Outcome #5: Provide appropriate data and information necessary to the development of societally relevant predictions and projections

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Motivation & Vision

The anthropogenically forced increase in atmospheric carbon dioxide is accompanied by a commensurate trend in the carbonate system of the global ocean, a phenomenon called ocean acidification, recognized by the IPCC to be "highly certain". As such, surface pH has been shown to be highly predictable at the global scale for a given emissions scenario within global Earth System Models (ESMs) well into the future. In coastal environments, local processes can modulate or exacerbate this trend, and these processes occur on spatial scales that are not well represented in ESMs. As a result, prognostic information from advanced prediction to support decisions facing coastal communities subject to ocean acidification impacts is largely lacking. Some regions do benefit from this kind of prognostic information, but it is largely inaccessible by non-experts because the data size is large, uncertainty measures are difficult to generate, and interfacing with it is complicated.

The UN Decade offers an opportunity to advance, globalize, and enable access to regional climate information through broadening our capacity, expanding our capabilities, and investing in the resilience of coastal communities. Several large endeavors are already well underway to bring forecasting and climate information to coastal communities and more localized scales (CoastPredict, OceanPredict, GOOS). Within this effort, it is of particular importance to include and expand our focus to include ocean acidification to enable communities to build resilience around this important aspect of ocean health.

A lot of attention has been focused on the predictability of warming and heat waves both within research and applications (Jacox et al. 2020), but considerably less effort has been applied to understanding the commensurate and often more severe consequence of ocean acidification. Ocean acidification variables are likely more predictable than physical variables. Ocean acidification variables also evolve differently within downscaled projections than global ESMs on climate timescales within coastal settings (Siedlecki et al. 2021), which makes downscaled products necessary for localized projection. The ocean acidification community is deeply rooted in attribution science, scenario planning, and working with stakeholders. In coastal regions, the community has close ties to stakeholder groups who are actively engaged (Cross et al., 2019). Research and products already exist that help inform decisions around the globe making those who are looking for stakeholder engagement as part of their forecasting or projection efforts well advised to partnering with this engaged community of practice (Table 1). But ocean acidification is not happening in a vacuum and those same engaged stakeholders need tools to inform decisions about the many changes and challenges they are experiencing in the changing coastal environment. As such, this Outcome will focus on the complete product of delivering climate information relevant to many sources of ecological stress, with the main focus of optimizing the design, delivery and utilization of bespoke knowledge ocean acidification products.

Table 1: A subset of examples of model forecasting and projection OA variable-based products that already exist and help inform decisions around the globe.

Project description	**Region**	**Decision the model supports**	**Timescale**	**Paper and or project website**
East coast estuary historical simulation	Chesapeake Bay, USA	Nutrient mitigation for the watershed into the bay	Climate	
J-SCOPE	Northern CCS, USA	Fisheries management	Seasonal	Siedlecki et al. 2016; Kaplan et al. 2016; J-SCOPE website[1]
East coast projections with NWA ROMS	NWA shelf, USA	Regional OA action planning for MA, NJ, and ME	Climate (>2050)	Siedlecki et al., 2021
West coast historical simulation	Southern CCS, USA	Nutrient mitigation and sewage treatment	Climate	Kessouri et al., 2021

[1] https://www.nanoos.org/products/j-scope/

		remediation actions in the S-CCS		
Alkalinity enhancement	Austrialia, Great Barrier Reef	OA mitigation	Climate	Mongin et al., 2020
FutureMares	North Atlantic and European Seas	Nature Based Solutions	Statistically downscaled CMIP6/Monthly/Climate	Project underway
MPA /coral reef? Reef watch?	Carribean			
ACLIM	Bering sea			

Our Vision

Ocean predictions and projections on the local scale to support decisions will require us to employ new technologies such as digital twins, machine learning, high resolution local predictions, and regional earth system models that seamlessly interface with large scale model output. Equitable, easy access to these ocean forecasts and projections in our everyday life will result in a more climate savvy public changing people's behaviours, increasing public awareness, expanding knowledge and perceptions, and contributing to the UN SDGs. The data will allow for mitigation of climate change impacts on coastal communities as well as the natural environment like coastal acidification driven by eutrophication by examining scenarios within these tools to develop more realistic plans for management within a multi stressor framework. The production of these projections and associated data products will enable better marine resource management decisions. These tools will allow for implementation of ocean acidification adaptation and mitigation strategies, and integration of this information into other adaptation and mitigation strategies like marine carbon sequestration and removal, thus enhancing our international capabilities.

How does this fit within OARS and the larger UN SDG goals

The UN Ocean Decade program "Ocean Acidification Research for Sustainability" (OARS) alongside GOOS: CoastPredict will provide a roadmap to achieve this vision. Outcome 5 activities are informed by stakeholder needs identified in Outcome 2, biological response products in Outcome 4, and will require strong data provision from Outcome 1 and Outcome 3 to inform and test model development. In return, it will identify gaps in global observations strategies, and this promotes optimal resource investment in ocean acidification monitoring. The provision of knowledge that is usable and understandable requires good communication with Outcome 6, and further to science policy equip nations and society to mitigate and adapt to ocean acidification with Outcome 7.

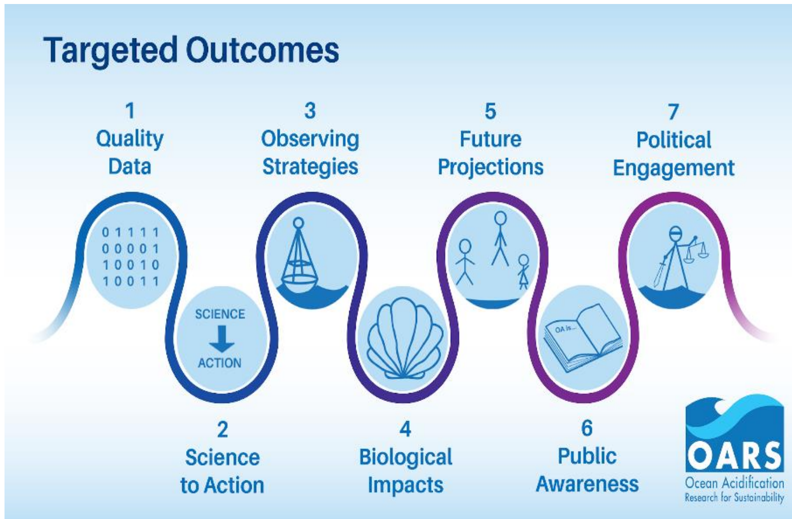

Figure 1: OARS seven targeted outcomes

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No tool currently exists that delivers localized ocean climate information which spans the timescales of short-term forecasts all the way to projection space. This is in part because of lack of access to the model data, regional capacity, and in part due to lack of knowledge about how regional climate data could be consumed. All of those barriers are traversable and the goal of this Outcome's activities.

What products and outputs do we expect from Outcome 5?

To achieve this outcome, key products will need to be produced including new modeling innovations as well as tools to apply existing global simulations to local scales, all while ensuring equitable access to the bounty of climate information produced. Development of innovative technologies that both integrate and guide autonomous real time observations including artificial intelligence, machine learning, digital twins, data assimilation, and future innovations will also be required. Collaboration with other UN decade activities with similar objectives like DITTO, CoastPredict, OceanPredict, and GOOS is vital to the success of this outcome. In many cases, these other programmes are not considering ocean acidification in their prioritization and thus it is up to our community to voice our potential as well as work toward its inclusion in these important activities.

Delivery of this information at hyper-localized scales will require additional visualization tools, which likely will demand the inclusion of a new community of practice and expertise in other disciplines like social science and data visualization.

Best practices will need to continue to be established for making near-term predictions, long-term projections of ocean acidification and other marine ecosystem stressors to support community decisions, and provision of localized ocean acidification climate information including novel applications of existing global ESMs. Some stakeholder groups like marine resource management, have been the target of these kind of activities on decadal to century scale downscale projection (Drenkard et al. 2021; Tommassi et al., 2017) on seasonal to decadal scales. These best practice recommendations have been US centric and rely heavily on large compute resources like supercomputers. There is a need to continue to develop best practices with developers of tools from broad international communities and to consider alternative approaches in order to ensure inclusive practices and continue to build capacity.

The long-term need for these kinds of tools and regional climate information at hyper local and temporal scales requires that capacity is established to broadly support development of these models and tools locally but also that capacity exists to enables local users to access near-term prediction and future scenario projection outputs. As such, educational and training workshops in all regions of the world will need to be provided. This will entail the development of modular educational activities that can augment existing scientific meetings and summer schools to be deployed globally.

Local observations and integrated products are key ingredients to the success of these activities as they are vital for model evaluation for development as well as trust building activities with stakeholders. Collaboration with the team working on Outcome 1 will facilitate this objective. Observation-based products include the generation of maps, atlases, and indices, which will involve collaboration with the team working on Outcome 4.

Regional forecasts and projections are fairly new tools that will require the generation of trust, especially in new implementations, as these products will be required over long timescales into the future. Trust needs to be established both the potential capabilities of the tools and the abilities of the scientific community to achieve them. Building trust with communities of potential stakeholders around models, projections, and forecasts of ocean acidification variables will require the development community to develop new methods to quantify and communicate uncertainty with these new tools and decision support systems in mind. In addition, partnering with real time observing networks (partner with Outcome 1), will be essential as weather forecasts and other atmospheric based products have the benefit of direct user experience to build trust, but without real time observations, stakeholders have no way to establish direct experiences with ocean conditions.

Delivery of this information locally will require additional collaborations between the model and tool developers with the private sector as well as social scientists to bring the visualization of these data sets into everyday life (e.g., Google maps). Funding mechanisms to support these kinds of collaborations currently are not easily accessible by the community and either need to be established or advertised broadly.

Research and outreach activities planned and needed - the roadmap to achieving this outcome

Several key actions can be taken early in the decade to move toward the success of this outcome and to develop concrete time horizons with broad community support and participation: and include workshops, papers, and educational module development. These activities will directly engage new collaborators, communicate the findings and methods necessary to globalize these products, and build trust through extended usage and transparency of the models themselves.

In order to motivate stakeholders, funders, and decision makers to support this activity broadly, establishing the clear value add of these computationally intense activities will be important early on. Collecting case studies or examples that exist already in this space is one approach, and not all these case studies need to pertain to ocean acidification necessarily to provide evidence. Focusing on achievable small scale success stories will provide a foundation to build upon. For example, several examples of predictable systems exist for ocean acidification variables on the west coast of the US on seasonal to decadal timescales (Siedlecki et al. 2016; Brady et al. 2020; Kessouri et al. 2021). The collection and curation can be accomplished through regional workshops that rely on the GOA-ON hubs and networks of other sister programmes within the decade. An integrated paper on the topic or even regional summaries where appropriate would greatly benefit the continued development of these tools globally.

Several best practices workshop(s) in collaboration with other UN Decade programmes and organizations outside of the ocean acidification community would provide fuel early in the decade for the vision to be enabled globally. In partnership with GOOS/CoastPredict and the core focus area FLAME, best practices for downscaling ocean climate information need to be extended from Drenkard et al. (2021) to allow for broader participation in this endeavor. The generation of a body of work or paper documenting these ideals will serve the further development of this important activity.

In addition, the conversation with other communities with experience forecasting and projecting on smaller timescales is critical to learn from and guide us. Well established communities in weather, sea level rise, flooding, HABs, and other folks working on these shorter timescales. Relocatable forecast systems are also being operated like OPENCoastS and SURF which could be augmented for ocean acidification variables. Given the highly variable and localized issues associated with coastal acidification, research would need to be done on how to best include these variables rigorously in these flexible systems.

Broadening the community, we learn from will also be critical. This includes turning to the private sector and business community who has streamlined the process by which stakeholder information is integrated into product development like AGILE (Raharjo and Purwandari, 2020). Stakeholder co-designed tools exist for weather, surf, and wind forecasts which could inform the development of similar tools for the ocean acidification community. Boundary organizations will be necessary when these systems move into new areas as, especially those that exist in the new regions already with long standing relationships with local stakeholders. Learning about these workflows or inviting the private sector into the process could speed up the process of co-design.

Stakeholders will continue to be critical to engage with as early and often as possible, which will require collaboration and coordination with OARS Outcome 2 activities. In particular, a gap analysis with observational needs in collaboration with OARS outcome 1 and 2 could also identify new knowledge potential from existing data mining. By creating an inventory of existing tools, applications, models, and products for ocean acidification and development of new knowledge from existing data. Workshops will define which groups of stakeholders to focus on first. They will identify what are the main stakeholder data requirements. Outcome 5 competence and ambition, alongside the high stakeholder relevance will be used in targeted funding meetings with, for example, research councils, government agencies, financial institutions, private companies, NGOs, philanthropists.

Specific communities are needed to engage with and ensure the data provided is relevant to decisions that can be supported from the forecasts and projections. We will work closely with Outcome 2 on this outreach to include:

- Marine resource/fisheries managers
- Conservation areas
- Wind farms
- Marine CDR industry
- Tourism
- Indigenous communities
- Blue carbon
- Aquaculture

Extending this work into new regions and sustaining it into the future will require additional capacity building in regional modeling, statistical downscaling, and using big data from global ESMs. This could be achieved by offering training sessions at international and national conferences as well as summer schools on this topic. Educational materials will need to be developed and distributed as well as tutorial videos generated.

With marine carbon dioxide removal work on the rise, the incorporation of ocean acidification baselines into newly developed recommendations for CO_2 removal and nature -based solutions is vital.

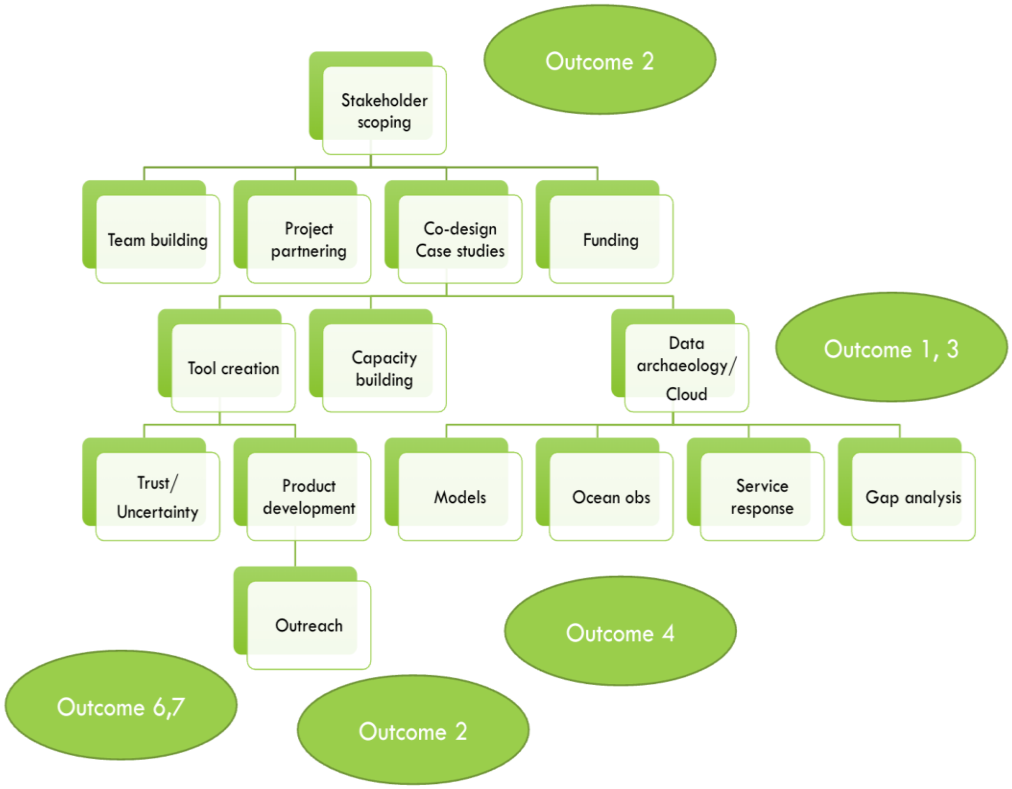

Figure 2: Early phase schematic of Outcome 5 structure, sub-themes, and information pathways

Data needs

We will also require FAIR, open and verifiable data from a variety of sources and in particular those available in real time for model evaluation through the platform in real time. This activity is vital to the development of trust with new communities surrounding these new tools. We will work closely with Outcome 1 on this research need.

In addition, new analysis and products from observations will also be required for evaluation of the local climate information. This includes climatologies, regional trends, and local attribution of trends. As the ocean acidification community's data finally extends long enough in some regions to begin this activity, or regional statistical models emerge to extend existing hydrographic information, these products will begin to emerge and will help inform the regional climate trends in collaboration with Outcome 3.

Finally, as new tools emerge in underdeveloped regions, evaluation using local data sets will continue to be critical. Satellite products are often available even if no other data is being collected. Extending satellite products to include localized ocean acidification relationships will be vital in these emerging locations.

Membership

To enable these activities in both the short and the longer decade, OARS Outcome 5 members will work to identify, collaborate, and engage with experts from a broad pool of topics including those listed in Table 2. We will identify additional members through boundary organizations, partner endeavors and programmes within the Decade, and through GOOS and GOA-ON regional associations and hubs.

Table 2: List of some potential partner organizations and programmes

Expertise	**Potential groups to engage**
Global climate modelers (ESMs)	OceanPredict; DITTO
Downscaling	CoastPredict; Jupiter;
Process based modeling	CoastPredict; Gordon conference; GEM
Visualization/map making	Geographers
Data Scientists	
Large Ensemble analysis/Uncertainty	OceanPredict
Real time delivery of quality-controlled biogeochemical data	GOOS
Ocean forecasting at various required scales for stakeholders	GOOS/CoastPredict; UNDRR[2]
Marine resource management and other key stakeholders' perspectives (Outcome 2)	OARS O2; boundary organizations like CFRF
Multimedia experts	

[2] https://www.undrr.org/theme/early-warning

The way forward

At the end of the Decade, because of the activities described here and the combined power of the sum total of the Decade's activities, societally relevant predictions of the impacts of ocean acidification will be freely available. This will require new approaches and partners to support the computationally intense requirements to provide climate information at hyper-local scales. For example, innovative technologies that integrate autonomous real time observations and visualize the output will need to be developed. Best practices for forecasting and providing localized projections of climate are needed. Furthermore, equitable distribution pathways for seamless existence in everyday life will need to be identified and established. Finally, capacity and trust building with the next generation of scientists as well as stakeholders and end users.

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