2022 Global Ocean Monitoring and Observing Program Review

Summary Report

July 11-14, 2022

Review Panel

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OVERVIEW

The National Oceanic and Atmospheric Administration's (NOAA) Global Ocean Monitoring and Observing Program (GOMO) funds, leads, partners, convenes, plans, advocates, and manages a wide range of ocean observing research. Their goal is to "Provide and support high quality global ocean observations and research to improve our scientific understanding and inform society about the ocean's role in environmental change." To achieve this, GOMO has developed a strategic plan to address the period of 2020-2025 with four goals that address not just GOMO's overarching goal and vision, but also align with NOAA's strategic plan. The scope of this review was to assess the quality, relevance and performance of research and activities sponsored or conducted by NOAA's GOMO over the last 5 years (2017-2021), and to provide recommendations for improvements moving forward. The panel was also asked to assess the progress of GOMO on implementing strategic plans and provide insights for future planning.

Laboratory and Program science reviews are conducted every five years to evaluate the quality, relevance, and performance of research conducted in NOAA Oceanic and Atmospheric Research (OAR) laboratories and programs. These reviews ensure that OAR research is linked to mission, strategic plans, and priorities; they are of high quality as judged by preeminence criteria; and are carried out with a high level of efficiency and effectiveness.

GOMO has a complex history, becoming a program only in 2020. Throughout its lifetime, it has catalyzed the development of the current global ocean observing system through the support of observations, data, science analysis, and capacity building. GOMO provides > 50% of global ocean observing systems and is the largest global ocean in-situ observing program in the world. GOMO receives $50M in annual appropriations, and supports more than a dozen observing systems, thousands of platforms, and hundreds of international partners. This external review was the first review for GOMO and after two years of pandemic, the first in person review conducted for any OAR program or laboratory since 2020. The on-site review was conducted over a four-day period, from July 11-14, 2022. Prior to the review, two virtual meetings were conducted with OAR and GOMO staff members and review panelists to discuss the review processes, the charge to reviewers, agenda, logistics, and field any questions from panel members. Review materials were posted on the GOMO website ahead of the review. In addition to presentations and background materials which provided summaries and highlights of activities, goals and objectives, strategic plans, and other program-relevant information, questionnaires were emailed to 20 stakeholders across the three Focus Areas that comprise GOMO to provide additional information on their perspectives of GOMO's performance and areas of growth. 13 questionnaire responses were received by OAR staff, which were provided to the review panel after the on-site review was concluded.

The review began on July 11, 2022, with a NOAA overview presentation by Ms. Emily Menashes, the OAR Deputy Assistant Administrator for Programs and Administration; this presentation introduced the context of Program reviews and provided the GOMO Charge to Reviewers. Following this, Dr. Wayne Higgins shared the structure of the OAR portfolios and linkages, and subsequently Dr. David Legler, GOMO Director, introduced the GOMO Program and its three Focus Areas:

- Focus Area 1: US leadership of an ocean and Arctic observing research enterprise.
- Focus Area 2: Frontiers in ocean observing.
- Focus Area 3: Information and product development to ensure data access and usability; and to increase the value/impact of ocean observations.

During the first day, reviewers were also provided an overview of GOMO's outreach and communication activities.

Each of the three Focus Areas were addressed during days 2-4 (July 12-14); these sessions began with an overview of the Focus Area provided by one of the Area's staff members and were followed by presentations that provided more context for the activities conducted by the specific Focus Area. Time for open discussion and questions were included, and GOMO staff and participating PIs and scientists also participated in hybrid form (some physically in the room, others via GoToMeeting). Closed stakeholder meetings were conducted each afternoon over days 2-4 for panel members to have private discussion with stakeholders regarding each focus area, followed by closed review panel sessions for internal panel discussion. Each day was concluded with a brief discussion between the review panel and GOMO staff, where clarifying questions about the day's content were asked.

This report is not a consensus, but a summary of individual reviewer reports. The following section provides a summary of program-wide findings and recommendations, summarized from the panelist individual evaluations.

SUMMARY OF PROGRAM-WIDE FINDINGS AND RECOMMENDATIONS

The panel was extremely impressed with the breadth and quality of activities carried out by GOMO in the last 5 years. The panel also noted that this is a review of a program that has only been active for 2 years, during a pandemic. The Program demonstrated its leadership in global ocean in situ observations, as well as its support of research that studies and tracks changes in global biogeochemical and physical ocean conditions and variables. GOMO's international significance in ocean observing and weight and importance in attracting partners and participants is noted and acknowledged. These global ocean observations provide the foundation for describing the changes over time in our ocean, and they are used every day in weather, climate, marine, and ocean prediction models, and help society understand our changing ocean and benefit a wide range of stakeholders.

The summary evaluation for the overall program and each GOMO Focus Area research area is found in Table 1. Most of the panel recommendations are focused on supporting GOMO to reach its full potential both within the NOAA structures and the broader national and international landscape and helping GOMO further improve in the Relevance and Performance elements of the evaluation; they do not point to significant deficiencies.

Table 1: Summary evaluation for the GOMO program as a whole, as well as per Focus Area. Basic rating as defined in the Guidance to Reviewers. H = Highest Performance; E = Exceeds Expectations; S = Satisfactory; N = Needs Improvement

Theme	Criteria	Reviewer							
		1	2	3	4	5	6	7	8
Overall GOMO	Overall	H	E	S	H	S	E	H	
Focus Area 1: US leadership of an ocean and arctic observing research enterprise	Overall	H	E	E	H	E	H	H	
	Quality	H	E	E	H	E	H	H	
	Relevance	H	H	S	H	E	H	H	
	Performance	H	E	S	E	E	H	E	
Focus Area 2: Frontiers in ocean observing	Overall	H	E	S	H	S	E	H	
	Quality	H	E	E	H	S	H	H	
	Relevance	H	E	S	H	S	E	H	
	Performance	H	E	N	H	S	E	E	
Focus Area 3: Information and product development to ensure data access and usability; and to increase the value/impact of ocean observations	Overall	H	E	N	E	S	E	E	
	Quality	H	E	S	E	S	E	E	
	Relevance	H	H	N	E	S	E	E	
	Performance	H	S	N	S	S	S	S	

GOMO’s leadership in ocean observing is expansive and provides essential and unique services to the oceanographic and climate research communities, key improvements to forecasts including extreme weather events such as hurricanes, and it provides critical infrastructure for monitoring the global climate as it changes. GOMO’s support of Argo in particular is a triumph for scientific understanding and climate modeling and the value of its support and expansion of this array cannot be overstated. In order to reach its full potential in this category, GOMO must find ways to expand the all-important Arctic observing network and, most importantly, develop practices that make the existing long-term observing networks more robust to contingencies, such as unexpected equipment failure, changes in industry support and even variable funding environments.

GOMO's relatively recent transition, from being the Ocean Observing and Monitoring Division under the Climate Program Office to an OAR Program level, is an indicator of the value of GOMO activities within NOAA. This review represents an opportunity to see the elevated position of GOMO and to identify real opportunities to strengthen its visibility and influence within NOAA and across the national and international community. The fantastic success of the early career mentoring at GOMO is testament to GOMO’s leadership and commitment in improving Equity, Diversity and Inclusion. Such a program will be critical in also addressing the succession issues we face across the ocean observing enterprise.

Program-wide Findings

GOMO’s role and leadership in the implementation of the ocean observing system though investing in key networks, intellectual leadership and funding support for international coordination is to be commended. Feedback from stakeholders suggest there wouldn’t be a global ocean observing system without NOAA’s steadfast leadership; this is truly leading by example. GOMO continues to provide critical support, in particular for the Global Ocean Observing System (GOOS). Without GOMO’s contributions, GOOS would be woefully incomplete, and countless OAR, NOAA and Global Climate Observing System measurement objectives simply could not be met. GOMO’s observational assets, research portfolio, and information services have the potential to reach the highest levels of relevance for NOAA, its partners and the international research and climate communities. Further growth and strong leadership will be required to fully reach this potential, but the fundamental pieces are all present within GOMO.

GOMO-Specific Findings

GOMO's leadership in global ocean observing is expansive and clear. GOMO staff and GOMO-supported researchers serve in leadership positions in most components of the global observing system, and GOMO-supported technologies drive these systems forward; GOMO resources support a significant fraction of the Operations & Management costs. Thus, GOMO exerts significant influence on the design, implementation, and operation of the observing system. Partnering at the national and international level to achieve observing goals is a critical pillar of GOMO's identity that should be maintained and built upon. The partnership with the Indian Ministry of Earth Sciences provides an excellent example, where over a decade of collaboration to improve weather and climate prediction has led to development of the Indian Ocean Observing System (IndOOS), including the Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA) and Ocean Moored Buoy Network for northern Indian Ocean mooring arrays and the introduction of Argo floats and drifters. GOMO staff appear to be keenly aware of this outsized influence and are admirably trying to modulate its impact, providing leadership while allowing space for other voices to be heard. The program has an effective and successful management team to execute its plans. While their rationale and objectivity could be further clarified to assure integrity, the program does have explicit measures for the relative merit of different elements of the observing system; this is noteworthy and is reassuring for the program's flexibility and readiness to adjust to different developments.

GOMO has done an excellent job of sustaining global observing systems while continuing to evolve them in a measured and deliberate way, and this is probably a key part of ensuring successful sustained measurements that can support climate science, monitoring and prediction. It engages successfully with key partners in research, industry, and international partners. Parts of this approach could be further developed and made more deliberate, and robust to personnel changes. While GOMO's performance over the past 5 years has been stellar, it must continue to evolve in terms of its leadership and flexibility and develop new tools for handling unanticipated events. The recent decline in the number of observations resulting from technical issues, budgetary constraints, and the pandemic are of concern; efforts to regain the scope of the observations should be of highest priority in future planning.

Recommendations for GOMO, OAR, and NOAA

1. Bring GOMO's identity into clear focus. Work to sharpen both internal and external understanding of GOMO's portfolio/position/value with the NOAA

enterprise. Define where the boundaries or ‘handoffs’ sit between GOMO and IOOS and GOMO and the broader climate effort and other relevant activities/applications. Look for points of collaboration and coordination.

2. GOMO is poorly known as a program nationally, and thus not deeply appreciated, by the wider ocean community and in Congress. Increasing GOMO’s visibility and their contribution to the larger NOAA mission is recommended, by specifically highlighting their contributions to critical baseline measurements that help fulfill NOAA’s mission. GOMO’s messaging should clearly articulate its contribution to our collective knowledge of the ocean and the climate system. These should also include illustrations of the merit of the expanding scope of the observing system, e.g., uncertainty of heat content change changing with the number of Argo profiles and the regions they cover, etc. See also Recommendations on Communication.
3. Within GOMO’s portfolio of ocean observations, develop a framework for prioritizing observational activities that can be used to guide investments in long-term, sustained efforts. Alongside this, develop and implement a process for regular review of sustained observing efforts, including an assessment of the observations’ fitness for purpose (the measurements remain important in light of changes in the environment and in scientific understanding), efficiency of the observational approach and quality of the data being delivered.
4. GOMO should develop best practices for interactions with Industry. GOMO must find ways to ensure that observational systems remain resilient to industry changes. This means developing strategies to foster competition and avoid sole sources for critical components (e.g., SeaBird CTDs in the Argo Array), while also nurturing developing technologies by allowing for risk to achieve advancement.
5. To capitalize fully on investment in ocean observing, GOMO should consider being more proactive in this unique leadership role to strive to strengthen the global enterprise and lead by example to guide the future of Global Ocean Observing.
6. GOMO should continue pursuing and championing conversations to link the open ocean and coastal areas better through conversations with partners like IOOS. Though Planning horizons and processes are different across programs, work on finding a common set of priorities, and consider developing joint projects on boundary currents, extreme events, etc.
7. GOMO should work to build leadership capacity and succession planning within program management, and within the science and technological ranks. GOMO

appears to be working on this problem, but the criticality of the need should be emphasized. For coordination and management staff, being clear or creating a clear policy about developing pathways for responsibility and leadership experience is useful. Consider secondment and exchange with partner programs, such as the GOOS office, as potential avenues for training or experience for GOMO staff. For succession strategy, there needs to be a strategy in place that will ensure that retirements/loss of personnel does not result in loss of information.

8. GOMO should consider devoting more dedicated human resources to key capacities needed to operate as a program. For example, to the areas of professionalized and tightly coordinated data and information management (e.g., a team led by a digital transformation manager), communications (e.g., social media, website), and in-house consultants (jack of all trades). These resources should be clearly aligned to GOMO's strategic and implementation plans.
9. Specific to Focus Area 1, GOMO should consider:
    a. Developing a set of (flexible) priorities so that GOMO can seize funding opportunities. An example could be marine carbon dioxide removal (mCDR).
    b. Better understanding stakeholder requirements. GOMO should identify who could be a new stakeholder/partner that then can use their data. It is part of the strategic plan.
    c. Developing a framework of decision making that will help dictate how/what GOMO will invest into in the future. This within the framework of sustained ocean observations. Consider also observing system design.
    d. Leveraging the increased visibility of the Arctic and NOAA’s renewed climate focus to lead the buildout of a sustained Arctic observing system. This could be started by extending key global observing networks, such as Argo, into the Arctic and partnering with IOOS to accelerate development of real-time, in situ observing networks that serve Arctic coastal communities.
10. Specific to Focus Area 2, GOMO should consider:
    a. Maintaining a continuous dialogue with co-design partners (e.g., Indigenous communities) to assure their interests are met by the observing systems, and to build on the trust and credibility of the process

for the future evolution of the observing systems. Their interests and support should be turned into an asset to help raise GOMO's profile.

b. Taking steps to resolve supply chain issues threatening its observing systems (e.g., pH sensors and CTDs for Argo floats). These threats are increasingly common, made more evident across society during the ongoing pandemic (e.g., baby formula, ventilator, masks), and is a problem that requires broader expertise beyond the technical scope of this review. GOMO should seek advice and input from supply chain experts to chart a solution.

c. Further progress is urgently needed in the observing system innovation, integration - specifically GOMO should be encouraged to systematically integrate processes to look across the observing system from an applications perspective, engaging with modeling and user groups into their work program. GOMO clearly plays a key leadership role through a number of specific examples, but this work needs to be bolstered and taken further. Hence the balance of scores in this section.

d. Better positioning ocean carbon work at GOMO to support future measurement verification and reporting (MRV) requirements for an ocean carbon industry that will only succeed if there is trust in science and technology. As ocean carbon work will be fundamental to the near future of climate mitigation and the blue economy, this is a major opportunity for GOMO to establish a position of intellectual leadership and leverage NOAA's placement in the Dept. of Commerce.

e. If GOMO is to be identified as a leader at the frontiers of ocean observing, it needs additional opportunities to be seen and heard within the community. It is incumbent on GOMO to develop a strong identity/vision/mission commensurate with this thought leadership role. NOAA leadership should ensure the program has the opportunity to present that both within the agency and the wider community.

11. Specific to Focus Area 3, GOMO should consider:

a. Developing a coherent and long-term data management policy. DMAC involves ingest, archive, and access of data, but the current situation seems to be a patchwork of activities, i.e. platform specific such as the glider DAC. What is needed is a Program wide strategic and consistent approach. This doesn't have to be an organic activity within GOMO, but it does need to be part of the planning and implementation of global observing systems.

b. NOAA/GOMO should increase effort in engaging in the international data management and data infrastructure landscape to ensure NOAA benefits from broader developments in this space across the international community.

c. GOMO should establish metrics to measure its progress in data management to guide its effort. For instance, having a long list of products is not by itself meaningful if individual products are not used. GTS, in particular, is not used by most in the research community. The number of users by itself is also not useful, as some are casual users while others depend critically on the provided data. Statistics should be obtained of the communities' usage of different products (e.g., amount [GB] of data used by whom). User community surveys should also be conducted to gauge the utility of the products, including their own metrics, and to assess areas for improvement

d. Establishing and accomplishing tangible milestones in a timely and pragmatic manner are more important than implementing a complete and perfect data system. As a first step, GOMO should consider establishing a simple "findable" system in which all known data can be easily identified given a search criterion (e.g., temperature at 100m±20m depth, within 300-km of 30N 40W, during January 2022) with links provided to corresponding DACs/websites for data access. Milestones should be collectively established, as what system engineers, data scientists, and oceanographers consider important are often different from one another. For instance, graphical/visualization interfaces and "toolboxes" are superfluous for most ocean research applications. Metadata are important for tracing potential data problems but are not always needed/used; although valuable, metadata are secondary to scientific data itself and, therefore, metadata availability should not detract from the data being findable. Finding scientific data should be simple, with the least amount of searching/scrolling/typing/reading. Model products and data syntheses (i.e., mapped and/or gridded data) should be clearly distinguished from observations.

e. GOMO should capitalize on efforts and expertise assessing data quality across different observing systems for research (modeling and syntheses). Different observing systems employ different quality control measures, necessitating expertise across systems. Quality control efforts by projects that utilize multiple components of GOMO data, such as the

World Ocean Database and NCEP Global Ocean Data Assimilation System, should be embraced and supported towards an integrated effort.

APPENDIX A – Review Process

Review Process Findings

The review process was very well-organized, and staff and PIs were very engaged and willing to answer all questions posed. The presentations and reference material were extensive and informative, which greatly facilitated the review. The panel appreciated the effort the GOMO team and OAR put into preparing the review despite the pandemic. The sessions with line organizations and stakeholders were illuminating and useful. The informal nature of these sessions allowed frank discussions, providing insights not captured in the formal presentations. In addition, the "Key Message" slides (especially days 2 and 4) were useful in anticipating elements to focus on in each days' presentation. Having each day's slide deck was helpful in following the discussion.

Observations for GOMO's consideration related to the review process

- Having a suggested order for reviewing the material would be helpful. For instance, numbering key documents would ease referencing among them and facilitate an ordered appraisal of the program - e.g., "1_GOMO_Strategic_Plan" instead of "GOMO_Strategic_Plan." The collection of material was very useful in understanding the program, but the volume was overwhelming. It may help to have all the material (including the presentations) available ahead of the review.
- Concrete and frequent examples of the program's characterization, such as "high-quality", "easier access", and "FAIR (Findable, Accessible, Interoperable, Reusable)-compliant", would be helpful. The measures are otherwise subjective and difficult to ascertain. Likewise, Evaluation Metrics of Quality, Relevance and Performance were broadly defined and sometimes hard to distinguish, as were the proposed indicator guidance for each focus area.
- Having only 4 potential scores for each made it hard to nuance the response. A 1-10 scale would be better.

APPENDIX B - General observations

General observations for GOMO, OAR, and NOAA’s consideration

- The synergy of GOMO's in situ observations with satellite observations and modeling should be articulated more clearly. While GOMO's observations are invaluable on their own, the synergy they provide make each component more robust than simply their sum. A clear example is altimetry, where NOAA is a partner on reference altimetry missions. Another example includes the use of GOMO data for satellite ocean color validation.
- Propose more work on articulating value chains, highlighting dependencies, use and impact – would enable work on codesign (Obs/Data/Prediction systems) with user community.
- GOMO should collaborate more tightly with other NOAA programs. Closer coordination and collaboration with programs across NOAA with complimentary tasks will help GOMO achieve its goals within its budgetary constraints; examples include Integrated Ocean Observing System Program (IOOS), National Centers for Environmental Prediction (NCEP), Ocean Acidification program (and get credit for observations), Ocean Exploration program, etc. This also includes building tighter bridges with the modeling community, such as streamlining modeling and observations to address the strategic objectives of the agency. As modeling is spread across NOAA, this is beyond just GOMO.
- Streamline those programs/areas within NOAA/OAR that have a tech sensor development program. How in NOAA are they looking at ocean tech development and how do they plan to work with others in the agency to do ocean technology? Scoping some solutions on how to better co-develop technology could be useful.
- Reinforce IOOS and GOMO messaging; this needs to be addressed at OAR/NOAA levels.
- Utilize the existing communications channels within NOAA to advocate and highlight GOMO work on the Hill.
- Leverage on GOMO’s work to address NOAA’s strategic plan focusing on Ocean-Climate nexus. Global/coastal ocean can be argued as an area of common ground. GOMO has those connections and is in great alignment with the vision of NOAA.
- GOMO/NOAA should consider how to better use modeling tools to provide feedback on the observing system design and strengthen connections between observation and modeling programs within NOAA.

- Due to increased competition for funding and less security in research careers, support/enthusiasm for more ‘risky’ innovative science is suffering, particularly with early/mid-career scientists. Areas such as technological development and piloting, and model development are critical to making advances in how we understand and predict the ocean. NOAA should consider how it can encourage/reward scientists and technicians who take risks (and sometimes fail) if we are to really push the innovation envelope. In this regard, NOAA should consider how it can encourage/reward scientists and technicians who take risks (and sometimes fail) if we are to really push the innovation envelope and make advances – perhaps a ‘trailblazer’ award or similar award to reward attempts that didn’t work, which in themselves are equally (sometimes more) important experiences required to forge progress.
- NOAA/OAR/GOMO should increase effort in engaging in the international data management and data sciences landscape, horizon scan for opportunities to ensure NOAA benefits from broader developments in this space across the international community.

GOMO-Specific Observations for consideration

a. GOMO’s identity and its relevance within OAR/NOAA

i. Consider having GOMO’s vision formulated in terms of oceanographic metrics (e.g., ocean heat content at some spatial and temporal resolution) rather than purely technical (e.g., X number of floats in the XX Ocean). A clearly stated requirement would engender stronger buy-in, public-private partnerships, and other coordinated efforts to tackle the problem.

ii. Move towards an enhanced organizational model (matrix) framing science themes and broadly defined application areas, to complement the current platform/system framework. This should reflect the portfolio defined above and would reinforce GOMOs identity, facilitate the formation of heterogeneous observing networks, strengthen partnerships and improve GOMO’s ability to message.

b. Public/private partnerships

i. GOMO’s interaction with the private sector appears rather ad hoc and reactive. A program wide methodology and focus on private-public partnerships should be established, well publicized, and nurtured, perhaps leveraging established industry bodies.

ii. GOMO might look to the theme of “public-private-partnerships” as one focus area for strengthening collaboration and integration with other NOAA programs. In particular, the role of the private sector in delivering new technologies for ocean observing is relevant across NOAA and GOMO. It should be embraced to enhance its impact and authority in the domain. Regardless, goals and interests across both GOMO and private partners should remain aligned.

c. NOAA GOMO’s International role and leadership.

i. Synergy of GOMO's in situ observations with satellite observations and modeling should be articulated more clearly. While GOMO's observations are invaluable on their own, the synergy they provide make each component more valuable than simply their sum; i.e., sustaining GOMO’s observations improves the value of other components and vice versa.

d. Defining (scientific) priorities

i. 75% of the budget flows to observation platforms and the program “Develops, deploys, operates, and improves” those systems. Given that GOMO is a program within NOAA Research, it should direct its focus on the “develop” and “improve” elements. Being a research arm, GOMO should make it a priority to evaluate, understand, and accelerate the systems of systems aspects of its portfolio. Rather than separate[assign rather than separate] the various platforms into separate categories, it should develop projects and ideas focused on scientific questions and operational needs that tie those different platforms together into more powerful research tools.

ii. GOMO is poised to actively engage in the UN Decade of Ocean Science for Sustainable Development if the opportunity/resources arise; GOMO should leverage on UN Decade activities, and take the Decade as an opportunity to plan for what they would like to accomplish, should that opportunity present itself.

iii. While it is natural to manage/fund an observing program by network/capability type as that is what needs to be funded/implemented, it is important to ensure the program considers more strongly the use/application/impact of those observations. GOMO could consider ways of working across the observation portfolio by science theme/application area, and consider the partnerships required.

iv. Modify the current platform/system framework to develop an organizational model that also frames GOMO activity by science themes and broadly defined operational needs. This should reflect the portfolio defined above and would reinforce GOMOs identity, facilitate the formation of heterogeneous observing networks and improve GOMO's ability to message.

v. Measures of merit and value/use and impact of GOMO's different observing systems should be established and periodically updated, to serve as a guide to allocate resources, plan future operations (sustaining and expanding), and communicate to the world what GOMO does (promote and advocate). Measures do not have to be absolute, unique, objective, or even made public. Different measures should be collected for different purposes and to see what works best; examples can include:

    1. Number and percentage of papers using different GOMO data sets in select prominent journals or among highly cited papers as a function of year of publication, to gauge their utility in research,
    2. Survey the research community (e.g., random samples at AGU) of their awareness of GOMO's observation, their view of what data is useful, and their rankings of different observing systems and products, to gauge effectiveness of GOMO's outreach to the community,
    3. Statistics at Data Access Centers (DAC) (access and download) of the different observing systems, to gauge what elements require attention.

vi. Develop a strategy that clearly articulates the design of an observing system that supports the climate record (climate quality, sustained measurements) GOMO is known for. Consider relying on GOMOC for this. Some questions to consider could include:

    1. How do you identify observations that need to be sustained?
    2. How do you prioritize investments, given that the list of high-priority needs will always exceed available resources and each 'choice' can lock up resources for long (indefinite) periods of time?
    3. How will observing activities be regularly evaluated to assure continued scientific/operational relevance, efficient execution (are there better ways to achieve goals?) and delivery of high-quality data?
    4. How do you maintain observations through inflation?

5. How do you maintain observations in a variable funding environment?
6. How do you maintain observations when vendors, or key products disappear?

e. Communications

i. GOMO should adopt a communications strategy that leverages the existing social media presence NOAA.

ii. GOMO should capitalize on the existing OAR/NOAA communication machinery and through institutional partners to communicate up (e.g. to Congress), and out through partners to user communities and stakeholders.

iii. GOMO should consider fostering an external community that supports GOMO's interests - External stakeholder base that would be interested in GOMO science.

iv. GOMO could consider developing pieces in other languages.

v. GOMO's website requires updating and more clarity on GOMO's investments and links to datasets. Website is the key access point and window to the world for GOMO.

vi. Think about more nuanced/3D ways of representing the status of the observing system via the story telling (the dots on the map are increasingly looking like the job is done!).

f. Workforce development

i. Steps should be taken to attract and retain skilled engineers and technicians necessary to develop and advance ocean observing systems. While hiring is a challenge for those who carry out the observing work for GOMO, the GOMO program should explore other avenues for personnel contracting/retention. Competition for human resources with other industries is a serious threat to expanding and to even maintaining the frontier of oceanographic observing systems. Expanding the scope of NOAA scholarships with incentives to remain in the field might help nurture skilled personnel and attract individuals, especially from under-represented communities that broadens the talent pool. Recruitment of interns or other fellowships to fill personnel gaps could be an avenue to address this in the short term (e.g. intern to manage social media). Career path incentives and flexible work schedules should also be part of this discussion.

ii. Consider a GOMO Early career Alumni network of some sort to capitalize on the legacy of the program, and also advertise the impact of the early career effort with partners and internationally so we can encourage similar initiatives across the community.

iii. Opportunities are limited if you don't qualify for any of the fellowships provided. Consider how to create opportunities for people 10 years beyond their graduation date, e.g. create an IPA or something similar to bring in temporary talent.

iv. Develop more internships if there are opportunities/projects to help shortcomings in GOMO staff. Streamline the internship process so that it is not burdensome on GOMO staff.

APPENDIX C – Specific findings and observations per Focus Area

Focus Area 1 Findings

GOMO has leadership roles throughout national and international organizations, and it continues to develop, influence, and advance observational requirements and to coordinate implementation. Within the US research endeavor, GOMO is the most sensible home for sustained, climate scale ocean observing, and already hosts many of the most important components of the existing system. GOMO leverages resources and expertise through establishing and maintaining mutually beneficial partnerships, and continuously engages with new and different stakeholders in order to increase the utility and effectiveness of their observations and supporting research throughout the value chain. GOMO prioritizes fostering and developing the next generation of ocean observing scientists and is developing capacity for all users of ocean and Arctic observing.

GOMOs contributions to climate-scale global ocean observing, through its support and leadership of entities including the Global Ocean Observing System (GOOS), the Arctic Council's Sustaining Arctic Observing Networks (SAON) and the Argo float program have been instrumental to the health and evolution of these critical systems. These efforts sit at the core of GOMO's identity. Beyond supporting hardware and operations, the key to this success is GOMO's intellectual investment in system design and governance, in sensor characterization and quality control, and in the delivery of data and products. GOMO should maintain, and perhaps seek areas to grow and deepen, its involvement with these and similar programs. This will require building leadership capacity within multiple sectors of GOMO and the programs it supports. The buildup of expertise to support Biogeochemical (BGC) Argo provides a good example of this put into practice.

GOMO's contributions to Arctic monitoring and research are also noteworthy. The Arctic is undergoing rapid change and plays important roles in modulating midlatitude weather and the global climate system. Retreating sea ice is opening the region to increased human activity. Despite its importance, the region lacks the sustained observing efforts needed to support predictive modeling at synoptic to climate time scales. GOMO invests in leadership activities within the Arctic observing community through its engagement in Interagency Arctic Research Policy Committee, support for the US AON and the broader SAON effort. It also supports foundational observing efforts that include the International Arctic Buoy Program (IABP) and the distributed Biological Observatory (DBO). These efforts have been effective and should be sustained. The region's current visibility, combined with NOAA's operational mission and renewed climate focus, provide an opportunity for GOMO to lead the implementation of an Arctic observing network. This could be started by extending key global observing networks, such as Argo, into the Arctic and partnering with IOOS to accelerate development of real-time, in situ observing networks that serve Arctic coastal communities. Also, coastal communities will likely play a key role in the design and implementation of localized Arctic observing networks. GOMO has the expertise to develop the relationships and the technologies to enable community-based Arctic observing. This might involve deepening engagement with northern communities toward co-design and implementation of observing systems, and development of low-cost instruments that can leverage local knowledge and capabilities.

Focus Area 1 Observations

A. General Observations for GOMO's consideration

i. Strengthen collaboration with modelers. Coordinate with others already undertaking these activities (e.g., Tropical Pacific Observing System (TPOS), Extreme events activities).

ii. Consider a re-design of GOMO's scorecard where GOMO's specific metrics are shown. Consider also linking well known GOMO data to indicators and things of value in a way that a relationship emerges between the value of observations and GOMO (the producer). Take into consideration the real time nature of products.

iii. Consider framing GOMO as an end-to-end program with big questions that GOMO's infrastructure could answer. Consider also linkages to coastal areas where people live.

iv. Access to suitable ships was flagged as a challenge for some GOMO programs. This seems to stem from structures that limit projects to NOAA vessels, of which only one, Ron Brown, is a modern, global class, general purpose R/V. Alternative structures that allowed easier access to vessels within the Academic Research Fleet and facilitated chartering of foreign and/or private vessels might significantly ease these difficulties.

B. GOMOC

i. The membership of the Global Ocean Monitoring and Observing Committee (GOMOC) needs to be boosted to reflect the goals and ambitions of the program. There are a number of representatives who benefit directly from GOMO Funding; more international voices, and voices from partner capability (modeling/data systems), users and the private sector would be useful. In addition, GOMOC might benefit from the addition of one or more Arctic-focused researchers that have strong ties within that community. Current membership includes Southern Ocean expertise, but the science, operational and social issues are different.

ii. The GOMOC is a useful body but would benefit from greater input from the private sector and more global voices. There isn't a private member on the board and so it's difficult for the board to talk about public/private partnership; perhaps a member of the Marine Technology Society to represent many industries.

C. Arctic

i. The Arctic work is important but, to a certain level, seems disjointed and distinct. Is there an elegant way to bring the Arctic into the current GOMO ocean work, and present a single global programmatic perspective?

ii. Arctic research almost always happens in shoulder seasons in terms of budget. This makes it difficult to react if something unforeseen happens. Consider forward funding to avoid impacts on Arctic work.

iii. Synthetic products, of which the Arctic Report Card is a premier example, have been well received and appear to have influence beyond the science community. Such products also serve to unite GOMO activities by science themes, which strengthens the program identity. Are there other such products that could be created?

D. Access to funding and broadening the PI/stakeholder pool

i. Awards are annual due to appropriations; this causes constraints for GOMO's funded science. Explore how to make multiannual awards. One barrier is timing and planning – plans need to be set ahead of time and this means a conversation with program managers. Nothing institutional : it just comes down to staff resource time. Recommendation: Plan for this!

ii. GOMO's budget is 75% infrastructure and leaves little room for competitive research and bringing on board new collaborators. There are some ways an expansion of the GOMO community can be attained with smaller pots of funds (an example was the supplemental funding for hurricane forecasting). A deep dive on the budget would be required to prioritize and ask the program managers how to best utilize the funds to offer a competition. Interagency collaboration may help GOMO identify future opportunities for competing funding in synergy with other agencies.

iii. Identify opportunities to support high risk/innovative research. Risk has a monetary cost and needs competitive research, which GOMO has a limited budget for. This will require better planning with forethought.

iv. Explore investments with the Office of Naval Research/Department of Defense on tech and other deployments.

v. Explore the possibility to frontload contracts to carry funding from year to year. Possible for third party contracts, difficult for labs.

vi. Consider carrying a contingency budget to cover possible stochastic events – e.g. a mooring that breaks.

Focus Area 2 findings

GOMO's extensive ocean observing and monitoring history makes it uniquely positioned to address new frontiers in global ocean observing, including emerging extreme weather and climate phenomena and biodiversity/ocean health. Because of its nature as a research program with a focus on valuing sustained observations, GOMO is well positioned to foster coordination between research communities, industry, and its national and international stakeholders. It must continue to remain flexible and grow its ability to simultaneously evolve and maintain key observational elements in order to achieve its full potential in this category. GOMO anticipates to continue to innovate and evolve the global ocean observing enterprise to be increasingly responsive to the research and modeling communities as well as stakeholders/end-users by developing and advancing technologies and encouraging the co-design of observing and modeling efforts across ocean basins. In this sense, it was good to see initial progress being made in innovating and integrating the observing system through the lens of priority regions/applications and engaging across line offices, national and international partners through some concrete technological, thematic and regional examples. Progress is also being made in innovating and integrating the observing system through the lens of priority regions/applications and engaging across line offices, national and international partners.

GOMO has chosen critical science objectives, including quantification of ocean heat and freshwater content, sea level rise and the role of oceans in the global carbon system. The program supports cornerstone elements of the ocean observing system required to address questions, as well as technology development to support the measurements. Stated focus on deep ocean, tropical and Arctic observing capitalizes on previous work building the international partnerships and developing the autonomous technologies required to support sustained observing in these environments. These are foundational contributions to the ocean science community.

In this context, GOMO plays a key leadership role, and with it the US is seen as a strong, trusted and supportive partner who motivates other parties to come to the table. However, further progress is urgently needed, and more systematic approaches to looking across the observing system from an applications perspective, engaging with modeling and user groups should be encouraged. Likewise, the work GOMO is currently performing does not necessarily push the frontiers of science. For example, the advances presented in terms of Saildrone and Argo technologies are incremental and err on the deployment side rather than prioritizing profound advances. Given the diverse portfolio GOMO manages and overall modest budgets this is not unexpected, but to exceed expectations GOMO must find a way to break through these constraints and deliver innovation and advances that are more profound and transformative.

The TPOS 2020 project was a real trailblazer in how to carry out an observing system redesign in a systematic way, engaging partners across NOAA and internationally. The project was strongly supported by NOAA GOMO providing secretariat support, intellectual leadership, ensured NOAA agency level support and led engagement with partners. The progress being made on the Extreme Events project is impressive, forging new/strengthened partnerships. GOMO is to be commended for seeing the opportunity to bring this activity together and taking a calculated risk to make it happen.

GOMO is collecting and validating ocean biogeochemical data from a variety of platforms, ranging from tried-and-tested shipboard platforms to new, cutting-edge Saildrone, BGC-Argo, and near-real time buoy systems. As such, GOMO is both ensuring continuity of reliable data collection methods and looking toward the future. Argo and BGC Argo provide examples of effective partnering (public and academic) for technology development and expansion into new areas. Investing in multiple commercial float vendors and, more recently, sensor manufacturers, clearly makes the system more robust while competition will hopefully lead to steady improvements in the instruments. Expansion of talent and support of DAC, coupled with ties to the older ship-based carbon program, dovetail well with BGC Argo buildout and will serve the program well. These were good examples of careful investments targeting future needs.

Focus Area 2 Observations

A. General Observations for GOMO's consideration

i. Technology transition pathways are often unclear. The time from R&D to transition is too long (~10 years), and needs to be reduced. GOMO has ceded the "Impacts" part of the value chain to others, which is primarily the delivery of services to end users, which results in a lack of visibility and recognition for the important observations GOMO is collecting and supporting.

ii. GOMO should take the initiative and lead to at least participate in observational-modeling activities as part of best practices when designing and deploying new observing systems.

iii. In the value chain analysis (Inputs, Processes, Outputs, and Impacts), the GOMO focus is on Processes and Outputs. That is reasonable, but taking a more proactive role on the Impacts, or the delivery of services to end users, would allow more visibility and recognition of the value of GOMO observations (identified as one of the weaknesses in the SWOT analysis). GOMO does put emphasis on getting observations to "harvestable" end points, but by more directly engaging with the delivery of products and services, GOMO would likely receive direct and valuable feedback which would allow them to make adjustments to their strategies in both the short and long term. Note, this wouldn't replace the subject matter expertise that GOMO funds for the dissemination of it's observations (Ocean Heat, Sea Level, World Ocean Database, Carbon, air-sea fluxes, surface currents, etc.), but augment those efforts, through more direct interaction and 2-way exchange of information that could provide feedback for future system designs.

iv. Consider how GOMO might encourage programs to think more flexibly about employing new technologies and approaches to achieve their goals.

v. GOMO should articulate its strategy for balancing core observations and expanding frontiers, preferably in consultation with partners and organizations such as the Interagency Ocean Observation Committee (IOOC). For example, there is concern that Deep-Argo and BGC-Argo will come at the expense of Core-Argo, the trade-offs of which are not clear.

vi. GOMO should closely monitor progress of its strategic investments to assure their success. TPOS in particular is a high-profile effort that warrants particular attention to reinforce GOMO’s leadership in the field.

vii. GOMO (and all Programs) should have a clear path to shaping NOAA SBIR calls. It is not GOMO’s fault that they don’t but they should campaign to change this for their benefit and the betterment of NOAA programs.

viii. The Argo program’s engagement with industry is poorly conceived/executed to extract best value from industry. The tangled interactions between universities, government and industry are complex at best. There is a lack of clear ownership and management for technology requirements and thus no clear targets for industry to aim towards. One example, if GOMO/NOAA fund the development of a technology element why does that end up licensed to only one vendor? Shouldn’t it be made an open license to all the vendors?

ix. Cooperative Research and Development Agreements (CRADA) are very useful tools, but there is not sufficient transparency as to how private sector players can access GOMO interests and establish CRADAs. Also since CRADAs do not include funding they, by definition, exclude companies that can’t afford to donate time and energy. This makes them biased toward more established (or better funded) firms. There should be an effort to balance this industry outreach to establish more effective and equitable public-private partnerships.

Focus Area 3 Findings

GOMO’s investments in data and data services are supporting high quality data, products and services that are of critical importance to the national and international community. They enable important activities such as enhancing the understanding of the ocean’s role in the carbon cycle and carbon-climate feedbacks, lead to improvements to models and forecasts, contribute to global policy making documents, such as the Intergovernmental Panel on Climate Change reports and the global carbon budgeting exercise, and contribute to important international community-wide efforts such as Surface Ocean CO_2 Atlas. GOMO’s data products are state-of-the-art, evidenced by their wide utilization resulting in preeminent research and operational applications. The quality of individual DACs, appear to vary from one observing system to another. The Argo data system is one of the most comprehensive and is a model to emulate.

GOMO continues to lead and evolve with the international community on data practices and supports a wide-ranging effort in data management to realize FAIR data. While individual elements are generally leaders in their respective domain, a program-wide integrated management strategy is under development. GOMO’s widely varying observational portfolio creates enormous challenges for development of data products and information of high value to key stakeholders. With requirements for access and usability growing more complex and expansive, GOMO may need to expand its human resources in this area to meet this demand. In addition, performance metrics are not obvious for various measures, e.g., high-quality, meeting needs, usage, interoperability, workflow, impact on decision-making, etc. - what makes data FAIR and the degree of its attainment. In terms of data management components, GOMO only provides limited support for integrated data management activities. Given funding levels and complexity of efforts, GOMO is doing well in bringing ocean observations to market for end user value. If the organization develops a stronger identity and adopts a slightly more forward leaning posture across the field, it could deliver even more. There were some concerns regarding the size of the data management teams (e.g. Pacific Marine Environmental Laboratory); the team has great expertise, but being small (and possibly overloaded) may make the response time and burden significant. Determining the value of ocean carbon data (incl. GOMO data) would be of great interest.

Focus Area 3 Observations

A. General Observations for GOMO's consideration

i. Address as a priority improving the delivery of quality controlled (QC) data streams for modeling and prediction applications and strengthening co-design of data/modeling systems (critical for addressing priorities also identified in Focus Area 1 and 2).

ii. Modelers don't always access most up to date QC'd datasets from DACs as it is not in a forum they can easily ingest - and use the archived Global Telecommunication System (GTS) or a 3rd party data aggregator. ERDDAP will help with this, but consistent with recommendations above, the handshake between data systems and models needs attention in the context of co-design approaches.

iii. Address as a priority improving the delivery of QC'd data streams for modeling and prediction applications and strengthen co-design of data/modeling systems and digital user tools

iv. Commercial data purchases appear increasingly common across NOAA. What are the parameters and restrictions that surround these purchases? In the context of GOMO observing, we need to ensure permanent full, free, and open access.

v. While GOMO can significantly improve its performance in this focus area, the potential for generation and dissemination of highly valuable products from GOMO is enormous, given its scope and assets. It is critically important that GOMO improve its visibility of this potential value both within NOAA and in the research and stakeholder communities.

vi. While GOMO’s data system should encompass all of GOMO’s observing systems and facilitate links to global datasets, as a leader in global ocean observations, GOMO should aspire to be a gateway to all ocean observations, including those from other programs as well as satellite data. The GOMO data server does not necessarily have to host these other data but simply facilitate users finding and accessing them.

List of Acronyms

BGC Biogeochemical

CDR Carbon Dioxide Removal

CO_2 Carbon Dioxide

CPO Climate Program Office

CRADA Cooperative Research and Development Agreements

CTD Conductivity, Temperature, and Depth

DAC Data Access Centers

DMAC Data Management and Cyberinfrastructure

ERDDAP Environmental Research Division's Data Access Program

FAIR Findable Accessible Interoperable Reusable

GOMO Global Ocean Monitoring and Observation Program

GOMOC Global Ocean Monitoring and Observing Committee

GOOS Global Ocean Observing System

GTS Global Telecommunications System

IndOOS Indian Ocean Observing System

IOOC Interagency Ocean Observation Committee

IOOS Ocean Observing System Program

MRV Measurement Verification and Reporting

NCEP National Centers for Environmental Prediction

NOAA National Oceanographic and Atmospheric Administration

OAP Ocean Acidification program

OAR Oceanic and Atmospheric Research

QC Quality Control

RAMA Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction

SAON Sustaining Arctic Observation Networks

SBIR Small Business Innovation Research

TPOS Tropical Pacific Observing System

US AON United States Arctic Observing Network