NURC - Partnering for Maritime Innovation

Submerged Remote Sensing (SRS) Approach

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Background

In the 1980's there was interest by the US Navy in the development of a Submarine Laser Communication (SLC) Program .

The idea was to develop climatologies of the spatial and vertical distributions of light attenuation in specified focus areas (North Pacific, North Atlantic and GIN Seas).

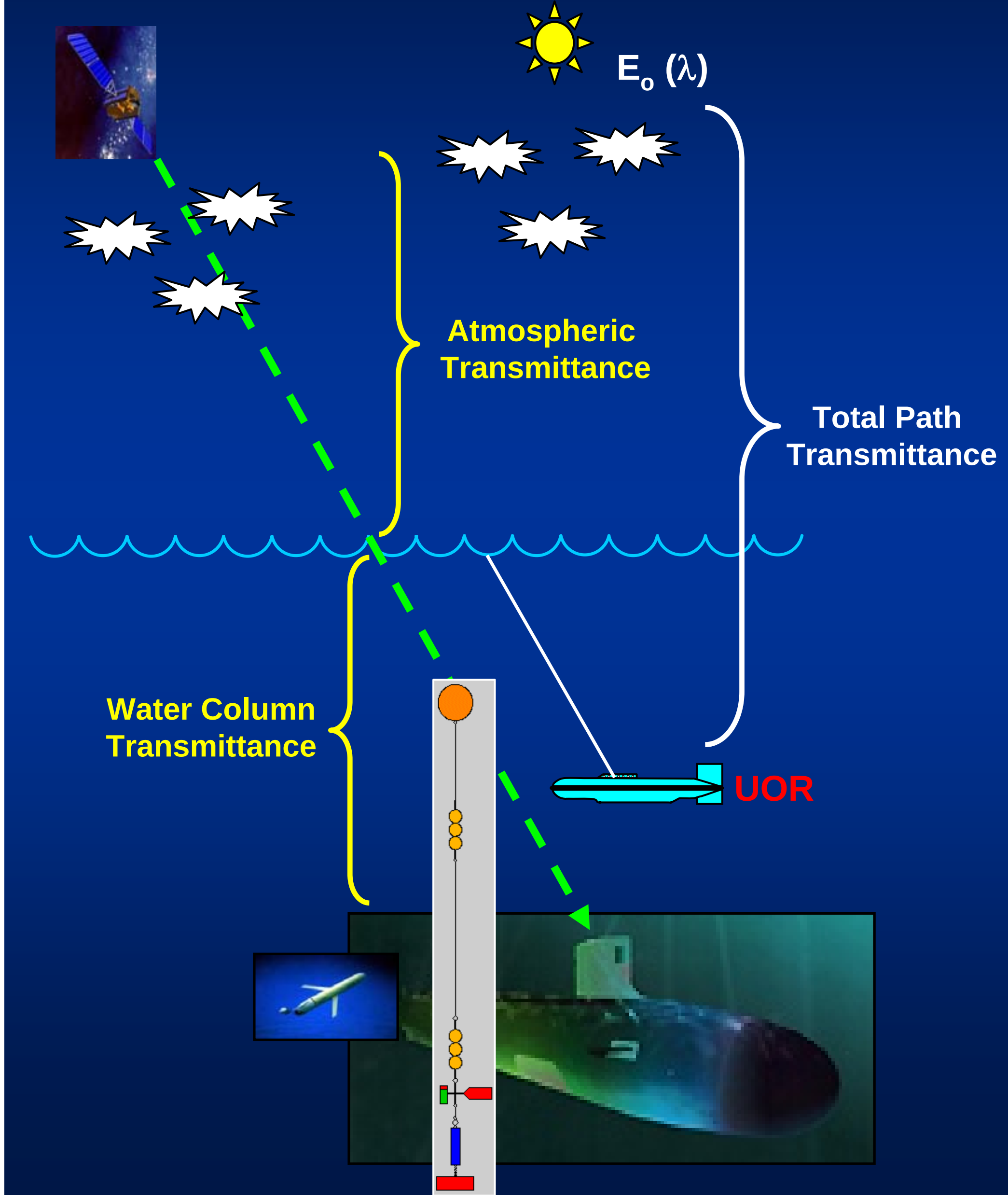
> "Is there a way to determine the loss due to the water and to the atmosphere separately without moving the submarine vertically?"

To successfully receive communication from a space-based laser system underwater then one would have to know

1. Atmospheric conditions.
2. Water clarity.

All without coming to the surface or vertically profiling!

Submarine Laser Communication (SLC) 1980's



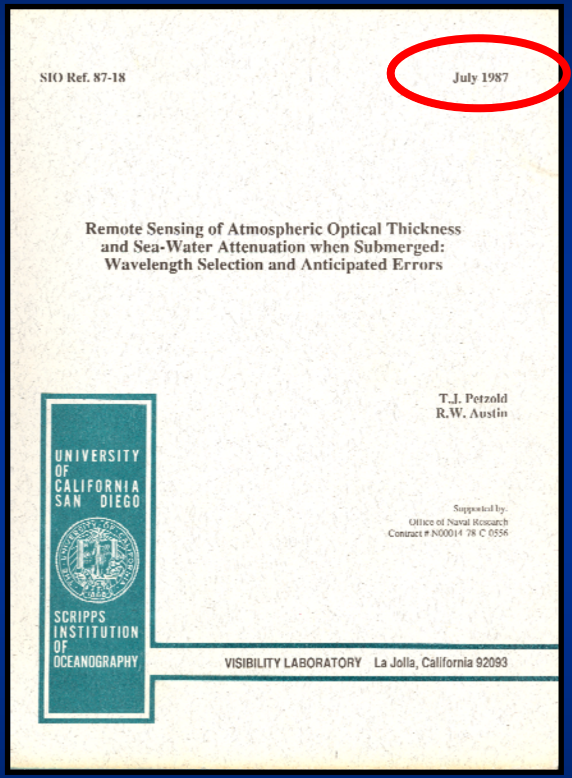
E_o (λ)

Atmospheric Transmittance

Total Path Transmittance

Water Column Transmittance

UOR



SIO Ref. 87-18

July 1987

Remote Sensing of Atmospheric Optical Thickness
and Sea-Water Attenuation when Submerged:
Wavelength Selection and Anticipated Errors

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R.W. Austin

Supported by:
Office of Naval Research
Contract # N00014 78 C 0556

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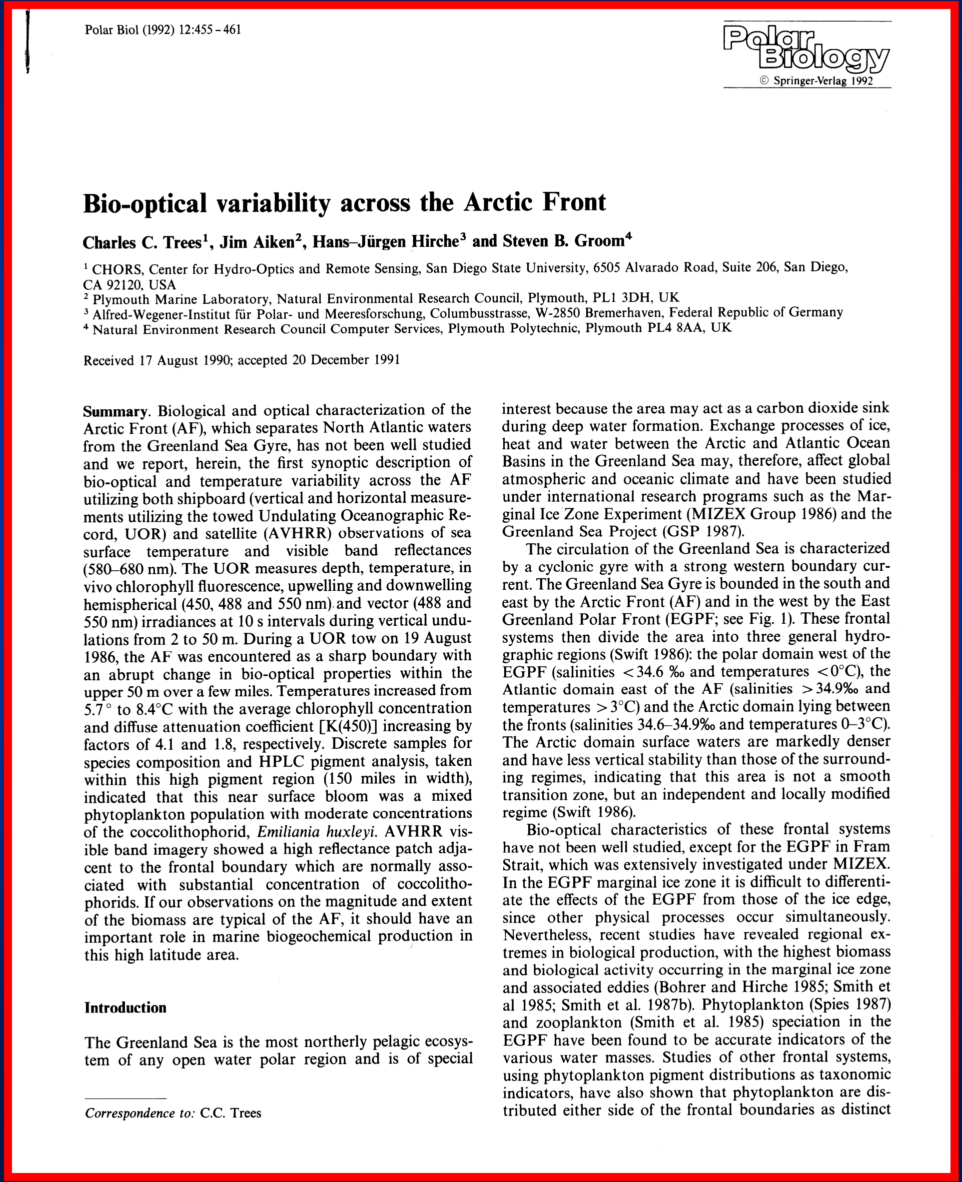
1st Joint Paper with Dr. Aiken (1992)

(Towed Undulating Recording Device)



Polar Biol (1992) 12:455 – 461

Polar Biology

Bio-optical variability across the Arctic Front

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Received 17 August 1990; accepted 20 December 1991

Summary. Biological and optical characterization of the Arctic Front (AF), which separates North Atlantic waters from the Greenland Sea Gyre, has not been well studied and we report, herein, the first synoptic description of bio-optical and temperature variability across the AF utilizing both shipboard (vertical and horizontal measurements utilizing the towed Undulating Oceanographic Record, UOR) and satellite (AVHRR) observations of sea surface temperature and visible band reflectances (580–680 nm). The UOR measures depth, temperature, in vivo chlorophyll fluorescence, upwelling and downwelling hemispherical (450, 488 and 550 nm) and vector (488 and 550 nm) irradiances at 10 s intervals during vertical undulations from 2 to 50 m. During a UOR tow on 19 August 1986, the AF was encountered as a sharp boundary with an abrupt change in bio-optical properties within the upper 50 m over a few miles. Temperatures increased from 5.7° to 8.4°C with the average chlorophyll concentration and diffuse attenuation coefficient [K(450)] increasing by factors of 4.1 and 1.8, respectively. Discrete samples for species composition and HPLC pigment analysis, taken within this high pigment region (150 miles in width), indicated that this near surface bloom was a mixed phytoplankton population with moderate concentrations of the coccolithophorid, *Emiliania huxleyi*. AVHRR visible band imagery showed a high reflectance patch adjacent to the frontal boundary which are normally associated with substantial concentration of coccolithophorids. If our observations on the magnitude and extent of the biomass are typical of the AF, it should have an important role in marine biogeochemical production in this high latitude area.

Introduction

The Greenland Sea is the most northerly pelagic ecosystem of any open water polar region and is of special interest because the area may act as a carbon dioxide sink during deep water formation. Exchange processes of ice, heat and water between the Arctic and Atlantic Ocean Basins in the Greenland Sea may, therefore, affect global atmospheric and oceanic climate and have been studied under international research programs such as the Marginal Ice Zone Experiment (MIZEX Group 1986) and the Greenland Sea Project (GSP 1987).

The circulation of the Greenland Sea is characterized by a cyclonic gyre with a strong western boundary current. The Greenland Sea Gyre is bounded in the south and east by the Arctic Front (AF) and in the west by the East Greenland Polar Front (EGPF; see Fig. 1). These frontal systems then divide the area into three general hydrographic regions (Swift 1986): the polar domain west of the EGPF (salinities <34.6 ‰ and temperatures $<0°C$), the Atlantic domain east of the AF (salinities >34.9‰ and temperatures $>3°C$) and the Arctic domain lying between the fronts (salinities 34.6–34.9‰ and temperatures 0–3°C). The Arctic domain surface waters are markedly denser and have less vertical stability than those of the surrounding regimes, indicating that this area is not a smooth transition zone, but an independent and locally modified regime (Swift 1986).

Bio-optical characteristics of these frontal systems have not been well studied, except for the EGPF in Fram Strait, which was extensively investigated under MIZEX. In the EGPF marginal ice zone it is difficult to differentiate the effects of the EGPF from those of the ice edge, since other physical processes occur simultaneously. Nevertheless, recent studies have revealed regional extremes in biological production, with the highest biomass and biological activity occurring in the marginal ice zone and associated eddies (Bohrer and Hirche 1985; Smith et al 1985; Smith et al. 1987b). Phytoplankton (Spies 1987) and zooplankton (Smith et al. 1985) speciation in the EGPF have been found to be accurate indicators of the various water masses. Studies of other frontal systems, using phytoplankton pigment distributions as taxonomic indicators, have also shown that phytoplankton are distributed either side of the frontal boundaries as distinct

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Collaboration with Dr. Aiken

- 30 Mar 1986 (6:45 pm) – Ocean Optics VIII Conference (Orlando, FL)
  - "A simple hemispherical, logarithmic light sensor",
    - Aiken & Bellan

- Aug 1986 - GIN Seas (*USNS Lynch*, SLC)
- Jul 1987 - GIN Seas (*USNS Lynch*, SLC)
- Jun 1991 - NE Atlantic (*RRS Charles Darwin*, BOFS)
- Feb 1992 - Equatorial Pacific (*RV Thompson*, US JGOFS)
- Sep 1992 - Equatorial Pacific (*RV Thompson*, US JGOFS)
- Aug 1994 - Arabian Sea (*RRS Discovery*, Arabesque 1)
- Oct 1995 - Arabian Sea (*RV Thompson*, US JGOFS)

- AMT 1, 2 & 3 Cruises – HPLC Pigment Analyses

SRS Approach

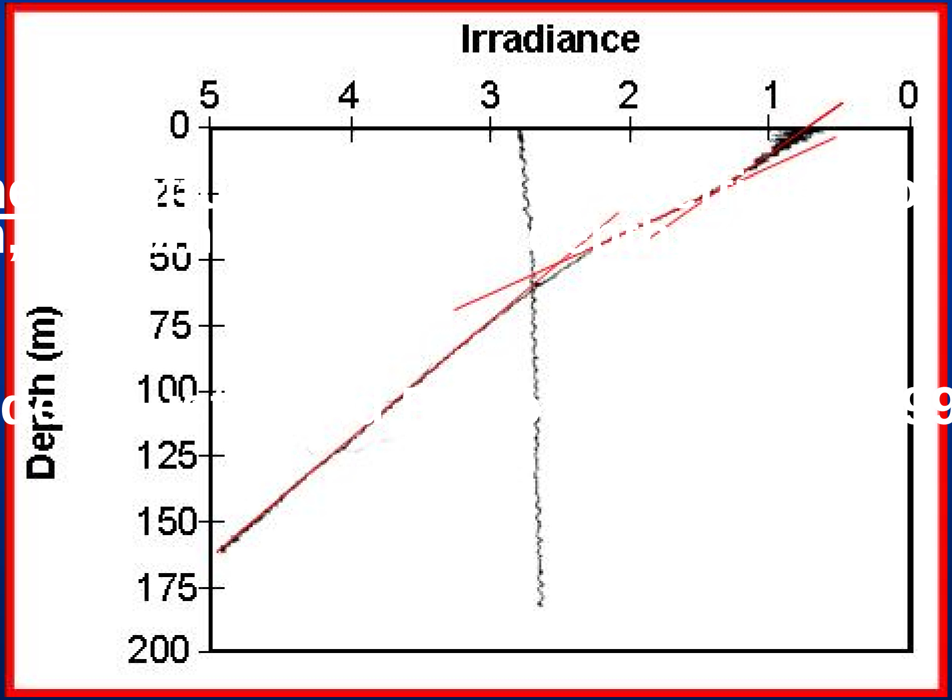
1. Using known values of extraterrestrial solar flux and models for atmospheric (air molecules, ozone and aerosols contributions) and seawater transmittance, the downwelling irradiance at a depth Z for any wavelength for a given set of environmental conditions can be estimated. This is possible because of the predictability of the optical characteristics of the atmosphere and seawater (spectral K model).

2. This estimate is done at two wavelengths to produce a pair of irradiance values, which is critical in separating the atmospheric and water column contributions by inverting the computations listed above.

3. Required inputs are (1) spectral irradiance of the sun outside the atmosphere, (2) solar zenith angle (function of date, time, latitude and longitude) and (3) depth at which the paired irradiances were measured.

Water Column Diffuse Transmittance

$$T_w(\lambda) = e^{-[K(\lambda)*Z]}$$

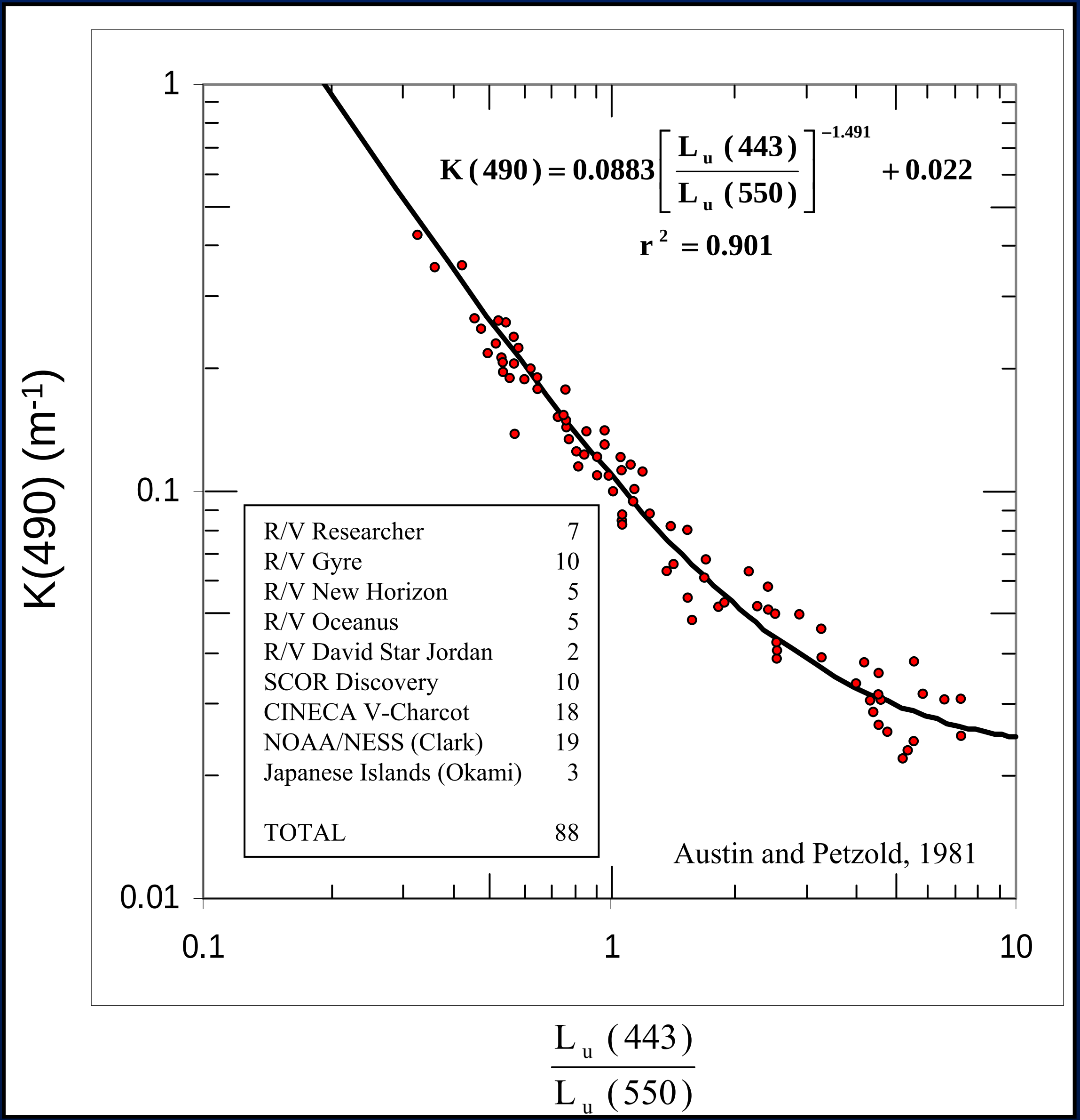


where:

K(λ) is the m… the water at wavelength,

Spectral K Mo… 990)

Irradiance/Radiance Ratio to K(λ)



$T_{atm}(\lambda) = e^{-[0.48\,\tau_R(\lambda)+\tau_o(\lambda)+\tau_a(\lambda)]/\mu_o}$

Atmospheric Transmittance

$$T_{atm}(\lambda) = e^{-\left[0.48\tau_R(\lambda)+\tau_o(\lambda)+\tau_a(\lambda)\right]/\mu_o}$$

where

$\tau_R(\lambda)$	**is the optical depth of one air mass due to molecular (Rayleigh) scattering,**
$\tau_o(\lambda)$	**is the optical depth of one air mass due to ozone absorption,**
$\tau_a(\lambda)$	**is the effective optical depth of one air mass for diffuse light due to the aerosol component,**
μ_o	**is the cosine of the solar zenith angle.**

Rayleigh Optical Depth

$\tau_R(\lambda)$ in the atmosphere varies very nearly with the inverse fourth power of wavelength.

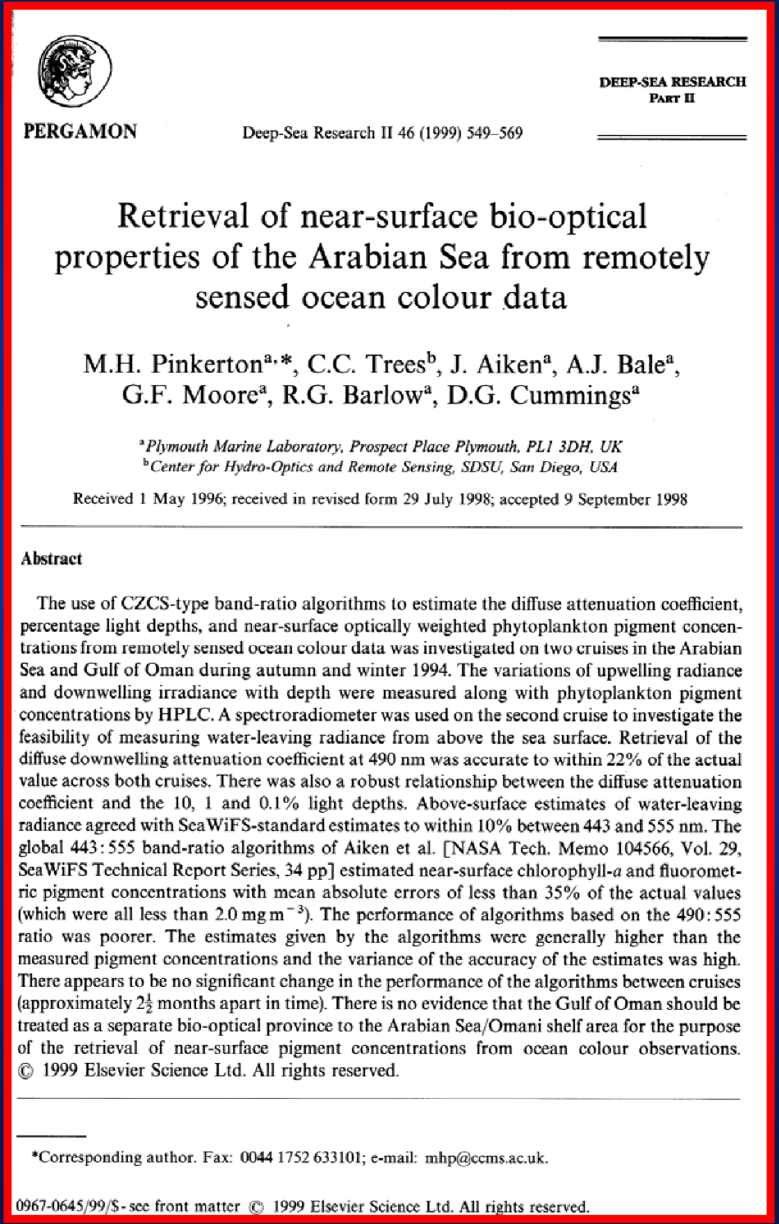
$$\tau_R(\lambda) = 0.044 * (\lambda / 670)^{-4}$$

The effective value, $\boxed{\overline{\tau_R(\lambda)}}$, over the pass band λ_1 to λ_2 is

$$\overline{\tau_R(\lambda)} = 0.044(\lambda_2 - \lambda_1)^{-1} * \int_{\lambda_1}^{\lambda_2} (\lambda / 670)^{-4} * d\lambda$$

$$= 2.956 \times 10^9 (\lambda_2 - \lambda_1)^{-1} * (\lambda_1^{-3} - \lambda_2^{-3})$$

Arabesque 1&2 Collaboration



PERGAMON

Deep-Sea Research II 46 (1999) 549–569

DEEP-SEA RESEARCH
PART II

Retrieval of near-surface bio-optical properties of the Arabian Sea from remotely sensed ocean colour data

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Received 1 May 1996; received in revised form 29 July 1998; accepted 9 September 1998

Abstract

The use of CZCS-type band-ratio algorithms to estimate the diffuse attenuation coefficient, percentage light depths, and near-surface optically weighted phytoplankton pigment concentrations from remotely sensed ocean colour data was investigated on two cruises in the Arabian Sea and Gulf of Oman during autumn and winter 1994. The variations of upwelling radiance and downwelling irradiance with depth were measured along with phytoplankton pigment concentrations by HPLC. A spectroradiometer was used on the second cruise to investigate the feasibility of measuring water-leaving radiance from above the sea surface. Retrieval of the diffuse downwelling attenuation coefficient at 490 nm was accurate to within 22% of the actual value across both cruises. There was also a robust relationship between the diffuse attenuation coefficient and the 10, 1 and 0.1% light depths. Above-surface estimates of water-leaving radiance agreed with SeaWiFS-standard estimates to within 10% between 443 and 555 nm. The global 443 : 555 band-ratio algorithms of Aiken et al. [NASA Tech. Memo 104566, Vol. 29, SeaWiFS Technical Report Series, 34 pp] estimated near-surface chlorophyll-*a* and fluorometric pigment concentrations with mean absolute errors of less than 35% of the actual values (which were all less than 2.0 mg m^{-3}). The performance of algorithms based on the 490 : 555 ratio was poorer. The estimates given by the algorithms were generally higher than the measured pigment concentrations and the variance of the accuracy of the estimates was high. There appears to be no significant change in the performance of the algorithms between cruises (approximately $2\frac{1}{2}$ months apart in time). There is no evidence that the Gulf of Oman should be treated as a separate bio-optical province to the Arabian Sea/Omani shelf area for the purpose of the retrieval of near-surface pigment concentrations from ocean colour observations. © 1999 Elsevier Science Ltd. All rights reserved.

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Ozone Optical Depth

The work of Klenk *et al.* (1983) is used to find the spectral absorption coefficient (Klenk 1980) for ozone as a function of latitude and season. This representation is a simple 4-parameter function representing the ozone amount in each of 12 atmospheric layers. The optical depth $\tau_o(\lambda)$ is taken to be equal to the total ozone absorption coefficient.

$$\tau_o(\lambda) = 0.300 * 0.13879 * e^{-A(\lambda)}$$

where

$$A = 0.0014717 * \left(\left|\lambda - 589.75\right|\right)^{1.5301}$$

The effective value over pass band λ_1 to λ_2 is

$$\overline{\tau_o(\lambda)} = (\lambda_2 - \lambda_1)^{-1} * \int_{\lambda_1}^{\lambda_2} \tau_o(\lambda) * d\lambda.$$

Aerosol Optical Depth

The optical depth for the aerosol, $\tau_a(\lambda)$, has a spectral dependency which appears to follow the power law

$$\tau_a(\lambda_1) = (\lambda_1 / \lambda_2)^{-\alpha} * \tau_a(\lambda_2)$$

The exponent, α, is known as the Angstrom exponent and is dependent on the amount and quality of the aerosol. It generally falls in to the range of 1.1 to 1.4 for clear atmospheres and approaches zero for very large aerosols (fog, overcast, etc).

Irradiance at Depth ‘Z’

$$E_Z(\lambda) = E_o(\lambda) * \mu_o * T_{atm}(\lambda) * T_s * T_w(\lambda)$$

$$E_Z(\lambda) = E_o(\lambda) * \mu_o * T_s * e^{-[\tau_b(\lambda) + \tau_a(\lambda)]/\mu_o} * e^{-[K(\lambda) * Z]}$$

The ratio of $E_Z(\lambda)$ at two wavelengths $\lambda_1$to λ_2 is

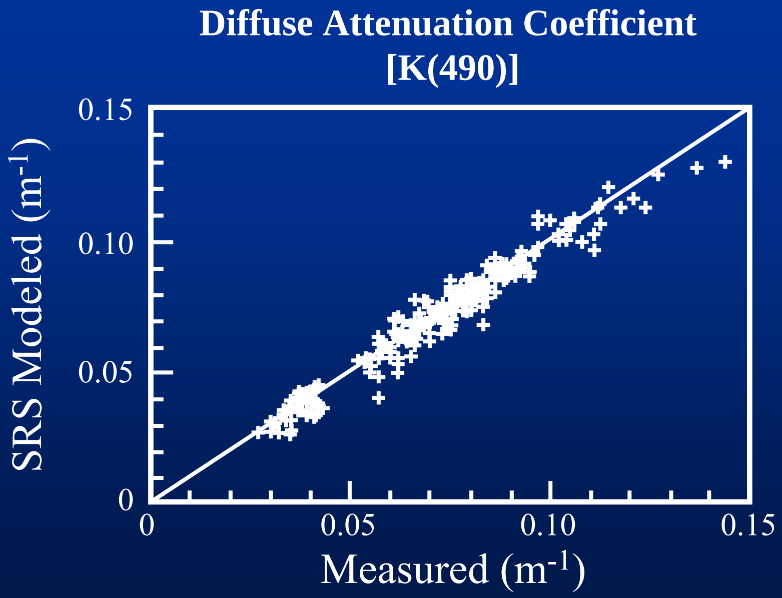
$$\frac{E_Z(\lambda_2)}{E_Z(\lambda_1)} = \frac{E_o(\lambda_2)}{E_o(\lambda_1)} * e^{-[\tau_b(\lambda_2) - \tau_b(\lambda_1) + \tau_a(\lambda_2) - \tau_a(\lambda_1)]/\mu_o} * e^{-[K(\lambda_2) - K(\lambda_1) * Z]}$$

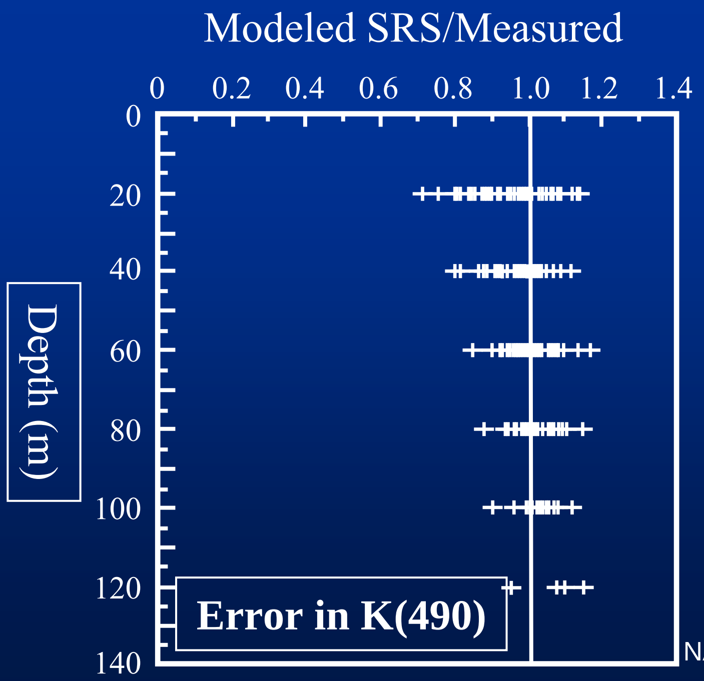
Assume that the aerosol component is constant for all wavelengths.

$$[K(\lambda_2) - K(\lambda_1)] * Z = \ln\frac{E_o(\lambda_2)}{E_o(\lambda_1)} - \frac{1}{\mu_o} * [\tau_b(\lambda_2) - \tau_b(\lambda_1)] - \ln\frac{E_Z(\lambda_2)}{E_Z(\lambda_1)}$$

Results/Conclusions

Stations = 51
Atmospheric Conditions
100% overcast, broken cumulus, haze to clear sky.
Number Obs. = 221
Water Column Attenuation at 490 nm = 0.03 to 0.4 m^{-1}
Ratio (SRS/Measured) = 0.986 ± 0.073
Difference (SRS-Measured) = 0.001 ± 0.005 m^{-1}





NATO UNCLASSIFIED

Future

1. **Implement the SRS approach using more recent values of the extraterrestrial solar flux and atmospheric models.**

2. **Implement the SRS approach using a much large *in situ* optical database (e.g. Mediterranean Sea, Black Sea, Ligurian Sea Cal/Val Experiment (Oct 08).**

3. **SRS approach was developed in Case I waters. Determine the uncertainties in applying this approach to coastal/littoral zones.**

4. **Published results in peer reviewed journal.**