Ocean Optics Protocols Workshop

October 25, 2014, Holiday Inn By The Bay, Portland, ME

Summary Report

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EXECUTIVE SUMMARY

International interest in the optical properties of natural water bodies has increased over the past several decades with the understanding that knowledge of how light interacts with ocean and inland waters can be used to detect and monitor changes in water quality, e.g., related to harmful algal blooms, sediment transport, and pollution, and to investigate issues of climate change, such as shifts in the global distribution of algal species and biomass and oceanic contributions to the global carbon budget. In response to this interest and in order to support a growing number of ocean color remote sensing missions, The National Atmospheric and Space Administration (NASA) commissioned the development of ocean optical measurement protocols that would serve as international reference standards and permit the collection and assembly of climate quality ocean optical data. Since publication of the last revision in 2004, ocean optical investigations have progressed at an increasing pace, fueled largely by the realization that human-induced climate change is occurring much faster than expected.

Given recent advances in observing capability an international Optics Protocols Workshop was convened in Portland, ME on October 25, 2014 to discuss the existing ocean optical measurement protocols and to establish plans for revising protocols to account for new instruments and modes of deployment. The workshop, supported by the National Aeronautics and Space Administration (NASA) Ocean Biology and Biogeochemistry Program and the International Ocean Color Coordinating Group (IOCCG), was attended by 47 scientists from 13 countries representing academia, government, and industry. The agenda consisted of morning plenary presentations, focusing on current protocols and areas of potential improvement, parameter-specific breakout discussions conducted in the early afternoon, and a final summarization plenary session.

Several areas of cross-cutting consideration were identified that apply to all protocols.

Scope. An expanded definition of protocols was adopted consisting of 1) pre-deployment instrument preparation, 2) best practices for instrument deployment, 3) data reduction and real-time quality assessment methods, and 4) prescriptions for metadata and reporting.

Approach. Revisions will include baseline information within the current protocols, journal articles, technical reports, and field experience accumulated over the past decade. In some cases, additional tests may be required in order to assess the accuracy and confidence of specific properties and associated parameters. However, each protocol will represent a snapshot in time with the understanding that future revisions will be necessary. Thus, protocols must be viewed as progress reports and that protocols should be updated ad needed to reflect advances in the field.

Measurement Uncertainty. The new protocols will discuss and, where possible, quantify the uncertainties involved in the various prescribed steps. Authors will consider methods of cross-referencing procedures so as to inform the reader of why that procedure is recommended as well as the consequences if the procedure is not followed.

Funding. Comprehensive revisions to existing protocols will likely require additional support, either as direct funding for specific tasks or support in kind. Thus, the newly formed IOCCG Protocol Coordination Activity will be a valuable resource, serving as a clearinghouse of protocol information, including emerging opportunities for additional international support.

Reporting. All protocols must be vetted within the international user community and made available through recognized electronic outlets and forums for such information. Summaries of final protocol documents should be published within leading methods journals in open access format.

Not all optical properties were discussed since several are the topic of on-going protocol development, e.g., absorption methodologies for dissolved and particulate matter are currently under review by the NASA Field Support Group (A. Mannino). Those discussed include beam attenuation due to all water impurities c_m, beam attenuation due to particulate matter c_p, the volume scattering function $\beta(\theta)$, with emphasis on backscatter b_b, and in-water and above-water quantities of radiance and irradiance.

Beam Attenuation, c_m and c_p: A writing team of seven participants was formed and Dr. Emmanuel Boss, University of Maine, will serve as coordinator. The target date for a final draft ready for community commentary is June 2015 and a final document is expected to be published by December 2015.

Volume Scattering Function, $\beta(\theta)$ and b_b: A writing team of nine participants was formed and Dr. James Sullivan, WET Labs, Inc., will serve as coordinator. The group expects to have a final draft ready for community commentary by January 2016 and a final published document by June 2016.

In- and Above-Water Radiometry: Dr. Giuseppe Zibordi, Joint Research Centre, Ispra, Italy**,** will serve as coordinator for the above-water writing team and Dr. Kenneth Voss, University of Miami will serve as the coordinator for the in-water writing team. Each discussion group expressed a need for additional support to complete the anticipated revisions. Recommendations for revisions will be solicited from the workshop attendees and a small number will be invited to participate in writing tasks. Outlines of required tasks and writing teams will be formulated by June 2015.

Each group expressed interest in using the joint International Ocean Color Science meeting (IOCS) and NASA Ocean Color Research Team Meeting (OCRT), scheduled to convene in San Francisco, June 2015, as an opportunity to hold face-to-face meetings with members of the writing groups and to present plans and progress to the research community at large.

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1. OVERVIEW

International interest in the optical properties of natural water bodies has increased over the past several decades with the understanding that knowledge of how light interacts with ocean and inland waters can be used to detect and monitor changes in water quality, e.g., related to harmful algal blooms, sediment transport, and pollution, and to investigate issues of climate change, such as shifts in the global distribution of algal species and biomass, and oceanic contributions to the global carbon budget. In response to these potential applications and in order to support a growing number of ocean color remote sensing missions, The National Atmospheric and Space Administration (NASA) commissioned the development of ocean optical measurement protocols that would serve as international reference standards and permit the collection and assembly of climate quality ocean optical data. This work, starting with the initial publication in 1992 (Mueller and Austin, 1992), extended through the following decade, and after four revisions, culminated in a seven volume instruction series (Muller et al., 2003-2004) addressing *in situ* and above-water measurements of inherent and apparent optical properties (see Appendix A: List of Symbols and Acronyms).

Since the publication of revision 4 of the ocean optics protocols, ocean optical investigations have continued internationally at an ever increasing pace, fueled largely by the realization that human-induced climate change is occurring much faster than expected (Pachauri 2014). New instruments have become commercially available to measure more accurately in-water and above-water light fields and *in situ* absorption and scattering properties. Instruments are increasingly being deployed on autonomous platforms, such as moorings, profiling floats, and gliders. New, ocean color satellites have been launched such as the NASA Visible and Infrared Imager Radiometer Suite (Wang et al, 2014), the Hyperspectral Imager for the Coastal Ocean (Lucke et al., 2011), and a Korean, multispectral, geostationary, ocean color imager (Ryu et al., 2012). Additionally, several countries are planning to launch new ocean color satellites in the coming decade, e.g. the NASA Pre-Aerosol, Clouds, and ocean Ecosystem (PACE), Hyspectral Infrared Imager (HyspIRI), and Geostationary Coastal and Air Pollution Events (GEO-CAPE) missions, the European Space Agency Ocean and Land Colour Instrument (OLCI) on Sentinel-3, and the Japan Aerospace Exploration Agency second generation Global Imager (SGLI) on the Global Change Observation Mission – Climate.

In response to these new, emerging, and planned capabilities, an international Optics Protocols Workshop was convened in Portland, ME on October 25, 2014 to discuss the existing ocean optical measurement protocols and to establish plans for updating protocols to account for new methods and instruments, whether from sensors deployed for short periods from research vessels or for extended deployments on autonomous fixed and mobile platforms (moorings, gliders, and profiling floats). To accomplish this, measurement protocol information from the past decade, including journal articles, technical reports published by instrument manufacturers, dedicated workshops and round robin exercises, and user experience will need to be examined and weighed against existing protocols (Fig. 1). Where possible, existing methods must be updated and information gaps filled with new knowledge. The newly drafted protocols must be made available to the user community for testing and commentary since any new procedures would be useless without buy-in from those responsible for collecting future data. Finally, the updated protocols must be made available through open information portals such as dedicated web sites and open access journals.

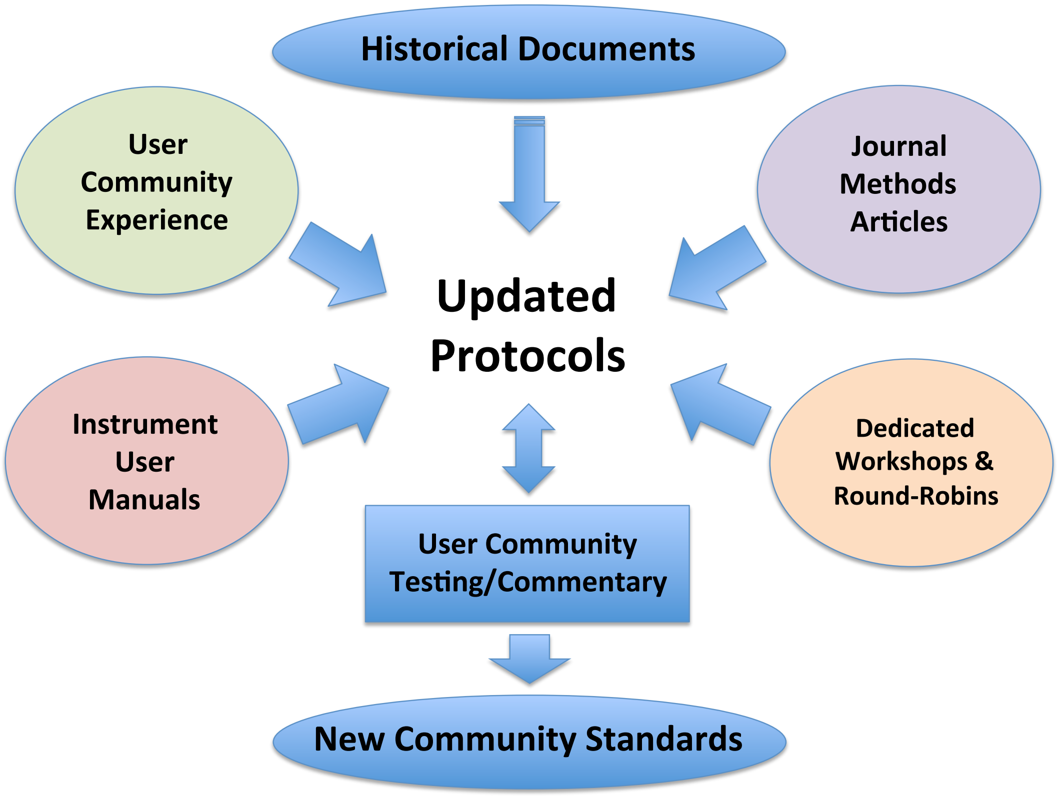

Figure 1. Conceptual approach for updating ocean optics protocols.

The workshop, supported by the NASA Ocean Biology and Biogeochemistry Program and the International Ocean Color Coordinating Group (IOCCG), was attended by 47 ocean optics and ocean color scientists from 13 countries representing academia, government, and industry. At the time that the workshop was initially conceived, potential topics for discussion included all of the optical properties covered in the existing protocols; absorption due to particulate and dissolved matter (a_p and a_g, respectively), attenuation due to water impurities c_m and particulate matter c_p, the volume scattering function $\beta(\theta)$ and the derived scattering b and backscattering b_b coefficients, and subsurface and above-water radiometry used to derive apparent optical properties; downwelling irradiance (E_d), upwelling radiance (L_u), and normalized water-leaving radiance (L_{wn}). However, it was soon realized that other activities have been established to revise the protocols associated with a_p and a_g, (Jeremy Werdell and Antonio Mannino, NASA, personal communication) and it was decided that the workshop should focus on c_m, c_p, $\beta(\theta)$, derivations of b_b, and parameters associated with in-water and above-water radiometry.

Furthermore, it was decided from the start that the discussion would focus solely on optical measurements and not the associated optically important water properties such as chlorophyll *a* concentration and colored dissolved matter.

The workshop was convened coincident with the Ocean Optics XXII conference in order to leverage travel and international participation of ocean optics experts, e.g., researchers, ocean observatory managers, and instrument manufacturers from around the world;. Workshop participants reviewed current protocols, discussed common problems associated with short and long-term sensor deployments, and established parameter-specific working groups that will serve to inform, guide, advise, and review future protocol activities.

The workshop was conducted in coordination with the NOAA Integrated Ocean Observing System Program Office (IOOS) and the NOAA Quality Assurance of Real-Time Oceanographic Data (QARTOD) program, charged with the development of quality assurance and control procedures (QA/QC) for long-term ocean time series measurements, including optical properties. The work was further coordinated with NASA Goddard Space Flight Center Field Support Group activities directed at the development of protocols for laboratory and *in situ* measurements of inherent optical properties.

2. BACKGROUND

Optical and biogeochemical sensors necessary to perform satellite ocean color sensor calibration and product validation and to examine ocean processes controlled by solar energy are increasingly being deployed on fixed and mobile platforms (moorings, gliders, and profiling floats) for extended periods in order to ensure data matchups with satellite observations, link surface observations to subsurface conditions, and to better understand temporal and spatial scales of variability (Gruber et al., 2009; Schofield and Glenn, 2010). It is anticipated that such deployments will continue to proliferate on an international scale and will play key roles in revealing biogeochemical trends within the global ocean linked to climate change and supporting sensor calibration and product validation activities for future ocean color satellite systems, such as the PACE, HyspIRI, GEO-CAPE, and SGLI, OLCI missions.

Problems pertaining to long-term deployments are that optical sensors drift and are prone to biofouling, resulting in degraded and ultimately compromised data. Since 2002, QARTOD has addressed the process of assigning quality flags to physical measurements and has recently published procedures for assessing wave, current, and dissolved oxygen data (Fredericks et al., 2009). However, the assignment of quality flags is only part of the problem. Standardized sensor maintenance and deployment procedures are necessary to ensure climate quality data, regardless of when, where, and by whom it was collected.

NASA, through the Sensor Inter-comparison for Marine Biological and Interdisciplinary Ocean Studies program, published a seven volume series directed at ocean optical and biogeochemical protocols in support of ocean color remote sensing (Mueller et al., 2003-04). While this series stands as a milestone in the standardization of *in situ* ocean optical measurements, it addresses the technology and deployment modes at the time and does not cover sensor maintenance and data quality assurance issues unique to long-term deployments. In addition, technological innovation and a greatly expanded experience base, driven by the ubiquity of autonomous platforms and moored ocean observatories, have added to our knowledge of instrument behavior and approaches to data processing. As such, the 2004 protocols must be re-evaluated and, where necessary, revised and expanded.

The need for standardized, international protocols for ocean observations in general was highlighted at the Ocean Obs 09' conference (Lindstrom et al. 2012). Given the proliferation of sustained optical and biogeochemical sensors deployed on fixed and mobile assets and the expectation that autonomous deployments will continue to increase in the future, an international workshop supported by NASA was convened in June 2012 at the University of Maine, Darling Marine Center, in order to discuss problems associated with sustained deployments and maintenance of optical and biogeochemical sensors. The workshop attracted 25 attendees representing academia, the US Integrated Ocean Observatory System (IOOS), the Australian Integrated Marine Observation System (IMOS), and the European system of ocean observatories. The workshop highlighted the need for standard protocols for deploying and maintaining optical sensors, especially for extended periods, as well as community acceptable approaches to data QA/QC (Boss et al., 2012; http://misclab.umeoce.maine.edu/research/oo/Data_QC_Workshop_Final_Report_2012-08-7.pdf).

Following the initial workshop, the Marine Alliance for Science and Technology for Scotland (MASTS) supported a half-day workshop in Glasgow, Scotland in October 2012 to address emerging optical and biogeochemical sensing capabilities associated with ocean observatories and to continue the discussions initiated at the NASA 2012 workshop. The MASTS workshop attracted 51 experts from around the world representing Australia, Canada, China, France, Germany, Korea, Spain, Sweden, United Kingdom, and United States. The consensus that emerged is that lessons are being learned from sustained deployments of optical sensors around the world and that the oceanographic community must incorporate this new knowledge into international standards for observational methods. The presentation from this workshop can be found at: http://misclab.umeoce.maine.edu/research/research25.php.

Finally, in early 2013, the IOCCG convened a meeting in Darmstadt, Germany to discuss outstanding issues associated with ocean color science. Several splinter discussions were conducted, including one focused on *in situ* optical and biogeochemical protocols in support of sensor calibration and product validation (http://iocs.ioccg.org/wp-content/uploads/splinter6-fargion-protocols.pdf). Among the recommendations that emerged from this meeting are that international protocols and data quality assurance standards need to be established and/or revised for sustained, *in situ*, optical observations in order to support future ocean color missions and ensure the collection of climate-quality data. Of the five high priority needs identified by the splinter group, the most urgent need was assigned to the review and revision of standard measurement protocols for inherent and apparent optical properties.

During the course of these discussions, it became apparent that the problem of insuring accurate and accessible data went well beyond the tasks required to convert sensor signal voltage to valid scientific units. The larger problem of obtaining accurate data and making it widely available can be described as a four-step sequence (Fig. 2). The first step is directed at understanding how sensors are to be deployed within a given environment in order to observe phenomena of interest and includes the preparation of sensors to operate accurately within that environment such as pre-deployment sensor calibration and measures, if necessary, to limit the impact of bio-fouling. Once deployed, the second step insures that the sensor suite functions simultaneously and unobtrusively, observing with multiple sensors as near identical water parcels as possible, non-destructively and within the expected scales of temporal and/or spatial variability as possible. This step is critical to insure maximum compatibility across multiple data streams and to accurately characterize the unperturbed ocean condition. The third step addresses data quality assurance through the assignment of confidence bounds and quality flags based on, for example, post-deployment instrument calibration and inter-comparison of multiple data streams with a priori knowledge of parameter co-variability. The final step involves describing the data adequately with community accepted metadata so that it may be easily discovered and assessed by other users; e.g., scientists, managers, and policy makers.

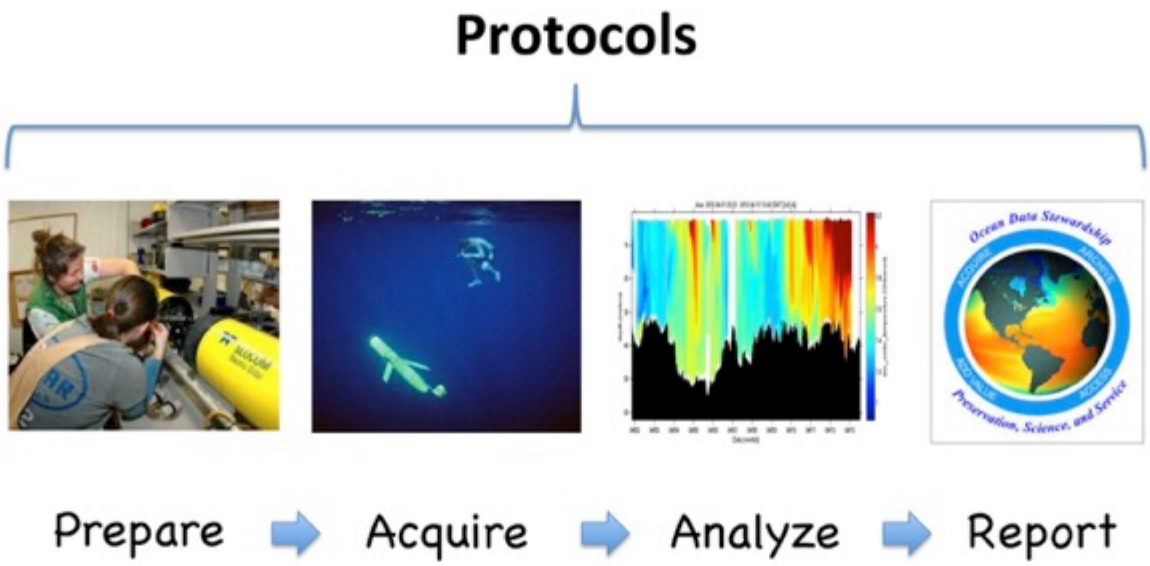

Figure 2. Expanded concept of ocean optics protocols encompassing instrument preparation, deployment and data acquisition, quality assurance based on post deployment sensor calibration and the assignment of quality flags, and reporting with metadata that provides accurate descriptions of the data and insures ease of discovery.

These steps together encompass the broader problem of data protocols and is an expansion of previous definitions. Workshop attendees were encouraged to think within this broader definition. The workshop conveners reached out to members of the QARTOD activity (http://www.ioos.noaa.gov/qartod/welcome.html) to participate in the workshop. A primary objective of QARTOD is to establish QA/QC procedures for the IOOS core variables, including ocean optical properties. Since QA/QC lies within the broader definition of protocols, the conveners felt that the workshop would benefit from the QARTOD experiences. In response, QARTOD agreed to send two representatives to participate in the workshop.

3. OBJECTIVES

The workshop objectives were 1) to discuss common problems and lessons learned associated with both short- and long-term sensor deployments, 2) to map out an international framework for developing and revising existing measurement protocols given the expanded definition and 3) to establish parameter-specific working groups tasked with reviewing current protocols in detail, including additional observational capabilities developed since the current protocols were published, advising about improvements, and identifying gaps where no community accepted protocols exist. These working groups will continue to inform and advise protocol development beyond the workshop and their work will ultimately conclude in revised, parameter-specific measurement, quality assessment, and reporting procedures.

4. APPROACH

The workshop structure consisted of morning plenary talks, afternoon breakout discussions directed at parameter-specific topics, and discussion summaries presented in plenary in the late afternoon (see Appendix B: Workshop Agenda). Breakout sessions covered the following topics:

- Required data accuracy
- Sensor deployment and biofouling mitigation
- Advances in data processing
- Real-time quality assurance procedures
- Quality control procedures for archived data
- Metadata requirements
- Potential funding sources for continued protocol development
- Timeline for protocol development

Breakout discussions were focused on two primary topics: Inherent Optical Properties (IOP) and Radiometry. The IOP discussions focused on properties for which advancements have been significant since the 2004 protocol publications; c_m, c_p and b_b, treated as a sub-topic within a larger discussion of $\beta(\theta)$. The Radiometry breakout discussions focused on methods of measuring in-water (E_d, and L_u) and above-water (E_o, E_{sky}, and L_w) radiometric quantities. While the oceanographic context of these discussions was broad, the primary focus was on how the measurements can support vicarious calibration of ocean color satellite imagery and product algorithm development and validation.

Breakout discussions were lead by community experts, identified prior to the workshop (Appendix C: Participant List and Roles). Their tasks were to organize their respective breakout session, present the results of the session discussions and findings at a concluding plenary session, aid in the writing of a workshop final report, and serve as the points of contact for future parameter-specific protocol development. Each breakout discussion leader was permitted to invite between 3 and 5 participants; experts that, if involved, would greatly increase the probability of success.

Participants in each breakout group, other than invited participants, were generally self-selected prior to the workshop and the workshop conveners and discussion leaders worked to ensure that each breakout group was adequately represented. The IOP Breakout Group consisted of 24 participants while the Radiometry Breakout Group was composed of 22 participants.

Each breakout group was tasked with identifying protocol writing teams of 5-8 members, selected from workshop participants, to 1) define the primary tasks required to make progress, 2) identify potential funding sources to support protocol revision activities, 3) establish a notional timeline for drafting revised protocols given the broader definition, and 4) drafting revised protocol documents.

5. DISCUSSION RESULTS

All plenary presentations and breakout discussion summaries are available on-line at: http://misclab.umeoce.maine.edu/research/research25.php.

Collectively, the breakout groups discussed protocol gaps and requirements for c_m, c_p, $\beta(\theta)$, b_b, in-water radiometry, and above-water radiometry. While subsets of the discussions resulted in parameter-specific recommendations (see following sections), much of the breakout group and plenary conclusions are overarching and applicable to all future protocol development efforts. They include the following.

Scope. It was decided within the morning plenary discussions that updated protocols will cover the expanded definition; 1) pre-deployment instrument preparation, including any necessary anti-biofouling measures, 2) best practices for optimum instrument deployment that will result in minimal environmental disturbance, 3) data reduction and quality assessment methods that yield the most accurate observations with community standard scientific units, and 4) prescriptions for metadata to fully inform potential users of the data.

Approach. The vast majority of the information to be compiled into protocols exists within the scientific literature in the form of earlier versions of protocols, journal articles, and technical reports. Thus, each effort must start with a thorough review of the existing literature and, for new methods and instrumentation, screening for methods that have been appropriately vetted through the research community. Compiling this information will perhaps be the most time-consuming part of the process.

For some protocols, the process may require additional tests in order to assess accuracy and confidence. Given that the process will rely primarily on vetted approaches, additional tests should be few in number and limited in scope. Essentially, each protocol will represent a snapshot in time with the understanding that future revisions will be necessary from time-to-time. Thus, protocols will be viewed as living documents with guidelines for when future revisions should be undertaken.

Measurement Uncertainty. New protocols will support a wide range of potential users having different target applications, i.e., water quality monitoring, bio-optical modeling, and ocean color product validation and system vicarious calibration. Thus, there is a need for application-specific, target uncertainties. This will be achieved by providing a quantification of the impact on uncertainties for each action prescribed by a protocol. Thus, revised protocols must discuss and, where possible, quantify the uncertainties involved in the various prescribed steps. Methods of cross-referencing procedures will be implemented so as to inform the reader of why that procedure is recommended as well as the consequences if the procedure is not followed.

Funding. Comprehensive revisions to existing protocols cannot rely solely upon voluntary contributions. Therefore, it is recommended that relevant national and international organizations provide adequate funding to establish and maintain an office, perhaps comprised of one person, ideally with science-editorial skills, responsible to lead the revision process, interact with contributors in charge of writing specific sessions, and coordinate the review process in order to reach consensus. Possible funding sources include NASA, IOCCG, the National Institute of Standards and Technology, and NOAA. Participants in the writing activities are encouraged to seek required funds within their home institutions and countries.

Reporting. Reporting of these and future protocols should rely, to the extent possible, on electronic solutions. All protocols must be vetted within the international user community and, therefore, must be made available through recognized outlets and forums for such information. These include the websites associated with the NASA Ocean Biology Processing group (http://oceancolor.gsfc.nasa.gov) and the IOCCG (http://www.ioccg.org). In order to accommodate the vetting process, these outlets should provide for the viewing and downloading of protocol documents as well as mechanisms to receive community feedback and commentary. After the vetting and final editing activities, summaries of protocol documents will be published in leading methods journals in open access format.

5.1. Beam Attenuation, c_m and c_p

The writing team responsible for c_m and c_p includes Emmanuel Boss (Coordinator), Ian Walsh, Ivona Cetinic, Wayne Slade, David McKee, Martina Doblin, and Nagur Cherukuru. It was recommended that the protocols build upon prescriptions initially published within the NASA Ocean Optics Protocols (Muller et al., 2003-04) and refined by the U. S. Joint Global Ocean Flux Study Synthesis and Modeling Project (http://usjgofs.whoi.edu/mzweb/smppi/gardner.html). The established timeline of milestones calls for a completed revised protocol by the end of 2015 (Table 1).

In addition to revising protocols, the writing team will identify gaps in knowledge that, if addressed, could lead to more accurate measurements and smaller uncertainties. While some of these activities could potentially impact the current revision process, most will likely fall outside of the scope and timeline of the current activity and, instead, impact future revisions.

Much of the planned work can be accomplished without any additional funding. However, it was noted that relatively small amounts of support could go a long way towards enhancing communication among the writing team members, such as convening a one or two day coordinating meeting, employing a professional technical writer to help with final editing, and covering open access journal publication charges.

Table 1. Timeline for Development of Revised c_m and c_p Protocols

Nov-14	Review of existing protocol documents
Mar-15	Receive proposed changes to existing protocols
Jun-15	Assembly of draft document; distribute for community comment
Oct-15	Receive comments and incorporate revisions
Dec-15	Post completed document on community web sites; submit journal article

This work will be conducted in coordination and, when appropriate, collaboration with other international activities involved with protocol development, such as QARTOD, the IMOS bio-optical working group, and the bio-optical activities associated with the international ARGO profiling float community (www.euro-argo.eu; IOCCG, 2011). It would be beneficial and cost-effective to conduct any meetings in association with other community meetings, such as the IOCS/OCRT meeting, scheduled to convene June 2015 in San Francisco and the IEEE Marine Technology Society OCEANS'15, scheduled to convene in October 2015 in Washington D.C.

5.2. Volume Scattering Function, $\beta(\theta)$ and b_b

The writing team responsible for $\beta(\theta)$ and b_b includes James Sullivan (Coordinator), Wayne Slade, David McKee, Mike Twardowski, Emmanuel Boss, Martin Ligi, Deric Gray, David English, and Edouard Leymarie. The established timeline of milestones calls for a completed revised protocol by the summer of 2016 (Table 2). The NASA Field Support Group is sponsoring a protocol workshop on volume scattering function and backscatter in March 2015 that will advance the development of this protocol.

Table 2. Timeline for Development of Revised b(q) and b_b Protocols

Mar-15	Review of existing protocol documents
Jun-15	Receive proposed changes to existing protocols
Jan-16	Assembly of draft document; distribute for community comment
Mar-16	Receive comments and incorporate revisions
Jun-16	Post completed document on community web sites; submit journal article

Initial tasks include outlining instrument-specific calibration methods and measurement uncertainties, comparison of b_b estimation with single versus multiple angle instruments, and estimating the effects of uncertainty in the depolarization ratio on pure water b_b. The updated protocol should also include an improved introduction to the problem, including a historical perspective, polarization of scattered light fields, and a cautionary discussion on the relationship between IOPs and measures of turbidity. Finally, with respect to the expanded protocol definition, the revised protocol should include a discussion of expected environmental variability and the possible impact on recommended data averaging.

Much of the work can be accomplished without any additional funding. However, it was noted that relatively small amounts of support could go a long way towards enhancing communication, such as convening a one or two day coordinating meeting among the writing team members, employing a professional technical writer to help with final editing, and publishing results in an open access journal. NASA has agreed to support a $\beta(\theta)$ and b_b protocols workshop in March 2015. In addition, the writing team will plan to meet during the next IOCS/OCRT meeting in June 2015 and may require funds or support in kind to arrange a meeting room. While the writing team may recommend additional workshops, round robins, or further analyses of existing data, it was acknowledged that these activities likely will not fall within the time constraints of the current charge but, may factor into future revisions.

This work will be conducted in coordination and, when appropriate, collaboration with other international activities involved with VSF protocol development, such as QARTOD and the bio-optical activities associated with the international ARGO profiling float community.

5.3. In- and Above-Water Radiometry

The discussions of in-water and above water radiometry were held jointly because of the many common discussion elements and overlapping experience of the participants.

Considering the wide range of topics to be addressed within revised protocol documents, the following strategy was envisaged:

- All the attendees will be invited to provide specific recommendations or requests for revision of current protocols.
- Smaller writing teams will collect contributions from the research community, produce extended and comprehensive outlines for protocol revisions, and provide suggestions for new sections.
- The outline will become the basis for revised protocols and motivation for soliciting funding.
- Ken Voss and Giuseppe Zibordi will lead the process and identify other willing participants among the workshop attendees.
- An early-career researcher (doctoral student or post-doctoral fellow), or other person new to the field, should participate in the writing teams to help identify areas where the documents are too dense or unapproachable.
- The Goal is a coherent and accessible document, useful for a variety of applications and users.

Revision of the current protocols should start from the existing NASA-SIMBIOS Rev.4 documents.

Comprehensive revisions cannot be completed solely with voluntary contributions.

An extended outline for the revised protocols will be presented at the IOCS Meeting in 2015 as well as possible funding sources to support the work.

6. CONCLUSION

Plans to revise existing ocean optics protocols for c_m, c_p, $\beta(\theta)$, b_b, and in-water and above-water radiometric quantities were outlined. IOP writing teams were established and plans for forming writing teams for radiometric quantities were formulated. In each case, notional timelines and milestones to insure progress were also established.

Several areas of cross-cutting consideration were identified that apply to all protocols.

Scope. An expanded definition of protocols was adopted consisting of 1) pre-deployment instrument preparation, 2) best practices for instrument deployment, 3) data reduction and real-time quality assessment methods, and 4) prescriptions for metadata and reporting.

Approach. The vast majority of the information to be compiled into protocols exists within the scientific literature in the form of earlier versions of protocols, journal articles, and technical reports. In some cases, additional tests may be recommended in order to assess accuracy and confidence. However, each protocol will represent a snapshot in time with the understanding that future revisions will be necessary. Thus, protocols should be viewed as living documents.

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Funding. Comprehensive revisions to existing protocols cannot rely solely on voluntary contributions. Possible funding sources include NASA, IOCCG, the National Institute of Standards and Technology (NIST), and NOAA. Additionally, the newly formed IOCCG Protocol Coordination Activity should prove invaluable as a clearinghouse for protocol information, including emerging opportunities for financial and in-kind support.

Reporting. All protocols must be vetted within the international user community and, therefore, must be made available electronically through recognized outlets and forums for such information. Summaries of final protocol documents will be published within leading oceanographic methods journals in open access format.

A writing team for c_m and c_p comprised of seven participants was formed and Dr. Emmanuel Boss, University of Maine, will serve as coordinator. The group expects to have a final draft ready for community commentary by June 2015 and a final document published by December 2015.

A writing team for $\beta(\theta)$ and b_b comprised of nine participants was formed and Dr. James Sullivan, WET Labs, Inc., will serve as coordinator. The group expects to have a final draft ready for community commentary by June 2015 and a final document published by December 2015.

Dr. Giuseppe Zibordi, Joint Research Centre, Ispra, Italy**,** will serve as coordinator for the above-water radiometry writing team and Dr. Kenneth Voss, University of Miami will serve as the coordinator for the in-water radiometry writing team. Each plans to solicit recommendations from the group of workshop attendees and invite participants to serve on writing teams. They expect to have outlines of required tasks by June 2014. The planned publication date is not yet determined.

Each group expressed interest in using the joint IOCS and NASA OCR Team Meeting, scheduled to convene in San Francisco, June 2015, as an opportunity to hold coordination meetings among members of the writing teams and to present plans and progress to the IOCS/OCR meeting attendees. Another community-wide meetings could also be leveraged, such as IEEE/MTS Oceans'15, scheduled to convene in October 2015, Washington, D.C.

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Appendix A: List of Symbols and Acronyms

Parameter	Definition
a_p	Absorption coefficient for particulate matter (m^{-1})
a_g	Absorption coefficient for colored dissolved organic matter (m^{-1})
b_b	Backscattering coefficient (m^{-1})
c_m	Beam attenuation coefficient for combined water impurities (m^{-1})
c_p	Beam attenuation coefficient for particulate matter (m^{-1})
E_d	Downwelling irradiance (mW cm^{-2})
E_{SUN}	Solar irradiance (mW cm^{-2})
GEO-CAPE	NASA Geostationary Coastal and Air Pollution Events mission
HyspIRI	Hyperspectral Infrared Imager
IMOS	Australian Integrated Marine Observing System
IOCCG	International Ocean Color Coordinating Group
IOCS	International Ocean Color Science Meeting
IOOS	Integrated Ocean Observing System
IOP	Inherent Optical Property
L_{SKY}	Sky irradiance (mW cm^{-2})
L_u	Upwelling radiance (mW cm^{-2} sr^{-1})
L_{wn}	Normalized water-leaving radiance (mW cm^{-2} sr^{-1})
MASTS	Marine Alliance for Science and Technology for Scotland
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
OCR	NASA Ocean Color Research Team Meeting
OLCI	European Space Agency Ocean and Land Colour Instrument
PACE	NASA Pre-Aerosol, Clouds, and Ocean Ecosystem mission
QARTOD	Quality Assurance of Real-Time Oceanographic Data
QA/QC	Data Quality Assurance and Quality Control
SGLI	Japan Aerospace Exploration Agency second generation Global Imager
$\beta(\theta)$	Volume scattering function

Appendix B: Workshop Agenda

08:30 Plenary: Welcome/Introduction **(Ackleson);** *Somerset Room*

09:00 Data Quality Assurance **(Bushnell)**

09:30 Beam Attenuation **(Boss)**

10:00 Break

10:30 Backscatter **(Sullivan)**

11:00 In-Water Radiometry **(Voss)**

11:30 Above-Water Radiometry **(Zibordi)**

12:00 Breakout Charge **(Ackleson)**

12:15 Lunch (informal)

13:00 Breakout Discussions

- c_p & b_b **(Boss/Werdell/Mannino/Sullivan);** *Somerset Room*

- *In Situ*/Above Water Radiometry **(Voss/Zibordi)**; *Cumberland/Kennebec Room*

15:30 Plenary: Breakout Summaries**;** *Somerset Room*

16:30 Concluding Remarks

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