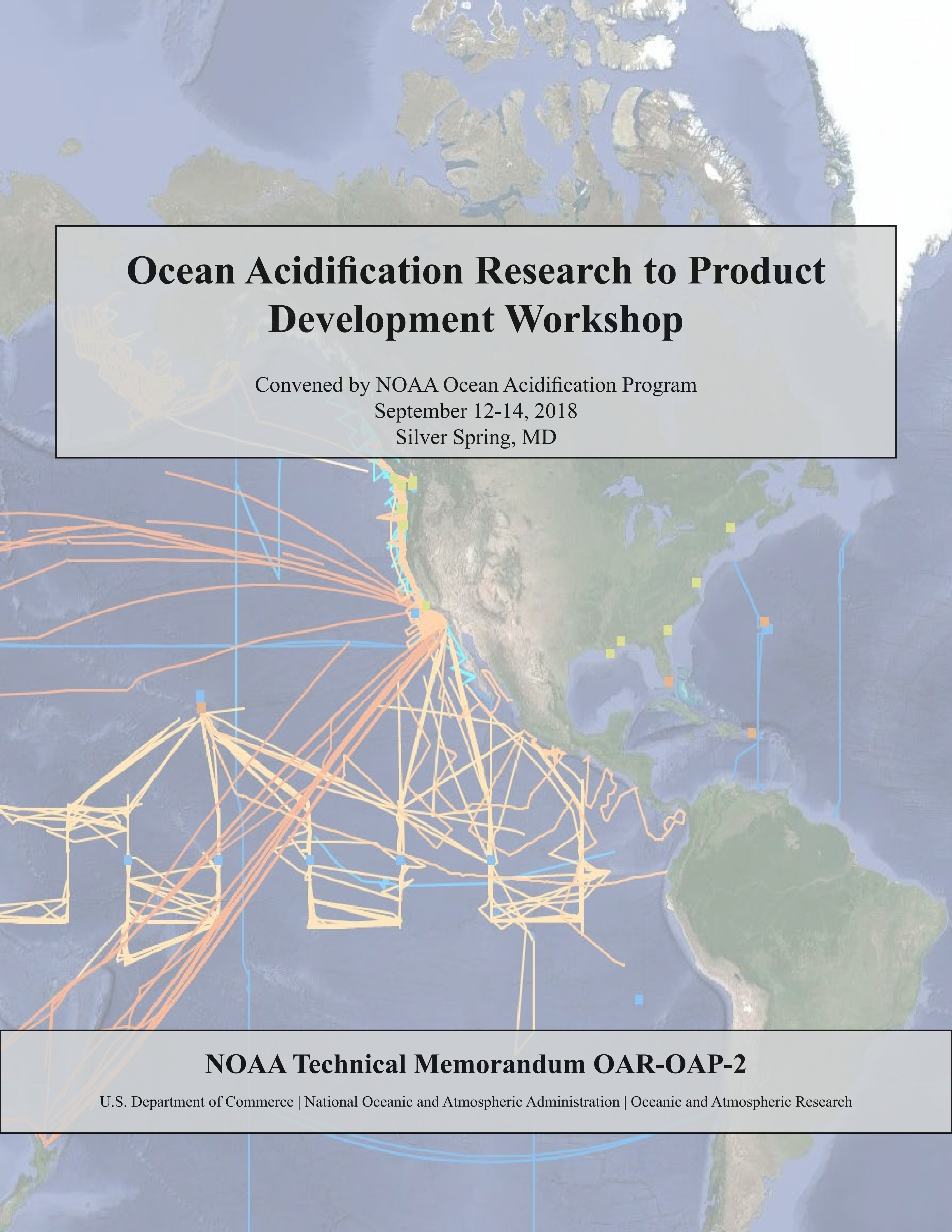

Ocean Acidification Research to Product Development Workshop

Convened by NOAA Ocean Acidification Program
September 12-14, 2018
Silver Spring, MD

NOAA Technical Memorandum OAR-OAP-2

U.S. Department of Commerce | National Oceanic and Atmospheric Administration | Oceanic and Atmospheric Research

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NOAA Technical Memorandum OAR-OAP-2
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U.S. Department of Commerce
Wilbur L. Ross, Jr., Secretary

National Oceanic and Atmospheric Administration
RDML Tim Gallaudet, Ph.D., USN Ret., Acting NOAA Administrator

Office of Oceanic and Atmospheric Research
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A special thanks to the presenters and panelists at the workshop: Veronica Lance (NOAA National Environmental Satellite, Data, and Information Service CoastWatch/OceanWatch/PolarWatch), Justine Kimball (NOAA National Ocean Service-National Coral Reef Monitoring Program), Melissa Karp (NOAA National Marine Fisheries Service - National Stock Assessment Program), Becky Shuford (NOAA Integrated Ecosystem Assessment Program), Colleen Roche (Center for Operational Oceanographic Products and Services), Beth Turner (Northeast Coastal Acidification Network), Darcy Dugan (Alaska Ocean Acidification Network), Leslie Wickes (Southeast Ocean and Coastal Acidification Network), Kaity Goldsmith (Mid-Atlantic Coastal Acidification Network), Maria Kavanaugh (Oregon State University), Liqing Jiang (NOAA National Centers for Environmental Information), Brian Katz (Oregon State University), Simone Alin (NOAA Pacific Marine Environmental Laboratory), Joe Salisbury (University of New Hampshire), and Wei-Jun Cai (University of Delaware).

Executive Summary

The National Oceanic and Atmospheric Administration (NOAA) Ocean Acidification Program (OAP) is working to better understand the research-to-product transition process for stakeholder-driven ocean acidification (OA) product development. With this in mind, an OA research-to-product transition workshop showcased product development, transitions, and operational delivery. Participants included academic and federal OA scientists, potential hosts of products, and representatives from regional coastal acidification networks who are best aware of the stakeholder needs in their regions. This workshop was designed to inform the development of a research-to-product framework for the NOAA OA science community that presents best practices for research transition and product development. A key element of this framework will include early and regular engagement with end-users to ensure that the research products developed will meet their needs whether those stakeholders are external or internal to NOAA.

The workshop was held September 12-14, 2018 at the Sheraton Hotel in downtown Silver Spring, Maryland. Over the course of 2 ½ days, participants engaged in panel discussions and worked in smaller collaborative teams to better define research-to-product terminology and identify potential barriers to transitioning research outputs. Participants also had the opportunity to work in groups to identify potential OA products that could be created based on the current research interests and identified stakeholder questions.

The workshop's **primary objectives** were to:

- Better understand the research to operation/application pathways and pitfalls.
- Define "operational" for the NOAA Ocean Acidification Program and discuss other mission-driven research and development terminology.
- Based on stakeholder interests, consider what existing products within NOAA would benefit from OA research and data synthesis outputs and brainstorm potential new applications and services based on the current OA state of knowledge.
- Propose solutions to overcome barriers that currently inhibit existing research outcomes from transitioning to applications and services.
- Identify OA research and data synthesis outputs which may already have transitioned to an application or service but have not previously been recognized in this context.

Primary Barriers Identified

- Successful products need to be focused on a defined user group as no one product can satisfy all stakeholders and be used for all purposes.
- Sustained long-term generation of operational product delivery requires a dedicated and reliable host office committed to continuous supporting of the product;
- Ensure upkeep is cost effective for the product and that upkeep costs are considered early in the product development.

Primary Advice

- Rather than start with the final product in mind, start with stakeholders' questions and needs.

- Involve stakeholders early and often.
- Know your product’s audience and be clear about it up front.
- When presenting products to stakeholders, invite stakeholder input on strawmen/draft products as early as possible in the development process.
- Identify the product host early, so that the product can be created in a framework that is easily transitioned to the host.
- When possible, operational products should be automated and maintained through technology (rather than by human effort). Autonomy should be central to product development, especially when for near-real-time, operational delivery.
- Leverage existing infrastructure and build onto existing applications and products where possible so that products are centrally located and easy to find. It is better for the product to find the audience than to attract a new audience to a stand-alone product.
- Allocate time and funding to promote awareness of and educate end users on product use.
- It is important to communicate the products intended users and limitations. Identify what the product can help with and what isn’t possible (yet).

Introduction

On September 12-14, 2018, forty-two individuals participated in the *Ocean Acidification Research to Product Development Workshop* in Silver Spring, Maryland. As a science-based service agency, the National Oceanic and Atmospheric Administration (NOAA) maintains a robust, high-quality research and development (R&D) portfolio that continually improves NOAA's products and services. However, R&D transitions and product development are largely a new arena for ocean acidification (OA) science. The state-of-the-science for OA has increased significantly over the past 15 years and as such, there is an emerging capacity to pursue product development that targets needs of a diverse array of stakeholders. This workshop was intended to inform a Research to Product Framework for OA, identify what OA products should be considered, and discuss best practices for transitioning research outputs to applications and operations. Identifying best practices will come from an understanding of how this process has worked for analogous products generated in other fields within NOAA and discussing opportunities where OA research outputs can be adopted into existing products.

The workshop participants included experts in NOAA product transition and delivery, OA researchers and product developers, interested NOAA and cooperative partnership researchers, Coastal Acidification Network coordinators (knowledgeable about stakeholder needs), and potential hosts within NOAA for ocean acidification products. OAP staff also attended as they can support research transition and assist in implementation plans. A full list of workshop participants can be found in Appendix A.

Over the course of the workshop, participants discussed how research-to-product terminology is best interpreted in the context of OA science and learned of potential barriers that, in general, can limit the transition of products. The sessions and panel discussions revolved around pathways and pitfalls of regularly generated products from other NOAA offices, stakeholder needs for OA products, and OA product development.

This workshop summary captures key discussions from the workshop and is not intended to be a transcript. The summary is organized into the following sections:

1. Introduction
2. Meeting Objectives
3. Welcoming Remarks
4. Lessons Learned from Current NOAA Products
5. Research to Product Terminology
6. Coastal and Ocean Acidification Stakeholders
7. Ocean Acidification Products in Development
8. Discussion of Potential Ocean Acidification Products
9. Peer-Review Process for Products
10. Role of Ocean Acidification Program in Facilitating Transitions

Meeting Objectives

The workshop's primary objectives were to:

- Better understand the research to operation/application pathways and pitfalls.
- Define "operational" for the NOAA Ocean Acidification Program and discuss other mission-driven research and development terminology.
- Based on stakeholder interests, consider what existing products within NOAA would benefit from OA research and data synthesis outputs and brainstorm potential new applications and services based on the current OA state of knowledge.
- Propose solutions to overcome barriers that currently inhibit existing research outcomes from transitioning to applications and services.
- Identify OA research and data synthesis outputs which may already have transitioned to an application or service but have not previously been recognized in this context.

Welcoming Remarks

Libby Jewett, NOAA Ocean Acidification Program (OAP) Director, welcomed the participants to the workshop. Dwight Gledhill, OAP Deputy Director, offered the background and charge of the workshop, and Ko Barrett, NOAA Oceanic and Atmospheric Research Deputy Assistant Administrator for Programs and Administration, provided her thoughts on research transition and product needs to a range of users including at high-level policy forums such as the Intergovernmental Panel on Climate Change (IPCC). Both Gledhill and Barrett emphasized the broadness of NOAA's definition of products and transition readiness levels to allow for flexibility in interpretation for all relevant research projects across NOAA's large enterprise. This flexibility creates latitude but also potential confusion, hence the motivation for this workshop.

Lessons Learned from Current NOAA Products

Five NOAA programs were invited to present and serve on a panel to discuss the development of products and the steps in transitioning research outputs to products. The goal of the session was for workshop participants to get a sense of what product development entails and what barriers there may be when transitioning research to operation. The speakers were asked to share product development journeys, including whom the product serves, why and how it developed from research to a product, and lessons learned from transitioning projects. A range of product types were presented, from near-real-time operational data products to semi-regular assessments and reports.

The presentations discussed the following products and highlighted these key messages:

- Veronica Lance (National Environmental Satellite, Data, and Information Service-CoastWatch/OceanWatch/PolarWatch) - Lance discussed the operational product Coral Reef Watch, which uses sea surface temperature data to derive anomalies and hotspots. This information is then used to identify a "degree heating week" which serves as an indicator for when coral reefs are experiencing stressful thermal conditions that may result in bleaching. Satellite products like this one can be largely autonomous and continue regular updates without constant attention of the producer or host. Some of the main challenges the program faces are making the tools accessible for new users (products often have to be focused to one particular user group) and identifying if and how much the product is getting used. Lance notes that CoastWatch/OceanWatch is capable of being a host for global satellite-related OA products and can help with the transition of these products.

- Justine Kimball (National Ocean Service-National Coral Reef Monitoring Program) – The National Coral Reef Monitoring Program (NCRMP) is a framework for collecting long-term data to create a cohesive picture of the status of coral reefs in the United States and its territories. The Program started to develop Report Cards and Status Reports after requests for a “simple status of the reefs” from policy makers and managers. NCRMP program managers needed an easy way to talk about how the reefs were faring. The reports detail the status of coral, fish, climate indicators, and human dimensions. One of those climate indicators is OA, for which the report adopts the use of aragonite saturation state. The development of the reports was contracted externally through the University of Maryland Center for Environmental Science Integration and Application Network. There have been changes to the report based on feedback from the users, such as moving from letter grades to descriptive words (“fair”, “good”, etc). The overall lessons learned through developing these reports were:
    - Involve stakeholders early and often.
    - Know your product’s audience and be clear about who your audience is up front.
    - Stakeholders want specific actions to be advocated for – be clear about the government science agency’s role.
    - There are pros and cons to contracting product development externally.
        - Can find contractor with expertise needed. No additional staff development or capacity is required.
        - Can be more affordable to pay by project rather than develop internal capacity.
        - Project/deliverable driven and will stick to timeline.
        - There is little flexibility once project is ongoing making it difficult to make big adjustments.
        - Set timeline which does not allow for flexibility in extending timeline - time is money.
        - Must have very clear deliverable.
        - Contract mechanisms are slow and require advance planning (> 6 months).
        - Extra layer of communication all around, which is an investment of time and energy.

- Melissa Karp (National Marine Fisheries Service (NMFS) - National Stock Assessment Program) – NMFS Stock Assessments take data related to fish catch, biology, and abundance and use it in models, which are peer reviewed. The model results are used to provide advice on sustainable harvest levels and stock status. There are many stock assessment models to choose from and the choice is largely driven by data availability as well as regional preference. Fully independent peer review process can extend the length of time needed to complete assessments, which limits the number of stock assessments that can be performed each year. NMFS is developing a Fisheries Integrated Toolbox (FIT), a web-based repository for peer-reviewed operational tools and models, which will overcome some of the barriers currently experienced in the product development process. This will combine the separate toolboxes for ecosystem models, protected resources, economics, and social sciences. FIT will overcome the challenges of the original research-to-product method by developing consistent modeling standards across regions, facilitating code sharing, increasing capacity for onboarding of operational tools, and streamlining updating of tools. Once standard models are established, FIT will reduce the time spent on novel model review each year freeing up scientists to do more research and development, and improve coupling across models. FIT is an example of a product improvement following identification and refinement of stakeholder needs to make a more efficient and useful product.

- Becky Shuford (NOAA Integrated Ecosystem Assessment Program) – Integrative Ecosystem Assessment (IEA) provides a framework to implement ecosystem-based approaches to management. It is a science-based iterative approach that assesses the system and the components therein, often summarized in Ecosystem Status Reports or "State of Ecosystem" reports, to provide an indicator-based snapshot of the status and trends in a given ecosystem. Building from this, qualitative and quantitative models and other tools are used to assess the risk or vulnerability to ecosystem components to natural and/ or human perturbations and to project future conditions to evaluate tradeoffs of alternate management strategies to best inform decisions. Partners and stakeholders for IEA products include state and coastal management agencies, National Marine Sanctuaries, and U.S. Regional Fishery Management Councils. Key lessons learned or take-aways from our IEA experience in terms of how to get better uptake of products by management partners include:
    - Engagement should start early (and continue to be often) in the process
    - Ensure stakeholders are full and equal partners in the process
    - Be sure management partners see the added value of helping them most effectively make informed management decisions
    - Bring a strawman of the product, and actively incorporate manager and/or stakeholder input to the final product
    - Make the effort and take the time to establish trusted relationships

- Colleen Roche (Center for Operational Oceanographic Products and Services) - Harmful Algal Bloom Forecast Products are currently produced for three United States regions. The product uses satellite products coupled with a hydrodynamic model to predict where a bloom is starting and where it is moving. This project benefits from robust engagement with stakeholders, who are very much in need of this information. The process for generating these products has three steps that continue in a loop:
        - Research – scientific understanding and technological advances
        - Development – system development and validation, demonstration/advancement, transition, and training
        - Operations – product in use, gaps identified, product enhanced internally or loops back to research, if more is needed

Panel Discussion

- How were stakeholders or end users identified?
  - There was a full spectrum of approaches discussed by the panel including:
    - Stakeholders who approach the agency unsolicited
    - Stakeholders who were identified from external surveys
    - Products dictated by congressional mandates without an explicit end user in mind
- Can one product be developed for multiple audiences?
  - It is likely impossible to produce a product which is perfect for all users. It is important to involve social scientists in developing a product so it is useful for the intended audience and is accessible to the intended users.
- How do you identify ecosystem indicators and thresholds for your products?
  - During the development of the NCRMP report cards, a lot of work went into collating historical data to establish baseline values. The discussion led to idea that identification of indicators and thresholds was enough of a process that it should be codified in a publication or technical document so others might apply the process or at least understand it. Currently, it is an informal/internal methods document within NCRMP.
- Question about time scales - what's the timeline behind these large products, and are most of the products delivered annually? Are there any products with longer time scale?
  - The stakeholder engagement process tends to be what takes the biggest amount of time. Harmful Algal Bloom Forecasts took five years to first develop and are produced on a biweekly basis during the bloom season.
- How do you know if your product is successful?
  - Increased efficiency in product delivery
  - User engagement
    - How many people use the product?
    - Is the product used in decision making?
    - If the product system goes down, do people complain?
  - Surveys can be used to identify product user and impact, although it is difficult to use surveys for this purpose if a product is used by multiple user groups.
- If you were to develop the products you discussed again, what would you have done differently?
  - Would start with stakeholders and their needs, rather than the product in mind.
  - The key is to offer a strawman product to completely and coherently engage users and stakeholders, and to offer your resources/expertise to incorporate feedback before the product has been finalized.
  - In addition, there should be time and funding allocated to educate end-users on how to use the product and promote awareness of the product after the product has been finalized.
  - Identify the host early, so that the product can be created in a framework that works for the site and it can be transitioned easily.

Emerging themes

Barriers

- Successful products need to be focused on a defined user group as no single product can satisfy all stakeholders and be used for all purposes.
- Sustained long-term generation of operational product delivery requires a dedicated and reliable host office committed to continually supporting of the product;
- Ensure upkeep is cost effective for the product and that upkeep costs are considered early in the product development, although this should not preclude product development.

Lessons Learned

- **Stakeholder Engagement**
    - Rather than start with the final product in mind, start with stakeholders' questions and needs.
    - Involve stakeholders early and often.
    - Know your product's audience and be clear about this up front.
    - When presenting products to stakeholders, invite stakeholder input on strawmen/draft products as early as possible in the development process.
    - Allocate time and funding to promote awareness of and educate end users on product use.
    - It is important to communicate the product intended users and limitations- what the product can help with and what isn't possible (yet).
    - Stakeholders want specific actions to be advocated for – be clear about what kind of information a federal science agency can provide.
    - Stakeholders must be full and equal partners in the product development process.
    - Trusted relationships must be built, which requires investment of time.
    - One size product will not serve all variable audiences, regions, etc.

- **Development Process**
    - There are pros and cons to contracting product development externally.
    - Operational products should be automated and maintained through technology (rather than by human effort). Autonomy should be central to product development, especially when for near-real-time, operational delivery.
    - Leverage existing infrastructure, e.g. add OA research outputs to inform existing Marine Sanctuary reports.
    - Avoid starting with the product in mind, instead start with the stakeholders and their needs.
    - Identify the product host early, so that the product can be created in a framework that is easily transitioned to the host.
    - Leverage existing infrastructure and build onto existing applications and products where possible so that products are centrally located and easy to find. It is better for the product to find the audience than to attract a new audience to a stand-alone product.
    - Ask "how do I facilitate the transition from research to product?" You may just be one link in the chain and that is ok. Be cognizant of whole chain and who you need to communicate with both upstream (research outputs your efforts depend

upon) and downstream (specific users of your research output may or may not be end-users) of your research.

- **Product Launch and Maintenance**
    - Bad news can be unpopular and politically sensitive (e.g. coral reef status and trends with respect to manager reception of the 'bad grade').
    - Ensure upkeep is cost effective for the product or that upkeep costs are accounted for before developing the product.
    - Allocate time and funding to promote awareness of the product and educate end-users on how to use the product.

Research to Product Terminology

Taylor Armstrong, visiting scientist with NOAA Ocean Acidification Program, presented on NOAA OAR research and development terminology and readiness levels (see NOAA NAO 216-105B: Policy on Research and Development Transitions and Appendix C) in transition plans. The workshop participants used this information and came to near consensus of research to product terminology to be used for the Ocean Acidification Program research outputs and data products. This allowed participants to understand and use common terminology when discussing product development and transition and will inform how the community interprets this language going forward. The terms below will henceforth be adopted by the Ocean Acidification Program:

Research Project: An activity or set of activities with defined start and end dates and discrete goals and objectives to produce outputs. It is recognized that many research and monitoring activities are sustained long-term, but these activities represent a repeated series of projects each exhibiting a defined set of milestones and deliverables with a discrete time-frame.

Research Output: A unit of information that directly results from a project that is accessible, discoverable, and/or citable.

Research Product: An output specifically designed for and tailored to the needs of a targeted user or user group.

Research Outcome: Changes in the knowledge or actions of the user or a societal or environmental change that results from a research output or product.

Data Synthesis: A value-adding activity which can yield either a research output (potentially a product) and/or facilitate product development by means of consolidating multiple research outputs to generate new information or previous information packaged in a more useable format by targeted users.

Transition: The step progression of research outputs or activities towards a product (either within or outside of NOAA).

Application: A one-time production of a system, process, product, service, or tool utilized by the user community to produce an outcome. An application is not intended for routine operational production but rather a single, unique issuance.

Operational Product: A product that is updated or refreshed on a regular/consistent basis and is maintained in the long-term. This can include products that are delivered on a low-frequency, though regular basis (e.g., regularly issued condition reports) but are not generally produced in an automated fashion.

Host: An individual or group that houses and is responsible for operational delivery. Marketing, training, and evaluation should be considered within the framework of hosting a product in addition to public access, maintenance, and user support.

Coastal and Ocean Acidification Stakeholders

Four Coastal Acidification Networks representatives served as panelists to discuss the results of various stakeholder surveys and workshops that the networks have hosted. The aim of this session was to allow participants to gain an idea of research and products that are needed in different U.S. regions. This session guided the subsequent discussion, which focused on products that could be created to meet stakeholder needs. The presenters were Beth Turner representing the Northeast Coastal Acidification Network (NECAN) and Darcy Dugan representing the Alaska Ocean Acidification Network (AOAN). They were joined for a panel discussion by Leslie Wickes representing the Southeast Ocean and Coastal Acidification Network (SOCAN) and Kaity Goldsmith representing the Mid-Atlantic Coastal Acidification Network (MACAN).

The presentations highlighted these key messages:

- Beth Turner (NECAN) - The Northeast region has reduced buffering capacity due to the colder temperatures compared to other U.S. regions and freshwater inputs. Precipitation is expected to increase in the region which will lead to higher nutrient loading from freshwater. The region is vulnerable to large economic impacts from OA as there is a high commercial reliance on two calcifying species, lobster and sea scallops. Additionally, there is a recent and growing emergence of shellfish aquaculture industries throughout the region, particularly in Maine, in need of OA science that improves industry outcomes and resilience. There are many successful citizen science projects in the region which help inform the public on ocean acidification and its impacts on the species, and contribute to monitoring in the region. NECAN held stakeholder workshops held in 2014 and 2015 in 7 states and Canada. The stakeholders present at the workshops expressed a need for the 2-3 year timescale forecasts so shellfish growers can incorporate projected ocean conditions into their business plans, improved understanding of local mitigation options, and how the suite of factors impacting coastal waters relate. See below for a full list of mentioned stakeholder OA needs.

  Northeast Needs
    - **Research Needs**
        - Shellfish are facing a variety of challenges and negative responses are not easily attributable to any single cause/factor.
        - OA is one of a suite of factors affecting coastal waters - how do these all relate?
        - Rigorous and long-term monitoring is essential - particularly in coastal areas where there are freshwater inputs.

        - Research on species and food chain impacts and adaptation potential
        - Improved understanding of local mitigation options.
        - Baseline information/research on juvenile growth of important species in field conditions is needed, to compare to laboratory research results.
        - Better describe temporal and spatial effects on wild shellfish recruitment.
        - Better define thresholds for juvenile and adult shellfish specific to the region and commercial interest.
    - **Communication Needs**
        - Products to increase awareness about OA.
        - Development of robust, targeted, simple messages about coastal acidification, given the difficulty in communicating about it.
    - **Product Needs**
        - The shellfish industry, both wild and aquaculture, is economically important and likely vulnerable; we need to provide clear suggestions for robust actions that industries could take. Understanding where OA science can explicitly inform decisions can better determine specific product needs. Many of the key decisions that directly impact ocean and coastal acidification reside outside of industry, and products should be tailored to state and federal water quality managers, in addition to industry.
        - Forecasts or projections on the 2-3 year time scale to compliment business planning timeframes for industry/shellfish grower. These forecasts and projections should couple both biogeochemical forecast capability as well as relevant commodity information (e.g. anticipated changes to shellfish grow-out duration).

- Darcy Dugan (AOAN) - The state of OA science in Alaska is quite young but growing. Alaska has unique challenges to studying OA because of the polar weather, remote 44,000 mile coastline, sea ice and seasonal swings. Alaska is particularly susceptible to OA because cold water can dissolve more carbon dioxide than warm water, the influence of glacial melt runoff, and seasonal algal blooms that draw down and then release carbon into the water column. There have been two state-of-the-science workshops (2014 and 2016) and a survey that was distributed to stakeholders about their needs in the region (2017). The survey results demonstrated a need for forecasts on short timescales - seasonally or 5-10 years with shellfish, salmon, and lower trophic species being a priority in the region (in that order). The scientific questions in the open-answer section included:
    - How will OA affect fisheries?
    - Which species will be impacted first?
    - Which species are particularly vulnerable?

  Alaska Needs
    - **Research Needs**
        - Cumulative effect of warming and OA
        - Potential food web effects
    - **Communication Needs**
        - Materials to educate others
    - **Product Needs**

        - Actionable information beyond awareness
        - Easily understandable state-of-the-science brochure
        - Heat map showing saturation state/OA hot spots (where ocean acidification is most likely to affect marine ecosystems)
        - Heat map overlaid with sensitive species distribution
        - OA forecasts on short timescales - seasonally or 5-10 years
        - Bio-economic forecasts for commercially important species
        - Forecasts based on climate action vs. no climate action scenarios

Panel Discussion

- Have you noticed any trends or preferences in the type of materials that resonate best with stakeholders in your region?
    - The best products seem to be those with minimal chemistry details and site-specific geographic area information that connect acidification information with other stressors important in the region.
- What have you heard from social scientists?
    - Some stakeholders, such as policy-makers, want the economic impact to formulate conclusions. Some industry stakeholders are hesitant to rely on economic analyses and are concerned with their accuracy and the potential for them to lead to poor management.
- What products are industry stakeholders asking for?
    - How and when OA is going to affect them
    - If there is anything that can be done to stop it
    - When the species that is their livelihood could be significantly impacted.
    - The industry stakeholders expressed a need for the 2-3 year timescale forecasts so growers can incorporate projected ocean conditions into their business plans. This is a problem as there is a difference in what stakeholders want (1-3 years) and what scientists feel comfortable providing.
- It would be helpful to know when and what key decisions are being made on an annual basis or longer time scale that could benefit from OA information (i.e., industry decisions such as when to slow production, where to place shellfish, when to switch species, etc).
    - This will be very localized and stakeholder specific, however it would be helpful to identify these management decisions for key stakeholders.
- Do you think products in your region should be focused to individual users (i.e., a specific hatchery) or the broader public?
    - Most stakeholders want the information to be very specific. It is not feasible to develop products for everyone so in many cases, it is best to work with a specific, highly engaged stakeholder subgroup to meet their needs.
- How do you balance identifying stakeholders needs with stakeholders not knowing what sort of information is needed?
    - This is a good question and there is not a clear answer. Sometimes guidance to the stakeholder is helpful in the product development process. Question-and-answer sessions can help stakeholders identify what they should be looking for in a product. Coastal Acidification Networks can be good at identifying who should be

part of the conversation and vetting the process for the product you are developing.

Ocean Acidification Products in Development

Researchers presented and served as panelists to discuss OA research outputs and potential products. The goal was for workshop participants to gain an understanding of select OA projects that exhibit operational potential or are currently being developed for operational delivery. The workshop participants proposed ways to overcome barriers that currently inhibit products from operational delivery.

The presentations highlighted these key messages:

- Maria Kavanaugh (Oregon State University) - The Seascapes project is a multiscale prediction for the California Current carbonate system. Collaborators include Burke Hales (Oregon State University) and Scott Doney (University of Virginia). Along the California Current, upwelling drives the primary productivity and high frequency carbonate system shifts. However, baseline conditions are regionally or water-mass dependent. This project integrates information from satellite sources into large-scale seascapes of entire ocean regions or basins. The project goals are to improve predictions of the carbonate system parameters and provide a near real-time operational product of the carbonate system. The product is near operational and will be hosted by NOAA CoastWatch. It will provide stakeholders with the mean state of the carbonate system and how it has changed, the magnitude of variability in the system, the rate of change, and serve as an early-warning system.

- Liqing Jiang (NOAA National Centers for Environmental Information) - The project is a data synthesis effort to compile discrete chemical measurements along North America's coasts. Users will be able to find data in one location and download the information as one package or download a subset of the data for a specific carbonate variable in a specific region. This will allow scientists to easily access coastal chemical data and stimulate OA products that help coastal community managers and policy makers. The biggest barrier to overcome with this data synthesis effort is identifying a method for QCing data from a large number of labs.

- Brian Katz (Oregon State University) - This project includes a geovisualization of the vulnerability and adaptation pathways for the Pacific Northwest shellfisheries to OA. The vulnerability map focuses on four important shellfish industries and creates a species transition matrix that incorporates species-response curves to OA and maps where and when they may be most vulnerable. The barriers foreseen for this product are identifying a long-term host for the product and creating a geovisualization capable of real-time analyses. It is also unknown how this product will influence stakeholder action and if it will require further recommendations to stakeholders (i.e., changing the time of spat dispersal, moving to a new location, earlier harvest, or buffering the water).

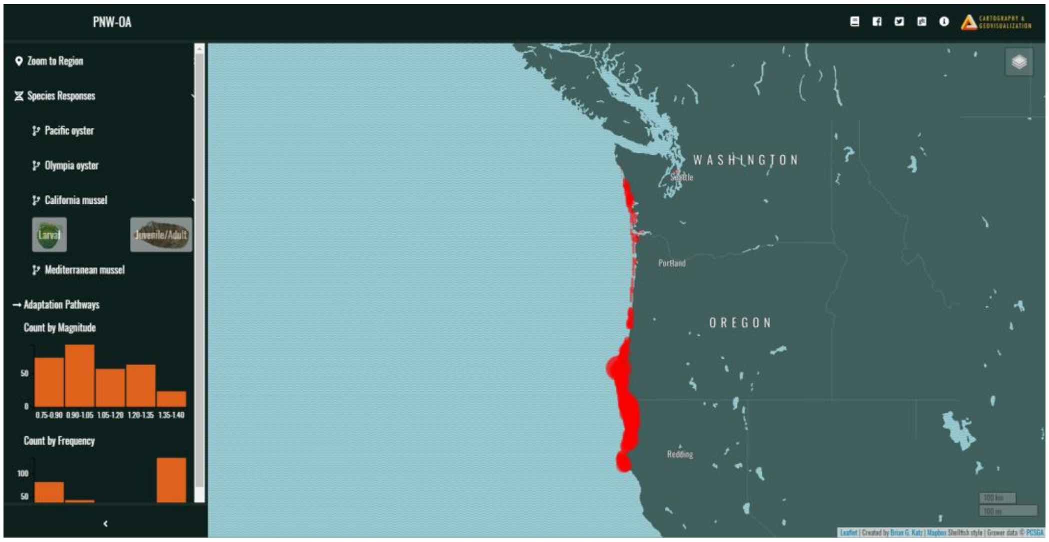

Figure 1. Prototype of geovisualization to identify vulnerability and adaptation pathways for the Pacific Northwest shellfisheries to Ocean Acidification built by Brian Katz.

- Simone Alin (NOAA Pacific Marine Environmental Laboratory) - There is a new PMEL data portal and interactive time-series climatologies, created by a collaboration between Adrienne Sutton and Simone Alin. Real-time data from the OA moorings in the United States are located on the PMEL site. Now there are interactive plots in the portal that allow the public to identify how long the water is below a certain threshold for two OA parameters (ex. See Fig 2 GOM Mooring). They are also creating 3D movies and infographic applications to facilitate science communication. The barrier with communication applications is identifying the right host where the product can easily found and accessible by the correct stakeholders.

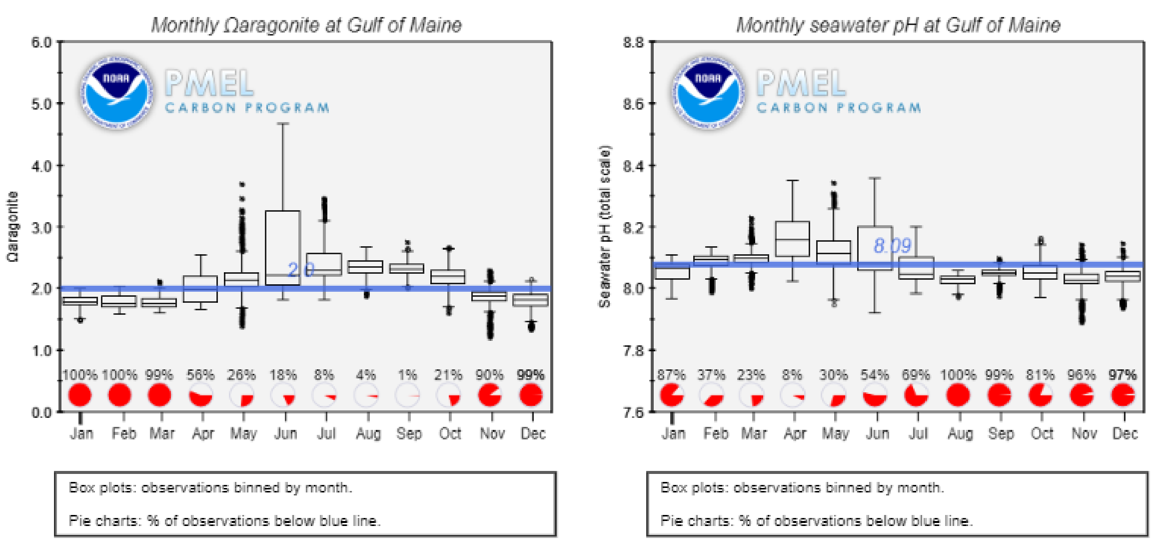

Figure 2. Monthly climatology of surface seawater aragonite saturation state and pH in the Gulf of Maine. Interactive box plots are observations binned by month as described in Sutton et al., 2016. Pie charts represent % of observations within each month that fall below the adjustable line. This adjustable line is meant to provide a tool for assessing potential biological thresholds. (NOAA Pacific Marine Environmental Laboratory Carbon Program)

- Joe Salisbury (University of New Hampshire) - The University of New Hampshire is developing a water-balance model to aid in the development of OA products. This will help scientists identify how carbonate parameters are altered by freshwater in their region and improve salinity and circulation forecasts. This is created by Alex Prusevitch, Joe Salisbury, and Hangshen Chen. The challenges with this product are calibrating the water-balance model and adding groundwater flux dynamics and vertical flux exchange to river networks in the model.

- Wei-Jun Cai (University of Delaware) - This project is collecting mooring data from Gray's Reef in the South Atlantic Bight and determining short-term pH and aragonite drivers of variability. This data-synthesis effort will provide an overview of how acidification parameters (pCO_2, dissolved inorganic carbon, and total alkalinity) have changed over the last 15+ years. One challenge is that stakeholders have not been brought in to provide input. At this time, this is primarily a research output but, as is the case with the broader NOA-ON network, the data produced could be transitioned to product development should specific user needs be identified.

Panel Discussion

- What have your interactions with stakeholders looked like?
    - Stakeholder groups vary based on the product; sometimes they approach the scientist requesting further information and other times are sought out for input. Many of the shellfish growers want to know what is going on currently and want a high-frequency refresh. It is recommended to not initially present a final version of the product to stakeholders, rather work with them throughout the development process.

- Do you try to guide stakeholders to help them understand what temporal scale might be useful to them?
    - This is a difficult conversation as most just want to know when they will start to see a problem. Coastal Acidification Networks are a good place to start having these conversations. Try to have a conversation about what the available OA science and products are and how this might help them identify questions.

- How do we talk to stakeholders who don't know what information they want and/or don't understand what's going on because OA is not being felt yet?
    - In some regions the science is not developed enough to inform stakeholders of the top priorities. Sometimes scientists have to be comfortable in the uncomfortable spaces, recognizing we do not yet have the answers for stakeholders.

- What are some of the barriers you have for creating your products?
    - For the stock assessment improvement plan, a barrier is the availability of data and consensus about the best models. There should be a better streamlined process for accessing data.

Discussion of Potential Ocean Acidification Products

The workshop participants gathered in a large circle to summarize the stakeholders' questions presented during the workshop and discuss products that could begin to answer those questions. The participants were then asked to break out into groups to develop one product and answer the following questions about the product:

- What is the question you are answering?
- What is your product?
- Who are your stakeholders?
- What are the existing resources that could be used to create the product?
- Are there any research gaps that need answers before creating the product?
- How will the information be presented so it is in a digestible form for stakeholders?
- Would your product be considered an application, operation, invention, or something else?
- Is the product something that needs continued updating? Who will do this?
- Who are the end-users/potential hosts of the product?
- What barriers do you foresee for creating this product?
- What would be the steps/recommendations for overcoming these barriers?
- What would the steps be for transitioning this project?
- What is the value to the broader ocean acidification community?

Peer-Review Process for Products

During the last day of the workshop, the group gathered for a final discussion of take-away lessons from the workshop and questions that needed further discussion. One question that arose was what the peer-review process for products should be.

- **Peer Review**. As a general rule, everyone agreed that products should not be released until they had gone through a peer-review process and this included any research outputs a product depended upon.
- **Early release**. The group recognized there are some data, like buoy data that are available on websites in real-time, often in an underdeveloped state; this is okay as long as the limitations of the data is clearly stated on the website. In addition, there are products that need to be piloted as early as possible to receive feedback to upgrade the product.
- **NOAA guidance**. Ultimately, the question that needs to be asked is: will this directly affect life and property? If the answer is yes, the product must go through rigorous peer-review before distribution to the public, even in prototype form. If the answer is no, the product needs to still go through peer-review, but it is likely that an early version could

be distributed for feedback. Further discussion with other NOAA offices is needed to understand how products are released.

- **Checklist**. There needs to be a checklist for transitioning research to a product with these required steps. This will be included in a subsequent technical memorandum.

Role of Ocean Acidification Program in Facilitating Transitions

An important objective of the workshop was for the Ocean Acidification Program (OAP) to better understand how they can help facilitate research-to-product transitions and the responsibilities of the Program during the process.

- **Better definitions**
  - Understanding OA indices. The group suggested a publication describing what biological and chemical OA indices are best to use in different scenarios would be a useful project that would help develop products
  - The program should develop a research-to-product framework and a checklist for transitioning research to a product.
- **OAP and product hosts**. OAP should be responsible for making sure finished products have a host and do not disappear.
- **OAP and costs**. OAP will help identify what the long-term costs are for maintaining the product.
- **Product communication**. OAP should have a products page on their website to point to where all of the current OA products are located.
- **Generate new products**. It is up to the OAP to identify existing products that OA information could be added to and identify the scientists that are best suited to facilitate this.

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Appendix A -Workshop Participants

Alin, Simone - NOAA OAR Pacific Marine Environmental Laboratory
Armstrong, Taylor - UCAR Cooperative Programs for the Advancement of Earth System Science CPAESS &

NOAA OAR Ocean Acidification Program
Barbero, Leticia - NOAA OAR Atlantic Oceanographic and Meteorological Laboratory
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Barrett, Ko - NOAA OAR
Bennett-Mintz, Jenn - NOAA OAR Ocean Acidification Program
Brady, Peg - NOAA NMFS Science and Technology
Busch, Shallin - NOAA OAR Ocean Acidification Program & NMFS Northwest Fisheries Science Center
Cai, Wei-Jun - University of Delaware
Canonico, Gabrielle - US Integrated Ocean Observing System
Cross, Jessica - NOAA OAR Pacific Marine Environmental Laboratory
Da, Fei - Virginia Institute of Marine Science
Dugan, Darcy - Alaska Ocean Acidification Network/ Alaska Ocean Observing System
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Santoni, Amanda – Environmental Protection Agency
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Siedlecki, Sam - University of Connecticut
Tartt, Mitchell - NOAA NOS National Marine Sanctuaries
Tedesco, Kathy - NOAA OAR Climate Program Office
Turner, Beth - Northeast Coastal Acidification Network/ NOAA NOS National Centers for
Coastal Ocean Science
Wanninkhof, Rik - NOAA OAR Atlantic Oceanographic and Meteorological Laboratory
Wickes, Leslie - Southeast Ocean and Coastal Acidification Network

Appendix B - Agenda

DAY 1: From Research to Operation - Examples, Terminology, and Ocean Acidification Needs

8:30 AM WELCOME AND OPENING REMARKS

8:45 AM NOAA OCEANIC & ATMOSPHERIC RESEARCH (OAR) RESEARCH TO OPERATION

Presentation by Ko Barrett (NOAA OAR Deputy Assistant Administrator)

9:00 AM NOAA OPERATIONAL PRODUCTS SESSION: Examples of NOAA products, brief history of how they were developed and transitioned and barriers overcome and advice during in the process.

Presentations by Veronica Lance (NOAA NESDIS CoastWatch), Justine Kimball (NOAA NOS NCRMP), Melissa Karp (NOAA NMFS Stock Assessments), Becky Shuford (NOAA NMFS IEA), Colleen Roche (NOAA NOS CO-OPS)

10:30 AM BREAK

10:45 AM OPERATIONAL PRODUCTS PANEL: Open discussion on the process of transitioning research outputs into the product and how to identify the need for the products

11:15 AM NOAA RESEARCH OUTPUTS TO APPLICATION, OPERATION, COMMERCIALIZATION, AND OTHER USES (R2X) TERMINOLOGY & TRANSITION READINESS LEVELS

Presentation by Taylor Armstrong (NOAA OAR OAP/ UCAR CPAESS)

11:25 AM SMALL GROUP DISCUSSION- DEFINING TERMINOLOGY

12:15PM LUNCH- Continuing to discuss terminology at nearby establishments

1:45 PM GETTING ON THE SAME PAGE: WORKING DEFINITIONS FROM RESEARCH TO OPERATION: Participants will come to near consensus on what an operational product means with respect to OA research

3:30 PM BREAK

3:45 PM COASTAL AND OCEAN ACIDIFICATION STAKEHOLDERS ACROSS THE U.S. AND BEYOND: Presentations and panel discussion by Coastal Acidification Networks about stakeholder needs.

Presentations by Beth Turner (Northeast Coastal Acidification Network) and Darcy Dugan (Alaska Ocean Acidification Network)

Panelists: Beth Turner (Northeast Coastal Acidification Network), Darcy Dugan (Alaska Ocean Acidification Network), and Leslie Wickes (Southeast Coastal and Ocean Acidification Network)

4:45PM WRAP UP

5:00 PM ADJOURN

DAY 2: Ocean Acidification Products: Where They Are and Can Go

9:00 AM OPENING REMARKS

9:10 AM OCEAN ACIDIFICATION RESEARCH AND TRANSITION SESSION: Examples of NOAA OA products, Presentations and panel discussion by individuals with OA projects that are nearing or could be transitioned to operational.

Presentation by Maria Kavanaugh (OSU), Liqing Jiang (NOAA NESDIS NCEI), Brian Katz (OSU), Simone Alin (NOARR OAR PMEL), Joe Salisbury (UNH), Wei-Jun Cai (UDel)

10:15 AM BREAK

10:25 AM BARRIERS AND OPPORTUNITIES FOR OPERATIONAL PRODUCTS - PANEL DISCUSSION

11:10 AM DIVING IN- OA PRODUCTS CIRCLE: Open discussion about ocean acidification products including those that were presented and other potential operational products

12:05 PM LUNCH

1:30 PM OCEAN ACIDIFICATION PRODUCT DEVELOPMENT: Participants identify early development concepts for future products and work to refine and prioritize throughout the afternoon.

2:35 PM PRESENTING AND PRIORITIZING PROJECTS. Combine/split/reject concept ideas and select subset of research→ operational products to further synthesize. Participants choose one product to work on.

3:15 PM BREAK

3:30 PM WORK WITH PRIORITY PROJECTS GROUPS

4:45 PM PRESENTATIONS BY PROJECT GROUPS

5:20 PM WRAP UP/ANNOUNCEMENTS

5:30 PM ADJOURN

DAY 3: Reflect and Identify Next Steps

8:30 AM OPENING REMARKS

8:45 AM GROUP DISCUSSION. Further discuss questions:

10:15 AM DISCUSSION OF NEXT STEPS

11:15 PM END OF WORKSHOP

Appendix C – NOAA OAR Transition Readiness Levels

See NOAA Administrative Order

Readiness Levels (RLs): A systematic project metric/measurement system that supports assessments of the maturity of R&D projects from research to operation, application, commercial product or service, or other use and allows the consistent comparison of maturity between different types of R&D projects. (Note: NOAA RL's are similar to Technology Readiness Levels developed by NASA (Mankins, 1995) and embody the same concept for quantifying the maturity of research). A project achieves a readiness level once it has accomplished all elements described within a readiness level. A program may include projects at different RLs depending on the goals of each project. Inventions may be generated at any RL. The nine readiness levels are as follows:

a. RL 1: Basic research, experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view. Basic research can be oriented or directed towards some broad fields of general interest, with the explicit goal of a range of future applications (OECD, 2015).
b. RL 2: Applied research, original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective. Applied research is undertaken either to determine possible uses for the findings of basic research, or to determine new methods or ways of achieving specific and predetermined objectives (OECD, 2015).
c. RL 3: Proof-of-concept for system, process, product, service, or tool; this can be considered an early phase of experimental development; feasibility studies may be included.
d. RL 4: Successful evaluation of system, subsystem, process, product, service, or tool in a laboratory or other experimental environment; this can be considered an intermediate phase of development.
e. RL 5: Successful evaluation of system, subsystem process, product, service, or tool in relevant environment through testing and prototyping; this can be considered the final stage of development before demonstration begins.
f. RL 6: Demonstration of a prototype system, subsystem, process, product, service, or tool in relevant or test environment (potential demonstrated).
g. RL 7: Prototype system, process, product, service or tool demonstrated in an operational or other relevant environment (functionality demonstrated in near-real world environment; subsystem components fully integrated into system).
h. RL 8: Finalized system, process, product, service or tool tested, and shown to operate or function as expected within user's environment; user training and documentation completed; operator or user approval given.
i. RL 9: System, process, product, service or tool deployed and used routinely.