The Prediction of Diver Visibility and its Relation to Spectral Beam Attenuation

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LONG-TERM GOALS

The goal of the proposed research is to determine the dependence of a simple diver visibility parameter (horizontal visibility of a black disk) on the spectral beam attenuation coefficient. In particular we will investigate whether the beam attenuation coefficient at a single wavelength can be used to predict visibility or whether accurate prediction requires spectral attenuation measurements.

OBJECTIVES

- Review the existing literature on diver visibility. Will a combination of Eq. 1 (see RESULTS section) and Blackwell's (1946) contrast tables reproduce Duntley's nomographs?
- Carry out experimental determinations of the sighting range of a black disk using Davies-Colley's method together with spectral absorption and attenuation measurements in a wide range of natural optical environments.
- Determine the proper wavelength or wavelength combination for the limiting beam attenuation for the horizontal black target (minimum c wavelength, photopic c, c(532), etc.)
- Verify results using observations from the GLOW experiments and other diver visibility experiments.
- Determine how many additional variables must be measured to predict the visibility of targets other than those used in this work.

APPROACH

We will begin by reviewing the existing literature on visibility measurements in the atmosphere and ocean. Much of the work was in the gray literature and is being lost. We propose to do a review of diver visibility and put the review on our web site. We have contacted Dr. Mueller of San Diego State

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14. ABSTRACT
The goal of the proposed research is to determine the dependence of a simple diver visibility parameter (horizontal visibility of a black disk) on the spectral beam attenuation coefficient. In particular we will investigate whether the beam attenuation coefficient at a single wavelength can be used to predict visibility or whether accurate prediction requires spectral attenuation measurements.

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University who will allow us access to his complete collection of the old Visibility Lab. publications. We will also talk with Mr. R. Austin of SDSU, who is a former director of the Visibility Lab.

By using an approach similar to that of Davies-Colley (1988), we will be able to obtain a large number of data points (horizontal visibility and spectral attenuation and absorption coefficients) in many different kinds of natural waters for a modest cost. In the proposed experimental work, the disappearance from human vision of a black Secchi disk in the horizontal direction is used to determine the horizontal sighting range

At the same time we will measure the beam attenuation and absorption coefficients at 9 wavelengths using an ac-9. In the Davies-Colley work the observer used an inverted periscope and the second person moved the target and measured the sight distance. Thus two people with simple tools and an ac-9 can obtain large numbers of data points in various natural waters. We will have a large dynamic range to examine the relationship between the spectral beam attenuation coefficient and visibility. By focusing on horizontal sighting range, data points can be obtained by using two small boats, alongside docks, wading in coastal waters, etc. We will examine the predictive capability of using beam attenuation coefficient measurements at a single wavelength (e.g. 532 nm) and compare that with the predictive capability of using the minimum beam attenuation coefficient.

We will examine the application of the existing nomograms of diver visibility to expand upon the applicability of our results to targets of different sizes. Digitizing Blackwell's tables in combination with Duntley's equation (Eq.1 in RESULTS section) should lead to a numerical equivalent of Duntley's nomographs. We also will examine the minimum data set required once additional complexities, such as, target shape and color are considered. Table 1 contains preliminary results of this analysis.

WORK COMPLETED

Funding for this contract was received on Sept. 23, 2002, so that work on this project has barely begun.

RESULTS

Visibility is a rather poorly defined concept that can mean many things. It ultimately predicts the ability of some observer (human or instrumental) to detect some object in a given environment. The resolution of the visibility problem can thus be very complex. In general it can be stated that if all the following are known:

- all the characteristics of the target (size, shape, spectral reflectivity, markings, etc.)
- the optics of the detector, including responsivity of the eye
- the inherent optical properties (spectral directional light scattering, absorption, and fluorescence characteristics) of the medium and the complete reflectance characteristics of the bottom
- the external lighting conditions of the medium

One can, by use of classical radiative transfer, combined with Fourier optics, predict with great accuracy what a given object will look like in a given detector system at a given distance. The number of parameters that enter in such calculations however, are very large; far too large to be of use in operational diver situations. While, in theory, solutions to such problems can be obtained, the large number of parameters involved, of which a number must be guessed, guarantee that the solution will not likely be close to reality. For divers the minimum contrast that each person can resolve changes so that no one solution can be found for all people. Such a complete solution is thus not appropriate for conflict situations, where quick deployment decisions must be made. What is needed is a simple but accurate approach to visibility of objects that would include mines and divers. Visibility of these objects in typical situations is not limited by the angle they subtend. For such objects in ambient lighting conditions it is appropriate to look at the contrast reduction as a means to describe visibility. That is the approach taken in this proposal. Once one bypasses Fourier optics (visibility of objects based on modulation transfer functions), however, one can no longer expect to be able to predict visibility of small features, such as letters, numbers, or other cm- scale details on objects. Only the detectibility of the objects themselves is analyzed.

Starting in World War II and continuing until the mid 1970's the U.S. Navy extensively funded research in visibility. This effort laid the groundwork for much of Ocean Optics as we know it today. The work of Preisendorfer, Duntley, Tyler, Petzold, and Lythgoe are legendary and are still frequently used today. Their visibility equations were derived directly from the equation of radiative transfer and are the basis of the proposed work.

A fundamental law of visibility as derived from the radiative transfer equation by Duntley (1963), Jerlov (1976), and Preisendorfer (1976), is that the difference of the target and background radiances attenuates as e^{-cr}. The beam attenuation c is the attenuation of the natural light present for visibility. The contrast reduction was then determined to be

$$\frac{C(\theta,\phi,r)}{C_0(\theta,\phi,0)} = e^{-[c-\overline{K}_B(\theta,\phi,r)\cos\theta]r} \qquad (1)$$

Where C is the contrast at a give distance r and the contrast is defined as

$$C_v = \frac{L_T(\theta,\phi,r) - L_B(\theta,\phi,r)}{L_B(\theta,\phi,r)}\,. \qquad (2)$$

L_T is the radiance from the target and L_B is the background radiance. Zenith angle and azimuth are given by θ and ϕ, respectively. $\overline{K}_B(\theta,\phi,r)$ is the average attenuation coefficient of the background radiance over the pathlength r. θ is the zenith angle of observation. Equations 1 and 2 are derived from the equation of radiative transfer in. Based on Eqs. 1 and 2 and Blackwell's (1948) contrast tables, Duntley and Preisendorfer (1976) produced a set of visibility nomographs. Note that in the horizontal direction $\cos\theta = 0$ and therefore the contrast reduction is due solely to the beam attenuation coefficient. For a black target $L_T = 0$ so the contrast is –1, *independent of the background light conditions*. Hence, for a black target (whose visibility is not limited by its angular subtent) in the horizontal direction, the contrast reduction is governed by e^{-cr}. This result is the simplest to which visibility can be reduced. Note that this is not an empirical result, but follows from the equation of radiative transfer and therefore, in its simplest form *visibility is an IOP*.

Duntley (1963) sums up decades of underwater visibility experiments by stating:

"Along an underwater path of sight a remarkable proportion of the objects ordinarily encountered can be seen at limiting ranges between 4 and 5 times the distance $1/[\, c - K(\theta,\phi,z) \cos\theta \,]$, regardless of their size or the background against which they appear, providing ample daylight prevails."

Similar results were found by Lythgoe (1971) and Davies-Colley (1988) who showed an excellent relationship between horizontal sighting range of a black 200 mm diameter disk and c (Figure 1), where c was measured with a white light source transmissometer equipped with a photopic (human eye sensitivity) response filter. The slope Ψ of the visibility range versus photopic c was found to be 4.8 with little curvature in the relationship. The small dependence of Ψ on c was also determined by Davies-Colley. When the two linear relationships were taken into account it was found that c could be determined from the visibility range to an accuracy of 8%. Inverting this relationship would thus seem to indicate that the visibility range in the horizontal direction can be predicted from c to an accuracy of better than 10 %. This would seem to be more than sufficient for operational situations.

The theoretical work of Preisendorfer and Duntley and the experimental work of Davies-Colley only partially address the issue of what wavelength or wavelengths of beam attenuation coefficient to use. Their work refers to photopic or broad band beam attenuation centered at 550 nm. We wish to determine what the limitations of using a measurement of beam attenuation at a specific wavelength are when predicting visibility. For example, what are the error bounds on using c(532) rather than photopic c when predicting visibility? Can simple spectral c models be used to determine photopic c from c at a single wavelength such as 532nm?

For a broad application of the proposed experimental work, it is advantageous to measure the beam attenuation coefficient in many narrow spectral ranges because those measurements can be used to predict the performance of other systems like laser-imaging systems and camera based systems that have different spectral responses than the human eye.

IMPACT/APPLICATIONS

Special Operations and Mine Warfare require the prediction of visibility for divers and cameras using ambient (natural) light. Theoretical models show that contrast reduction in the horizontal direction and hence the simplest description of diver visibility depends directly on the beam attenuation coefficient (see Appendix). This parameter can be modeled using combined physical, biogeochemical, and optical models, or it can be estimated from ocean color imagery. The beam attenuation coefficient of interest is the attenuation of the natural light spectrum convolved with the spectral responsivity of the human eye (photopic response function). In practice, it is more common to measure the beam attenuation coefficient at one or more narrow wavelength bands. The spectral beam attenuation coefficient so measured must then be combined with the natural light field and eye characteristics to determine visibility. The proposed work investigates the relationship between diver visibility and spectral beam attenuation to determine the minimum number of wavelength bands at which the attenuation coefficient should be measured in order to provide an accurate measure of diver visibility.

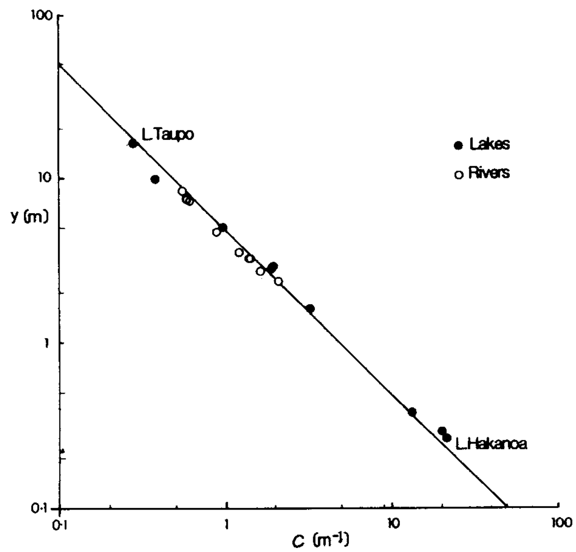

Figure 1. The visibility range (y) of a black target versus the photopic beam attenuation coefficient (c).
[graph: The visibility range (y) of a black target versus the photopic beam attenuation coefficient (c for 17 data points from lakes and rivers in New Zealand. The straight line indicates the relationship visibility range y = Ψ/c. The average value of Ψ is 4.8, with a small linear dependence on c. (From Davies-Colley, 1987)]

TRANSITIONS

None as yet

RELATED PROJECTS

None

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PUBLICATIONS

None as yet.

PATENTS

None