Sufficiently Realistic Simulation of Oceanic Conditions for Air-Sea Gas Exchange at the Re-Engineered Heidelberg Aeolotron

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Heidelberg Collaboratory for Image Processing

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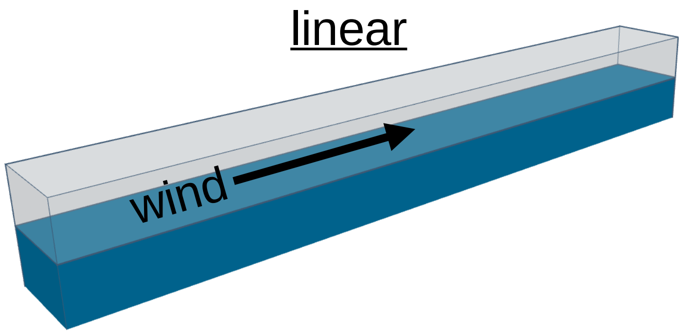
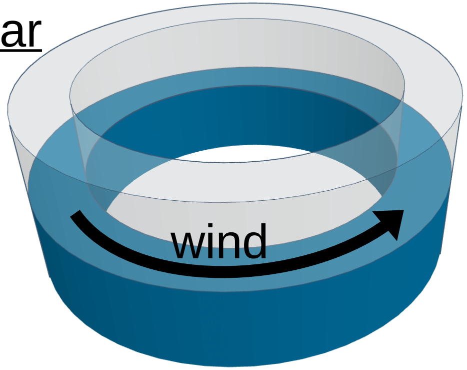
Types of wind-wave tanks



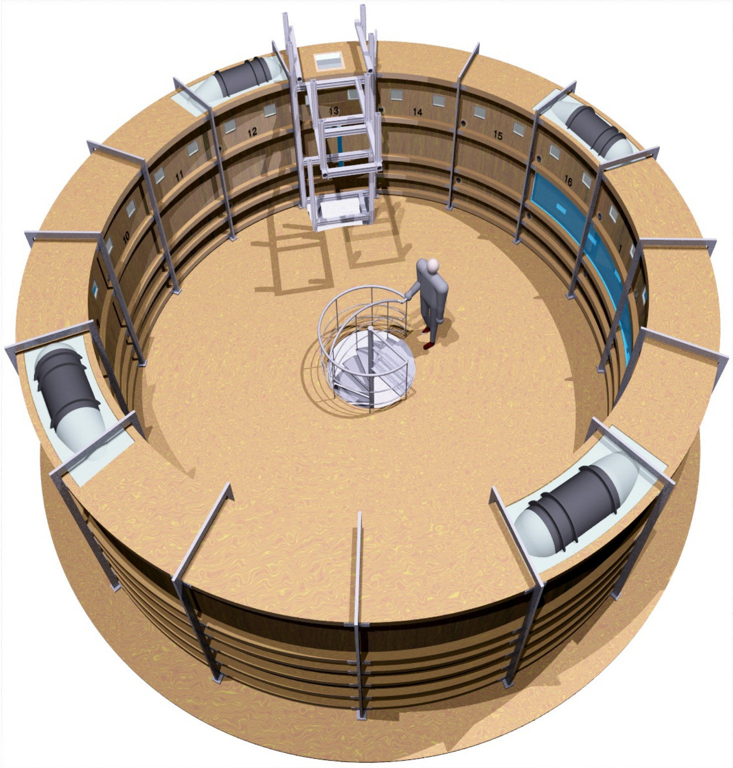


Main differences

linear	annular
Limited fetch	Virtually unlimited fetch
Inhomogeneous wave field	Homogeneous wave field
Logarithmic wind profile	Secondary currents hinder formation of logarithmic wind profile
Surfactants are pushed downwind to the wave absorber, inhibiting their effects	Surfactants stay on water surface
Mechanical wave generation possible	mechanical wave generation not possible

The Heidelberg Aeolotron

The world's largest operational annular wind-wave tank



Diameter:	10 m
Flume width:	60 cm
Flume height:	240 cm
Water level:	up to 100 cm
Wind speed u_{10}:	up to 24 m/s
Water temperature:	10-30^{o}C

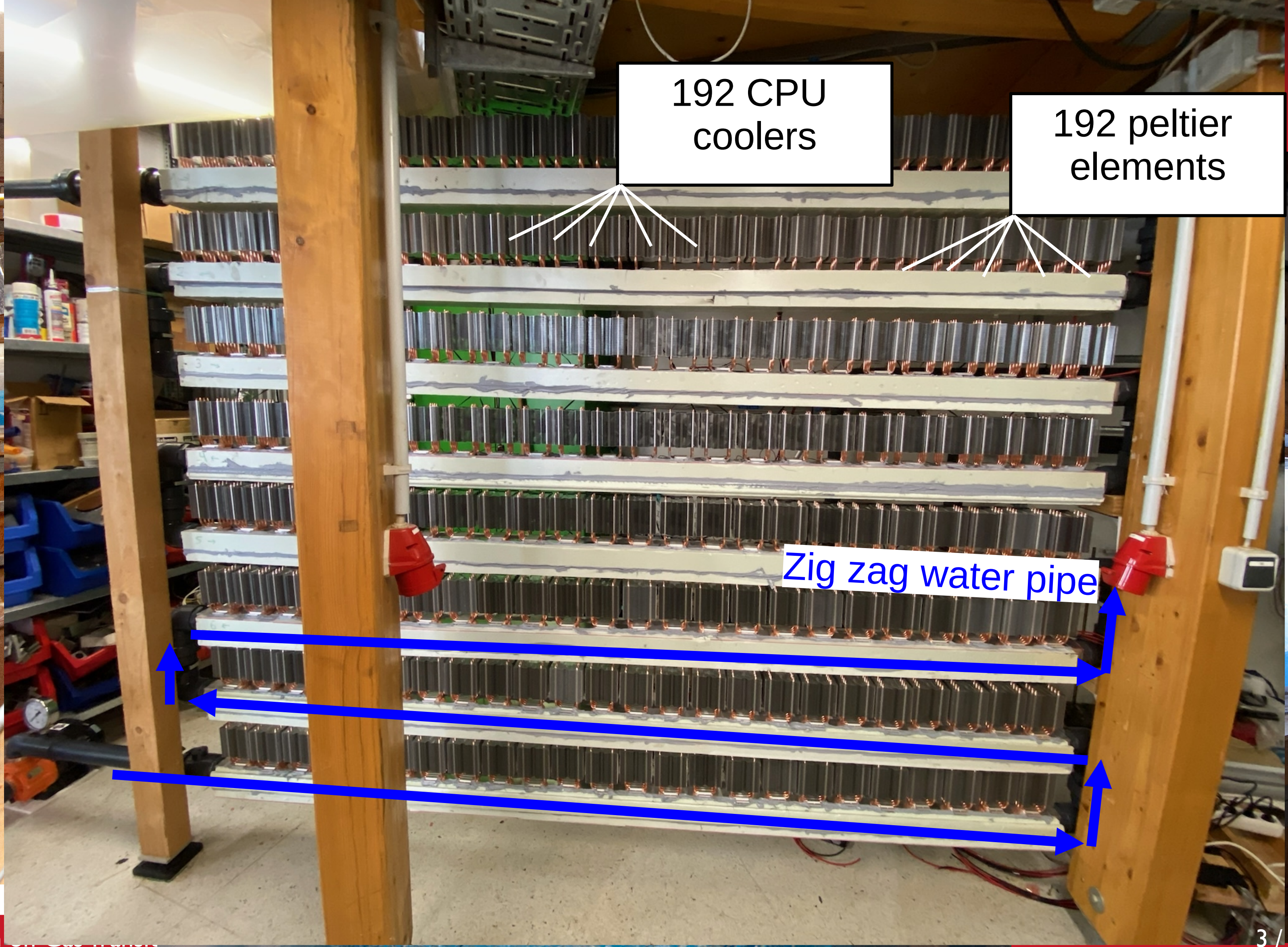
closed or flushed air space (90 seconds residence time)

thermally insulated

PTFE coated walls

nds residence time)

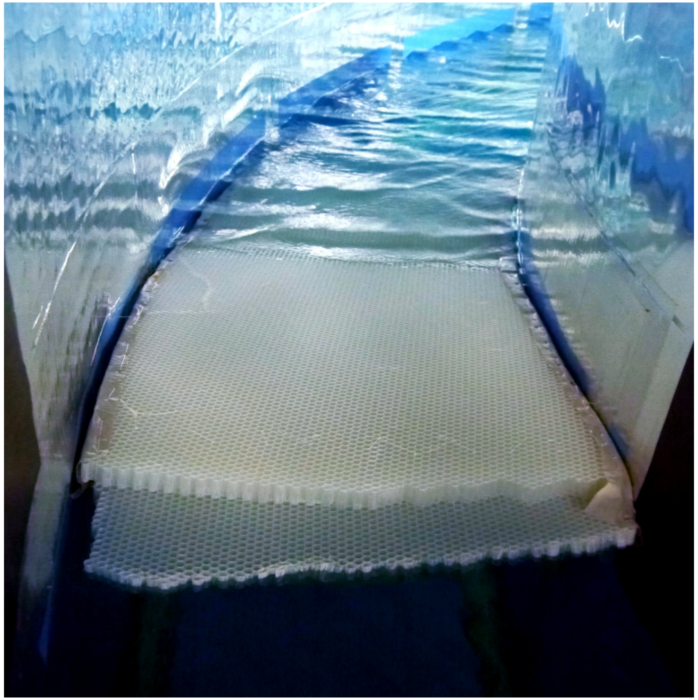



192 CPU coolers
192 peltier elements
Zig zag water pipe

Fetch

In linear tanks, the fetch is limited to the length of the tank.

In the Aeolotron, we can simulate a linear tank with a fetch < 25 m by installing a wave absorber.



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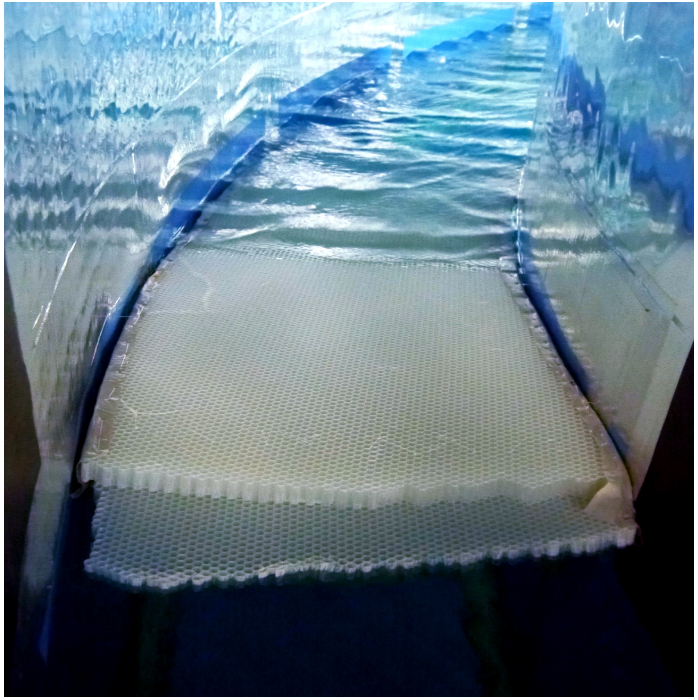
What about longer fetches?

→ replace distance with time



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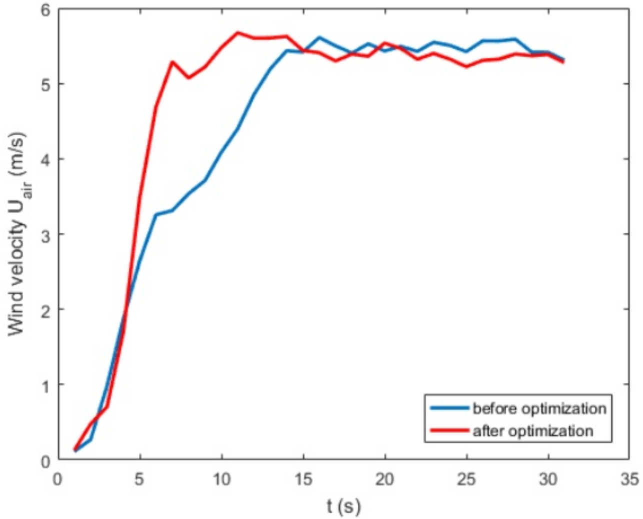
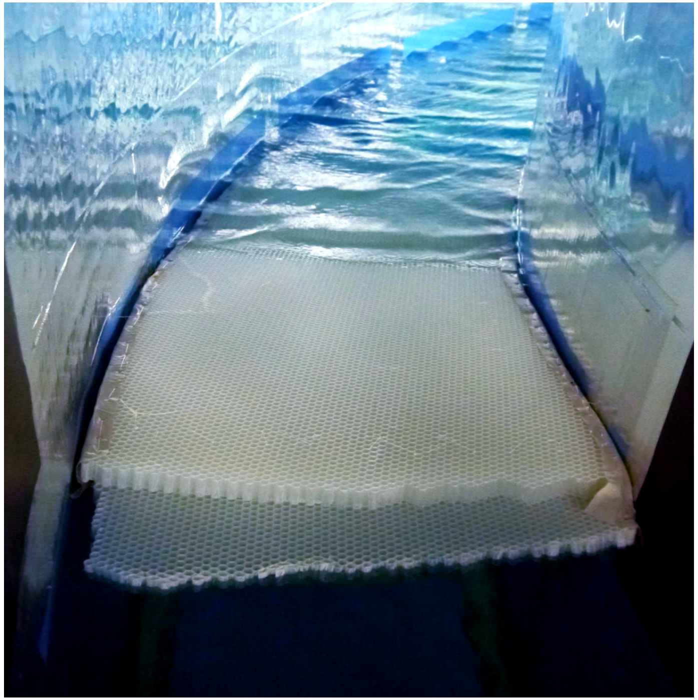
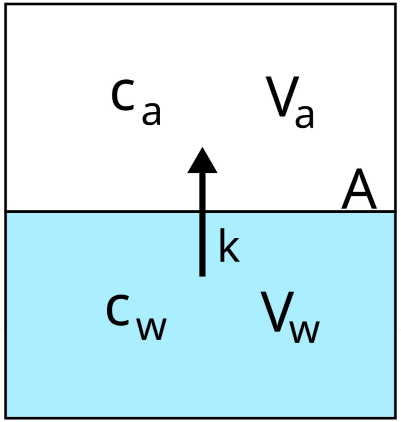
The wind in the Aeolotron can be turned on within seconds





Fast techniques to measure gas transfer velocities

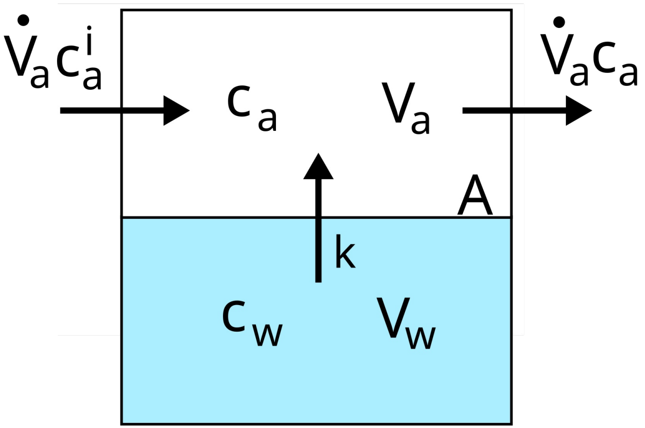
Classical evasion experiments



There's a big problem: Time scales of hours to days

Fast techniques to measure gas transfer velocities

Controlled leakage method



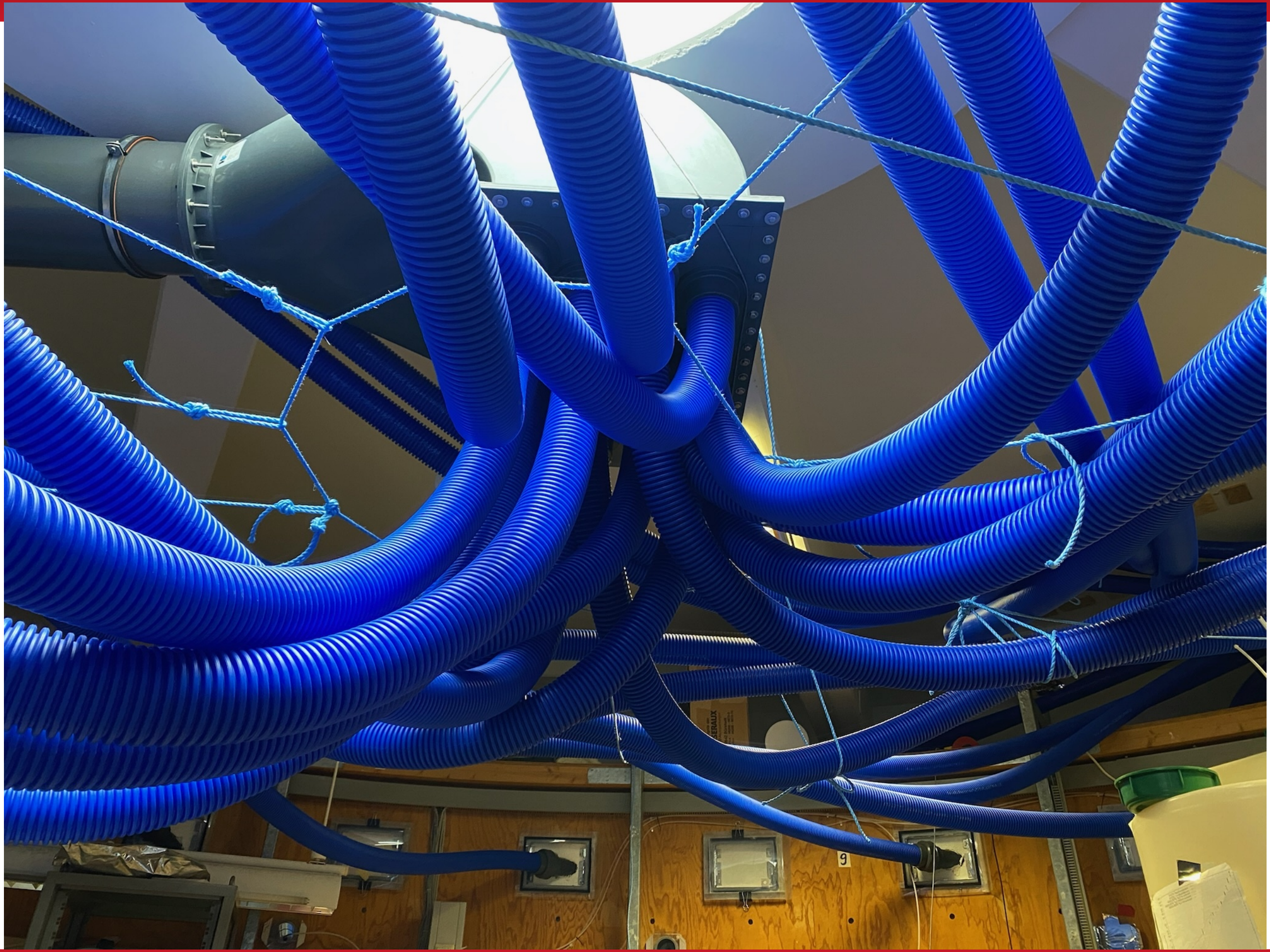
Assume tracer is not present in outside air, i.e. $c_a^i = 0$

Air side mass balance equation yields:

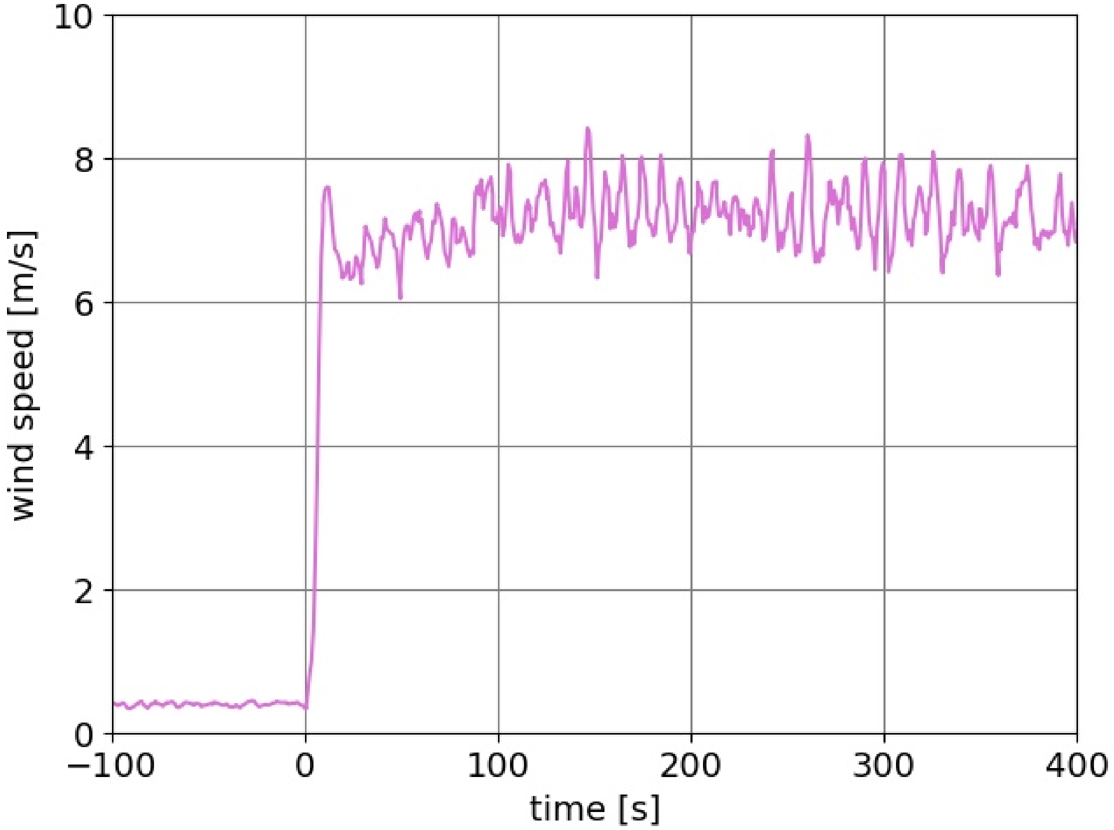
$$k = \frac{V_a}{A} \cdot \frac{\lambda_a c_a}{c_w} \cdot \frac{\lambda_a + \dot{c}_a / c_a}{\lambda_a} \cdot \frac{1}{1 - \alpha\, c_a / c_w}$$

By measuring **air and water side concentration time series** and the leak rate λ_a we can get **time resolved transfer velocities**

Fast techniques to measure gas transfer velocities



Fast techniques to measure gas transfer velocities



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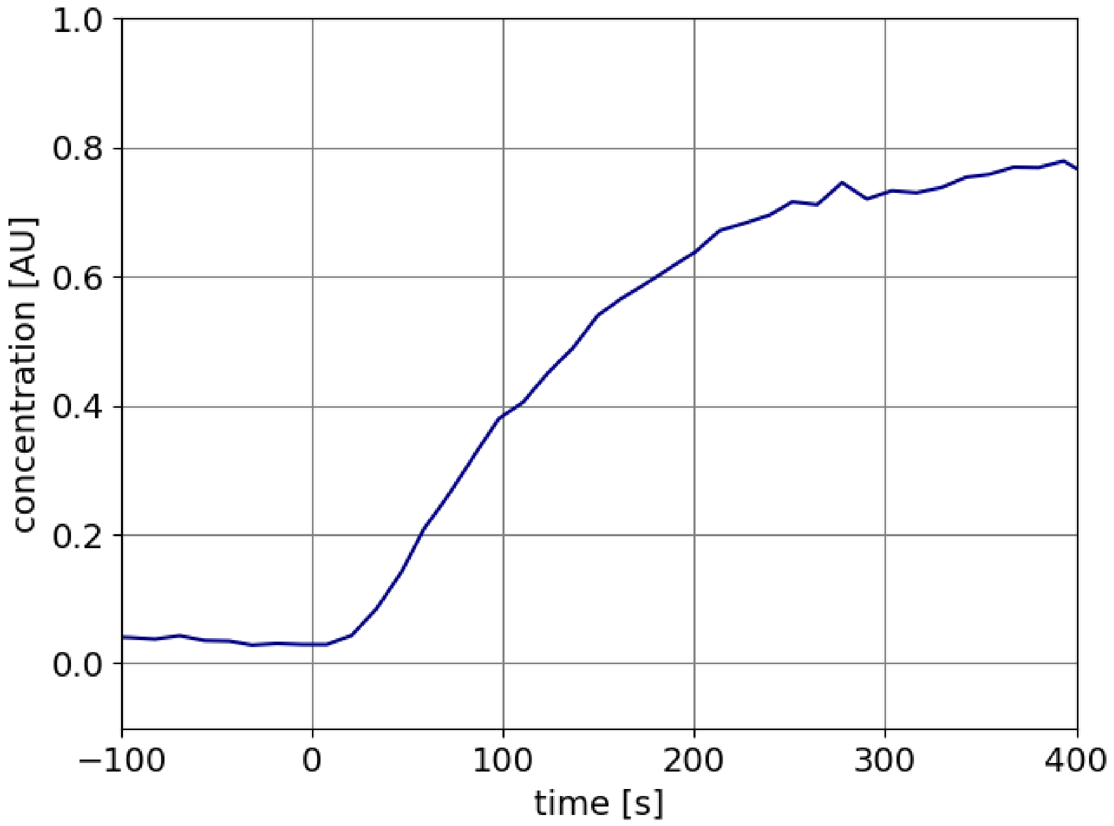
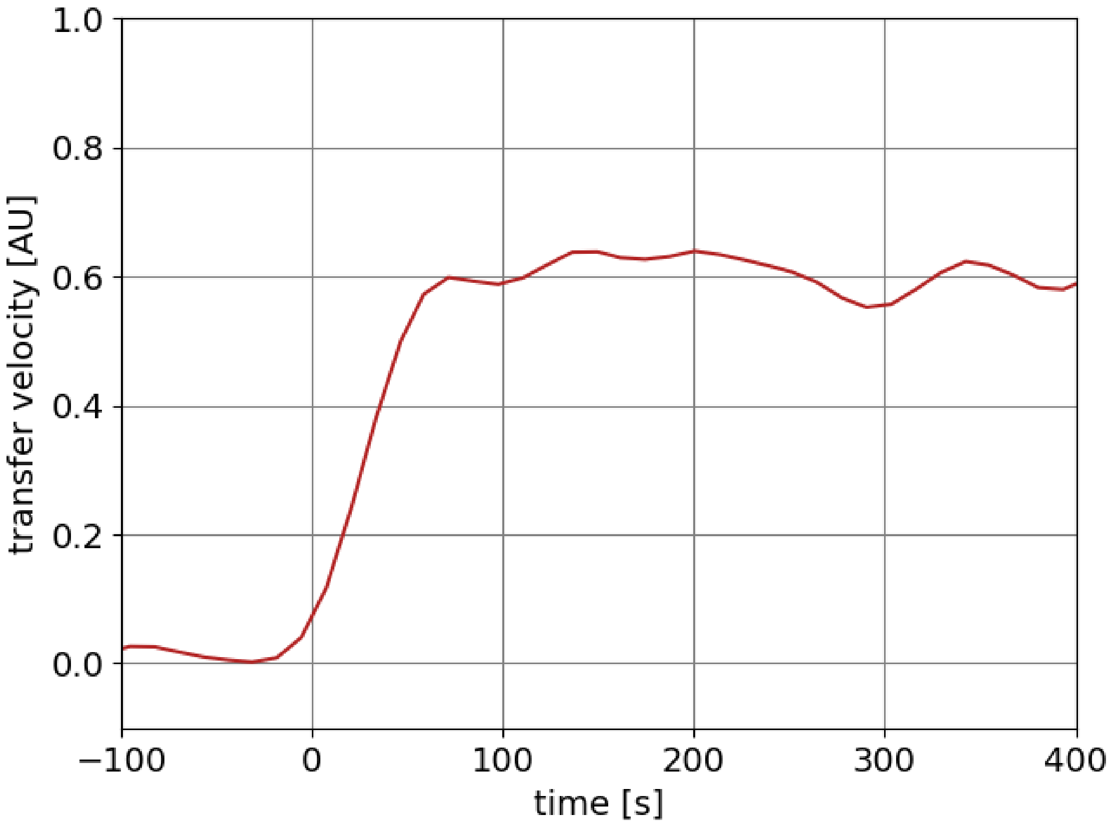


Fast techniques to measure gas transfer velocities



Local techniques

Boundary layer imaging

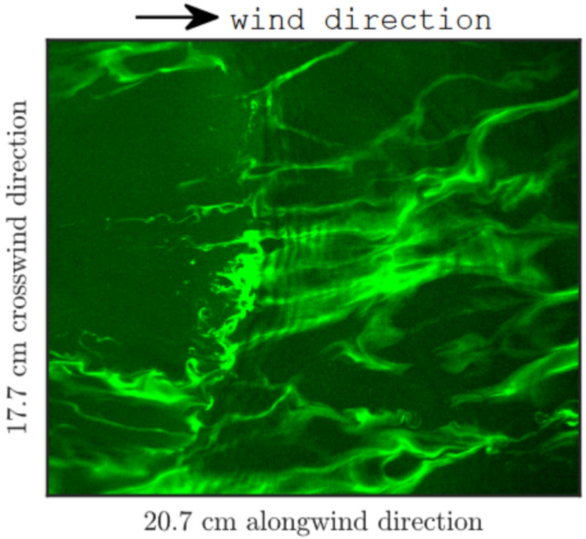
Measures mass boundary layer (MBL) thickness

$$z_* = \frac{D}{k}$$

pH sensitive fluorescent dye in acidic water

Alkaline trace gas

Fluorescence intensity proportional to MBL thickness

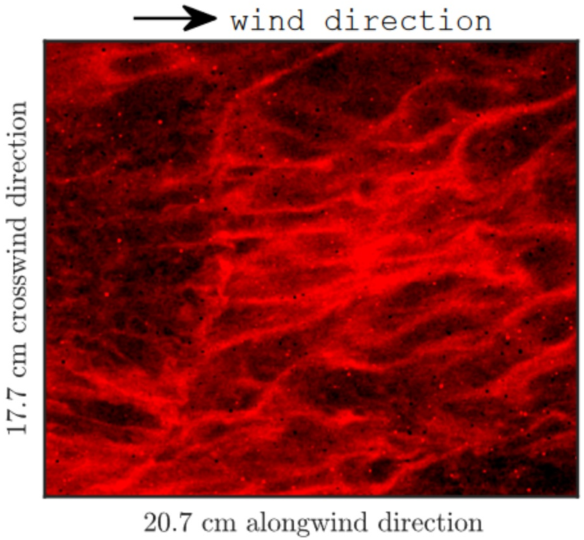


Thermography

Measures either heat exchange time constant

$$t_* = \frac{D}{k^2}$$

by periodically heating the water surface with a CO_2 Laser



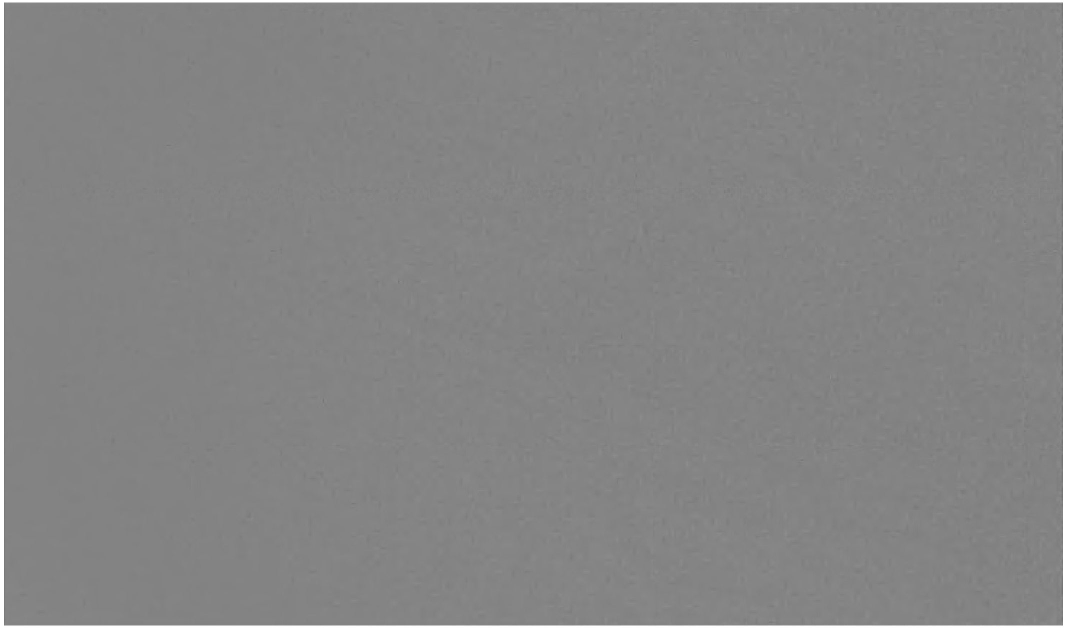
Or measures the change in temperature after reaching thermal equilibrium due to heating

$$k = \frac{j_h}{\rho c_p \Delta T}$$

A. Klein, "The Fetch Dependency of Small-Scale Air-Sea Interaction Processes at Low to Moderate Wind Speeds", 2019. doi: 10.11588/heidok.00026559.

Wave field development

0 s Intensity coded slope in alongwind direction



13.2 cm

22.4 cm

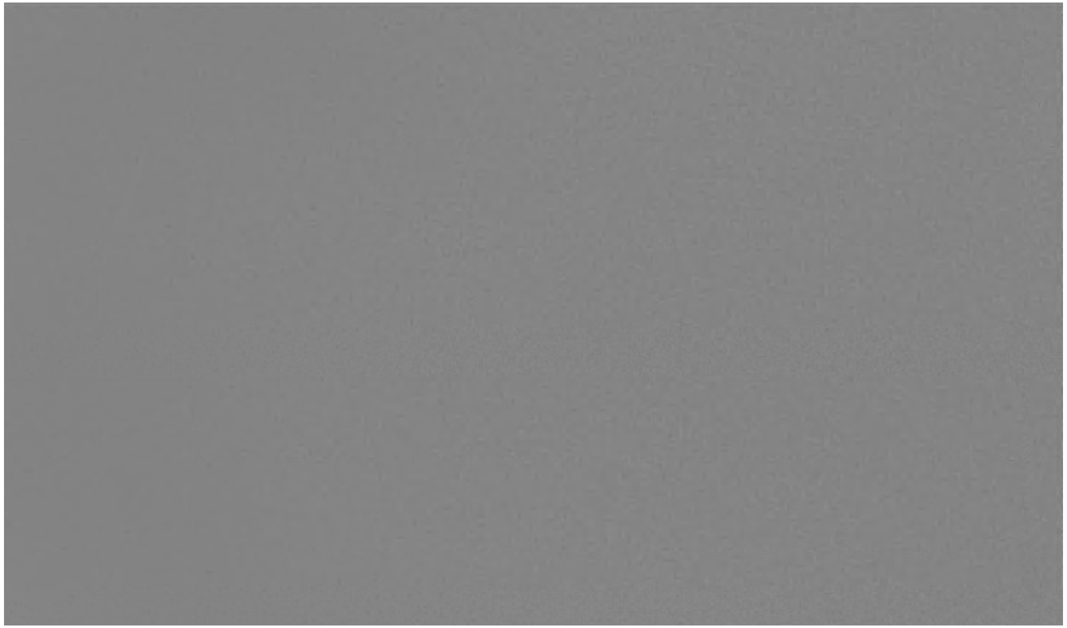
Wind

A. Rennebaum, “Spatio-Temporal Properties of the initial Wave Formation Phase at the Aeolotron,” doi: 10.11588/heidok.00023754

Wave field development

5 s

Intensity coded slope in alongwind direction



13.2 cm

22.4 cm

Wind

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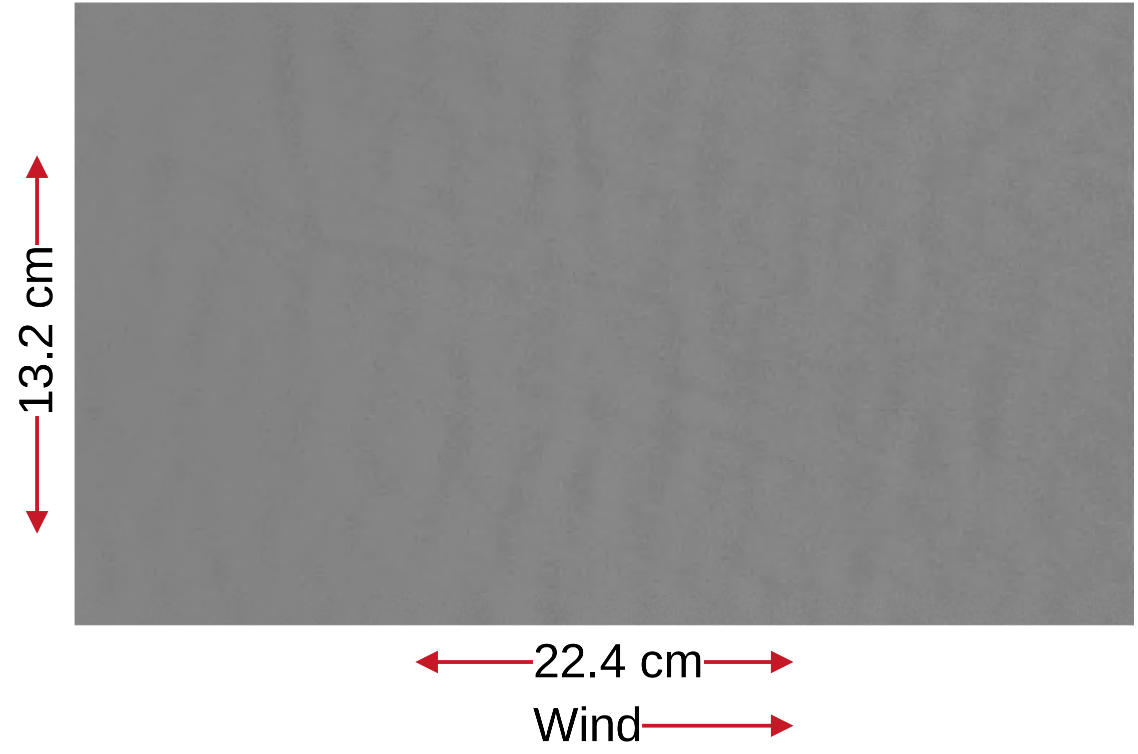
Wave field development

5.5 s   Intensity coded slope in alongwind direction



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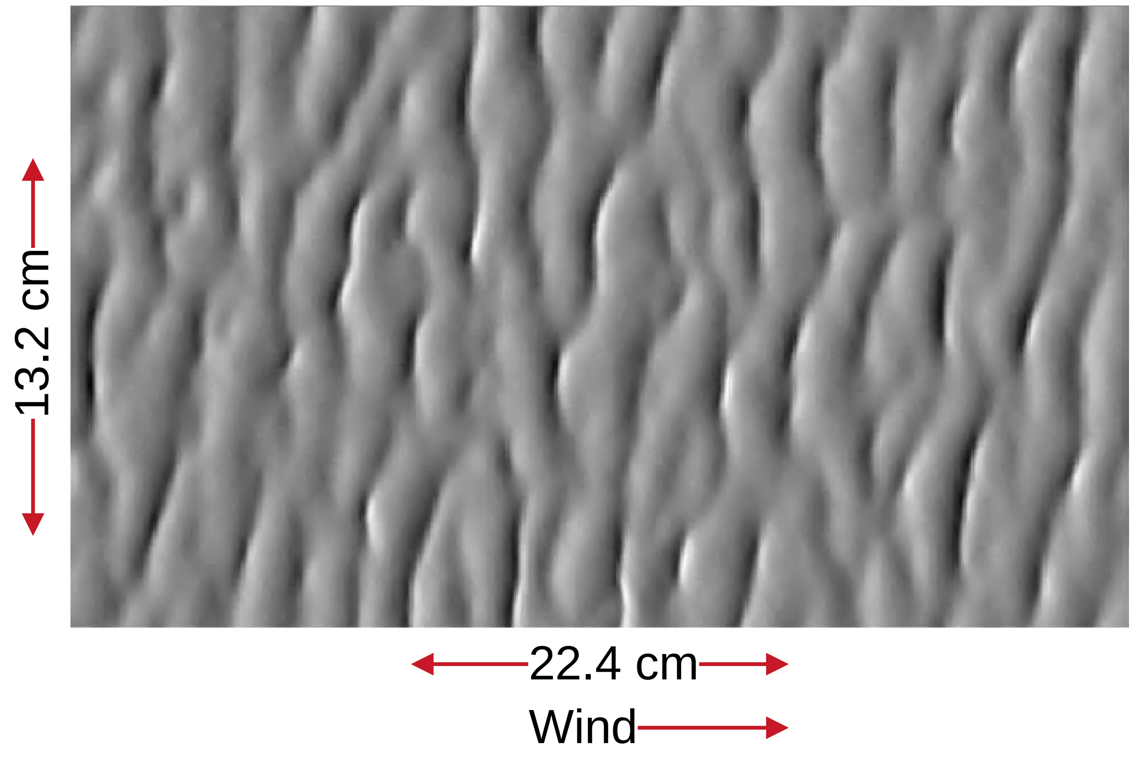
Wave field development

6 s Intensity coded slope in alongwind direction



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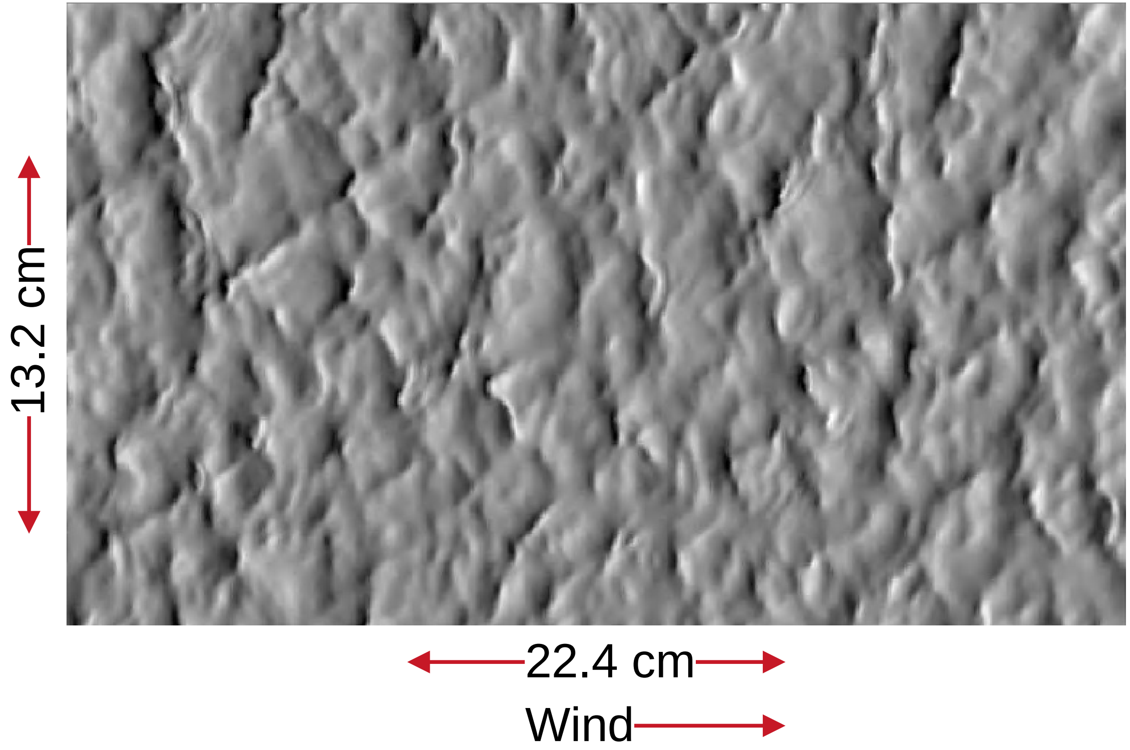
Wave field development

6.5 s Intensity coded slope in alongwind direction



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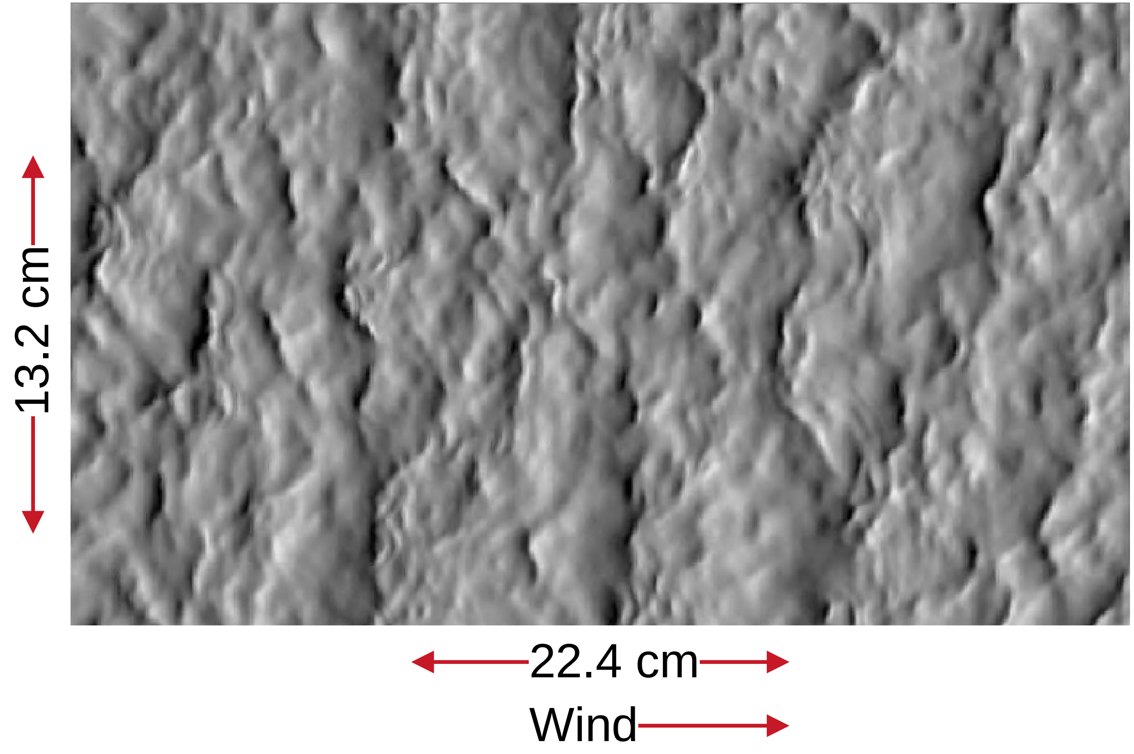
Wave field development

7.5 s Intensity coded slope in alongwind direction



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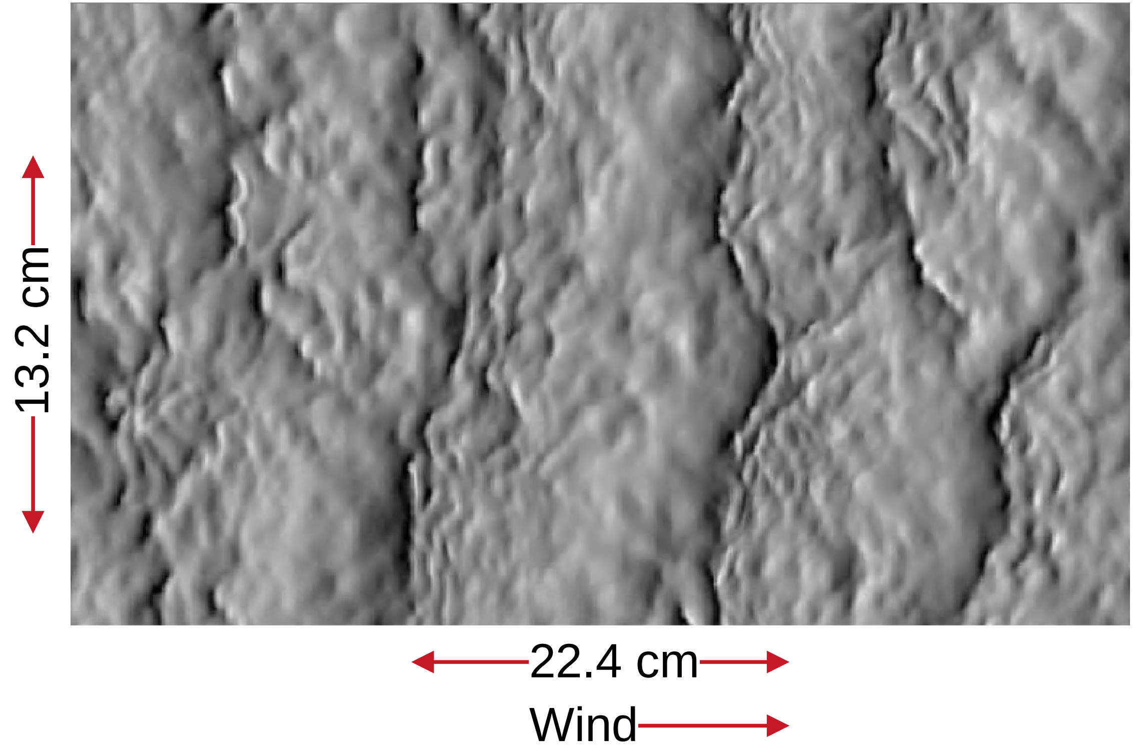
Wave field development

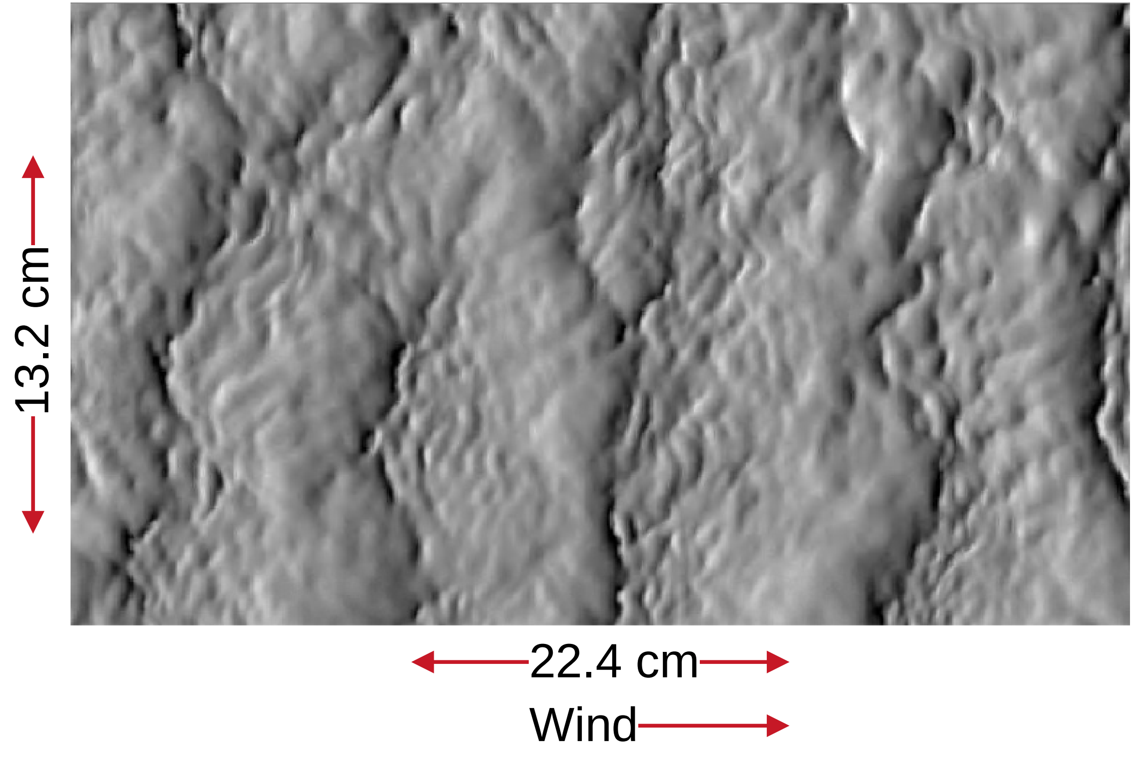
8.5 s Intensity coded slope in alongwind direction



A. Rennebaum, “Spatio-Temporal Properties of the initial Wave Formation Phase at the Aeolotron,” doi: 10.11588/heidok.00023754

Wave field development

9.5 s Intensity coded slope in alongwind direction



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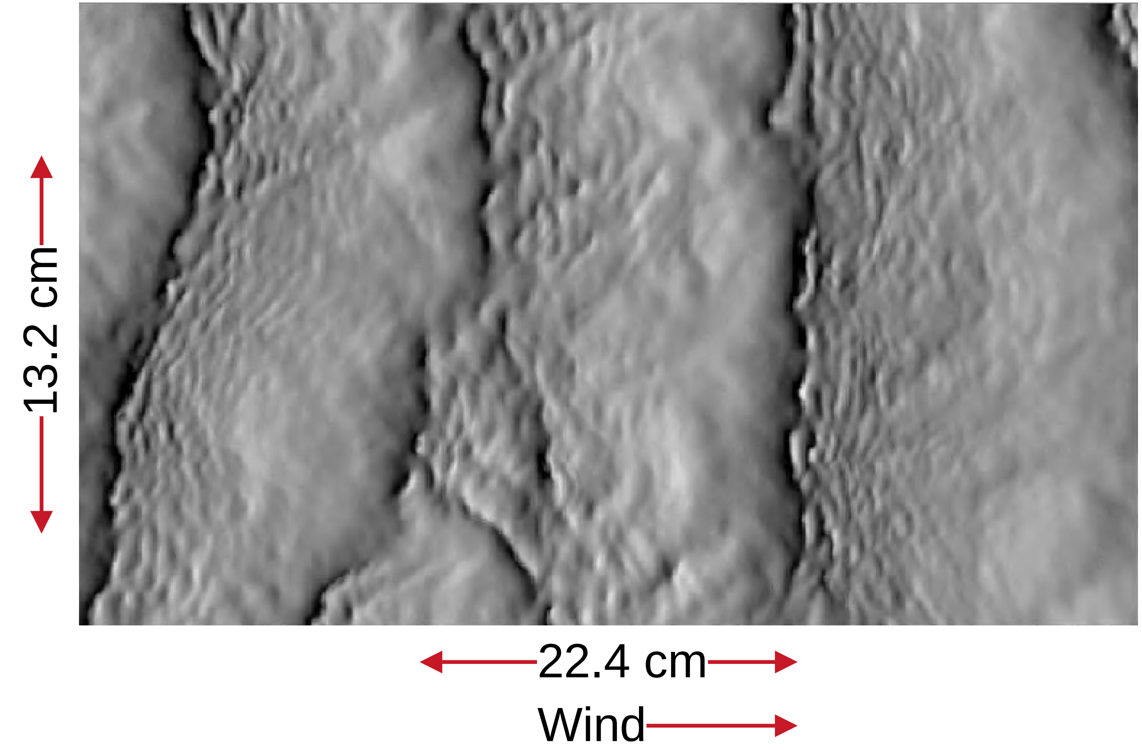
Wave field development

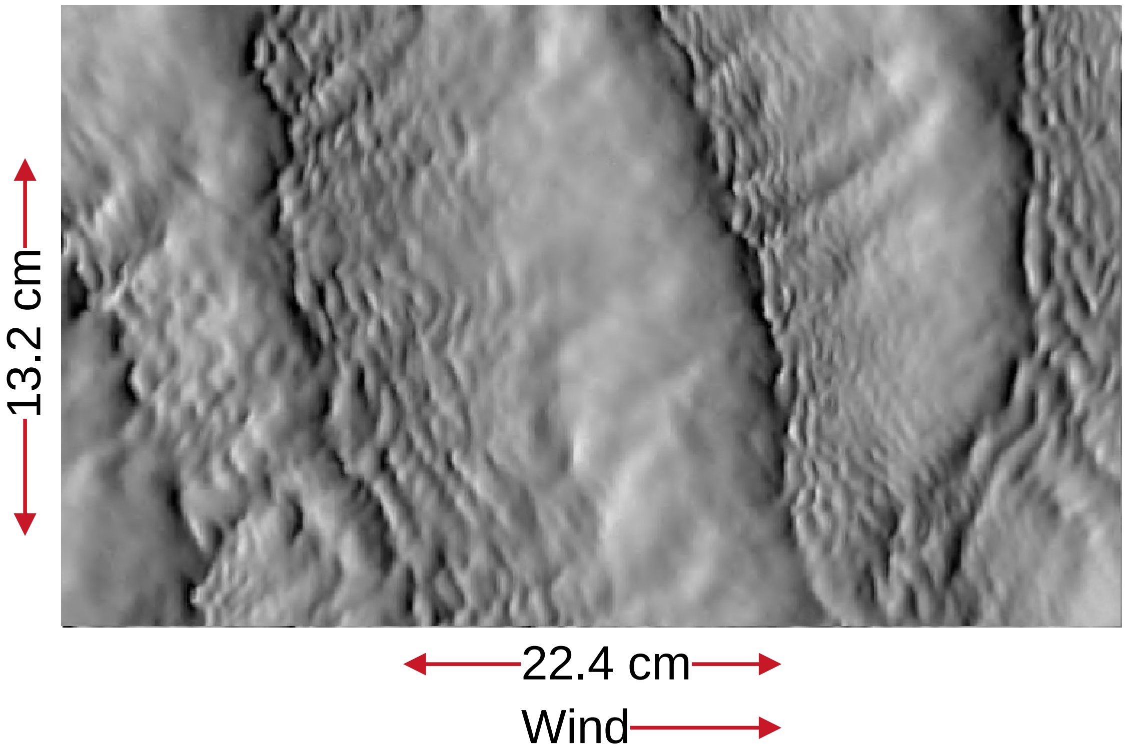
10.5 s Intensity coded slope in alongwind direction



A. Rennebaum, “Spatio-Temporal Properties of the initial Wave Formation Phase at the Aeolotron,” doi: 10.11588/heidok.00023754

Wave field development

11.5 s Intensity coded slope in alongwind direction



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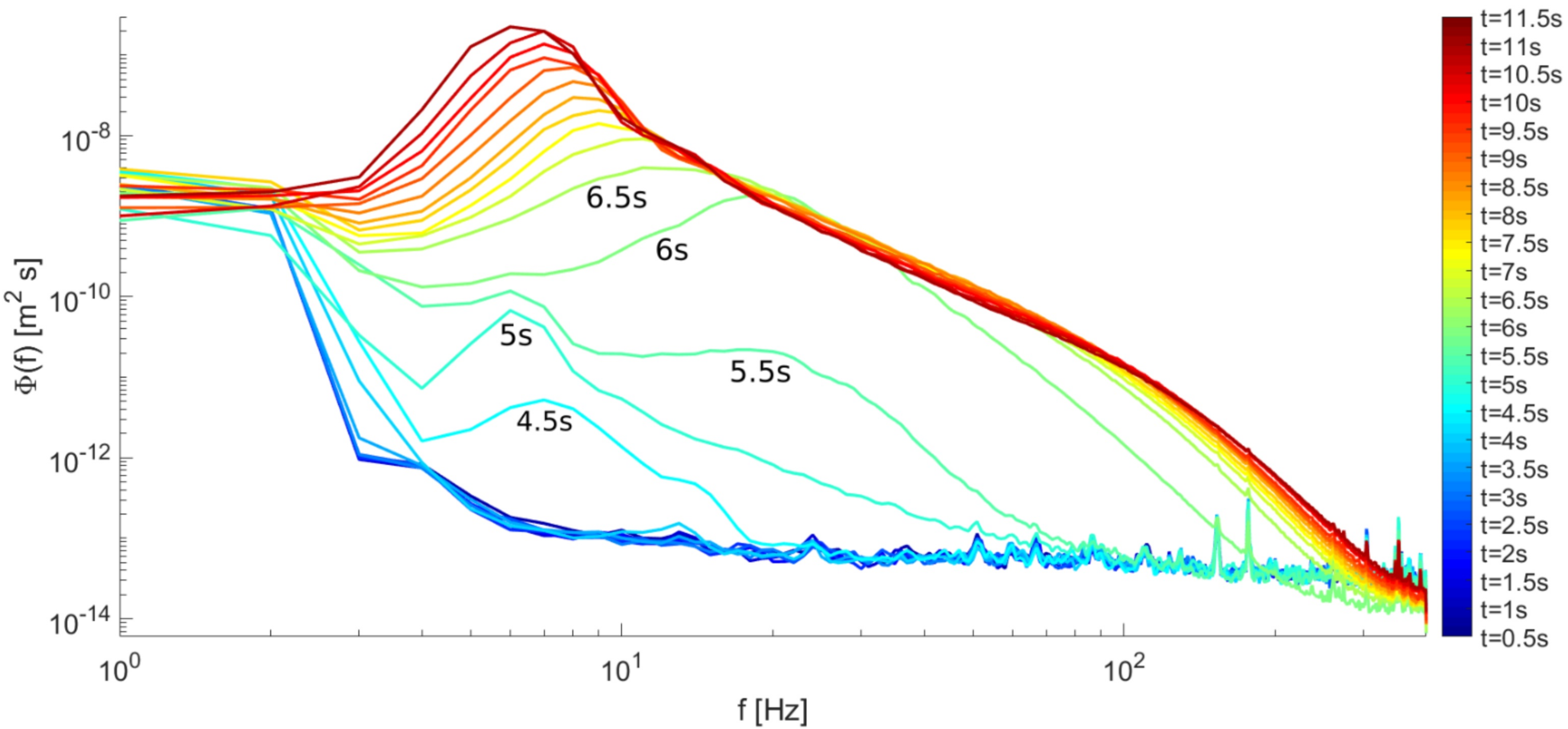
Wave field development



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Wave age limit

Can long wave ages $a = \frac{c_p}{u_{10}}$ be achieved in an annular tank?

No, because of the limited water depth h, the wave phase speed is limited to $c_p \leq \sqrt{g h} \approx 3\, m\, s^{-1}$

The water level in the Aeolotron can be reduced to a minimum of 20 cm

This allows us to study and possibly correct for this wave age limit

In addition, we plan to replace the air with a heavier gas

This allows for higher momentum transfer at the same wind speed as with air

Summary

2 additional wind generator fans allow for fast spinup of the wind, which allows to study the **whole fetch range** by replacing fetch length with time

Improved fresh and waste air handling finally enables **fast mass balance techniques** to measure **the gas transfer velocity** with time scales of below 1 minute

PTFE coating of the walls allows to use a wide selection of **surfactants**

A new water heating and cooling system allows to study a wide range of temperatures encountered in nature

Fast, local imaging techniques give insight into the **physical mechanisms** of heat and gas transfer, the **Schmidt number exponent** and **wave formation**