Glittering Light on Water

on Water

Light that glitters off a lake at sunset is more than just a beautiful picture, it tells a story of wind direction, air temperature, and more.

BY JOSEPH A. SHAW

On a November evening in 1982 I was on a train slowly wandering around the edge of a bay in southern Japan. The setting sun created a magical streak of glittering light reaching across the water (see Fig. 1, page 44). Even though I had no formal optics training at that time, I took special care to photograph this optical treat, even thinking that someday I would like to understand this glittering light better. I knew, at least, that this would be a nice addition to the slide show I would share with my family and friends back home when telling them about Japan—the "Land of the Rising (or, in this case, setting) Sun."

Thirteen years later I was on an inverted ship in the Pacific Ocean (see Fig. 2) measuring glitter patterns created with a laser. With the passage of time, I have discovered that understanding how glitter patterns are formed, and even forming my own glitter patterns to measure sea-surface roughness, helps me enjoy nature's glitter even more.

How glitter patterns are formed

The name "glitter pattern" implies a moving and changing phenomenon. Glitter patterns consist of many bright points of light that come and go, blending together to form a smooth path of glittering light when viewed at a distance. If you look closely at a glitter pattern, you can see individual points of light. Each of these points is a specular reflection of the Sun, called a sun glint. Glints occur on the water where the local slope provides a direct specular reflection of the Sun. A perfectly smooth surface would contain only one glint. It is this kind of glass-like surface that produces the nearly perfect images we see in nature calendars of mountains reflected in lakes. But when the water's surface is rippled by even the slightest wind, reflected images become wrinkled and blurry. If light from the Sun or Moon, or even a streetlight or distant illuminated window, then hits the water it is reflected from multiple spots on the surface (see Fig. 3). As the wind-rippled surface moves, so do individual glints, and the ensemble of glints produces a glitter pattern whose shape and size can be related to the roughness of the water and the viewing geometry.

Glitter patterns are roughly elliptical, with an aspect ratio that depends on the source elevation angle.[1, 2] For example, the Sun produces a circular glitter pattern when it is directly overhead (90° elevation angle) and an elongated elliptical pattern near sunrise or sunset (small elevation angle). This all assumes a uniformly rough surface; quite often, however, wind gusts increase or surface slicks reduce the roughness in a localized region. These kinds of effects are evident in Figure 1, especially near the shore where the glitter pattern is much wider than elsewhere (perhaps partly because of the wind generated by the passing train).

Figure 1. Glitter pattern created by the setting sun. Notice how the width of the pattern varies, depending on the local surface roughness.

Figure 2. The Floating Instrument Platform (FLIP, operated by Scripps Institution of Oceanography), where NOAA deployed laser-glint sensors in September 1995 for measuring ocean surface roughness.

For a high light source, the angular length of a glitter pattern is equal to four times the angle of the maximum wave slope (see Fig. 3). Waves inclined both toward and away from the observer create glints, resulting in a factor of two times the maximum wave slope; the additional factor of two is a result of angular doubling on reflection. The ratio of the glitter-pattern width to its length is given by the sine of the source elevation angle. If the light source is at the same elevation as the observer, the glitter pattern dimensions are half as large as with an infinitely high source, but the width-to-length ratio is the same. As the Sun or Moon drops lower in the sky, the glitter pattern gets progressively narrower until the width-to-length ratio reaches a minimum when the source elevation angle is twice the maximum wave slope. Beyond this angle, as the Sun or Moon approaches the horizon, the glitter pattern becomes shorter because of shadowing, and eventually disappears.

Glitter patterns on water are similar to vertical light pillars in the sky, caused by reflection from ice crystals floating or falling with a distribution of slopes.[1-5] Growing up in Alaska, I often saw light pillars above city lights during the winter when the ice-laden atmosphere was calm and cold. But sun pillars can be seen even in more temperate climates, especially near sunrise or sunset in the vicinity of thin cirrus clouds.
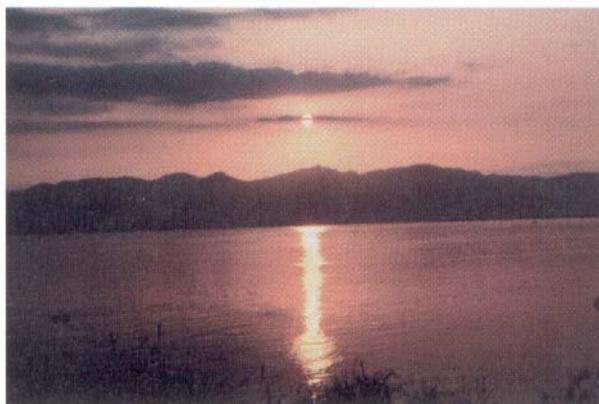
Better weather forecasts from glitter patterns

Have you ever been rained on during an afternoon forecast as "mostly sunny?" This kind of event might happen less often if our knowledge of the wind speed and its direction over the ocean three or four days earlier improved. Satellite sensors can see large regions of ocean where there are no people to measure winds, but they rely on models to infer wind speed and direction from surface roughness. It turns out that much of the information relating surface roughness to wind speed and direction comes from studying patterns of light glittering on the ocean's surface.

Recall that the maximum wave slope can be determined from the geometry of glitter patterns. In 1951, Charles Cox and Walter Munk found a more quantitative way of using glitter patterns to derive a statistical

model for the complete wave-slope distribution.[6, 7] They used cameras in the bomb bay of a World War II surplus B-17G aircraft to photograph sun glitter on the Pacific Ocean near Hawaii. By relating the photographic density to the probability of a sun-glint wave slope, Cox and Munk derived a wave-slope probability density function (pdf). The photographs used to derive this model were actually recorded with the camera lenses removed, resulting in a blob of light with smoothly decaying brightness at the edges. This experiment was limited to measuring slopes smaller than about 28° because larger slopes, which occur with lower probability, contribute light that gets lost in the background.

By examining multiple images at different wind speeds, Cox and Munk showed that the pdf for ocean wave slopes can be described as a Gaussian distribution plus higher-order skewness and kurtosis terms. The actual pdf tends to have higher probability for very small and very large slopes than a Gaussian distribution. Furthermore, the along-wind distribution is skewed, showing a higher probability for downwind than for upwind slopes. This makes sense because the wind causes the small waves to lean downwind. The pdf variance (mean-square slope) increases approximately linearly with wind speed, indicating that the surface gets steadily rougher as the wind blows harder.

Forty-four years after Cox and Munk flew their B-17G over the Hawaiian Islands, my colleagues and I set out to examine the ocean wave-slope probability model in more detail.[8, 9] This time, however, we used laser-glitter patterns to avoid the explicit dependence on solar angle and sky conditions. In September 1995, we measured laser-glint patterns from the ship shown in Figure 2, about
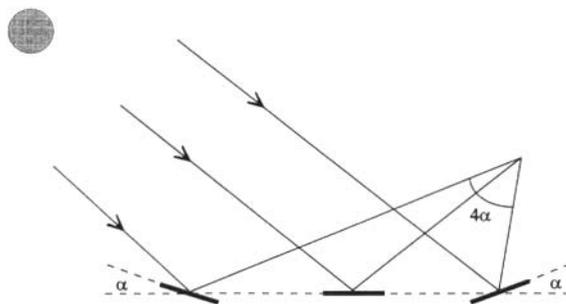
Figure 3. A light source much higher than the observer produces a glitter pattern of angular length 4α on a water surface with maximum wave slope α.

20 km off the Oregon coast. By counting the number of glints in angular bins as a narrow laser beam was scanned repeatedly over the ocean surface, we derived wave-slope probability density functions that agreed well with the Cox and Munk model under similar conditions. We found, however, that surface roughness depends on air-sea temperature differences (which were nearly zero in the Cox-Munk experiment).[8] At a given wind speed, water warmer than the adjacent air leads to a rougher surface than predicted by the Cox and Munk model, and water colder than air results in a smoother surface. Therefore, the wind cannot be determined uniquely from surface roughness alone.

We also used video cameras to record images of the surface illuminated by a wide cone of laser light. The image at the top of Figure 4 is a laser-glint pattern seen by a video camera looking straight down at a smooth ocean surface (1 m/s wind speed). Nine successive video frames have been averaged to provide a 0.3 s integration time, resulting in an image similar to what would be seen by a human observer. Large closed loops are formed by glints moving in pairs around waves of finite length and width as the surface undulates. Similar loops can be seen in the reflection of overhead street lights or the moon from water, or, as shown on the bottom of Figure 4, in the reflection of a camera flash from the water in a swimming pool.[1, 2] To see such loops, the surface must be smooth enough that the wave crests are large and slowly varying. When surface roughness increases, the loops become smaller and change rapidly. In fact, we found that the number of bright pixels in these glint images is a fractal process whose fractal dimension varies with surface roughness.[9]
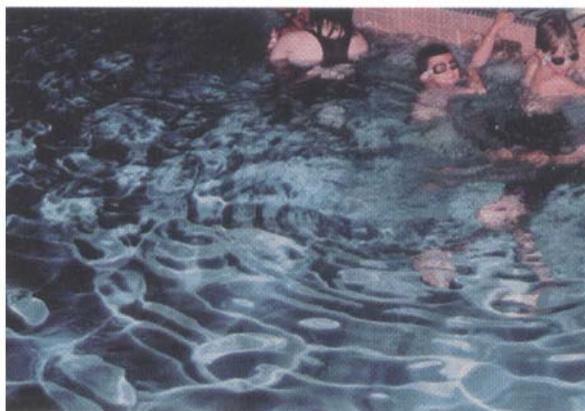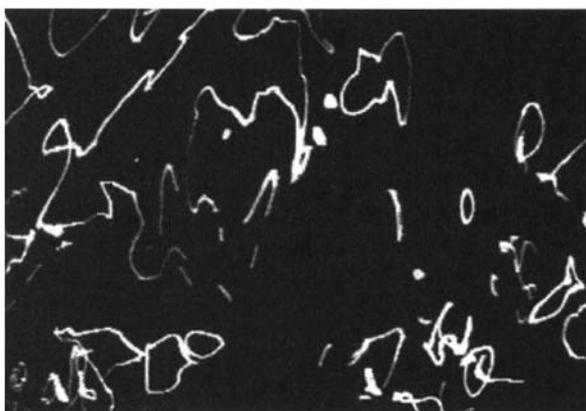
Figure 4. (Left) Light loops created by laser light reflecting from a mildly undulating ocean surface (nine video frames were averaged, providing a 0.3-s integration time to approximate what a person would see).
(Right) Light loops formed by light from a camera flash reflected from water in a swimming pool.

1-A—Ph.D. in Physics and Mathematics. Seeking R&D or project leader position. Expertise in nonlinear optics. Experience in laser applications, computer signal processing, and RF photonics. Twenty-year academic career—10 as an experimental laboratory team leader and 10 lecturing and supervising graduate students.

12-A—Ph.D. (1993). Seeking a postdoctoral or R&D position. Eleven years experience in nonlinear optics and holographic storage. Familiar with several kinds of laser and laser components. Broad background in testing equipment, such as OMA and spectrometers. Good computer programming skills that include C++ and FORTRAN, and excellent laboratory skills. Publications.

12-B—Ph.D. in Nonlinear Optics. Seeking a permanent R&D or academic position. Experimental experience in nonlinear optics, laser spectroscopy, diffraction optics, practical setup of gas lasers. Current experience in electro-optics and diffraction optics in liquid crystals. Hands-on experience at work in clean room, photolithography, etching, polymer coating, preparation of ultrathin LC cells, and displays. Five years teaching experience; 17 publications. Available after 3/15/99. Willing to relocate.

12-C—Ph.D. (1987) in Optical Engineering. 20 years experience in R&D light-scattering sensors and instruments, and 15+ years in mathematical modeling and software design (FORTRAN, C++) for optimization of optical sensors, signal processing, and measurement errors suppression. Over 30 publications in refereed journals. Extensive experience in numerical analysis of interaction of electromagnetic waves with dispersed systems (colloids, aerosols, biological cells, and powders) for remote sensing, radar design, and particle sizing (1 nm–5 mm) in the semiconductor industry, medicine, and fine particle technology.

Glittering Light

So, in addition to being beautiful and fun to watch (especially in motion), these light loops also convey quantitative information about the surface and its environment.

Where glitter paths lead

You do not have to be a remote sensing expert to appreciate glitter patterns. From sidewalk puddles to the ocean, beautiful light shows can be seen by anyone. Depending on the amount of patience you have, you can either casually notice these patterns or spend hours examining them in detail. Either way, there is much to be learned and much to be appreciated about nature by watching light glittering on water.

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We must start somewhere. Submissions of optics knowledge sites are currently being sought. Of course there are still many issues that need to be addressed, including the veracity and appropriateness of each addition. To test veracity there are essentially two methods: editors evaluating sites prior to addition or ratings by readers. To ascertain the appropriateness of each link, the number of "hits" over time could be a good gauge.

So submit away to the e-mail addresses listed below. Suggestions, thoughts, and any other information will also be appreciated. Initially, this project will be a grassroots effort, but in the not-too-distant future we plan to let this evolve into a funded effort so the database can be maintained and updated through the efforts of technical editors. The content editing, however, will be the purview of the readers.

After reading this article, please visit our initial efforts via a link at www.osa.org/Pub_svc/Opn. Click on the "Shedding More Light" icon for March.

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