# Combined Visualization of Wind Waves and Water Surface Temperature

R. Rocholz[1], U. Schimpf[1], C. S. Garbe[1,2], and B. Jähne[1,2]

[1] *Institute of Environmental Physics, Im Neuenheimer Feld 229*
*University of Heidelberg, Germany*
[2] *Heidelberg Collaboratory of Image Processing (HCI) at the Interdisciplinary Center for Scientific Computing, Speyerer Straße 6, University of Heidelberg, Germany*
*{Roland.Rocholz,Uwe.Schimpf,Christoph.Garbe,Bernd.Jähne}@iwr.uni-heidelberg.de*

The impact of wind, rain, and surface slicks on the transport of heat and gas at the water surface was measured in experiments in the Hamburg linear wind wave flume in cooperation with the Institute of Oceanography at the University of Hamburg, Germany. Within this framework, imaging techniques for the measurement of wind wave topography and the measurement of surface temperature were combined. Both cameras were synchronized at high a frame rate of 312.5 Hz to allow for a visual study of the mechanisms which are suspected to alter the transport of gas- and heat through the air-sea interface. Infrared imagery is capable to identify microscale breaking (e.g. Zappa et al. 2004) and Langmuir circulation on small scales (Melville et al. 1998). Also the effect of rain drops on the thermal boundary layer has been be studied with this technique for the first time. In contrast to previous studies, the image sequences are geometrically registered and the surface elevation is reconstructed.

For the wave field both slope components were measured optically at a fetch of 14.4m using a *color imaging slope gauge* (CISG) with a footprint of 223 x 104 mm and a resolution of 0.7 mm. The CISG was improved considerably versus earlier versions (e.g Balschbach et al. 1998) with respect to the frame rate and accuracy (see Rocholz (2008)). The evolution of the waves can now be followed in time, even for waves in the capillary range. Thus, it is now possible to distinguish waves traveling in and against wind direction, which proved useful to distinguish wind waves from ring waves caused by rain drop impacts. Ho et al. (2000) showed that the gas transfer rate in a rain-driven system is no longer in distinct correlation with the surface roughness. The separation of the ring wave contribution and the wind wave contribution to the surface roughness is essential to improve the mean square slope

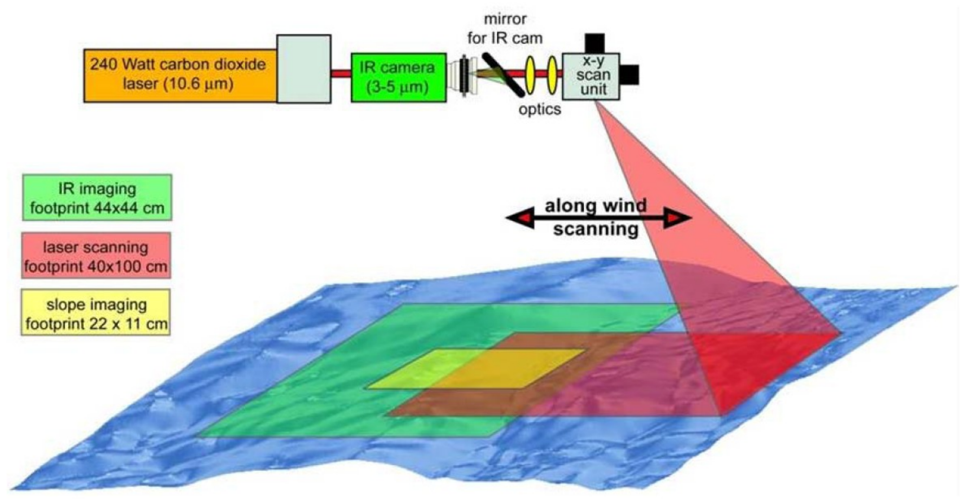


**Figure 1: Schematic drawing of the overlapping footprints of the CISG camera (yellow) and the infrared camera (green), as well as the scanning range of the infrared laser (red).**

parameterization of heat and gas exchange. With 57 mm/h rain rate (drop diameter 2.9mm and 90% of terminal velocity), even at 8 m/s wind speed and for clean surface conditions, 50 to 70 percent of the mean square wave slope originate from ring waves.

The surface temperature measurements were performed with an *active thermography* (ACFT) setup. The ACFT essentially consists of an infrared camera that acquires images of the water surface temperature and a high power (240 W) carbon dioxide laser (see Figure 1). The laser is used to precisely deposit heat in the skin layer (20 µm) of the water surface. The position and period of the heating is controllable by means of a scanning unit.

A visual synthesis of the wave and temperature data is achieved by a custom made and interactive computer program which is based on OpenGL. The surface temperature images are mapped in false color onto an animated graphical model of the reconstructed surface elevation. The surface slope is used for shading, so that also the capillary ripples are visible, even though their amplitudes are very small compared to the amplitudes of the dominant waves. The resulting visualization is a powerful tool for the inspection of the above mentioned processes. We will discuss the influence of microscale wave breaking, micro Langmuir circulation, and the impact of rain drops in enhancing near-surface turbulence and thus air-water gas exchange. As an example, Figure 2 displays several snapshots of the animated data for a condition where micro Langmuir circulation is apparent at the rear of a dominant wave crest.

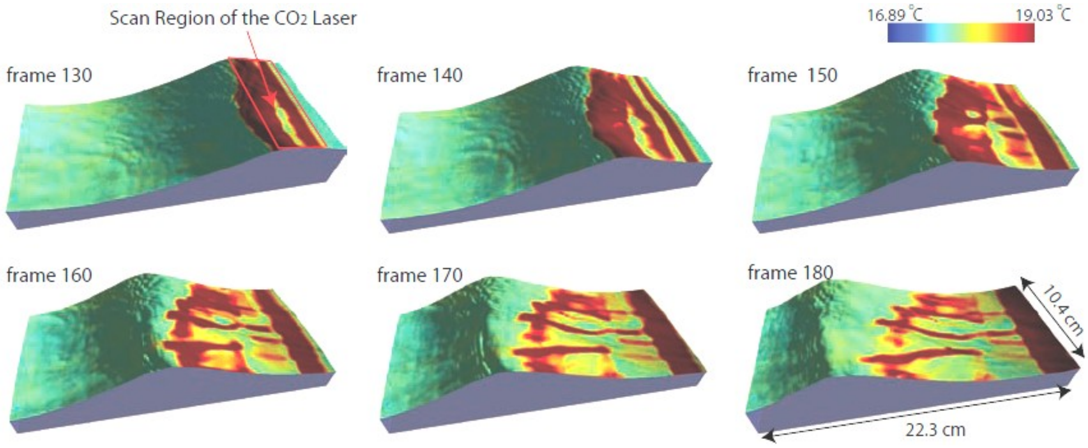


**Figure 2: Combined visualization of surface temperature and waves. For a wind speed of 6 m/s elongated streaks appear which can be attributed to micro Langmuir circulation (Melville et al. (1998)). The initial temperature signature is artificially generated by a $CO_2$-Laser and observed by an infrared camera. Wind is blowing from the right to the left. (The time interval between two consecutive snapshots (which are 10 frames apart) is 0.032 seconds).**

**References**

G. Balschbach, J. Klinke, and B. Jähne. Multichannel shape from shading techniques for moving specular surfaces. *Computer Vision - ECCV'98*, 1998

W. K. Melville, R. Shear, and F. Veron. Laboratory measurements of the generation and evolution of Langmuir circulations. *J. Fluid Mech.*, 364:31–58, 1998.

D. T. Ho, W. E. Asher, L. F. Bliven, P. Schlosser, and E. L. Gordan. On mechanisms of rain-induced air-water gas exchange. *J. Geophys. Res.*, 105(C10):24,045–24,057, October 2000.

R. Rocholz, Spatio-Temporal Measurement of Short Wind-Driven Water Wave, Dissertation, University of Heidelberg, 2008, http://hci.iwr.uni-heidelberg.de/publications/dip/2008/Rocholz_2008_Diss.pdf

C. J. Zappa, W. E. Asher, A. T. Jessup, J. Klinke, and S. R. Long. Microbreaking and the enhancement of air-water transfer velocity. *J.Geophysical Res.*, 109:C08S16, 2004