2. Recommended Procedure for the Measurement of Solar Radiation in the Sea

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The rate of reduction of light with depth in the sea (commonly referred to as transparency) is indicated by the value of the attenuation coefficient k defined below.

$$k = \frac{\log_e H\lambda z_1 - \log_e H\lambda z_2}{z_2 - z_1},$$

where H refers to irradiance, λ the spectral band width of the sensor and z_1 and z_2 the shallower and deeper depths, respectively. Or

$$\frac{H}{H_o} = e^{-k\Delta z}$$

where H_o = irradiance at the shallower water depth, H = irradiance at the deeper depth, and Δz = the vertical distance between the depths in meters. This value may be calculated between any two depths one of which may be located at the sea-atmosphere interface.

A gimbals-mounted deck photometer, which monitors ambient irradiance is used to correct the output of the submerged detector for any changes in incident radiation during each series of measurements.

Since irradiance, H, is defined as

$$H = \int_o^{\pi/2} N \cos\theta \, d\omega$$

where N is radiance, θ the angle of incidence, and ω the solid angle measure, both underwater and deck photometers should be provided with a diffusing disc which will collect according to the cosine law, but which will not reduce the sensitivity of the photometer unduly.

For most situations (high sun or overcast conditions) a flush mounted plastic disk somewhat larger than the detector (fabricated from plexiglass Rohm and Haas No. 7420, 1/16 inch thick abraded with 1F emory), is probably a sufficiently accurate cosine collector for general biological use when incident and downwelling irradiance are being measured (see Tyler, John E. 1960. An instrument for the measurement of the volume absorption coefficient of horizontally stratified water. Visibility Laboratory, University of California. Report 5-4, Contract NObs 72039. U.S. Navy, Bureau of Ships. Project NS 714-100. 35p.). For more accurate measurements, the cosine collectors should [illegible] carefully constructed and tested (see Boyd, R. A. 1951. A photocell that obeys the cosine law of illumination and the integrating sphere. Appendix C to The development of prismatic glass block and the daylight laboratory. Res. Bull. No. 32. Engineering Research Institute. Univ. Mich., 64-70. Foster, Norman B. 1951. A recording daylight illuminometer. Illum. Eng. XLVI (2): 59-62.).

Irradiance has been specified as the quantity to be measured since it is a useful quantity in air as well as water (Preisendorfer, R. W. 1961. Application of radiative transfer theory to light measurements in the sea. Symposium on radiant energy in the sea. Int. Union of Geodesy and Geophysics, Monograph No. 10: 11-30). In studies where orientation, migrations, behavior, etc. of organisms are being investigated, irradiance may not necessarily be the appropriate quantity for measurement. Investigators working on special problems such as these may require radically different types of collectors and thus will not necessarily be interested in measuring irradiance.

The irradiance meter (underwater and deck units). Weston Type 1 856 RR or RB Photronic cell (or equivalent) is suitable for use as the detector in the photometer measuring incident as well as submarine irradiance. This cell possesses the advantage that it requires no power for its operation other than the ambient flux being measured. On the other hand, the current generated by the cell must be measured with a low impedance device (i.e. less than 100 ohms when the output is in excess of 200 μa), since the response of the cell to light becomes non-linear at high levels when the impedance of the measuring device is in excess of 100 ohms. To maintain linearity of response the light reaching the detector must be kept low by the use of neutral filters or screens, or else the circuitry must be designed to prevent the output from saturating at high light levels. In any event, it is advisable before use at sea to determine the curve of response for the equipment (including cable) on an optical bench or by exposing each photometer with its diffusing disk in place to daylight (high sun and clear sky). In sunlight, a succession of calibrated neutral filters or screens selected to cover the necessary density range may then be used to determine the curve of response of both photometers.

Absolute standardization is also desirable. Any available, suitable, artificial standard source may be used in the laboratory, or comparison may be made in daylight with a suitable instrument at a U. S. Weather Station. Due allowance must be made for differences in the spectral sensitivities of the instruments being compared and the spectral emission of the source being used.

The signal generated by the deck photometer may be monitored with a recording galvanometer of low internal resistance or read directly on a microammeter at frequent intervals. If the deck photometer is also being used to estimate quantitatively "total" incident solar radiation, it may be calibrated approximately in energy units (gram calories/cm^2 x min. or microwatts/cm^2) for the spectral region within which it is sensitive.

Measurement Procedure

During an irradiance measurement below the sea surface, the output of the deck and submerged photometer may be read at each depth alternately on one microammeter , or simultaneously on two meters by two observers. Another method has been devised which employs a null-circuit in which the percentage of subsurface flux is read directly on the dial of a precision potentiometer. This method has the advantage that changes in ambient flux are compensated for automatically and the disadvantage of using somewhat complicated circuitry and in being somewhat more expensive to construct. A commercial instrument incorporating this null-indicating system has recently been developed by Marine Advisors, Inc. (La Jolla, California).

Regardless of the type of equipment employed, reducing screens or electronic means are required to keep the response of the instrument nearly linear under all measurement conditions. The response of the irradiance measuring instrumentation should be examined and checked periodically in the manner suggested above.

Accuracy

While in physical studies an accuracy of at least ± 5% is desirable, many biological applications can probably tolerate measurements of lower precision. Temperature, flux level, and external circuit resistance effect the output of Photronic cells in a complicated manner. If measurements of high accuracy (e.g. ± 5%) are required under widely varying temperature and flux level regimes and the external resistance of the measuring circuit exceed roughly 300 ohms, it becomes necessary to correct the data for variations in temperature and flux level. Adequate information is generally supplied by the manufacturer of such detectors to permit the investigator to evaluate the significance of such corrections and to correct for such effects.

Spectral Sensitivity

Due to the differing transmission characteristics of sea water in different parts of the ocean, it is difficult to make general recommendations for filters to be used for spectral isolation. An irradiance meter with a peak spectral sensitivity at roughly 480 mμ and a half band width of 30-40 mμ or less is suggested as a reasonable match to the transmission characteristics of offshore (blue) water (Weston Photronic cell and a Wratten 45 filter, for example). A peak spectral sensitivity at roughly 525 mμ and a similar half band width (Weston Photronic cell and Wratten 61 filter, for example) is likewise appropriate when measurements are made in coastal (green) water.

It is recommended that an irradiance meter with a peak sensitivity of roughly 480 mμ and a half band width of 30-40 mμ or less be adopted as standard for ocean work. Whenever a series of measurements can be repeated with additional filters, a correspondingly greater amount of useful information on the selective absorption of sea water is obtained. Measurements made without any filters for spectral isolation are difficult to interpret if the transmission characteristics of the water are not known, but can be of limited use if an estimate of these transmission characteristics is available.

Certain filters undergo changes in spectral transmission characteristics when exposed to light. Such changes make it mandatory for investigators to evaluate the spectral stability of filters used for irradiance measurements.

Depth Determination

It is further recommended that for each measurement the wire angle be reported in addition to the length of wire out (in meters). In situations where wire angles exceed 10 to 20 degrees and wire paid out exceeds 25 to 30 meters, the depth of the instrument is not always accurately estimated by the use of trigonometric functions, and depth sensing equipment should be used. A variety of depth sensors are available (strain gauges, pressure potentiometers, etc.) and may be incorporated into the instrument design. The accuracy of depth measurement equipment should be of the order of ± 3%.