Global Monitoring Laboratory (GML)
Science Review
October 21-23, 2024

GML Response to Panel Review Recommendations

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Submitted by:
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On behalf of the GML Leadership Team

Introduction

The National Oceanic and Atmospheric Administration (NOAA)'s Office of Oceanic and Atmospheric Research (OAR) conducts independent peer reviews of each of its laboratories and programs every five years. The purpose of the reviews is:

- to evaluate the quality, relevance, and performance of the research conducted and sponsored by OAR laboratories and programs;
- to develop and implement recommendations to improve the quality, relevance and performance of OAR research;
- to strategically position the laboratory or program in its planning for future research and development.

The reviews comply with the requirements of NOAA Administrative Order 216-115B: Research and Development in NOAA and OAR Circular 216-3: OAR Laboratory and Program Science Evaluations.

The NOAA Global Monitoring Laboratory Science Review took place on October 21-23, 2024. The review was conducted in person at the David Skaggs Research Center (DSRC) in Boulder, Colorado. The scope of the GML review covered the research and development activities conducted by the Laboratory over the last six years. The GML mission is to acquire, evaluate, and provide accurate, long-term records of atmospheric trace gases, aerosol particles, clouds, and surface radiation and to investigate observed trends and chemical and physical processes causing them. The laboratory was established in 1972 as part of the NOAA Environmental Research Laboratories. The research in GML is organized around three research themes, which include greenhouse gases and understanding of carbon cycle, guiding recovery of stratospheric ozone, and monitoring and understanding changes in surface radiation, clouds, and aerosol. Monitoring stratospheric ozone and the compounds that deplete it is a Congressional mandate for NOAA carried out by GML. The laboratory also operates under several global monitoring mandates and has served over the decades as the core of the World Meteorological Organization (WMO) Global Atmosphere Watch (GAW) Programme.

The Science Review Panel grouped their recommendations into the Overarching (OR) and Specific Recommendations (SR). In this response, these recommendations are addressed and their respective actions with timelines for completion are summarized in the Action Sheet.

Evaluation Criteria

The criteria for the review are quality, relevance, and performance, as defined below, consistent with NOAA Administrative Order 216-115B: Research and Development in NOAA.

Quality is a measure of the novelty, soundness, accuracy, and reproducibility of a specific body of research. Indicators include publications, technology development, data contributions, and awards.

Relevance is a measure of how well a specific body of research supports NOAA's mission and the needs of users and the broader society.

Performance is a measure of effectiveness and efficiency. It includes an assessment of the

organization's leadership, management, organizational culture, strategic planning, progress towards performance targets and milestones, efficiency in resource utilization, and transition of research to operations.

FMC's Strategy

The GML's strategic approach can best be described as balancing the continuity of GML's mission with the renewed vision on priorities, technological innovation, collaborations and partnerships as well as refreshed approaches to delivering on GML's mission. Many of the recommendations provided in this review help us formulate a revitalized strategy for the years ahead.

As emphasized by the review panel, the visibility of GML within NOAA, including NOAA Research, needs to be increased. While well-known and highly regarded at the national and international level, GML is not nearly as prominent within NOAA, due in large part to NOAA Research historical legacies and the primary focus being placed on matters of global importance by the previous Laboratory's leadership.

Any potential expansion of some of the networks or Laboratory's research activities will need to be achieved through balanced growth, ensuring the stability and resilience of the highest priority long-term environmental observations and by protecting staff against overburdening. Expanding collaborations, within and outside of GML, and achieving a stronger integration of observations and modeling, much of it to be achieved through collaborations, will be part of the renewed GML strategy. As a data provider, GML needs a fresh take on data management to increase efficiencies and widen access to its data holdings.

The current ratio of Federal to Cooperative Institute (CI) staff (1:1.8) is suboptimal and poses challenges with respect to critical expertise gaps and program management. At the beginning of FY25, GML had developed an ambitious staffing plan for Federal positions to address succession planning, fill out key Federal vacancies, bring new talent onboard in targeted areas, and improve the ratio of Federal to CI staff. That plan was put on hold in January 2025. Going forward, we will be looking to replenish federal staff ranks as permitted by new federal hiring opportunities and within the scope of our budgets.

Response to Recommendations from Review Panelists

Overarching Recommendations (ORs)

OR1: Grow
Do not shrink GML. This requires funding increases in every area, not necessarily huge, but solid and sustained. Federal hires, 10-12 of them divided evenly between senior management/group leaders and more junior scientists, need to occur as soon as possible.

OR1 Response:
We thank the review panel for their sentiment and this recommendation. We agree with their assessment that sustained environmental observations and attendant research, the type of work GML does, requires sustained funding levels that, at a minimum, should keep up with inflation.

It also requires careful succession planning to ensure continuity of operations and expertise in calibrations, measurements, data collection, engineering, and scientific research. New Federal hires were an integral part of GML's plan for FY25. Unfortunately, reductions in Federal workforce due to probationary staff terminations, regular and early retirements, and budget cuts in FY25 took us further in the opposite direction. As we move forward, GML will be proactive in pursuing new Federal hire opportunities if and when they arise, to bring new talent onboard in key strategic areas, in particular at junior scientific ranks. Any Federal hiring plan will have to be commensurate with our base funding and other resources.

OR2: Expand

The science conducted by GML must expand to meet the demands for climate-related data across all these areas and to enable partnerships that transfer knowledge for even greater benefit to the Nation and beyond. OAR's priorities must shift to ensure that GML can expand its measurements of chemical species across broader geographical regions. NOAA's budgets and personnel must continue to support a range of activities stemming from national and international commitments to data collection, calibration, scientific reviews, and the assessment process.

OR2 Response:

We thank the review panel for their recommendation. We strongly agree that GML funding level and workforce size need to be commensurate with the scope of activities GML commits to, ensuring proper staffing and other resources. NOAA Congressional mandates, other statutory authorities and international commitments and agreements, such as the Montreal Protocol, continue to provide firm standing for GML's sustained measurements, data collection, calibration activities, scientific research, and for the national and international engagement and leadership on societally important topics of relevance to NOAA and the Nation. While expanding the scope of current GML activities across the board is not feasible, pursuing targeted expansion in certain areas as opportunities arise is part of our organizational DNA. To that end, partnerships have been and continue to be an important mode for GML to expand our measurements of important physical quantities such as trace gas abundances and aerosol across broader geographical regions. Our growing public-private partnerships in sustained environmental observations promise to facilitate the expansion of these observations in scale and scope beyond what has been possible thus far and would be possible in the future with federal funding only. The "federated" network strategy, which lies behind our NOAA Federated Aerosol Network (NFAN), and the leadership and participation in the World Meteorological Organization's (WMO's) global Baseline Surface Radiation Network, are viable and complementary approaches that provide a broader coverage by data and best practices exchange across several partner organization sites.

OR3: Funding

Budget and hiring plans must support their work, and both need to expand to enable GML to better fulfill its mission. Funding from NOAA must be increased in all areas. Atmospheric baseline observatories must be maintained as there is no redundancy. The decline in the number of federal personnel, particularly senior staff, must be reversed. Succession planning to attract

experienced leaders and put promising junior scientists on a career track must begin as soon as possible.

OR3 Response:
We thank the review panel for their sentiment and this set of recommendations. While we agree, we also note that the current federal budget environment is not particularly conducive to growing the NOAA Research enterprise. However, we will continue working on securing needed base funding for sustained environmental observations. The immense value of sustained environmental observations and GML's stewardship of long data records of high-quality research-grade measurements is recognized by the OAR and NOAA leadership. The Atmospheric Baseline Observatories (ABOs), with their long measurement records (BRW - 1973, MLO - 1956, SMO - 1974, SPO - 1957), lie at GML's core. As such, it is GML's programmatic priority to maintain operations and data collection at those sites but also at a range of other key locations across our measurement networks. Furthermore, we will pursue opportunities to bring additional funding for our research and other activities beyond our base. As stated in our response to ***OR1*** GML will proactively pursue opportunities for new Federal hires to replenish our federal ranks in key strategic areas, both in the leadership and junior scientist ranks. Succession planning is more directly addressed in our response to ***OR9***.

OR4: Visibility
NOAA and GML both need to make GML's work and its scientists more visible. Actions could include: **(1)** more publications postings, press releases, and updated personnel websites; **(2)** NOAA awards and promoting recognition by professional societies such as the American Geophysical Union, American Meteorological Society, and American Association for the Advancement of Science.

OR4 Response:
We thank the review panel for this set of recommendations. We strongly agree. **(1a)** GML is committed to investing in communication to increase the visibility of our work within NOAA and beyond. In addition to a full time Communication Specialist – currently, a Cooperative Institute employee – the Laboratory top leadership, including the Director, Deputy Director, Associate Director for Science and the Senior Scientist, meets on a weekly basis with the Communication Specialist to review and discuss candidate items, such as R&D accomplishments, latest publications or data product releases, to be publicized as "hot items", NOAA Research web stories, social media postings, or via NOAA press releases. Recent expansion of the GML communications team includes a graphics artist (a contractor) who works closely with the Communication Specialist on improving the visual appeal of our communication materials and on enhancing the GML brand recognition. The GML Communication Specialist is part of a broader OAR Communications team, led by the OAR Communications Director, and includes comms specialists from other OAR Labs and Programs, OAR web team, and the OAR Public Affairs Officers who interface directly with the news media. **(1b)** We agree that the externally-facing GML website is in need of an overhaul and have formulated a plan for its redesign as a collaborative effort between GML and the OAR web team. This work is in progress with the projected completion by CYE 2026. To keep the content of our webpages dynamic and up-to-date after the webpage redesign, we are looking at the expansion of our graphics designer

contractor's role to include the web content management. **(2)** The GML long-standing Awards Committee was re-energized. The committee's portfolio of activities includes the solicitation of nominations for GML, OAR and NOAA awards, decisions on the GML awards, and assembly of nominations for the OAR and NOAA awards. GML will continue pursuing these internal opportunities for recognition of our staff for their outstanding accomplishments while also looking for opportunities for engagement with the OAR and NOAA award boards. To that end, the GML Director has signed up to serve as the new OAR representative on the NOAA Incentive Awards Board (NIAB) for a three year term (2026-2029). Beyond the NOAA awards, the committee plans to expand the scope of its nominating activities to include major awards by professional societies and organizations. We anticipate this being an area of expanded efforts in the coming years.

OR5: Collaboration

Collaborative opportunities for all of GML's groups should be better exploited within GML, across NOAA, and with external organizations. The impact and reach into policy can be further boosted by collaborating with modeling groups at NOAA labs, NASA, NSF, and Universities. The collaboration work that has started in the boundary layer modeling and analysis with GSL should be strengthened and expanded to other areas, such as flux inversions, as well. Coordination and cooperation with existing networks should be a high priority with GML. NOAA GML should try and take a leading role with the WMO G3W, while doing significant cooperation with AGAGE.

OR5 Response:

We thank the review panel for their overarching recommendation on collaboration. We agree there are additional collaborative opportunities GML could explore and exploit, with sister Laboratories within the NOAA Research ecosystem and beyond. We also note that the current environment is not particularly conducive to some of the specific things the panel recommends, such as a leading role with the WMO G3W. Similarly to partnerships (***OR2)***, collaborations are part of GML's organizational DNA. Consequently, our long-standing collaboration and cooperation with other observational networks (e.g., AGAGE, ICOS, GRUAN) that are part of the WMO Global Climate Observing System (GCOS) and the Global Atmospheric Watch (GAW) will be continued. We will continually evaluate new collaborative opportunities and pursue those that are in line with our strategic priorities. As an illustration, GML has recently joined the UFS-Chem effort that brings together modelers from a number of NOAA Research laboratories on development of atmospheric composition aspects of the Unified Forecasting System (UFS).

OR6: Strategic Planning

Together with GML senior leadership, GHG/CC needs to develop a strategic plan that defines goals for the next 5 and 10 years, along with appropriate implementation strategies. The plan should also include better integration of measurements and models within the themes, and with NOAA's climate model Labs and beyond.

OR6 Response:
We thank the review panel for this recommendation and we agree. In addition to evaluating the quality, relevance, and performance of research conducted by the NOAA Research Laboratories, the objective of scientific reviews, conducted every five years, is to help strategically position Laboratories in their planning for the future. The formulation of the new GML Strategic Plan was divided into two phases. **Phase 1**, which focused solely on the formulation of a new 5-year science plan, was initiated and completed ahead of the October 2024 science review. **Phase 2** will build upon Phase 1 and cover other strategic elements that are important for positioning GML for future successes such as workforce development, data management, and alignment of our science objectives with research infrastructure. We anticipate entering Phase 2 of the GML strategic planning process upon the completion of this response. All GML divisions took part in the formulation of a new science plan and its strategic goals. We welcome the recommendation for a tighter integration of measurements and modeling within all three GML's research themes and envision this to be reflected in the new GML Strategic Plan, among other places in the section on collaborations and partnerships. The new GML Strategic Plan will be accompanied by an implementation plan. The development of the new Strategic Plan will be in alignment with strategic priorities and plan developments for OAR and NOAA.

OR7: Leadership
Refresh GHG/CC leadership at all levels. There needs to be clear career paths and timetables for promotion of federal staff, and for hiring promising CIRES scientists to federal appointments. The group should focus on writing fewer external proposals.

OR7 Response:
We thank the review panel for their two-part recommendation. While we agree with the need to refresh the leadership at all levels in all parts of GML, we disagree with their recommendations regarding the cooperative institute staff and the external proposals. As stated in our response to ***OR1***, new federal hires are critically needed to replenish our federal staff ranks that have been further slimmed down by the loss of federal probationary staff and regular and early retirements. The latter led to several divisional and group leadership positions becoming vacant, creating room for the recommended leadership refresh. Given the current federal hiring limitations, however, many of those leadership positions are currently occupied by federal staff performing divisional lead duties in the acting capacity. These "internal details" represent a great growth opportunity for those federal staff members, many of whom have been in GML for a long time but have never served in the leadership capacity. As we look to hire new federal staff to replenish our ranks, we note that it is neither a federal laboratory responsibility nor obligation to hire cooperative institute staff into federal positions. Our federal hiring processes are open and competitive and we strive to recruit the best talent. Regarding externally-funded proposals: These have always been an important driver of innovation and scientific inquiry at GML and continue to be developed on a regular basis. To ensure there is a clear strategic alignment of externally-funded research activities with the GML mission and our strategic objectives, we have instituted an internal review process of every proposal that is written either by the federal or the cooperative institute staff. Furthermore, what is essential in this area is to manage and maintain an optimal balance between the base- and externally-funded activities. A specific action plan related to the externally-funded proposals is presented in our response to ***OR10***.

OR8: Modeling
GML should plan on an optimum observation-modeling mix. GML should nurture/expand their communication with the other NOAA labs to achieve this mix (see Collaboration above). The modeling should mainly be to help GML "operationalize" the observations, which are critical for national and international leadership. Modeling (e.g., Carbon Tracker) and analysis should be well supported to ensure full utilization of observations. The modeling activities allow harvesting of key policy-relevant information from the various arrays of observations.

OR8 Response:
We thank the reviewers for this insight and their recommendation. As stated in our response to ***OR5*** on collaboration, we agree that the integration of observations and modeling could be effectively achieved through extended collaborations within the NOAA Research ecosystem and beyond. The utility of GML's ability to measure and monitor parameters, conditions, and processes that are critical to understanding the atmospheric composition and Earth's energy budget can and should be extended using numerical models, both the forward and inverse ones. These models can be used to interpolate point data, integrate *in situ* and remotely-sensed data, estimate unmeasured quantities, and be used for process studies. We will include integration of observations and modeling, much of it to be achieved through collaborations, into specific objectives of the new GML Strategic Plan. That stated, we also recognize the value of independent data sets – observations that are not assimilated into prediction models – for verifying model predictions and satellite measurement calibration and validation. The recommendation regarding the in-house inverse modeling (i.e., CarbonTracker) is addressed in response to ***SR3(a)***.

OR9: Staffing
The high-caliber calibration, standardization, and maintenance of the state-of-the-art laboratory are being managed by one or two senior scientists. GML and NOAA leadership should implement a transition plan well ahead of eventual retirements to allow sufficient time for trust-building and mentorship of young scientists. Furthermore, for many of the GML activities, the number of scientists managing them is quite limited. NOAA OAR and GML leadership should be cautious not to overburden the existing staff as this could impact data collection.

OR9 Response:
We thank the review panel for this recommendation, and we principally agree. Succession planning is an important component of workforce management for any organization. GML had developed a staffing plan for Federal positions at the beginning of FY25 to address succession planning, fill out key Federal vacancies, bring new talent onboard in targeted areas, and improve the ratio of Federal to CI staff. That plan was put on hold in January 2025. At the time of the review in October 2024, the GML workforce consisted of 48 Federal, 74 Cooperative Institute (CI) staff, 4 contractors, and 2 NOAA Corp officers. While the CI staff represents most of our workforce, leadership positions need to be, and are, occupied by Federal staff. The imbalance between the Federal and CI staff has been further exacerbated by downsizing of the NOAA Federal workforce and currently stands at 1:1.8. As already noted in response to ***OR1*** and ***OR7***, we will reinitiate hiring of Federal staff as circumstances and budgets allow. As we go forward, we will examine meeting our workforce needs via a combination of CI and contract workforce.

While in some cases early retirements have prevented us from creating overlaps between the senior and junior staff to facilitate direct knowledge transfer, we find that there is sufficient knowledge within the current GML blended workforce to substitute for that. Also, we have been able to bring back some of our retired experts as scientific visitors to facilitate mentorship of early career staff.

OR10: Overburdening

GML operational levels appear to be overburdening staff. It is critical to not overwhelm staff with laboratory analysis and the production of standards. GML management should quantify staffing levels to ensure they can meet observation requirements and provide necessary scientific analysis. While long work hours and weekend work regularly are common for career-advancing scientists, management needs to monitor and adjust staffing levels to prevent overburdening.

OR10 Response:

We thank the review panel for sharing their findings and this recommendation. We agree. While long work hours in the observational and measurement science research laboratories is common, protective measures against overburdening and burnout are very important given the need for long-term sustainability of our operations. Prompted by FY25 budgetary uncertainties, the GML Leadership Team (LT) has examined the scope of our program and has identified areas that could be scaled down to make the program commensurate with our budgetary and staffing levels. Furthermore, during the last three fiscal years, we have transitioned to an activity-based budgeting. In this new approach, we take a holistic look at all the Laboratory activities, those funded on base and those funded by external grants, and build our budgets from the bottom up. As part of the budget formulation process, the GML LT works on ensuring that all planned activities and projects are staffed to appropriate levels and, vice versa, that individual staff members are not programmed to more than a full-time equivalent (FTE) through a combination of their roles in the calibration, measurement and monitoring programs funded on base plus their planned contributions to externally-funded research projects. With that, we can exercise better control over staff assignment levels. Over the last two fiscal years, we have also made a concerted effort to bring more project management expertise and discipline and a more deliberate approach to launching new, shorter-term projects that come on top of ongoing monitoring activities in the Laboratory.

Specific Recommendations (SRs):

SR1: Monitoring & Understanding Changes in Surface Radiation, Clouds and Aerosol Distribution Recommendations:

a. Commit resources to fill out instrumentation at existing networks, e.g. add SURFRAD type instruments to existing UV, aerosol and latent/sensible heat flux sites and vice versa, to provide denser sampling of US climate zones.
b. Expand measurements at existing sites, e.g., install ceilometers and cloud optical depth spectrometers.

c. More closely integrate the aerosol group science within GRAD. If possible, combine the two groups to achieve closer to critical mass.
d. Expand products useful for the renewables market.

SR1 Response:
We appreciate the Review Panel's acknowledgement of the high quality of radiation and aerosol data produced by GRAD (Global Radiation and Aerosols Division) and their research on the role of internal variability of global surface radiation patterns on decadal time scales. We largely agree with their recommendations. ***(a)*** and ***(b)*** GRAD will continue working toward achieving similar instrumenting of their radiation network sites (e.g., SURFRAD and SOLRAD), wherever permissible by site constraints and as feasible based on budgetary and other resources. This work will be done in partnership with other GML Divisions (e.g., CCGG) and other OAR Laboratories (e.g., ARL) to facilitate a strategic shift from several specialized networks with a relatively small number of sites to one larger network with a higher site density. Examples of work in progress include adding latent and sensible heat flux and cloud optical depth measurements at existing SURFRAD sites. ***(c)*** The aerosol and radiation groups have already been combined in one Division (GRAD) to help achieve a critical mass to support the scientific theme of "*Monitoring and Understanding Changes in Surface Radiation, Clouds, and Aerosols*". Further integration of the two groups is being pursued by the new acting Division Lead by exploring deployment of aerosol instrumentation alongside radiometers, ceilometers, and other specialized instrumentation at "enhanced" GML collaborative sites, and by the attendant combined data analysis from a suite of collocated instruments at such sites. Bondville, IL and Table Mountain, CO are two of these sites. (***d)*** GRAD plans to create and expand a range of new data products of direct value to trace gas measurements but also to NWP. One of those products is the boundary layer height for which the group is exploiting GML's ceilometer measurements and employing AI/ML techniques.

SR2: Guiding the Recovery of Stratospheric Ozone Recommendations:
a. The network of total ozone ground observations should be maintained to both validate satellites across latitudes and seasons, but also to ensure the credibility of ozone and water vapor variability and trend estimates. Provide sufficient resources to keep ODS data-collection techniques current.
b. Sonde observations are critical to both ground-based trend and variability estimates but also key to satellite validation. The network of sondes and total ozone ground observations should be maintained to both validate satellites across latitudes and seasons, but also to ensure the credibility of ozone and water vapor variability and trend estimates.
c. While some useful work on ozone and water technology was evident, GML should develop and coordinate a long-term plan to sustain and improve the ozone and water vapor profile and ozone column observations for the future.
d. Implement a succession plan for group leadership and consider combining the LOGOS and OZWV groups.

SR2 Response: We thank the reviewers for their recommendations regarding the measurements of ozone, water vapor and ozone-depleting substances (ODS). We agree with these recommendations with the exception of the last one. ***(a)*** No reductions are currently planned to

total ozone ground-based measurements based on science considerations. Development efforts to improve and make more resilient water vapor and ozone measurements. Consequently, trend estimates for total column ozone and stratospheric water vapor are ongoing (e.g., software upgrades for improved data processing to provide near-real-time measurements) as are advances in ODS measurements (e.g., new in-situ instrumentation and automated flask sampling in remote areas). New developments in the measurements of total ozone (e.g., evaluation of fully automated systems such as Pandora and BiTech Sensor (BTS) ultra-violet/visible spectral radiometers as potential replacements for Dobson spectrophotometers) and ODSs are being pursued. ***(b)*** GML has every intent to continue ozone sonde flights from the existing network to the extent possible given available funding and personnel. We have recently expanded water vapor balloon soundings geographically to ensure that all latitude bands are covered, and surface ozone monitors are being added at some ozone sonde launch locations. ***(c)*** The need for a long-term plan to sustain and improve the ozone and water vapor profile measurements and ozone column observations has been recognized and is being addressed in conjunction with the development of plans for stratospheric monitoring. Several technological improvements are currently underway including the in-house work on alternative coolants for the frost-point hygrometer sensor to replace a radiatively potent gas HFC-23, and collaborations with the Chemical Sciences Laboratory (CSL) on a new balloon ozone sensor and with the University of Houston on a new SO_2 balloon sensor. ***(d)*** While recognizing that there are scientific synergies between the LOGOS and OZWV Divisions, also recognizing that the two Divisions have a small number of federal employees, we still do not find the recommended combination to be the most optimal for the following reasons. The LOGOS Division, as its name implies (**L**ong-term **O**bservations of **G**reenhouse gases and **O**zone-depleting **S**ubstances) is focused on measurements of long-lived trace gases from flasks and a few in-situ instruments using chromatographic techniques. Those measurements include both long-lived major greenhouse gases (CO_2, CH_4, N_2O, etc) and ozone depleting substances (ODSs). LOGOS also creates and prepares gas standards to ensure these trace gas measurements are well calibrated. As such, LOGOS is more closely aligned with OBOP and CCGG, which focus, respectively, on the network operations in support of these measurements and the data QA/QC and scientific data analysis, then it is with OZWV with its focus on measurements of shorter-lived constituents, such as ozone, water vapor, and SO_2 that are measured and monitored by *in* situ surface and balloon-borne profiling sensors and by spectrometric measurements of total column ozone. Given scientific synergies between LOGOS and OZWV, centered on the recovery of the stratospheric ozone layer, more scientific collaborations can and should occur between these two Divisions. Those will be facilitated via cross-cutting research areas within the new GML science plan.

SR3: Tracking Greenhouse Gases and Understanding the Carbon Cycle Recommendations:

a. Modeling (e.g., Carbon Tracker) and analysis should be well supported to ensure full utilization of observations. The modeling activities allow harvesting of key policy-relevant information from the various arrays of observations. The models provide key connections from observations to policy and should be supported as part of GMLs overall mission.
b. GML should consider the sampling of HFCs at some of the long-term Greenhouse Gas Reference Network stations outside of North America. On a global scale, HFC emissions

derived from the analyses of measured atmospheric concentrations are significantly higher than the emissions reported to the UNFCCC by Annex I countries. There is a large and growing gap between reported HFC emissions and measured emissions, with about 60% of current emissions going unaccounted. The dramatic increase in this emission gap over time is consistent with substantial growth in HFC production, use, and emissions in non-Annex I countries that are not obligated to report emissions to the UNFCCC. Unfortunately, in the absence of controls, about 85% (~60 gigatons) of HFC emissions between now and 2050 are expected to occur in these developing countries where there is currently no monitoring of regional emissions by atmospheric monitoring. This massive blind spot means we cannot even begin to know if countries are on track to meet the emissions reductions expected from their commitments to reduce production and use that they made by ratifying the Kigali Amendment to the Montreal Protocol. If collection systems at some GGGRN stations (close enough to source regions) were to be optimized for the measurement for HFCs (with addition of flask packages to increase from weekly to daily sampling), it could be a very cost effective way to greatly enhance the visibility and transparency of HFC emissions around the world, which is critically needed for managing these powerful climate forcers.

c. Maintain the US Emission Tracker for Potent GHGs Tracking emissions over the contiguous U.S.
d. Support the timely QA/QC on the F-Gas measurements, as well as ongoing inverse model analyses.
e. Additional support is needed for staffing/labor the periodic meetings with EPA inventory compilers for joint analyses and comparisons of the activity data/emission factor information with the regional distributions and temporal variations in the emission estimates from the inverse modeling of atmospheric concentration gradients.

SR3 Response: We appreciate the panel's recommendations and agree with most of them. ***(a)*** We agree that the CarbonTracker modeling and analysis effort should be supported as part of GML's overall mission to ensure full utilization of observations and we confirm that it is. CarbonTracker analyses are a critical part of GML's efforts to advance understanding of carbon fluxes, including tracking of emissions and removals and carbon-climate feedback mechanisms. The track record of 24 transparent and fully documented public releases since 2007 is unmatched among similar modeling systems. Dedicated base funding for CarbonTracker development since fiscal year 2022 has allowed re-development of CarbonTracker-CH_4 and the hiring of a scientific programmer. A number of development activities suggested by the panel are already in progress (e.g., incorporation of new streams of data, including satellite total columns from OCO-2 CO_2 and GOSAT+TROPOMI CH_4; incorporation of a terrestrial biosphere model (SiB4-GFED) to include wildfire; development of the use of near-real-time "Active Fire" products from VIIRS that will drive the fire model and remove an important limitation to low-latency CarbonTracker flux estimates.) The plan for future developments of a more flexible and unified CarbonTracker inverse modeling system has already been developed. This system will allow assimilation of data not just for CO_2, CH_4, but also for radiocarbon (^{14}C), COS, and F-gases to provide "top-down" estimates of plant photosynthesis and F-gas emissions. As needed to achieve our scientific aims, we will continue to collaborate on the above efforts, also on the development of UFS-Chem (cf. ***OR5***), with a broad range of partners across OAR and NOAA (e.g., GFDL, CSL, ARL, GSL, PSL, AOML, PMEL, NWS, NESDIS), other federal agencies, and the international research

community, including academic and private sector partners. ***(b)*** To allow measurements of HFCs at additional sites, we will work on modifying sampling systems to take advantage of the greater GGGRN flask network. This effort will proceed as the funding and other resources allow. To maximize efficiency and resources, the effort will be combined with modeling to first target sites that are most effective for constraining emissions. While many sites in the GGGRN may not provide useful constraints on regional emissions, in the way that the reviewers envision, some certainly may, and we intend to target those first. Furthermore, expansion of measurements to more remote areas is planned in certain regions as that is important for improving our understanding of atmospheric gradients on a broader scale. This, in turn, is important for enabling constraints on continental-scale emissions of HFCs, which will also help address the issue highlighted by the reviewers. ***(c)*** The U.S. Emission Tracker for Potent GHGs has been updated each year since its initial development. The last update was in 2025, with tracking results for 4 HFCs now spanning the period from 2008 (or 2011) through 2023. The LOGOS Division will work together with the CCGG Division to make updating the Potent GHG Emission Tracker a priority for gases that are currently included. We have tentative plans to broaden this Emission Tracker to include additional gases as the needs of the community and science priorities evolve. ***(d)*** We will work on decreasing the latency for fully vetted F-gas measurements, and, in collaboration with GML inversion modelers, to streamline the regular yearly release of data. ***(e)*** We will continue collaborating with EPA to the degree that the areas identified by the reviewers remain EPA's priority.

SR4: Standards

Standards and laboratory analysis should be well funded and staffed to ensure the continued outstanding data quality for GML's state-of-the-art observations.

SR4 Response: We thank the review panel for this recommendation, and we fully agree. We will take steps, as funding allows, to sufficiently staff the measurement laboratories, Central Calibration Laboratory (CCL), and the gravimetric standards laboratory. We recently began the process of modernizing and updating much of the measurement laboratory data processing to better enable cross-training the existing staff to help increase resilience and ensure outstanding data quality. GML has also taken steps to upgrade equipment used for measurements and calibration. Similarly, we have begun modernizing the calibration data management within both the CCL and the gravimetric standards laboratory, to ensure the continuity of records relating to standard production through staffing changes.

SR5: Balanced Expansion

GML needs a careful balance between new measurements against boosting continuity and depth of critical long-term data observations. A careful balance of expansion while making sure of the stability and resilience of existing long-term observations should be made. When possible, expansion through collaboration with existing networks at NOAA and/or international (e.g. AGAGE, Global Greenhouse Gas Watch, GRUAN, etc).

SR5 Response: We thank the review panel for this recommendation, and we agree to the degree that new measurements in this recommendation are taken to mean new measurement sites within

the existing networks. We fully agree that the GML teams need to be deliberate and resource conscious when contemplating addition of new sites to our existing networks, especially when operating in a resource constrained and, potentially, declining funding environment. As stated in our responses to ***OR2*** and ***OR5***, we anticipate that partnerships and collaborations, also closer cooperation with other NOAA Research laboratories that manage and operate observational networks, will be of growing importance in the upcoming period. Of equal importance is a closer cooperation and collaboration of groups within GML at collocation of sites and consolidation of our networks (e.g., ***SR1***) to increase efficiency of our operations, freeing up resources for balanced expansion.

SR6: Innovation

GML needs to be innovative in its communication and automation along with the development of new techniques and measuring systems (as was evident in the theme presentations). Research on better automation, simplification, and cost reduction should be a high priority. There also needs to be an emphasis on training young scientists and students in the operation of these new systems.

a. The measurements with both GC-MSs and flasks should be expanded to improve regional quantification of emissions for multiple species across the globe. This expansion should be achieved in coordination with other observational networks and international organizations. Enhanced observations would enable better information and support for US policy makers.
b. The flasks collected at the very large number of sites are currently only analyzed for CO2 and CH4. These could be analyzed for F-Gases leading to a denser network of F-Gas measurements and provide data needed for more coverage and granularity for inverse model footprints and the resulting emission estimates. This would help attribute the 60% (and rising) of global HFC emissions currently unattributed to regions and countries of origin.

SR6 Response: We thank the panel for this set of recommendations. We agree. The Technology, Transition, Engineering and Applications (TTEA) Division at GML has a mandate to innovate and transition measurement and sampling systems, also measurement platforms, to higher technical readiness levels, closer to the operational state. Given its limited capacity, the initial focus of TTEA has been on enhancing sampling capacity on the ground and throughout the atmospheric column of long-lived trace gases that influence stratospheric ozone and the climate system. The innovations pursued include sampling systems automation, reducing the need for oversight by personnel, and standalone autonomously operated instrumentation that will enable deployment on platforms of opportunity. ***(a)*** GML aspires to double the capacity for analyzing flasks to measure long-lived trace gases that influence the climate system and stratospheric ozone over the next five-year period as our budgets allow. This is to be accomplished by building another set of the MAGGIC and PERSEUS flask analysis systems. Concurrent with this plan are the efforts to augment flask sampling at sites operated by GML and cooperative partners. This is to be done through the coordination and collaboration with external organizations (e.g., AGAGE, the Ozone Secretariat, university partners) who are pursuing the goal of increasing measurements of these gases worldwide. ***(b)*** Consistent with the recommendation, we are already in the process of expanding measurements of F-gases from flasks collected at sites where only CO_2 and CH_4

have been measured by GML. We plan to continue pursuing this expansion given the aspiration to increase the flask analysis capacity in GML as elaborated in part ***(a)*** part of this response.

SR7: Data Recommendations:

a. Data management at GML has not received the attention and resources needed to keep up with the fast-moving management and archival advances. It is understood that data management and delivery are large and costly enterprises. With limited resources, prioritizing data delivery may not seem viable within GML, so potentially leveraging capabilities in other parts of NOAA should be considered. In terms of leveraging internal capabilities, the aerosol group is likely the most advanced in this area with the development of their FORGE software. The emerging use of this software by radiation groups is a good start. At a minimum, GML could benefit from consulting with managers of large archives to gain insights into how to structure and maintain a modernized archive. Given their uniformity through time, some data management functions should be relatively simple to structure and automate. We are already in the time of cloud services and computing, with on-prem data access and computation becoming less central. If GML invests significant resources into building a local, unique system while the rest of the world goes with more centralized solutions, it could hamper cross-collaboration within NOAA and the development of a broader user base, both nationally and internationally.
    - Modernization of the GML data delivery framework to meet FAIR principles. Look to other parts of NOAA (NCEI) that might be able to take on some of the mechanistic aspects of data management, leaving the process and quality assessment to GML scientists and ask OAR to support this effort.
    - Provide uniform data formats (NetCDF) and metadata for reported variables to improve access to data for integrative research topics and higher scientific impact.
    - Build reportable data use metrics for the range of data that GML produces to help with prioritization of resources.
    - Mint all data sets with a DOI.
    - Remove barriers such as requiring passwords for data access.
    - Improve data latency through development of standard processes, timelines, and automation where possible.
    - Data plots on the web provide a zeroth order check on data files, but these data plots need to be routinely updated and timely.
    - The documentation of analysis products and tools needs to be enhanced. E.g., CarbonTracker.
b. Meta-data and data-archiving work should continue. In addition, GML should seriously think of improving data latency of the in-house data but also encourage, when possible, other partners (GAW stations etc.) for a quicker delivery and dissemination. GML needs to scale-up the impact of their data while rewarding Diamond data that is not seen on time loses its impact in policy and is a loss for GML as well.
c. GML should make a greater effort to lead global observation networks.
    - Make SURFRAD into a central location for other surface observations (perhaps with a better interface to US Climate Reference Network, SOLRAD, and the DOE ARM).
    - Interfacing with the AGAGE network would link the mutual data sets, and provide coverage for gaps in the respective networks.

- NFAN aerosol data should be consistent and submitted to the World Data Center for Aerosols (WDCA) – EBAS archives so these data are available to the international community.

SR7 Response: We thank the reviewers for their insightful comments and recommendations. We principally agree. GML has made substantial progress in its data management practices in recent years, yet much more remains to be done. As NOAA's official repository for scientific data, the NCEI archive provides many useful checkoffs of federal requirements and scientific best practices, including record keeping, standardized metadata, machine readable content negotiation, indexed searchability, standardized NetCDF file formats and DOI minting for all datasets. All GML data archived with NCEI, as well as data made available on the GML web site, are available without use of passwords. While the NCEI archive allows GML to meet most federal requirements and technical aspects of FAIR data principles, it is not ideal for several reasons, including ones raised by the reviewers. Furthermore, DOC and NOAA have identified the migration to the cloud as the highest priority for the Department and the Agency.

(a) & (b) Given the strategic importance of data management area for GML, our plan moving forward includes: 1) Dedicating resources for a laboratory-wide data management to facilitate coordination of data management activities across GML, focusing on data acquisition, processing, metadata management, and regular data update/distribution cycles. In the new hiring plan (cf. ***OR1),*** we have identified a GML data manager among the priority hires to coordinate data management activities and ensure adoption of consistent and efficient data management practices across GML such as: i) standardizing and expanding access to creating DOIs within GML, ii) use of ORCID personnel identifiers in all DOI metadata, iii) ensuring that metadata associated with GML datasets meet requirements under NOAA directives, and iv) implementing standard practices for file formats, citation language, data use restrictions, and data release schedules. 2) Dedicating one-time investment resources for website redesign and long-term resources for content management and graphics design. As stated in response to ***OR4***, we agree that the GML website is in need of an overhaul and have launched a high-priority redesign effort in collaboration with the OAR web team. GML data working groups (WG) have been working closely with the OAR web team to ensure GML data dissemination needs are met. This includes website data distribution and dissemination for enhanced discoverability, usability, and interactive data exploration using FAIR data principles. As part of this redesign, the GML web site will be migrated to the cloud and managed long term by the OAR web team. 3) NOAA has identified migration to the cloud as a strategic priority. To facilitate migration of GML data holdings to the cloud, we have set up another high-priority project managed centrally by a dedicated GML project manager. The cloud migration effort is a collaboration between the GML IT team, a working group of GML scientists, and the OAR HQ IT team. The completion of this project will be dictated by the overall NOAA cloud migration timeline.

(c) We will continue to pursue leadership as well as integration and collaboration with other organizations operating national and global observational networks.

GML Science Review Action Sheet					
Recommendation	**Action**	**Champion**	**Start Date**	**Target Completion Date**	**Status/Notes**
OR1: Grow	Develop a new federal hiring plan to fill federal vacancies in mission-critical areas.	GML Director	Q2 FY26	Q3 FY26	A new hiring plan for 14 federal employees was developed in Q3 FY26 in response to renewed opportunities for federal hiring. Two new federal hires approved.
	Perform annual review and update of the GML staffing plan.	GML Director	FY27	FY30	
OR2: Expand	Advance collaborative work with United Airlines under the existing CRADA to integrate and fly a trace gas sensor on one dedicated commercial aircraft.	TTEA Lead	FY25	FY26	
	Establish a new CRADA with Georgetown University for surface flask collection and analysis from three new sites abroad.	LOGOS Lead	FY25	FY26	
	Establish two light aircraft monitoring sites in Africa via international collaboration supported by external funding.	CCGG Lead	FY26	FY30	
	Set up new NFAN sites through collaborative proposals with external partners.	GRAD Lead	FY25	FY30	

OR3: Funding	Develop an action plan to secure positioning within OAR of sustained environmental observations.	GML Director	FY25	Q1 FY26	Working with the OAR ELT have positioned sustained environmental observations among the OAR foundational capabilities.
	Identify, review the mission alignment, and pursue external funding opportunities as supplement to base funding for R&D.	GML Associate Director for Science in collaboration with Division Leads	FY25	FY30	
	Institute and perform annual review of externally funded R&D activities portfolio to ensure balance is maintained.	GML Associate Director for Science with support by the GML Deputy Director	FY26	FY30	
OR4: Visibility	Reorganization and revamping of the GML Awards Committee.	GML Director	FY25	Q1 FY26	The Award Committee has shared leadership between the members of the scientific and administrative staff and it follows a yearly cadence for identifying award opportunities.
	Increase the overall number and success rate of nominations for OAR, NOAA and external awards.	GML Awards Committee Co-Chairs	FY25	FY30	
	External website redesign and migration to the cloud.	GML Director with execution support by the GML Senior IT Manager & Senior GML DO Project Manager	FY26	Q2 FY27	In progress through GML collaboration with the OAR web team.
OR5: Collaboration	Formulate plans for increased collaboration with other OAR labs and programs engaged in atmospheric composition research.	GML Director	Q4 FY25	Q1 FY27	

	Pursue collaborative opportunities via UNEP Ozone Secretariat to expand halocarbon measurements at new remote sites with flask measurements to be conducted by NOAA.	Senior Scientist	FY25	FY30	
	Advance collaborative work with NOAA OMAO to build capacity through deployment of GML instruments on NOAA ships and aircraft.	TTEA Lead	FY25	FY27	
	Advance collaborations with EU colleagues on aerosol measurements and monitoring.	GRAD Lead	FY26	FY27	
OR6: Strategic Planning	Develop Science Plan	Senior Scientist	Q3 FY24	Q4 FY26	Implementation of phased approach.
	Develop Strategic Plan	GML Director	Q1 FY27	Q4 FY27	
	Develop Implementation Plan	GML Deputy Director	Q3 FY27	Q4 FY27	
OR7: Leadership	Replenish divisional leadership ranks.	GML Director	FY26	FY28	
OR8: Modeling	Formulate a plan for increased integration of diagnostic modeling tools into analysis of GML's ozone, aerosol and radiation measurements.	GML Associate Director for Science in collaboration with OZWV and GRAD Leads	Q4 FY26	Q1 FY27	
	Demonstrate capabilities of UFS-Chem for long-lived trace gases (CO_2 or CH_4).	GML UFS-Chem Lead	FY26	FY28	

OR9: Staffing	Develop and implement succession plan with an increase in number of mid-career leaders on the federal workforce.	GML Director	FY25	FY27	See ***OR1***. Two new federal hires have been approved in FY26, one of which is mid-career.
	Institute an annual review of staffing needs and proposals to meet these needs via a combination of federal, cooperative institute, and contract workforce.	GML Deputy Director	FY27	FY30	
OR10: Overburdening	Perform a bottom up and top down assessment of FTE need vs. allocations to identify and eliminate tasks that are no longer possible with the current workforce.	GML Deputy Director	In FY25, we started by performing budgetary scenario planning for identifying potential scale down areas.	Q4 FY26	In FY26, we completed our transition to activity-based budgeting that forms the basis for top down assessments of FTE need vs. allocations. A bottom up assessment of activities and FTE needs is required to identify misalignment with needs and expectations.
	Continue performing this assessment annually.	GML Deputy Director	FY27	FY30	
SR1: Monitoring & Understanding Changes in Surface Radiation, Clouds and Aerosol Distribution	Formulate a plan to consolidate GRAD networks into a single network.	GRAD Lead	FY25	Q1 FY27	
	Formulate a plan to merge existing *in situ* aerosol measurements with remote measurements used to assess radiation and boundary layer physics.	GRAD Lead	FY26	FY27	

	Hire a scientist dedicated to measuring vertical structure of aerosols in the atmosphere.	GRAD Lead	FY26	FY27	
SR2: Guiding the Recovery of Stratospheric Ozone	Prepare a long-term plan that will ensure sustained, high-quality column ozone measurements into the future.	OZWV Lead	FY26	Q4 FY27	Personnel turnover and the need to modernize ozone column measurements is prompting identification of instrumentation for the next decade to enable critical monitoring of ozone recovery.
	Transition 80% of water vapor sonde operations to use the GML-developed "environmentally-friendly cryogen.	OZWV Lead	FY26	FY27	Technique for using environmentally friendly cryogens is fully operational (TRL9) and needs to be deployed throughout the network.
	Modernizing ODS data-collection techniques by adopting common processing-based software throughout the division for related instruments.	LOGOS Lead	FY25	FY27	Significant progress has been made to enable automated transition of ODS data to a GML database.
	Develop risk management plans to assess risks of personnel or instrumentation loss either through planned or unplanned attrition/disrepair.	GML Deputy Director in consultation with LOGOS Lead OZWV Lead	FY26	FY27	
SR3: Tracking Greenhouse Gases and Understanding the Carbon Cycle	Formulate CarbonTracker R&D plan.	CCGG Lead	Q3 FY25	Q4 FY26	
	Add sampling of air for halocarbon measurements at up to three additional existing sites for carbon cycle gas measurements.	LOGOS Lead	Q3 FY25	FY27	This has already been implemented at six sites. Necessary technical capabilities are being built for implementation at additional sites.

	Reduce latency of fully vetted F-gas measurements to 6 months after calendar year end.	LOGOS Lead	Q2 FY25	FY27	
	Reduce latency of fully reported long-lived gas measurements to 8 months after calendar year end.	CCGG and LOGOS Leads	Q2 FY25	FY27	Integration between instrumentation and databases improved in FY25 and FY26, laying groundwork for more rapid QA//QC.
SR4: Standards	Action plan for GML calibration labs to enhance comparability for stratospheric ozone, long-lived tropospheric tracers, and surface radiation.	GML Associate Director for Science with engagement by LOGOS, GRAD, and OZWV Leads	FY25	FY27	One of two FY26 hires directed to support the Central Calibration Lab (CCL) operations.
SR5: Balanced Expansion	Reflect plans for balanced expansion, as funding and technology developments permit (cf. ***OR2*** and ***OR5)***.	GML Director	FY25	Q4 FY27	
SR6: Innovation	Inclusion of innovation plan for automation and platform and instrumentation upgrades enabling higher accuracy, precision, durability and atmospheric intelligence.	TTEA Lead	FY25	Q4 FY27	
	Expand measurement backup capacity of flask network with new MAGGIC and PERSEUS flask analysis (cf. ***SR5***).	LOGOS and CCGG Division Leads	FY25	Q4 FY27	

	Implement NextGen measurement systems for high-frequency GHG measurements at all four ABOs.	OBOP Lead	FY26	Q4 FY27	
SR8: Data	Create a position of laboratory Data Manager and maintain critical mass of data management expertise in GML	GML Director	FY26	FY30	
	Redesign the external GML website with special focus on the data delivery framework (cf. ***OR4***).	GML Director	FY26	Q2 FY27	Work is underway on the website redesign and migration of it to the cloud.
	Include of a plan for improving discoverability, usability and interactive data exploration using FAIR principles. in the GML strategic implementation plan (cf. ***OR6***)	GML Director	FY26	Q4 FY27	
	A detailed plan for use of cloud and NCEI and other shared resources that help reduce cost and improve accessibility of data to the public.	GML Director	FY26	FY28	