Summary Report of the Review of the NOAA Air Resources Laboratory

May 3-5, 2011

Silver Spring, MD

Review Panel

Mr. Mark A. Nilles, U.S. Geological Survey, Chair

Dr. Mae Gustin, University of Nevada

Dr. Belay Demoz, Howard University

Mr. James Bowers, Kona Science Consulting

Dr. Brian Lamb, Washington State University

Dr. Kenneth Kunkel, North Carolina State University

Dr. Gregory Carmichael, University of Iowa

INTRODUCTION

A review of the Air Resources Laboratory (ARL) was conducted 3-5 May, 2011 in Silver Spring, MD. This Summary Report is a compilation of individual Panel member comments. No attempt has been made to develop a consensus position on any specific Theme or topic. The format for the Panel Summary Report continues the Theme Areas approach used by the ARL staff to present its research program. The review was very well coordinated and organized and all information, including written material, on-line resources, conference calls, informal meetings and oral presentations were clearly and nicely presented. The scientists and all other NOAA personnel were very helpful, open and responsive to questions. The review team greatly appreciated their efforts and hospitality. We also noted that follow up questions and requests for additional documentation were quickly addressed. The review was well planned, competently managed, and executed in a very efficient and organized manner by the many people involved.

OVER-ARCHING COMMENTS AND RECOMMENDATIONS

Comments

Overall the NOAA ARL consists of a highly competent group of researchers and support staff that perform an important role within the NOAA mission, including collecting observational data, developing data collection methods and modeling systems, and doing research on issues that are relevant to the atmosphere, ecosystems, and oceans. Their work is focused on highly relevant atmosphere-ocean issues that are important for the nation and internationally. The ARL applied research focus and collection of observational data fill an important niche within NOAA. Without ground based observational data, the scientific community cannot develop models that are needed to understand the ocean and atmosphere's natural behavior and response to human perturbations.

The group as a whole does solid quality science and has a strong commitment to supporting other agencies and organizations with good service, application of the best methods and developing effective partnerships. The employees clearly pride themselves on doing high quality work and collecting the best data possible. The stakeholders who support NOAA research and data collection were overwhelmingly impressed with the work done for them by ARL, the professionalism of the employees, and the quality of the products. The ARL scientists are also highly involved with outreach and communication with stakeholders and other researchers.

The indicators of preeminence are many including good publication track records in high quality journals (in spite of the many other obligations and deliverables) and development of widely used modeling programs and measurement methods, as well as awards, active memberships in prestigious organizations, service, and excellent collaboration with other agencies.

One of ARL's current goals is to transition to a more unified laboratory with greater coordination between its geographically widespread divisions. ARL's employees constitute an excellent group of scientists who appear very happy with their current leadership and the "transitioning" of the lab. One objective of the ongoing laboratory transition is better coordination of activities across the three research areas, which would benefit ARL as a whole.

Recommendations for the Laboratory:

1.1 Over all, ARL could use additional technician support for the scientists, who appear to be stretched thin with many hats to wear – from collection of data, to maintaining and repairing field instrumentation, to processing and writing up results, as well as seeking stakeholder support and maintaining connections with stakeholders. Technical support would allow for better focus on research by senior scientists and more time to work on publishing results and to participate in scientific endeavors that would benefit ARL and NOAA.

1.2 During the review, ARL scientists mentioned that the review process had been very synergistic for their group since it was one of the few times they were able to meet together to discuss ARL programs. Having more regular meetings within and between ARL divisions would facilitate collaboration and allow NOAA to better capitalize on the skills within ARL. A regular all-hands meeting of all ARL staff/scientists also could strengthen the sense of belonging by all employees. The employees themselves expressed a desire for all-hands meetings/workshops. It is at such meetings that ideas hatch and new business is created. Notwithstanding the obvious challenges of logistics and costs, additional opportunities to bring together scientists from the different sites should be created and/or exploited as they arise.

1.3 Inter-group interaction at all levels should be encouraged and rewarded. A lab effort/plan to increase the collaboration between sub-groups/themes could lead to increased visibility of the data sets within ARL and increase publication rates. Another likely outcome of increased collaboration is that the prolific writers in the laboratory would interact more with those that now spend most of their time collecting data in the field.

1.4 Interaction should also increase across themes and projects within ARL that are engaged in various national and regional monitoring efforts. The lab was described as being in transition with the shift to a Planetary Boundary Layer focus as an overarching theme for their programs. Within this theme better coordination and cooperation with research will

likely occur. For example, there could be better coordination and interaction between precipitation instrumentation performance testing and NOAA CRN under the climate area and ARL participation in NADP.

1.5 Although employees reported that there is recognition by present management of the need to increase field office involvement in the overall NOAA/ARL planning efforts and budget discussions, more could be done to involve those personnel located in offices away from Silver Spring, MD in collaborative decision making and other ARL team processes. The projects funded by other agencies and located away from Silver Spring are especially vulnerable to a sense of detachment from the overall NOAA mission within ARL.

1.6 A persistent and significant problem is the lack of depth in human capital within some ARL projects and focus areas. Some of the highly visible and productive areas of ARL are poorly staffed (Dispersion and Climate-modeling are examples). ARL's leadership in these areas could be lost if appropriate levels of human resources with succession plans and alternatives to traditional hiring practices are not devised. This is perhaps the most serious issue that ARL needs to address and should be done as soon as possible. Some significant examples of this thinness in human resources are key scientists being diverted from their tasks to cover management and overhead type tasks, the difficulty in bringing in post-docs because of funding constraints and a shortage of people to train them, and difficulty to explore and develop new areas of research due to nearly all resources being committed to ensuring that ongoing monitoring and other service work is functioning properly. Support for hiring young scientists upon completion of their doctoral degrees and from postdoctoral positions could energize ARL as well as provide new research perspectives.

Other suggested opportunities for integration and enhancement include:

1.7 Create an ARL Fellows program by selecting a small cohort of scientists and providing resources for the cohort to develop and lead ARL integrated research development.

1.8 Design use of the mesonets as an integrated ARL testbed for boundary layer and model development and evaluation (incorporate modeling teams—WRF, HYSPLIT, and CMAQ—in the design and use of these testbeds).

1.9 Integrate PBL climatology work with surface energy network analyses, WRF-CMAQ and HYSPLIT developments, and regional climate modeling (WRF) to create value-added analysis results.

1.10 Design ways to rotate scientists for short or long periods among divisions.

1.11 Continue to develop ARL wide communications and interaction, including regular science meetings among divisions.

1.12 Employ the Weather Research and Forecasting Model (WRF) (both forecast and regional climate modeling), Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT), and Community Multi-scale Air Quality modeling system (CMAQ) developments as a focal point for integration of surface energy budget network, N, Hg, precipitation chemistry and

other measurement capabilities to develop enhanced and much more integrated research programs.

1.13 Continue to encourage scientists to publish their results in high quality journals.

1.14 Grow the scientific workforce with careful selection and nurturing of new, young scientists—explore ways to use post-docs as the entry point for new scientists.

1.15 Link the WRF improvements via the regional climate modeling program with ongoing wind energy and PBL research to yield simulation and forecast tools.

A complete list of abridged recommendations contained in this report is included as an appendix. The numbering scheme for recommendations throughout this report matches that of the appendix.

AIR QUALITY (Lead reviewers Mr. Nilles and Dr. Gustin)

The **Air Quality Group** applies and tests models developed within NOAA that are highly utilized by the atmospheric research community as well as by local, state and federal agencies and NGOs (HYSPLIT and CMAQ). These models are important for forecasting, understanding the distribution of pollutants and furthering science in terms of understanding atmospheric chemistry and deposition. The air quality group is also actively involved in improving these models by comparison with empirical and satellite data. Some laboratory work is also being done within NOAA to better understand processes.

Quality

The review presentations, documents and discussions with the stakeholders provide very strong evidence that ARL continues to provide high quality research products that are highly valued and used. The metrics used to assess quality, including number of peer reviewed publications, citations, awards, etc. are appropriate. Additional measures of quality include a record of leadership in national and international organizations and the recognition of a long record of continuing to produce top quality measurements from research monitoring networks.

Overall the work in the air quality (AQ) research area is of high quality. Research initiatives use state of the art instruments as well as applying the most advanced technology. They also serve an important role in their capability to ground truth new methods to be assured that these are collecting quality data. They are working on applying and testing new methods for measurement of nitrogen deposition. They have been significant participants in work developing methods for quantifying Hg deposition, and making air Hg measurements using ground based and aircraft platforms. The scientists in the AQ group are well respected in their fields with good outreach and strong and consistent publication records.

Relevance

All contaminants being studied are associated with major AQ issues facing the country as well as the international community. Contaminants include ozone, particulate matter, mercury and nitrogen. The work being done by this group contributes to international and national networks as well as initiatives that are important to stakeholders. This ARL group contributes to developing data and measurement methods and advancing science.

The ozone and particulate forecasting research is highly relevant with respect to human health. The current work regarding nitrogen deposition and mercury monitoring addresses issues of national concern. Despite shifting research priorities due to their need to address regulatory and cooperating agency mandates this group has managed to build strong relevant research programs and get this information out to the public.

The AQ group's current research effort fits in well with the "new" planetary boundary layer (PBL) focus of ARL and NOAA's focus on pollutants deposited from the atmosphere and their impact on ocean ecosystems. The PBL as a cross cutting theme for the ARL research focus (especially surface fluxes) is a valid and an important foundation.

The AQ group has an important niche within government agencies for as a research laboratory they can focus on collecting relevant data and process based information that can be used to validate models and ground truth satellite observations. They play an important role for both the international and national research communities through their use, testing and development of AQ measurement methods.

The AQ program at ARL continues its tradition of providing research in support of specific areas of AQ that are responsive to federal laws, plans, and interagency and international relationships. Its current focus on modeling and measurements is set well within both NOAA's and ARL's strategic plans. The modeling efforts are unique within NOAA (and other federal agencies) and provide critical research pathways that support improved operational products of high value to society. While developing pathways to support operational products is an often stated objective of research organizations, the degree to which ARL has actually accomplished this, both in the depth and quantity of such pathways and tools is an outstanding accomplishment.

The AQ forecasting research activities are of critical importance to the National Weather Service (NWS). This group within ARL has made a successful transition in their relationship with EPA and is focusing on high priority elements to improve nation-wide AQ forecasting. Notable progress was demonstrated in improving ozone processes, and treatment of smoke and dust emissions. Challenges remain in improving particulate matter (PM) forecasting and they are

working on important elements in this regard, including updating Service Oriented Architecture (SOA) mechanisms and developing data assimilation capabilities that will certainly be needed to achieve PM forecasting requirements. This group is doing excellent work but also faces many challenges and upcoming opportunities. Establishing new leadership after the loss of Dr. Daewon Byun is a real challenge, and the team is to be commended for their ability to continue to function effectively over these past months.

There are opportunities for ARL in the area of closer integration of AQ and weather. Many weather services are expanding their AQ activities and beginning to see improvements in weather products by adding AQ components.

The group has an effective working relationship with NWS, but there remain challenges, in that weather elements (such as mixing layer heights) are critical to AQ but not of much interest to weather forecasts. Getting better PBL parameterizations into weather models must compete with other priorities of weather forecasting.

The efforts at enhancing and implementing chemical data assimilation into AQ forecasts are also of high value, and ARL is making excellent contributions to this topic. It is becoming widely recognized that chemical data assimilation is needed to improve AQ forecast quality. ARL's position in the field is strong and provides a high visibility gateway to other ARL research activities. The challenge of data assimilation provides additional research footings in the monitoring activities. The US will need to expand the chemical observing system to support AQ forecasting, and there are research needs related to what are the observing system needs. ARL is well positioned to lead in this area.

The AQ program has good connections with other programs such as dispersion, and more opportunities are possible with climate and the connections between climate and AQ (e.g., in the area of short lived climate forcing agents -- ozone and black carbon) are gaining importance.

In the longer term there will be a continued need to evaluate the WRF/CMAQ configuration, and there may come a time where they need to transition to a different model e.g., WRF coupled with chemistry (WRF-Chem). ARL should develop a plan and process by which this issue is addressed and identify what specific needs and advances will prompt changes in models used.

HYSPLIT activities are of critical importance to ARL and continue to provide hybrid research/operations projects that cross many applications. It remains a widely used model by a broad research community (especially the trajectory capabilities). They continue to successfully expand the model capabilities. The work related to Hg modeling is strong and links well within an important/relevant problem that needs process studies, modeling analysis and advances in

monitoring -- all work that ARL is doing. There is a clear need for a transition plan for employees with unique skill sets, such as when Roland Drexler retires.

The precipitation chemistry activities are also a strong asset. ARL provides strong leadership at the international level, for example through the World Meteorological Organization Global Atmosphere Watch (WMO GAW), and provides valuable data sets for trends and for process improvements. The transition to a nitrogen focus is an excellent idea and a research area of growing importance. Because of the large interagency participation in precipitation chemistry monitoring, NOAA-ARL should focus, as they historically have done in other operational systems, on applied research that improves the quality and breadth of operational monitoring efforts, and on analysis and interpretation of monitoring datasets in areas of ARL expertise such as mercury and nitrogen.

The activities within the group related to emissions are also highly relevant and necessary. AQ forecasting and analysis of environmental issues for near real time applications require estimates of total emissions. Emissions inventories used for regulatory purposes are based on statistical information that by its nature is several years out of date. So the work on dust, fires and rapidly updating anthropogenic emissions is important.

Performance

The AQ research group has good indicators of preeminence and as a whole are well recognized researchers within the emphasized research areas. Clearly, the customers and stakeholders of this group are happy with this group's work and their research efforts. This group serves many agency partners and has a clear focus for future work.

The AQ program at ARL has a strong record of performance. This is reflected in their publication record averaging 10 papers per year. The journals where they are publishing represent top journals covering AQ and related topics. The program is also supplying products of high value. These include the modeling products used operationally by NOAA and a broader community, and their ability to maintain top quality research monitoring networks. The stakeholder groups indicated strong satisfaction with ARL.

Recommendations for Air Quality:

2.1 ARL has a strong suite of AQ models. However a closer relationship between HYSPLIT and the Eulerian AQ forecasting system should be considered. This is already happening in the sense of the fires and dust emissions development in one model being implemented in the other model. But there may be value in developing a more systematic strategy of linking the two models. For example, whenever possible, having parameterizations etc. that are consistent between the two modeling systems has merits, and also could balance workloads

between the groups. Activities could also include interfacing HYSPLIT with mesoscale met models and developing HYSPLIT/Eulerian model nesting capabilities. A key need within the community is to develop ways to provide source attribution information within Eulerian models; embedding HYSPLIT trajectory capabilities within CMAQ could be a way to address some of these source/receptor questions.

2.2 To link with the climate focus of NOAA, initiation of research on black carbon wet deposition is recommended.

2.3 Continued efforts to strategically link AQ forecasting to weather forecasting for the benefit of both are encouraged. Research activities that can document the mutual benefits will better embed the role of AQ forecasting and the continued development of processes and monitoring needs to support better and enhanced environmental services.

2.4 Better coordination, integration and communication between ARL researchers working in areas focused on different AQ parameters (O3, PM, Hg, N) could provide a more efficient means of addressing specific research questions.

2.5 Some projects within the AQ group have very limited opportunity for publication production, particularly for journal article publication. ARL should ensure that all projects within the ARL AQ area have the opportunity to publish the results of their work, even if this means supplementing cooperator funding with NOAA funding for publication.

2.6 Nationally coordinated monitoring data from automated instrumentation to measure speciated mercury in air concentrations is now available from the National Atmospheric Deposition Program, Atmospheric Mercury Network (NADP-AmNet). NOAA ARL should consider taking a leadership or co-leadership role in the analysis and summarization of this extensive information at the national or regional level.

2.7 ARL is an active partner in many interagency monitoring network efforts. Vast amounts of data from regional and national air and deposition monitoring networks, along with research data are increasingly available to all participants in these networks and to the broader scientific community. What is often lacking is the ability to consolidate and mine these data sets to address questions of regional and national concern. The AQ group should dedicate at least some resources to identifying and producing high-value and high profile products from this large amount of available data. Additional resources may be available from existing partnerships with other organizations to produce these products and should be pursued. National Research Council post-docs may be one type of human resource that would be appropriate for this type of product production.

2.8 It would be useful if this group could focus on getting descriptions of research method development and testing, and other efforts out into the peer reviewed literature. However this is currently limited by their lack of technical support and their need to wear many hats in their job. Funding for technical support staff would significantly enhance their scientific

productivity. Additionally, support for new scientists could help expand this group's capability.

ATMOSPHERIC DISPERSION AND BOUNDARY LAYER (Lead reviewers Mr. Bowers and Dr. Lamb)

The **Atmosphere Dispersion/Boundary Layer group** also fills an important role with facilities and resources that are important for research on the dispersion of environmental contaminants and hazardous materials. The DOE Nevada and Idaho sites provide settings where ARL research can be done to understand the atmospheric fate of materials that could impact human health. It is critical that any modeling initiatives are backed up by observations, and ARL provides an important role in supporting intensive field measurement programs to collect observational data that may be used to develop and/or validate dispersion and boundary layer models.

The HYSPLIT and the READY modeling programs developed within NOAA ARL are very useful tools that have had and will continue to have significant use by the atmospheric research community. One concern is that HYSPLIT is vulnerable as currently operated with only one person really understanding the model's scientific basis, limitations, and intricacies. Additionally HYSPLIT needs to be updated to work within new meteorological models. The current urban meteorological measurement effort should be revisited as to its overall usefulness to ARL's dispersion and boundary layer research goals.

Quality

ARL activities in the Atmospheric Dispersion and Boundary Layer theme are divided among the very successful HYSPLIT model development and application efforts, nationally prominent experimental tracer and mesonet meteorological measurements from the Idaho Falls Field Research Division (FRD) and the Nevada Special Operations and Research Division (SORD), and internationally recognized biosphere/atmosphere flux measurements from the Atmospheric Turbulence and Diffusion Division (ATDD). Related activities include the Washington, DC mesonet operations, boundary layer modeling investigations and improvements via the regional climate modeling group, and grid model development activities associated with the national air quality forecast group.

It is obvious that the HYSPLIT program continues to be a very successful and prominent effort that is in many ways the flagship of ARL modeling activities. The quality of this effort is demonstrated by the large number and wide range of HSYPLIT users, a productive publication record that is highly cited, recognition through agency awards, and an active community outreach program to help educate users and provide specialized application products. It is significant and valuable that the HYSPLIT program includes an active model evaluation

component with an emphasis upon model improvement as well as development of new applications that span near and far field emergency response, local and regional air quality, and climate change topics. It is also significant that the HYSPLIT program is at the forefront of science in each of these areas, which is probably why the model is so widely used among the science community. In summary, the HYSPLIT group continues to operate at a very high level of quality and productivity.

The FRD group is a national resource in terms of atmospheric dispersion measurement technology, and this is evident from the invitations this group receives to play a central role in homeland security and dispersion community field programs. The FRD tracer group has been involved in almost every major dispersion program conducted in the US in the past decade. This work has been recognized through a NOAA Bronze Medal Award in 2007 for contributions to homeland security and air quality. The group also provides a valuable service to the Idaho National Laboratory (INL) in terms of mesonet and forecast modeling programs, and the quality of these contributions has been clearly recognized by INL clients. SORD provides a similar service for the National Nuclear Security Administration (NNSA). Stakeholder comments were very explicit in terms of the high quality and value with which these contributions by SORD are viewed.

The boundary layer flux measurement capabilities and associated science provided by ATDD scientists have international recognition that is clearly reflected in the publication and citation record for this area. The group has produced significant advances in technology, such as the open path CO_2/H_2O sensor and aircraft turbulence probe, and they have used these new technologies to push the boundaries of our understanding of surface energy and biosphere/atmosphere trace gas fluxes. The quality of these efforts is measured in terms of publications, citations, agency awards, and invitations for national and international collaborations.

Overall, the ARL dispersion and boundary layer modeling and measurement groups have established national and international reputations based upon a high level of quality, a steady stream of new technology developments, and contributions to important scientific advancements. These are documented through publication records, agency awards, invitations for community collaborations, and specific comments and ongoing support by ARL clients. The quality of ARL contributions, which is certainly at a level that equals or exceeds similar efforts in other NOAA laboratories and other agencies and institutions, provides a strong basis for continuing ARL dispersion and boundary layer research in the future.

Relevance

The ARL atmospheric dispersion and boundary layer research in both modeling and measurements directly addresses topics of significant national concern in terms of homeland security, emergency response, air quality and health, and climate change. In several cases, the capabilities and technologies of ARL scientists represent unique national resources that are not duplicated by other agencies. The research topics appear to be in direct line with NOAA strategic goals and plans, and NOAA clients are actively engaged in providing feedback to ARL to assure continued relevance for specific applications as well as for broad national priorities. The topics addressed by ARL in this area appear to be quite appropriate.

Performance

Overall, the performance of ARL groups working on dispersion and boundary layer measurements and modeling is very good. For the HYSPLIT modeling activities, there seems to be clearly defined objectives and plans and there is an ongoing progression moving from model development to operations. There is a realization that plans are needed to assure the ongoing success of the HYSPLIT program, but there is not yet a clear path identified to do this. For the tracer technology group, the main focus seems to be continued involvement with community field programs, but there is no overall set of scientific objectives to provide a framework for how results from these field programs are analyzed to advance the science. Similarly, for SORD there should be opportunities to place the mesonet and modeling activities provided to the NNSA within a broad scientific framework, but there is no mechanism in place to achieve this. For the ATDD flux measurements group, the emphasis is clearly science driven with specific objectives and steady progress to achieve these objectives.

The efficiency and effectiveness of the various ARL groups working on dispersion and boundary layer research also are very good. Strong arguments can be made that the HYSPLIT group is understaffed, but there is a high level of productivity in spite of these limitations. Both of the western field divisions appear to operate effectively and successfully as service providers for on-site clients, and the FRD group is effective in their collaborations with external funding groups in terms of providing high quality tracer data to large field programs. There is recognition that there should be more integration of the various field and modeling group activities, and there are some steps taking place to achieve this integration. The ATDD flux measurement group is highly effective at translating the technology development and measurements into published scientific contributions.

Recommendations for Atmospheric Dispersion and Boundary Layer:

Specific recommendations based upon the review of the dispersion modeling and boundary layer research programs are given below.

3.1 Encourage development of a more cohesive dispersion measurement and modeling research program by hiring a mid-career dispersion modeling lead for the FRD group—the intent is to provide a more rigorous scientific framework within which dispersion measurement data can be collected, analyzed, and published. A mid-career scientist is suggested to help mitigate the problem that ARL's single senior HYSPLIT researcher is nearing retirement.

3.2 Provide for continuation and development of HYSPLIT by creating a larger and more distributed HSPLIT team with less reliance on single PI expertise.

3.3 The use of HYSPLIT by external organizations with varying degrees of expertise, especially during high-profile atmospheric release events, raises the question whether ARL should explore planning and executing model runs and providing model output products in addition to providing the model.

3.4 The use of HYSPLIT in work and publications produced by external organizations is extensive and, in some cases, is not well documented by ARL due to the difficulty in locating all of these applications and publications. ARL should consider a small project, possibly by supporting a library sciences graduate student, to develop a system to better identify and archive publications by external organizations utilizing HYSPLIT.

3.5 Develop and maintain a 5-year laboratory-wide plan that provides for integration of modeling and measurement capabilities. This plan should include specific goals and tasks for both individual divisions and programs and for integration across divisions and programs. This plan could be developed by a small, selected group of ARL scientists and should be a working, evolving document. Regular (twice a year) face-to-face meetings among division scientists should be a part of the development, evolution, and execution of the research plan. The plan should include external collaborations as an important element. The plan also should include development of an appropriate budget and identification of needed resources.

CLIMATE (Lead reviewers Dr. Demoz, Dr. Kunkel and Dr. Carmichael)

The Climate group has three focus areas. The earth surface flux focus fills a very valuable and unique niche investigating methods to collect observations, developing information on surface processes, climate trend analysis and ground truthing satellite measurements and models. NOAA ARL can and does make significant contributions to the national and global research community within this area given their current staff. The leadership work within the Global Climate Observing System Reference Upper Air Network (GRUAN) in WMO is one example. The

climate reference monitoring network (CRN) will produce excellent data, though some specific locations may be redundant with other networks and cooperation with other agencies would be useful. The regional climate modeling and analysis researchers are engaged with the climate research community and investigating important research questions. Some of the research emphasis in this group has been on the middle atmosphere. This work is highly significant and relevant. If ARL moves towards focusing on research within the planetary boundary layer this previous work should not be abandoned for the scientists have built a program and reputation for work within this area of the atmosphere.

Quality

Overall, ARL's Climate research area has a demonstrated an exceptional competence that has allowed it to be a leader in the upper air sonde analysis research and is making a significant impact on the science. A summary of the Quality indicators are given below.

ARL's total number of refereed publications per scientific Full Time Equivalent staff (FTE) ranges for the entire lab between 0.6 and 1.2 between the years 2001-2010. This number is on the low side but should be expected when one considers the many other responsibilities that the scientists have; service to other agency and instrument upkeep are some examples. The scientists in the climate group in ARL do very well against this average (1.5 or more and some individuals publishing 2-3 or more papers per year). The group's work is considered the cutting edge in their field and they are as productive as any. This is also confirmed by the citation analysis done; they are cited more than their peers. For the lab, an average number of 27.5 citations per paper is excellent.

The Climate group has designed and built an important infrared gas analyzer in the past that contributed significantly to the study of water vapor and carbon dioxide fluxes.

Four of the five international awards, 3 of 3 of the professional society and university awards, and 3 of 7 DoC Gold/Silver awards in 2000-2010 were given for ARL's climate related work. This is a distinguished record within ARL for this group.

The ARL Climate group has made extensive and important contributions in technical and scientific societies as well as in journal editorships. However, the majority of the service work tends to be contributed by 1-2 individuals in the group. While this work takes time and effort, it is necessary work for creating new-business as well as staying connected with new and evolving needs and science areas.

ARL history is long and the quality of their work has not diminished as can be seen in their production of publications. The lab's approaches must be appropriate. However, as most of the

scientists are nearing or at retirement eligibility; appropriate precautions and planning needs to be in place to continue ARL's good record and relevance.

The two ARL scientists with the highest H-index values are in the climate group. Three of their papers were given awards by the World Meteorological Organization or Chinese Academy of Sciences. Four papers were recognized as NOAA Outstanding Journal Articles. One scientist was recognized as a Fellow of the American Meteorological Society. However, there is also some weakness as a few of the scientists have a low number of publications relative to the number of years of publishing.

Involvement in prestigious organizations is primarily limited to a single individual. There are several scientists who served as editors or associate editors of scientific journals.

The surface energy budget group has been prominent nationally in establishing and operating stations and in analyzing and publishing results of the observations. They have also made significant contributions to the chronic problem of closure of the surface energy budget.

The instrumental support of the CRN has demonstrated its value through the high performance metrics on station data retrieval.

The observational networks (CRN and surface energy budget) produce research quality data that is central to NOAA's mission.

Relevance

NOAA/OAR's mission is to conduct environmental research and provide scientific information and research leadership that cater to the needs of the nation. ARL's work addresses this mission and is also in line and relevant for the attainment of NOAA's larger goals.

The ARL Climate group addresses the NOAA Charter for Climate Monitoring and Observation as well as the Charter for Climate research and Modeling requirement by providing "climate data and information that meets rigorous scientific standards for quality". The work in the Climate group, namely the reference observation, change and variability analysis, modeling and regional assessment work the group is involved in, is all directly relevant to the NOAA general goals and NOAA's climate goals. The Climate group is closely aligned and gets a high mark from its stakeholders. The group as a whole is highly relevant within the NOAA science plan and customers (IPCC, NCDC for example) are highly engaged. Its continuous and active interaction with the stakeholders is an excellent example that will ensure the long term relevance of their work.

As ARL makes the boundary layer a unifying theme of its different groups, the Climate group needs to think hard and fast how their work can inform this PBL theme and the "lab in

transition" and how they will remain relevant. In addition, as NOAA's proposed climate service takes shape, the ARL group should find a way to help lead that transition and stay well connected with upper NOAA management. Further, the climate analysis focused scientists should find a way to exploit the data that is being collected by the reference observation network and the Climate Monitoring Network within ARL.

Research results on upper air and water vapor trends have appeared in high-level national and international assessments, indicating the relevance of this work to current issues regarding climate change.

Performance

The Climate group has a clearly defined strategic plan and future tasks that they are aiming to complete. The strategy, developed with input from stakeholders, is a clear guiding document. Almost all the activities within the climate group (e.g. research analysis and expansion of the CRN's) do not fall or are not planned to be transitioned to operations. The group is doing a superb job in interacting with stakeholders, in dissemination of knowledge through publication, reports and even podcasts.

Historically, ARL's divisions are located at several states in the nation and this makes it difficult for close communication and planning of activities and cross-breeding of ideas. The inter-group interaction and idea fertilization (e.g. modeling-analysis-observation branch within the climate theme group and different theme groups within ARL) could and should be expanded. While it is true that the differing locations and the focus of their research (e.g. upper air analysis as compared to the CRN) makes it hard for effective communication, it should be emphasized that regular creative online or other means of communication should be devised. The regional climate modeling can be utilized more to integrate the different teams within the climate group.

The staff (in particular from the field offices) is appreciative of the recent effort to involve them in the overall NOAA and ARL planning process and that should be continued and expanded by the management.

A clear concern across the ARL lab is the relative lack of depth in personnel associated with the themes. Most areas of work are supported by very few, sometimes a single person team (e.g. regional climate modeling). A serious consideration should be given on how to rectify this point. Perhaps the regional modeling has a role to play in informing and assessing the location of the CRN as well as effects of "instrument location" into climate analysis.

Recommendations for Climate:

4.1 Inter group collaboration between the analysis, modeling and climate network instrument scientists should be expanded and used to create new opportunities, increased publication and visibility of all members.

4.2 The national and international leadership shown in the upper air analysis work should be extended to all data within ARL/National Climate Data Center (NCDC) (e.g. analysis of data from the CRN, NADP, AIRMon-wet, etc). Granted that this will depend on how well individual scientists work together, but clear performance/expectation from the management would be a requisite. Specifically, some of the longer data sets collected by ARL appear to be of sufficient length, quality, and relevance to warrant a study of trends. A particular example is the AIRmon-wet data. Collaboration between the climate group and the scientists in charge of the relevant data sets could be quite fruitful, both to understand whether there have been trends and, if so, what are the relevant meteorological/climatic changes associated with the trends.

The inter-group collaboration is undoubtedly hampered by the different locations/offices of the scientists but management is encouraged to find creative solutions that mitigate this obstacle.

4.3 Encourage a much more robust use of the regional climate model (CWRF) as an assessment tool for regional climate impacts and its role in air quality studies.

4.4 Concrete goals should be enumerated on how ARL-Climate fits in the “lab in transition” processes. This can start with a clear definition of how the “PBL theme” as a cross-cutting theme will fit into the Climate strategy goals and plans.

4.5 The group is encouraged to take a pro-active stance in the overall NOAA climate services discussion and define its role with the proposed reorganization. With all the excellent work they do in climate analysis, they should be leading the science discussion and not standing on the side.

4.6 Changes in the climate of the planetary boundary layer could have potential impacts on human and environmental systems, not the least of which is air quality. Ascertaining whether any changes have occurred is a difficult challenge, as is typical of all research focused on the atmosphere above the surface. Some research is already occurring. This should continue and perhaps be expanded. It plays to the strengths of the climate group and has potential synergism with other parts of ARL.

4.7 A stronger across-the-board publishing performance would enhance the scientific contributions of the climate group. This is also needed to establish a broader presence in national and international assessments and participation in prestigious groups. There are strong performers in this group but there are also some weak performers who may not be taking full advantage of publishing opportunities.

4.8 The current prominent position of the group in upper air research should be maintained as this will likely continue to be a critical issue for climate change detection and attribution. Efforts to bring together scientists from the different sites would be valuable. It is noteworthy that this review was the first occasion that this has occurred.

APPENDIX

A Complete List of Abridged Recommendations:

1: Overarching Recommendations:

1.1 ARL could use additional technician support for the scientists

1.2 Having more regular meetings within and between ARL divisions would facilitate collaboration and allow NOAA to better capitalize on the skills within ARL

1.3 Inter-group interaction at all levels should be encouraged and rewarded

1.4 Interaction should increase across themes and projects within ARL that are engaged in various national and regional monitoring efforts

1.5 More should be done to involve those personnel located in offices away from Silver Spring, MD in collaborative decision making and other ARL team processes

1.6 ARL's leadership and vital staff could be lost if appropriate levels of human resources with succession plans and alternatives to traditional hiring practices are not devised. This is perhaps the most serious issue that ARL needs to address and should be done as soon as possible.

Other suggested opportunities for integration and enhancement of ARL programs include:

1.7 Create an ARL Fellows program by selecting a small cohort of scientists and providing resources for the cohort to develop and lead ARL integrated research development.

1.8 Design use of the mesonets as an integrated ARL testbed for boundary layer and model development and evaluation (incorporate modeling teams—WRF, HYSPLIT, and CMAQ—in the design and use of these testbeds).

1.9 Integrate PBL climatology work with surface energy network analyses, WRF-CMAQ and HYSPLIT developments, and regional climate modeling (WRF) to create value-added analysis results.

1.10 Design ways to rotate scientists for short or long periods among divisions.

1.11 Continue to develop ARL wide communications and interaction, including regular science meetings among divisions.

1.12 Employ the WRF (both forecast and regional climate modeling), HYSPLIT, and CMAQ developments as a focal point for integration of surface energy budget network, N, Hg, precipitation chemistry and other measurement capabilities to develop enhanced and much more integrated research programs.

1.13 Continue to encourage scientists to publish their results in high quality journals.

1.14 Grow the scientific workforce with careful selection and nurturing of new, young scientists—explore ways to use post-docs as the entry point for new scientists.

1.15 Link the WRF improvements via the regional climate modeling program with ongoing wind energy and PBL research to yield simulation and forecast tools.

2: Air Quality Recommendations:

2.1 A closer relationship between HYSPLIT and the Eularian AQ forecasting system should be considered. There may be value in developing a more systematic strategy of linking the two models.

2.2 To link with the climate focus of NOAA, initiation of research on black carbon wet deposition is recommended

2.3 Continued efforts to strategically link AQ forecasting to weather forecasting for the benefit of both are encouraged

2.4 Better coordination, integration and communication between researchers within this area focused on different AQ parameters (O3, PM, Hg, N) could provide a more efficient means of addressing specific research questions.

2.5 ARL should ensure that all projects within the ARL AQ area have the opportunity to publish the results of their work, even if this means supplementing cooperator funding with NOAA funding for publication.

2.6 NOAA ARL should consider taking a leadership or co-leadership role in the analysis and summarization of monitoring data from automated instrumentation to measure speciated mercury in air concentrations, which is now available (NADP-AmNet), at the national or regional level.

2.7 The AQ group should dedicate at least some resources to identifying and producing high-value and high profile products from the large amount of available data from regional and national air and deposition monitoring networks

2.8 It would be useful if this group could focus on getting descriptions of research method development and testing, and other efforts out into the peer reviewed literature. However this is currently limited by their lack of technical support and their need to wear many hats in their job.

3: Atmospheric Dispersion and Boundary Layer Recommendations:

3.1 Encourage development of a more cohesive dispersion measurement and modeling research program by hiring a mid-career dispersion modeling lead for the FRD group

3.2 Provide for continuation and development of HYSPLIT by creating a larger and more distributed HSPLIT team with less reliance on single PI expertise.

3.3 The use of HYSPLIT by external organizations with varying degrees of expertise, especially during high-profile atmospheric release events, raises the question whether ARL should explore planning and executing model runs and providing model output products in addition to providing the model.

3.4 ARL should consider a small project, possibly by supporting a library sciences graduate student, to develop a system to better identify and archive publications by external organizations utilizing HYSPLIT.

3.5 Develop and maintain a 5-year laboratory-wide plan that provides for integration of modeling and measurement capabilities.

4: Climate Recommendations:

4.1 Inter group collaboration between the analysis, modeling and climate network instrument scientists should be expanded and used to create new opportunities, increased publication and visibility of all members.

4.2 The national and international leadership shown in the upper air analysis work should be extended to all data within ARL/NCDC (e.g. analysis of data from the CRN, NADP, AIRMon-wet, etc).

4.3 A much more robust use of the regional climate modeling (CWRF) as an assessment tool of regional climate impacts and the role of this in AQ studies should be encouraged.

4.4 Concrete goals should be enumerated on how ARL-Climate fits in the "lab in transition" processes. This can start with a clear definition of how the "PBL theme" as a cross-cutting theme will fit into the Climate strategy goals and plans.

4.5 The group is encouraged to take a pro-active stance in the overall NOAA climate services discussion and define its role with the planned reorganization

4.6 Expand or at least continue work related to changes in the climate of the planetary boundary layer

4.7 A stronger across-the-board publishing performance would enhance the scientific contributions of the climate group. This is also needed to establish a broader presence in national and international assessments and participation in prestigious groups. There are strong performers in this group but there are also some weak performers who may not be taking full advantage of publishing opportunities.

4.8 The current prominent position of the group in upper air research should be maintained as this will likely continue to be a critical issue for climate change detection and attribution