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PRELIMINARY RESULTS OF OPTICAL STUDIES MADE IN THE SOUTHERN OCEAN

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Abstract. During the austral summer of 1997/98 measurements of downwelling irradiance, upwelling irradiance, beam absorption coefficients, and beam attenuation coefficients were made in the Southern Ocean aboard the research vessel *S. A. Agulhas*. The measurements were carried out in three areas: in the marginal ice zone (65°–59° S, 6° E), in the Antarctic polar front (55°–49° S, 6° E), and in the area between them, in the interfrontal region (57°–55° S, 6° E). The diffuse attenuation coefficients calculated from the downwelling irradiance profiles were on average 0.3 m^{-1} nm^{-1} in the 400 to 700 nm range. Beam absorption was dominated by water molecules and it was practically the same in all areas. Scattering, which was calculated using the beam attenuation, was nearly wavelength independent in the 400–700 nm range being between 0.3 and 0.6 m^{-1} in the marginal ice zone, 0.1 m^{-1} in the interfrontal region, and between 0.2 and 0.3 m^{-1} in the Antarctic polar front. There was a good correlation between the diffuse attenuation coefficients calculated from the beam absorption and scattering coefficients and the diffuse attenuation coefficients calculated from the irradiance profiles. The waters in the marginal ice zone and interfrontal region were classified as belonging to Jerlov water type II and the Antarctic polar front water was classified as belonging to Jerlov water type III.

Key words: irradiance, diffuse attenuation coefficient, beam absorption coefficient, scattering coefficient, optical classification.

INTRODUCTION

Seas around the Antarctic are very rich in nutrients because of the upwelling of nutrient-rich Atlantic Deep water (Pickard & Emery, 1990). This causes a vigorous phytoplankton growth that then leads to a large population of zooplankton. Sources of terrestrial material are far away and therefore the pigments of phytoplankton and its decay products, together with the sea water itself, are the main optically active substances. Such optically two-component waters, where the components are the biological substances and the sea water, are called Case 1 waters according to Morel (1994).

The inherent optical properties of the water, the beam absorption and scattering coefficients, and the volume scattering function combine with the radiant light field to produce the apparent optical properties, one of which is the diffuse attenuation coefficient (Preisendorfer, 1961). Links between the inherent and apparent optical properties have been sought after using for example Monte-Carlo simulations (Kirk, 1994).

The present study was made as part of FINNARP 97 in co-operation with SWEDARP 97/98, on board cruise number 86 of the South African research vessel *S. A. Agulhas*, which belongs to the Sea Fisheries Research Institution of South Africa. Measurements of downwelling irradiance, upwelling irradiance, the beam absorption coefficients, and the beam attenuation coefficients were made in January 1998 in the Southern Ocean along 6° E. The correlation between the apparent and inherent optical properties was studied and an attempt at classification into Jerlov water types was made using the results gained by Jerlov (1978).

MATERIALS AND METHODS

Measurements were made in the Southern Ocean along the 6° E meridian between 60° S and 49° S in three main areas (see Fig. 1). These areas were the marginal ice zone (65°–59° S, 6° E), the Antarctic polar front (55°–49° S, 6° E), and the region between them, the interfrontal region (57°–55° S, 6° E). Measurements of downwelling and upwelling spectral irradiance were made with an LI-1800 UW spectroradiometer, between 300 and 850 nm with a 2 nm resolution. This instrument was deployed from the aft end of the ship, and irradiance was measured at depths of 1, 3, 5, 7, 10, 12, 15, and 20 m. LI-1800 UW measurements were affected by changes in the incoming irradiance. An LI-200 SA pyranometer was used to monitor the level of incoming total irradiance and these data were stored as one-minute averages. These average values were then used to correct the LI-1800 UW measurements.

Beam absorption and beam attenuation of light were measured directly at nine wavelengths (412, 440, 488, 510, 532, 555, 650, 676, and 715 nm) using an AC-9 absorption and attenuation meter. This instrument was deployed from the starboard side of the ship up to a maximum depth of 20 m. It measured continuously but the water in the first 20 m was homogeneous and so the values were averaged for the whole layer. Both instruments drifted a great deal in the oceanic environment even though they had 25 kg weights hanging from them. LI-1800 UW measurements are sensitive to tilt so this drift may have caused slight errors in the measurements. The AC-9 was not affected by the drift.

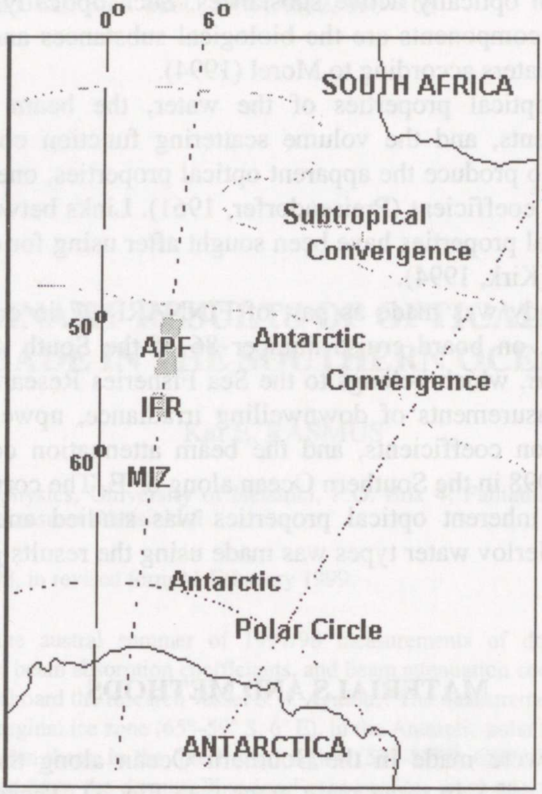

Fig. 1. Map showing approximate locations of the three main study areas and the main frontal systems. APF, Antarctic polar front; IFR, interfrontal region; MIZ, marginal ice zone.

The diffuse attenuation coefficients were calculated from the spectral irradiance profiles using an exponential law for the attenuation of irradiance. This leads to the following expression for the diffuse attenuation coefficient K_d:

$$K_d(\lambda) = -\frac{1}{z}\ln\left(\frac{E_d(z,\lambda)}{E_d(-0,\lambda)}\right) \qquad (1)$$

where E_d is downwelling irradiance, z is depth, and λ is wavelength. Although –0 denotes zero depth it refers to just underneath the surface of the water. The diffuse attenuation can be linked to the beam absorption and scattering coefficients using the formula by Kirk (1994):

$$K_{d,ave} = \frac{1}{\mu_0}\sqrt{a^2 + (0.425\mu_0 - 0.190)ab}\ , \qquad (2)$$

where the subscript ave indicates the average K_d for the zone from the surface down to the 1% light level (the euphotic zone), μ_0 is the cosine of the refracted photons just underneath the surface of the water, a is the beam absorption coefficient, and b is the scattering coefficient. The scattering coefficient is equal to $c - a$, where c is the beam attenuation coefficient.

RESULTS

A total of ten vertical profiles of downwelling irradiance spectra were measured. Of these six were measured in the marginal ice zone, two in the interfrontal region, and two in the Antarctic polar front. A profile from the marginal ice zone is shown in Fig. 2. All the profiles were very similar in shape but the absolute level of irradiance varied with the level of the incident irradiance. No regional variations could be detected. A slight shift can be seen with increasing depth in the wavelength of maximum irradiance towards longer wavelengths, from 450 nm at 3 m to 490 nm at 20 m. Spectral irradiance measurements made using the LI-1800 UW take around 1 min to complete and in that time the up and down motion of the ship due to waves and the induced change in the depth of the instrument can cause errors in the spectra measured. This effect disappears below a depth of 3–5 m and after this depth the spectra are no longer affected by the wave action. In Fig. 2 the measurement at 1 m has been totally spoiled, but the values deeper down are almost totally unaffected. The upwelling irradiance shows one maximum at approximately 470 nm and a second one at 420 nm. This second maximum can be attributed to water fluorescence (Jerlov, 1976).

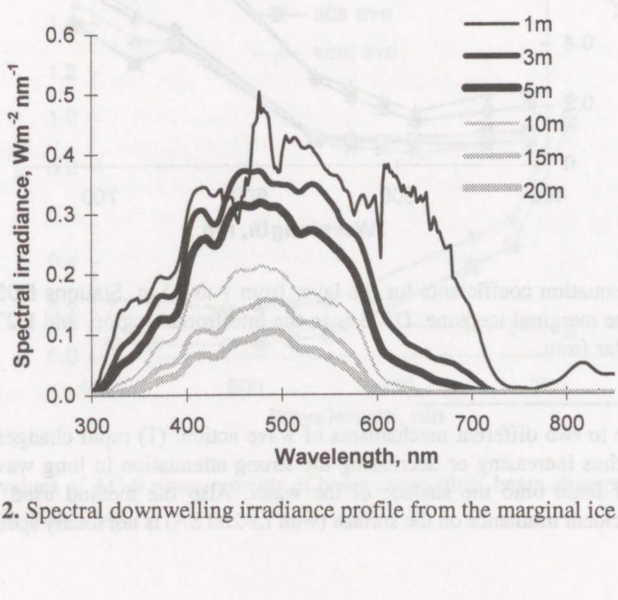

Fig. 2. Spectral downwelling irradiance profile from the marginal ice zone.

Diffuse attenuation coefficients were then calculated from the irradiance spectra using Eq. (1). The coefficients were calculated separately for the whole 15 m layer and for each layer. When calculating the K_d for the different layers, the ratio of irradiances in Eq. (1) was changed to $E_d(z_2)/E_d(z_1)$ (with $z_2 > z_1$) and the depth z was replaced by the thickness of the layer $(z_2 - z_1)$. The diffuse attenuation coefficients for the different layers were very similar except for the first layer (1–3 m), which showed stronger (by almost $+2\ m^{-1}$) attenuation in wavelengths larger than 720 nm compared to the other layers.[1] The values of the diffuse attenuation coefficients corresponding to the AC-9 wavelengths at the different stations are shown in Fig. 3. Most of the spectra are similar to each other except in the wavelengths above 650 nm. However, two stations situated in the Antarctic polar front show stronger attenuation across the whole spectrum. The diffuse attenuation coefficients, except for the two stations in the Antarctic polar frontal region, coincide with those measured by Boucher & Prezelin (1996) in the marginal ice zone west of the Antarctic Peninsula. On the basis of the diffuse attenuation coefficients the water was classified as belonging to Jerlov types II and III. The waters of the marginal ice zone and the interfrontal region were classified as belonging to type II and the Antarctic polar frontal water as belonging to type III. Jerlov (1976) classified the Southern Ocean water as being of types II and III in the Pacific sector and IA in the Indian Ocean sector.

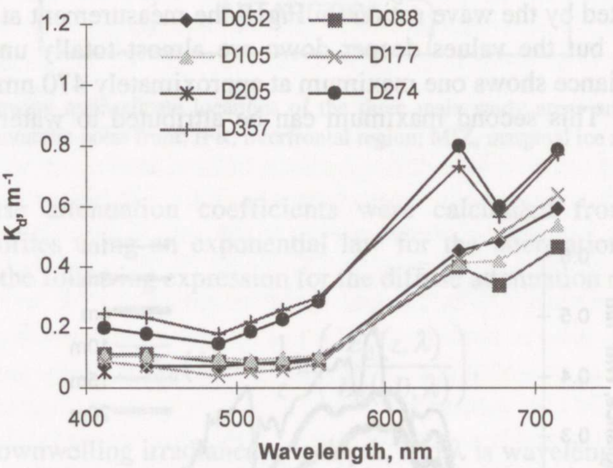

Fig. 3. Diffuse attenuation coefficients for the layer from 1 to 15 m. Stations D052, D088, D105, and D177 are in the marginal ice zone, D205 is in the interfrontal region, and D274 and D357 are in the Antarctic polar front.

[1] This may be due to two different mechanisms of wave action: (1) rapid changes in the depth of the instrument (thus increasing or decreasing the strong attenuation in long wavelengths) or (2) the formation of foam onto the surface of the water. Also the method used for tracking the changes in the incident irradiance on the surface (with LI-200 SA) is not totally spectrally reliable.

A total of 34 AC-9 measurements were made. These were fairly evenly distributed between the different areas. The AC-9 measurements are averages for the layer from the surface to 20 m. Values obtained for beam absorption from the AC-9 measurements are dominated by the absorption of light by the water molecules. Beam absorption values are therefore practically the same in all areas. Scattering coefficient values are almost totally wavelength independent, being only slightly higher in the shorter wavelengths than in the longer wavelengths. In the marginal ice zone the scattering coefficients, averaged over the wavelengths, are between 0.3 and 0.6 m^{-1}. In the interfrontal region they are 0.1 m^{-1} with very little variation, and in the Antarctic polar front they are between 0.2 and 0.3 m^{-1}. A spectrum of beam attenuation, beam absorption, and scattering from the Antarctic polar front is shown in Fig. 4.

Values for the diffuse attenuation coefficients were also calculated from Eq. (2) using the beam absorption and scattering coefficients. The angle of incidence of the photons was calculated from the latitude and the time of day, which was chosen to correspond to the LI-1800 UW measurements and it was not the time that the AC-9 measurements had been made. These values for the diffuse attenuation coefficients are shown in Fig. 5. The results show that the diffuse attenuation coefficients calculated from the AC-9 measurements correlate reasonably well with the diffuse attenuation coefficients calculated from the measured irradiances at 1 and 15 m. The correlation coefficient is 0.83. A comparison with the values in Fig. 3 shows that the diffuse attenuation coefficients calculated from the AC-9 measurements do not show all the spectral features correctly in the longer wavelengths and they do not show the larger attenuation for the two stations in the Antarctic polar front. However, Eq. (2)

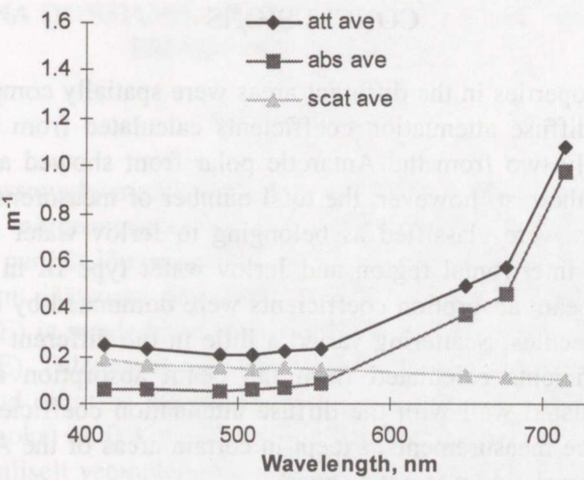

Fig. 4. Average values of AC-9 measurements of beam attenuation, beam absorption, and scattering from the Antarctic polar front.

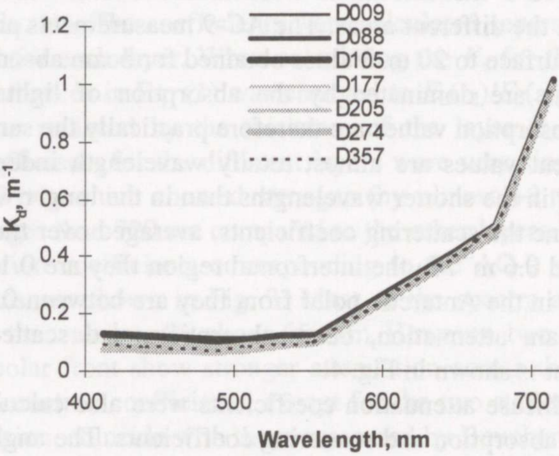

Fig. 5. Diffuse attenuation coefficients calculated from the beam attenuation and scattering coefficients. The station numbers are the same as in Fig. 3 (D009 is in the marginal ice zone).

does seem to work for the marginal ice zone where the scattering coefficients are similar to those at the two different stations in the Antarctic polar front. This could be due to very different volume scattering functions in the waters of the different areas, which would then indicate that the water constitution is different.

CONCLUSIONS

The optical properties in the different areas were spatially comparable to one another. Of the diffuse attenuation coefficients calculated from the irradiance measurements only two from the Antarctic polar front showed any significant differences from the rest: however, the total number of measurements was very small. The waters were classified as belonging to Jerlov water type II in the marginal ice and interfrontal region and Jerlov water type III in the Antarctic polar front. The beam absorption coefficients were dominated by the absorption by the water molecules. Scattering varied a little in the different areas. Diffuse attenuation coefficients calculated from the beam absorption and scattering coefficients correlated well with the diffuse attenuation coefficients calculated from the irradiance measurements, except in certain areas of the Antarctic polar front where the correlation was not as good.

ACKNOWLEDGEMENTS

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LÕUNA OOKEANIL TEHTUD OPTILISTE MÕÕTMISTE ESIALGSED TULEMUSED

Kai E. RASMUS

Alla- ja ülessuunduva päikesekiirguse kiiritustihedust ning suunatud kiirguse neeldumis- ja nõrgenemiskoefitsienti mõõdeti Lõuna ookeanil uurimislaeva S. A. Agulhas pardalt lõunapoolkera 1997/98. aasta suve jooksul. Mõõtmispiirkondi oli kolm: jäätsooni ääreala (65–59° S, 6° E), antarktiline polaarfront (55–49° S, 6° E) ja nende kahe piirkonna vaheline ala, frontidevaheline regioon (57–55° S, 6° E). Tulemused näitavad, et allasuunduva kiiritustiheduse profiilide põhjal määratud difuusne nõrgenemiskoefitsient (keskmistatud spektripiirkonna 400–700 nm jaoks) on 0,3 m^{-1}. Suunatud kiirguse neeldumiskoefitsiendi väärtus formeerub põhiliselt veemolekulide toimel ja on praktiliselt sama kõigis kolmes uuritavas rajoonis. Hajumiskoefitsient, mis arvutati nõrgenemis- ja neeldumiskoefitsiendi andmetest vahemiku 400–700 nm jaoks, sõltub nõrgalt valguse

lainepikkusest, olles 0,3–0,6 m^{-1} jäätsooni äärealal, 0,1 m^{-1} frontidevahelises regioonis ja 0,2–0,3 m^{-1} antarktilisel polaarfrondil. Difuusse nõrgenemiskoefitsiendi väärtused, arvutatud ühelt poolt veealuse kiiritustiheduse profiilide ja teiselt poolt suunatud kiirguse neeldumis- ja hajumiskoefitsiendi põhjal, korrelleerusid hästi omavahel. Autori hinnangul kuuluvad jäätsooni ääreala ja frontidevahelise regiooni veed Jerlovi II veetüüpi, antarktilise frondi veed III veetüüpi.