

Mean Square Slope Measurements with the Reflective Stereo Slope Gauge

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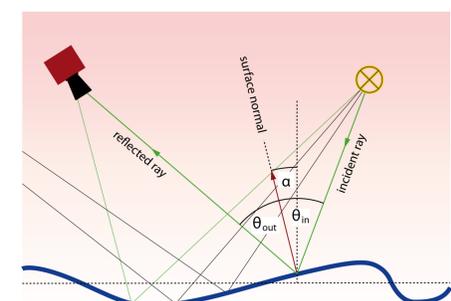
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Mean Square Slope

- Small scale water waves are important for the exchange of gas, heat and momentum across the air-sea interface [1]
- Mean square slope (mss) is the variance of the slope probability distribution function (pdf) and a measure for sea surface roughness due to the small waves.
- Parameter for air-sea gas exchange rates [1]
- Method for local, high resolution and non-invasive measurements, independent of environmental conditions and daytime, has been developed: the *Reflective Stereo Slope Gauge (RSSG)* [2]
- Unlike other reflection based methods like sun glitter or Stilwell/polarimetric imaging [3], it uses artificial light sources and is thus independent of daytime and environmental conditions
- Can provide local wave statistics during field experiments, even at night

Reflective Slope Measurement



- If light from the light source is reflected into the camera, surface slope $s = \tan \Theta_s$ is known from reflection condition $\alpha_{in} = \alpha_{out}$
- Slope pdf for slopes near zero (± 0.1) is proportional to the distribution of reflection density in images [2]
- Pixel size on water surface $0.6 \times 0.6 \text{ mm}^2$ (at 5.5 m distance)
- capillary waves are resolved

Data Processing

- Image processing involves a number of steps to correct for inhomogeneities of the image acquisition and illumination system
- Ship motion is measured with an inclination sensor and accounted for

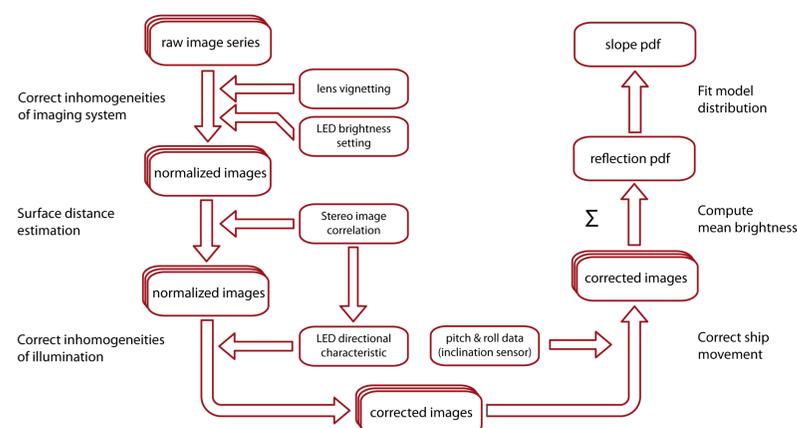
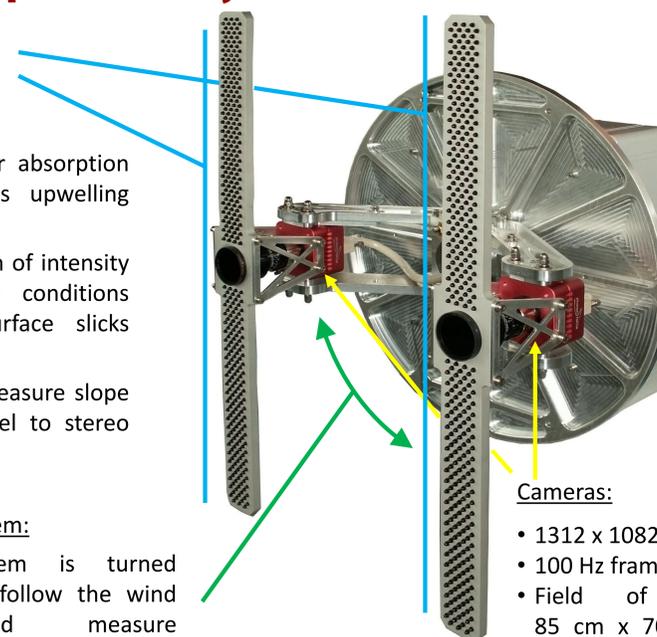


Image Acquisition System

Light sources:

- 2 x 350 IR-LEDs ($\lambda_{Peak} = 940 \text{ nm}$)
- matched to water absorption peak to suppress upwelling light
- On-line adaptation of intensity to environmental conditions (wind speed, surface slicks etc.)
- Line arrays can measure slope component parallel to stereo base precisely



Cameras:

- 1312 x 1082 pixel
- 100 Hz frame rate
- Field of view: 85 cm x 70 cm in 5.5 m distance

Wind following system:

- Acquisition system is turned automatically to follow the wind direction and measure upwind/crosswind slope

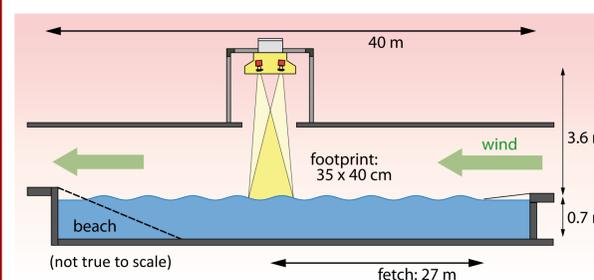
Experiments

Field Campaign

- The RSSG was deployed to the Baltic Sea in July and September of 2010 to measure wave statistics during heat transfer experiments (the RSSG is the yellow hat)
- Measuring wave statistics at same footprint aids the evaluation of heat transfer rates
- Data evaluation is currently in progress



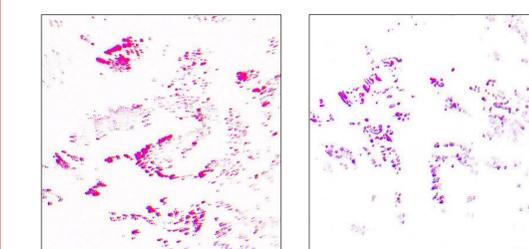
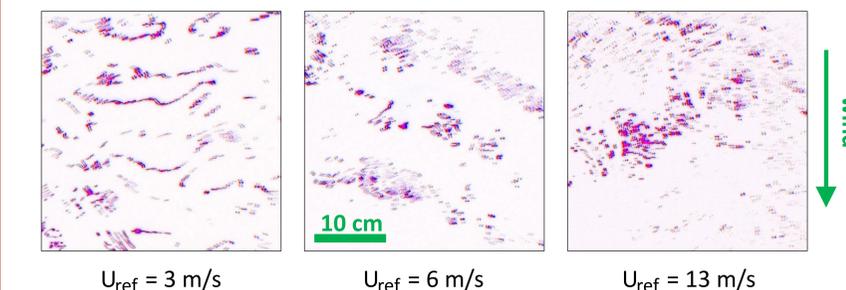
Laboratory Measurements



- Reference experiments at the IRPHE wind-wave facility in Luminy (Marseille) were conducted in March 2011 (bottom figures)
- mss values in these experiments can be compared to those obtained with a Laser Slope Gauge [4] under the same conditions (fetch, wind speeds)

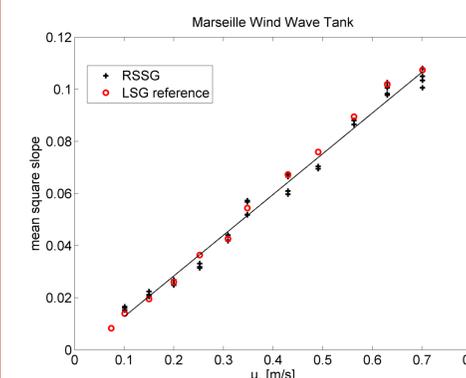
Sample Images

- False color stereo overlay (blue = left camera, red = right camera) images from Marseille experiments
- Trains of short gravities with capillaries visible, surface roughness clearly increases with wind speed



- Images from Baltic Sea measurements for reference wind speed of 4 m/s (left) and 8 m/s (right); wind speed measured at 7 m height

Mean Square Slope Comparison



- To a first approximation, mss is proportional to the inverse of the mean gray value of the image [2]
- Comparison with reference measurements (see *Experiments*) show a good correlation for a wide range of wind speeds ($U = 3 - 13 \text{ m/s}$)

Outlook

- An efficient stereo evaluation algorithm is currently under development which allows the measurement of height statistics, such as the significant wave height and wave age
- Cross-validation experiments with other techniques in the field are planned for the second half of 2011