Air Resources Laboratory

ADVANCING ATMOSPHERIC SCIENCE AND TECHNOLOGY THROUGH RESEARCH




ARL
STRATEGIC PLAN
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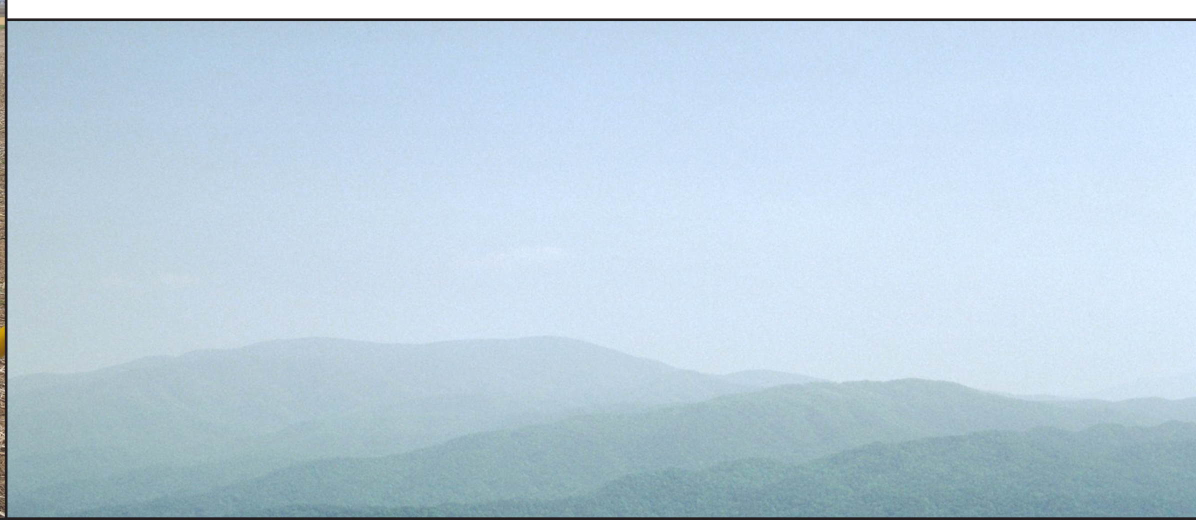

A Message from the Acting Director (Richard Artz)

The Air Resources Laboratory (ARL) began as a Special Projects Section of the US Weather Bureau in 1948. We are an applied science lab with a long history with dispersion, air quality, and climate studies, and have experienced many organizational changes while maintaining our scientific focus. Currently, we are one of seven federal research laboratories within the National Oceanic and Atmospheric Administration (NOAA) Office of Oceanic and Atmospheric Research (OAR), with a cadre of about eighty-five talented and dedicated scientists, engineers, and technicians working at the forefront of many important societal issues. Our science themes described in this Strategic Plan are direct outcomes of research pursued from the early days of the lab. From the dawn of the nuclear age, the lab has provided critical information on air-surface exchange and atmospheric transport and dispersion of hazardous materials. Concurrently, we began measuring and modeling climate relevant variables, recognizing potentially important changes in atmospheric composition and possessing the necessary skills to measure changes in the relevant variables. Using ever more advanced tools, our main focus areas reflect the needs of our constituents. There are still accidental or intentional releases of harmful materials to the air. Air pollution continues to be a major problem in many parts of the United States. And, changes in weather and climate continue to influence every sector of our society.

ARL has experienced massive change during the past two decades. Reorganizations within OAR, retirements of two long-serving directors, and changes in business practices between federal agencies forced the retrenchment of ARL. During the 2011 Laboratory Review, Director Steven Fine presented a revised path forward. The materials presented in this Strategic Plan refine and incorporate findings from the previous review and deliver a clear vision for ARL, reflecting priorities defined within NOAA's long term goals.

ARL makes its research products readily available to a wide range of customers via formal pathways into operational NOAA entities, as well as directly through web-based application systems, which serve broad national and international clientele. Through these products, ARL routinely serves two Department of Energy (DOE) nuclear facilities and has contributed to national response programs including Deep Water Horizon, the Eyjafjallajokull volcanic eruption in Iceland, and the Fukushima nuclear reactor disaster. We contribute to international climate assessments, the understanding of global mercury cycling and to the understanding of nutrient loadings to sensitive ecosystems. Multi-decadal agreements, a commitment to transferring products to operations, and a multitude of seminal publications in collaboration with many of our partners attest to the quality and service of ARL scientists to the science community.

When reviewing this document it is important to understand that the majority of our research is conducted through collaborative partnerships. In addition to the longstanding provision of meteorological support to DOE reservations in Idaho and Nevada, we maintain a strong partnership with the National Weather Service for ongoing emergency response dispersion programs and forecasting of ozone and fine particulate matter under the National Air Quality Forecasting Capability. ARL federal scientists are ably supported by various contractual arrangements, as well as a multi-decadal collaboration with Oak Ridge Associated Universities, and a highly productive collaboration with the Cooperative Institute for Climate and Satellites - Maryland that has flourished following our move to state-of-the art laboratory facilities in the M Square Research Park in College Park, Maryland. We work collaboratively with several NOAA line offices, as well as numerous academic, state, federal, and international organizations. Our programs are focused, top quality, and well integrated into NOAA's mission.

Introduction and Historical Context

The Air Resources Laboratory (ARL) is a research laboratory within the National Oceanic and Atmospheric Administration (NOAA) Office of Oceanic and Atmospheric Research (OAR). It is headquartered at the NOAA Center for Weather and Climate Prediction in College Park, Maryland and has Divisions in Oak Ridge, Tennessee; Idaho Falls, Idaho; and Las Vegas, Nevada. ARL's primary focus is on improving the understanding of the chemical makeup and complex behavior of the atmosphere.

ARL Vision

A world-renowned research laboratory highly regarded for its scientific accomplishments in atmospheric dispersion, atmospheric chemistry, climate observations and analysis, and boundary layer science.

ARL Mission

Provide the highest quality atmospheric and meteorological research and services to our partners, the research community, and society to protect human health and our environment.

ARL traces its origins back to 1948 when it was known as the Special Projects Section (SPS) of the U.S. Weather Bureau (now the National Weather Service or NWS). The SPS was located in Washington, DC and served as an interface between other federal agencies' needs for research and the meteorological products provided by the Weather Bureau. Dr. Lester Machta, Director of the SPS, was joined by four other meteorologists to engage in research utilizing meteorology to assist with the atomic energy and weapons activities at that time.

The SPS was among the first meteorological organizations to use meteorology to interpret air quality measurements and to contribute to assessments of hazards from the release of radionuclides and other pollutants to the atmosphere. These functions, conducted in a far more sophisticated fashion today, continue to be important facets of ARL's Research and Development Themes: Atmospheric Transport and Dispersion and Atmospheric Chemistry and Deposition.

In 1956, a U.S. Weather Bureau Research Station, the Mauna Loa Observatory (MLO), was dedicated. Beginning in March of 1958, the SPS began collaborating with Dr. Charles Keeling of the Scripps Institute of Oceanography to precisely monitor atmospheric concentrations of carbon dioxide (CO2) at the MLO in Hawaii. Efforts to measure CO2 and other physical and chemical species led ARL to the development of the global Geophysical Monitoring for Climatic Change (GMCC) program in the 1970s. The GMCC, with sites at MLO and three other remote locations, remained a part of ARL until the formation of NOAA's Climate Monitoring and Diagnostic Laboratory in 1989. The program continues in Boulder, Colorado and is presently referred to as the Global Monitoring Division (GMD) of NOAA's Earth System Research Laboratory. However, ARL scientists in Boulder continued their research in collaboration with other ARL scientists, as part of a total surface energy balance program. The surface radiation portion of the program was subsumed by GMD.

ARL continued its support for the GMCC program and other NOAA climate activities through analyses of climate records, including global upper-air temperature, stratospheric ozone, and U.S. cloudiness, becoming a leader in NOAA in climate variability and trends analyses. However, the climate science community recognized there was a lack of high quality surface or upper air data for climate analyses; this hampered the ability of climate scientists to fully characterize the national and regional climate signals with confidence. Many climate scientists believed that dedicated climate reference observing networks were needed, both to monitor climate change in situ and to calibrate measurements collected from other observing systems (e.g, satellites), to make data more suitable for climate work.

To improve the quality of surface data, ARL joined forces with NOAA's National Climatic Data Center, who had initiated a program in the late 1990s to have long-term (50-100 years), high-quality climate observing stations across the country. The U.S. Climate Reference Network now provides the nation with real-time observations of surface air temperature and precipitation and serves as a platform for additional measurements of solar radiation, relative humidity, wind speed, soil moisture and land surface temperature. These earlier climate research endeavors by ARL serve as the backbone for today's R&D Theme: Climate Observations and Analyses.

Over the course of many decades, ARL has maintained divisions around the country—often in collaboration with other federal partners, such as the U.S. EPA and the U.S. Department of Energy (DOE). At one time, ARL operated with up to six divisions across the country, including the programs managed out of the Headquarters office. Today, ARL has four divisions; two of them, located in the western U.S. , provide research support to the DOE.

Laboratory Structure and Functions

The R&D conducted by ARL over the past 65+ years is directed toward the protection of human health and the environment. This includes improving the understanding and/or prediction of serious societal issues, such as air pollution, airborne release and dispersion of harmful materials from accidents or through malicious intent, deposition of harmful materials onto our terrestrial and aquatic ecosystems, and changes in our climate. When necessary and where appropriate, ARL scientists work across locations to conduct research via atmospheric modeling, assessments, and field studies.

ARL Headquarters is collocated with the NWS's National Environmental Prediction Center (NCEP) and the National Environmental Satellite Data and Information Service (NESDIS) at the NOAA Center for Weather and Climate Prediction in College Park, MD. ARL Headquarters is composed of a talented group of scientists and technicians who develop and improve dispersion and air quality models; collect research-grade air quality and deposition measurements of select air quality parameters, and provide new products concerning climate variability and trends. Many products developed by ARL Headquarters augment the operational product suites of the NOAA service-oriented line offices, particularly the NWS. Other products are state-of-the art, web-based assessment tools that serve university researchers, federal research agencies, and international partners. Headquarters, on behalf of the entire Laboratory, also has a strategic research partnership with the Cooperative Institute for Climate and Satellites –Maryland (CICS-Maryland), one of NOAA's Cooperative Institutes, located at the University of Maryland, College Park. ARL scientists work cooperatively with CICS-Maryland on atmospheric research of mutual interest.

The Atmospheric Turbulence and Diffusion Division (ATDD) is located in Oak Ridge, Tennessee. It was first created in the 1950s as a research office of the U.S. Weather Bureau to study atmospheric dispersion characteristics of the Oak Ridge area. The research supported the Atomic Energy Commission's operations, as well as the emerging local nuclear industry. ATDD has highly qualified scientists and engineers conducting research on air-surface exchange of gases and particles, atmospheric dispersion and turbulence in the boundary layer, and climate reference observations. ATDD undertakes a variety of atmospheric studies across the U.S., as well as operates two permanent, long-term research stations: one at the Walker Branch Watershed forested experimental area, and the other at the Chestnut Ridge Environmental Study site. The ATDD is heavily supported by staff on assignment from the Oak Ridge Associated Universities.

The Field Research Division (FRD) is located in Idaho Falls, ID. FRD was created in 1948 as part of the U.S. Weather Bureau with the purpose of describing the meteorology and climatology surrounding the area of the National Reactor Testing Station, now known as the Department of Energy's (DOE) Idaho National Laboratory (INL). In a long-standing cooperative agreement between NOAA and DOE, FRD's highly skilled scientists and technicians use their capabilities to support the INL with meteorological measurements, mesoscale modeling and forecasts, and atmospheric dispersion modeling in the event of an accidental chemical or radiological emergency at the INL. FRD also carries out studies around the country; focused on improved understanding of atmospheric transport and dispersion, air-surface exchange of particles and gases, and boundary layer processes.

The Special Operations and Research Division (SORD) is located in Southern Nevada, at both the DOE National Nuclear Security Administration (NNSA) Complex in North Las Vegas and on the DOE/NNSA's Nevada National Security Site (NNSS). SORD was first established in 1956 as an office of the SPS working for the U.S. Weather Bureau to support the U.S. nuclear weapons testing program. The office remained with the U.S. Weather Bureau until it joined ARL in 1992 as a division. The NNSS is an expansive outdoor laboratory and experimental area that conducts hazardous chemical spill testing, emergency response training, conventional weapons testing, waste management and environmental technology studies, and other activities that focus on national security. Through a long-standing Inter-Agency Agreement with DOE and its predecessors, SORD's highly skilled and experienced professional and technical staff provide research support and applied meteorological activities, including atmospheric characterization and atmospheric transport and dispersion.

Research and Development Themes

ARL's R&D is conducted in four research areas with an emphasis on transitioning Research to Applications (R2A) within NOAA and to operations in other agencies. ARL also produces assessments and reports; publishes in the peer reviewed literature; and develops and operates internet-based applications and display systems. The R&D described in the first three research themes have been core facets of ARL since its beginning. The fourth research theme emerged around 2009 in recognition of the societal need for improved boundary layer predictions to address issues such as wind energy, aviation, fire weather, and severe storms. In large part, ARL's boundary layer research is built upon its existing tools and capabilities that had been developed for other purposes related to dispersion, atmospheric chemistry, and climate science.

The activities, described later in this plan, often encompass more than one research area, providing a more holistic view of the Earth system and/or establishing broader applicability of ARL's tools or approaches. ARL's four R&D Themes are:

Atmospheric Transport and Dispersion: Considers the release, transport, and dispersion of harmful materials through the air. The focus is typically on acute events; a limited number of chemical transformations; and a connection to emergency-type responses.

Atmospheric Chemistry and Deposition: Considers the emissions, transformation, transport, and fate of important atmospheric pollutants known to have an impact on human health and/or the environment. The focus is typically on specific pollutants that contribute to poor air quality; contribute to ecosystem decline; are associated with many emissions sources; and are significantly influenced by chemical transformations.

Climate Observations and Analyses: Concentrates on developing reference observing systems to meet climate requirements and analyzing long-term observational datasets and models to understand climate variability and change on diurnal to multi-decadal time scales.

Boundary Layer Characterization: Focuses on using state-of-the-art methods, techniques, and tools (and developing new ones as necessary) to better understand atmospheric boundary layer structure and processes in order to improve prediction of near-surface weather and climate conditions.

This Strategic Plan describes ARL's R&D goals, priorities, and select ongoing and emerging activities for the next five years. In identifying its goals and objectives, ARL considered NOAA's priorities, societal needs, input from stakeholders, and current and anticipated Laboratory capabilities and capacity. The goals, priorities, and activities described within each research theme were selected to optimize ARL's contributions to addressing key issues faced by society. They are aligned with those of the broader NOAA mission goals, the NOAA Five Year R&D Plan (2013-2017), and the OAR Strategic Plan (April, 2014).

Atmospheric Transport and Dispersion

The accidental or intentional release of chemical, biological, or nuclear agents, as well as ash associated with volcanic eruptions, can have significant health, safety, national security, economic, and ecological implications. Understanding and predicting how, where, and when harmful materials are atmospherically transported and deposited is essential for responding appropriately to protect the health and welfare of the public and emergency response personnel.

NOAA has a number of responsibilities, both nationally and internationally, for which ARL's Atmospheric Transport and Dispersion (ATD) prediction tools and guidance for using those tools are required and/or requested. These responsibilities include:

Partnership with the Interagency Modeling and Atmospheric Assessment Center, which is the designated federal point of contact identified in the Nuclear/Radiological Incident Annex to the National Response Framework, to provide atmospheric dispersion modeling.

Coordination with the International Civil Aviation Organization, to operate two of nine Volcanic Ash Advisory Centers that are responsible for coordination and dissemination of information on atmospheric volcanic ash clouds that may endanger aviation.

Coordination with the World Meteorological Organization (WMO) to operate a Regional Specialized Meteorological Center that provides information to the International Atomic Energy Agency about expected transport of radiation and to the Comprehensive Test Ban Treaty Organization about possible source regions of clandestine nuclear and/or radiological releases.

Support to local NWS weather forecast offices which provide dispersion predictions to local emergency managers dealing with an incident, such as a chemical spill or wildfire.

Support to the DOE's Idaho National Laboratory and Nevada National Security Site for consequence assessments. Consequent assessment in this instance is defined as the process of identifying or evaluating the potential for or actual effects of a release of radioactive materials or harmful chemicals.

In addition, needs for improved ATD tools are continually evolving, driven by demands for more accurate predictions, estimates of uncertainties, finer spatial resolution, easier-to-use tools, and tools to address evolving risks. For instance, in 2008 the U.S. Government Accountability Office recommended that the Secretary of Homeland Security "work with the federal plume modeling community to accelerate research and development to address plume model deficiencies in urban areas and improve federal modeling and assessment capabilities. Such efforts should include improvements to meteorological information, plume models, and data sets to evaluate plume models." Also, the large, complex incident at the Fukushima Daiichi facility highlighted multiple ways in which atmospheric dispersion predictions could be improved to better address incidents with ongoing, uncertain releases and that affect the oceans.

Many important decisions are influenced by ATD model predictions, including the deployment of emergency response resources, evacuation of the public, issuance of health advisories, identification of sources, and routing of vehicles. Results of ARL's ATD modeling are applied by NOAA's NWS and National Ocean Service (NOS); other U.S., state, local, and international agencies; universities; and the private sector. Some modeling capabilities are accessed through ARL's web-based Real-Time Environmental Application and Display sYstem (READY). Multiple federal agencies rely on ARL's atmospheric transport and dispersion modeling and meteorological field studies to support their prediction needs. For example, ARL provides ongoing NOAA support to DOE's INL and NNSS and collaborates with other agencies, such as the EPA and the Nuclear Regulatory Commission, concerning nuclear incidents. These divisions provide meteorological measurements, mesoscale modeling and forecasts, and atmospheric dispersion modeling capabilities in the event of an accidental chemical or radiological emergency. Capabilities are also used to provide site-specific weather data and forecasts and radiological and chemical plume dispersion modeling during regularly held emergency response exercises and drills.

Relationship to NOAA

ARL conducts its ATD R&D in support of the NOAA long-term goal, "Weather-Ready Nation: Society is prepared for and responds to weather-related events" and its objectives:

> "Reduced loss of life, property, and disruption from high-impact events", and
>
> "Healthy people and communities due to improved air and water quality services."

The R&D also supports NOAA's Science and Technology Enterprise objective:

> "An integrated environmental modeling system."

The R&D also seeks to address several questions in the OAR Strategic Plan (April, 2014), including:

> How are atmospheric chemistry and composition related to each other and ecosystems, climate, and weather?
> How can modeling be best integrated and improved with respect to skill, efficiency, and adaptability?
> What are the best observing systems to meet NOAA's mission?

ARL's Primary ATD R&D goal is to:

Improve the quality and understanding of ATD predictions and assessments, including estimation of uncertainties.

Included implicitly in this goal is the transition of ARL R2A within NOAA and at other agencies and organizations. To support this primary goal, ARL has identified four high-priority areas. Several, key activities are described within each priority, and some activities support more than one priority.

Priority 1: Improving Dispersion Modeling

The HYSPLIT model is the core of ARL's transport, dispersion, and deposition modeling capability. When provided with the appropriate meteorological fields, HYSPLIT can be applied to scales ranging from a kilometer to global. ARL's strength in transitioning research into operational products is shown via the support given to the NWS NCEP on operationalizing and improving the HYSPLIT model. ARL R&D on HYSPLIT will focus on the following activities:

- HYSPLIT computational improvements: General HYSPLIT improvements to computational performance, better representation of winds and turbulence on fine scales, and predicting dispersion in stable conditions.
- HYSPLIT functionality improvements: ARL recently collaborated with the NOS's Office of Response & Restoration (OR&R) to link HYSPLIT and the Areal Locations of Hazardous Atmospheres/Computer-Aided Management of Emergency Operations (ALOHA/CAMEO) model, providing a short-range transport tool for hazardous chemical releases. ARL will continue its work with OR&R to make needed improvements to this seamless and integrated modeling system for short- and long-range transport applications. In addition to HYSPLIT functionality improvements, other changes will be made based on end-user requests and any problems encountered. Also, support will be provided to the University Corporation for Atmospheric Research COMET® program responsible for updating the HYSPLIT training module to include this new capability.
- In-line dispersion model development: ARL will develop a version of the dispersion model that runs in-line with the prognostic meteorological model. This allows the dispersion model to access the meteorological fields at a much higher frequency than is available in the output files, which is expected to improve the quality of fine-scale predictions.
- Model uncertainty estimation: ARL will estimate the effect of uncertainties in source terms, meteorological fields, and ATD representations on plume predictions, which provides valuable information for decision-makers. ARL will investigate approaches for estimating ATD uncertainties, such as generating representative ensemble members for ATD applications.

Priority 2: Developing Decision Support Tools

The ability to quickly and accurately model dispersing plumes and assimilate available information is critical to decision makers for situations requiring rapid responses. In an emergency response environment, for instance, the user interface must minimize the amount of detail that a user has to supply manually while still producing an accurate simulation. To improve capabilities in this area, ARL will pursue the following activities:

- Communicating forecast uncertainty: ARL will investigate methods to display ATD prediction uncertainty so that it will not be confusing to decision makers. Uncertainties in ATD predictions need to be communicated to decision makers in a manner that is quickly and easily understood. There is no generally accepted approach for communicating uncertainties in dispersion predictions and this valuable information could have a significant impact on protective actions.

- Data assimilation of in-situ or remote measurements: ARL will conduct research to assimilate measured air concentrations and/or satellite retrievals of, for example, volcanic ash mass loadings, into model predictions to help in the estimation of the strength of an emission source, which is otherwise highly uncertain. ARL will apply assimilation techniques to radiological accidents and volcanic eruptions where accurate source information is one of the most critical aspects of the risk analysis.

- Decision support tool development: ARL will develop specialized source estimations approaches and/or unique displays for specific applications such as radioactive releases, volcanic ash, semi-volatile compounds (e.g., dioxins), smoke forecasting, and support for DOE sites.

Priority 3: Improving ground truth data for ATD model evaluations

Model evaluation is crucial for improving models and gaining confidence in the models. ATD models are typically evaluated by comparison of model output to measured tracer samples from field studies as the ground truth observation. In a typical tracer study, a gaseous compound is released and then its concentrations at different locations are measured. ARL will pursue the following activities:

- Tracer field studies: ARL will address issues that have arisen in estimating short-range dispersion based on limited field data from the 1950s and 1960s. ARL will conduct new field studies with modern instrumentation during several seasons to address some of the concerns with past research results. Tracer field studies provide essential data for evaluating and improving ATD models.

- Improved model evaluation methods: ARL will conduct further research to devise new statistical methods that recognize different sources of variability related to observed and modeled concentrations. Simple pairwise comparisons of observed and modeled concentrations fail to account for the differences in uncertainty in observed and modeled concentrations and therefore often lead to misleading results.

- Evaluations at shorter distances: Many shorter-range experiments (<10 km) have been conducted at FRD over the last 50 years. In conjunction with recent advances in high resolution meteorological modeling, ARL will incorporate these measurement data into a common database with the meteorological data for model evaluation and testing. This would provide an ideal testbed for evaluating the planned developments in linking HYSPLIT with WRF for in-line computations and linking the Gaussian plume model ALOHA with HYSPLIT.

Priority 4: Enhancing meteorological and decision support services for DOE

ARL's long standing partnership with the DOE has generated numerous advances in dispersion meteorology. These advances, which came during the years of the nation's nuclear weapons testing program, have mutually benefitted NOAA and DOE. Today, ARL leverages its partnership with DOE to continue to advance and evolve meteorology and atmospheric transport and dispersion in areas that benefit both the NOAA and DOE missions.

The ARL Divisions work together and with other NOAA Laboratories to share mesonet and boundary layer data, as well as host other national data collection platforms. ARL will enhance meteorological and decision support services for DOE through the following activities:

- Mesoscale model improvements: ARL will examine mesoscale model results unique to the Idaho and Nevada climates and explore improvements to the models that would improve forecast accuracy.

- Expand HYSPLIT model applications and capabilities: ARL will continue to integrate and expand HYSPLIT's capabilities to meet DOE's needs.

- Hazardous material consequence assessment: ARL will apply the mesonet collected to run routine dispersion model simulations for hazardous material releases to the atmosphere for emergency response decision support services.

- National security decision support services: ARL will apply the mesonet data and specifically collected data to support the safe conduct of unique national security experiments, which are to be used by DOE scientists to advance areas of national security.

- DOE site safety meteorological services: ARL will continue the long standing relationship with the DOE to provide comprehensive meteorology programs, including site specific weather surveillance, expertise, and advisement, in support of safe operations at the Idaho and Nevada DOE sites.

Atmospheric Chemistry and Deposition

Pollutants released into the air can impact air quality, as well as terrestrial and aquatic ecosystems when the pollutants deposit to Earth. Effective targeting of air pollution controls depends on having good scientific understanding of which specific pollutant sources and regions are contributing to air and water quality issues. It also requires assessing whether policies and regulatory actions achieved the desired outcome and whether new approaches are needed to protect public health and the environment.

Although air quality science has made great strides in advancing the understanding of atmospheric chemistry and air-surface exchange processes over the past several decades, significant uncertainties and challenges remain. Formation pathways and controlling processes of fine particulate matter ($PM_{2.5}$); emissions from large events such as biomass burning and dust storms; and atmospheric chemistry and air-surface exchange mechanisms remain poorly understood. A related challenge is the effective and efficient transfer of improved scientific understanding of physical, chemical, and biological processes into atmospheric models that can then be used for real-time air quality forecasting or longer-term ecological predictions and climate assessments.

ARL's Atmospheric Chemistry and Deposition R&D provides many benefits. Predictions from ARL-developed forecast models inform decisions by communities and individuals to take measures to mitigate episodes of poor air quality and their health impacts. Improvements in the quality of these models support reduced health risks and better targeted actions. Assessments of issues, such as the sources and fate of atmospheric mercury, inform policies and plans for mitigating contamination. ARL's studies of physical, chemical, and biological processes improve atmospheric chemistry models used for forecast assessments of important societal issues. Long-term monitoring of deposition provides essential information about the impacts of current environmental policies and the need for future mitigation strategies. In addition, ARL's development and evaluation of measurement approaches for nitrogen, mercury, and biogenic volatile organic compounds improves the quality and value of the observations taken by the entire air quality community.

ARL's Primary Atmospheric Chemistry and Deposition R&D goal is to:

Advance scientific understanding and predictive modeling capabilities of the emission, transport, chemical transformation, and air-surface exchange (including deposition and bi-directional processes) of air pollutants that impact human and ecosystem health.

Relationship to NOAA

ARL conducts its Atmospheric Chemistry and Deposition R&D in support of two NOAA long-term goals:

A Weather-Ready Nation, specifically the objective:

> "Healthy people and communities due to improved air and water quality services." and

Resilient Coastal Communities and Economies, specifically the objective:

> "Improved coastal water quality supporting human health and coastal ecosystem services."

The R&D also heavily contributes to the three objectives in NOAA's Science and Technology Enterprise:

> "A holistic understanding of the Earth system through research",
> "An integrated environmental modeling system", and
> "Accurate and reliable data from sustained and integrated earth observing systems."

The R&D also seeks to address the question in the NOAA Five-Year R&D Plan:

> "How are atmospheric chemistry and composition related to each other and ecosystems, climate, and weather?"

To support this primary goal, ARL has identified four R&D priorities. Several key activities are described within each priority.

Priority 1: Improvement in model predictions of PM and photochemistry

More accurate and reliable atmospheric chemistry models of particulate matter, ozone, and related compounds are necessary for improved air quality forecasting, assessment of trends in atmospheric composition, ecological impact prediction, and climate assessments. ARL will improve models through the following activities:

- Emissions estimates: ARL will investigate new approaches, primarily ones based on utilizing data that reduce uncertainties and/or capture emissions variations that are not properly reflected in existing approaches. For instance, scientists will use satellite observations to evaluate uncertainties in anthropogenic emissions and will improve estimates of emissions of dust and smoke from biomass burning. Anthropogenic and natural emissions are key inputs for accurate prediction and assessment of the concentrations and variability of air pollutants. Current approaches for estimating emissions have significant uncertainties and can be several years or more out of date or nonexistent.
- Identify and address sources of model deficiencies: ARL will continue to compare model results with observations, both routine and intensive, to identify biases or other deficiencies that significantly affect predictions of PM and ozone. Researchers will then work to address those deficiencies. This will include development and application of new parameterizations to address key issues, such as emission and oxidation of biogenic volatile organic compounds and resulting effects on O3 photochemistry, formation of the secondary organic aerosol component of $PM_{2.5}$, and surface-atmosphere exchange processes that affect both O3 and $PM_{2.5}$.
- Reanalysis of 3-dimensional PM and ozone: ARL scientists will develop and apply approaches that utilize state-of-the-art models, chemical data assimilation, and observations from multiple networks. Reanalysis fields are generated by conducting a simulation for a past period and using observations to guide the model towards the conditions that actually occurred. Reanalysis datasets are valuable for a number of applications, such as studying air quality impacts and initializing models, because they can provide spatially and temporally contiguous information, higher resolution than observations, and are connected to actual conditions.

Priority 2: Precipitation Chemistry

ARL provides support to national and international networks that measure the most abundant trace chemicals (referred to as "major ions") commonly found in precipitation. These substances include sulfur and nitrogen compounds, as well as chemicals found in soil and seawater. The primary products of these networks are high quality data sets of chemical fluxes made available on publicly accessible web sites and other venues as appropriate. These data sets inform evaluation and development of policies, plans, and models. ARL will pursue several activities for this priority:

- Lead the Global Atmosphere Watch: Under the auspices of the World Meteorological Program Global Atmosphere Watch Precipitation Chemistry Program, ARL will continue to lead a group of international experts to establish global measurement and analysis standards for major ions in precipitation, operate an ongoing global laboratory intercomparison program, and make data freely available by providing a portal to well established program archives and to an online archive of data from emerging nations.
- Collect high quality observations: ARL will continue to support the collection of daily precipitation chemistry data as part of the Atmospheric Integrated Research Monitoring Network to anchor and evaluate broader observing networks.
- Conduct precipitation chemistry analyses and assessments: ARL will conduct and/or participate in analyses and assessments of national and/or international precipitation chemistry data sets to inform policy and to evaluate broader observing networks measurement communities. Information from these assessments will be used to help guide future investments in support of emerging issues associated with chemical cycling.

Priority 3: Mercury Monitoring and Studies

To address significant uncertainties in the amount of atmospheric mercury deposition to sensitive ecosystems and the sources of that mercury, ARL will pursue several complementary activities.

- Long-term mercury monitoring sites: ARL will operate a small number of stations for the long-term monitoring of mercury and related species (typically common primary and secondary gaseous pollutants). The long-term data records are used to directly measure or infer the exchange of mercury between the surface and the atmosphere; better understand and characterize the natural and anthropogenic sources of atmospheric mercury species; detect trends in atmospheric concentrations of mercury; elucidate the chemical and physical processes governing the transport and fate of emitted mercury; and provide data for the evaluation of atmospheric mercury models. Based on its mercury monitoring experience, ARL has helped lead the formation of NADP's Atmospheric Mercury Network (AMNet) for measuring ambient mercury using consistent approaches. These efforts will be expanded to address key measurement uncertainties for gaseous oxidized mercury (GOM) and advanced measurement techniques.
- Intensive mercury field studies: ARL will conduct or contribute to intensive, process-level studies aimed at resolving key questions surrounding the transport, transformation, and fate of mercury species in the atmosphere.
- Mercury modeling: Building on measurements and insights from field work by ARL and others, ARL will improve its mercury model and apply it to produce robust, policy-relevant information (e.g., source-attribution for atmospheric deposition). Potential improvements include incorporation of new bromine chemistry, better methods of providing concentrations of key reactants (e.g., hydroxyl radical) to the model, and a more realistic simulation of surface-exchange processes. In addition, modeling efforts will be used to interpret long-term data sets collected at the surface.

Priority 4: Reactive Nitrogen Research

An overabundance of nitrogen results in a number of harmful environmental conditions (e.g., acidification in coastal waters and reduced biodiversity in forests) that can negatively impact communities. Ammonia, the dominant form of reduced reactive nitrogen, readily deposits from the atmosphere under certain conditions, but exchange rates are highly uncertain and difficult to model over time and distance. ARL will conduct the following activities:

- Chemical processes research: ARL will investigate the processes that influence the transfer of reactive nitrogen to aquatic and terrestrial ecosystems, with a focus on measurement of ammonia air-surface exchange in agricultural regions and coastal areas. Results will provide information to improve emission estimates and modeling capabilities on local and regional scales.

- Integrate chemical measurement studies: ARL will better integrate measurement studies to include multiple forms of reduced and oxidized reactive nitrogen compounds because the abundance of these compounds and their impact on the environment fluctuates temporally and spatially.

- Quantify organic and inorganic reactive nitrogen in the environment: ARL will investigate the development of techniques to quantify organic forms of reactive nitrogen, in addition to refining methods for inorganic nitrogen.

- Support air quality modeling: ARL will work to incorporate inorganic and organic reactive nitrogen data into air quality modeling efforts conducted by ARL, other NOAA labs, and academic partners.

Climate Observations and Analyses

Weather and climate influence every sector of society. Changes in the climate can influence economic prosperity, human and environmental health, and national security. Citizens, communities, businesses, governments, and international organizations are demanding climate information and products to cope with climate variability and to adapt to and mitigate climate change.

ARL's Climate Observations and Analyses research provides essential information for decision-makers to understand how and why climate has changed and what changes might occur in the future. National and international climate scientists and decision-makers use ARL's information to understand climate trends and variability and the need for mitigating and adapting to climate change. Better data makes for better decisions now and in the future.

Relationship to NOAA

ARL's Climate R&D contributes to the NOAA strategic goal "Climate Adaptation and Mitigation: An informed society anticipating and responding to climate and its impacts" and to the following associated objectives:

"Improved scientific understanding of the changing climate system and its impacts", and
"Assessments of current and future states of the climate system that identify potential impacts and inform science, service, and stewardship decisions."

The R&D also contributes to advancing the NOAA Science and Technology Enterprise Objectives:

"A holistic understanding of the Earth system through research", and
"Accurate and reliable data from sustained and integrated earth observing systems"

The R&D seeks to address several questions in the NOAA Five-Year R&D Plan (2013-2017), including:

What is the state of the climate system and how is it evolving?
What causes climate variability and change on global to regional scales?

ARL's primary goals are:

Advance understanding and assessment of climate change through analysis and evaluation of atmospheric observations and models

Improve the network of global climate observing system measurements

To support these goals, ARL has identified two high priorities within each goal. Several, key activities are described within each priority.

Goal 1: Advance understanding and assessment of climate change through analysis and evaluation of atmospheric observations and models

Priority 1: Air-surface interaction studies

Observation-based studies will provide the basis for improving the understanding of important climate-related physical and chemical processes. Within this priority, ARL will focus on the following activities:

- Maintain energy, water, and CO_2 flux measuring observing systems: ARL will maintain sites to measure energy, water, and CO_2 fluxes and analyze their relationships. Future work with the OAR Earth System Research Laboratory Global Monitoring Division may result in integrated measurement sites that include both detailed physical and radiation flux measurements to provide a more holistic understanding of the relationship of climate and the land surface. A predictive understanding of the surface energy budget and related feedbacks for the most dominant ecosystems is critical to the understanding of climate forcing factors at the land surface and the ability to credibly predict future conditions, especially those related to water resources.

- Trace gas measurements for climate change in melting permafrost regions: ARL and academic partners will address significant uncertainties in methane emissions from thermokarst lakes and surrounding regions by conducting aircraft- and land-based field studies. This information will help climate modelers predict the Arctic soil's contribution to climate change.

- Determining the soil water budget: ARL will create a database of soil characteristics measurements. With observations of soil moisture from NOAA's U.S. Climate Reference Network (USCRN) and energy and carbon fluxes from co-located Surface Energy Balance Network towers, evaluations of current Land Surface Models can be made and improvements in components that govern soil-plant-atmosphere interactions can be made in the models. Data analyses of the various observations and associated processes brings a special insight into how these various processes can be efficiently and accurately represented in both synoptic and longer term models.

Priority 2: Analyses of atmospheric climate variability and change

Changes in atmospheric conditions above the vicinity of the surface can be important indicators of climate change, and patterns of change can help in attributing climate change to specific causes. ARL has particular strengths in analyzing variability and change in the atmosphere, from the boundary layer through the stratosphere, collecting and analyzing upper atmospheric measurements, with emphasis on atmospheric temperature, stability, and circulation and on clouds. ARL R&D for this priority will focus on the following activities:

- Free troposphere and stratosphere investigations: ARL will conduct investigations of stratospheric temperature changes on multiple time scales, including sudden stratospheric warmings. ARL will also pursue additional work to clarify uncertainties in tropospheric temperature trends. Improved understanding of stratospheric temperature variability clarifies the natural and anthropogenic causes of climate change as well as the mechanisms by which the stratosphere can affect surface climate.

- Analyze cloud records: ARL will conduct studies aimed at improving and analyzing the record of past cloudiness derived from ground observations and comparing that record to other sources of related information. Changes in clouds can have large effects on the radiative balance of the climate system and are a major factor in uncertainties surrounding climate system sensitivity to radiative forcings. Our knowledge of past changes in cloud cover is nevertheless limited by large observational uncertainties.

- Develop a climatology of atmospheric constituents: ARL will develop climatologies of dust and/or other key constituents. Key atmospheric constituents, such as dust, are affected by and affect climate. Understanding past behavior is important for understanding the climate system.

Goal 2: Improve the network of global climate observing system measurements

Understanding and addressing issues affecting climate observations is critical to being able to confidently assess and predict climate variability and change. One component of this is establishing and maintaining climate reference networks that provide highly accurate and reliable observations of key essential climate variables to anchor the broader global climate observing network. To address such issues, ARL will pursue the following priorities:

Priority 1: Advance the quality and quantity of reference observations

Adequate monitoring of climate change and variability is dependent on long-term, high-quality climate records to constrain and calibrate data from more spatially-comprehensive global observing systems. ARL participates in reference climate networks, both at the Earth's surface and aloft. ARL plans to conduct the following activities:

- Surface networks: ARL is responsible for the design, testing, and evaluation of instruments and the establishment and maintenance integrated measurement platform for NOAA's USCRN. ARL will continue to evaluate the quality and reliability of the USCRN measurement system and will also identify approaches to meet outstanding measurement requirements, such as how to maintain reliable observations in harsh and remote Arctic locations.

- Support the GCOS (Global Climate Observing System) Reference Upper Air Network or GRUAN: ARL will provide leadership in guiding the full implementation of the international GRUAN. Existing upper-air observing systems (ground-based and satellite-based) were developed for observing weather and do not meet the needs of long-term climate monitoring and research. Under the auspices of the GCOS, GRUAN has been established to provide high-quality, long-term observations, traceable to international measurement standards and with complete uncertainty estimates. ARL's research has been instrumental in demonstrating the need for such a network and continues to help define the details of its design and operation.

Priority 2: Evaluate observing systems for climate studies

ARL will also continue to evaluate selected observing systems for their ability to satisfy ongoing and evolving climate requirements. This will include the following activities:

- Evaluate climate instruments: ARL will evaluate selected instruments to characterize their ability to measure essential climate variables. ARL is co-leading the World Meteorological Organization (WMO) Solid Precipitation Experiment Intercomparison (SPICE), which is designed to develop transfer functions between the various solid precipitation gauge configurations. This will improve estimates of liquid water equivalent snowfall in support of real-time applications, hydrological models and data continuity in the climate record. ARL will also evaluate the impact of the instrument's location (e.g., proximity to the built environment) on measurements.

- Support satellite calibration/validation: ARL and its collaborators will use aircraft measurements at selected USCRN sites to quantify the spatial variability and representativeness of the single-point skin temperature measurement already being made at the USCRN sites. ARL will also provide more accurate ground-truth data to improve satellite infrared skin temperature measurements. Skin temperature, also known as Land Surface Temperature (LST) over land masses, is an important climate variable and is related to surface energy balance and the integrated thermal state of the atmosphere within the planetary boundary layer. The validation of satellite-derived LSTs with ground measurements is a challenging problem because of the heterogeneity of land surfaces both in temperature and emissivity.

Boundary Layer Characterization

The Planetary Boundary Layer (PBL) is the mixed layer of the atmosphere directly influenced by the Earth's surface. It has a significant influence on a number of important atmospheric and environmental issues, including the dispersion of airborne hazardous materials, low-level winds and turbulence which affect wind energy production and transportation, initiation of convection which affects aviation, evolution of hurricanes, air quality, regional climate changes, the transfer of compounds between land/water and the atmosphere, and the behavior of wildland and agricultural fires and the smoke they produce. ARL's PBL research and development provides essential information and tools for improving the characterization and prediction of those issues. The purpose of this research is to improve understanding of key boundary layer processes necessary to address issues of contemporary concern.

Weather and climate models require realistic parameterizations of the PBL if they are to make accurate forecasts of conditions near the surface where people live. These parameterizations can be complex, since the surface characteristics are highly variable over time and space. PBL parameterizations may include detailed information about such things as plant canopies, snow physics, and even building effects in urban areas. Existing parameterizations typically were developed from idealized experiments over homogeneous surfaces; their applicability to heterogeneous surfaces is questionable. Often the parameterizations require inputs that may be difficult to obtain, such as soil water content. ARL has an active program to better understand PBL structure and improve the modeling of this layer. These activities sometimes have a narrow focus such as wind energy or issues associated with convective initiation, but general improvements in PBL modeling also directly contribute to ARL's other research themes.

Relationship to NOAA

ARL conducts its Boundary Layer Characterization R&D primarily in support of NOAA's long-term goal:

A Weather-Ready Nation—Society is prepared for and responds to weather related events. Specifically the following two objectives:

> "Reduced loss of life, property, and disruption from high-impact events" and
>
> "A more productive and efficient economy through environmental information relevant to key sectors of the U.S. economy."

The R&D also seeks to address a key question in the NOAA Five-Year R&D Plan:

> "How can we improve forecasts, warnings, and decision support for high-impact weather events?"

ARL's Primary Boundary Layer Characterization R&D goal is to:

Improve our understanding and modeling of the structure of the PBL.

To support this primary goal, ARL has identified four R&D priorities. Several key activities are described within each priority.

Priority 1: Convective Initiation (CI) research

There are two goals for the CI project: 1) develop a probabilistic 0-6 hour product using machine-learning approaches operating on real-time observations and 2) improve the numerical models that predict CI. Activities to be conducted in the next five years include:

- Field experiments: Through partnerships with OAR/ESRL and the University of Alabama Huntsville, ARL will collect key observations used to validate model predictions of convection and surface fluxes. The data will also complement a training database of actual CI occurrences and identify critical surface and boundary layer processes associated with CI.

- Improvements to forecast models: ARL will collaborate with other NOAA groups to evaluate the current land-surface and PBL parameterizations used in existing forecast models such as HRRR, and suggest enhancements to the existing parameterizations to better capture convective initiation events in the southeast.

Priority 2: Wind energy research applications

Wind energy research has recently become an additional focus of ARL due to collaboration requests with partners. An example of this is a signed Cooperative Research and Development Agreement (CRADA) with Duke Energy in 2010 to partner on wind energy research. This partnership has yielded improvements in wind forecasts. The main activity to be conducted over the next five years is:

- Participating in the Wind Forecast Improvement Project (WFIP): ARL will continue its partnership with OAR/ESRL and DOE in WFIP Phase 2, which is to be conducted in the Columbia River Gorge. This will include the deployment of a wind profiling radar, sodars, 3-D sonic anemometers and an eddy covariance flux and surface energy balance system in a wind farm environment. ARL will also provide analysis of the results.

Priority 3: Application of ARL mesonets for use as testbeds for PBL research

ARL maintains meteorological observation networks (mesonets) in Idaho and Nevada through long-term partnerships with the Department of Energy (DOE). These mesonets support the safe operation of DOE facilities, including assessments of consequences from releases of hazardous materials. The activities to be conducted in the next five years include:

- Mesonet upgrades: ARL will upgrade its mesonets to provide critical PBL observations. The Idaho mesonet will start collecting surface (skin) temperature, the short- and long-wave components of net radiation, and better observations of PBL depth. The Nevada mesonet will be completely updated and standardized to include new towers, data loggers, and additional instrumentation to measure three dimensional wind, turbulence, and solar radiation. SORD will install a new SODAR (SOnic Detection And Ranging) and upgrade the radiosonde balloon launching capability.
- Evaluate and improve WRF and HRRR models: Once the upgrades are complete ARL will use the data from the enhanced mesonets to evaluate and improve the PBL parameterizations used in forecast models. Particular emphasis will be placed on the NOAH and RUC land-surface parameterizations, since they are both used in operational NOAA forecast models. ARL will seek to improve model performance in dry environments; current parameterizations show specific weaknesses in forecasting night-time temperature and humidity.

Priority 4: Wind flow in complex terrain

Boundary layer flows in complex terrain commonly deviate from the assumptions used to describe and model flows in more homogeneous, idealized situations. There is a critical need for high resolution spatial and temporal data sets of winds and turbulence in mountainous terrain. Existing datasets are very limited. Over the next five years, activities will include:

- Birch Creek Valley Project: ARL will collaborate with partners, such as the US Forest Service (USFS) and Washington State University (WSU), to pursue measurements of wind and turbulence to analyze the structure of the boundary layer in complex terrain.
- Project Sagebrush: ARL will collaborate with WSU in the instrumentation of an ARL tall tower to aid research in atmospheric dispersion and intermittent nocturnal turbulence.
- Diagnostic wind field modeling: ARL will evaluate diagnostic wind field models using mesonet observations from the Nevada mesonet.

Research Partnerships

ARL has collaborative research partnerships with other OAR Laboratories and Programs; other NOAA Line Offices; other federal agencies; other countries and international agencies; universities; non-governmental organizations; and industry. These partnerships are instrumental to ARL for the day to day operations and for ongoing multi-decadal projects, as well as for identifying emerging projects.

Partnerships fundamental to day-to-day operations are with:

- the NWS for ongoing emergency response dispersion programs and forecasting of ozone and fine particulate matter under the National Air Quality Forecasting Capability;

- the Cooperative Institute for Climate and Satellites-Maryland for air quality programs supporting R2O with the NWS;
- the Oak Ridge Associated Universities, providing technical support for climate and dispersion applications;
- the DOE, providing dispersion and meteorological support to their facilities in Idaho, Nevada, and occasionally at other DOE facilities.

Partnerships with organizations for ongoing, multi-decadal projects are listed below within each research theme.

- Atmospheric Transport and Dispersion: Department of Defense; NOAA's NWS, National Ocean Service, and National Environmental Satellite, Data, and Information Services; and the World Meteorological Organization.
- Atmospheric Chemistry and Deposition: Global Atmosphere Watch of the World Meteorological Organization; U.S. EPA; National Atmospheric Deposition Program; state agencies; and various academic institutions (e.g., University of Delaware, University of Illinois, Pennsylvania State University, Cornell).
- Climate Observations and Analyses: Research partnerships are ongoing with OAR's Geophysical Fluid Dynamics Laboratory and Earth System Research Laboratory; NESDIS and NWS; NASA; universities (e.g., NCAR, University of Maryland, Colorado State, University of Colorado); other countries (e.g., China and the United Kingdom); and the private sector (e.g., Belfort).
- Boundary Layer Characterization: OAR's Earth System Research Laboratory; U.S. Forest Service; Duke Energy; universities (e.g, University of Alabama, University of Washington). Emerging partnerships are with various Department of Defense organizations and with the Quantitative Observing System Assessment Program, a joint effort across multiple NOAA institutions designed to quantify the effectiveness and utility of current and future observation systems.