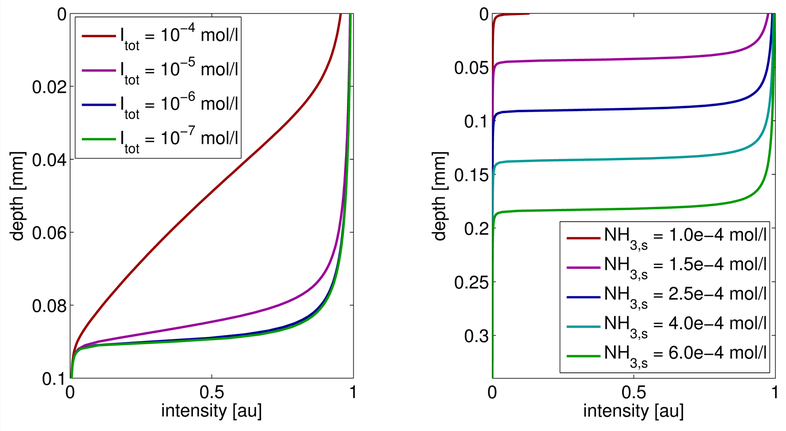

Fig 4: Simulated depth profiles of the normalized intensity for different concentrations (a) $NH_{3,s}$ = 2.5e-4 mol/l, (b) I_{tot} = 10e-6 mol/l and (a,b) pH_{start} = 4.

- Numerical simulation using autoprotolysis, mass and charge conservation
- Depth profiles are simulated with the surface renewal model [3]
  → To find best concentration of indicator, ammonia and starting pH value

Preliminary results

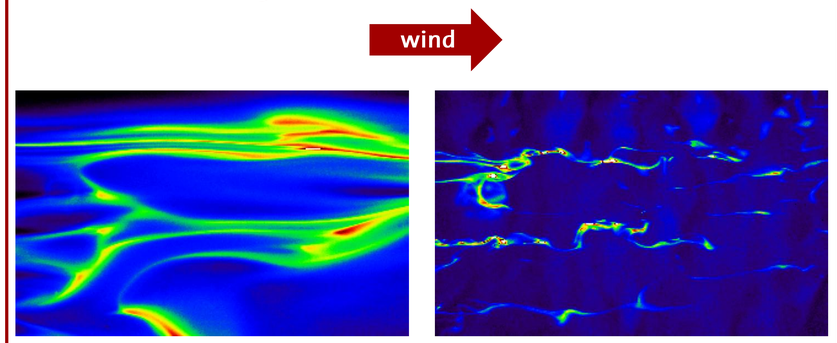

Fig 5: Image of the water surface (4×7 cm) showing two dimensional horizontal structures of the mass boundary layer thickness in false color at a wind speed of 1.5 m/s (left) and 5.5 m/s (right).

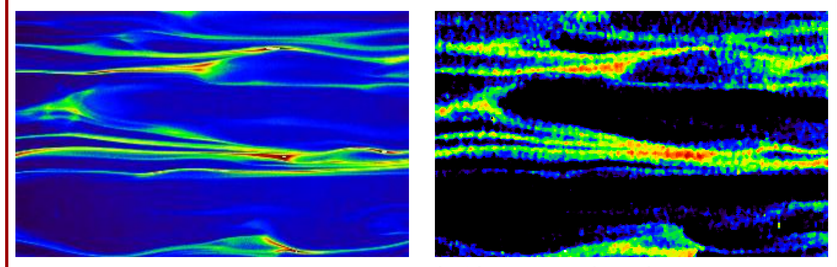

Fig 6: Simultaneous and collocated gas (left) and heat (right) visualization at 3.5 m/s.

- First test measurements conducted at a small linear wind-wave facility at different wind speeds
- Only fluorescence from the surface layer is visible
  → technique is applicable to wind-wave tanks
- Simultaneous and collocated measurements of heat and gas exchange
  → same structures, maybe sharper due to lower diffusivity of heat or better resolution of sCMOS camera

Outlook

- Simultaneous concentration, thermal and wave visualization at a large wind-wave facility
- Controlled change of the thickness of the alkaline layer to investigate the depth dependence of turbulent eddies

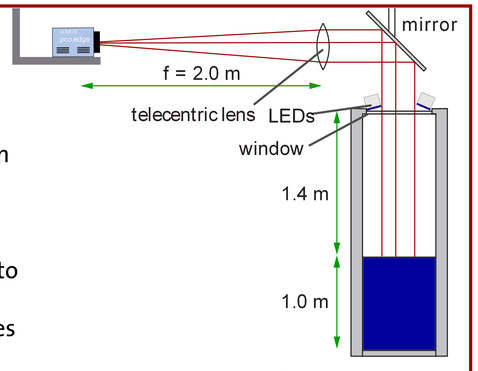

Fig 7: Set-up at large wind-wave facility, Aeolotron.

References:
[1] **Hiby, J. W. et al. (1967).** *Eine Fluoreszenzmethode zur Untersuchung des Stoffübergangs bei der Gasabsorption im Rieselfilm*, Chemie-Ing.-Techn., 39, pp. 297-301
[2] **Wolfbeis, O. S. et al. (1983).** *Fluorimetric Analysis*, Fresenius Z Anal. Chem., 314, pp. 119-124
[3] **Jähne, B. et al. (1989**). *Investigating the transfer process across the free aqueous boundary layer by the controlled flux method*, Tellus , 41B pp. 177-195

Corresponding author: **Christine Kräuter**
Christine.kraeuter@iup.uni-heidelberg.de