A thermographic approach to measure the wind shear stress at the water surface

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Overview

- Introduction
- Motivation
- Novel active thermographic method
- First results
- Outlook and conclusion

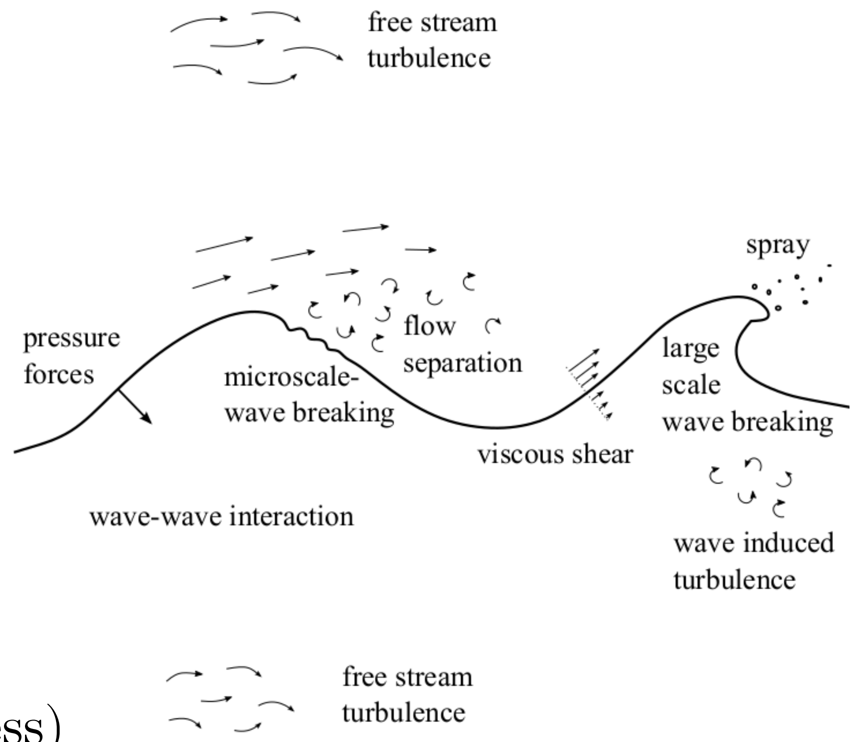
Introduction

Partitioning of the stresses at the surface:

- Form drag
  - wave build-up
  - delayed source of turbulence by wave breaking

- Viscous shear stress $\tau_{\text{visc}} \propto \partial_z u$
  - direct turbulence generation in the shear layer
  - controls BL thickness δ

- Partitioning crucial for understanding the transfer mechanisms
- Air-sided: only wind speed measured (total stress)



(Bopp [2018])

Introduction

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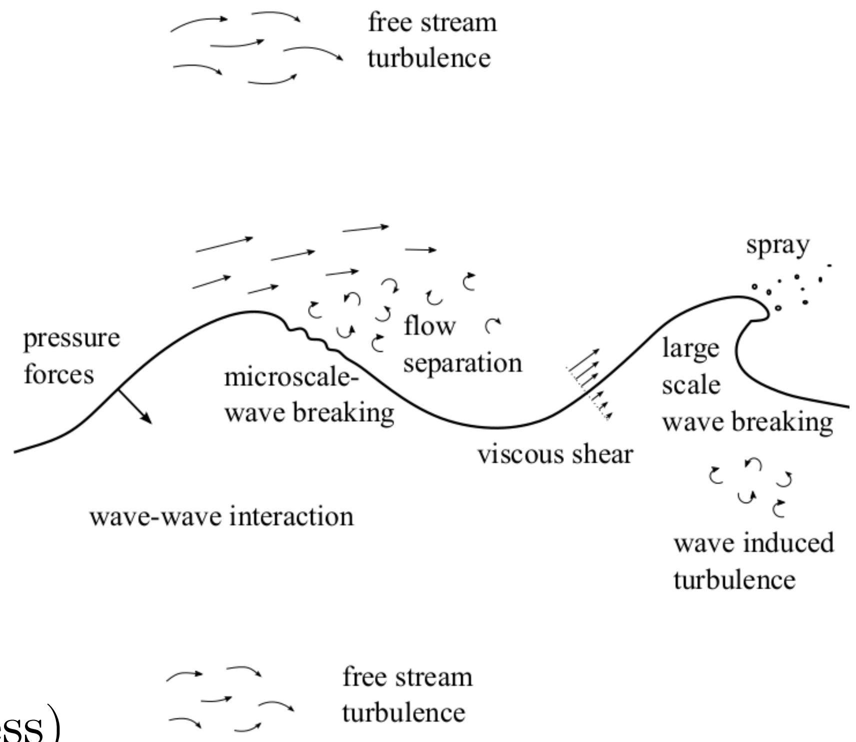
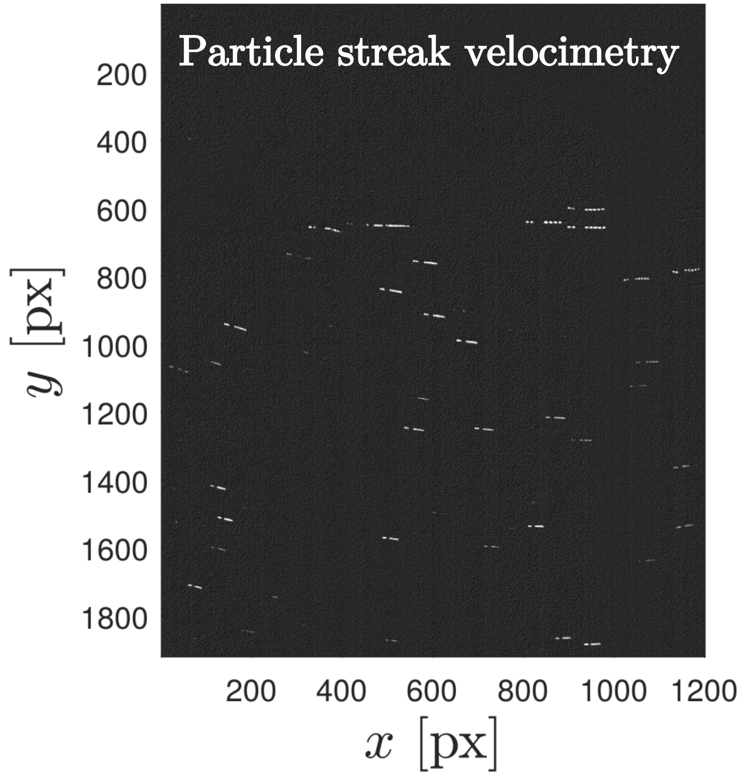


(Bopp [2018])

Motivation

Water-sided measurements of τ_{visc}:



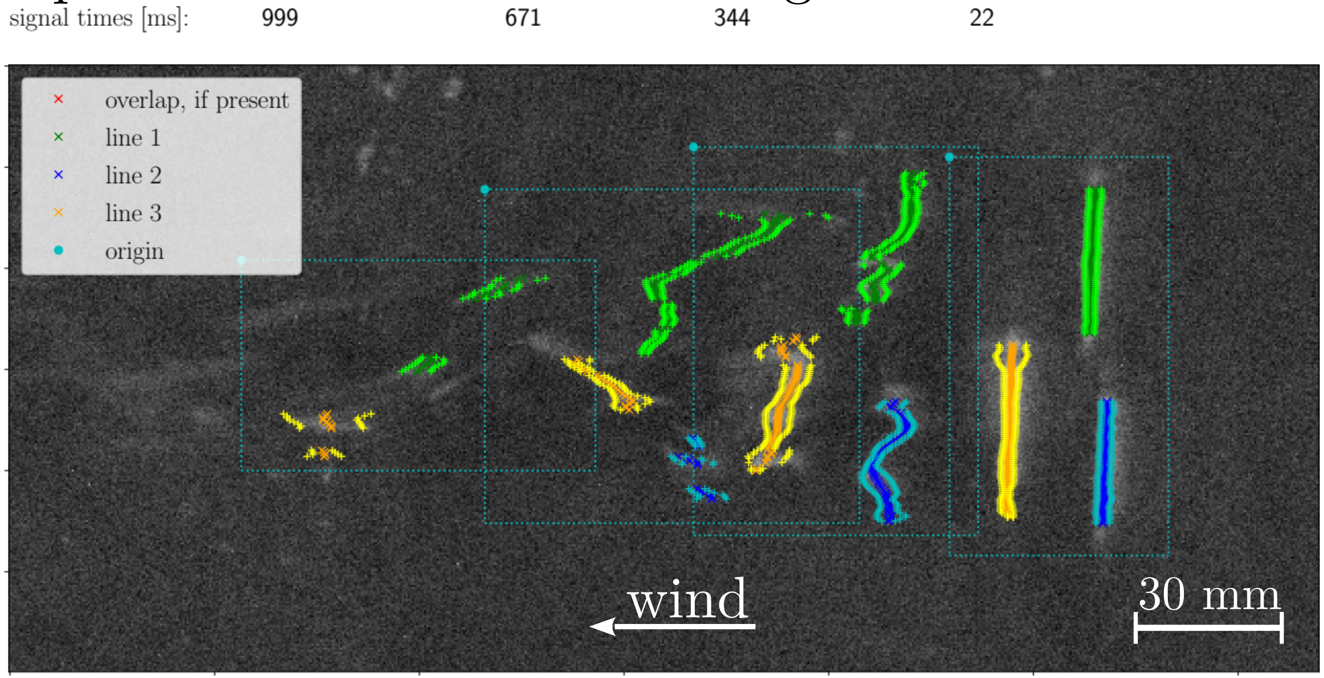
- Imaging techniques:
  - direct,
  - but demanding, poor temporal resolution and invasive (field-conditions)

- Novel approach: active thermography
  - indirect,
  - but non-invasive, air-sided setup and temporal resolution of seconds

(Voigt [2021])

Active thermographic method, principle

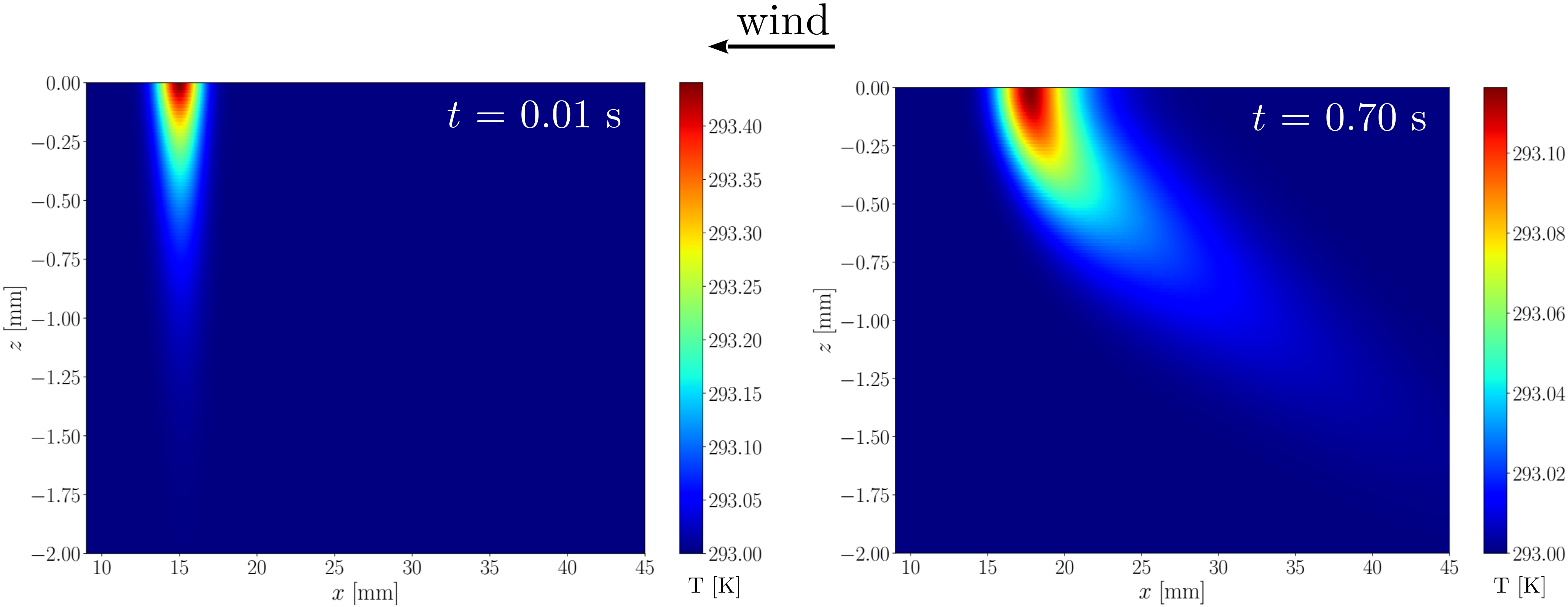
- Heating thin line perpendicular to the wind direction
- Monitoring the line width $\sigma(t)$ with an IR-Camera
- Taylor dispersion: enhanced broadening with increased τ_{visc}



(Voigt [2021])

Simulation of the problem

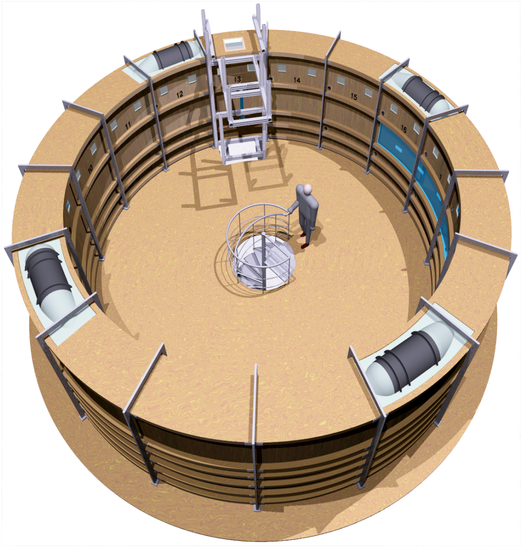
- Interpolate output to get shear stress as function of line width



(Voigt [2019])

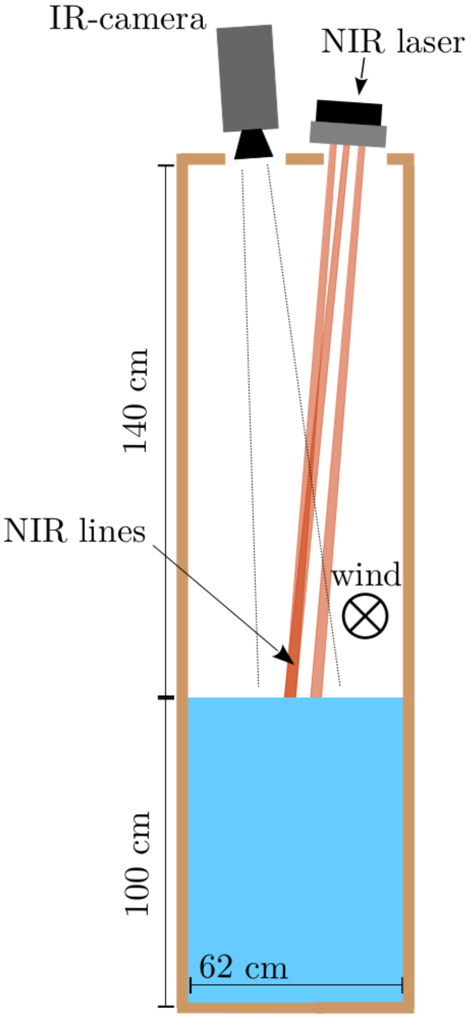
Facility and pilot setup

- The Aeolotron (Heidelberg Univ., Germany)
- Large annular wind-wave tank, diameter of 10 m



(Krall [2013])

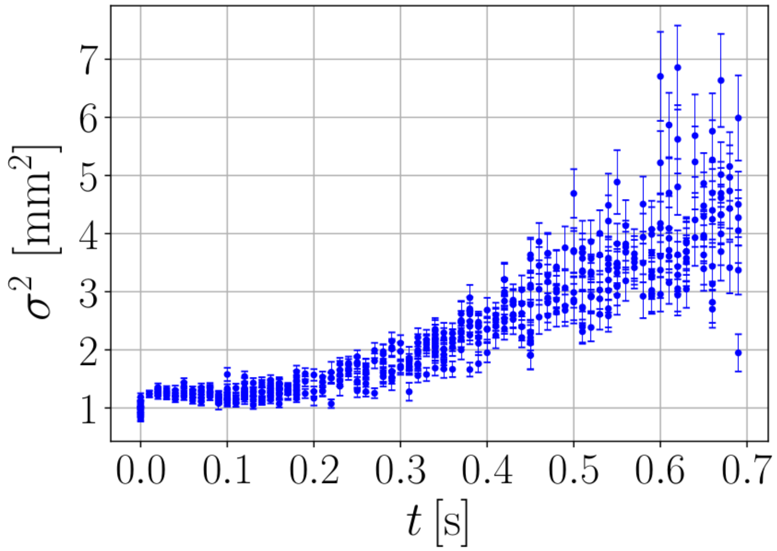
- IR camera: 512x640 px, 100-200 fps
- NIR-laser: 1450 nm diodes, penetration depth: 320 microns, power: ~1 W cm^{-1}
- Pulse duration: 10-15 ms, ΔT~0.4 K
- Line length: 20-35 mm



(Voigt [2021], modified)

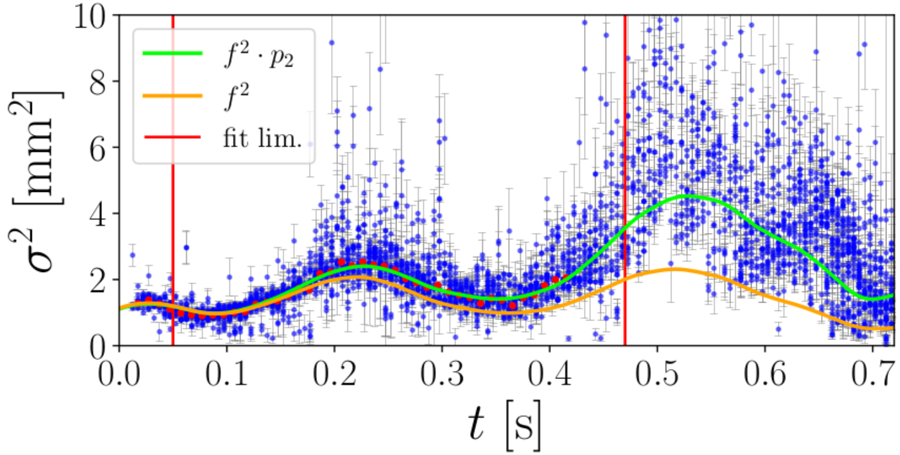
Real world examples – individual lines

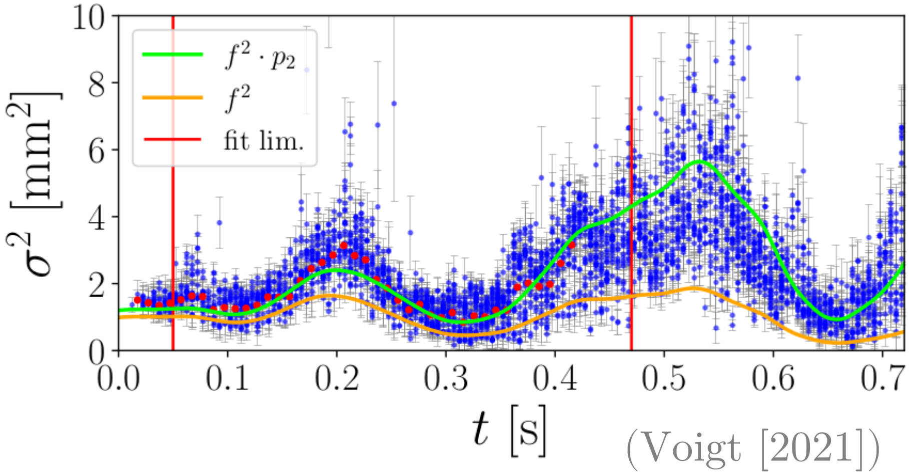
without waves



(Voigt [2019])

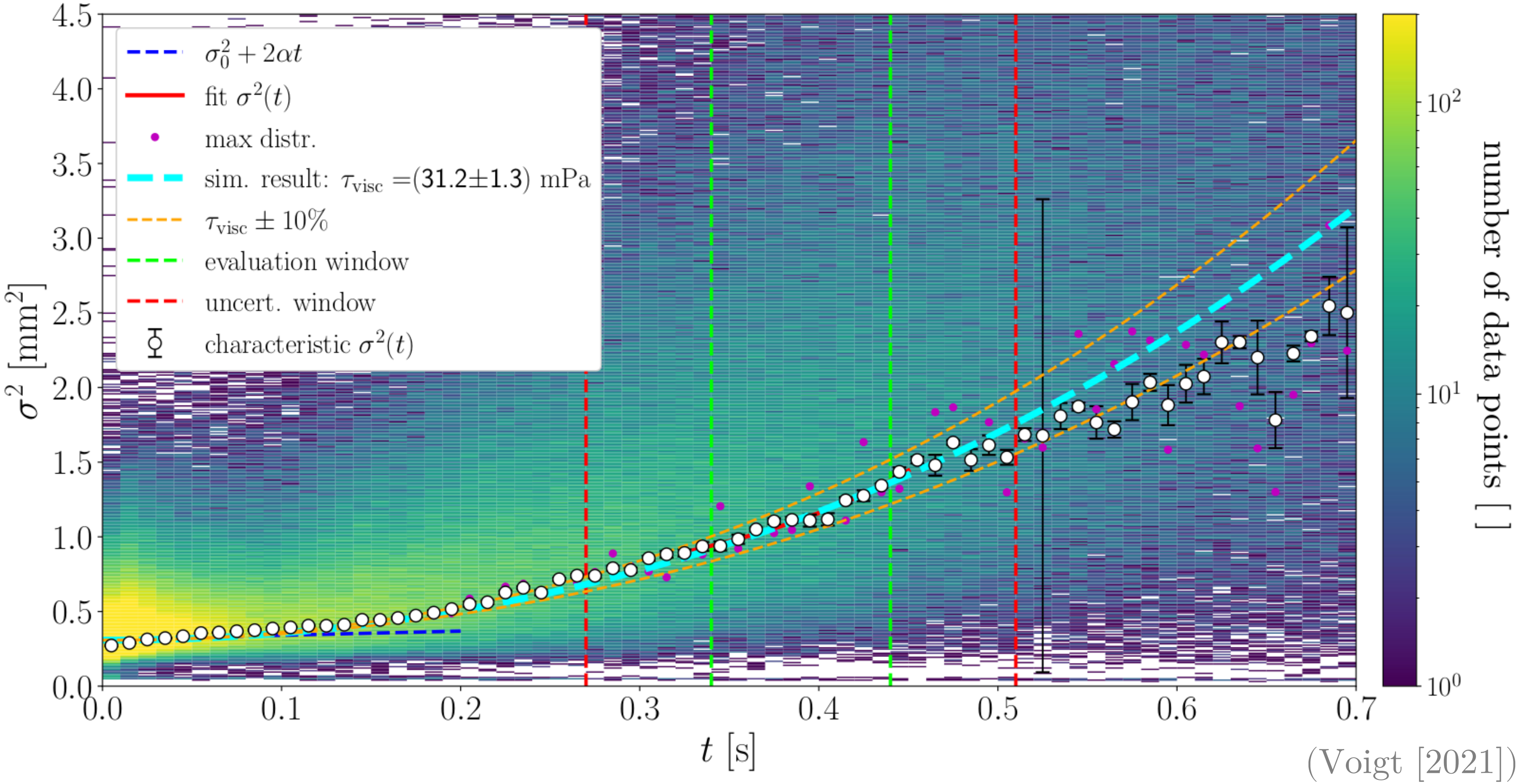
with waves





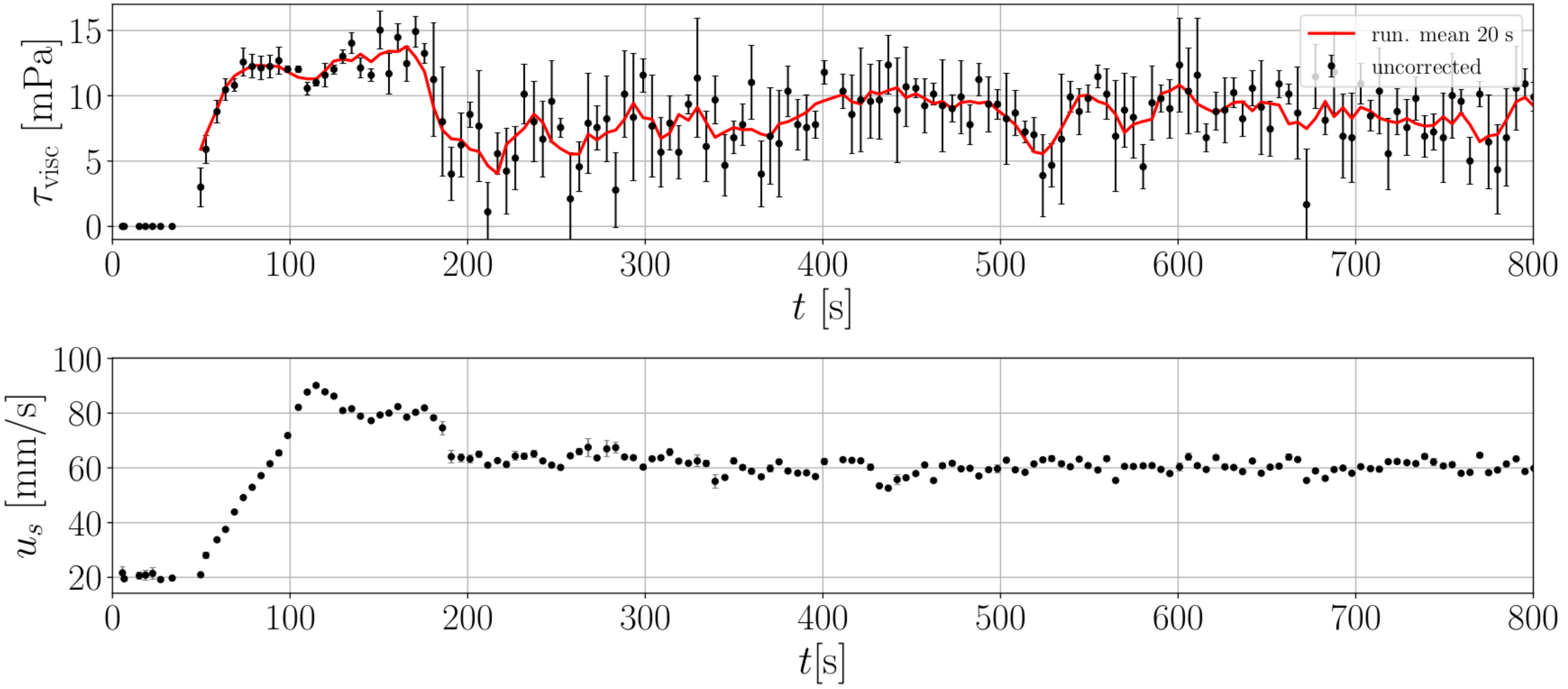
(Voigt [2021])

First results (large number of lines) - $u_{10} \approx 4.8$ m/s



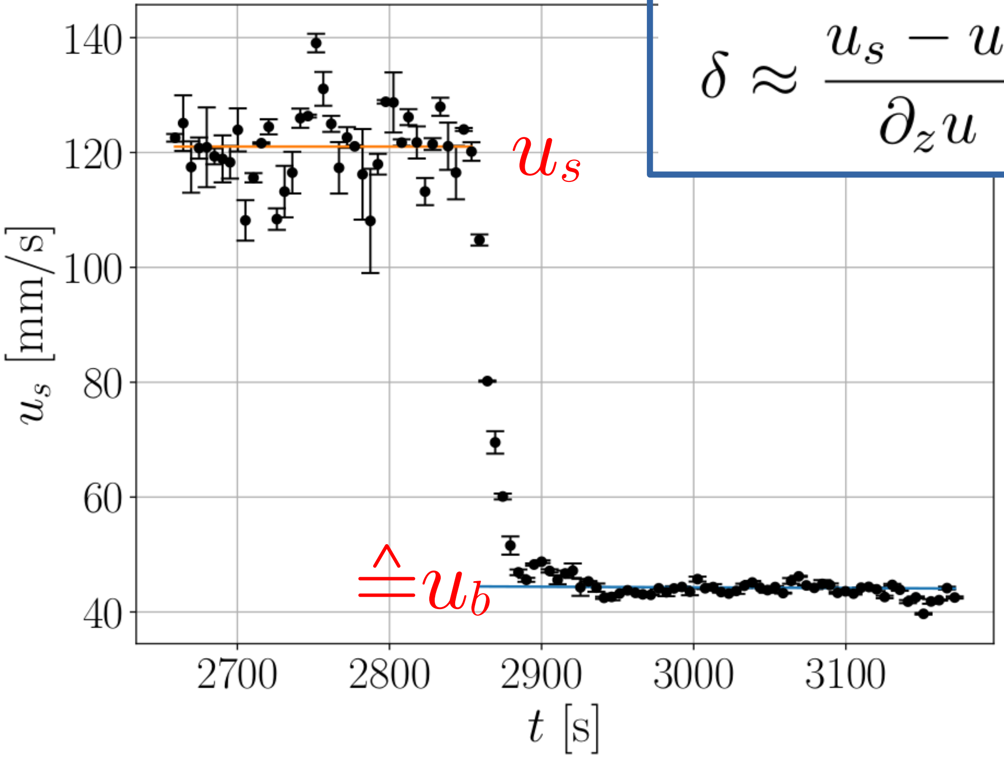
(Voigt [2021])

Time series, non-stationary conditions ($u_{10} \approx 2.4$ m/s)

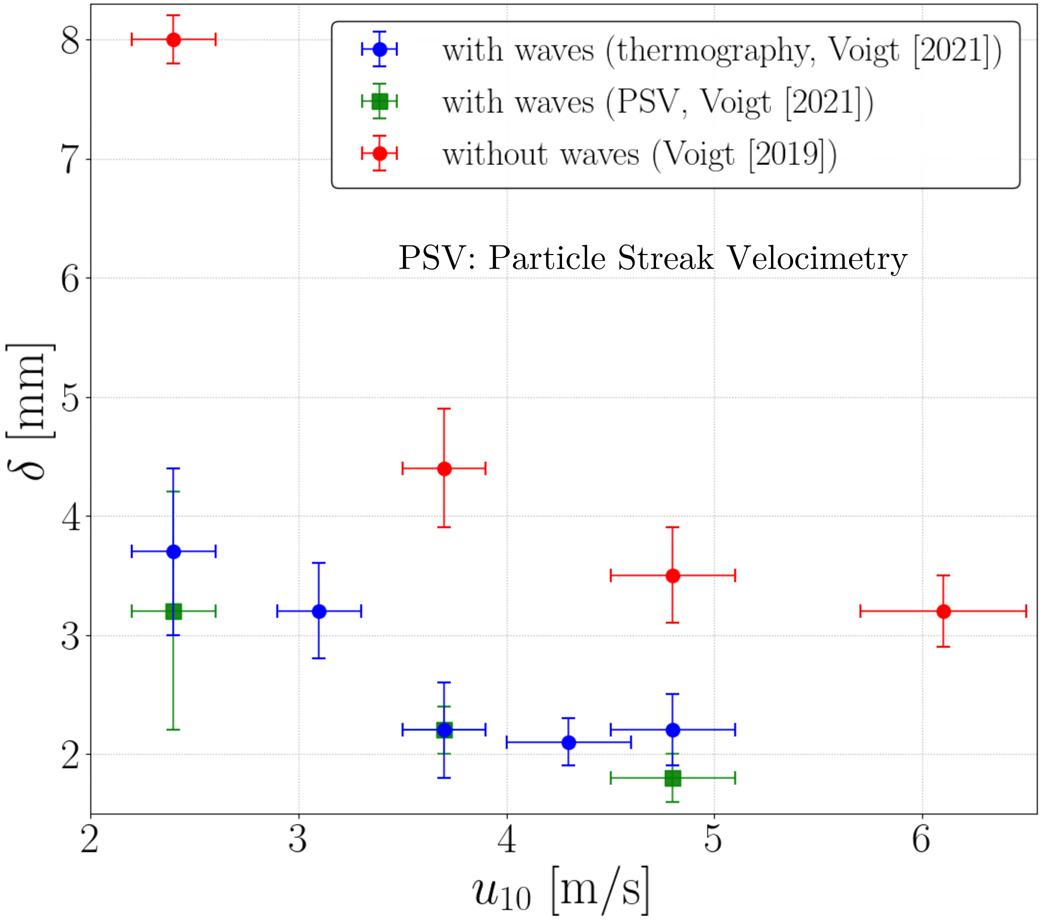


(Voigt [2021])

BL thickness δ and surface velocity u_s



$$\delta \approx \frac{u_s - u_b}{\partial_z u}$$



(Voigt [2021])

Outlook and conclusion

- Novel thermographic method for measurement of τ_{visc} at low wind speeds
- Non-invasive, air-sided setup, field deployable and temporal resolution of seconds
- Promising results from pilot setups
- Systematic deployment with new laser planned at the Aeolotron

Further reading (open access):

- Voigt, P. I.: Simulation and Measurement of the Water-sided Viscous Shear Stress without Waves, Bachelor thesis, Institute of Environmental Physics, Heidelberg University, Germany, doi:10.11588/heidok.00026653, 2019.

- Voigt, P. I.: Investigation of the Water-Sided Shear Layer at a Wind-Driven Wavy Surface by Active Thermography, Master thesis, Institute of Environmental Physics, Heidelberg University, Germany, doi: 10.11588/heidok.00030834, 2021.

Figure references

- Bopp, M.: Air-Flow and Stress Partitioning over Wind Waves in a Linear Wind-Wave Facility, Dissertation, Institute of Environmental Physics, Heidelberg University, Germany, doi: 10.11588/heidok.00024741, 2018.

- Krall, K. E.: Laboratory Investigations of Air-Sea Gas Transfer under a Wide Range of Water Surface Conditions, Dissertation, Institute of Environmental Physics, Heidelberg University, Germany, doi: 10.11588/heidok.00014392, 2013.