Ocean Carbon and Biogeochemistry Program

Ocean Acidification Principal Investigators' Meeting

March 22-24, 2011

Woods Hole, MA

Meeting Report

www.us-ocb.org
www.whoi.edu/OCB-OA
www.whoi.edu/workshops/OAPI2011

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July 22, 2011

Executive Summary

Acidification of the oceans in response to rising atmospheric CO_2 concentrations is now irrefutable. Ocean acidification (OA) has become an important research focus worldwide over the last decade. The Federal Ocean Acidification and Monitoring (FOARAM) Act, passed in 2009, authorized funds to both NOAA and NSF to address OA in their research plans; investigators within other federal agencies have also been studying OA-related questions since then. As the OA research community grows, it is increasingly important to maximize coordination across projects, increase efficiency, and stimulate future research.

In keeping with the Ocean Carbon and Biogeochemistry Program's (OCB's) overall mission (www.us-ocb.org), OCB organized a national meeting in March 2011 for principal investigators working on OA-relevant research projects. This was the first national gathering of OA principal investigators, and it was designed to build capacity within the OA research community, to advance scientific research on OA as efficiently as possible, and to clarify the scientific frontiers within OA research. To make the meeting as inclusive as possible, organizers invited representatives from all OA-relevant research projects supported by NSF, NASA, NOAA, USGS, EPA, and other federal agencies interested in OA.

This meeting was planned around six broad goals that focus on themes and challenges common across all OA-related disciplines.

1. Strengthen scientific collaborations and minimize duplication of efforts
2. Build capacity for improving OA research
3. Identify short- and long-term research goals
4. Promote effective data management
5. Enhance communication with the public
6. Solicit feedback from the scientific community to guide future OCB activities

The meeting included plenary talks reviewing the state of the science, synthesis presentations relating present research efforts, plenary discussions, and breakout discussion groups. The meeting website (www.whoi.edu/workshops/OAPI2011) contains all of the meeting presentation files, the book of participant abstracts, project introduction slides from participants, videos of presentations, breakout group reports, and lists of potential community activities generated during plenary discussions.

A short post-meeting survey conducted by the OCB Project Office found that most meeting participants agreed that the 6 meeting goals were largely fulfilled. Participants provided valuable suggestions about improving breakout group productivity in the future, activities to include in future meetings, and the usefulness of this particular meeting and its format.

Plenary and breakout discussions identified potential avenues for the OA research community to consider in the next few years. OCB or a national OA program could facilitate many of these

activities by helping coordinate researchers, supporting planning and scoping activities, and linking research with other national and international researchers.

Introduction: Workshop Background

Ocean acidification has become an important research focus both nationally and internationally over the last decade. While acidification of the oceans in response to rising atmospheric CO_2 concentrations is now irrefutable, the details of the chemical, geological, and biological consequences of OA require much further study (National Research Council, 2010). The US government sanctioned further research by passing the Federal Ocean Acidification Research and Monitoring (FOARAM) Act in 2009, which authorizes funds to both NOAA and NSF to address OA in their research plans. In Spring 2011, NSF supported approximately 96 investigators on 78 projects that address OA, which were funded on a project-by-project basis rather than in a single coordinated program. At the same time, many NOAA labs were working on OA-related science, from monitoring chemical changes to forecasting ecosystem shifts, while NOAA established a central coordinating office for OA. Investigators within other federal agencies have also been studying OA-related questions. As the number of OA projects and investigators grows, it is increasingly important to organize the research in ways that maximize coordination across projects, increase efficiency, and stimulate future research.

At the 2010 Ocean Carbon and Biogeochemistry Program (OCB; www.us-ocb.org) summer workshop, the OCB Scientific Steering Committee (SSC) recognized the need to bring together OA investigators to support the growing OA research community. In keeping with OCB's overall mission "to promote, plan, and coordinate collaborative, multidisciplinary research opportunities within the U.S. research community and with international partners,"[1] the SSC recommended to organize a national meeting in early 2011 for principal investigators working on OA-relevant research projects. In response, members of the OCB Project Office and the OCB Ocean Acidification Subcommittee developed the meeting agenda, circulated invitations, and worked with speakers, session chairs, and agency representatives to refine the plan for the three-day gathering.

This meeting was the first national gathering of principal investigators funded to conduct OA research, and it was designed to build capacity within the OA research community, to advance scientific research on OA as efficiently as possible, and to clarify the scientific frontiers within OA research. To make the meeting as inclusive as possible, organizers identified OA-relevant research from lists of funded NSF and NASA projects (e.g., NSF core and OA (10530) awards; NASA ROSES 2010 Carbon Cycle awards) and by consulting program managers from NSF, NOAA, USGS, EPA, and other federal agencies interested in OA. One representative from each of these projects was invited to the meeting. Attendees included ecologists, paleoceanographers, instrumentation specialists, chemists, biologists of all types, social scientists, ocean modelers, and communications specialists.

[1] "About OCB." http://www.us-ocb.org/about.html. Accessed January 11, 2011.

Workshop Goals and Structure

OA is a priority area within OCB, but it also overlaps many disciplines not traditionally covered by OCB scientists. Encompassing the entire realm of OA research in the United States requires building much stronger linkages between research sponsored across the five NSF supporting programs and divisions: OPP (Office of Polar Programs, Arctic and Antarctic); GEO (Geosciences Directorate, Ocean Sciences); BIO (Biological Sciences Directorate, including Integrative Organismal Systems and Molecular and Cellular Biosciences), as well as building strong ties to research sponsored by other agencies such as NOAA, NASA, USGS, and EPA. To serve participants from so many disciplines, this meeting was planned around six broad goals that focus on themes and challenges common across all OA-related disciplines. Each goal was developed to complement the objectives of capacity building, scientific advancement, and clarification of frontiers, in ways specifically helpful for the OA research community:

1. *Strengthen scientific collaborations and minimize duplication of efforts*— It is particularly important to promote exchange among OA researchers newly funded by NSF, the existing OA research community, and agencies that might not normally interact with these investigators. Fresh ideas and carefully planned collaborations are more likely to arise from researchers familiar with their colleagues.
2. *Build capacity for improving OA research*--- Entraining scientists from disciplines that are not yet within mainstream OA research, as well as early career scientists and under-represented groups, will provide innovative perspectives on problems and make new and powerful specialized research tools and techniques widely available.
3. *Identify short- and long-term research goals*--- Much effort has been devoted to scientific scoping activities, both nationally and internationally. In a discipline as broad and fast-moving as OA, it is imperative that the short- and long-term research goals are continually reassessed. Bringing together such a broad group of OA researchers at the early stages of research is important for building new collaborations and spawning fresh ideas.
4. *Promote effective data management*--- Organizations like BCO-DMO are well established and available to support OA research and data management. Researchers new to OA or from different disciplines may not be aware of these resources. At this early stage of national OA research, the time is right to emphasize effective data management.
5. *Enhance communication with the public*--- OA has many potential overlaps with human communities, from being a topic of public interest, a policy-relevant issue, and a potential socioeconomic influence. From research, education, and outreach standpoints, early development of plans to integrate OA activities with these issues will pay off.
6. *Solicit feedback from the scientific community to guide future OCB activities*--- As a "bottom-up" organization, OCB relies on continuing dialogue among the scientific community and agencies to identify how to serve the research community effectively. Gathering feedback from OA researchers at this early phase of national research will enable OCB to continue to respond to their needs.

Meeting activities mapped to these goals. Present OA research was grouped around five major themes, including:

- Past ocean acidification events
- Improving ocean acidification observations
- Physiological responses to ocean acidification
- Ecological responses to ocean acidification
- Biogeochemical responses to ocean acidification

1-2 hour sessions were devoted to each of the five major scientific themes. Each session began with a 30-minute plenary talk that provided an overview of the state of the science, in support of meeting goals 1-2. The chair of the session then provided a synthesis of currently funded research on the topic, using schematic diagrams or other visual aids to comprehensively summarize ongoing research, where overlaps occur, and where gaps exist. Next, the session chair moderated a discussion among 5-6 panelists and all the meeting attendees about where the research is headed, how it can be improved, and what research frontiers can be anticipated over the next 5-10 years. Together, the synthesis talks and short panel discussions helped support meeting goals 1-4.

The meeting also included special plenary discussions and plenary talks on topics of broad interest. The first special plenary discussion concerned how best to integrate all of the biological research, analytical and interpretive tools, and diverse results into a unified body of knowledge. The second special plenary discussion, held at the end of the meeting, focused on the most compelling research that the community should pursue in the next 5 years. These discussions supported meeting goals 1-6. Plenary talks focused on data management, on present international OA research activities and future opportunities, and the developing U.S. national OA program.

During four meeting breakout sessions, cross-cutting issues and challenges common to many OA researchers were discussed, to support meeting goals 1-6. Breakout session topics included:

Meeting chairpersons and organizing committee:

The organizers of this meeting include members of the OCB Project Office (http://www.us-ocb.org/about/office.html) and volunteers from the OCB Ocean Acidification Subcommittee (http://www.us-ocb.org/about/subcommittees.html).

Co-chairs:

Joanie Kleypas, National Center for Atmospheric Research, kleypas@ucar.edu
Sarah Cooley, Woods Hole Oceanographic Institution, scooley@whoi.edu

Organizing Committee:

Dick Feely, NOAA Pacific Marine Environmental Laboratory
Dave Hutchins, University of Southern California
Lisa Robbins, US Geological Survey
Chris Langdon, Rosenstiel School of Marine and Atmospheric Science
Jean-Pierre Gattuso, INSU-CNRS, France
Heather Benway, Woods Hole Oceanographic Institution

- Teaming up to get it all done: facilities, infrastructure, and collaborations
- The human side: making OA human-relevant via education, outreach, & socioeconomic studies.
- Adding up the results: temporal/spatial scaling, modeling, and multiple stressors
- The OA toolbox: measurements and tools we have and need

Breakout session leaders moderated discussion sessions guided by charge questions to identify challenges common to all OA research themes and to inspire new solutions by fostering dialogue among researchers with different specialties, perspectives, and methods.

The meeting included social activities to promote informal networking, including a poster session and reception, many breaks, group lunches, and a meeting dinner. These unstructured periods helped promote meeting goals 1-2 and 4-5.

Workshop Outcomes

Products

Presentation files

This meeting generated several reference products that are currently archived on the workshop website (www.whoi.edu/workshops/OAPI2011), including:

- Book of participant abstracts
- Project introduction slides from participants
- Presentation files
- Videos of presentations
- Synthesis discussion presentations
- Breakout group reports and summary presentations
- Lists of potential community activities generated during plenary discussions (biological plenary and summary plenary)

Summary articles

The OCB Project Office also wrote three articles summarizing the meeting activities and outcomes, including:

Cooley, S.R. OCB Hosts First Meeting for Ocean Acidification Researchers. OCB News, Spring/Summer 2011. 4(2):17-19.

Cooley, S.R., J. Kleypas, H. Benway. (submitted) First National Meeting for U.S. Ocean Acidification Researchers. EOS.

Cooley, S.R. J. Kleypas. First National Meeting for U.S. Ocean Acidification Researchers. www.oceanacidification.wordpress.com. 12 May 2011.

Survey results

The OCB Project Office also developed a short survey for OA PI workshop participants, which is reproduced in full in Appendix B. In all, we received 53 responses from the pool of 112 meeting attendees, for a response rate of 47%. Almost all survey respondents answered every question, and many provided explanatory comments to further explain their answers. Most survey respondents had not attended previous OCB workshops (71%). On average, the respondents included mostly early career scientists (56%), females (54%), and those who were not part of a minority or underrepresented group (88%). In addition, all 6 meeting attendees who had attended the 2009 OCB-OA short course as students responded to the survey. Given that workshop attendees included 38% females and 33% early career scientists (OCB Project Office data; early career estimate may be low), the survey respondent pool was slightly skewed towards more junior female meeting attendees.

Respondents were generally satisfied with most logistical aspects of the meeting. More than two-thirds of all respondents felt that the workshop website (67%), pre-meeting email communication (90%), travel information and arrangements (92%), the meeting space (79%), and the abstract booklet (87%) were "very effective." Of these features, the workshop website received the lowest score, although one comment suggested that this may have been because email communication precluded some of the need for the website. Some commenters suggested that the relatively isolated location posed some difficulty and the meeting space was not quite large enough.

Responses were more mixed concerning meeting content. Most respondents (96%) liked the organization of the meeting into scientific sessions guided by active areas of research, although one commenter pointed out that OA research requires an integrative approach and dividing up the meeting into scientific sessions seemed contrary to that goal. Survey respondents were asked to rate meeting elements as "not useful and interesting," "somewhat useful and interesting," or "very useful and interesting." Only the scientific plenary talks were especially highly rated as "very useful and interesting" (79%). Fewer respondents, but still a majority, felt that research synthesis presentations (62%), meeting-wide plenary discussions (56%), and agency updates (64%) were also "very useful and interesting." The majority of respondents felt that the short panel discussions (60%), afternoon breakout sessions (49%), poster session (65%), screening of "Tipping Point" (56%), workshop updates (50%), and breakout group reports (57%) were only "somewhat useful and interesting." No meeting element received a majority of "not useful and interesting" votes. Several commenters noted that breakout sessions could have been better moderated and could have had clearer objectives. Also, others noted that some breakouts were too large to spur effective conversation. A commenter noted that he would have appreciated explicit guidance about whether to bring a poster or not, and another noted that he wished he had brought one. Panel discussions seemed a bit rushed, to another commenter.

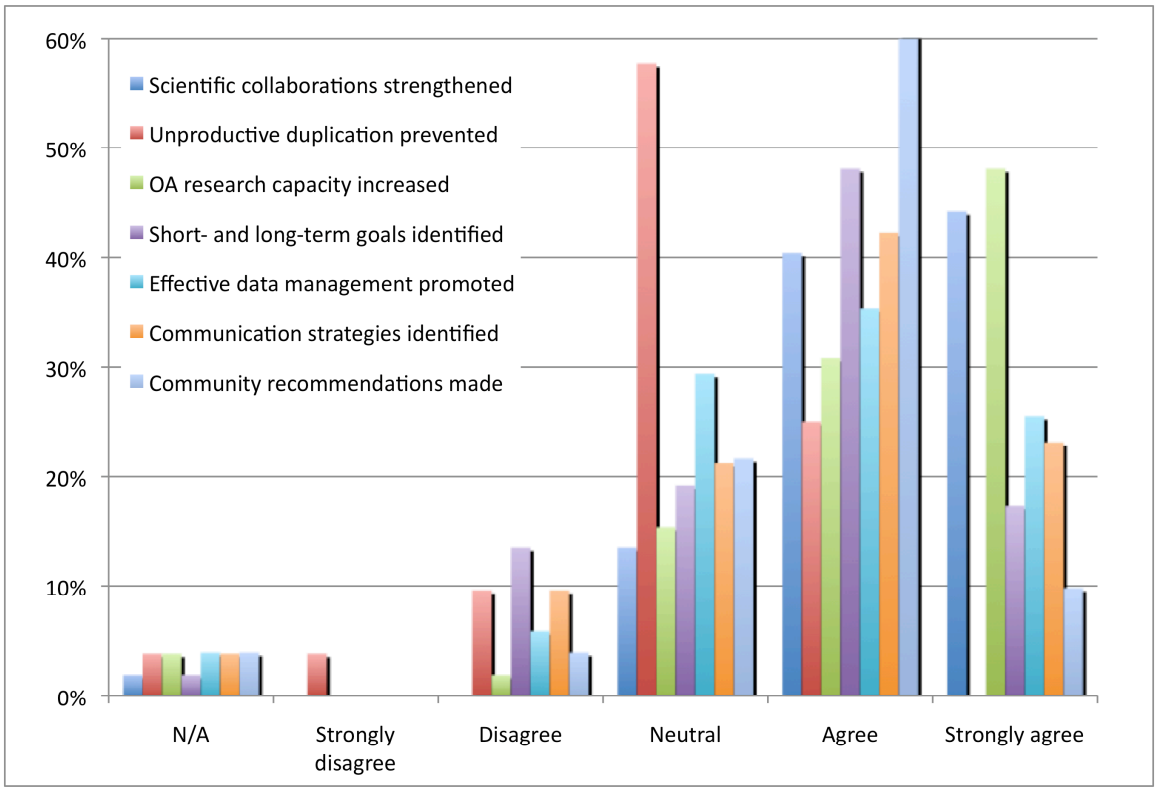

Figure 1: *Survey answers to question 5, concerning the attainment of each meeting goal.*

A large majority of commenters felt that this meeting was "very useful" for networking (81%), for connecting them to other programs and scientific initiatives (69%), and for informing them of ongoing planning and agency activities (69%). Slightly smaller majorities rated this meeting "very useful" for fostering new and existing collaborations and cross-disciplinary interactions (60%) and fostering scientific ideas and research directions (53%). The meeting was only "somewhat useful" for informing respondents about funding opportunities (62%). One commenter noted that the federal agencies were "discouragingly vague about future funding opportunities" but attributed this to likely budget uncertainties. Several commenters noted that they were able to meet people doing similar research and initiate new collaborations. Most of the commenters seemed enthusiastic about how the meeting brought together people funded by many different initiatives and provided unstructured time for networking. Respondents used a six-point scale ranging from "strongly disagree" to "strongly agree" that included "not applicable" to assess whether each specific meeting goal was fulfilled (Figure 1). In general, respondents agreed or agreed strongly that most meeting goals were fulfilled. One commenter pointed out, however, that the meeting did not "[culminate] with definitive action plans or identification of research goals."

We asked respondents which changes would improve future meetings for U.S. OA researchers. Surprisingly, only 36% felt that planning the meeting farther in advance would help; some

commenters noted that advance planning would allow attendees to plan better for future meetings. Over half of the respondents (57%) felt that including more science presentations would be an improvement. Other changes that might prove helpful include bringing in more student/early career representatives (41%), and/or holding meeting back-to-back with an international OA activity (43%). Comments again focused on the breakout/discussion sessions: they needed more focus; breakout conversations could have been encouraged with a panel; at times they overlapped previous workshops' discussion topics; and breakout session leaders needed more preparation. One commenter felt that the meeting's attendance limitations (one PI per project) excluded early career representatives, and a different balance of participants should have been sought.

The majority of respondents felt that they would attend a future meeting, even if a sponsor could not fund their participation. Most felt that they would be willing to pay between $400-$599 in travel costs (37%) and $1-$199 in meeting registration costs (41%) to attend a future meeting. However, 96% of respondents felt their travel costs were covered adequately for this meeting.

Lessons Learned

Survey results

In general, the meeting succeeded in achieving almost all of the seven goals that organizers developed. Responses concerning whether each meeting goals was attained (Figure 1) are generally dominated by "agree" or "strongly agree" for all goals, except preventing unproductive duplication of effort (dominated by "neutral"). It is possible that since attendees were already funded and their research projects are underway, they did not feel that knowing what the rest of the research community was working on helped them adjust their experiments accordingly. No comments addressed this, so some follow-up may be necessary to understand this survey response.

Some of the less traditional elements of the meeting, like breakout sessions, synthesis talks, and panel discussions, may have been less well received than traditional science talks simply because attendees are accustomed to meetings dominated by science talks. Nevertheless, several lessons can be learned about structuring these types of sessions better in the future. **Breakout sessions should have been smaller and more focused.** One possibility for promoting conversation would be to charge multiple small groups with the same sets of questions, then combine their answers at the end. **Breakout session leaders also needed more preparation and interaction among themselves and with meeting organizers to fulfill their role most effectively.** Having a clear objective for the breakout session (report, etc.) may have provided the structure that many participants sought. Asking breakout leaders and rapporteurs to provide a short report as part of their work would have also aided the completion of post-meeting archives. Research synthesis talks may have been more effective if organizers had more time before the meeting to work with meeting attendees and make sure their science

was being well represented. Synthesis speakers could also have referred to participants' posters where appropriate.

As for general meeting planning, **organizers should provide explicit instructions on whether or not to bring a poster, what sort of abstract to prepare, and consider providing pointers on effective presentation methods and discussion-leading approaches**. These procedural issues have also come up in other OCB workshops and meetings, and suggest that OCB may do well to assemble a packet of information on running meeting sessions for general use.

This particular meeting was planned on relatively short notice. Surprisingly, survey respondents did not seem to feel that more advance planning would significantly improve future meetings, even though **the general sense of the organizing committee was that advance planning would have eased their job markedly**.

Most respondents were willing to pay a total of $401-$798 for travel, lodging, and registration for a future meeting if their participation could not be supported externally. However, OCB Project Office data shows the average reimbursed travel and hotel cost was $1050 per attendee, and the meeting "registration" cost (including all meeting materials, local shuttle, and conference meals) was $300. **This total average cost of $1350 per attendee represents a significant mismatch between participants' willingness to pay and the actual meeting costs**. If a future meeting were held at a larger venue that had to be rented, this might further increase the costs associated with registration, and significant sacrifices might have to be made regarding meeting support (shuttles, personnel), location and time of year, and meals and receptions to keep the meeting affordable for participants.

Breakout Sessions

The first and second afternoons were devoted to breakout sessions that focused on four overarching topics: improving science through stronger collaborations, facilities, and infrastructure; ocean acidification and society: making OA human-relevant via science, communication, capacity building; scaling and modeling across time and space; and improving research on the physiological and ecological responses to OA. In all of these breakouts, participants considered similar questions: What pressing issues need to be tackled soonest? Are there obstacles preventing this? Can existing facilities be used differently to increase their impact? Can capacity be built in key areas to accomplish the community-wide to-do list? And, what can OCB do to help facilitate answering these questions?

Breakout discussion groups identified a range of common activities that the community could undertake right away to help answer these cross-cutting questions. Many of these activities would support outstanding issues that came up in multiple breakout sessions. For example, promoting strong collaborations between natural and social scientists would advance societally relevant OA research and communications, and it would also enhance our ability to develop holistic OA models including all influences on nearshore marine communities. Also, maximizing better use of physical facilities/infrastructure such as flowing seawater labs, ships of

opportunity, the LTER network, and satellite resources would help maintain the collaborations and collect the data needed to understand OA. This data would directly improve models spanning multiple time and space scales targeting OA. Similarly, incorporating autonomous sampling technologies (e.g., gliders, floats, buoys) as well as pursuing research that borrows from non-oceanographic biological studies (e.g., "-omics" research, behavioral or evolutionary adaptation research, mechanistic ecosystem studies, and model systems) could help both improve OA research and provide scalable information that could be incorporated into predictive models. Such models could ultimately be used to provide decision-relevant information that would help link OA's effects on ocean ecosystems from the smallest micro-scale to the largest human community scale.

Specific activities suggested by breakout participants that would promote OA science included:

- More collaborative use of physical facilities (labs, field sites, ships of opportunity, coastal labs, LTER sites, satellites) and continued maintenance of virtual resources (CDIAC, best practices guides)
- Integrated studies that span molecular to environmental and community scales (e.g., microsensors or gene expression evaluation in environments with realistic pCO2 levels and variability; using the ocean observing system under development; looking at chemical/biological links via micronutrients, particulate pools, etc.)
- Establishment of national mesocosm facilities or Free Ocean Carbon Experiment (FOCE) sites, equipped with networks of sensors that could be re-used elsewhere
- Workshops to determine biological measurement needs and to promote international collaboration establishment of a global sensor network.
- Increased use of existing pathways (research coordination networks, graduate traineeships, fellowships) to entrain new researchers with disparate specialties and train the next generation of OA researchers
- Choosing OCB-OA subcommittee members with linkages to federal agencies and international entities interested in OA, observing networks, and biological expertise.
- Exchange between natural and social scientists (beyond simply economists) leading to collaborations
- Effective communication between the research community and the public via training for researchers and strategic communications partnerships between researchers and communications specialists.
- "Smart models" that can capture the most important processes shaping a system or address the most planning-relevant issues; requires bringing together a variety of specialists to get it right
- Addressing uncertainty better throughout analyses and modeling of OA's effects
- Autonomous chemical and biological measurements at spatial and temporal densities required (some technical development is still required)
- Borrowing methods from other non-oceanographic fields, including paleobiology, paleoecology, "-omics," quantitative and theoretical ecology, and evolutionary biology, to understand organismal and population-scale responses.

In many breakout sessions, **participants identified common overarching obstacles as well**. Lack of customary interaction between natural scientists and social scientists hinders the development of shared language or common priorities to examine problems such as OA. This is even true for different types of natural scientists, for example, for evolutionary biologists and seagoing biological oceanographers. Ongoing efforts to bridge these gaps by a group like OCB or a national/international organizing group are needed. This will help put different types of scientists in touch with each other and facilitate overcoming the natural barriers that presently exist. In modeling efforts, the community needs to come up with better ways to handle and convey uncertainty, as well as different types of data; generating integrated multi-scale smart models that can predict OA's likely effects requires incorporating different kinds of data (qualitative and quantitative) that has widely ranging uncertainties (from as small as ±0.1% to as big as the direction of change). Similarly, participants discussed the need for more funding, perhaps from centralized sources, to support larger-scale collaborative initiatives, or from foundations and agency initiatives, to support interdisciplinary research objectives less typically related to traditional oceanography goals.

For more detail regarding breakout session findings, please refer to Appendix A, "Breakout Discussion Reports."

Plenary Discussions

In a plenary discussion on Wednesday, the group explored how the scientific community can integrate all the different types of biological OA research occurring now and planned for later. Participants discussed ocean acidification studies in the context of global change biology, in which researchers need to think about changes in the physical environment as well as the ecosystem to understand the current environment and any changes in organism physiology that they notice. Therefore, the OA research community might learn from the existing field of (terrestrial) systems biology and the collaborative institutes already assembled to study it. However, the more ways that the research community uses to look at a particular question, the more information it will gain about the system. Highly collaborative approaches were identified as the most likely fruitful direction for integrating biological OA research, taking advantage of joint efforts and multiagency opportunities such as CAMEO (NOAA/NSF effort). The community needs to consider both what individual labs or investigators can contribute, and how individuals can team up on process studies that will examine ecosystem mechanisms from a multidisciplinary perspective. One of the most pressing knowledge gaps to consider this way is how physiological effects of OA on one organism result in ecosystem-scale outcomes. Some participants felt that studies of terrestrial systems and theoretical ecological work could inform ocean studies. At least one scientist (S. Collins, U. of Edinburgh) is examining evolutionary responses in microalgal populations to high-CO2 conditions, which may lead to the development of some general principles. Finally, participants felt that if the grand biological challenges facing OA research could be identified soon during symposia at the national and international scale, research questions for the next several years could be best tailored to answer them.

In a second plenary discussion on Thursday, the group explored the most compelling OA research questions that could be addressed in the next five years. In general, the points that participants brought up tended to summarize the most important needs identified during the breakout sessions. In this plenary, the group identified the following possibilities:

- Host an interdisciplinary FACE-like experiment at a mutually interesting site.
- Develop a set of deployable sensors for use by the community at large for short-, medium-, and long-term studies, similar to the ocean bottom seismometer network used by the marine seismology community.
- Develop an order-of-magnitude assessment of OA's effects vs. other influences to allow researchers and decisionmakers to prioritize activities, expenditures, and policies.
- Compare sensitivity to OA across systems using biological approaches like comparative phylogeography, evolutionary studies, and biodiversity surveys to develop indices across ecosystems.
- Quantify carbon fluxes into and variability within particulate pools, and sedimentation fluxes to examine OA's effects on remineralization length scales.
- Assemble a comprehensive global monitoring system that would use satellite, in situ, geochemistry, and biodiversity measurements in a coordinated effort spanning multiple time and space scales.
- Identify the best way(s) to assess change over time relative to a moving and perhaps accelerating baseline.
- Bring in social scientists and other scholars to address the human side of OA, in terms of both marine management (CO2 emissions, fisheries decisions, environmental policy) and effects on human communities (changes in ecosystem services). This may involve placing special sessions in social science meetings, teaming up with existing marine policy specialists, and obtaining funding to help pay for social scientists' initial involvement.
- Develop cheap, user-friendly biological and chemical sensors for regional and long-term studies to facilitate answering more complex questions about OA without spending too much time on getting basic measurements correct.
- Determine the consequences of large pH change on the carbonate system; as pH shifts the carbonate system may respond in ways different from the range we customarily measure. Multiparameter CO2 measurements would help address this.
- Conduct synthesis activities to compile available insight about ecosystem dynamics on other ecosystem-wide studies.
- Perform mechanistic research on organisms, populations, and ecosystems
- Continue to perform multifactorial experiments to assess effects of ocean acidification, rising temperature, and other stressors together.

Future Directions

Immediate follow-up activities

Directly following the OA PI meeting, the OCB OA subcommittee **refreshed its membership** to replace six members who were rotating off. We received 26 nominations after we circulated a

request to the entire OCB community, and all of those nominated were willing and eager to serve if elected. As a result of the enthusiasm and the need to expand the OCB-OA subcommittee to include a broader range of specialties, the existing OCB-OA subcommittee decided to bring aboard eight new scientists, one of whom should have expertise in the social sciences. This will expand the number of subcommittee members from 10 to 12.

During the workshop, one of the attendees (Francis Chan, OSU) proposed that **OCB help organize a synthesis project designed to identify known sites where ocean acidification is acting strongly now and where OA is likely to be a strong stressor**. The OCB Project Office suggested that this activity had natural synergies with the present Coastal Interim Synthesis Activity (http://www.whoi.edu/workshops/coastal_synthesis/). The Coastal Interim Synthesis Activity is presently developing regional teams that will collate data, publications, and studies that could contribute to the development of regional carbon budgets, and it seeks to determine the key fluxes and processes affecting regional carbon cycling. Ultimately, the Activity seeks to develop a science plan for coastal ocean carbon and biogeochemical research that will identify knowledge gaps and rank research priorities. Chan suggested that as part of such a complementary effort, a team of OA/Coastal Synthesis scientists should begin by synthesizing the most current observations of OA in nearshore waters to evaluate the present extent of OA and to identify the systems most vulnerable to OA. Subsequent joint activities would seek to examine the synergistic or antagonistic effects of multiple processes on the nearshore carbonate system. Coastal Interim Synthesis Activity participants are enthusiastic about this idea and the Project Office is continuing to help organize this joint activity.

Longer-term activities

From all the products generated as part of the meeting activities, we can begin to develop a single list of OA activities that would support OA science in the United States. OCB may be able to help organize some of these activities alone or in combination with other groups.

- Have an annual meeting**
- Conduct intercomparison exercise/training for carbonate system measurements*
- Host observing system workshop*
- Coordinate interdisciplinary process studies
- Engage social science community via “dating service”, “phone book” or workshop*
- Improve outreach & messaging*
- Host modeling workshop**
- Carry out large-scale biological experiments along a continuum (mesocosms? testbeds? ecosystems?)
- Develop shared research instrumentation for larger-scale in situ experiments
- Develop implementation plan/strategies
- Assemble smaller-scale science plans
- Organize a group similar to EPOCA’s Reference User Group
- Engage foundations/NGOs working on messaging (e.g., COMPASS)*
- Establish centers of excellence

- Organize a response team (Work with COMPASS*/expand FAQ*/blog/messaging research?)
- Assess the likely regions where OA may be a strong stressor, in coordination with NACP/OCB Coastal Interim Synthesis Activity*

* Something that OCB-OA could begin working on in the short term (1-2 years)
** Something that OCB-OA could begin working on as a secondary priority, in cooperation with the IWG-OA (2+ years)

Concluding Remarks

Although one of the major goals of the three-day workshop for OA principal investigators was simply to bring together researchers to develop the OA research community via networking, updates on current research, and some science presentations, this workshop also spawned fertile discussions exploring future possibilities, given current science and organizational directions. The OCB OA subcommittee is exploring ways to facilitate many of these multi-investigator activities, such as intercomparison exercises or planning/data synthesis activities. We hope that March's PI workshop will be the first of many meetings for OA investigators in the United States as the research continues to gather momentum.

Discussions are already underway about possible future OA activities. Several of these activities, including supporting intercomparison activities, developing biological or chemical sensors that are robust and user-friendly, entraining social scientists, and planning integrated biologically focused process studies, will probably require planning workshops at their outset. Multiple organizations, including OCB, could help facilitate these efforts in an organizing or communicating role. It is clear, however, that the collaborative, multiagency, multidisciplinary approach that resulted in the successful completion of the OA PI workshop will be required to continue supporting these broad-based efforts.

References

National Research Council, 2010. *Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean.* National Academies Press, Washington DC.

Acknowledgments

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Appendices

A: Breakout Discussion Reports

Group 1

Improving science through stronger collaborations, facilities, and infrastructure
Rapporteur: Jeremy Mathis

Following morning sessions focusing on paleoceanographic OA studies and observation and monitoring of OA, and a brief talk about OA public opinion research, one of the first day's breakout groups discussed how the scientific community can improve OA science by building collaborations, sharing facilities, and making the most of existing or planned infrastructure. This topic was relevant for many types of OA research, especially biological and chemical research, and the session helped identify the community's needs for interdisciplinary, broad collaborative networks building on present resources.

The group considered what resources existed for supporting OA research and whether they could be better utilized in the near term. Some of the resources identified included physical facilities, such flowing seawater labs (EPA), natural lagoons that naturally span a wide range of pCO2s (HIMB), statewide networks of coastal laboratories, ships of opportunity, the LTER network, and existing satellite resources. Satellite resources need continued investment and development, however, to achieve their full usefulness. Many researchers are willing to develop collaborations that will maximize their own equipment (e.g., pCO_2-controlled aquaria or tanks, FOCE systems, SHARQ enclosures). Time-series stations (e.g., HOT, BATS) continue to be useful, but they should also be expanded to include more interagency, interdisciplinary, and international collaborations. Helpful non-facility resources include the best practices publications (EPOCA, Dickson SOP), and data archives like CDIAC. New sensors being developed show great promise for supporting expanded OA monitoring activities, but participants noted that any new sensors should be included in intercalibration and standardization tests such as those of ACT (http://www.act-us.info/), regardless of the agency affiliation of the research from which the technology originated. To maximize use of existing resources, participants suggested that a central database should be developed listing resources, their capabilities, and collaborative opportunities.

The group also discussed what improvements in facilities, infrastructure, or approaches would promote OA research. Participants generally agreed that infrastructure and methods should be planned to support interesting science questions, rather than vice versa. There is a clear need for integrated, collaborative approaches that span from the molecular to the community scales. For example, molecular-scale processes like gene expression should be assessed at legitimate experimental pCO_2 levels; broadening such an experiment could include collaborations to investigate larger-scale physiological processes at the same time. At the same time, environmental conditions should inspire laboratory experimental design (e.g., simulating

realistic chemical variability observed in nature). The group also identified some specific needs, including: microsensors and geochemical approaches to follow calcification at micro and macro scales; simultaneous measurements of biological, chemical, and physical parameters; study of exchanges between inorganic and organic material pools; enhanced study of the particulate inorganic carbon pool and the role of biological processes on PIC; observation and modeling to overcome challenges in measuring and calculating total alkalinity; determining proper pCO_2 controls for CO_2 enrichment experiments; open ocean in situ experiments, especially to establish the role of zooplankton; and enhancing satellite resources, especially for monitoring salinity. Participants especially wanted to underscore the importance of integrating OA with the ocean observing system (OOS) being developed. In addition, national mesocosm facilities are also strongly needed, because mesocosm experiments with bubbling CO_2 may help bridge the gap between lab experiments and in-situ responses for organisms with rapid generation times or those that normally experience wide or rapid ranges of pCO_2 conditions. However, not all conditions can be properly simulated in mesocosm experiments. Any new monitoring sites should be chosen so that biological/ecological experiments can be easily pursued in combination with chemical experiments and vice versa; logical sites for these types of analyses and/or deployment of standard sensors could include regional networks such as LTER sites. Because there is no single biological parameter or analysis that can summarize OA's effects on marine environments, a range of biological measurements must be developed and linked to geochemical measurements. Some of the biological measurements suggested included: repeatable methods to measure community calcification (improvements over photoquadrats), active chlorophyll fluorescence sensors, coupled biological/DIC measurements, and biological/chemical sensors to deploy on CTDs (TA, DOC, pH, etc.). The linkages between chemistry and biology via micronutrients such as metals should also be examined.

Next, the group discussed whether the community can organize across existing institutions (facilities, sites, volunteer observing ships, etc.), agencies, disciplines, or nations to strengthen OA research. Participants felt that a combination of workshops, information, and funding support would lay the groundwork for large-scale research efforts. The group felt that one of the greatest cross-cutting scientific needs is for broad-scale measurements at regional and global scales that can distinguish among different causes of local acidification (e.g., atmospheric CO2, respiratory CO2, other acidic chemical species). Capacity for open ocean experiments should be built at the same time as coastal experiments are developed. To help resolve what biological measurements would be most universally useful in OA research at all scales, participants suggested a workshop focused solely on biological measurements. A workshop on biological measurements might also help encourage adoption of cross-disciplinary methods using genomics, evolution/adaptation theory, and other cutting-edge biological and molecular approaches. Then, researchers should submit joint proposals that include integrating biological and chemical measurements relevant for different research questions. Participants suggested that establishing a research coordination network (RCN) for OA would help fulfill these organizational needs. Existing funding opportunities through NSF (e.g., RCN support, future OA requests for proposals, the biology directorate's interest in providing cross-disciplinary funding opportunities) may help accomplish this domestically. At the same time, international efforts are needed to promote and coordinate regional and global-scale efforts. International

collaborations could be especially useful for developing a set of core sensors for moorings and long-term observational sites. To increase the effectiveness of international coordination efforts, international funding agencies or an international coordinating body (e.g., the SOLAS-IMBER OA working group or its descendant) might need to agree on joint goals and collaborative efforts to pursue.

The group identified multiple existing opportunities to build human capacity in the OA research community. These could include: taking students to sea and entraining them in lab research, and providing opportunities for undergraduate and graduate students (e.g., REUs, student semesters like at UCB Gump station, courses at Friday Harbor Labs or USC's Catalina campus, NERR student programs, EPA programs, NOAA Hollings Fellowships). Many of the options listed above are not OA-specific, yet they can be used in the context of OA research; nevertheless, numerous OA-specific opportunities also exist. Group participants suggested recruiting expertise from other fields, including materials science, physical chemistry/physics, catalysis chemistry, biomedical engineering (teeth, bone), genomics/bioinformatics, biophysics (role of skeletons), and toxicology.

Group participants also discussed the possibility of a national OA program. They felt that a national program office should implement the national program's strategic plan, organize community workshops and research activity updates, coordinate measurements, coordinate education and outreach efforts, and help provide data management and website management. One difficulty facing development of the national program and program office is that agencies interested in OA science all have different responsibilities for data management and reporting. They mentioned that OCB would likely be involved in OA coordination regardless of its involvement with a national program office or not. Therefore, OA subcommittee members should be strategic partners with IOOS, the national program, and federal agencies interested in OA to ensure good representation of the breadth of OA research. This also provides an opportunity for OCB to expand broadly into other relevant ecosystems (coastal, intertidal, coral, etc.).

Group 2

Ocean acidification and society

Rapporteur: Michael O'Donnell

The other afternoon breakout session on the first day of the OA Principal Investigators' meeting focused on discussing what the research community can do to promote linkages between ocean acidification research and society as a whole. This discussion considered the research implications for understanding ocean acidification's human impacts as well as the education and outreach work needed to inform the public. Participants in this discussion ranged from communications specialists to researchers involved in detecting and observing ocean acidification signals.

The first discussion theme of the breakout session was that natural and social scientists needed to find more ways to exchange ideas, data, and information. Many of the breakout participants did not have a clear idea of what social scientists do, both in terms of research focus and research methods. This is probably a result of the traditional separation between natural and social scientists, but some anticipate that this separation will naturally narrow as present efforts to combine social and natural sciences in new ways (e.g., sustainability studies) continue. Ironically, each group (natural and social scientists) thinks the other's job is easier. A possible way to begin closing this gap would be to begin providing information to natural scientists about what social scientists do, how they do it, and how to get in touch with potential collaborators; discussion participants suggested developing some kind of directory or "matching service" that includes both natural and social scientists interested in OA-relevant issues.

Early attempts at combining natural and social science datasets and methods to study ocean acidification have focused on coordinating natural scientists with economists. The November 2010 Monaco workshop "Economics of ocean acidification: Bridging the gap between ocean acidification and economic valuation" brought together natural scientists (mostly ecologists) and social scientists to discuss advancing OA research. To feed economics models, economists seek information on the value of ecosystem services, but these are difficult questions to answer either from an economics or a natural sciences perspective. Economists treat most services as fungible and, often, monetizable, so without information on the price or value of environmental change, ecosystem services cannot be thoroughly included into policy models.

The second major breakout discussion theme was effective communication between the research community and the public. Until now, OA has been very well communicated by a group of key scientists, and the issue has remained largely unpoliticized. Given multiple factors including the increasing profile of OA science, its linkage to CO_2 policy, etc., this may change soon. Effective communication can not only educate the public on why citizens should care and why OA should be part of policy discussions, but it can also help strengthen research by leading to fruitful industry-research partnerships and/or natural/social science collaborations. Identifying what science needs to be done and which aspects of OA have strong human interest should be done to promote this type of communication. Scientists were concerned that they may not always be the best individuals to communicate about OA, because they may not have sufficient communications training, talents, etc. The decision to communicate about OA should probably be left to the individual scientist, but the group agreed strongly that any communication to the public about OA should be done well. Poor or incomplete communication can have serious consequences in terms of developing misunderstandings, stirring up controversy, etc. Several training opportunities (e.g., COMPASS, Aldo Leopold) exist for scientists interested in learning how to communicate more effectively. Multiple related questions are still unanswered, for example: to what extent communications should address OA complexities, and how to describe overlaps with other environmental issues without bringing aboard political baggage. Discussing OA in context with other complexities could prove overwhelming to the public, if it's done poorly, but it could provide valuable information to policymakers because the full range of anthropogenic change and its effects could be then

addressed in policy development. Ways to reach the public could include communicating via interest groups such as shellfish/aquaculture/recreational user organizations, churches, or other community groups where people receive opinion-shaping information.

The third major theme to the breakout discussion focused on identifying adaptation strategies for OA. Adaptation has begun to enter the policy discourse as a viable option, but it is difficult to prescribe for OA because models are not especially clear yet. In certain locations, as for the west coast of the U.S., shellfish farmers can choose times to pump in local water that will minimize stress on organisms, but other ecosystems don't have options that are as clear-cut. Furthermore, society doesn't have mechanisms in place to deal with problems (like OA) over longer time scales. Advancing the discussion of what good adaptation options exist for different communities that may be affected by OA will require strong links between natural scientists and social scientists and communication specialists.

Group 3

Scaling and modeling across time and space

Rapporteur: Andreas Andersson

One of the breakout discussions on the second day of the OCB-OA PI workshop focused on addressing how the scientific community can conduct individual research projects so that conclusions will support the development of models and general forecasts by spanning relevant space and time scales and including multiple stressors. This temporal and spatial scaling question was of interest to a wide variety of specialists, including chemists, biologists, observational scientists, and modelers.

First, the group considered what most helpful scientific approaches could be for understanding future changes in ocean BGC and ecosystems, and whether they were sufficient. The group agreed that biogeochemical modeling, physiological/ecosystem studies, paleo research, socioeconomic modeling, and evolutionary approaches would be informative. However, developing these models and approaches first requires a great deal of careful planning, to identify species that are especially ecologically relevant and/or vulnerable. These efforts also need more long-term data collection. Future work requires building "smart models" that are designed to capture the most important processes, or that are designed to answer the key questions relevant for society or policy decisions. Taking time to identify relevant research questions or improve outstanding shortcomings in the models (e.g., present incorrect carbonate dissolution or subsurface circulation) is a first step in developing smart models. Participants then discussed which parts of the integrated "view" of ocean acidification (biota from microbes to ecosystems influenced by changing biogeochemistry and influencing human communities) do we know best. On the chemical side, we can make calculations and predictions with certainties on the order of 0.1%, but on the biological side, we can only make predictions whose sign (direction) may even be uncertain. Regardless of model construction, we need to come up with better ways to test the skill of biological and ecosystem predictions

within those models. In any model, the ultimate goal should be to identify the most sensitive parameters in an ecosystem to any kind of environmental change, and understand how the ecosystem would respond to change. All of these activities require much stronger interactions between modelers, biologists, biogeochemists, and physicists.

Next, the group considered whether observational research focusing on mechanistic biological responses will provide information that is scalable over space, time, and multiple stressors. Studies to date have not been sufficient, because they have been too short, focused on too few stressors, and have focused on too few life stages. Further research should also examine the role of variability in environmental parameters, which fundamental mechanisms could be affected, and each organism's potential for adaptation. One possible approach to improving this area of research would be to organize process studies in natural environments having high CO2, using enclosures like FOCE and/or established long-term research programs like LTER. Remote sensing's potential has yet to be fully realized, as well. Both of these undertakings may require more funding via bigger programs.

When discussing whether we can trade space for time when investigating the role of natural OA gradients and/or CO2 fertilization, the group agreed that much could be learned from the natural system. An inventory of ongoing studies would be helpful. Participants cautioned, however, that natural system studies could be informative but could not entirely replace controlled experiments (e.g., FOCE, FOCE-like experiments where CO2 was lowered, experiments where bicarbonate or liquid CO2 was added, or in which deep water was pumped up). Different types of controlled experiments would also have different public perceptions (e.g., FOCE vs. lowering CO2).

The group also discussed which environments need more study and how this work could relate to scaling exercises. "Important" environments need first to be identified by deciding what makes them important – for example, whether they provide important services or include key vulnerabilities. Participants agreed that coral reefs and high-latitude environments were environments with potential key vulnerabilities. At the same time, heterogenous environments like coastal zones, estuaries, and embayments are important because they are subject to multiple stressors and they provide a range of important services. For these highly variable nearshore environments, it will be difficult to assess when changes from OA or other stressors move conditions outside the range of natural variability. Processes that need to be quantified on a global scale include primary productivity, calcification, and dissolution.

Certain statistical or analytical approaches can be used to help when scaling, extrapolating, or layering experimental results to develop large-scale conclusions. Regression analyses on a global scale might help provide insight into broad trends, whereas Monte Carlo simulations can be used to investigate uncertainty and sensitivity to various factors. However, applying Monte Carlo analyses first requires better measurement of many biogeochemical and ecosystem parameters to develop quantitative relationships. The IPCC approach of examining the state of knowledge, the level of evidence, the level of agreement, and the level of confidence associated with each event could be helpful for comparing possible outcomes. In every case,

analytical approaches should address uncertainty explicitly, which provides both mathematical and communication challenges.

OCB can help facilitate integrative scaling studies of OA in a number of ways. It can assist with data and metadata compilation, by connecting investigators with appropriate organizations (e.g., BCO-DMO and others). OCB can also help by keeping the community informed about what different groups and stakeholders and programs (e.g., EPA's 303(d) request last year) need. OCB could host a targeted workshop on OA and modeling (including international scientists), to promote better dialogue between observational and modeling scientists. Holding this workshop in conjunction with an international meeting (e.g., the Oceans in a High-CO2 World meeting) would be ideal. Offering annual opportunities for interaction will also be helpful, in the form of special sessions, other workshops, etc.

Group 4

Improving research on the physiological and ecological responses to OA

Rapporteur: Nichole Price

The second breakout group on the second day of the OA PI meeting considered what measurements and tools from other non-oceanographic disciplines could be particularly helpful for addressing questions within OA research. This discussion session followed morning sessions on present physiological and ecological OA research, and a plenary discussion on integrating biological research, which touched on some of the issues expanded on in the breakout session.

First, the group considered specific different approaches or subdisciplines that used innovative and possibly helpful approaches. Physiological sciences and systems/evolutionary biology offer ways to look at the whole transcriptome to examine emergent properties based on coexpression that studies of individual traits would miss. "Omics" research, fundamentally based on sequencing biomolecules, must first identify what to sequence (genes, transcriptomes, etc.) and how to target these sequences (by species, community, or environmental characteristics). This may prove helpful for providing broad diversity indices or population surveys. Some standardization and data repository development are needed, however, before this can be universally applied. Autonomous chemical and biological monitoring via moorings, gliders, etc. could help evaluate a broader suite of biogeochemical parameters (e.g., overdetermining the carbonate system, measuring nitrate, acoustics, sedimentation, etc.) and providing information similar to what can be gained during shipboard studies. Other autonomous technologies might be used for quickly assessing microbial diversity via microarrays or antibodies. In situ or lab-based studies could examine the cost and the processes involved in behavioral or evolutionary adaptation of organisms. Other systems where adaptation has already occurred could be used as model examples. Paleobiology and paleoecology studies, and proxy development, could help researchers compare the historical response to short-term manipulative studies. Cellular and molecular biology studies do need more tools, such as microelectrodes, to measure cellular and subcellular level processes such as biomineralization, acid/base balance, and the like.

Participants also considered how research efforts could be scaled up to draw conclusions about species assemblages and communities in the field. One option would be to incorporate quantitative and theoretical ecology, and to pair time series data with mathematical frameworks. Mechanistic approaches to ecosystem modeling that include species replacement, energetics modeling, or population dynamics modeling may also be helpful. To understand physiological tipping points or guard rails, we must also quantify natural variability and tolerances in physiological assortments and in current populations. At the same time, we must determine how to quantify natural variability in carbonate chemistry also. Reciprocal transplant studies may help identify how natural variability affects biological populations. Intercomparison efforts are important to make sure that lab and field studies are actually studying the same organism with the same behaviors (biorhythms, gene expressions, etc.). Finally, multiple-stressor studies must also be done to place OA in environmental context with other processes occurring in the same ecosystem. In any case, it is very important to define the terminology, methods, and assumptions used clearly and to follow best practices in each experiment.

Lessons may be learned from studies that have been conducted in terrestrial or freshwater environments. Some techniques (e.g., continuous plankton recorders) are known to have oceanographic and terrestrial similarity; data interpretation methods may thus also have similarities. The community should consider using genomically abled model systems such as *Arabidopsis, Drosophila,* and/or *Daphnia.* Past work in other environments has overcome some difficulties relevant to OA including: scaling from lab to field, monitoring over different time and space scales, and performing large scale perturbation experiments (e.g., FACE, FOCE). Other large environmental challenges have been addressed in multipronged research efforts (e.g., acid rain, habitat fragmentation, climate change). We must also consider land/sea connections between terrestrial processes and ocean changes. There is an added challenge in studying the marine environment, which is a 3-dimensional challenge, whereas terrestrial environments are largely 2- dimensional. A practical challenge is the permitting difficulties associated with setting up large scale perturbation experiments.

An array of obstacles prevents completing some of this science. Disciplinary barriers among scientists may hinder some collaborations, because scientists have different motivations, rewards, interests, and languages. Funding for large-scale experiments may be difficult to get, and it may be difficult to get support from multiple sources, given agency and university structures. In addition, communicating to nonscientific audiences also remains an obstacle. Stakeholders must be informed and engaged in this work to help refine the outcomes. Policymakers, in particular, need to be engaged by advocacy groups that use scientific information accurately.

A number of opportunities exist to facilitate this science. First and foremost are collaborations among scientists, agencies, disciplines, public/private organizations, and international entities. Biologists and chemists can team up to make the most of their work, as can genomics facilities and bioinformaticians. Some natural separations, however, may emerge based on regional

differences (e.g., coral reef environments vs. high-latitude environments). Researchers working on different taxa or biogeographic units may also successfully team up. In all cases, best practices guides will help unify standards and approaches. Multidisciplinary projects can help bring these groups together. GLOBEC, Ideas Labs, and similar groups provide good precedents for existing infrastructure or successful achievement of these goals. Participants also felt that programs should be developed to facilitate interaction of graduate students. Furthermore, putting together a list of analytical opportunities could help facilitate collaborative science. At the same time, facilitation of synthesis activities such as meta-analyses and modeling studies is needed as the body of OA knowledge grows. To find untapped funding resources, participants felt that scientists could reach out to industry and community/philanthropic groups, either independently or by teaming up with OCB or a US National OA program.

Opportunities to help facilitate physical/ecological are numerous. OCB can support small-scale workshops, data synthesis activities, and provide linkages to the data management community (e.g., BCO-DMO and others). OCB can also support a cross-calibration/intercomparison activity including chemical and biological methods. Participants also felt that scoping and synthesis workshops would be useful, and a Gordon Research Conference could be proposed to create an annual opportunity to facilitate OA science.

B: Survey Questions and Results

[Unless otherwise noted, all numerical survey results are percentages of the response. Each question was answered by 51-53 respondents.]

OCB OA PI Meeting Survey

Welcome
Thanks again for coming to the Ocean Carbon and Biogeochemistry Program's meeting for ocean acidification principal investigators in March! Please help the OCB Project Office with our ongoing self-evaluation efforts by completing this brief, 10-minute survey about the OA PI meeting.

1. Please comment on the effectiveness of the following logistical items:

	Not effective	*Somewhat effective*	*Very effective*
Workshop website	0.0	32.7	67.3
Pre-meeting email communication	0.0	9.6	90.4
Travel information and/or arrangements	0.0	7.7	92.3
Meeting space	0.0	21.2	78.8
Abstract booklet	1.9	11.5	86.5

Additional comments or suggestions regarding logistics:

- Didn't need to use the website that much because of the strong email communication (Thanks Mary)
- I have no complaints. I appreciated it very much.
- Mary and Sarah did a great job as usual!
- The Abstract booklet was particularly useful.
- The abstract booklet was a great idea!
- The logistics was excellent
- Very nicely organized.
- I very much enjoyed this meeting. It was a great way to meet people working on OA issues. I especially liked the abstract booklet. It was great that it also included pictures of mostly everyone. It made finding people I was interested in talking to very easy. My only criticism was that the caterer did not take my food allergies under consideration even though I called beforehand. Also, because of the location, it was not easy to go find food elsewhere.
- It is always a pleasure to come to a meeting at Woods Hole as it is so well organized. (Pity it's a bit out of the way :-)
- Communication regarding the meeting was very clear and effective. Meeting room felt a bit crowded for an all-day, 3-day meeting.
- Location at WHOI was great for meeting logistics. However, travel to get to Cape Cod is not convenient, particularly if coming from the West Coast or further.
- I and others did not provide the right kind of information because the purpose of the booklet and the manner in which it would be used were not totally clear.

Meeting content

2. How useful & interesting was each meeting element?

	Not useful & interesting	*Somewhat useful & interesting*	*Very useful & interesting*
Scientific plenary talks	0.0	21.2	78.8
Research synthesis presentations	3.8	34.6	61.5
Short panel discussions	13.5	59.6	26.9
Afternoon breakout sessions	9.8	49.0	41.2
Poster session	6.1	65.3	28.6
Meeting-wide plenary discussions	6.0	38.0	56.0
Screening of "Tipping Point"	11.1	55.6	33.3
Updates on agency IWG-OA, NSF, NOAA, EPA activities	4.0	32.0	64.0
Workshop updates	2.1	50.0	47.9
Breakout group reports	4.1	57.1	38.8

3. Did you like the organization of the meeting into scientific sessions based on active areas of research (e.g., paleo/proxies, observations/monitoring, physiology, ecology, biogeochemistry/modeling)?

96.1% Yes
3.9% No

Additional comments or suggestions about specific elements included in this OA PI meeting:

- Breakout sessions could have been better moderated.
- I missed the last day of the meeting.
- I thought it was an excellent meeting
- The poster session was well organized. I just personally have trouble focusing on posters.
- The research synthesis presentation that included my work had some incorrect information.
- It was not exactly clear what the purpose of the break out groups was for. Were we just there to talk or was there some specific objective? More guidance would have been useful.
- This is a highly interdisciplinary meeting covering a wide range of scientific fields. I for one, am not familiar with some of the topics and jargons presented by speakers. I think that some speakers were too hurry to cover a topic. They should be given more time, so that their presentations are understood by all the attendants. A number of speakers failed to define the experimental conditions rigorously. For example, results of the effect of pCO2 on growth rate or DNA sequence were presented without specifying DIC and/or Total Alkalinity in the growth media. An inorganic carbon chemistry model requires at least 2 variable to define the system.
- I also found the unstructured break times to be an important time for interacting one-on-one or in small groups with colleagues about OA research.

- For future meetings/ workshops, I urge you to strongly encourage participants to bring posters highlighting their work! As all of the "synthesis" speakers mentioned, it was difficult to cram everyone's research into a single, short synthesis talk. To facilitate more collaboration (seemingly the ultimate goal of workshops like this) and interest in people's specific research topics, it would have been great to have more posters! In hindsight, I really wished I had brought one.
- Poor afternoon breakout session score above I believe could improve with more prep by the session facilitators. I spoke to those at other sessions that agreed those breakouts were not very productive.
- The meeting was very well organized. The only thing I would have like to see done differently is to break into smaller breakout groups. The small group results could then be combined into one summary. Also, it would have been nice to have a little more time to discuss the breakout group reports.
- The poster session could have been advertised more effectively up front. It was unclear whether we were supposed to bring a poster or not.
- In general, I think this topical division is a reasonable way to do it . . . there are always issues with overlap and these were perhaps greater than they needed to be (especially physiology, ecology, and biochemistry) - perhaps the topical bounds could have been better defined by the organizers ahead of time . .
- I would have also included federal programs as a key topic with more time for representatives to speak.
- Our poster was setup in the back room and we received very little traffic - both from visitors and from wait staff. It would be better to find a location to house all the posters and food in a single location. It seemed like most of the panel discussions consisted primarily of individual researchers (audience members only) promoting their own research.
- I did not like that the meeting was organized in to set areas. Understanding the potential effects of OA requires an integrative approach, and separating areas works in the opposite. Maybe a separate area should have been "integrative research approaches".
- It would be more productive to have a more focused, structured discussion with very specific questions to discuss to prevent people from wandering in all directions and talking about unrelated questions. It might be useful to have 5-6 specific questions listed, break down of the large group into smaller groups of 5-7 people and charge them with discussing the specific questions, and then integrate and discuss answers from all participating groups.
- At least one of the break-out discussions was so vague and suggesting a need for such huge expenditures that it did not seem grounded in reality and thus I tended to drift away.
- The first few plenary talks were excellent examples of how NOT to give a talk. The slides were terrible: some cramped four figure panels with multiple figures in a slide - ridiculous. The font size required a spotting scope. Apparently and sadly enough, you have to INSTRUCT people how to prepare slides. Also, you need to remind the speakers that they should address the scientist in the audience that are not (NOT) in their field. Some speakers were better than others. Brian Gaylord gave a talk that was boring to ecologists but probably very informative to the oceanographers - that was what asked for IMHO.
- the breakouts did not have enough structure or any strong direction in the conversation. Additionally they were too large to get any real conversation going.

- I don't like to separate modeling from observation, but I don't know of a better organizing principal. 2. With a couple exceptions, the synthesis talks were not well done. In one or two cases, the content of the synthesis was very much driven by personal interests of the presenter. Part of this is because the presenters didn't have much time before the meeting (I guess).
- It would have been nice to have more time for the panel discussions. They felt rushed and only were able to answer a few questions. The afternoon breakout sessions felt like just a stream of questions with few answers. Maybe a panel would be good for the breakout discussions in the future?

Meeting Outcomes

4. How useful was this meeting for you with regard to the following outcomes?

	Not useful	*Somewhat useful*	*Very useful*
Networking	1.9	17.3	80.8
Fostering new and existing collaborations and/or cross-disciplinary interactions	7.7	32.7	59.6
Inspiring new scientific ideas and research directions	9.8	37.3	52.9
Connecting you to other programs and scientific initiatives	3.8	26.9	69.2
Informing you of ongoing planning and agency activities	3.8	26.9	69.2
Informing you of funding opportunities	23.1	61.5	15.4

Please share any additional outcomes that you attribute to the meeting:

- I think it was extremely useful to bring together NSF-funded and agency PIs in one place.
- I was able to make new contacts and start up new collaborations.
- I've already had great follow up discussions with someone I met at the meeting.
- This meeting encouraged the organization I work at to organize an OA workgroup
- I established and firmed up several key collaborations because of this workshop. The value of this cannot be overestimated.
- Through interactions at the meeting, I have been able to hook up with other colleagues that I knew, but that I did not know were now working on OA.
- Turf issues were very much in evidence at the meeting, with many participants keeping their cards close to the vest. Ideas and concerns about current research directions were not always fully acknowledged, sometimes because of the pace of the discussion, but sometimes because the thinking may be a bit inbred. This is the nature of NSF-funded science and not the fault of the organizers, but there needs to be a way to get around it.
- For me, the ability to meet with other PI's on an informal basis was the most useful part of the meeting.
- I had high expectations for the meeting and they were definitely exceeded! The way the day and breaks were organized I had a lot of opportunities to meeting people and start new

collaborations. As a new PI this was extremely valuable. The large group discussions have also really helped how I shape future grant proposals.

- The federal agencies were discouragingly vague about future funding opportunities. But this is probably due to budget uncertainties.

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5. Please indicate your agreement with the following statements about the meeting's specific goals.

	Strongly disagree	*Disagree*	*Neutral*	*Agree*	*Strongly agree*	*Not Applicable*
Scientific collaborations were strengthened or initiated.	0.0	0.0	13.5	40.4	44.2	1.9
Unproductive duplication of scientific effort was prevented.	3.8	9.6	57.7	25.0	0.0	3.8
OA research capacity was increased by including representatives from multiple research agencies and other disciplines, early career scientists, and/or underrepresented groups.	0.0	1.9	15.4	30.8	48.1	3.8
Short- and long-term research goals were identified.	0.0	13.5	19.2	48.1	17.3	1.9
Effective data management strategies were promoted.	0.0	5.9	29.4	35.3	25.5	3.9
Strategies for enhancing communication with the public were identified.	0.0	9.6	21.2	42.3	23.1	3.8
Community recommendations for future OCB activities were made.	0.0	3.9	21.6	60.8	9.8	3.9

Additional comments about meeting goals or outcomes:

- I missed the last day so I don't know what to say about the last 4 items
- I think the goals were appropriate, but the "new scienties" and "multiple research agencies" parts need more work.
- There were a lot of good discussions, but I don't think the meeting culminated with definitive action plans or identification of research goals.

Future Meetings

6. Which of the following would improve future meetings for U.S. OA researchers? (Check all that apply.)

[36.4] Plan meeting farther in advance
[20.5] Allow open registration (no limits on number of investigators from each program)
[56.8] Include more science presentations
[6.8] Host meeting elsewhere
[0.0] Lengthen meeting
[40.9] Include more student/early career representatives
[43.2] Hold meeting back-to-back with an international OA activity (EPOCA or High-CO2 world meetings, etc.?)
[15.9] Include fewer discussions

List any other changes that would improve future meetings.

- Better poster session set-up. I realize the facilities were not optimal for posters.
- Decide how often they will occur so we can plan for them.
- Have clearer goals for the discussions
- Having a more focused topical discussions would help
- I wouldn't change anything
- Include policy makers and economists
- Maybe just have more organized, structured discussions with a panel
- Once again - very few complaints - meeting was very well designed and executed
- more focused or fewer discussions
- Some of the discussion topics had been hashed out at similar meetings that many of the same people attended. E.g., I, Andrew Dickson, Richard Zeebe, and Barbel Honisch had all recently attended a Paleo-OA workshop on Catalina IS funded by NSF. Some of the dicussion topics at the WHOI meeting were identical to those on Catalina Is. I, along with the others, retreated from these topics because we had already engaged in an intense debate about them and I don't think anyone wanted to re-hash things. To prevent this type of redundancy in the future, it may be beneficial to consult with leaders of similar workshops (or at least the agenda/outcomes of these workshops) that have taken place in the recent past.
- I thought the meeting was very well organized and effective. Its moderate size was a benefit in many ways.
- panel discussion may be structured by giving a specific topic/ problem to discuss. If the goal was to introduce the OA scientific groups to each other the meeting worked well, if the goal was to talk about how to deal with politics and public perception, social scientists would have been needed. Maybe an introductory lecture by one to the topic would have been a good compromise.
- "Farther in advance" would allow synthesizers to do a better job, I think. Maybe not. Maybe they need to have some incentive. I think you are assuming that "new to OA" is synonymous with "early career," which is of course totally absurd. Need to find a way to attract experts from other fields. Consider replacing "early career" with "new to OA.
- "Science presentations" don't necessarily need to be talks, but larger poster sessions would be great to give researchers the opportunity to promote their work to interested parties

- In general, I thought the meeting was well organized and attended by the right amount of people. I think we need improved structure during discussions to limit grand standing.
- The poster session didn't work as well as it could have due to people congregating near the food/bar. It might have been nice to put the bar in the back room one night to encourage more traffic.
- I would select a venue that would allow more people to attend. Also, I think there should be a report out from the break out groups right after.
- I actually think that most of the areas above were well handled. A longer meeting with more attendees would probably have been less useful.
- Could there be a balance between "open registration" and invitation only? By limiting the meeting to PIs many early career representatives were likely excluded. Perhaps in the future allow more early career / student applicants, but require they pay their own way if cost is an issue.
- More plenary discussions, less smaller breakouts. More prep by facilitators for breakout sessions.

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7. In case future meetings cannot be funded directly by the sponsoring organizations, how much would you be willing to pay from your own grants/travel funds/business accounts to attend a future meeting of U.S. OA investigators?

	Would not attend	*$0 - Would require external funds to attend.*	*$1-$199*	*$200-$399*	*$400-$599*	*$600-$799*	*$800+*
Travel costs	6.1	16.3	2.0	20.4	36.7	12.2	6.1
Meeting registration costs	6.1	18.4	40.8	28.6	6.1	0.0	0.0

8. Please provide us with some information about yourself:

	Yes	*No*
Have you attended previous OCB summer or scoping workshops?	28.8	71.2
Do you consider yourself an early career scientist?	44.2	55.8
Did you attend the OCB-OA short course 2009 as a student?	11.5	88.5
Are you female?	46.2	53.8
Are you part of a minority or underrepresented group?	11.8	88.2
Were all of your costs for this meeting covered adequately?	96.2	3.8

Thank You!
Thank you for taking our survey! Your response is extremely valuable to us, because it will help us improve OCB activities in the future. If you have additional questions or comments about this survey or about the OA PI meeting in general, please contact Sarah Cooley (scooley@whoi.edu).

C: Participant List

Name	Organization
Lori Adornato	SRI International
Andreas Andersson	Bermuda Institute of Ocean Sciences
Justin Ashworth	Institute for Systems Biology
Marlin Atkinson	University of Hawaii
Barney Balch	Bigelow Laboratory for Ocean Sciences
Heather Benway	Ocean Carbon & Biogeochemistry (OCB) Project Office
Joan Bernhard	WHOI
Jim Bishop	University of California Berkeley
Rusty Brainard	NMFS Pacific islands Fisheries Science Ctr
Denise Breitburg	Smithsonian Environmental Research Center
Colleen Burge	Cornell University
Ron Burton	Scripps Institution of Oceanography
Shallin Busch	NOAA Northwest Fisheries Science Center
Bob Byrne	College of Marine Science, University of South Florida
Wei-Jun Cai	University of Georgia
Elaine Caldarone	NOAA/NMFS/NEFSC
Ed Carpenter	Romberg Tiburon Center for Environmental Studies
Bob Carpenter	California State University, Northridge
Emily Carrington	UW Friday Harbor Labs
Francis Chan	Oregon State University
Cyndy Chandler	Woods Hole Oceanographic Institution BCO-DMO
Robert Chapman	SC Dept. Nat. Res.
Francisco Chavez, MBARI	MBARI
Anne Cohen	Woods Hole Oceanographic Institution
Clay Cook	Harbor Branch Oceanographic Institute at Florida Atlantic University
Sarah Cooley	WHOI
Ned Cyr	NOAA Fisheries, Office of Science and Technology
Prof. Andrew Dickson	Scripps Institution of Oceanography
Scott Doney	Woods Hole Oceanographic Institution
Lisa Dropkin	Edge Research
Paul Falkowski	Rutgers
Richard A. Feely NOAA/PMEL	Pacific Marine Environmental Laboratory
Robert Foy	Alaska Fisheries Science Center, NMFS, NOAA
Heather Galindo	COMPASS
Nathan Garcia	University of Southern California
David L. Garrison	National Science Foundation, Division of Ocean Sciences
Jean-Pierre Gattuso	CNRS
Brian Gaylord	Bodega Marine Laboratory, University of California at Davis
Dwight K. Gledhill	Cooperative Institute for Marine and Atmospheric Studies
David Glover	Woods Hole Ocenaographic Inst.
Jason Grear	US EPA - Office of Research and Development
Martin Grosell	RSMAS, University of Miami
Baerbel Hoenisch	Lamont-Doherty Earth Observatory
Gretchen Hofmann	UC Santa Barbara
Kris Holderied	NOAA Kasitsna Bay Laboratory
Brian Hopkinson	University of Georgia
Stephan Howden	The University of Southern Mississippi
Libby Jewett	NOAA/CSCOR
John Joseph	Naval Postgraduate School
Laurie Juranek	JISAO-UW/NOAA-PMEL
Eric Kaltenbacher	SRI International
Cheryl Kerfeld	UC Berkeley / JGI
Joanie Kleypas	National Center for Atmospheric Research
Eun Young Kwon	Princeton University
Chris Langdon	RSMAS
Gareth Lawson	Woods Hole Oceanographic Institution
Derek Manzello	UM/CIMAS -- NOAA/AOML/OCD
Bill Martin	Woods Hole Oceanographic Institution
Todd Martz	Scripps Institution of Oceanography
Jeremy Mathis	University of Alaska Fairbanks
Jim McClintock	University of Alabama at Birmingham
Daniel C McCorkle	Woods Hole Oceanographic Institution
Paul McElhany	NOAA Northwest Fisheries

	Science Center
Christina McGraw	Clark University
Shannon Meseck	NOAA NMFS
Edward Miles	School of Marine and Environmental Affairs
Lisa Milke	NOAA Fisheries Milford Lab
Margaret W. Miller	NMFS-Southeast Fisheries Science Center
Andy Mount	Clemson University
James W. Murray	University of Washington
Janet Nye	Environmental Protection Agency
Moose O'Donnell	Friday Harbor Laboratories, University of Washington
Monica V. Orellana	Institute for Systems Biology
Kenric Osgood	NOAA National Marine Fisheries Service
Jim Palardy	Abt Associates, Inc.
Uta Passow	Marine Science Institute
Adina Paytan	UCSC
Beth A. Phelan	NOAA,NMFS Howard Marine Sciences Laboratory
Sean Place	University of South Carolina
Matthew Poach	NOAA/NMFS
Nichole Price	Scripps Institution of Oceanography
Julie Reichert	EPA/ORISE Fellowship
Justin Ries	University of North Carolina - Chapel Hill
Lisa Robbins	USGeological Survey
Jeffrey Runge	School of Marine Sciences, University of Maine
Grace Saba	Rutgers University
Chris Sabine	NOAA Pacific Marine Environmental Laboratory
Annette Salmeen	DOE Joint Genome Institute
Astrid Schnetzer	University of Southern California
Uwe Send	SIO
Samantha Siedlecki	JISAO/PCC
Sergio Signorini	NASA Goddard Space Flight Center
Inna Sokolova	University of North Carolina at Charlotte
Adrienne Sutton	NOAA Pacific Marine Environmental Laboratory
Taro TAKAHASHI	Lamont-Doherty Earth Observatory
Christina Tanner	Scripps Institution of Oceanography
Josi Taylor	Monterey Bay Aquarium Research Institute (MBARI)
Phil Taylor	National Science Foundation - Division of Ocean Sciences
Dr. Lars Tomanek	California Polytechnic State University
Aradhna Tripati	UCLA
Ed Urban	Scientific Committee on Oceanic Research
George Waldbusser	College of Oceanic and Atmospheric Sciences
Shanlin Wang	University of California, Irvine
Zhaohui Aleck Wang	Woods Hole Oceanographic Institution
Rik Wanninkhof	NOAA/AOML
Mark Warner	University of Delaware, School of Marine Science and Policy
Peter Wiebe	Woods Hole Oceanographic Instituiton
Tim Wootton	University of Chicago
Matt Wright	COMPASS
Pauline Yu	University of California, Santa Barbara
James Zachos	University of California
Richard Zeebe	School of Ocean and Earth Science and Technology, U. Hawaii

D: Workshop Agenda

Day 1. Tuesday March 22

7:30 – 8:30	*Continental Breakfast*	
8:30 – 8:45	**Welcome, Introduction, Logistics, Announcements (Kleypas, NCAR)**	
8:45 – 9:00	**Meeting Goals and Structure (Kleypas)**	
9:00 – 10:00	**Theme 1: Paleo & Proxies / Modeling** (Chair: Benway, WHOI)	
9:00	Plenary Talk: Constraints from the Past (Hoenisch, LDEO)	
9:30	Synthesis of Paleo Projects (Benway)	
9:45	Panel Discussion Paleo, Proxies	
10:00 – 10:30	*Break*	
10:30 – 12:00	**Theme 2: Observations & Monitoring** (CHAIR: Robbins, USGS/Feely, NOAA)	
10:30	Plenary Talk: An National Ocean Observing System for Ocean Acidification (Feely)	
11:00	Synthesis of Facilities, Sensors & Platforms (Sabine, NOAA)	
11:15	Synthesis of Observations Research Projects (Robbins)	
11:30	Panel Discussion of Facilities, Sensors, Platforms and Observations	
12:00-12:15	CGBD Update on OA Public Opinion Research (Lisa Dropkin, Edge Research)	
12:15-12:20	Breakout instructions	
12:20 – 1:30	*Lunch*	
1:30 – 5:00	**Breakouts**	
1:30	**Breakout Session I** Improving science through stronger collaborations, facilities, and infrastructure.	**Breakout Session II** Ocean acidification and society: making OA human-relevant via science, communication, capacity building
3:15 – 3:45	*Break*	
3:45	**Breakouts continued**	
5:00 – 7:00	***Hors d'oeuvres reception and Poster Session***	

	Dinner on your own

Day 2. Wednesday March 23

7:30 – 8:30	*Continental Breakfast*	
8:30 – 10:00	**Theme 3: Physiological responses to OA** (Chair: Kleypas)	
8:30	Plenary Talk: Organismal & Evolutionary Biology in OA Research (Ron Burton, SIO)	
9:00	Synthesis of unicellular organism physiology (Kleypas)	
9:15	Panel Discussion	
9:30	Synthesis of multicellular organism physiology (Hofmann, UCSB)	
9:45	Panel Discussion	
10:00 – 10:30	*Break*	
10:30 – 12:00	**Theme 4: Ecology & System Responses to OA** (Chair: Langdon, U.Miami)	
10:30	Plenary: Ecological Responses to OA (Gaylord, UC Davis)	
11:00	Synthesis of ecology projects (Langdon)	
11:15	Panel Discussion	
11:30	**Special plenary discussion: How to integrate biological research?**	
12:00 – 1:30	*Lunch.* Screening of "Tipping Point", a documentary following EPOCA researchers	
1:30 – 5:00	**Breakouts**	
1:30	**Breakout Session III** Scaling & modeling across time and space	**Breakout Session IV** Improving research on the Physiological and Ecological Responses to OA
3:15 – 3:45	*Break*	
3:45	**Breakouts continued**	
6:00 – 8:00	***Meeting dinner***	

Day 3. Thursday March 24

7:30 – 8:30	*Continental Breakfast*
8:30 – 9:30	**Theme 5: Biogeochemistry & Modeling** (Chair: Cooley, WHOI)
8:30	*Plenary Talk:* Overview on BGC (Passow, UCSB)
9:00	Synthesis of BGC Projects (Cooley)
9:15	Panel Discussion BGC
9:30	Synthesis of Modeling Projects (Cooley)
9:45	Panel Discussion Modeling
10:00 – 10:30	*Break*
10:30 – 11:00	**Data Management (Chandler, BCO-DMO)**
11:00 – 11:30	**"European Projects and International Activities" (Gattuso, EPOCA)**
11:30 – 12:00	**The US National OA Program [Ned Cyr (NOAA) and Phil Taylor (NSF)]**
12:00 – 12:15	**Comments from other Agency Program Managers** **NASA** (Carlos Del Castillo) **USGS** (Lisa Robbins) **Christine Ruf** (EPA) **Libby Jewett** (NOAA)
12:30 – 1:30	*Lunch*
1:30-2:00	**Update on recent workshops:** 1:30-1:40 ECCO (Hofmann) 1:40-1:50 PAGES-NSF (Hoenisch) 1:50-2:00 Oceans in a high-CO2 world III (Urban, SCOR)
2:00 – 3:00	**BOG reports & discussion on:** - Increasing Quality of Science - Increasing Collaboration (National and International) - Future Directions in OA Research - OCB's Role in OA
3:00 – 3:30	*Break*
3:30 – 3:55	**FINAL OPEN PLENARY DISCUSSION:** **The Most Compelling OA Science We Should Tackle Within the Next 5 Years**
3:55 – 4:00	OCB Project Office meeting wrap-up (Doney, WHOI)
4:00	*Meeting Adjourned*