ATTENUATION OF LIGHT IN CLEAR DEEP OCEAN WATER

H. Bradner
Institute of Geophysics & Planetary Physics
Scripps Institution of Oceanography
University of California, San Diego

for the DUMAND Collaboration *

Introduction.

Clear water has a sharp optical transparency window in the blue-green. Figure 1 (from Smith and Baker[1]) shows their compilation of the most accurate data on the diffuse attenuation coefficient for clear ocean waters. The small spread of these data is not characteristic of the many measurements in the published literature, where there is a disagreement of nearly half an order of magnitude in the attenuation coefficient for blue-green light in very clear waters. Critical reviews of experimental data include publications by Jerlov[2], Morel[3], Smith and Tyler[4], Querry *et al*[5], and others.

The deep sea in the Eastern Mediterranean has been reported to be among the clearest natural waters of the world, comparable with double-distilled water, so we will limit our discussion to clear water, with about 0.01 mg/liter of scatterers which are characteristically about 1 micron diameter; inorganic and organic scatterers are usually present in comparable amounts.[2] Jerlov characterizes sea water as a dilute suspension of independent particles of various sizes, shapes and compositions. The particles and the pure water are capable of scattering and absorbing photons. Fluorescence is negligible in waters of low plankton content.

Beam Attenuation Measurements.

Measurements of attenuation of light in water usually have been made with a rigid instrument having a well-collimated light path about one meter long. Rays scattered more than about 0.01 radian are lost to the beam. This collimation is important for establishing the fundamental optical properties of the water and for characterizing its image-forming characteristics. It is analogous to "good geometry" cross-section measurements in elementary particle physics. In clear ocean water approximately 20% of the light flux is scattered out of the detected beam.

Light is attenuated by geometrical spreading, (eg. inverse square of distance), plus several wavelength-dependent processes:

Absorption by pure water and by impurities in the sea water.

Scattering by pure sea water (taken to be the same as pure water in the visible wavelengths) and by impurities in the water.

Light intensity at a distance R from the source can be expressed as

$I/I_o = 1/R^2 \exp(-kR)$ where the attenuation

coefficient k is given by the sum of the scattering and absorption coefficients:

$k = s + a.$

Thus the combined effects of these wavelength-dependent processes normally are considered to produce an exponential reduction in light flux. More detailed considerations by Learned[6] on the transmission of Cerenkov light in PILOS and DUMAND show that the spectral effects of Cerenkov source, water transmission, instrument housing and photomultiplier quantum efficiency can be combined to give a non-exponential expression for photon survival probability versus distance. In this report we will assume exponential attenuation, to conform with the usual publications on water clarity, but we note that an expression such as Learned's should be used in monte-carlo calculations of detector array performance.

Historically most observations have been made by direct measurements of well collimated light in spectrophotometers and scatterance meters, in situ or in the laboratory, with natural or with "pure" waters. (Jerlov[2] describes several representative instruments.) In clear deep ocean water like the NESTOR site, the attenuation length of blue-green light is about 45 meters so that a 1 meter baseline instrument will show a reduction of only about 1 - exp(-l/45) or 2.2% in light. For this reason measurements often are made with red light in a 1 meter path length, where intensity is reduced by 20% or more. The attenuation length for blue-green light is then calculated by invoking lab. measurements of pure water attenuation at different wavelengths. Unfortunately the measurements by careful observers give ratios for red/blue-green total absorption coefficients that disagree by a factor of 5.

In neutrino detectors such as DUMAND and NESTOR we are interested in photon flux. This is analogous to "poor geometry" physics measurements with wide angle sources, in which as many photons are scattered into the detector as out of the direct beam. The attenuation coefficient is just the absorption coefficient, so we could try to predict the attenuation length (ie. the reciprocal of the absorption coefficient) of light in DUMAND or NESTOR from measurements that have been made with well-collimated beams if we had an independent measurement of the scattering. Unfortunately scattering measurements are difficult and irreproducible in very clear water; investigators report troubles caused by bubbles from warming and pressure release, disintegration of living cells, marine snow aggregates, and wall effects in the containers even when teflon coated bottles are used. In the light of these difficulties it is common to assume that the scattering contributes about 20% to the total attenuation coefficient in clear ocean water.

A reasonable figure is obtained for attenuation length in NESTOR if we make this assumption. Measurements by Matlack[7] in the Eastern Mediterranean and by NESTOR Russian collaborators (Reported elsewhere in these Proceedings) are compatible with an attenuation length of 30 to 50 meters.

Other Methods.

Improved accuracy in light absorption of clear waters has been attempted by other measures of light attenuation including adiabatic laser calorimetry (Hass and Davisson[8]), split pulse laser (Querry *et al*[5]), and laser optoacoustic spectroscopy (Tarn and Patel[9]). These methods have not yet been used in determining the light attenuation length at the NESTOR site.

Long Light-Path Measurements.

The attenuation length appropriate to the "poor geometry" optics of DUMAND (Bradner and Blackinton[10]) and NESTOR (elsewhere in these Proceedings) has been determined by using an uncoilimated source and detector, with light path adjustable to more than an attenuation length. Measurements made at two or more source-detector separations eliminate the need for knowing the intensity of the source or the sensitivity of the detector. Scattering of light does not need to be considered. The attenuation length determined by this instrument and conventional instruments are in good agreement.

References

1. Raymond C. Smith and Karen S. Baker, Appl. Opt. 20, 177 (1981).
2. N. G. Jerlov, *Marine Optics* (Elsevier, New York, 1976) .
3. A. Morel, in *Optical Aspects of Oceanography,* N. G. Jerlov and E. Steeman Nielson, Eds. (Academic, New York, 1974).
4. R. C. Smith and J. E. Tyler, in Photochemical *and Photobiological Reviews, Vol. 1,* K. C. Smith, Ed. (Plenum, New York, 1976).
5. M. R. Querry, P. G. Gary, R. C. Waring, Appl. Opt. 17, 3587 (1978).
6. John Learned, Hawaii DUMAND Center Memo HDC 81-10, (1981).
7. D. E. Matlack, Naval Ordnance Laboratory Report NOLTR72-284. (Cited by J. Ronald V. Zaneveld in Proceedings of the 1980 International DUMAND Symposium, July 24-August 2, 1980).
8. M. Hass and J. W. Davisson, J. Opt. Soc. Am. 67, 622 (1977).
9. A. C. Tarn and C. K. N. Patel, Appl. Opt. 18, 3348 (1979).
10. Hugh Bradner and Grant Blackinton, Appl. Opt. 23, 1009 (1984).

* DUMAND Collaboration

C.M. Alexander[3], W. Anderson[16], T. Aoki[10], Jf.G. Berns[14], U. Berson[13], P. Bosetti[13], J. Bolesta[3], P.E. Boynton[14], H. Bradner[8], U. Braun[13], U. Gamerini[15], R. Clark[17], S.T. Dye[2], M. Fukawa[11], J. George[14], E. Gergin[2], P.W. Gorham[3], P.K.F. Grieder[1], W. Grogan[15], H. Hanada[9], D. Harris[3], J. Hauptman[16], T. Hayashino[9], E. Hazen[2], M. Jaworski[15], M. Jenko[2], H. Kawamoto[9], T. Kitamura[6], K. Kobayakawa[5], S, Kondo[3], P. Koske[4], J.G. Learned[3], C Ley[13], J.J. Lord[14], T. Lozic[2], R. March[15], T. Matsumoto[9], S. Matsuno[3], A. Mavretic[2], L. McCourry[14], M. Mignard[3], K. Miller[12], P. Minkowski[1], R. Mitiguy[3], K. Mitsui[10], s. Narita[9], T. Narita[15], D. Nicklaus[15], K. O'Brien[16], Y. Ohashi[10], A. Okada[10], D. Orlov[2], V.Z. Peterson[3], A. Roberts[3], M. Sakuda[11], V.J. Stenger[3], R. Svoboda[17], T. Takayama[9], S. Tanaka[9], S. Uehara[11], M. Webster[12], C.H. Wiebusch[13], R.J. Wilkes[14], G. Wilkins[3], G. Wurm[13], A. Yamaguchi[9], I, Yamamoto[7], K.K. Young[14].

1) University of Bern, Switzerland; 2) Boston University, USA; 3) University of Hawaii, USA; 4) University of Kiel, Germany; 5) Kobe University, Japan; 6) Kinki University, Japan; 7) Okayama Science University, Japan; 8) Scripps Institution of Oceanography, USA; 9) Tohoku University, Japan; 10) ICRR, University of Tokyo, Japan; 11) KEK, Tsukuba, Japan; 12) Vanderbilt University, USA; 13) Vijlen Institute for Physics, Netherlands; 14) University of Washington, USA; 15) University of Wisconsin, USA; 16) Iowa State University, USA; 17) Louisiana State University, USA.

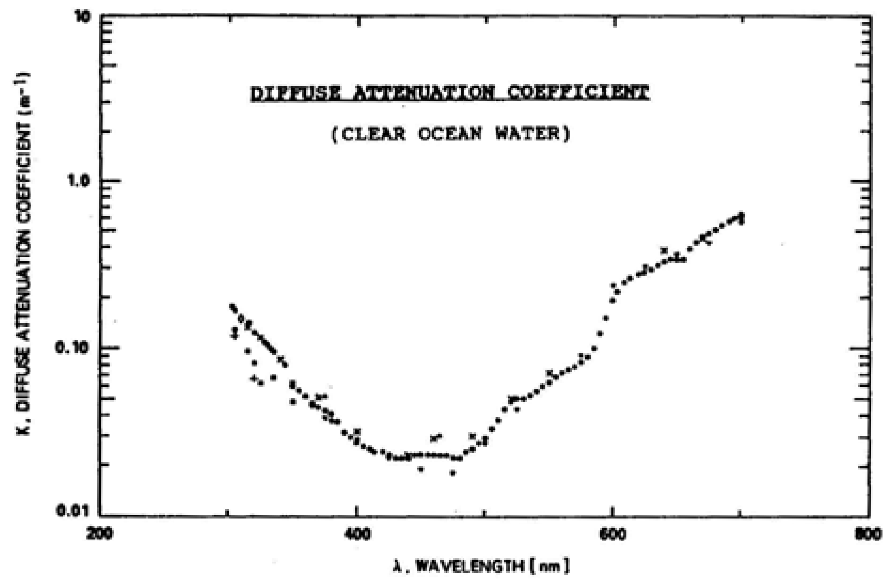

Fig. 1. Diffuse attenuation coefficient for irradiance [$K_w(\lambda)(m^{-1})$] vs wavelength [λ(nm)] as determined by various authors for clear ocean waters: ●, (350–700 nm), present work plus Smith and Baker[34]; ●, (300–350 nm) Smith and Baker[16]; ■, +, and ×, present work; ◊, Jerlov[27] and Hojerslev[28]; □, Calkins[29]; ▼, Jerlov water type I.[7]