Summary Report

Pacific Marine Environmental Laboratory Review

March 3-5, 2020

Review Panel

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Overview

A review of the NOAA Pacific Marine Environmental Laboratory (PMEL) at Sand Point in Seattle, WA was conducted by an independent review panel over a three-day period March 3 – 5, 2020. NOAA Office of Oceanic and Atmospheric Research (OAR) requested the review as part of the required 5-year research laboratory review cycle. OAR and PMEL staff organized two pre-review teleconferences that described the review scope, discussed the proposed review agenda, and highlighted areas of review evaluation, to help prepare the panel. The three-day review began with an overview from OAR and PMEL leadership, followed by presentations and shorter lightning talks on key topics within each of the laboratory's four research themes: Climate-Weather Research, Marine Ecosystems Research, Ocean and Coastal Processes Research, and Research Innovation and Development. The review panel also benefited from a stakeholder feedback session, laboratory tours, sessions with the Cooperative Research Institutes' leadership and staff, a session with early career professionals, and an evening poster session providing the panel members the opportunity to interact with a wide range of PMEL staff describing their individual projects.

Five of the eight panel members participated in the review in person, the remaining three joined remotely due to the nascent novel coronavirus outbreak. Despite some early concerns about traveling and meeting in large groups, the PMEL staff provided ample disinfectant supplies while on-site and encouraged an early form of social distancing and elbow-bump greetings. The panel appreciates the extra effort the staff made to provide a safe environment for the panel review.

Panel consensus was not sought in the preparation of this report. Panel members provided individual numerical ratings for each of the major research themes as well as comments on strengths and concerns for each theme and for the Laboratory as a whole. The report attempts synthesis but includes alternate panelist impressions in places. All comments are meant to be constructive, with the goal of helping NOAA OAR and PMEL navigate a changing scientific landscape and complicated staffing and management issues.

The primary recommendations of the review committee are:

- Develop and enact a succession plan for the key positions in the Laboratory nearing retirement age to ensure continued excellence.
- Codify a protocol for initiating new research themes and for sunsetting completed themes.
- Establish a formal mentoring program for junior staff at PMEL and encourage a parallel program for collaborating researchers and technicians functioning under cooperative institutes.

These and other findings and recommendations are expanded below. A full list of suggestions and recommendations may be found at the end of this report. The Chair would like to thank the panel members for their time during and after the review, under extraordinary circumstances, and for their positive and professional review comments. The panel hopes this

review is taken in the manner in which it was intended and is found to contain useful recommendations sustaining and improving PMEL to extend its long history of excellence into the future.

Summary of Laboratory-Wide Findings and Recommendations

PMEL is an outstanding institution as evidenced by the large number of scientific publications published annually, the citation rate of those papers and the number of prestigious awards and fellowships their staff have received. They are national leaders in the fields they are working in and exhibit a high level of organizational competence across all of the staff. According to one reviewer the emphasis for the Director and OAR management should be less about what needs to be fixed and more about what steps should be taken to maintain this level of excellence.

Succession planning

Many of the leading scientists, engineers and IT staff at PMEL are nearing retirement eligibility with few junior individuals in place to assume responsibility and leadership in the coming decade. Moreover, there does not appear to be a coherent plan to replace the outgoing leaders. Much of PMEL's work is to support long-term monitoring programs and continuity of their research is deemed vital. Management should develop a succession plan to ensure continuity of leadership. This issue is particularly concerning because it was raised by the previous PMEL Review Panel and little evidence was presented that anything has been done to address it. The problem is now 5 years closer to critical. The complexity of the lab, its work and culture, all of which contributes to the productive history of PMEL, argues that it is now time to hire and/or groom the next generation of laboratory leaders. This is particularly important in order to afford continuity to the timeseries that have been a hallmark of the lab.

Reliance on cooperating institute labor

The succession planning concern is exacerbated by PMEL having more than half of its work force employed through cooperative institutes based at the University of Washington (JISAO, CICOES), Oregon State University (CIMRS), and University of Hawaii (JIMAR). Cooperative Institutes (CIs) have some advantages, notably the ability to tap into the expansive skill sets available in the larger university settings where they are housed. CIs also provide a buffer against budget fluctuations, which is important in the present situation in which a large percentage of the PMEL budget is derived from programmatic funds, rather than dedicated laboratory support. However, cooperative institutes are by their nature, temporary relationships. When the cooperative institute staff were asked by the Review Panel how many anticipated being at PMEL five years from now, less than 5% responded affirmatively. Cooperative Institute members voiced their belief that employment at PMEL through the cooperative agreement did not provide them a path to a more permanent position at PMEL, even if one opened up. As a result, most of these staff told us they are presently seeking alternative employment. Reliance on a mechanism where a sizable fraction of the technical know-how resides in what are essentially temporary employees is not in the Laboratory's best interest.

When the review group discussed this issue with NOAA leadership, both nationally and locally, the response was not fully satisfactory. The concern was dismissed because of the perception that the CI staff just wanted federal jobs, which was not consistent with what the review panel heard from the CI group. Cooperative Institute staff generally understood federal hiring constraints requiring an open competitive process, yet they still were searching for a more transparent process. It seems that concerns expressed by cooperative institute partners were not considered to be NOAA problems, but unless a more proactive approach is taken, the performance of the laboratory may suffer in the future.

The review panel feels that a cooperative institute arrangement would be more advantageous to PMEL if there were more mentoring and greater transparency such that CI staff understood the pathways to permanent PMEL employment for those people who demonstrate leadership qualities.

Maintaining the culture

PMEL is successful in part because of the excellent scientific work ethic that promotes a positive culture. Maintaining that culture will be challenging as senior leadership evolves with impending retirements. It was apparent throughout the review that PMEL staff understand that its measures of success extend beyond simply counting publications and ultimately reside with whether other NOAA divisions, and beyond, are adopting the products they develop. It was evident to the review team that the PMEL staff throughout the facility recognized this and have been effective in bringing clients into the product development process throughout, from early planning about project goals, during the data collection process and even in the data interpretation phase. Beyond staff recognizing the goal of product adoption, our interviews with the Laboratory's clients illustrated how responsive they felt staff were to their suggestions and needs. The ability of staff to look beyond the publication, and client understanding of that attitude, is rare among scientific institutions and should be continually recognized and reinforced.

A critical part of achieving client adoption is scientific collaboration. Clients will be more receptive to products when they have been accepted by the larger scientific community, rather than just the product of a singular group. PMEL staff understands this and have effectively involved themselves into leadership roles in many scientific societies and participation in many client advisory group settings. PMEL leadership also understands this as evidenced by their illustrating for the Review Panel the number of collaborative publications they have with other organizations. The collaborative attitude of the organization also extends internally, as the close working relationship among the scientists and engineers is enviable and one of the reasons for PMEL's success.

Another important aspect of the PMEL culture, as referenced by several of the PMEL staff, is a "license to fail" – staff members having the opportunity to explore new research directions and technical developments without fear of being judged poorly while in the early stages of a bold idea. Obviously, there is a limit to that philosophy so as to avoid putting too many resources

into a bad idea, but PMEL management appears to have struck the right balance and created a culture where staff strive for innovation, rather than just playing it safe and following the mainstream.

One of the strengths of the lab is collocation of scientific staff with engineers and data managers resulting in ability to design, build and deploy novel technology and distribute the observations. Collocation alone is not enough. PMEL has a history of encouraging and fostering collaboration among staff. This collaboration is an important ingredient of the success of PMEL and the overall positive workplace culture.

Closely related to the subject of lab culture, reviewers were dismayed by the poor morale and future outlook of the junior PIs from both PMEL and the cooperative institutes. No coherent and structured mentoring program is presently offered to CI staff beyond annual evaluations. It should be noted that mentoring and evaluation are distinct activities. NOAA leadership is encouraged to address this personnel management shortcoming. Lack of guidance left many junior staff uncertain about their future career path and role in the greater environmental research enterprise. With PMEL's ability to meet its objectives now critically dependent on cooperative institute contributions, more effort must be made to improve the working environment for these individuals.

Onboarding and offboarding of research themes

PMEL is focused on supporting long-term research programs, meaning that a large percentage of the available effort is already allocated across multiple years. In an era of fixed budgets, this presents a challenge to innovation. PMEL must develop a strategy for identifying when a project area has reached its research plateau and should transition from research to operation, effectively shifting the budget burden for that topical area to the operational side of NOAA (or to another client of the product). That such a strategy/protocol exists was not apparent. Moreover, staff felt that transition process for the TAO array in the Pacific was poorly executed and diminished efforts they had expended in developing the system. As such, they seem reticent to let other programs transition, as evidenced by maintenance of the tsunami warning system, where the research increments at this point are small as the system is largely operational. There have been some successes in transitioning individual technologies to the commercial sector, but PMEL lacks an overall program strategy and culture for implementing such transitions. There was also lack of clarity about how success of a research them is measured. The PMEL website developed for the review offered specific spreadsheets that outline operational metrics. These were incomplete and not used during the review, suggesting they are not relevant to decision processes. It would be useful to have a stronger and more specific sense of what will be the governing metrics (i.e., papers, citations, transitions, patents) for PMEL in the future.

In similar vein, PMEL needs a strategy for onboarding new research themes, particularly since continued investments in existing research lines limits new opportunities. That strategy, or even the decision-making process for developing new research themes, was not apparent to

the staff we interviewed. (To be clear, the staff felt good about the process for initiating new project ideas within an existing research theme; the challenge is with the process for originating a new research theme). The lab's newest research theme investment is in genomics, which has great potential. However, genomics has already become a crowded field and it was not apparent what PMEL will offer that differentiates it from other laboratories, even some within NOAA, that are already working in that field. Similarly, when asked what the next big investment might be, multiple staff members suggested microplastics, which is another crowded field. For both genomics and microplastics, there are several possible research niches that could serve to leverage the strengths of PMEL, notably their existing monitoring assets in harsh environments and the lab's strong linkage between science and engineering. But for neither area did staff effectively convey that vision. In other areas that it presently works, PMEL is a leader with clear differentiation from the activities of other laboratories with which it collaborates. PMEL needs a research onboarding strategy that clearly defines that vision at the outset and uses identification of its unique role as one of the criteria for investment decisions.

Access to the sea

An overarching issue relating to how PMEL conducts observational research was revealed during the review: ship time. Despite the dramatic expansion in autonomous and un-crewed observing systems and platforms, crewed vessels are still required to field and support these assets as well as support measurement programs for which there are no viable automated instruments. PMEL has been able to maintain a near constant level of ship usage days per year over the last decade through international collaborations. Collaboration is vital to science, but one must ask, is a significant reduction in domestic support for the research fleet in the best strategic interest of the United States?

Given the loss of direct funding of ship time but the dependence of the long-term measurements on that ship time, it would be good to develop an issue paper that evaluates the risk of the programs to loss of future ship time. There may be efforts underway to develop more autonomous systems, but those efforts might be better defended if they can be directly linked to metrics on ship time (e.g., reduced costs per measurement). This is clearly an issue that extends beyond PMEL, but the concern must be voiced.

The role of PMEL and NOAA in the future

In the past, PMEL's mission was motivated in large part by discovery since so little was known about the oceans and its impacts on society, especially for oceanography. Much of the research in the field of physical oceanography, excluding tides, was conducted without much need to be relevant at the national level. However, with an increased concern for climate change and a greater emphasis on resource management with its coupling to physical oceanography, as well as shrinking budgets, PMEL is transitioning from a more discovery science organization to a federal laboratory that is integrated into defined national needs.

A recent document from the White House states, "We have extraordinary opportunities before us to steward, explore, and utilize the vast resources of America's oceans by embracing public-private partnerships in ocean science and technology" and "Expanding our understanding of the ocean can improve our economic competitiveness, strengthen our national security, protect our environment, and promote continued prosperity.[1]" While NOAA and OAR continues to promote scientific discovery while serving the nation and societal needs, one reviewer wonders if PMEL should shift towards a capability that is more linked with economic, safety, and security concerns? If so, this reviewer believes PMEL should think strategically about how this fundamental shift should result in changes in organization, balance, and research structure. Some questions management could ask include: What is the proper balance between government-directed applied and transitional research and PI-led research? Should a government lab focus on transitional research into decision making tools rather than fundamental discovery which may be better for academics? Should PMEL seek requirements directed from OAR to strengthen the required tools to improve environmental "decisions" at the national level? Would responding to requirements make more efficient use of resources?

Findings and Recommendations by Research Theme

Review panelists split up to delve deeper into the four main Research Themes currently active within the Laboratory: Climate-Weather Research, Marine Ecosystems Research, Oceans and Coastal Processes Research and Innovation and Development. Panelists were asked to grade each assigned theme from 1 to 4 with 1 = Highest Performance; 2 = Exceeds Expectations; 3 = Satisfactory; 4 = Needs Improvement. Detailed reports on each follow the table.

Research Theme Ratings

(1 = Highest Performance; 2 = Exceeds Expectations; 3 = Satisfactory; 4 = Needs Improvement)

	Rev 1	Rev 2	Rev 3	Rev 4	Rev 5	Rev 6	Rev 7	Rev 8
Climate-Weather								
Quality		1	1				2	
Relevance		1	1				2	
Performance		1	1				2	
Marine Ecosystems								
Quality	1							1
Relevance	1							1
Performance	1							1
Oceans and Coastal								
Quality	2	3	2	1	2			
Relevance	2	2	2	2	2			

[1] Kelvin Droegemeier Director, White House Office of Science and Technology Policy and Mary Neumayr Chairman, Council on Environmental Quality. Summary of the 2019 White House Summit on Partnerships in Ocean Science & Technology

Performance	2	2	2	1	2			
Research Innovation								
Quality			2	1			2	
Relevance			2	1			2	
Performance			2	1			2	

Climate-Weather Research

PMEL is one of few institutions that routinely carry out sustained ocean observations on global scales. At the time of this review, the multi-decadal timeseries of PMEL observations forms one of the cornerstones for the climate research community. The impressive diversity of platforms (moorings, floats, AUVs) and co-location with a world-class engineering facility allows for both important and innovative research to be conducted. The data generated by the various groups in the climate research group at PMEL has facilitated ocean climate research world-wide and transformed our understanding of the role of the ocean in the climate system. It is evident that without PMEL observations, the ocean community would not be able to carry out important work.

The assemblage of scientists, engineers, technicians and IT personnel (along with postdocs and graduate students) associated with the Climate-Weather Research theme at the Pacific Marine Environmental laboratory are first class. A notable aspect of the PMEL research effort is its focus on long time observations of the ocean-atmosphere-cryosphere state. In the U.S., NOAA is often pointed to as the standard bearer for sustained observations. PMEL investigators are doing the work. Investigations conducted by these scientists are world renowned.

Climate observations and research in the lab are separated by historical divisions, which may not be optimal for future directions. These are:

Tropical Moorings: Following the success of the Pacific tropical mooring array, PMEL is now a leader of international efforts in both the Atlantic (PIRATA) and Indian (RAMA) tropical oceans. The arrays are designed to enhance understanding of major climate variability modes (e.g., ENSO, IOD), with significant impacts on global weather patterns and by extension societal needs. The work led by PMEL has resulted in hundreds of publications over the years and more importantly, fundamental understanding of the climate system.

Ocean Climate Stations: The OCS maintains meteorological and ocean moorings in three locations designed to understand air-sea interactions and their impact on the climate system. These observations are crucial to the development of global forecast models, such as NOAA's GFS.

Large-scale physics: The large-scale physics group at PMEL is one of the world leaders of the Argo effort, which without a doubt has transformed our understanding of the ocean and its role in the climate system. PMEL is also one of the leaders for the development and

deployment of Deep Argo, which will help address some of the more pressing questions relating to the fate of the heat being absorbed by the ocean. Together with the group's work on repeat hydrography and satellite data, it forms a premier center for observations relating to the role of the ocean in the climate system.

Ocean Carbon: The Ocean Carbon group at PMEL is a world leader in documenting ocean carbon cycle and its variability. Their research involves not only documenting changes in CO_2 and temperature but how they impact the ocean ecosystem. The group is a leader in the ocean acidification and ocean carbon uptake research fueled by observations carried out by PMEL.

Western Pacific (WestPac) boundary currents: The WestPac boundary current group focuses on glider observations of transport through the Solomon Sea. The group's role is to focus on a process that can be of significant importance to ENSO dynamics, but cannot be resolved by the global observational networks (such as TAO). Over the last 10+ years, the group has built a timeseries that can now be used to study interannual and seasonal variability of transport in the region.

Atmospheric Chemistry: The Atmospheric Chemistry Group at PMEL maps the spatial and temporal distributions of natural and anthropogenic aerosol particles in remote marine regions. The research emphasis of the group is on the formation and transformation of aerosol particles and ultimately on the impact on air quality.

One panelist viewed these titles as a disjoint collection of methodologies, physical processes and phenomena. The individual suggests a more consistent set of groupings might be:

- Tropical Air-Sea Interaction and Global Responses,
- Seasonal to Decadal Global Ocean Variability and Dynamics, and
- Atmosphere-Cryosphere-Ocean Exchanges and Climate Impacts.

Using this 3-element grouping, the first encompass the in-situ arrays of moored surface buoys in the tropics, investigations of atmospheric teleconnections originating at low latitude and meridional ocean exchanges via boundary currents. The buoy project, in operation now for some 40 years (a remarkable, unprecedented achievement), is the legacy of the eastern equatorial Pacific current meter mooring program initiated by PMEL scientist Dave Halpern and the subsequent TAO temperature (and salinity) buoys instituted by Dave's colleague Stan Hayes, both realized with the engineering support of Hugh Milburn and his associates, along with many sea-going and shore-based technicians and data handlers. Observations deriving from the now-merged array under the TAO array label support numerous scientific and operational investigations leading to peer reviewed papers and improved operational forecast systems. Recent advances in satellite remote sensing systems and synthesis techniques have perhaps lessened somewhat the importance of the moored buoy arrays to the forecast systems, but the arrays provide vital subsurface information and direct velocity observations that are otherwise unobtainable. Moored tropical arrays are now in place in all three oceans.

Point people for the present-day programs are Dr. McPhaden (science), C. Meinig (engineering) and E. Burger (IT).

At the time of the previous PMEL review, the TAO array in the Pacific had only recently transitioned from PMEL to NOAA National Weather Service (NWS) and was experiencing a significant decrease in quality data return. The 2020 review team was encouraged to learn that the data return has improved, but we believe that sustained vigilance by scientists, skilled data analysts and engineers "looking over the shoulders" of the operational agency will be required to ensure high quality continuation of this valuable long-term climate record. The arrays in the Atlantic and Indian Oceans, being maintained through international collaborations, are currently judged to be experimental and thus the U.S. contributions to these observing systems are deemed not ready for transition to an operational agency. As such, PMEL is tasked with maintaining these buoys and receives significant NOAA funding to do so. There is widespread community consensus that the moored buoy programs remain vital elements of the global environmental observing system and that PMEL is effective in sustaining the field assets and delivering the data to stakeholders, collaborators and the public.

That said, efforts at PMEL and elsewhere are researching ways to improve and enhance the tropical observing system. One such effort fielded in recent years utilizes ocean gliders to estimate mass, heat and freshwater transport exchanges between subtropical and tropical latitudes via western boundary currents. The PMEL activity in this area led by Dr. Kessler focused on the flow through the Solomon Sea. Outcomes of this glider-based project (and research by others addressing different boundary currents using similar technology) show promise for efficient long-term measurement of these strong, important flows. On broader scale, PMEL investigators are leading a major effort to explore new, more effective and efficient ways to conduct sustained observation of the tropical Pacific Ocean state: TPOS 2020. Reviewers were given a brief status report on this activity by its PMEL lead, Dr. Kessler.

On the atmospheric side of the air-sea interface, a new study of Madden-Julian Oscillation (MJO) influences on sub-seasonal weather variability was presented by Dr. Chiodi that led to a U.S. rainfall prediction metric based on outgoing longwave radiation signals. The study evolved into a partnership with the U.S. Forest Service providing guidance for optimizing times of prescribed burning in conjunction with forest management. The serendipitous nature of this project was noted, and its success applauded as a great example of basic science leading to a practical application.

In the arena of Seasonal to Decadal Global Ocean Variability and Dynamics, the panel was given presentations about the PMEL contributions to the international Ocean Sites time series stations, several Argo float efforts, the global repeat hydrography program and the closely related ocean carbon and transient tracer activities. Dr. Cronin gave an overview of PMEL's Ocean Climate Station program that, beyond the low-latitude buoy project, involves maintaining bottom-anchored surface moorings in the western subtropical and eastern subpolar Pacific. The first of these, named KEO, is a legacy of the KESS process study (Kuroshio Extension System Study) conducted in the mid 2000's. The latter is the modern continuation of

the Ocean Weather Ship Station Papa, most recently augmented with additional observing resources by NSF's Ocean Observatory Initiative. Time series of boundary layer atmospheric and upper ocean parameters are returned from these systems from which so-called bulk-formula-derived estimates of air-sea exchanges are obtained. Sustained observations about the air-sea interface remain important for developing understanding of atmosphere-ocean interaction and providing validation data for operational air-sea flux climatologies, as discussed in OceanObs 2019 papers. PMEL investigators are also heavily involved in looking beyond fixed buoy platforms for such observations (see discussion of the PMEL Engineering program below).

On a much broader scale, PMEL investigators are making a significant contribution to the core Argo float program, currently responsible for 1/7th of the active global array. Beyond fielding instruments, Dr. Johnson detailed how their group is active in producing science quality data products as well as carrying out analyses of the observations. A leading example of the latter is Johnson and colleagues' assessment of ocean heat content change and contributions to IPCC assessment reports. PMEL has also taken a lead in the Deep Argo float program with deployments in the South Atlantic and with BioGeoChemical Argo (where several additional sensors are integrated into the profiling floats). Loss of PMEL's contributions to the greater Argo float activity would be severely missed.

While Argo has revolutionized the community's ability to assess global ocean change, even with BGC Argo augmentations there remain fields that are not observable with current sensor technology. The GoShip international effort, an outgrowth of the World Ocean Circulation Experiment Hydrographic Program (WHP), seeks to address this observing gap. PMEL investigators including Dr. Johnson are playing a leading role planning and directing these repeat hydrographic sampling cruises and making the observations at sea. Critically, the accuracy of the Argo float data, especially salinity, is directly tied to the state of the art GoShip observations. Here again, absent PMEL's involvement, GoShip and Argo would be hard pressed to meet their objectives.

Two measurement activities associated with GoShip require additional comment. The first of these, the CO_2 program led by Dr. Feely, extends well beyond GoShip. Dr. Feely's lightning talk presentation nicely stated the overarching question they are addressing ("how does the ocean carbon cycle affect humankind's ability to predict and respond to climate change and its impacts") and the lab's mission ("advance scientific understanding of the natural and anthropogenic perturbations of the ocean carbon cycle"). This group at PMEL addresses these topics by collecting and analyzing CO_2 data from GoShip and other cruises and from surface moorings and other un-crewed platforms (as was reinforced by the Dr. Sutton-led tour of their laboratory). Together, PMEL engineers and scientists have evolved the sensor technology to make the observations. Their role in the U.S. and, arguably, the international carbon study effort is irreplaceable.

The other GoShip project to highlight is the transient tracer sampling and analysis activity presented to the review panel by Dr. Sonnerup. This effort is the legacy of the late John Bullister who is greatly missed. From the spreading rate of waters naturally tagged with

anthropogenic chemicals (such as CFC's and SF6) at the air-sea interface, much may be learned both about the strength of the ocean circulation and intensity of turbulent mixing. As such, transient tracer observations are an important validation for ocean climate models and source of basic understanding of the ocean state. Moreover, these transient tracer data are integral to discriminating between natural and anthropogenic carbon concentrations in the ocean. From all evidence, the PMEL lab produces state of the art observations. In the wake of Bullister's passing and recognition that other leaders in this field around the U.S. (e.g. Weiss, SIO, Smethie, LDEO; Fine, RSMAS; Ledwell, WHOI) have formally retired (though several remain active), the ocean tracer community must figure out how to extend their capabilities into the future. PMEL appears well positioned to take a leadership role.

The third collection of climate research themes encompasses several foci. Dr. Quinn introduced the review team to PMEL's work on atmospheric aerosols: the cloud condensation nuclei (CCN). Clouds, a major modulator of incident solar short wave and radiated long wave radiation on earth, are key players in earth's climate state. Indeed, much uncertainty in long-range forecasts can be traceable to model cloud parameterizations. Observations from the western N. Atlantic made during 5 cruises in the 2014-2018 period revealed that biogenic sulfate frequently contributes more CCN than does sea spray. As presented by Dr. Quinn, this finding suggests that biogenic sulfate provides the sought-after link between marine ecosystems, aerosols and cloud properties. One reviewer believes the next challenge to this PMEL group will be to develop autonomous measurement systems able to operate for long time from moored buoys and un-crewed vehicles.

PMEL's Arctic program ranges widely across the subdisciplines of atmospheric sciences, sea ice investigation, physical oceanography, and biogeochemistry. Dr. Wang's lightning talk highlighted some of this group's recent investigations and contributions, including co-authoring the annual Arctic Report Card and IPCC reports. In one reviewer's opinion, many of PMEL's "Arctic" programs might be better characterized as subarctic, with some extension north of Alaska but by no means transpolar. It is widely appreciated that the Arctic is changing rapidly with decreased sea ice thickness, age and extent. The ecosystem implications are profound (e.g. timing of spring bloom versus zooplankton phrenology). Moreover, the impacts of Arctic change may extend to mid-latitudes via disturbances in the polar vortex and Jetstream. While clearly important, some panel members are unsure how PMEL's contributions in this last area relate to the work of many other climatologists now working on the problem. On the other hand, at least one reviewer was disappointed that no mention was made of the nascent profiling float program being co-led by PMEL/JISAO that holds promise for returning year-round water column data from the Arctic shelves and seasonal sea ice domains.

The final flash talk of the climate theme reviewed PMEL's work on marine heat waves documented in the Gulf of Alaska. Owing to the close physical and scientific proximity of PMEL investigators who span many subdisciplines, Dr. Bond and colleagues were able to jointly investigate the physical mechanisms responsible for the ocean warming event of 2014-16 and its profound impacts on the ecosystem and fishery. Moreover, exciting work is underway on developing predictive skill for ocean temperature and in turn, commercial fish abundance and

distribution.

Taken in total, the panel is impressed with the breadth and quality of research being conducted by PMEL and CI investigators under the Climate and Weather theme. The panel believes the group, together with PMEL engineering support personnel, are on par with the better physical oceanography departments across the U.S.

Marine Ecosystems Research

Marine ecosystem research at PMEL includes five elements: 1) Ecosystems & Fisheries-Oceanography Coordinated Investigations (EcoFOCI), 2) Earth–Ocean Interactions, 3) Acoustics, 4) Ocean Acidification, and 5) Genomics. PMEL maintains a level of excellence for all of them. This was well-evidenced by the impressive number of refereed publications, citation rate of those publications, and the list of awards and professional recognition of its scientific staff. Every one of these research areas is managed by a recognized leader in their field and they have achieved a level of partnership with other leaders in their field that ensures continued innovation and quality.

PMEL's research in this topical area is highly relevant to NOAA's desire to provide management information that achieves the stated goal of "healthy ecosystems, communities, and economies that are resilient in the face of change." PMEL has created a client-oriented culture that is apparent when talking with both staff and in the stakeholder interviews and is particularly apparent in two of the research areas, Acoustics and Ocean Acidification. The acoustics program addressed an impressive scope of societal concerns, with a clear linkage to management of shipping and naval activities so as to lessen effects on marine mammals. In addition, the work they are doing in a variety of environments is unparalleled and provides the monitoring baseline to assess changes over time.

Perhaps even more impressive is the relevance of their ocean acidification work, which is well-connected to a number of management issues. PMEL played a founding role in daylighting the ocean acidification issue through their partnership with the shellfish industry and in the formation of C-CAN (California Current Acidification Network), which continues to provide a link among scientists, management agencies and industry. PMEL scientists are active in State level management groups, providing leadership for the West Coast Ocean Alliance and with PMEL's work directly influenced OA Action Plans developed by the States of Washington and California. At a global level, PMEL is also playing a leading role in development of GOA-ON (Global Ocean Acidification Observing Network), with other countries following their lead.

Reviewers were instructed to assess performance with respect to three criteria: a) Research Leadership and Planning, b) Efficiency and Effectiveness, c) Transition of Research to Applications. The laboratory does well with respect to all three, but particularly does well in the third. With regard to research planning, the Ecosystems research staff all have clear scientific objectives, rationale and methodologies for their projects. Of these, ocean

acidification stands out as having the clearest path, with that team clearly integrated into work throughout the world.

As to efficiency, all of the programs are doing well. In every group, the team competence was apparent from the leadership all the way through the laboratory technicians who support the research. In no case, did there appear to be any barriers to the team working effectively and there were numerous examples of collaboration across disciplines that enhanced efficiency.

The third criterion of transition to applications is where PMEL particularly shines. Interviews with end users of the research illustrated success in delivering applications and clear involvement of the clientele all the way through the research process, which greatly enhances likelihood of adoption.

Most of the recommendations transcend this individual research theme and can be found above and below in this report to laboratory management. All of those are applicable to this theme as well, but in particular the genomics research needs greater definition. There is high confidence in the ability of the laboratory, and the talented people involved, to deliver on this fledgling research theme, but they are presently lacking a clearly defined niche that differentiates what they do from that of other laboratories working on marine genomics. Several possible research subspecialties within genomics, such as deepwater or harsh environment genomics that leverage some of PMEL's strengths, were mentioned by staff as potential differentiators, but these need better articulation.

Oceans and Coastal Processes Research

The Ocean and Coastal Processes group focuses on understanding the physical and chemical interactions of the ocean with the solid earth and the atmosphere, as well as determining the implications for climate, marine ecology, and human society. The primary strengths of this PMEL theme is the focus on 1) ocean tracers, 2) tsunami forecasting, and 3) Earth-Ocean interactions. These focus areas are well established and the opportunity for the group to leverage off each other to develop a suite of products that directly meets critical society needs. The relevance to marine ecology is much less developed.

The Ocean Tracer group is a world leader, providing long sustained maps of global ocean circulation and atmosphere communication. The efforts enabled through the Go-Ship efforts provides a rich data set that complements a range of other climate observational and modeling efforts at PMEL. These efforts are providing one of the global data sets using the best available approaches.

The Center for Tsunami Research is developing a wide range of modeling and observational tools to improve the ability to forecast and respond to tsunamis. The quality of their products has resulted in a range of users. The users include the Tsunami Warning Centers operated by the National Weather Service and some coastal states as part of the National Tsunami Hazard Mitigation Program. The Tsunami Warning Centers use the tsunami forecast and coastal

inundation models developed at PMEL to issue warnings when tsunamis occur. The team conceived and developed the real-time Detection and Reporting of Tsunami buoys that are now deployed around the world. The team is continuing to innovate especially in the development of computation approaches in tsunami modeling.

The Earth-Ocean-Interaction (EOI) group has a diverse portfolio spanning from mapping, to hydrothermal vent microbiology. The strength of this group lies in the seafloor mapping and helium laboratories. The hydrothermal research is interesting but differs from the other groups in lack of relevance. This group would benefit from a strong focus on prioritization in both the near and long term.

A number of stakeholders indicated their use and appreciation for this work and the personnel that supports this effort. According to one reviewer, while this group exceeds expectations in terms of relevance to specific stakeholders, the role of the individual programs working in concert with the rest of the community can seemingly be improved.
Consider the two overarching goals for NOAA:

- Blue Economy: Increase the sustainable economic contributions of our fishery and ocean resources
- Weather Act: Reduce the impact of extreme weather and water events

Using these two overarching goals as a means of gauging relevance, is it time to transition some of the operational technologies and/or build more relationships to other programs to help NOAA provide greater impact? To do so would require more integration into the climate change and BioGeoChemical and fisheries thrusts, which seems tenuous at present.

To measure performance, one reviewer considered the need to develop, deploy, maintain, and distribute key ocean data to support science, resource management and environmental direction. The groups within the Ocean and Coastal Processes theme have demonstrated their ability to maintain that capability in times of reduced funding and ship time. It is a big ocean and it would be easy to not acquire sufficient data to make statistically significant results in the required time (especially for tsunami warnings), but this group continually produces significant results thus indicating “Highest Performance.”

Several reviewers felt that it would be useful to have a high-level review of the Oceans and Coastal Processes Research theme to see how well it currently contributes to NOAA’s goals and how it might more significantly contribute in the future. It is clear that each of the groups within Ocean and Coastal Processes are experts in their field and support their area of research, but the relative contributions to the overall goals of NOAA seem unclear. One needs to ask what critical new research is not being done? Are there higher priorities? Should any of the groups change its focus? What new elements might be added? Should the Ocean and Coastal Processes group extend to the understanding, forecasting, and mitigation of major “weather” and for PMEL the associated ocean events that seem to be increasing in frequency and magnitude and tie into the biological, fishing, shipping, and other such impacts on humans, the economy, and the environment?

This research theme seems heavily dependent on ship time. The reduction in NOAA-provided ship time means that some form of contingency plan as well as a plan to reduce the dependency on ship time would seem valuable. The number of significant results this theme produces with so few measurements is impressive. It would be valuable to evaluate new technological capabilities to support and increase these measurements (and the associated additional value of those measurements).

It would be useful to examine the role of PMEL's Earth Ocean Interaction's group with regard to other work being done by NSF (e.g., Neptune, Regional Scaled Nodes), Office of Naval Research, and private industry (e.g., oil and gas) to identify PMEL's optimum role. Hydrothermal vents, methane seeps and associated biogeochemical relationships are all key to climate prediction, resource management and environmental stewardship but a clearer definition of PMEL's role would be useful.

Another reviewer noted that the areas of research included in this theme are rather disparate, making it difficult to assess with a single set of ratings. According to one reviewer the tracer group is world-class and would rank it as high performing in all categories. The figure in the overview presentation showing the NOAA contribution to the observational program pretty much says it all, except that one also has to recognize that this group is not only taking a lot of observations, but is also widely recognized as experts on how to make the measurements and also to interpret these data.

The Earth-Ocean Interactions group is a little more difficult to assess. In the past this group appears to have focused mainly on hydrothermal vents, but more recently has been working on methane seeps and how these inputs are related to seafloor biology and to climate change. The panel got the impression that they might benefit from some new focus. As PMEL strives to encourage research to support stakeholders needs, should this group focus on providing parameters to support climate change predictions or to work with other federal agencies (e.g., BOEM, USGS) on seafloor resource management and community structure?

Several reviewers found the tsunami group direction to be problematic. The tsunami group identifies three areas of development. The first area is the development of a next generation DART buoy that can be deployed nearer to the coast with the justification being to reduce the time needed to make warnings. This improvement is not relevant for far field events (tsunamis sourced from far away) and the group was unconvincing about where and how this development would matter anywhere. The time saved for near-field events will be minimal. Perhaps a cost/benefit analysis that included stakeholder input would reveal the value of such improvements in terms of warnings. The second area is the use of terrestrial GNSS receivers to characterize crustal motions that might cause tsunamis and allow better determination of the characteristics of the generated wave. It is not clear if such an array would be of much use for most tsunamis so an analysis to quantify the improvement would be warranted. The third area the group is developing is improved processing speed of the numerical models used to propagate the wave across the basin. There was disagreement amongst the reviewers whether this improvement is needed. Comments from the few tsunami stakeholders who participated

in the review were positive, so more time to evaluate whether this group is fully meeting stakeholder needs may be necessary.

In summary, the panel did not have sufficient expertise to make definitive recommendations regarding the value of existing efforts nor to suggest areas for future development for this theme. The panel suggests that this research theme would benefit from a more rigorous review conducted by specialists and stakeholders to reveal areas for improvement and prioritization.

Innovation and Development

PMEL provides critical long time series observation data, experience, and systems that are critical to serving the needs of the nation. The quality of the expertise of the engineering group (mechanical, electrical, software and field units) within the Research Innovation and Development as a core competency is on par with the top maritime units in the country (e.g., WHOI, UCSD-Scripps, APL-UW) and efficiently leverages new technological advances, as well as develops, integrates, tests, operates, and transitions observing systems to operational use. This is echoed by review stakeholders across a range of interactions including academia, industry, government, and users who were very complimentary and supportive of PMEL's efforts and provided positive comments about collaborations, developments, products and transitions.

Innovation and Development group head C. Meinig presented an overview of the activities being conducted by PMEL engineers, data management, and IT specialists. This work is currently grouped into three subsections: engineering, data integration and Arctic exploration. The divisions appear to be largely administrative with fluid interaction among group members and others in the PMEL/JISAO family. A notable and important feature of the engineering and data groups at the laboratory is their close working relationships with the scientists and technicians at the lab. These working relationships are encouraged by close physical proximity and by the demonstrated mindset that to be successful, the personnel engaged in the science, engineering and data handling must work together from the beginning of research projects.

A key aspect of the PMEL technical development effort, stressed by the group lead and by many others, is having the "license to fail," meaning the laboratory's willingness to "push the envelope" without fear that development programs will be curtailed even if a test reveals a flaw in design or implementation. The review panel stresses the importance of this philosophy for successful development and transition of ocean instrumentation to routine, operational use. The challenge remains how to obtain sufficient funding to overcome failures revealed during development projects and push through to operational systems. PMEL investigators and management should be applauded for having figured this out.

PMEL investigators have been on the forefront of new protocols for environmental observation utilizing autonomous wind-propelled surface vehicles through a CRADA (Cooperative Research and Development Agreement) with a startup commercial company, Saildrone, Inc. The cooperative project has led to advances in the vehicle mechanical design and subsystem

configurations, sensor integration, data protocols and analysis procedures. Quoting one of the PMEL program participants, "PMEL has invented Saildrone science." For the demonstration programs that PMEL has conducted with Saildrone to date, the NOAA team has had direct responsibility for sensors and sensor data quality and distribution. Some questions were raised by a few PMEL stakeholders/collaborators, independent academic researchers in the field and some review panelists regarding future observing system contributions by commercial entities. How will data be made available to researchers and operational programs, and what if any restrictions will be placed on the use of the observations? What ability will users of data from such observing system assets have to evolve the measurement protocols? How will commercial entities recoup their initial investments and operational expenses, and will the resulting data costs associated with research using these products be in line with future federal and philanthropic funding levels? In parallel with efforts to optimize environmental sampling, sensor integration and data handling/synthesis using Saildrones and other un-crewed measurement systems, PMEL investigators and management are encouraged to consider issues of data availability from commercial and other non-traditional sources.

Similar questions of the public-private relationship surround the PMEL Oculus glider project. As described, the Oculus is a derivative of the Seaglider originally developed at the U. Washington and subsequently licensed to Kongsberg/Hydroid (now a subsidiary of Huntington Ingalls Industries). Oculus employs the UW control software but is fitted with a larger-capacity buoyancy engine and an adaptable sensor payload module. With Hydroid experiencing difficulties transitioning the UW Deep Glider to production, one wonders if Oculus will suffer similar complications. In the meantime, PMEL researchers demonstrated successful applications of the technology.

The DART tsunami buoy development project appears to have been a clear success with the technology and operational responsibility transitioned to the National Data Buoy Center (NDBC) with an operational array now in place. The review panel was presented with new ideas for enhancing the DART buoy, however many panel members did not have the expertise to assess the efficacy of the ideas or to help prioritize which to pursue. Another PMEL technology in the process of transitioning to commercial production is the PRAWLER – a sensor platform able to ratchet along a conventional surface mooring tether under the action of surface wave heave. The concept follows similar developments out of the Bedford Institute of Oceanography that was subsequently licensed to Brooke Ocean Technology, and the Wire Walker developed at Scripps Institution of Oceanography. It is unclear how PRAWLER differs from these other devices, but the system has promise for becoming a useful observing tool.

The PMEL Research IT and Integrated Science Data Management group appears to be well integrated into the on-going measurement programs operating throughout the laboratory. Dr. Burger provided an example from the Challenger Expedition demonstrating the value of good physical sample archival practices. In addition, it appears that the PMEL group is well connected with personnel at NOAA's National Center for Environmental Information (NCEI). Particularly for long-term measurement programs, archival of the observations and associated metadata is vital. Given the small numbers of staff of the unit, it will be a challenge to respond

to the increase in the amount of data collected across a much wider range of systems/sensors (i.e., the additional need for long term measurements of bio, geo, chemical, and genetic information as well as the physical oceanography data). PMEL appears on the leading edge of this important field and working to develop best practices for handling observations made by new measurement platforms. Given the times, it is likely that data security issues will impede the progress of this group. All suggest a growing need for skilled staff. It was noted during the review that resource allocation for data management has not always meet these needs. This is not unique to PMEL, but leadership might be reminded to not overlook this critical function.

The previous 2014 Strategic Plan review noted, "Relatively low cost, low earth orbiting satellite communication technology (e.g., microsat) is rapidly advancing in other arenas, driven by the high cost of large communication satellites. Exploring communication alternatives to avoid reliance on a single network would be a wise investment." The current review panel concurs with this comment and suggests looking at the range of satellites (including CubeSats and MicroSats) for communication and sensors. Similar to the new genomics and bioinformatics effort at PMEL, these new areas could be a motivation for acquiring new engineering staff in a new capability area.

Though not discussed during the review, one reviewer wondered about the use of employee "interns" for summer work within the engineering group. Given the proximity to UW and other nearby community colleges and universities, there seems like good opportunities to have students participate in PMEL engineering. Perhaps a specific program could be put in place to facilitate the use of students, especially for the Science Data Integration Group.

At least one reviewer expressed concerned with the ITAE (Innovative Technology for Arctic Exploration) activities showcased during the review. PMEL's field work barely reaches into the Arctic proper and the review made note of a Saildrone expedition in summer 2019 that ran into difficulties. It was noted during one of the stakeholder breakout discussions that despite arrangements being made before the fieldwork to exchange information with a concurrent ONR cruise, nothing about the Saildrone mission actually reached the ONR cruise participants at sea. One reviewer asked if Saildrone is the right platform to observe in and about the Marginal Ice Zone. Perhaps the previously mentioned ALAMO float program is a better avenue to pursue. Maybe a focused measurement program to address well-posed scientific questions is the way forward. Sending Saildrones that far north seemed to one review panelist little more than a publicity stunt.

Looking ahead, the review panelists believe it would be valuable for the Information Science and Engineering group to identify a prioritized list of information needs (as a function of time such as the next five years) that balances need versus development cost and time, as well as technology transition. Such a roadmap could assist in the creation of new technologies and help management with prioritizing the sunsetting of existing technologies (e.g., what's good enough) and the transition of technologies to operations versus research (and allow for budget definition between those two efforts). It would be useful to develop other metrics for performance such as days at sea, systems at sea, system reliability, amount of data collected,

geographical areas covered, etc. Keeping track of these metrics would be especially helpful with regard to needed ship time versus ship time available (and the impact of lost or potentially lost ship time).

Overall, it is clear that the engineering and data management efforts at PMEL are well integrated into the sustained measurement and scientific analysis efforts ongoing at the Laboratory. All involved are to be applauded.

Comments on the Review Process

Panel members very much enjoyed learning more about the research conducted at PMEL and getting (re)acquainted with the staff. There were a variety of reactions and responses to the review agenda and schedule. Some reviewers felt the 3-day schedule included too much presentation material and not enough time for questions and discussion. One reviewer suggested the amount of time allocated for questions should be roughly equivalent to the amount of time allotted to the presentations themselves. Moreover, the question session format was mostly limited to panel discussions at the end of a series of presentations. This was judged less effective than had review team members been given the opportunity to ask questions immediately following each presentation. The panel acknowledged the difficultly of scheduling presentations and discussions for such a diverse research and support portfolio.

Some of the timing issue could have been reduced if an overview of lab research projects could be presented as written briefs made available to the review team *prior* to the event. By doing so, more valuable on-site review time could be allocated to small group meetings and discussion. A few documents did not make it in the pre-review package. It would have been good to have had the (draft) PMEL Strategic Plan and the 2014 comments on the previous review prior to the beginning of the review rather than at the end.

The group meetings we had with the junior staff and CI PIs were welcomed and appreciated – time for more such discussions with other groups would have been good. Another reviewer particularly appreciated the laboratory tours in which we were given the opportunity to interact with, and assess the skills and commitment of, the support staff. We also appreciated the opportunity to speak with the cooperative institute staff independently of the PMEL staff.

There was disagreement among panel members about the value of the stakeholder meetings. One member was not sure how valuable our time was with the “stakeholders.” They thought it could have been more efficient for the strategic plan to identify the requirements to support the stakeholders and then we derive our analysis based on that. In the stakeholder meeting we received the “opinions” of just a few vocal stakeholders and we’re not sure how to properly weight that in the review analyses. Especially for a government laboratory, an alternative would be to see requirements, needs and metrics. Other panel members felt that the stakeholder discussions were highly valuable. Despite the low turnout due most likely to the oncoming coronavirus concerns, they deemed the stakeholder discussions enlightening.

One panel member believes that the most valuable time was when the PMEL director interacted directly with the review panel. More time might be made for this type of interaction in future reviews, with maybe a little less technical detail.

Compilation of Specific Recommendations

1. Management should be grooming "heirs-apparent" to ensure continuity of leadership. This is particularly concerning because the same issue was raised by the previous PMEL Review Panel and little has been done to address it.

2. The cooperative institute arrangement would be more advantageous to PMEL if it were used as a pathway to permanent PMEL employment for those people who demonstrate leadership qualities. Relying on a mechanism where a high percentage of the leadership team are essentially temporary employees is not in the laboratory's best interest.

3. Management should recognize and reward three aspects of the present culture: a) Client orientation, b) Collaborative attitude, and c) "License to fail".

4. PMEL must develop a strategy for identifying when a project area has reached its research plateau and should transition from research to operation, effectively shifting the budget burden for that topical area to the operational side of NOAA (or to another client of the product).

5. PMEL needs a strategy for onboarding new research themes, particularly since the continued investments in existing research lines provides limited new opportunities.

6. PMEL is a leader with clear differentiation from the activities of other laboratories with which it collaborates. PMEL needs an onboarding strategy for science topics that clearly defines that vision at the outset and uses identification of its unique role as one of the criteria for investment decisions.

7. The time is now to groom the next generation of leaders. This is particularly important in order to afford continuity to the timeseries that have been a hallmark of the lab.

8. With PMEL's ability to meet its objectives now critically dependent on CI contributions, more effort must be made to improve the working environment for these individuals.

9. Regarding systems that originated at PMEL and then were transitioned to another entity to operate, the 2020 review team was encouraged to learn that the data return has improved, but we believe that sustained vigilance by scientists, skilled data analysts and engineers "looking over the shoulders" of the operational agency will be required to ensure high quality continuation of valuable long-term records.

10. Use the opportunity with a new director to make some changes to the research thrusts and move towards evolution rather than succession.

11. PMEL should continue to ensure that collected data are available to users in a timely fashion especially as systems are operated by contractors and/or transitioned to other organizations. Specifically, a careful review of the Saildrone contract with regard to data rights would be useful to ensure open access to the collected data.

12. In parallel with their efforts to optimize environmental sampling, sensor integration and data handling/synthesis using Saildrones and other uncrewed measurement systems, PMEL investigators are encouraged to think hard about the issues of data availability from commercial and other non-traditional sources.

13. It was noted during the review that resource allocation for data management did not always meet the need. This is not unique to PMEL, but leadership might be reminded to not overlook this critical function.

14. It would be valuable for the Science and Engineering groups to identify a prioritized list of information needs that balances need versus development cost and time, as well as technology transition. Such a roadmap could assist in the creation of new technologies, the sunset-ing of existing technologies (e.g., what's good enough), and the transition of technologies to operations versus research (and allow for budget definition between those two efforts).

15. It would be useful to develop metrics for performance such as days at sea, systems at sea, system reliability, amount of data collected, geographical areas covered, etc., especially with regard to needed ship time versus ship time available (and the impact of lost or potentially lost ship time).

16. The development of the Science Data Integration Group is a good start to better (i.e., more relevant, timely) and more efficient use of PMEL data. However, as the breadth of PMEL becomes more multi-disciplinary the range of data inputs and the utilization of data to support science and decision makers will make this group more critical. Security issues will impede the progress of this group. We recommend evaluating the needs of the group in order to accomplish future goals. The group may need to be larger, especially to support at-sea operations and interactions with users.

17. PMEL needs to review the cost of supporting quality engineering in Seattle and work to ensure that competitive salaries and benefits are available. Engineering of all types, but especially electrical and software, are in high demand by industry. The high cost of housing and commuting is making it difficult for the engineers in the maritime domain to support a family. The new generation is also much more mobile and willing (and able) to change jobs in response to better opportunities, internal dissatisfaction and boredom. Hence, it becomes more difficult to find quality stable staff to work long hours on complex problems (especially at sea).

18. We concur with the previous 2014 Strategic Plan review, "Relatively low cost, low earth orbiting satellite communication technology (e.g., microsat) is rapidly advancing in other

arenas, driven by the high cost of large communication satellites. Exploring communication alternatives to avoid reliance on a single network would be a wise investment." Consider looking at the range of satellites (including CubeSats and MicroSats) for communication and sensors. This, like the new genomics and bioinformatics effort, could be a means of acquiring new engineering staff in a new capability area.

19. PMEL should explore the use of employee "interns" for summer work within the engineering group. Given the proximity to UW and other Universities, there may be good opportunities to have students participate in PMEL engineering. We suggest that a specific program be put in place to facilitate the use of students, especially for the Science Data Integration Group.