

Aspects of the Point Spread Function in the Coastal Zone

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ABSTRACT

Measurements of the point spread function in the coastal zone will be presented. While measurements appear to be very similar to the deeper ocean measurements, other factors in the coastal zone that could influence the point spread function (PSF) were investigated. Laboratory experiments were performed to look at the effect of inhomogeneities, or layering, on the point spread function, and the layering was found to have a significant effect on the PSF.

Keywords: Point spread function, forward scattering, ocean optics

2. INTRODUCTION

The point spread function (PSF) is an important factor in predicting the system performance of in-water imaging systems. The PSF is defined as the radiance distribution at some range, R , resulting from a point, lambertian, source.¹ In homogeneous waters the PSF is equivalent through reciprocity² to the beam spread function (BSF), which is the irradiance distribution on a sphere of radius R , resulting from a source initially collimated at the origin.¹ In this paper we will concentrate on the PSF, but much of the same discussion could be related to the BSF.

The PSF at a given range is influenced mainly by the small angle scattering of particulates in the water, but also can be affected by the single scattering albedo (scattering/attenuation).³ Theory relating the volume scattering function to the PSF, using the small angle approximation, has been developed.⁴ For imaging purposes, the PSF for small angles, on the order of milliradians, is desired. But in this region it is difficult to measure the scattering function. Thus, if the PSF is desired for investigation of imaging systems, the PSF should be measured directly. Instrumentation to measure the PSF in the open ocean was originally developed by Honey.⁵ A modern version has been fielded to make these measurements in the open ocean and coastal areas.⁶

The open ocean PSF has been investigated,⁷ but with new interest in optical imaging in coastal waters, aspects of the PSF relating to coastal areas become important. Two main features of the coastal environment that affect the PSF are the large variations in particle type and quantity, and the large inhomogeneities in water properties, vertically and horizontally, that can exist. We have modified our ocean instrumentation to make measurements of the PSF in shallow waters, including the surf zone, to investigate the effects of the different particles on the PSF. To investigate the PSF for a inhomogeneous water column a laboratory facility was built which allows the water properties to be varied along the measurement path. Thus, the PSF for layered systems could be investigated in a controlled manner. Our preliminary results from these two measurement programs will be outlined in this paper.

2. INSTRUMENTATION

The basic system to measure the PSF has been described in detail elsewhere.⁶ Several modifications were required for measurement in the coastal zone. The basic system has a cosine source to simulate a lambertian source, and a cooled CCD camera, focused at infinity. The spectral region of the measurements, 500 nm, is selected by an interference filter on the front of the camera lens. In open ocean measurements the system is typically separated by ranges between 10 and 150m. In the shallow coastal region the attenuation properties of the water are typically much greater than in the open ocean. Thus, we make measurements of the PSF over ranges from 0.5 - 3 meters. Also, since we wanted to make measurements in very shallow water, an alternative mounting scheme was required. In our coastal measurements we mounted the flashlamp source and camera on an aluminum bar. The two devices were held horizontally so that profiles of the PSF at specific depths could be measured, or measurement of the PSF in very shallow water could be performed. In one case, we wanted to

make measurements of the PSF as a function of distance offshore, so floats were attached to each end of the aluminum bar to suspend the instrumentation at a constant depth of 1 m below the surface.

The cosine source has a 5 cm diameter. At the longer ranges used in the open ocean this could approximate a point source. With the shorter ranges used in the coastal zone and in the laboratory, a smaller source was needed, thus a pinhole aperture (1 mm diameter) was placed over the cosine source to approximate a point lambertian source. While this probably does not have as accurate a cosine emission profile over the angular range of our measurements, 0-12 degrees at most, the non-lambertian properties will not affect the results.

The laboratory measurements were performed in a specially built tank. This tank was approximately 4 meters long and constructed so that Plexiglas separators could be placed at 0.5 m intervals along the measurement path. This allowed the water scattering properties of segments of the measurement path to be varied in an independent and controlled fashion. The inside of the tank was painted with a black epoxy to reduce reflections and the surface of the water was covered with a black neoprene to reduce surface effects at the air-water interface.

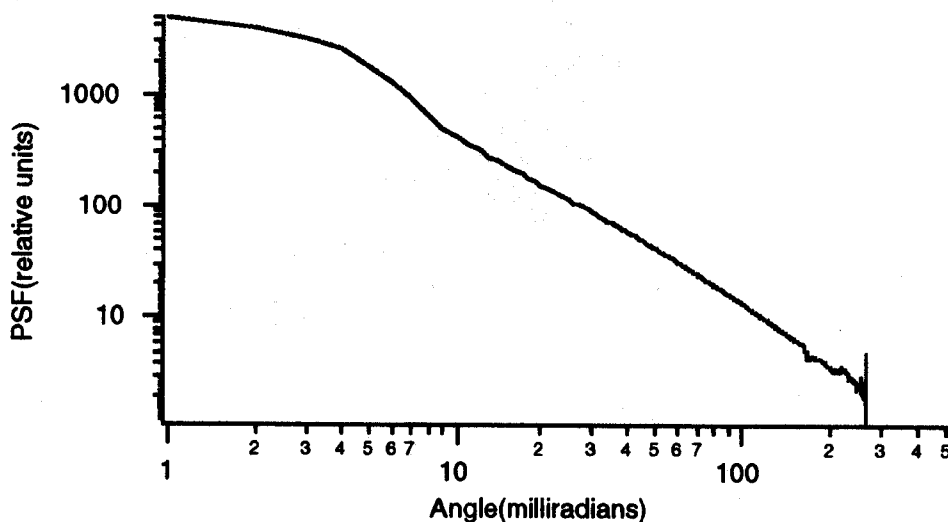


Figure 1) Example PSF measurement. This measurement was over a 1m pathlength. The total optical pathlength (τ) was 3.03. The measurement depth was 1 m, and the measurement was made off of Oceanside, Ca.

3. RESULTS

We have made measurements of the PSF in two littoral zones, off of Ft. Walton Beach, Fl. on two occasions and off of Oceanside, Ca. A typical PSF measurement is shown in Fig. 1. Two general features are worth noting in this measurement. First the region between 0 and 6 milliradians is the area in which the physical size of the source dominates the measurement. Next the region between 10 and 100 milliradians is typically fairly linear in this $\log(\text{PSF}) - \log(\text{angle})$ representation. We have used this to parameterize and represent the PSF in this angular range as:

$$\text{PSF}(\theta) = B \theta^{-m} \quad (1)$$

For a specific measurement series in the water column in the open ocean, we have found that the m varies with optical pathlength ($\tau = c * l$, where l is geometrical pathlength and c is the beam attenuation) in a regular manner.⁷ Our coastal measurements show the same general pattern. In fact if one plots the optical pathlength vs slope, m , for all of our measurements a general pattern emerges. Figure 2 shows the totality of our field PSF measurements, both coastal and open ocean. The open ocean measurements include measurements in the Sargasso Sea, clear water off Hawaii, Tongue of the Ocean (Bahamas), and off San Diego, Ca.

While the general trend is fairly constant, getting accurate predictions in coastal water is more difficult than oceanic measurements. In the open ocean, more accurate predictions can be made if the optical pathlength for a specific cast is plotted against the slope as a very regular pattern exists. For example, the small angle scattering theory of Wells⁷ can be used to predict the PSF for other ranges very accurately.⁸ In the littoral zone, groups of measurements for a single station or day show much more variation due to the local inhomogeneities of the water column, both horizontal and vertical. To get a more quantitative measure of the effect of layering on the PSF, laboratory measurements were made in the specially constructed tank described above.

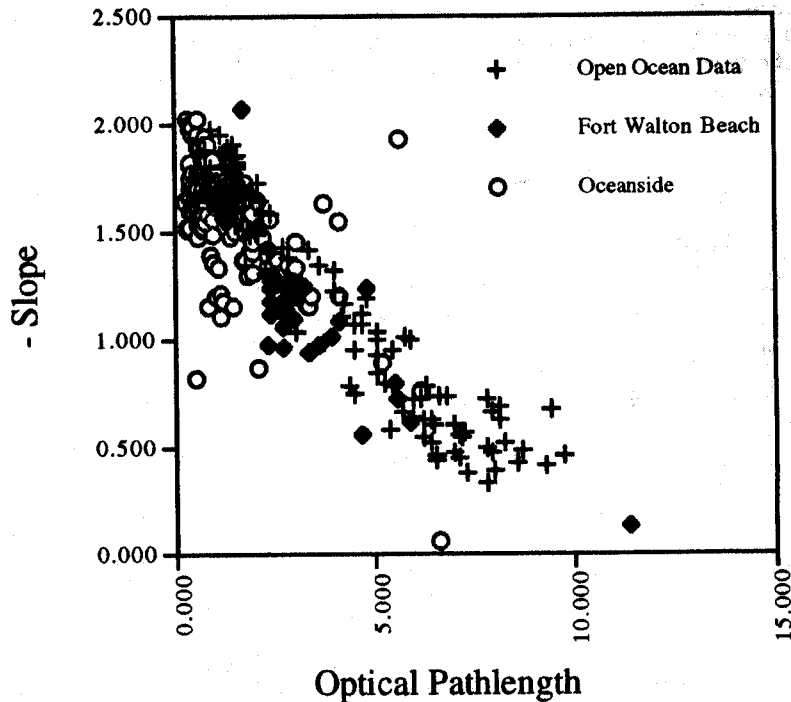


Figure 2) Slope of $\log(\text{PSF})-\log(\text{angle})$ vs optical pathlength for measurements in open ocean and two littoral sites.

These measurements are described in more detail elsewhere,⁹ but the general trend was that if inhomogeneities of the water path exist, the structure of the water path can have a significant effect on the overall PSF. Figure 3 shows the slope vs total optical path for three different water structures. As can be seen, the scattering layer has the greatest effect on the PSF if it is closer to the camera (imaging side) rather than the flashlamp. Also, it can be seen that the scattering layer positioned in the center is very close to the case of a homogeneous water path. This data shows that the structure of the water path is an important factor. We will be using this data to investigate models to predict the effect of the structured water path.

4. CONCLUSION

These measurements show that while the PSF for coastal waters generally fits the trend of the oceanic measurements, various effects specific to the littoral zone (vertical and horizontal variability) can be important. More work needs to be done to improve understanding of the water path structure effects. We will be making additional measurements in our tank system and modeling these results in the near future.

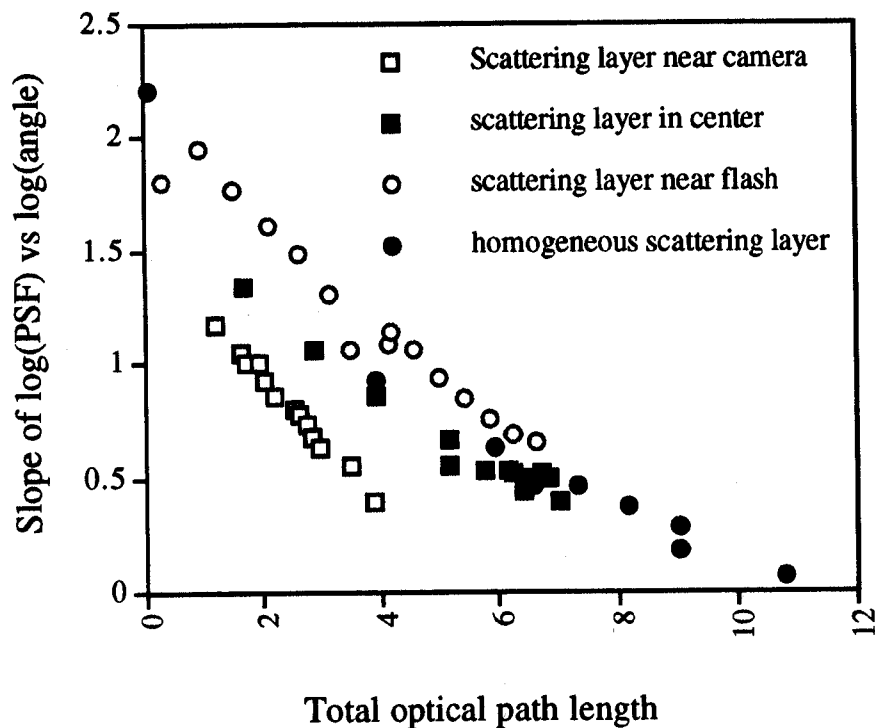


Figure 3) Illustrates the effect of an inhomogeneous measurement path on the PSF. In each case the scattering layer was confined to 1/3 the total pathlength in a region specified as near the camera, in the center or near the flash (source).

5. ACKNOWLEDGMENTS

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6. REFERENCES

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