6th IOCCG Summer Lecture Series

Frontiers in Ocean Optics and Ocean Colour Science

https://ioccg.org/what-we-do/training-and-education/ioccg-sls-2024/

International Training Centre for Operational Oceanography (ITCOOcean),
Indian National Centre for Ocean Information Services (INCOIS)
Hyderabad, India, 14-16 November 2024

In addition to recurrent support from all IOCCG contributing agencies, specific additional contributions are acknowledged for the 2024 edition, from the following agencies and institutions:

Our host

INCOIS

Our sponsors

PROGRAMME OF THE EUROPEAN UNION Copernicus Europe's eyes on Earth IMPLEMENTED BY EUMETSAT

PML Plymouth Marine Laboratory

IOCCG International Ocean Colour Coordinating Group

OCB Ocean Carbon & Biogeochemistry

It is also noted that all lecturers provide their time as in-kind, which is to be credited to their institutions (as listed in Appendix 1 of this report)

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1 Introduction

The International Training Centre for Operational Oceanography (ITCOOcean) at the Indian National Centre for Ocean Information Services (INCOIS), located in Hyderabad, India, hosted the sixth edition of the International Ocean Colour Coordinating Group (IOCCG) Summer Lecture Series (SLS). Due to the temperatures in India in the summer, the date was shifted to November for this edition.

The course was coordinated by Dr. Nimit Kumar (INCOIS) with support from Dr. Udaya Bhaskar (INCOIS) with assistance from an organizing team selected by IOCCG, which consisted of Drs. Shubha Sathyendranath, Vittorio Brando, Laura Zoffoli, Susanne Kratzer, David Antoine, and Raisha Lovindeer. All are gratefully acknowledged for their contribution to the planning of the SLS.

The IOCCG SLS is an advanced, 2-week course dedicated to training in the fundamentals of ocean optics, bio-optics, and ocean colour remote sensing. It was delivered by 12 lecturers (Appendix I) and covered the fundamentals of ocean optics as well as cutting edge research.

2 Student selection

A total of 126 applications were received from 26 countries (Fig. 1).

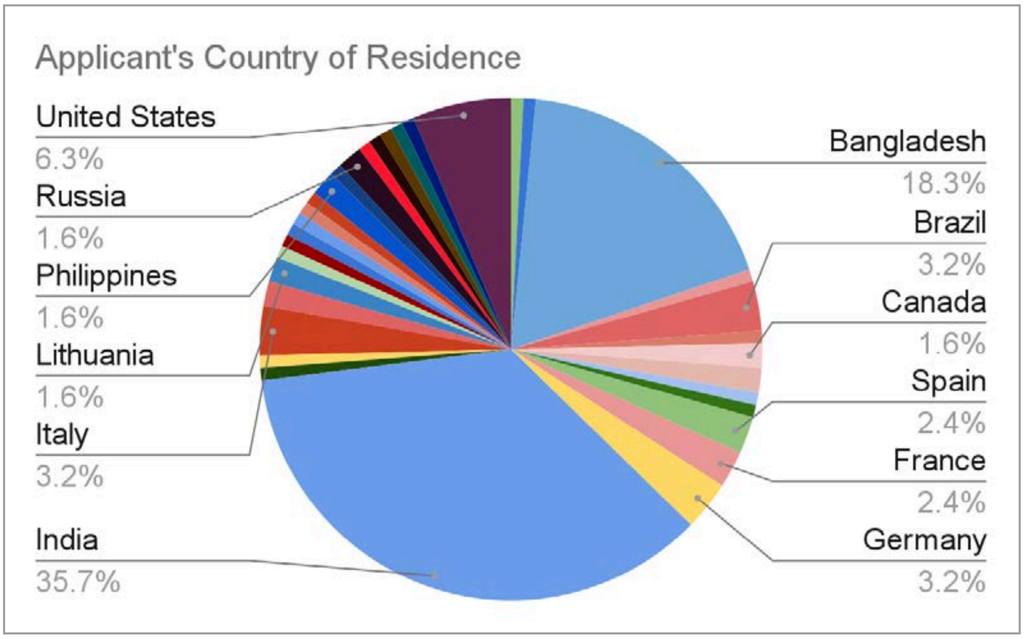

Fig. 1: Distribution of applications by the country of residence based on the location of the applicant's associated institution.

Thirty (30) students from 19 countries were selected (Appendix II). The number of students selected in 2024 was increased over previous years (~ +6) due to the capacity of the venue while still ensuring good interaction between students and lecturers. Selection of candidates was based on their motivation statement, knowledge of remote sensing, current area of research, previous training opportunities, and potential to apply the knowledge and skills that they would gain with the SLS to their future research and/or teaching. Applications were reviewed by a selection committee which consisted of David Antoine, Laura Zoffoli, Nimit Kumar and Raisha Lovindeer.

A final tally of 28 students attended the 2024 SLS due to Indian visa complications with 2 students. Most were PhD students with a few Masters students and early career scientists.

3 Course organisation

The objective of the SLS is to provide opportunities for students to improve their knowledge and skills for applications to their current and future research. The SLS2024 brought together remote sensing specialists from various fields of ocean colour. The format of the SLS has typically been a series of lectures and open discussion sessions on pre-arranged topics to allow interaction between the students and lecturers. Hands-on practical sessions are also included.

The 2024 course content covered a wide range of topics, and maintained a general focus on the theory of the fundamentals of ocean optics in the first week, and specific applications in the second week. The SLS started with the fundamentals in optics, bio-optics and ocean colour science, including the inherent and apparent optical properties of seawater, and hands-on practical sessions about these properties. This is meant to lay the groundwork for all students to adequately understand and benefit from lectures that follow on inversion techniques, and applications. A copy of the lecture schedule is available in Appendix III. In order to help students prepare for the course, lecture synopses prepared by the lecturers (Appendix IV) were shared with the students by email ahead of the course.

The course opened with a welcoming address on behalf of INCOIS by Dr. Udaya Bhaskar, followed by course logistics by Dr. Nimit Kumar, and a summary of IOCCG activities by the IOCCG Chair, Dr. Shubha Sathyendranath. Students got the opportunity to introduce themselves (5 mins each) using 2 slides, including their current area of research. This was an opportunity to get acquainted with the participants' academic backgrounds, their current positions, and their experiences. This was also a chance for the students to form contacts and acknowledge other participants with similar interests. As not all lecturers were in attendance for the start of the SLS, this same information from the selected students' applications were shared with the lecturers by email.

Fig. 2: Photo of students and lecturers during the welcoming session on the first day of SLS2024.

The lectures were delivered more or less as described in Appendix III. The first week also included practicals with AC instruments to understand absorption, scattering, and the colour of the ocean; to learn the intricacies of calibrating the instrument; and to measure absorption by coloured dissolved organic matter (CDOM) and particulates as well as light attenuation, with the aim to help students understand how to collect high-quality in situ data and interpret the measurements, and 2) HydroLight radiative transfer model to give an introduction and experience with radiative transfer modelling. In addition to lectures on the application of ocean colour in the second week of the course, practical sessions using satellite data from NASA (hyperspectral data from PACE was substituted for MODIS data due to bandwidth issues) and ESA Copernicus Sentinel series were conducted.

Fig. 3: Group photo of students and lecturers taken during the first week of SLS2024.

4 Course evaluation

At the end of the course, students and lecturers were given the opportunity to share their experience on various aspects of the lectures and practical course organization via an online anonymous feedback questionnaire. These forms are valuable for future planning and organization of the SLS, helping to understand which lectures were most effective, and where gaps and weaknesses exist.

A main strong point was the collaboration and knowledge exchange that the SLS is known for, and continued for 2024. A few redundancies in lecture material were highlighted, and lecturers suggested they meet beforehand to ensure smoother planning and delivery of the lecture content. As the SLS transitions, a stronger focus on content coordination was highlighted. All results of the evaluations were shared with the IOCCG Executive, and will continue to inform future planning to enhance the delivery of the SLS.

5 Conclusion

The 2024 IOCCG Summer Lecture Series was held for the first time in Hyderabad, India, hosted by INCOIS. Students and lecturers enjoyed the exchange of knowledge and interaction that could lead to future collaborations, and students gained valuable insights from attending. Valuable feedback was gained from participants that IOCCG will consider for future editions.

As with previous sessions, video recordings and PDF presentations of the lectures are available online at: https://ioccg.org/what-we-do/training-and-education/ioccg-sls-2024/

6 Acknowledgments

The IOCCG thanks the staff and faculty at INCOIS, the host of the 2024 SLS, as well as all the lecturers and students for their contributions, cooperation, and enthusiasm for sharing knowledge. We also acknowledge the institutions of all the lecturers listed in Appendix I for their in-kind contributions of lecturers' time for planning and executing Sls2024. We are also grateful to the contributions from all sponsoring agencies, and to all organizations that provided and managed financial support for the participants, as they made the training course possible.

The 2024 SLS benefited from financial or in-kind support from the following:

- Indian National Centre for Ocean Information Services (INCOIS) for hosting the SLS, including providing accommodation, ground transportation, facilities, and staff.
- Ocean Carbon & Biogeochemistry (OCB) Project Office, Woods Hole, MA, USA for providing financial support to students and lecturers from the USA.
- Trevor Platt Science Fund held at Plymouth Marine Lab, in collaboration with the Trevor Platt Science Foundation (TPSF) for providing funding for students from developing nations.

- EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites) for providing funding for students and lecturers from the EU.
- International Ocean Colour Coordinating Group (IOCCG) for providing staff support and travel funding for lecturers and some students.
- All lecturer institutions (Appendix I) for the lecturers' time provided in-kind.

IOCCG would also wish to thank the following key people for their help in the organization and their support during the course:

- The SLS2024 Coordinator Nimit Kumar, supported by Uday Bhaskar for planning and overseeing the SLS at INCOIS, organizing the logistics of transportation, food, and accommodation, and setting up the facility for training, including attempting to secure AC instruments from other institutions.
- Dr. PremKumar R (INCOIS) who provided valuable assistance on the ground at INCOIS during the SLS, as well as follow-up afterwards to ensure lecture recordings were carefully transferred to IOCCG.
- The planning team of Vittorio Brando, Laura Zoffoli, Susanne Kratzer, David Antoine, Shubha Sathyendranath, Raisha Lovindeer, and Nimit Kumar for orchestrating and overseeing the SLS2024, rating and selecting students from 126 applications, developing the agenda, and selecting the invited lecturers.
- Raisha Lovindeer, IOCCG Scientific Coordinator for management of the SLS website and budget, and for administration of financial support for students and lecturers, including administering funding from EUMETSAT and the Trevor Platt Science Fund.
- Hayley Evers-King for organizing support from EUMETSAT Copernicus programme, including funding for 9 students, and sending lecture material for HABs.
- Shubha Sathyendranath for organising support from the Trevor Platt Science Fund through the Plymouth Marine Lab to fund travel for 5 students.
- Heather Benway and Mary Zawoysky, Ocean Carbon & Biogeochemistry Program, for management of OCB financial support to 4 students and 1 lecturer.
- David Antoine for the transportation and loan of an AC instrument from Curtin University, Australia.
- The staff of the INCOIS restaurant and accommodation facilities.
- The INCOIS IT team
- All the lecturers for their time and support during the course

7 Appendix I – Lecturers

Lecturer	Institution	Country
Ana Ruescas	EUMETSAT / Brockmann Consult, Universitat da València	Spain
Aneesh Lotliker	INCOIS	India
Dariusz Stramski	Scripps Institution of Oceanography	United States
David Antoine	Curtin University	Australia
John Hedley	Numerical Optics Ltd.,	United Kingdom
Lachlan McKinna	Go2Q Pty Ltd	Australia
Matthew Slivkoff	In-situ Marine Optics	Australia
Mike Twardowski	Harbor Branch Ocean. Inst. Florida Atlantic University	United States
Nimit Kumar	INCOIS	India
Shubha Sathyendranath	Plymouth Marine Lab	United Kingdom
Wayne Slade	Harbor Branch Ocean. Inst. Florida Atlantic University	United States
ZhongPing Lee	Xiamen University	China

8 Appendix II – Selected students

1. Edward Alburqueque, Instituto del Mar del Perú-IMARPE, Perú
2. Christine Atuhaire, Makerere University, Uganda
3. Karl Bosse, Michigan Technological University, USA
4. Tu Bui, Météo-France, France
5. Leon Ćatipović, University of Split, Croatia
6. Nahia Chowdhury, Shahjalal University of Science & Technology, Bangladesh
7. Margherita Costanzo, CNR-ISMAR, Italy
8. Dmitriy Deryagin, Moscow Institute of Physics and Technology/Shirshov Institute of Oceanology, Russia
9. Paige Dillen, University of Hawaii at Manoa, USA
10. *Congju Fu, Institute of Marine Sciences & Sapienza University of Rome, Italy
11. Jorge García, Universitàt de Valencia, Spain
12. Shriya Garg, CSIR National Institute of Oceanography, India
13. Dalia Grendaite, Vilnius University, Lithuania
14. Md Rony Golder, Curtin University, Australia
15. Raphael Mabit, Université du Québec, Canada
16. Julien Masson, Laboratoire d'Océanologie et de Géosciences (LOG) – Wimereux, France
17. Annabeth McCall, Alfred Wegener Institute, Germany
18. Aditi Modi, Indian Institute of Tropical Meteorology, India
19. Mar Roca Mora, Institute of Marine Sciences of Andalusia, Spanish National Research Institute (ICMAN-CSIC), Spain
20. Saritha Parakkil Kongad, Indian Space Research Organization, India
21. Arnab Paul, Louisiana State University, USA
22. Andrea Pellegrino, Sapienza University of Rome/CNR-IREA, Italy
23. Ana Piazza Forgiarini, Federal University of Rio Grande – FURG, Brazil
24. Humeshni Pillay, University of Cape Town, South Africa
25. Ayana S, Indian National Centre For Ocean Information Services (INCOIS), India
26. Ziad Sari El Dine, Centre d'études biologiques de Chizé (CEBC) – CNRS, La Rochelle Université, France
27. Eva Scrivner, University of Connecticut, USA
28. Maya Sinurat, IPB University Bogor, Indonesia
29. Andrea van Langen Rosón, Gent University and Flanders Marine Institute, Belgium
30. *Hongwuyi Zhao, University of Exeter, United Kingdom

* unable to attend due to visa complications

9 Appendix III – Course Schedule

WEEK #1		
Date	**Subject**	**Lecturer(s)**
Sunday 3 Nov 2024 Participants arrive in Hyderabad		
OPENING - 6th IOCCG Summer Lecture Series		
Monday 4 Nov 2024		
09h00 - 09h10	Welcome & Logistics	INCOIS, Nimit Kumar
09h10 - 09h30	Introduction to IOCCG	Shubha Sathyendranath
09h30 - 10h45	Brief student introductions (~5 min each) - (15 students)	Students
10h45 - 11h15	Coffee Break	
11h15 - 12h30	Brief student introductions (~5 min each) - (15 students)	Students
12h30 - 14h00	Lunch break	
14h00 - 15h30	The nature and properties of light	Dariusz Stramski
15h30 - 16h00	Coffee Break	
16h00 - 17h30	Practical: playing with light	Mike Twardowski / Wayne Slade / ZhongPing Lee
Inherent optical properties, scattering		
Tuesday 5 Nov 2024		
09h00 - 10h30	Interaction of light and matter	Dariusz Stramski
10h30 - 11h00	Coffee Break	
11h00 - 12h30	Introduction to IOPs	ZhongPing Lee
12h30 - 14h00	Lunch break	
14h00 - 15h30	Ocean Scattering	Mike Twardowski
15h30 - 16h00	Coffee Break	
16h00 - 17h30	Inversion of IOPs from Rrs	ZhongPing Lee
18h30 - 20h30	Welcome ice-breaker	
Inherent optical properties, scattering		
Wednesday 6 Nov 2024		
09h00 - 10h30	Optics of Marine Particles	Dariusz Stramski
10h30 - 11h00	Coffee Break	
11h00 - 12h30	Application of IOPs	ZhongPing Lee
12h30 - 14h00	Lunch break	

14h00 - 15h30	Practical: AC-lab (1/4)	Mike Twardowski / Matthew Slivkoff / Wayne Slade
15h30 - 16h00	Coffee Break	
16h00 - 17h30	Practical: AC-lab (2/4)	Mike Twardowski / Matthew Slivkoff / Wayne Slade
Radiometry, Apparent optical properties and radiative transfer		
Thursday 7 Nov 2024		
09h00 - 10h30	Radiometry and apparent optical properties (AOPs), fundamentals	David Antoine
10h30 - 11h00	Coffee Break	
11h00 - 12h30	Introduction to Radiative Transfer Theory and Numerical Modelling	John Hedley
12h30 - 14h00	Lunch break	
14h00 - 15h30	Practical Session - HydroLight Lab	John Hedley
15h30 - 16h00	Coffee Break	
16h00 - 17h30	Practical Session - HydroLight Lab	John Hedley
Radiometry, Apparent optical properties and radiative transfer		
Friday 8 Nov 2024		
09h00 - 10h30	Radiometry, apparent optical properties, measurements & uncertainties	David Antoine
10h30 - 11h00	Coffee Break	
11h00 - 12h30	Inexpensive but robust approaches for determining optical and biogeochemical properties	Mike Twardowski / Wayne Slade
12h30 - 13h45	Lunch break	
14h00 - 15h30	Practical: AC-lab (3/4)	Mike Twardowski / Matthew Slivkoff / Wayne Slade
15h30 - 16h00	Coffee Break	
16h00 - 17h30	Ocean colour applications in the Indian Ocean Region	Aneesh Lotliker
Wider context		
Saturday 9 Nov 2024		
09h00 - 10h00	Past, present and future of satellite OCR	David Antoine
10h30 - 11h00	Overview: UN Ocean Decade & satellite OCR	Nimit Kumar
10h30 - 11h00	Coffee Break	
11h00 - 12h30	Practical: AC-lab (4/4)	Mike Twardowski / Matthew Slivkoff / Wayne Slade
12h30 - 14h00	Lunch break & FREE	

WEEK #2		
Date	**Subject**	**Lecturer(s)**
Sunday 10 Nov 2024 FREE		
Atmospheric corrections & in-water constituents		
Monday 11 Nov 2024		
09h00 - 10h30	Atmospheric corrections of satellite OCR observations (1/2)	David Antoine
10h30 - 11h00	Coffee Break	
11h00 - 12h30	Atmospheric corrections of satellite OCR observations (2/2)	David Antoine
12h30 - 14h00	Lunch break	
14h00 - 15h30	Designing and building ocean optical instruments	Wayne Slade
15h30 - 16h00	Coffee Break	
16h00 - 17h30	Practical on IOPs and impact on Rrs	David Antoine
Applications		
Tuesday 12 Nov 2024		
09h00 - 10h30	Shallow water remote sensing	John Hedley
10h30 - 11h00	Coffee Break	
11h00 - 12h30	Phytoplankton community composition derived from optics and remote sensing	Lachlan McKinna
12h30 - 14h00	Lunch break	
14h00 - 15h30	Marine primary production	Shubha Sathyendranath
15h30 - 16h00	Coffee Break	
16h00 - 17h30	Application of satellite OCR to ecosystems and human health	Shubha Sathyendranath
19h00- late	Group dinner	
PACE PRACTICALS		
Wednesday 13 Nov 2024		
09h00 - 10h30	Perspectives on hyperspectral optics and remote sensing	Lachlan McKinna
10h30 - 11h00	Coffee Break	
11h00 - 12h30	Practical on application of PACE data	Lachlan McKinna
12h30 - 14h00	Lunch break	
14h00 - 15h30	Practical on application of PACE data	Lachlan McKinna

15h30 - 16h00	Coffee Break	
16h00 - 17h30	Practical on application of PACE data	Lachlan McKinna
COPERNICUS PRACTICALS		
Thursday 14 Nov 2024		
09h00 - 10h30	Harmful algal blooms	Ana Ruescas
10h30 - 11h00	Coffee Break	
11h00 - 12h30	Practical on satellite datasets: coastal and inland waters	Ana Ruescas
12h30 - 14h00	Lunch break	
14h00 - 15h30	Practical on satellite datasets: coastal and inland waters	Ana Ruescas
15h30 - 16h00	Coffee Break	
16h00 - 17h30	Practical on satellite datasets: coastal and inland waters	Ana Ruescas
STUDENT PRESENTATIONS		
Friday 15 Nov 2024		
09h00 - 10h30	Student presentations	Students
10h30 - 11h00	Coffee Break	
11h00 - 12h30	Student presentations	
12h30 - 14h00	Lunch break	
14h00 - 15h30	Student presentations	
15h30 - 16h00	Coffee Break	
16h00 - 17h00	Student presentations	
17h00 - 17h30	Closing	
CLOSURE - 6th IOCCG Summer Lecture Series		
Saturday 16 Nov 2024 Participants leave Hyderabad		

10 Appendix IV – Lectures Synopses

10.1 The nature and properties of light

Monday 4 November 2024 14.00-15.30

Lecturer: Dariusz Stramski

- Dual wave-particle nature of light
    - Classical electromagnetic-wave description of light (Maxwell equations, wavelength, frequency, phase velocity, radiant energy, Poynting vector)
    - Particle-photon description of light (photoelectric effect, photon energy, single- photon interference)
    - Electromagnetic-photon spectrum
- Polarization properties of light
- Wave-like optical phenomena: interference, reflection, refraction, diffraction

Useful reading material:

- Mobley, C. et al., Ocean Optics Web Book, https://www.oceanopticsbook.info/
- Mobley, C. The Oceanic Optics Book, https://ioccg.org/wp-content/uploads/2022/01/mobley-oceanicopticsbook.pdf

Textbooks:

- Hecht, E., Physics, Brooks/Cole Publishing Co, 1994.
- Hecht, E., Optics, Addison-Wesley, 1998.
- Johnsen, S. 2012. The Optics of Life, A Biologist's Guide to Light in Nature. Princeton University Press.
- Woźniak, B. and J. Dera. 2007. Light Absorption in Sea Water. Springer.
- Jonasz, M. and G. R. Fournier. 2007. Light Scattering by Particles in Water. Theoretical and Experimental Foundations. Academic Press.

10.2 Practical: playing with light

Monday 4 November 2024 16.00-17.30

Practical with Mike Twardowski, Wayne Slade & Zhongping Lee.

Prepared by Emmanuel Boss

Hand-on practical to explore the properties of light when encountering matter (reflection, refraction, diffraction, absorption, fluorescence) and the interaction with some of the instrumentation we use (lenses, polarizers, diffraction grating). Students will divide into small groups and will migrate through the stations where written material will provide guiding questions and instructions of the relevance of the station to our science.

10.3 Interaction of light and matter

Tuesday 5 November 2024 9.00-10.30

Lecturer: Dariusz Stramski

- Emission of light/radiant energy, basic radiation laws (Planck, Stefan-Bolzmann & Wien's laws, solar radiation, Earth radiation)
- Absorption of light/radiant energy (quantized internal energy of atoms and molecules, basic features of absorption by molecular water and pigments)
- Scattering of light/radiant energy (oscillating dipole, elastic and inelastic scattering, basic features of molecular and particle scattering)

10.4 Inherent Optical Properties: Basics, Inversion, and Applications

Tuesday 5 November 2024 11.00-12.30, 16.00-17.30

Wednesday 6 November 2024 11.00-12.30

Lecturer: Zhongping Lee

Inherent optical properties (IOPs) play a central role in radiative transfer, which is the linkage (or bridge) between ocean color (water-leaving radiance) and biogeochemical properties (biomass, suspended matter, colored dissolved materials, etc.). In my presentations, I will describe the basics of IOPs, such as the absorption characteristics of pure (sea)water, phytoplankton, and gelbstoff, as well as the scattering characteristics of pure (sea)water and particles. Further, details will be discussed regarding the inversion algorithms of IOPs, which will include simple empirical algorithms, AI-based algorithms, and algorithms based on radiative transfer. From these, examples of the applications of IOPs products will be introduced. These talks are expected to present a complete picture regarding the concept of IOPs and their values in ocean-color remote sensing.

10.5 Ocean Scattering

Tuesday 5 November 2024 14.00-15.30

Lecturer: Mike Twardowski

This lecture will provide more detail on the Inherent Optical Property of Scattering, ranging from theory, to measurement and closure, to interpretation in terms of ocean biogeochemistry. Background material for the lectures can be found in section 3.8 of Mobley (1994) Light and Water, and in Ch. 4 of Kirk (1994) Light and Photosynthesis in Aquatic Ecosystems.

Part 1: Scattering background

Theory, definitions, and sources of scattering in water will be reviewed in this lecture. Angular, spectral, and polarization properties of scattering will be discussed. A detailed examination of aspects involved in measuring scattering will be provided, including technological considerations.

Part 2: Interpretation of scattering

Distributions, variability, and closure for scattering properties will be discussed. State-of-the-art knowledge in measurement of the volume scattering function and the relation of scattering to ocean biogeochemical properties will be presented. Various applications for scattering will be briefly touched on, including passive and active remote sensing, particle field characterization, and imaging. The lecture will conclude with a discussion of current issues and gaps in our understanding of ocean scattering.

References (copies of papers below are inside this Google folder):

- Stramski, D., and Kiefer, D. A. 1991. Light scattering by microorganisms in the open ocean. Progress in Oceanography, 28, 343–383.
- Stramski, D. E. Boss, D. Bogucki, and K. Voss. 2004. The role of seawater constituents in light backscattering in the ocean. Progress in Oceanography, 61:27–56.
- Sullivan, J., M. Twardowski, J.R.V. Zaneveld, and C. Moore. 2013. Measuring optical backscattering in water, In: A. Kokhanovsky (Ed), Light Scattering Reviews 7: Radiative Transfer and Optical Properties of Atmosphere and Underlying Surface, Springer Praxis Books, DOI 10.1007/978-3-642-21907-8_6, pp. 189-224.
- Twardowski, M.S., E. Boss, J.B. Macdonald, W.S. Pegau, A.H. Barnard, and J.R.V. Zaneveld. 2001. A model for estimating bulk refractive index from the optical backscattering ratio and the implications for understanding particle composition in Case I and Case II waters. Journal of Geophysical Research, 106(C7):14,129-14,142.
- Twardowski, M.S., H. Claustre, S.A. Freeman, D. Stramski, and Y. Huot. 2007. Optical backscattering properties of the “clearest” natural waters. Biogeosciences, 4, 1041–1058, www.biogeosciences.net/4/1041/2007/.
- Twardowski, M., X. Zhang, S. Vagle, J. Sullivan, S. Freeman, H. Czerski, Y. You, L. Bi, and G. Kattawar. 2012. The optical volume scattering function in a surf zone inverted to derive sediment and bubble particle subpopulations, Journal of Geophysical Research, 117, C00H17, doi:10.1029/2011JC007347.

10.6 Optics of Marine Particles

Wednesday 6 November 2024 9.00-10.30

Lecturer: Dariusz Stramski

- Linkage between the single-particle and bulk optical properties
- Absorption and scattering properties of individual particles
- Dependence of particle optical properties on physical and chemical characteristics of particles
- Optical properties of various types of marine particles
- Understanding the roles of various types of particles in ocean optics: from rudimentary approaches such as chlorophyll-based approach to higher-level approaches such as reductionist approach

Useful reading material:

- Mobley, C. et al., Ocean Optics Web Book, https://www.oceanopticsbook.info/
- Mobley, C. The Oceanic Optics Book, https://ioccg.org/wp-content/uploads/2022/01/mobley-oceanicopticsbook.pdf
- Morel, A. and A. Bricaud. 1981. Theoretical results concerning light absorption in a discrete medium and application to specific absorption by phytoplankton. Deep-Sea Res., 28, 1375-1393.
- Bricaud, A. and A. Morel. 1986. Light attenuation and scattering by phytoplanktonic cells: A theoretical modeling. Appl. Opt., 25, 571-580.
- Morel, A. and A. Bricaud. 1986. Inherent optical properties of algal cells including picoplankton: Theoretical and experimental results, p. 521-555. In Photosynthetic picoplankton, Can. Bull. Fish. Aquat. Sci. 214.
- Stramski, D., and A. Morel. 1990. Optical properties of photosynthetic picoplankton in different physiological states as affected by growth irradiance. Deep-Sea Res., 37, 245-266.
- Morel, A. and Y-H. Ahn. 1991. Optics of heterotrophic nanoflagellates and ciliates. A tentative assessment of their scattering role in oceanic waters compared to those of bacterial and algal cells. J. Mar. Res., 49, 177-202.
- Stramski, D., and D. A. Kiefer. 1991. Light scattering by microorganisms in the open ocean. Prog. Oceanogr., 28, 343-383.
- Mobley, C. D., and D. Stramski. 1997. Effects of microbial particles on oceanic optics: Methodology for radiative transfer modeling and example simulations. Limnol. Oceanogr., 42, 550-560.
- Stramski, D., A. Bricaud, and A. Morel. 2001. Modeling the inherent optical properties of the ocean based on the detailed composition of planktonic community. Appl. Opt., 40, 2929-2945.
- Terrill, E. J., W. K. Melville, and D. Stramski. 2001. Bubble entrainment by breaking waves and their influence on optical scattering in the upper ocean. J. Geophys. Res., 106, 16815-16823.
- Babin, M. and D. Stramski. 2004. Variations in the mass-specific absorption coefficient of mineral particles suspended in water. Limnol. Oceanogr., 49, 756-767.
- Stramski, D., and S. B. Woźniak. 2005. On the role of colloidal particles in light scattering in the ocean. Limnol. Oceanogr., 50, 1581-1591.

10.7 Practical: AC-lab

Wednesday 6 November 2024 14.00-17.30

Friday 8 November 2024 14.00-15.30

Saturday 9 November 2024 11.00-12.30

Leaders: Mike Twardowski, Matthew Slivkoff & Wayne Slade

Practical manual with full instructions and supplementary material are available inside this Google folder.

10.8 Radiometry and apparent optical properties (AOPs), fundamentals

Thursday 7 November 2024 9.00-10.30

Lecturer: David Antoine

The *inherent optical properties* (IOPs) will have been defined in lectures before this one. Here we will define the radiometric quantities, namely the radiance and various irradiances, which describe the light field within the water, and from which the *apparent optical properties* (AOPs) can be derived (reflectances, diffuse attenuation coefficients etc..).

This lecture will review the radiometric variables and most commonly used AOPs in optical oceanography and ocean colour remote sensing, how they relate to the IOPs and will also illustrate how they vary in the natural environment and how we measure them.

Suggested readings:

- Essentially everything can be found in the Light and Radiometry chapter of the Ocean Optics Web Book at www.oceanopticsbook.info/view/light_and_radiometry
- The pages on AOPs, reflectances, and K functions beginning at www.oceanopticsbook.info/view/overview_of_optical_oceanography/apparent_optical_properties

If you have more appetite:

- Mobley CD, 1994. Light and Water: Radiative Transfer in Natural Waters, Academic press.
- https://ioccg.org/wp-content/uploads/2020/09/gordon-book_nov_2019_with_doi.pdf

Also:

- Morel, A. and R.C. Smith (1982) Terminology and units in optical oceanography, Marine Geodesy, 5, 335-349.
- Remote Sensing of Coastal Aquatic Environments, Technologies, Techniques and Applications. Editors: Miller, Richard L., Del Castillo, Carlos E., McKee, Brent A. (Eds). Kluwer Publishing. A number of chapters in this book are relevant here:

10.9 Intro to Radiative Transfer Theory and Numerical Modelling

Thursday 7 November 11.00-12.30

Lecturer: John Hedley

Radiative transfer theory describes how light interacts with materials and hence propagates in the natural environment. It is what connects the optical properties of materials to the actual light fields that occur in nature, and to measurable radiometric properties such as reflectances. Radiative transfer models embody this theory and permit numerical modelling of the propagation of light in water and the resulting remote-sensing reflectance. Such models are essential for studies in ocean optics, and have uses in algorithm development, optical closure experiments, and as components of ecosystem models.

This lecture will provide a brief primer in radiative transfer theory, sufficient to understand the nature of the problem to be solved and the benefits and drawbacks of the different modelling approaches available. The software HydroLight is a well-known and commonly used radiative transfer model in ocean optics; I will describe the theoretical structure of the model and the practicalities of using it. The inputs, outputs, functions and limitations of HydroLight will be reviewed. The underlying solution method used in HydroLight is different to the majority of other available models, understanding this is key to understanding the advantages HydroLight provides, but also its limitations. The importance of accurate light calculations in ecosystem models will also be discussed.

References:
https://www.oceanopticsbook.info/view/radiative-transfer-theory/level-2/hydrolight

10.10 Practical Session - HydroLight Lab

Thursday 7 November 14.00-17.30

Lecturer: John Hedley

A demo version of HydroLight will be supplied which can be installed on students' laptops (MS Windows or Mac). The software is fully functional but the license will expire at the end of the course. The session will start with a demonstration of typical HydroLight usage drawing attention to some of the options and available outputs. Students can then run HydroLight on a series of suggested exercises designed to consolidate their understanding of hydrological optics and how AOPs depend on IOPs. Various simulations can be run, using standard bio-optical models for Case 1 waters, Case 2 waters or shallow waters with a given bottom type. Students with experience of HydroLight can also use this opportunity to discuss one-to-one any specific questions they may have. HydroLight can continue to be used after this session until the end of the course and I will also be available until the end of the course to answer any further questions.

References:

- HydroLight 6.0 Users' Guide and HydroLight 6.0 Technical Documentation. These can be downloaded at the bottom of this page: https://www.numopt.com/hydrolight.html

10.11 Radiometry, apparent optical properties, measurements & uncertainties

Friday 8 November 2024 9.00-10.30

Lecturer: Matthew Slivkoff

Recap of the radiometric measurement fundamentals of radiance and irradiance and description of the different design principles used in multispectral and hyperspectral radiometers. Includes radiometric calibration uncertainties and uncertainties associated with practical oceanographic AOP deployment techniques and subsequent data analysis.

Some suggested readings:

- Mueller, J. L., et al. (2003). Instrument Specifications, Characterisation and Calibration. Ocean Optics Protocols For Satellite Ocean Color Sensor Validation, Revision 4. J. L. M. a. G. S. F. a. C. R. McClain. Greenbelt, Maryland, National Aeronautical and Space Administration. II: 1-57.
- Talone, M., et al. (2016). "Stray light effects in above-water remote-sensing reflectance from hyperspectral radiometers." Applied Optics 55(15): 3966-3977. https://doi.org/10.1364/AO.55.003966
- Zaneveld, J. R., et al. (2001). "Influence of surface waves on measured and modeled irradiance profiles." Applied Optics 40(9): 1442-1449. https://doi.org/10.1364/AO.40.001442
- D'Alimonte, D., et al. (2013). "Regression of in-water radiometric profile data." Optics Express 21(23): 27707-27733. https://doi.org/10.1364/OE.21.027707
- D'Alimonte, D., et al. (2018). "Effects of integration time on in-water radiometric profiles." Optics Express 26(5): 5908-5939. https://doi.org/10.1364/OE.26.005908

10.12 Inexpensive but robust approaches for determining optical and biogeochemical properties

Friday 8 November 2024 11.00-12.30

Lecturers: Mike Twardowski & Wayne Slade.

This lecture will introduce inexpensive approaches to carrying out ocean optics research with acceptable accuracies for many applications. Approaches include viewing a black disk horizontally, using a secchi disk, and using a Forel-Ule color scale. We will discuss ways a cell phone may be used for optics research. Possibilities of developing inexpensive sensors with readily available technologies will also be discussed.

References (copies of papers below are inside this Google folder):

- Hou et al. (2007)
- Kilroy and Biggs (2002)
- Lee et al. (2015)
- Leeuw and Boss (2018)
- Leeuw et al. (2013)

- Pitarch et al. (2019)
- Zaneveld and Pegau (2003)

10.13 Ocean colour applications in the Indian Ocean Region

Friday 8 November 2024 16.00-17.30

Lecturer: Aneesh Lotliker

10.14 Past, present and future of satellite OCR

Saturday 9 November 2024 9.00-10.00

Lecturer: David Antoine

This lecture will cover:

- A reminder of some basics about how ocean colour sensors work.
- A historical review of the steps taken towards developing the present day capability, and the future of passive Ocean Colour Radiometry.
- Present complementary solutions to low-Earth orbit passive OCR that have already started to be developed, including sensors on geostationary orbits, polarimeters, and satellite-borne Lidars, and give an overview of the scientific and technical challenges behind developing these new capabilities

Suggested readings:

- Acker J., 2015, "The color of the atmosphere with the ocean below: a history of NASA's ocean color missions". CreateSpace Independent Publishing Platform, USA ©2015, ISBN:1507699220 9781507699225
- Loisel H, L. Duforet, D. Dessailly, M. Chami, and P. Dubuisson, 2008. Investigation of the variations in the water leaving polarized reflectance from the POLDER satellite data over two biogeochemical contrasted oceanic areas," Opt. Express 16(17), 12905–12918. https://doi.org/10.1364/OE.16.012905
- Hostetler, CA, et al., 2018. Spaceborne Lidar in the Study of Marine Systems. Annu. Rev. Mar. Sci. 2018. 10:121–47. https://doi.org/10.1146/annurev-marine-121916-063335
- Choi, JK, et al., 2012, GOCI, the world's first geostationary ocean color observation satellite, for the monitoring of temporal variability in coastal water turbidity, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 117, C09004, https://doi.org/10.1029/2012JC008046
- IOCCG (2012). Ocean-Colour Observations from a Geostationary Orbit. Antoine, D. (ed.), Reports of the International Ocean-Colour Coordinating Group, No. 12, IOCCG, Dartmouth, Canada.

10.15 Overview of the UN Ocean Decade and link to satellite OCR

Saturday 9 November 2024 10.30-11.30

Lecturer: Nimit Kumar

10.16 Atmospheric corrections, 1&2

Monday 11 November 2024 9.00-12.30

Lecturer: David Antoine

As far as satellite ocean colour is concerned “Atmospheric correction” refers to the process by which most of the recorded signal (~90-95%) has to be estimated before being subtracted to access the remaining part (5-10%), which is the marine signal of interest. The quality (accuracy) of this process is therefore crucial for successful retrieval of the marine reflectances, and of any product derived from these reflectances.

The lecture will address:

- The accuracy requirements for atmospheric correction of satellite OCR. What an algorithm has to achieve to be qualified for OCR atmospheric correction?
- What the total signal measured by the sensor is made of, and how the various contributions vary spectrally
- Some basic principles of OCR atmospheric corrections
- How OCR atmospheric correction can be performed under simplified assumptions in a number of situations
- How most modern OCR atmospheric correction schemes work
- Alternative approaches to the “aerosol-model-based” schemes
- Under which conditions modern OCR atmospheric correction schemes still fail
- Current issues (turbid waters, absorbing aerosols, high spatial resolution sensors)

Suggested readings:

- Gordon, H. R. (1997), Atmospheric correction of ocean color imagery in the Earth observing system era, J. Geophys. Res., 102, 17081-17106. https://doi.org/10.1029/96JD02443
- Antoine, D. and A. Morel (1999), A multiple scattering algorithm for atmospheric correction of remotely-sensed ocean colour (MERIS instrument) : principle and implementation for atmospheres carrying various aerosols including absorbing ones, Int. J. Remote Sensing, 20, 1875-1916. https://doi.org/10.1080/014311699212533
- IOCCG (2010). Atmospheric Correction for Remotely-Sensed Ocean-Colour Products. Wang, M. (ed.), Reports of the International Ocean-Colour Coordinating Group, No. 10, IOCCG, Dartmouth, Canada.
- IOCCG (2012). Mission Requirements for Future Ocean-Colour Sensors. McClain, C. R. and Meister, G. (eds.), Reports of the International Ocean-Colour Coordinating Group, No. 13, IOCCG, Dartmouth, Canada.

10.17 Designing and building ocean optical instruments

Monday 11 November 2024 14.00-15.30

Lecturer: Wayne Slade

This lecture will explore the "whys," "whats," and "hows" of designing and building instrumentation to make measurements in ocean optics research. Why are optical measurements so useful as proxies for properties of ocean constituents? What properties of light can we use to most effectively probe the oceans? How do we combine various optical components, electronics, and algorithms to build instruments?

10.18 Shallow water remote sensing

Tuesday 12 November 2024 9.00-10.30

Lecturer: John Hedley

This lecture will discuss marine remote sensing applications that depend on the visibility of the bottom, such as deriving bathymetry or benthic mapping of coral reefs and seagrasses with high spatial resolution imagery (pixels < 30 m). A wide range of techniques have been applied to these objectives, from fully empirical to those based on radiative transfer models, and machine learning. However many of the challenges and limitations are common to all approaches. Benthic complexity, surface glint, difficulties in atmospheric correction and spatial variability in IOPs all contribute to the challenge of deriving meaningful information. In this lecture I will discuss some of these issues, and give an overview of some of the practical methods that can be applied and their limitations. I will also discuss how uncertainty propagation can be used to give an indication of when these limitations are approached.

References:

- Kutser T, Hedley J, Giardino C, Roelfsema C, Brando VE (2020). Remote sensing of shallow waters – A 50 year retrospective and future directions. Remote Sensing of Environment 240, 111619. https://doi.org/10.1016/j.rse.2019.111619 [access it here]
- Hedley JD, Roelfsema CM, Chollett I, Harborne AR, Heron SF, Weeks S, et al. (2016) Remote sensing of coral reefs for monitoring and management: A review. Remote Sensing 8: 118-157. https://doi.org/10.3390/rs8020118
- Hedley JD, Roelfsema C, Brando V, Giardino C, Kutser T, Phinn S, et al. (2018) Coral reef applications of Sentinel-2: coverage, characteristics, bathymetry and benthic mapping with comparison to Landsat 8. Remote Sensing of Environment 216, 598–614. https://doi.org/10.1016/j.rse.2018.07.014
- Dekker A, Phinn S, Lyons M, Roelfsema C, Anstee J, Bissett P, et al. (2011) Intercomparison of methods for physics-based shallow water remote sensing. Limnology and Oceanography Methods 9: 396-425. https://doi.org/10.4319/lom.2011.9.396
- Kay S, Hedley JD, Lavender S. (2009) Sun glint correction of high and low spatial resolution images of aquatic scenes: a review of methods for visible and

near-infrared wavelengths. Remote Sensing 1, 697-730. https://doi.org/10.3390/rs1040697

10.19 Phytoplankton community composition derived from optics and remote sensing

Tuesday 12 November 2024 11.00-12.30

Lecturer: Lachlan McKinna

Phytoplankton form the foundation of the marine food web and play a crucial role in marine biogeochemical cycling. Phytoplankton are diverse, with different types filling ecological roles that can affect the marine carbon cycle, fisheries and aquaculture, human health, and water resources. Morphology, size, and pigment composition can be used to distinguish phytoplankton types with optics and remote sensing. Accordingly, ongoing efforts spanning the past two decades have focused on developing optical observing technologies and analysis methods for estimating phytoplankton community composition. In this lecture we will explore contemporary approaches, both in situ optics and remote sensing, and future directions.

Topics covered

- A historical overview of deriving phytoplankton community composition with optics and remote sensing.
- Contemporary technology and measurement approaches: in situ and remote sensing.
- Analysis methods, algorithms, and data exploration/mining
- Discuss benefits, challenges, and limitations.
- Synergies with modelling and emerging technologies and the path forward
- Applications/case studies.

Some suggested reading:

- Cetinić, I., Rousseaux, C.S., Carroll, I.T., et al., 2024. Phytoplankton composition from sPACE: Requirements, opportunities, and challenges. Remote Sensing of the Environment, 302, 113964. https://doi.org/10.1016/j.rse.2023.113964
- IOCCG, 2014. Phytoplankton Functional Types from Space. Sathyendranath, S. (ed.), Reports of the International Ocean-Colour Coordinating Group, No. 15, IOCCG, Dartmouth, Canada.
- Kutser, T., Metsamaa, L., Dekker, A.G., 2008. Influence of the vertical distribution of cyanobacteria in the water column on the remote sensing signal. Estuarine, Coastal and Shelf Science, 78, 649-654. https://doi.org/10.1016/j.ecss.2008.02.024
- Mouw, C.B., Hardman-Mountford, N.J., Alvain, S., et al., 2017. A Consumer's Guide to Satellite Remote Sensing of Multiple Phytoplankton Groups in the Global Ocean. Frontiers in Marine Science, 4. https://doi.org/10.3389/fmars.2017.00041
- Olson, R.J., Sosik, H.M., 2007. A submersible imaging-in-flow instrument to analyze nano-and microplankton: Imaging FlowCytobot. Limnology and Oceanography: Methods, 5, 195-203. https://doi.org/10.4319/lom.2007.5.195

- Poulton, N.J., 2016. FlowCam: Quantification and Classification of Phytoplankton by Imaging Flow Cytometry. In N.S. Barteneva, I.A. Vorobjev (Eds.), Imaging Flow Cytometry: Methods and Protocols (pp. 237-247). New York, NY: Springer New York.

10.20 Marine primary production

Tuesday 12 November 2024 14.00-15.30

Lecturer: Shubha Sathyendranath

Useful references

- Antoine, D, Morel, A. (1996a) Oceanic primary production. 1. Adaptation of a spectral light-photosynthesis model in view of application to satellite chlorophyll observations. Global Biogeochemical Cycles. 10(1); 43-55.
- Antoine, D, André, J, and Morel, A (1996b) Oceanic primary production. II. Estimation at global scale from satellite (Coastal Zone Color Scanner) chlorophyll. Global Biogeochemical Cycles, 10(1): 57–69.
- Behrenfeld MJ, Boss E, Siegel D, and Shea DM (2005) Carbon-based ocean productivity and phytoplankton physiology from space. Global Biogeochemical Cycles 19. https://doi.org/10.1029/2004GB002299.
- Bouman, H, Platt, T, Sathyendranath, S, and Stuart,V (2005) Dependence of light-saturated photosynthesis on temperature and community structure. Deep-Sea Res. I, 52: 1284-1299
- Bouman, HA, Platt, T, Doblin, M, Figueiras, MG, Gudmundsson, K, Gudfinnsson, HG, Huang, B, Hickman, A, Hiscock, M, Jackson, T, Lutz, VA, Mélin, F, Rey, F, Pepin, P, Segura, V, Tilstone, GH, van Dongen-Vogels, V, Sathyendranath, S (2018) Photosynthesis–irradiance parameters of marine phytoplankton: synthesis of a global data set. Earth Syst. Sci. Data, 10: 251–266. https://doi.org/10.5194/essd-10-251-2018
- Bouman HA, Jackson T, Sathyendranath S, Platt T (2020) Vertical structure in chlorophyll profiles: influence on primary production in the Arctic Ocean. Philosophical Transactions A of the Royal Society, 378: 20190351. http://dx.doi.org/10.1098/rsta.2019.0351
- Brewin, RJW, Tilstone, GH, Jackson, T, Cain, T, Miller, PI, Lange, PK, Misra, A, and Airs, R.L. (2017). Modelling size-fractionated primary production in the Atlantic Ocean from remote sensing. Progress in Oceanography, 158, pp.130-149.
- Brewin, RJW, Sathyendranath, S, Platt, T, Bouman, H, Ciavatta, S, Dall'Olmo, G, Dingle, J, Groom, S, Jönsson, B, Kostadinov, TS, Kulk, G, Laine, M, Martínez-Vicente, V, Psarra, S, Raitsos, DE, Richardson, K, Rio, M-H, Rousseaux, CS, Salisbury, J, Shutler, JD, Walker, P Sensing the ocean biological carbon pump from space: A review of capabilities, concepts, research gaps and future developments. Earth-Science Reviews 217 (2021) 103604. https://doi.org/10.1016/j.earscirev.2021.10360
- Chisholm, SW, and Morel, FMM (1991) What controls phytoplankton production in nutrient-rich areas of the open Sea? Limnology and Oceanography. Volume 36.
- Cox, I, Robert J. W. Brewin, RJW, Dall'Olmo, G, Sheen, K, Sathyendranath, S, Rasse, R, Ulloa, O (2023) Distinct habitat and biogeochemical properties of low-oxygen-adapted tropical oceanic phytoplankton. Limnol. Oceanogr. 9999: 1–18. https://doi.org/10.1002/lno.12404
- Eppley, RW (1972) Temperature and phytoplankton growth in the sea. Fishery Bulletin, 70.
- Claustre, H, Babin, M, Merien, D, Ras, J, Prieur, L, Dallot, S, Prasil, O, Dousova, H, and Moutin, T (2005) Towards a taxon-specific parameterization of bio-optical models of primary production: a case study in the North Atlantic. J. Geophys. Res., 110. C07S12
- Falkowski, PG, and Woodhead, AD (1992) Primary productivity and biogeochemical cycles in the Sea. New York: Plenum Press.
- Field, CB, Behrenfeld, MJ, Randerson, JT, and Falkowski, P (1998) Primary production of the biosphere: Integrating terrestrial and oceanic components. Science, 281(5374):237–240.
- Franks, PJS (2015) Has Sverdrup's critical depth hypothesis been tested? Mixed layers vs. turbulent layers. ICES Journal of Marine Science. 72 (6): 1897–1907. https://doi.org/10.1093/icesjms/fsu175
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- Jackson, T, Sathyendranath, S Platt, T (2017) An exact solution for modelling photoacclimation of the carbon-to-chlorophyll ratio in Phytoplankton. Frontiers in Marine Science. 4:283. https://doi.org/10.3389/fmars.2017.00283
- Kovač, Ž, Platt, T, Sathyendranath, S, Lomas, MW (2018a) Extraction of photosynthesis parameters from time series measurements of in situ production: Bermuda Atlantic Time-Series Study Remote Sensing. Remote Sensing. 10: 915. https://doi.org/10.3390/rs10060915.
- Kovač, Ž, Platt, T, Gladan, ŽN, Morović, M, Sathyendranath S, Raitsos, DE, Grbec, B, Matić, F, Veža, J (2018b) A 55-year time series station for primary production in the Adriatic Sea: data correction, extraction of photosynthesis parameters and regime shifts. Remote Sensing. 10: 1460. https://doi.org/10.3390/rs10091460
- Kulk, G, Platt, T, Dingle, J, Jackson, T, Jönsson, BF, Bouman, HA, Babin, M, Brewin, RJW, Doblin, M, Estrada, M, Figueiras, FG, Furuya, K, González-Benítez, N, Gudfinnsson, HG, Gudmundsson, K, Huang, B, Isada, T, Kovač, Ž, Lutz, VA, Marañón, E, Raman, M, Richardson, K, Rozema, PD, Poll, WH, Segura, V, Tilstone, GH, Uitz, J, Dongen-Vogels, V, Yoshikawa, T, Sathyendranath, S (2020) Primary Production, an Index of Climate Change in the Ocean: Satellite-Based Estimates over Two Decades. Remote Sensing, 12, 826. https://doi.org/10.3390/rs12050826
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- Moore, JK, Doney, SC, Glover, DM, and Fung, IY (2001) Iron cycling and nutrient-limitation patterns in surface waters of the World Ocean., Deep Sea Research Part II: Topical Studies in Oceanography, 49(1-3), 463-507
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- Sathyendranath, S, Stuart, V, Nair, A, Oka, K, Nakane, T, Bouman, H, Forget, MH, Maass, H, and Platt, T (2009) Carbon-to-chlorophyll ratio and growth rate of phytoplankton in the sea. Marine Ecology Progress Series. 383: 73-84.
- Sathyendranath, S, Platt, T, and Jackson, T (2016) Phytoplankton and Primary Productivity Baselines/ IPCC Assessment of Potential Future Impact. Chapter 5.2 in “UNESCO IOC and UNEP (2016). The Open Ocean: Status and Trends”. United Nations Environment Programme, Nairobi, pp. 148-153.
- Sathyendranath, S, Platt, T, Kovač, Ž, Dingle, J, Jackson, T, Brewin, R JW, Franks, P, Marañón, E, Kulk, G, and Bouman, HA (2020) Reconciling models of primary production and photoacclimation [Invited]. Applied Optics, 59: C100-C114. https://doi.org/10.1364/AO.386252

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- Uitz, J., Huot, Y., Bruyant, F., Babin, M., Claustre, H. (2008) Relating phytoplankton photophysiological properties to community structure on large scales. Limnol. Oceanogr., 53 (2) (2008), pp. 614-630
- Uitz, J, Claustre, H, Gentili, B, and Stramski, D (2010) Phytoplankton class-specific primary production in the world's oceans: Seasonal and interannual variability from satellite observations. Global Biogeochemical Cycles, 24(3): 1–19.
- Westberry, T, Behrenfeld, MJ, Siegel, DA, and Boss, E (2008) Carbon-based primary productivity modeling with vertically resolved photoacclimation. Global Biogeochemical Cycles, 22(2) GB2024, doi:10.1029/2007GB003078

10.21 Application of satellite OCR to ecosystems and human health

Tuesday 12 November 2024 16.00-17.30

Lecturer: Shubha Sathyendranath

10.22 Perspectives on hyperspectral optics and remote sensing

Wednesday 13 November 2024 9.00-10.30

Lecturer: Lachlan McKinna

With the launch of NASA's PACE mission in 2024, we have entered the era of hyperspectral ocean color remote sensing. In response, our community has actively been developing advanced approaches for extracting information from spectrally rich measurements to derive novel ocean color data products. The path to PACE has been paved by a decades-long foundation of hyperspectral theory and field measurements (in situ and airborne). We will review the history of hyperspectral optics and remote sensing, the current capabilities, challenges, limitations, and case studies using hyperspectral data.

Topics covered

- A historical overview of hyperspectral optics and remote sensing.
- Hyperspectral radiometer design types.
- Considerations for atmospheric and bio-optical algorithms
- Data volume and processing
- Emerging methodologies (machine learning).
- Case studies: phytoplankton pigments and bio-optics.

Some suggested readings:

- Chase, A.P., Boss, E., Cetinić, I., et al., 2017. Estimation of Phytoplankton Accessory Pigments From Hyperspectral Reflectance Spectra: Toward a Global Algorithm. (Kutser et al., 2008) Journal of Geophysical Research: Oceans, 122, 9725-9743.
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- Kostakis, I., Twardowski, M., Roesler, C., et al., 2021. Hyperspectral optical absorption closure experiment in complex coastal waters. Limnology and Oceanography: Methods, 19, 589-625.

10.23 Practical on application of PACE data

Wednesday 13 November 2024 11:00-17:30

Lecturer: Lachlan McKinna

In this full-day practical, we will briefly review the design and capabilities of the PACE mission’s hyperspectral Ocean Color Instrument (OCI) as well as limitations and challenges. We will use the remainder of the day to explore PACE ocean color data products. We will learn how to search for, order, and download NASA ocean color datasets. We will then visualise and analyse Ocean Color products using NASA’s SeaDAS software. In addition, we will use NASA’s Ocean Color Science Software (OCSSW) to perform multi-level processing to generate level-2 (swath resolution) and level-3 (mapped) products from level-1 (raw) ocean color data. The data processing skills learnt in this practical can be extended to other NASA-supported mission (e.g., SeaWiFS, MODIS-Aqua, VIIRS-NPP).

What you will need before attending:

- Your own laptop (Windows, Mac, or Linux)
- A NASA EarthData account (https://urs.earthdata.nasa.gov)
- SeaDAS installed
- The OCSSW processors installed
- Additional OCSSW data needed for processing OCI, MODIS-Aqua, and SeaWiFS (see installation guide)

Software Installation Information:

- SeaDAS system requirements: https://seadas.gsfc.nasa.gov/requirements/
- SeaDAS 8 Installation guide: https://github.com/seadas/seadas-toolbox/wiki/SeaDAS-8.x-Download,-Installation-and-Run-Instructions
- OCSSW processor installation (Mac or Linux): https://seadas.gsfc.nasa.gov/downloads/#seadas-processing-programs-and-source-code
- OCSSW installation (Windows): https://seadas.gsfc.nasa.gov/client_server/.

Ocean color data resources:

- NASA Ocean Color Web: https://oceancolor.gsfc.nasa.gov
- NASA Ocean Color Level 1&2 Browse: https://oceancolor.gsfc.nasa.gov/cgi/browse.pl
- NASA Ocean Color Level 3&4 Browse: https://oceancolor.gsfc.nasa.gov/l3/
- NASA WorldView: https://worldview.earthdata.nasa.gov
- File naming conventions: https://oceancolor.gsfc.nasa.gov/resources/docs/filenaming-convention/

PACE Mission resources:

- NASA PACE Mission: https://pace.gsfc.nasa.gov
- Get Ready to Work with PACE Data: https://pace.oceansciences.org/work_with_pace_data.htm

Some suggested readings:

- Baith, K., Lindsay, R., Fu, G., et al., 2001. Data analysis system developed for ocean color satellite sensors. Eos, Transactions American Geophysical Union, 82, 202-202. https://doi.org/10.1029/01EO00109
- McClain, C.R., Franz, B.A., Werdell, P.J., 2022. Genesis and Evolution of NASA's Satellite Ocean Color Program. Frontiers in Remote Sensing, 3. https://doi.org/10.3389/frsen.2022.938006
- Meister, G., Knuble, J.J., Gliese, U., et al., 2024. The Ocean Color Instrument (OCI) on the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) Mission: System Design and Prelaunch Radiometric Performance. IEEE Transactions on Geoscience and Remote Sensing, 62, 1-18. https://doi.org/10.1109/TGRS.2024.3383812
- PACE Science Definition Team, 2018. Pre-Aerosol, Clouds, and Ocean Ecosystem (PACE) mission science definition team report. In I. Cetinić, C.R. McClain, P.J. Werdell (Eds.), PACE Technical Report Series Vol. 2. NASA Goddard Space Flight Center. https://ntrs.nasa.gov/citations/20190000977

10.24 Harmful algal blooms

Thursday 14 November 2024 9.00-10.30

Lecturer: Ana Ruescas for Hayley Evers-King

Prepared by Hayley Evers-King

Harmful Algal Blooms, occurring naturally or as the result of human activities, represent a potential threat to ecosystem and human health in coastal regions. Harm can be caused by blooms through a wide range of mechanisms, including through deoxygenation events, presence of various toxins, as well as physical impacts on other organisms and wider ecosystem dynamics. As a result of these impacts, monitoring HABs is a necessary activity for fishery and aquaculture industries, as well as those managing interactions between the public and our oceans (for tourism and recreation etc). Ocean colour remote sensing offers a cost-effective way to monitor HABs at high spatial and temporal resolution. However, developing appropriate methodologies for using data for these applications is challenging. High biomass levels are not captured readily by all sensor types, or within the range of many classic algorithm approaches. Similarly, decision making requires more detailed information relating to the potential sources of harm, such as the presence of certain species, cell sizes, and/or risks relating to persistence. This lecture will look at the challenges facing the application of ocean colour remote sensing to HAB monitoring, and share some of the latest research and operational approaches being developed to address these issues.

10.25 Practical on satellite datasets: coastal and inland waters

Thursday 14 November 2024 11.00-17.30

Lecturer: Ana Ruescas

Prepared by Ana Ruescas, Hayley Evers-King, Ben Loveday

The use of optical remote sensing data has increased dramatically over the last ten years, particularly for coastal and inland waters where impacts between the aquatic environment and human activities may be particularly intense. Many of these waters will be turbid because of high concentrations of suspended particulate matter caused by a variety of processes including high biomass algal blooms, sediment resuspension by wind/tide, river plumes, etc. Within this session the specific challenges and opportunities presented by turbid coastal and inland waters will be presented, where “turbid” is understood here to indicate waters with high particulate scattering. We will also consider the complications of dealing with waters where optical properties are highly variable, from turbid to CDOM-rich and occasionally clearer waters.

There are two major additional difficulties for optical remote sensing in turbid waters. Firstly, atmospheric correction is more difficult because it is not possible to assume zero near infrared marine reflectance (“black pixel assumption”), thus complicating the decomposition of top of atmosphere measurements into atmosphere and water reflectances. Secondly, the optical properties of non-algal particles, such as mineral particles from bottom resuspension or from river discharges, need to be considered in addition to algal particles. If the absorption and scattering of non-algal particles is significant compared to that of algal particles it may become difficult or even impossible to distinguish the optical properties of the algal particles. In such conditions the estimation of chlorophyll a may become severely degraded or suffer from a detection limit problem. In turbid waters both the atmospheric correction and the chlorophyll retrieval problems are highly dependent on the technical specification of the remote sensors being used, and in particular on the spectral band set.

In this session we will embed practical skills needed for working in these waters, including data access and working with open-source software. Participants will be encouraged to take the workflows presented and apply them to an area of interest to share images with the rest of the course.

This topic will be split into 3 parts:

1. Sentinel-3 data offers near daily, multispectral measurements of the open ocean and coastal zones at 300m resolution. Designed for ocean remote sensing specifically, it is used in a growing suite of operational water quality monitoring activities. During a practical exercise, students will learn how to download this data routinely, open it in the SNAP software, and learn about the data characteristics that support use in complex waters.

2. Derivation of accurate reflectances and biogeochemical parameters in complex waters is a challenge. Multiple approaches to atmospheric correction and parameter retrieval have been developed, including some simultaneous approaches using machine learning methods. In this part of the practical, we will look at applying the Case 2 Regional CoastColour (C2RCC) processor, through the SNAP software.

3. The colored dissolved organic matter (CDOM) variable is the standard measure of humic substance in waters optics. CDOM is optically characterized by its spectral absorption coefficient, aCDOM at reference wavelength (e.g., ≈ 440 nm). Retrieval of CDOM is traditionally done using bio-optical models. As an alternative, we will derive CDOM using machine learning methods applied to Sentinel-3 simulated reflectance (Rrs) data. Statistics comparison with other well-established polynomial regression algorithms will be used as validation of the methods. Application to an atmospheric corrected OLCI image using the reflectance derived from the alternative neural network (C2RCC) will also be developed.

In addition to aspects of chlorophyll retrieval in turbid waters, other relevant parameters will be discussed, including diffuse attenuation coefficient, euphotic depth, suspended particulate matter, detection of harmful algal blooms etc. The links with applications in aquatic science and coastal and inland water management will be described.

Requirements for the practicals

- A basic knowledge of the definitions of optical properties (scattering, absorption, attenuation) from other lectures from this IOCCG summer school.

- An account on the EUMETSAT EO portal for accessing OLCI data (https://eoportal.eumetsat.int/)

- An installation of Python that can be used to run Jupyter Notebooks. Details of the installation requirements, and code that will be used are in the following git repositories. Please follow the README instructions within each git repository. Please make sure to clone each of the 3 repositories using the commands provided.

- First install anaconda (further guidance in this video).
- Then clone the repository from your command line prompt (or the anaconda prompt) using the commands in the README.
- Then install the necessary environment in advance of the lecture series – see the README – this is done using an environment file (.yml) provided in each cloned repository.
- For any questions, contact ana.ruescas@brockmann-consult.de and ben.loveday@external.eumetsat.int
- Repository for OLCI tutorials: https://gitlab.eumetsat.int/eumetlab/oceans/ocean-training/sensors/learn-olci
- Repository for forward model tutorials: https://gitlab.com/benloveday/oc_forward_model
- o Repository for machine learning tutorials: https://gitlab.com/benloveday/mlregocean_cdom

- Download and install the latest version of SNAP (https://step.esa.int/main/download/snap-download/), connecting it to your Python executable.

Suitable background reading

- Ocean Optics WebBook https://www.oceanopticsbook.info/view/remote-sensing/ocean-color
- Sentinel-3 knowledge base: https://eumetsatspace.atlassian.net/wiki/spaces/SEN3/overview
- Prior to the practicals, you may wish to go through the introductory notebooks in the learn-olci repository linked above. We will focus on some advanced examples, but the introductory section provides good background for those not familiar with the data.
- Machine Learning Regression Approaches for Colored Dissolved Organic Matter (CDOM) Retrieval with S2-MSI and S3-OLCI Simulated Data, *Remote Sens. 2018, 10(5), 786;* https://doi.org/10.3390/rs10050786.