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Irradiance and Beam Transmittance Measurements off the West Coast of the Americas

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Measurements of total irradiance versus depth and beam transmission versus depth were made at stations near shore along the west coast of the North and South American continents. The water types at each station were optically classified according to the system of Jerlov (1976), thus providing additional information for the description of the distribution of the world's ocean water types. In addition, the parameter k/c, where k is the irradiance attenuation coefficient and c is the beam attenuation coefficient, has been shown to be a useful parameter for determining the relative particle concentrations of ocean water.

INTRODUCTION

Optical classification of ocean water is an important means of distinguishing water types. *Jerlov* [1951] presented a method of classification according to spectral transmittance of downward irradiance at high solar altitude. Downward irradiance is defined as the radiant flux on an infinitesimal element of the upper face (0°–180°) of a horizontal surface containing the point being considered, divided by the area of that element [*Jerlov*, 1976]. *Jerlov*'s [1951] classification defined three different oceanic water types and five coastal water types, but further experimentation [*Jerlov*, 1964; *Aas*, 1967, 1969; *Matsuike*, 1967, 1973; *Matsuike and Sasaki*, 1968; *Højerslev*, 1973, 1974*a*, *b*; *Matsuike and Kishino*, 1973; *Shimura and Ichimura*, 1973; *Morel and Caloumenos*, 1974; *Rutkovskaya and Khalemskiy*, 1974] has shown that the world's ocean waters may better be classified by 10 different curves of irradiance transmittance versus depth (Figure 1 shows the approximate curves of irradiance versus depth for each of the water types from *Jerlov* [1976]). Unfortunately, measurements of irradiance penetration are lacking in many areas of the world.

In this experiment, irradiance penetration measurements were made in conjunction with measurements of the water transmissivity. These measurements yield a parameter which, when used with the irradiance attenuation coefficient, can define water types even more clearly than the irradiance attenuation coefficient alone. The more parameters used to identify water types, the more accurately the water type can be described. It is shown in this paper that the method of water type identification by irradiance penetration measurements alone may yield untrue conclusions about the similarities in particle content or yellow matter content of the two water masses. That is, two water masses may have nearly identical values of an irradiance attenuation coefficient (thereby classifying them as the same water type, optically, according to *Jerlov* [1976]) but may in fact have very different profiles of light transmission versus depth. An explanation for this discrepancy is presented.

EXPERIMENTAL PROCEDURE AND RESULTS

Measurements with the irradiance meter and transmissivity meter were taken once a day at 1200 hours local time approximately 250 miles apart from Newport, Oregon, to Chimbote, Peru (Figure 2). Observations were made to depths of approximately 75 m. At two stations (8 and 9), equipment malfunctions prevented measurements from being taken.

The irradiance meter used had a flat opal glass diffuser as a cosine collector and contained a signal log amplifier to provide an output signal between ±4 V dc. The spectral response of the irradiance meter is shown in Figure 3. The transmissivity meter consisted essentially of a light-emitting diode (wavelength = 650 nm), collimating lenses, and a photodiode. The optical path length of the meter was 0.25 m.

The irradiance meter indicated values of the logarithm of the irradiance versus depth. From this information the value of the irradiance attenuation coefficient k could be calculated as follows [*Jerlov*, 1976]:

$$k = \frac{d(\log E)}{dz} \simeq \frac{\Delta(\log E)}{\Delta z}$$

where E is the measured irradiance and z is the depth below the ocean surface. Variations in solar elevation due to changes in latitude were considered in the calculation of k.

The transmissivity meter indicated the ratio of the radiant flux transmitted through 0.25 m of seawater to the incident radiant flux. The total attenuation coefficient c can be obtained from the measured transmissivity as follows [*Jerlov*, 1976]:

$$T = e^{-cr}$$

where T is the percent transmission, c is the total attenuation coefficient, and r is the geometrical path length of the meter. In this experiment, r = 0.25 m; therefore

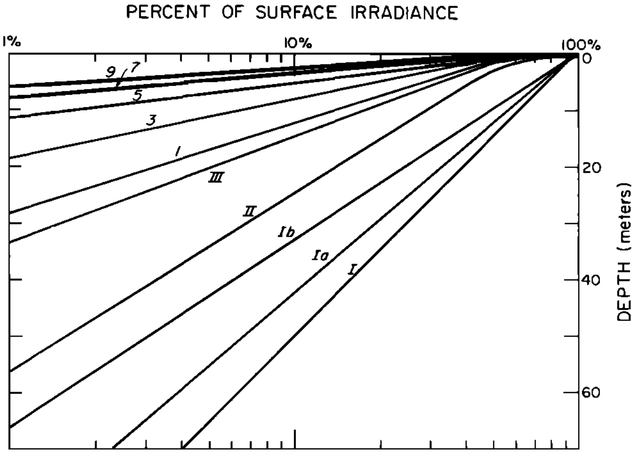

Fig. 1. Irradiance transmittance versus depth for 10 water types.

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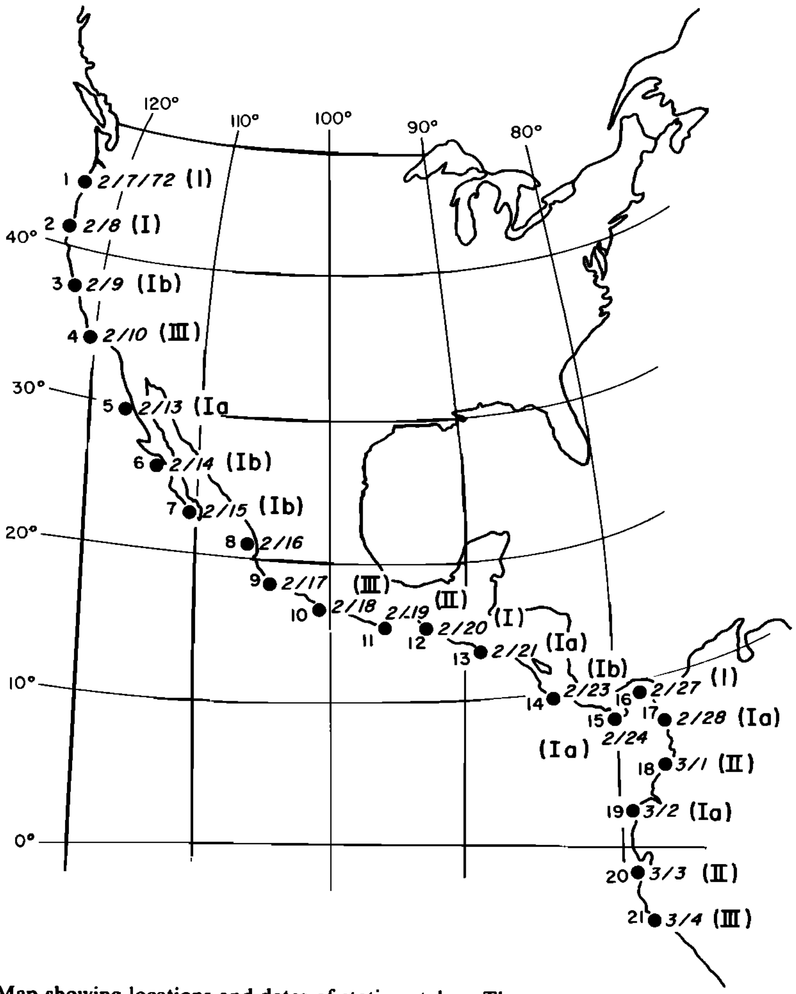

Fig. 2. Map showing locations and dates of stations taken. The water types are shown in parentheses.

$$T = {}^{-0.25c}$$

or

$$c = -4 \ln T$$

The high degree of accuracy obtained from the c meter is attributed to the precise collimation of the main beam and the small solid angle of detection [see *Bartz et al.*, 1978].

In Table 1 the measured values of k, T, and c and the quantity k/c are shown for each of the stations. Variations in transmissivity with depth indicated that for a given decrease in transmission (corresponding to an increase in c) the irradiance attenuation coefficient k increased proportionally. Therefore, neglecting slight variations (less than 5%), the values of k/c were quite constant with depth below the 3 or 4 m of surface

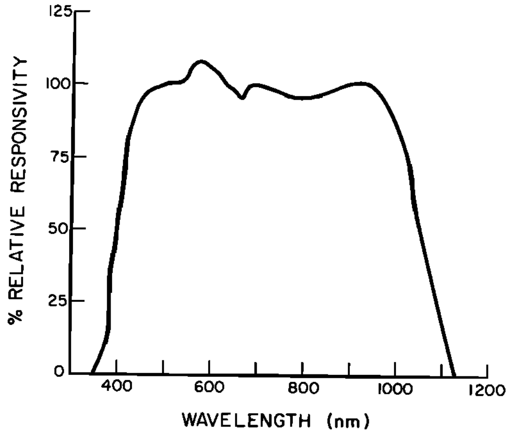

Fig. 3. Spectral response of the irradiance meter.

TABLE 1. Irradiance and Transmissivity Results From All Stations

Station	k, m^{-1}	Percent Transmission	c, m^{-1}	k/c
1	0.063	81.0	0.843	7.5×10^{-2}
2	0.021	82.0	0.794	2.64×10^{-2}
3	0.031	88.5	0.489	6.37×10^{-2}
4	0.055	85.5	0.627	8.78×10^{-2}
5	0.022	82.9	0.750	2.98×10^{-2}
6	0.029	85.5	0.628	4.66×10^{-2}
7	0.032	83.0	0.745	4.34×10^{-2}
10	0.053	82.5	0.770	6.89×10^{-2}
11	0.039	82.5	0.770	5.07×10^{-2}
12	0.013	84.0	0.697	1.92×10^{-2}
13	0.024	82.0	0.794	3.02×10^{-2}
14	0.029	57.3	2.23	1.32×10^{-2}
15	0.023	21.0	6.24	0.37×10^{-2}
16	0.068	50.8	2.713	2.52×10^{-2}
17	0.023	62.0	1.91	1.21×10^{-2}
18	0.034	83.5	0.721	4.73×10^{-2}
19	0.027	51.8	2.63	1.02×10^{-2}
20	0.043	77.3	1.03	4.19×10^{-2}
21	0.052	71.3	1.35	3.83×10^{-2}

TABLE 2. Classification of Water Types by Irradiance Attenuation Coefficient *k*

Water Type [*Jerlov*, 1976]	k, m^{-1}	Stations of This Water Type
I	0.016	2, 12
I*a*	0.025	5, 13, 15, 17, 19
I*b*	0.030	3, 6, 7, 14
II	0.035	11, 20, 18
III	0.055	4, 10, 21
1	0.068	1, 16
3	0.095	
5	0.154	
7	0.223	
9	0.282	

water. Table 2 shows the values of *k* used to define water types optically [*Jerlov*, 1976]. This table also shows the classification of the water types from this experiment as identified solely by the irradiance attenuation coefficient *k*.

In Figure 4 the values of *k* for each station have been plotted against the values of *c* for the same station. Constant values of *k*/*c* are shown in the figure, and the values of *k* for various water types are shown along the abscissa.

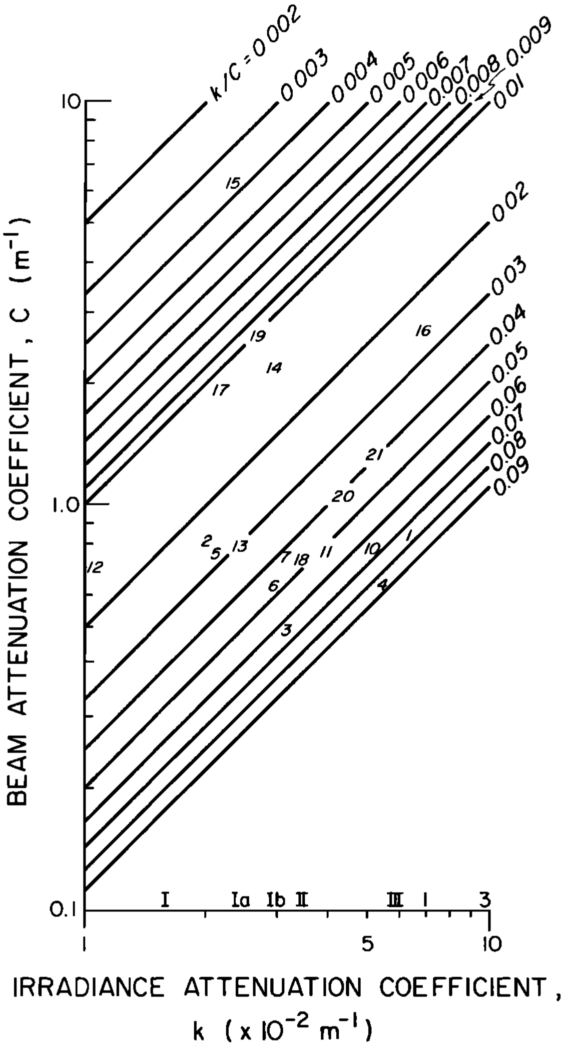

Fig. 4. Irradiance attenuation coefficient and beam attenuation coefficient measured at each station. Numbers correspond to station numbers.

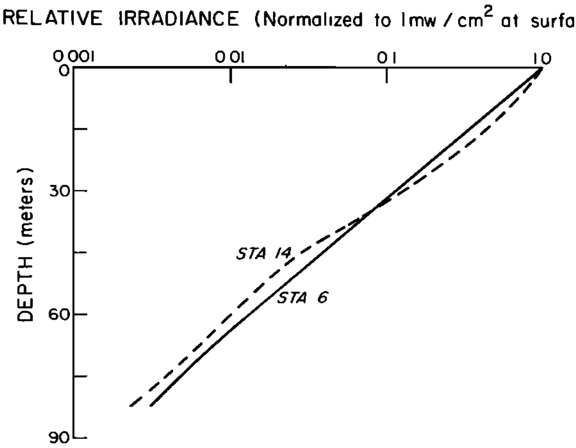

Fig. 5. Irradiance profiles with depth at stations 6 and 14.

OBSERVATIONS AND CONCLUSIONS

As Table 1 shows, a given water column may have a similar or identical value of *k* as another water column, but the value of *c* may be quite different. This is also seen in Figures 5 and 6, which show typical profiles of irradiance and transmissivity at stations 6 and 14. An important factor to consider is that *c*, in this experiment, was measured at a single wavelength of light (650 nm), whereas *k* was measured for the range of wavelengths from approximately 400 nm to 1000 nm. The fact that the value of *c* at 650 nm may be different for two water columns having identical values of *k* is an indication that the types of material in the two samples may differ significantly. The existence of yellow matter in the seawater could not be detected by the transmissivity meter alone, since the absorption of light by yellow matter is negligible for light of wavelength 650 nm [*Jerlov*, 1976]. However, particulate light attenuation at that wavelength is quite significant [*Burt*, 1958]. At the shorter wavelengths of light, both particulate matter and yellow substance contribute significantly to light attenuation.

The parameter *k*/*c* is a useful indication of relative amounts of particulate matter and yellow substance in seawater. The higher the value of *k*/*c* is, the more yellow matter or the less particulate content there is in the sample. The value of *k* for wavelengths of 400–1000 nm may be the same for a particle-laden sample as for a sample of water containing much yellow matter. The two samples would be quite different in nature and so should be classified as such. The use of a transmissivity

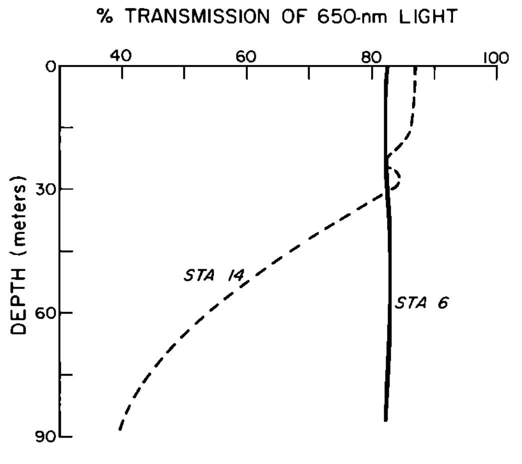

Fig. 6. Transmissivity profiles with depth at stations 6 and 14.

meter in conjunction with an irradiance meter allows such a classification. For example, stations 1, 3, 4, and 10 all have high values of k/c. The hypothesis that this represents large amounts of yellow matter may be justified by the fact that each of these stations is near a large river or city (possible sources of yellow matter). Station 1 is near the mouth of the Columbia River; station 3 is near the mouths of the Sacramento and American rivers at San Francisco; station 4 is offshore of Los Angeles; and station 10 is near the mouth of the Rio Balsas, one of the largest rivers on the west coast of Mexico. Conversely, the stations with the lowest values of k/c are in the region of the Gulf of Panama, an area which contains very few rivers and which may act as a depository for particulate matter being transported by the Equatorial Countercurrent.

The results of this experiment, as shown in Figure 4, indicate the use of the parameters k and c as water type identifiers. Unfortunately, these were the only oceanographic measurements taken at these stations, so correlations between the values of k/c and other hydrographic, chemical, or biological measurements are unobtainable. It would appear, however, that the values of k and k/c together provide useful parameters for water type identification. The measurement of k alone gives an indication of solar energy penetration into the sea: a measurement useful for mixed layer studies and biological analysis. The measurement of k/c indicates the type of material suspended or dissolved in the water.

The implications of this experiment are twofold. First, *Jerlov*'s [1976] chart of water types has been expended to include measurements off the west coast of North, Central, and South America. Second, the use of the parameter k/c together with the parameter k has been shown to be of value in the identification of ocean water types according to material suspended or dissolved within the water.

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