SOFI Workshop Report WS 08 08

Underwater optics: measurement, interpretation and implications for modelling marine processes

Glasgow, 16-17 March 2009

1. Introduction

The SOFI Underwater Optics Workshop was held in the Millennium Hotel, Glasgow on 16-17 March 2009. There were 19 participants; 8 from Oceans 2025 partners, 9 from HEIs and 2 from other organisations (see Appendix 1 for details). In addition, PowerPoint presentations were sent by several colleagues from PML and SAMS who were unable to attend in person. The guest speaker was Dr Heidi Dierssen from the University of Connecticut, who discussed the optical effects of wind-induced Langmuir circulation on the Great Bahama Bank. The aims of the workshop were to:

i) review the existing state of the art of active and passive optical measurement techniques, particularly those suited for deployment on moorings, AUVs and gliders.
ii) devise protocols for generating standardised products from optical data suitable for archiving and dissemination within the wider community.
iii) identify emerging requirements for optical measurements and modelling within Oceans 2025.
iv) explore possible mechanisms of cooperation (for example through joint research proposals, participation in cruises, and the communication of results).

The workshop did not explicitly consider remote sensing, which would have involved a change of focus towards radiative transfer modelling and image processing rather than the application of optical techniques to problems arising in other areas of marine science.

2. Workshop structure

The workshop was divided into three sections: an introduction in which participants reviewed their objectives and requirements, a technical session where specific optical questions were addressed, and a group discussion which identified common themes, problems, and routes for further progress. In addition to a general exchange of views on best practice for instrument deployment and data processing, the workshop considered three categories of optics-related activity which present opportunities for the advancement of NERC marine science.

3. Topics of strategic importance with an optical dimension

Participants identified six key areas where the explicit consideration of underwater optics could assist effective delivery of NERC science objectives. As follows:

3.1 *Coupled physical/ biological modelling of shelf-sea ecosystems*

The coupled shelf sea models currently run by NERC-funded centres, the Met Office and Defra incorporate simplistic and demonstrably erroneous underwater light fields. Teams at the Proudman Oceanographic Laboratory and Cefas (Lowestoft) have independently identified this as a factor which significantly affects their ability to model patterns of primary productivity. Accurate light field modelling is a prerequisite for predicting the timing of major events such as the spring phytoplankton bloom. The workshop recommended that this deficiency should be remedied as a matter of urgency, and noted that NERC Network or Knowledge Exchange funding could provide a suitable mechanism.

3.2 *Primary productivity and carbon cycling in high-latitude ecosystems*

High levels of primary productivity occur in spring at the edge of retreating ice shelves, but these areas are difficult to access and sample. The acquisition of *in situ* data from optical sensors deployed on over-wintering moorings (such as those planned by the Scottish Association for Marine Science) could make a valuable contribution to this area of research, and assist attempts to model the ecological consequences of reduced ice cover in nutrient-rich northern seas.

3.3 *Absorption of solar radiation in the upper ocean*

Heat fluxes from solar inputs have significant implications for water column stability and for understanding patterns of thermally-driven circulation. Factors which affect water clarity (sediment suspension, phytoplankton growth, yellow substance input) influence the depth of penetration of solar radiation and can modify temperature-dependent patterns of water column stratification.

3.4 *The effect of changing climatic factors*

The anticipated consequences of a rise in global mean temperatures include changes in freshwater runoff and increased storm frequency. Concomitant changes in concentrations of CDOM and suspended minerals in shelf seas will have a profound effect on seawater transparency, with implications for both primary productivity and predator behaviour at higher trophic levels.

3.5 *Particle fluxes in oceanic water columns*

The flocculation of senescent phytoplankton blooms is known to promote the rapid sinking of organic material, and flocs may also scavenge fine mineral particles from the water column. Recent work has shown that the onset of flocculation in the North Atlantic can be detected using optical sensors on gliders. This information is important for understanding the timing as well as the magnitude of organic carbon transport to the deep ocean.

3.6 *Tracking the dispersion of anthropogenic nano-particles in the aquatic environment*

There has been a rapid increase in the use of very small particles in industrial processes, raising concern that some of these may have a significant ecological impact. NERC already participates in an inter-agency Environmental Nanosciences Initiative. Optical measurements could be developed to identify such particles in mixed natural hydrosols and thus extend the possibilities for experimental studies of their behaviour in the marine environment.

4. Emerging applications of optical measurements in marine science

4.1 *Physiological adaptation to the underwater light climate and its effect on primary production efficiency*

There are complex interactions between the spectral quality of the underwater light field, phytoplankton photoadaptation, and rates of primary productivity in light-limited ecosystems. Examples include high latitude spring blooms, deep chlorophyll maxima in ocean basins, and diatom light harvesting in strongly coloured shelf seas. This is a fruitful area for exploring the interaction between physical and biological factors in determining rates of carbon fixation in marine ecosystems, and improved understanding of these interactions is required for assessing the vulnerability of these systems to changing environmental conditions.

4.2 *Dissolved organic matter concentration and fluxes*

Dissolved organic matter is a major reservoir of carbon in the world's oceans. This material is ill-characterised in terms of chemical structure and optical properties, but a significant proportion absorbs light in the visible and ultra-violet wavebands and an unknown (and probably variable) fraction responds to short wavelength excitation by emitting broadband fluorescence. The relationship between total DOC and optical signals varies from one water body to another, but once this has been determined it may be possible to quantify rates of input and dissipation by optical means. This could prove useful set for quantifying the anticipated increase in dissolved organic carbon fluxes to the marine environment in response to warmer Arctic temperatures.

4.3 *Flocs and turbulence*

There is much current interest in the dynamics of particle aggregation and disaggregation in response to varying levels of turbulence. Optical techniques offer the possibility of measuring changes in the size of structurally delicate flocs in the water column with minimal interference or damage. Promising advances in this area include the development of laser diffraction techniques and holographic imaging systems.

4.4 In situ *measurements of suspended sediment concentration and grain size*

Sediment grain size is important for predicting rates of re-suspension and transport. Optical techniques are emerging as the method of choice for *in situ* measurements of both size distribution and mass concentration, and they have the advantage of providing rapid data acquisition at high spatial resolution for incorporation in numerical models of sediment dynamics. Applications in this area are expected to increase with the emergence of large scale projects on marine renewable energy such as tidal turbines, wind farms and possibly tidal barrages.

4.5 *Constituent concentrations from Inherent Optical Properties*

One major achievement of ocean optics over the past decade has been the development of new sensors for measuring inherent optical properties (IOPs). In principle, it should be possible to mathematically invert IOP measurements to provide quantitative information on the concentrations of optically significant constituents (suspended minerals, phytoplankton and yellow substance). Recent work has demonstrated practical IOP inversion strategies (with traceable error budgets) based on prior knowledge of the specific optical properties on the relevant constituents. This opens the possibility of measuring constituent concentrations at the same spatial and temporal resolution as CTD measurements, which has a wide range of potential applications in marine research.

4.6 *Sediment load and light climate.*

In areas such as the Southern North Sea, suspended sediment concentrations have a major influence on underwater light levels. They thereby play a large part in determining the timing of the spring phyto-plankton bloom, with important consequences for zooplankton population growth and ultimately fish larval survival. An over-simplified approach to light attenuation currently results in very poor predictions of bloom timing. This is an ideal area for the application of radiative transfer theory to understand attenuation mechanisms and devise parameterisations for incorporation in numerical shelf sea models.

5. Requirements for new technology

5.1 *Extending the range of measured particle size distributions*

Suspended particles play a major role in marine optics: they scatter and attenuate the underwater light field, and strongly modify the reflectance measured by remote sensing. Particle size distributions are currently measured by electrical zone sensing instruments such as the Coulter counter (typical size range 3 to 30 μm for a single orifice) or by laser diffractometers such as the Sequoia LISST 100 (size range 1.5 to 250 μm or 3.0 to 500 μm depending on the model). There are, however, important particle classes that lie outside these ranges. Particles below 1 μm include minerals, marine bacteria and viruses, and fine particles originating from industrial processes. Particles larger than 500 μm include many of the chain-forming diatoms and colonial species that are responsible for intense blooms in shelf seas, and also flocs which may modify sediment transport dynamics in coastal regions and are responsible for accelerating the flux of carbon from the surface layer to the deep ocean. New approaches to the measurement of size and numerical concentration are required at both ends of naturally occurring particle size distributions.

5.2 *Increasing the efficiency of discriminating between phytoplankton groups*

Requirements for the rapid discrimination of phytoplankton taxa arise from the use of ‘functional groups’ in ecosystem models and remote sensing, and from the need to detect the presence of harmful alga species at relatively low concentrations. The inspection of preserved samples by optical microscopy is usually employed for this purpose, but it is slow, labour intensive and prone to quantitative errors due to under-sampling. Optical instrumentation such as imaging or slit scanning flow cytometry offers a promising solution to this problem, and recent advances in the miniaturisation of electronic and optical components suggests that these techniques may be feasible even for *in situ* deployments.

5.3 *Optical measurements under ice*

Plans were presented at the workshop for deploying thermistor strings from buoys frozen into Arctic sea ice as it forms and thaws. The addition of optical measurements would give information on brine rejection during freezing through enhanced scattering from refractive index inhomogeneities and on phytoplankton growth in spring when thinning ice cover leads to increased light availability.

5.4 *Planar optics for gliders: implementation and interpretation*

Ambitious plans for employing gliders to complement ship-based observations are being formulated at three institutions represented at the workshop (SAMS, POL and UEA). The standard CTD payload of commercial glider designs can be augmented by optical measurements of fluoroscence and backscatter with only a modest increase in power requirements. Work has still to be done, however, on optimising sensor wavelengths to provide information on CDOM, phytopigment and suspended particle concentrations, and on data interpretation. It would be feasible to measure the underwater light climate by adding a scalar irradiance sensor to the sensor suite, though this may require miniaturisation of existing designs.

5.5 *Antifouling techniques*

Experience from long-term mooring deployments in UK waters indicates that the severity of sensor fouling varies according to deployment site and sensor design. The enclosed tubes of the ac-9 and ac-S scattering and absorption meters are likely to be particularly sensitive to contamination, whereas fluorometers and backscattering meters generally have flat windows that can be mechanically wiped or covered with copper shutters. The latter class of sensors appear more promising for long term deployments.

6. Wider recommendations

The workshop noted that NERC currently under-exploits the potential contribution of underwater optics to its marine science programmes, and made two general recommendations:

- There is need to promote optical methodology as a standard component of many inter-disciplinary marine research programmes. For example, high quality optical measurements can support work on patterns of primary productivity, organic carbon fluxes, photochemical mediation of air-sea gas exchange and suspended particle dynamics.
- Observing systems for coastal and shelf seas are undergoing a period of rapid evolution, and many countries are installing moorings or cabled observatories to monitor the changing status of their territorial waters. Efficient use of this expensive infrastructure requires the measurement of the widest possible range of environmental variables, and this requirement can be partly met by modifying current optical sensors and inventing new ones. A recent example is the introduction of optrode technology for measuring dissolved oxygen concentrations.

7. Conclusion

The organisers thank the SOFI Workshop Fund (and the Oceans 2025 Directors) for enabling us to hold this Underwater Optics workshop. Its success was evident from the high quality of the presentations and the degree of participation in the ensuing discussions. We anticipate that these discussions will lead to stronger collaborations within the UK marine science community, and propose to engage NERC Theme Leaders and others in discussions in the near future on how such collaborations can be facilitated.

Alex Cunningham (University of Strathclyde)
Alex Souza (Proudman Oceanographic Laboratory) *8 April 2009*

Appendix 1. **Participants in SOFI Underwater Optics Workshop**

Name	Affiliation	Category
John Watson	University of Aberdeen	HEI
Phil Hwang	Scottish Association for Marine Science	Oceans 2025
Keith Davidson	Scottish Association for Marine Science	Oceans 2025
Alex Cunningham	University of Strathclyde	HEI
Danielle Creanor	University of Strathclyde	HEI
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Peter Hunter	University of Stirling	HEI
Alex Sousa	Proudman Oceanographic Laboratory	Oceans 2025
John Howarth	Proudman Oceanographic Laboratory	Oceans 2025
Dave Bowers	Bangor University	HEI
Gay Mitchelson-Jacob	Bangor University	HEI
Victor Vicente	Plymouth Marine Laboratory	Oceans 2025
Takafumi Hirata	Plymouth Marine Laboratory	Oceans 2025
Heather Bouman	University of Oxford	HEI
Rodney Forster	Cefas	Cefas/Defra
Johan van der Molen	Cefas	Cefas/Defra
Karen Heywood	University of East Anglia	HEI
Heidi Dierssen	University of Connecticut	Guest