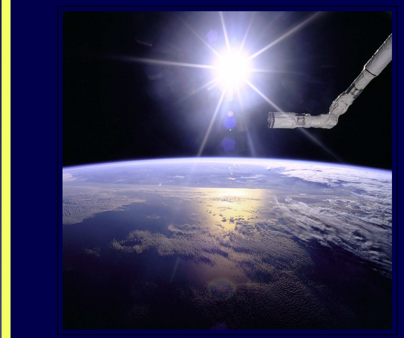

Sunglint: An Investigation Under Controlled Laboratory Conditions

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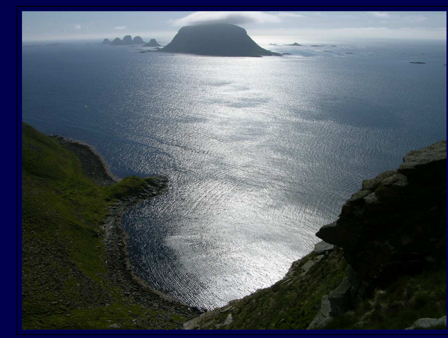


Introduction

Reflection of Sun light off a wavy water surface, often referred to as Sunglint, is a well-known feature that presents challenges, but also hitherto untapped opportunities in remote sensing based on satellite imagery (MODIS). Despite being extensively investigated, Sunglint lacks a fundamental characterization obtained under controlled laboratory conditions. We present a suitable setup to time-resolve light reflection off different wave states. The goal is to establish the link between glint dynamics and their average over space and time resulting in the familiar Sunglint display.

Experimental apparatus

- We make use of the **wave tank** located at the Air-Sea Interaction Research Facility at NASA Wallops Flight Facility, VA. Controlled wave states, ranging from capillary to gravity waves, can be created in the tank by means of a hydraulic unit (pusher), a wind flow and an underlying current.

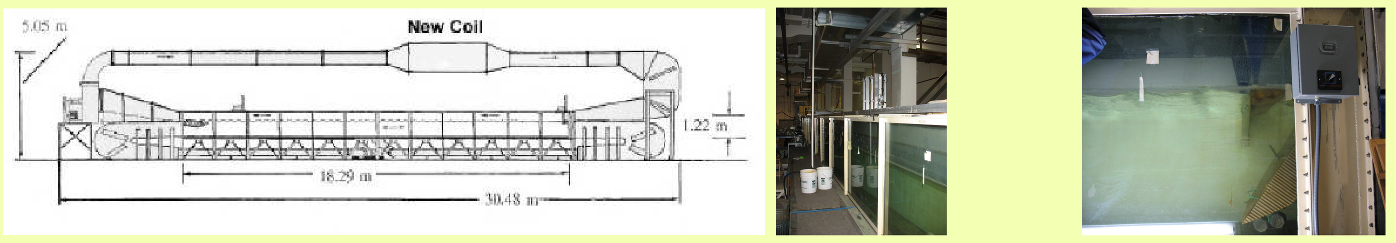


Figure 1: Images of the wave tank and the pusher at work, driving gravity waves.

- Vertical **capacitance-wire probes** partially immersed in the tank (adjacent to the illuminated spot) measure the longitudinal and transversal surface elevation and slope.
- A special semi-circular mount **black rainbow** has been assembled to allow accurate positioning (within $0.1°$) of the source and the detector over the water surface at a range of polar angles spanning the principal plane. Movement is engaged with finely-tunable geared tripod heads installed on carriages.
- The **source** consists of a fiber-coupled laser diode working at 632.8nm. The polarization state is selected by rotating a linear polarizer (the reference is the position that minimizes the reflection at Brewster's angle, corresponding to incident p-light). A reference detector samples the beam for normalization purposes.

Figure 2: The supporting structure (*Black Rainbow*) and the source. The polarizer is visible at the center of the cage system.

- The **detector** is based on a Division-of-Amplitude Photopolarimeter (DOAP) design[1,2]. By using a polarizing beam splitter, it simultaneously detects the intensities associated with three of the four parameters of the Stokes vector.

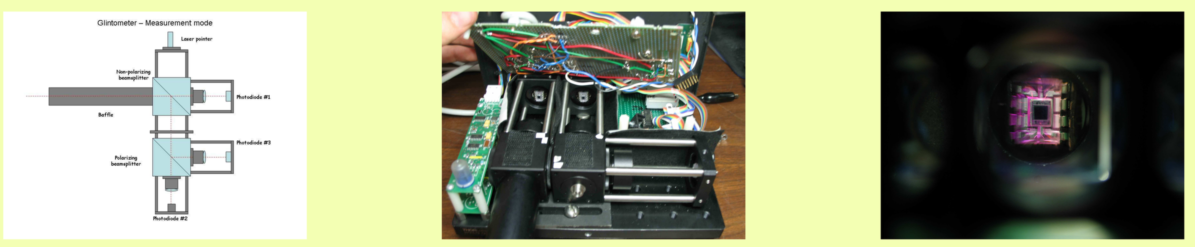


Figure 3: (*Left*) Schematics of the optics of the "glintometer". For accurate pointing, a mirror can be slidden in between the two beam splitters to reflect a laser pointer's beam down the baffle. (*Center*) the assembled prototype; (*right*) a macroshot from the instrument entrance window (baffle removed) shows the overlapped images of the three photodiodes.

Observational facts about glints

Logging the output from the capacitance wires and the three photodiodes we obtain an actual representation of the wave state with the the glint intensities overlapped with the slopes at which they occur!

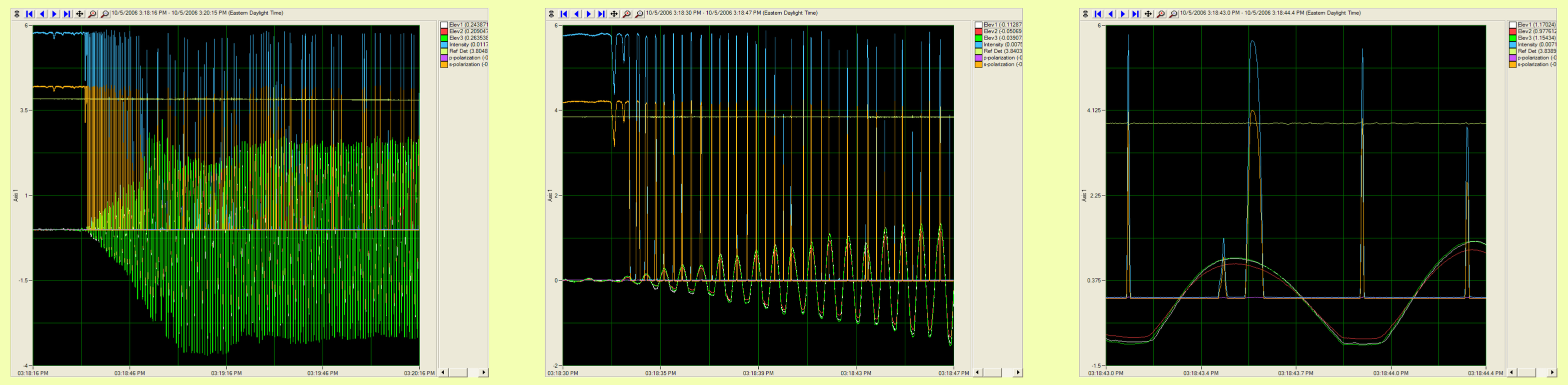


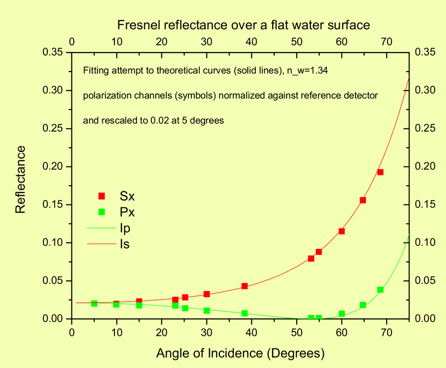
Figure 4: (*Left*) the flat surface is disturbed as paddle-driven waves (green channel) start running down the tank; (*Center*): with source and detector at equal angles, the reflected beam enters the field of view only when reflecting off a crest or a trough. The absence of p-polarized intensity (purple channel) is due to the Brewster geometry. Missing glints are due to non-monodimensional waves redirecting the reflection off the principal plane; (*Right*) a curious "double-glint" from a crest.

- Within the **tangent plane approximation**, glints are observed every time the surface slope is oriented as to realize the **specular geometry** between the source and the detector
- The reflected beam will project onto the upper hemisphere trajectories whose boundaries are determined by the slopes of the underlying waves.

Figure 5: Overhead picture of the laser shining on patches of capillary waves: the refracted beam looks smeared on the bottom of the pool as a result of the mid-long exposure (~ 1s). A blitz with the camera flash generates the glints observed as bright spots: waves evolving on a faster time scale than the flash make some of the glints also appear as trails.

- The glints' FWHM (linear velocity) depends on the observation distance
- Gravity waves ($1-3$Hz in frequency), with their gentle slopes, have the reflected beam span smaller angular range
- Capillary waves' steeper slopes and faster time evolution redirect the reflection in a more unpredictable fashion. Their glints are $5-10$ times shorter-lived, consistent with their typical frequency of $14-15$Hz

Mastering the flat surface



Before introducing waves, the Fresnel equations were tested by measuring the specular reflection from the flat surface at a grid of angles.

Figure 6: Fresnel reflectance on a calm water surface for incident light polarized at 45 degrees. The experimental points (representing the polarization components of the reflected intensity) show very good agreement with the theoretical curves.

A zoo of glints

How do glints microscopically look like? Are they different from one another?

- Gravity glints are evenly spaced. Their evolution in time is slower than for capillary glints and the profile looks smoother
- Capillary glints are often grouped together as a result of the higher speed. They often graze repeatedly in and out the field of view, spending a considerable portion of time at the edge. This accounts for the finer modulation of their profile

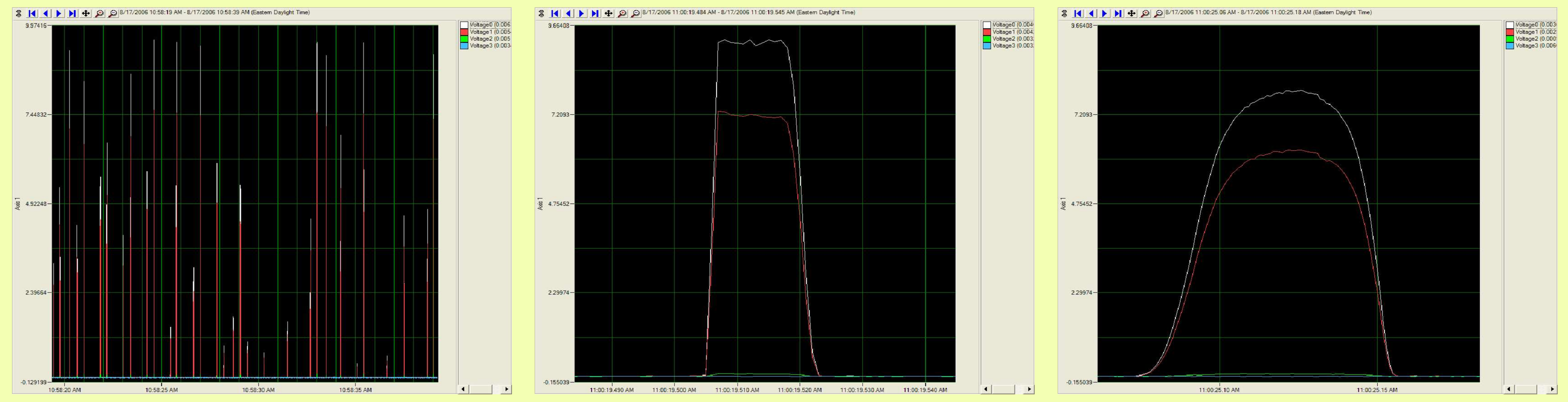


Figure 7: (*Left*) A family of "gravity" glints (20 s series) captured at 1kHz, Brewster geometry. Total intensity is in white and its (un-normalized) s-polarization component in red. (*Center*) A nice specimen of top-hatted glint; (*Right*) A smoother glint with more of a "sombrero" shape.

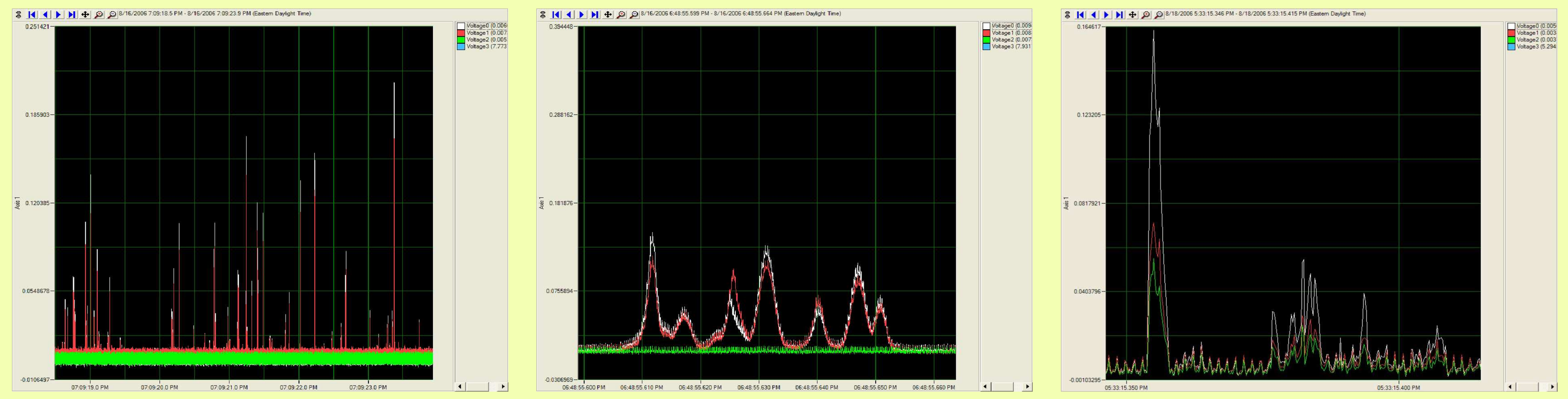


Figure 8: (*Left*) "Capillary" glints at 5kHz, light wind conditions; (*Center*) Zooming into the previous display; (*Right*) Source at 23 degrees from zenith, nadir-looking detector. 4kHz, strong wind. Note the onset of the *p*-polarization signal (green channel).

Outlook

The illustrated experimental apparatus shows the capability of detecting the polarization signatures of a beam reflecting off a wavy surface created under controlled, repeatable laboratory conditions.

- The surface statistics will be derived from the combined use of capacitance-wire probes and a fast imaging system
- The investigation will be systematically extended to a range of wave states to develop a model connecting surface statistics with polarized BRDF

References

1. R. M. A. Azzam, "Division-of-amplitude photopolarimeter (DOAP) for the simultaneous measurement of all four Stokes parameters of light," Opt. Acta **29**, 685-689 (1982).
2. R. M. A. Azzam, "Beam splitters for the division-of-amplitude photopolarimeter (DOAP)," Opt. Acta **32**, 767-777 (1985).

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