

# Optical measurement of surface ocean waves

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## The Reflective Stereo Slope Gauge

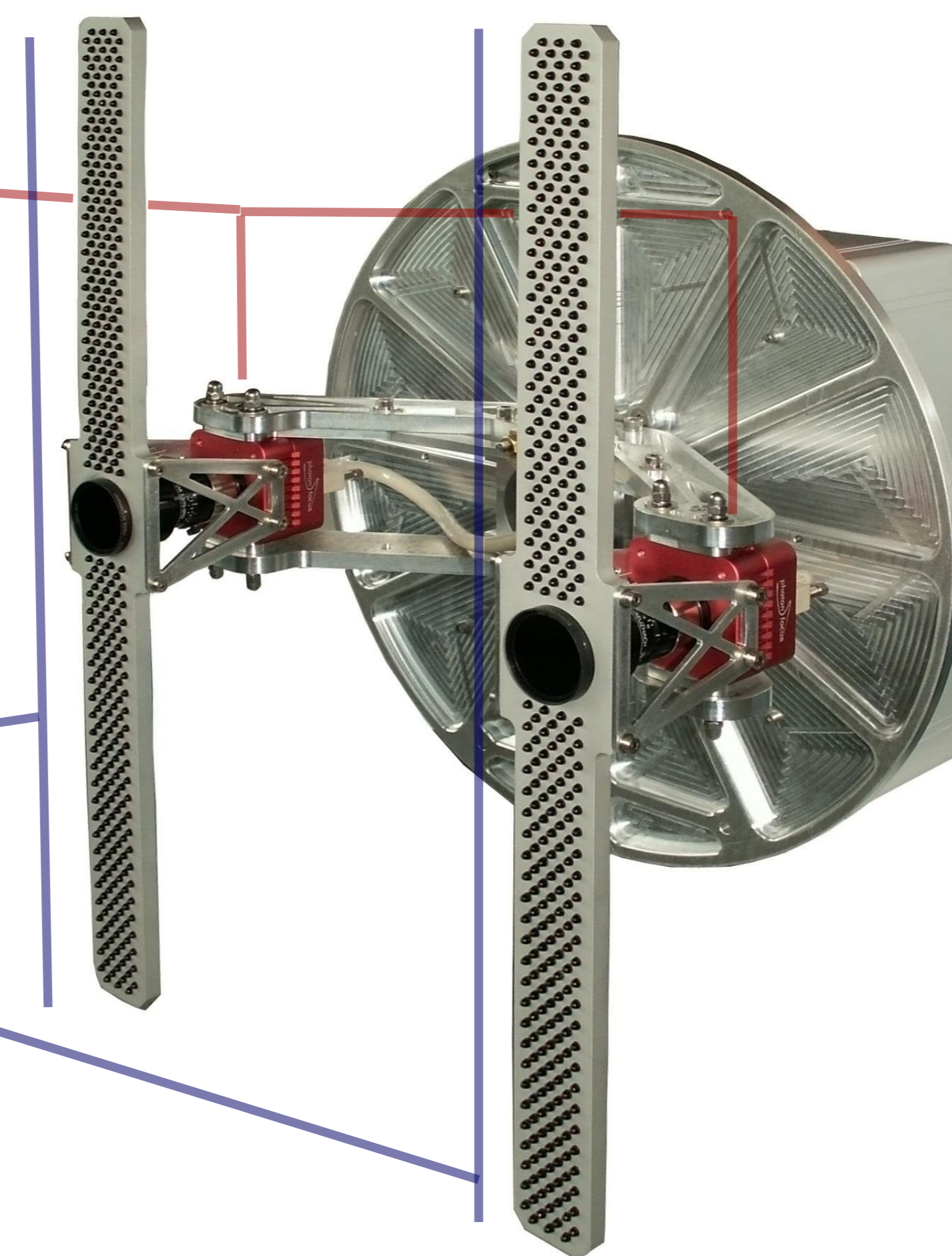
- Multi-scale wave measurements:
  - Statistical surface roughness measurements (similar to Cox & Munk [1] sun glitter technique) for short waves
  - Water height measurements from stereo triangulation for long waves
- Active technique → measurements independent of natural light
- Reflection based → non-intrusive & easy to employ, no submerged parts necessary
- Built to provide wave measurements at the footprint of gas transfer velocity measurements with the active controlled flux technique (ACFT) [2]

### Cameras:

- 1.4 mega pixel
- Up to 108 fps
- Extended near-IR sensitivity (up to 1100 nm)
- Field of view: 117 cm x 96 cm in 8 m distance ( $4.2^\circ \times 3.4^\circ$ )

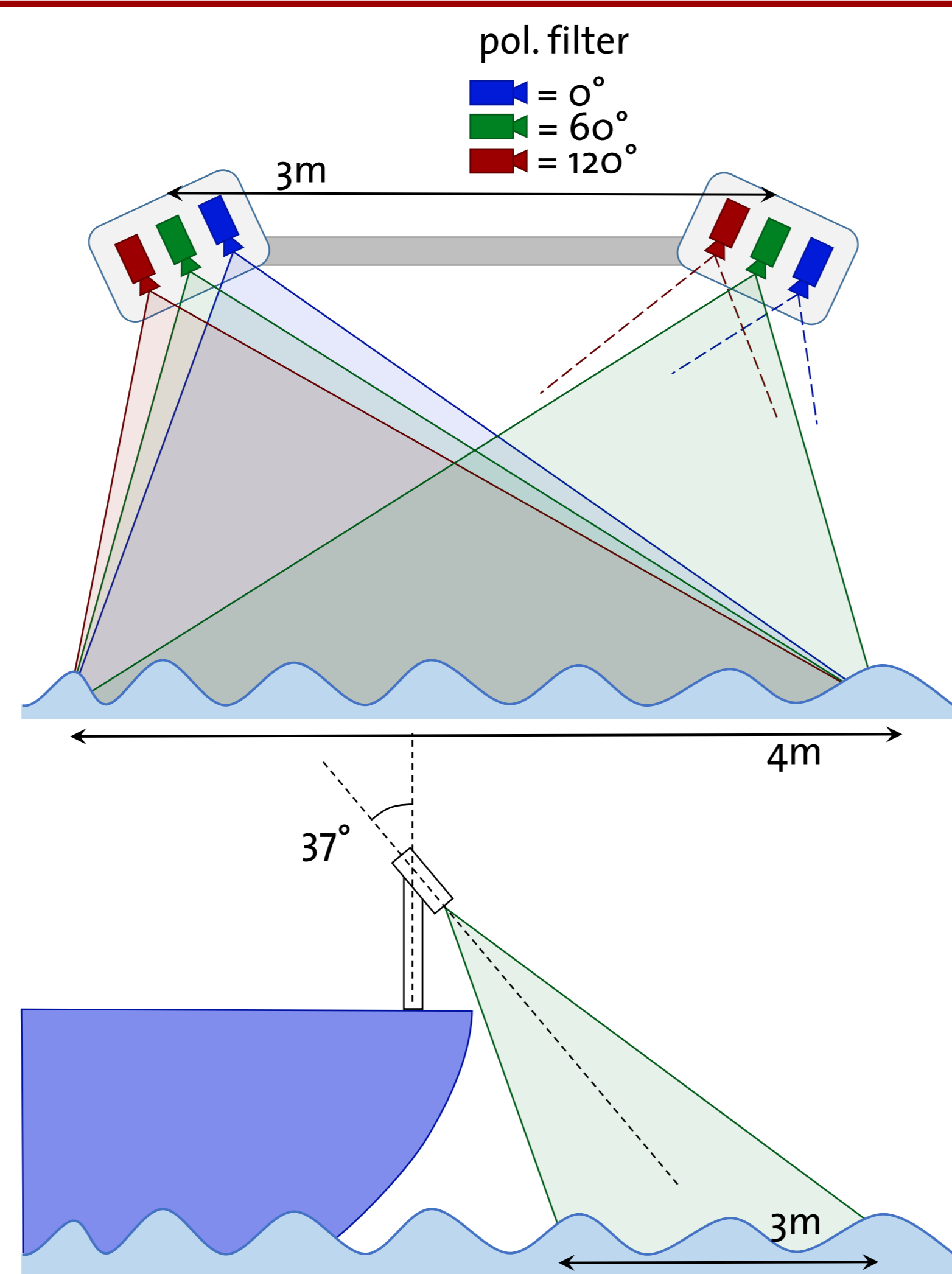
### Light sources:

- 2 x 350 IR-LEDs ( $\lambda_{\text{Peak}} = 950 \text{ nm}$ )
- matched to water absorption peak to suppress upwelling light



## The Stereo Polarimeter

- Reflected sky light is partly polarized
- Can retrieve surface slope from degree of linear polarization and polarization orientation [5]
- Stereo setup allows measurement of 2D wave height (3m stereo base, 4x3 m footprint)
- Limited to overcast sky for polarization measurements, daylight for stereo
- Calibration is crucial: intrinsic and extrinsic parameters of cameras → need precise registration of images with different polarization
- Instrument was tested for the first time during Dec 2012 experiment

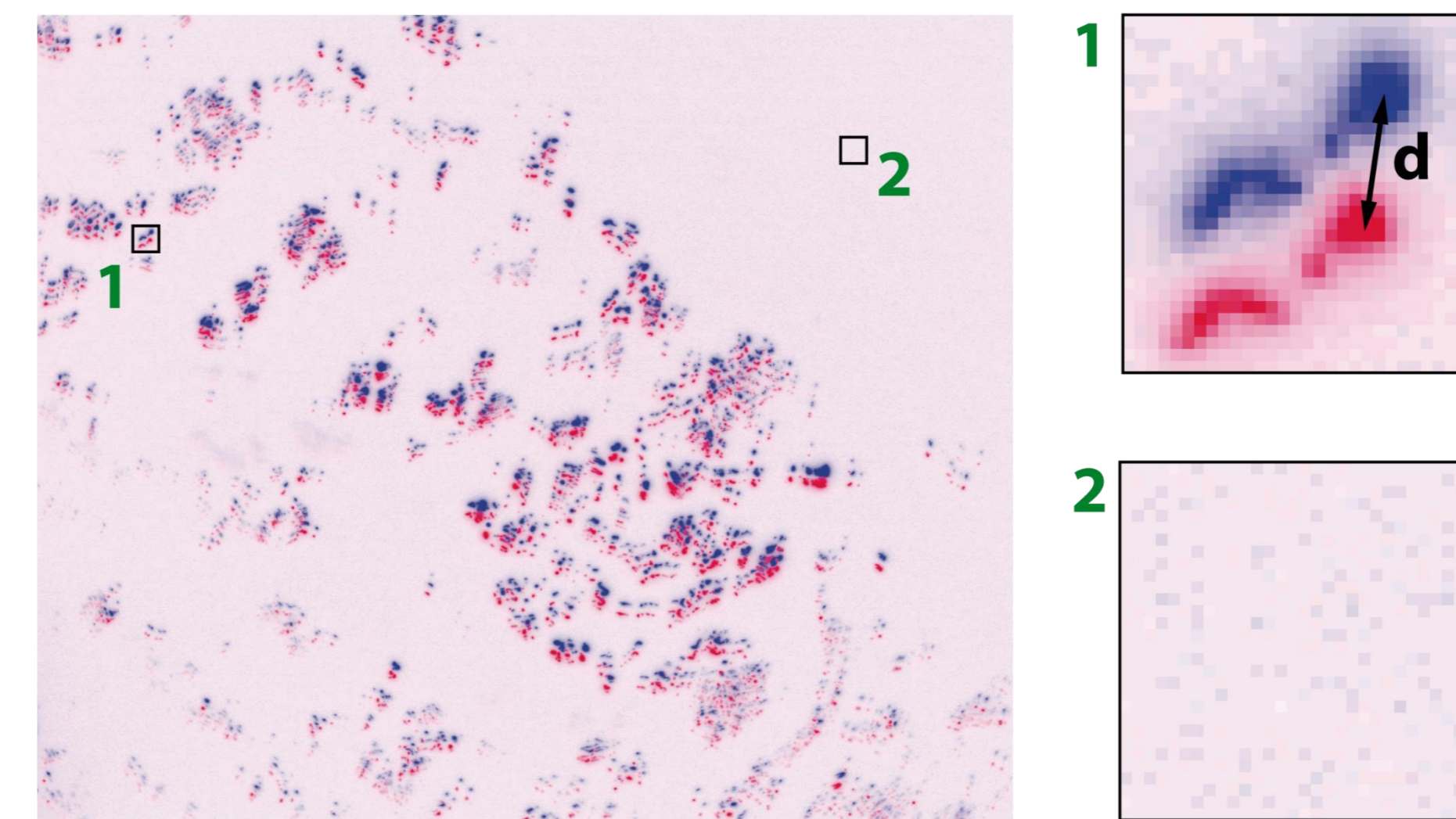


## Experiments



- Instruments were deployed to the tropical Pacific Ocean on R/V Kilo Moana (Dec 2011) and FS Meteor (Dec 2012) as well as to the Marseille wind-wave facility
- Measured wave height and slope statistics under wide range of conditions
- Variable wind speeds between 2 and 13 m/s
- Varying biological activity → change in surfactant cover
- Gas/heat exchange measured simultaneously
- Hope to find parameters of wave field that describe gas exchange → space based measurements?

## Surface elevation measurements

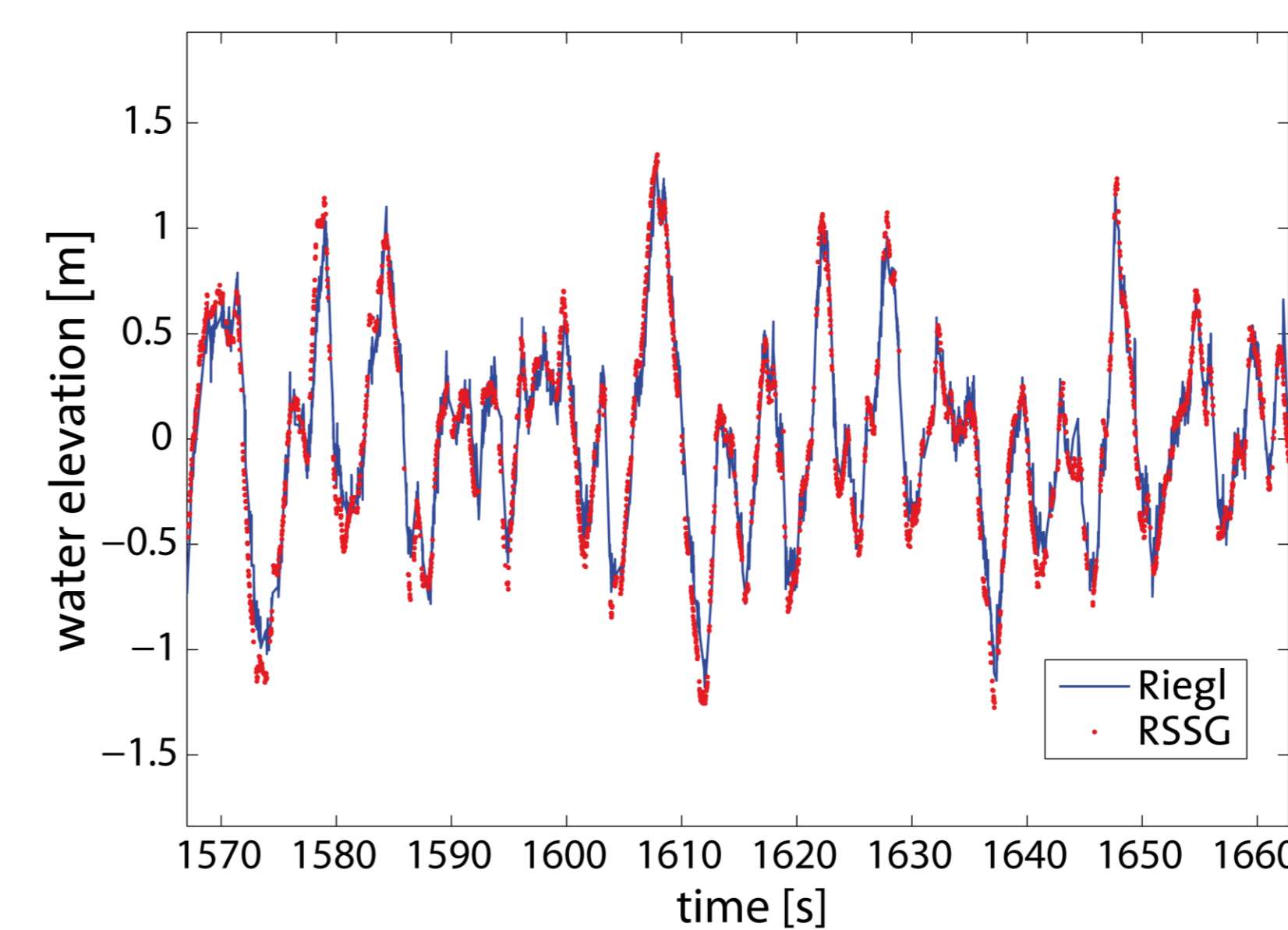


The stereo disparity  $d$  is unambiguously related to the water surface distance

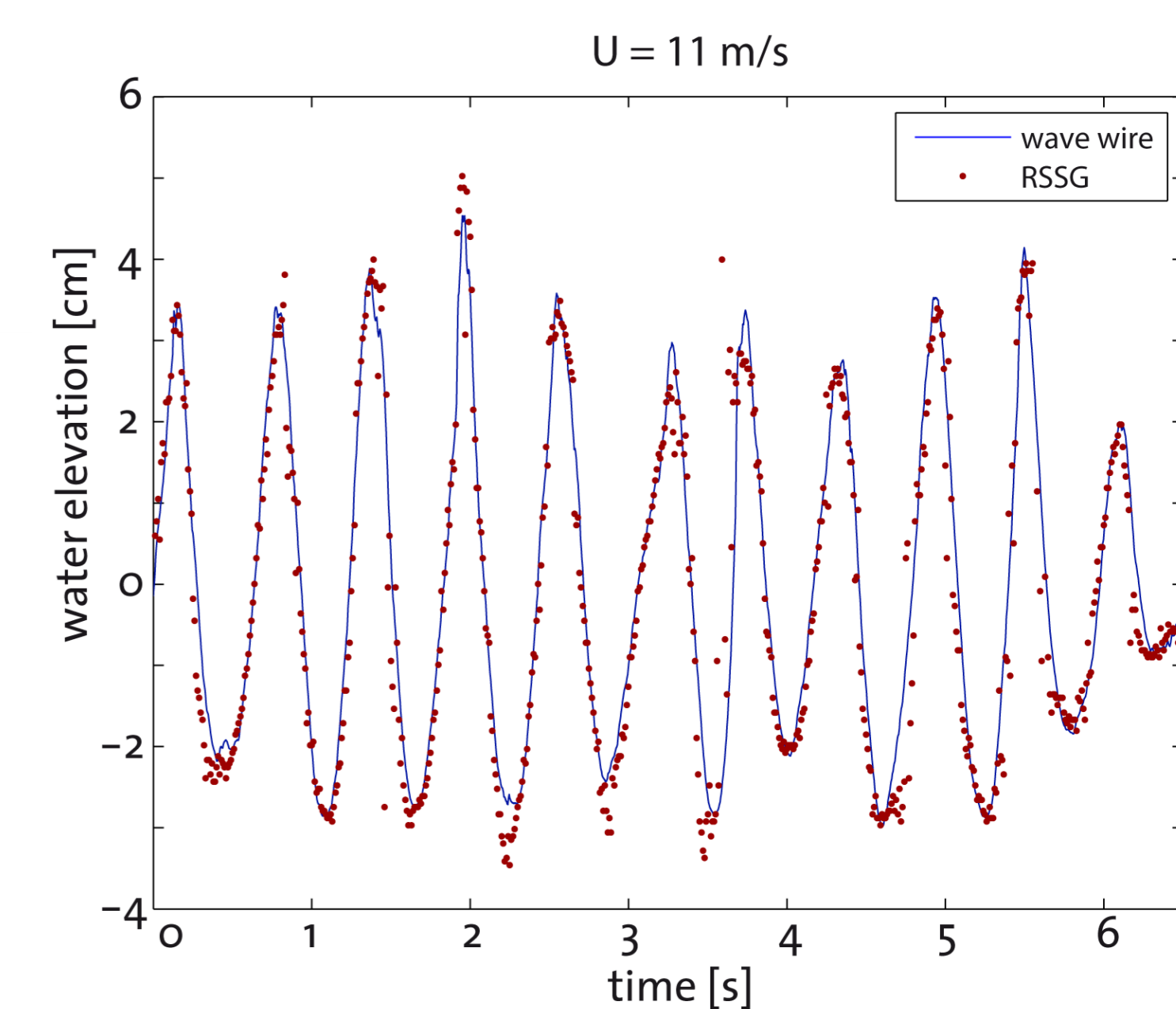
In some parts of the image, there are no specular reflections → No measurement possible

RSSG stereo image: inverted false-color overlay of two monochrome images  
left camera: red, right camera: blue

- Stereo surface elevation measurement: block matching of window with footprint of 0.2 m x 0.2 m
- Small window leads to high dropout (see detail 2 above), large window decreases measurement accuracy (theoretical resolution few mm)

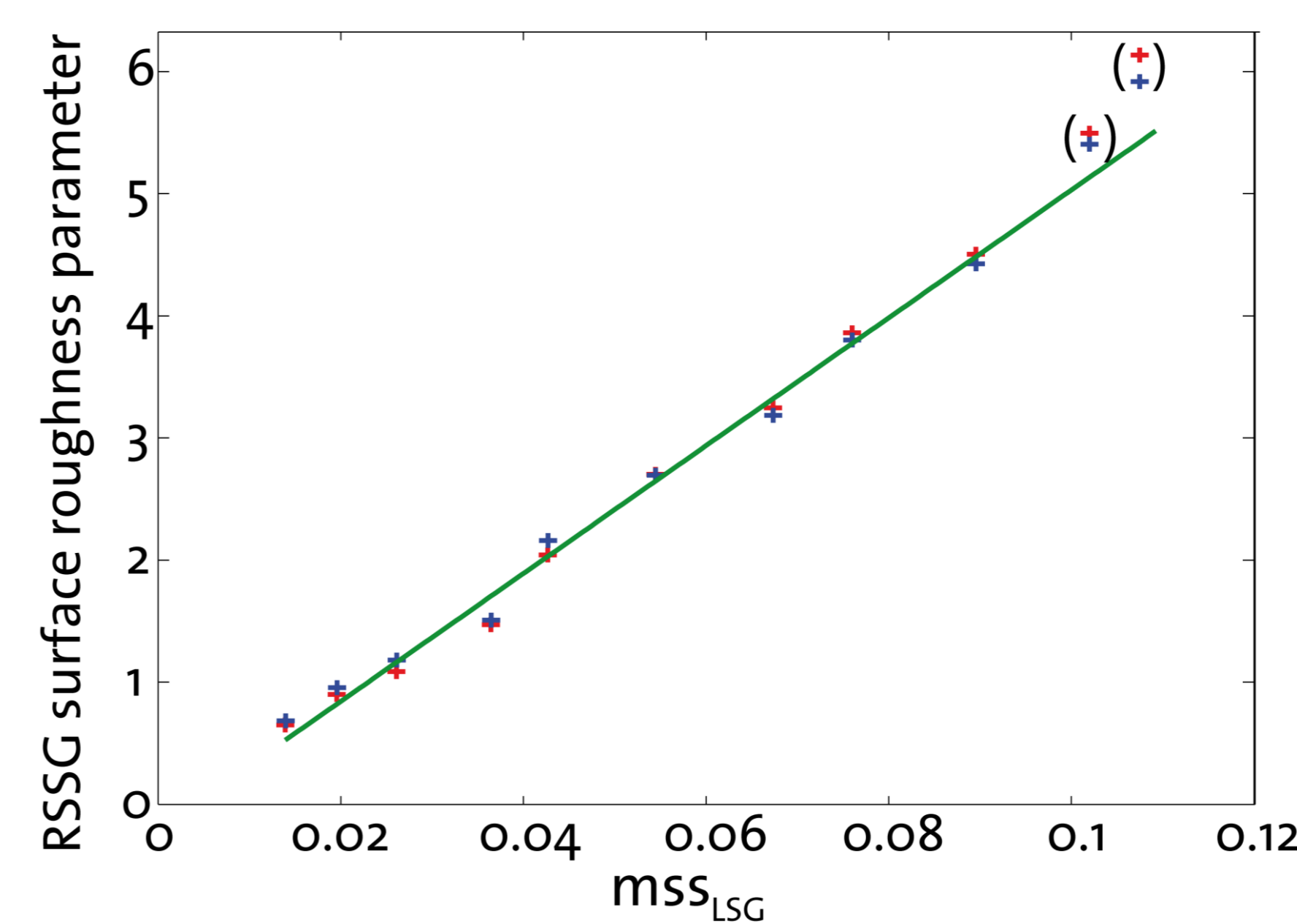


Comparison of Riegl laser altimeter (blue line) and surface elevation from stereo with the RSSG (red dots) during the OSSPRE cruise on R/V Kilo Moana.



Comparison of capacitance type wave wire (blue line) and surface elevation from stereo with the RSSG (red dots). Data from experiment at Marseille wind-wave facility.

## Surface slope (mss)



Comparison of the RSSG surface roughness parameter to mean square slope measured with a laser slope gauge [4]. Data from experiment at Marseille wind-wave facility (red and blue crosses from different days).

- The surface roughness parameter from the statistical slope measurement that is similar to the Cox & Munk sun glitter technique is proportional to mean square slope [3]
- Surface roughness parameter related to inverse mean gray value of images, at very high wind speeds the illumination brightness is not sufficient, causing a slight overestimation of mss.

## Outlook

- Stereo Polarimeter calibration, comparison to RSSG measurements
- Detailed analysis of sea state during Dec 2011 and Dec 2012 cruises
- Study of effect of sea state on gas exchange rates