Research products, information and services, and an assessment of their impact by end users

ARL has developed several research products and provided numerous kinds of information and services to a variety of users. The items described below are primarily for the period 2000 – 2010.

Assessments

ARL actively contributes as authors and reviewers to national and international scientific assessments, such as the Intergovernmental Panel on Climate Change, the U.S. Global Change Research Program synthesis and assessment products, the World Meteorological Organization/United Nations Environment Programme (WMO/UNEP) Scientific Assessments of Ozone Depletion, and various SPARC (Stratospheric Processes and their Role in Climate) Assessment Reports. National and international climate scientists and decision-makers use this information to understand climate trends and the need for mitigating and adapting to climate change. By comparing model simulations of past climate changes with observations, scientists can better assess the validity of model projections of future climate changes. For more information about these assessments, please review the Laboratory Review poster: ARL Contributions to National and International Scientific Assessments by Angell, Free, and Seidel.

ARL serves as Chair of the WMO Global Atmosphere Watch (GAW), Science Advisory Group for Precipitation Chemistry. With this international group of precipitation chemistry experts, ARL has contributed as an author and reviewer to the development of a Guidance Manual for the GAW Precipitation Chemistry Program (2004) and to the development of a global precipitation chemistry assessment (in progress). The assessment will be based on a quality assured global deposition data set. This initial assessment and the accompanying data set are widely sought after for global air quality and climate modeling studies.

Hardware

ARL has long been involved in the development of advanced turbulence instrumentation for aircraft platforms. The latest result of this work is the Best Aircraft Turbulence (BAT) probe. This probe was originally deployed on a small experimental research aircraft operated by ARL, but has since been adapted for a variety of aircraft operated by universities and government entities in the United States, Europe, and Australia. In addition, a special aluminum version of the BAT probe was developed for deployment on the NOAA WP-3D Orion aircraft. These hardened probes were used to obtain measurements of turbulence and fluxes in the hurricane boundary layer. More recently, an offshoot of the BAT probe effort is the development of a ground-based instrument called the Extreme Turbulence (ET) probe. ARL's ET probe uses the same basic principals as the BAT probe but is designed to be deployed at a fixed location on land or sea to measure turbulence and fluxes in hurricane conditions.

ARL has a long history of using altitude controlled balloons to aid in dispersion and air quality

experiments. Recent ARL adaptations of the balloons have allowed scientists to monitor ground-level ozone in the 2004 New England Air Quality Study and around the Houston area during the 2006 Texas Air Quality Study. Another adaptation currently being developed, uses the balloons for hurricane forecast improvements. These balloons will provide very low altitude (50 meter above sea level) real-time meteorological information in data-sparse areas of the ocean where hurricanes develop. For a better look at this product, please review the ARL News article: http://www.arl.noaa.gov/balloon_launch.php

Data Sets

ARL provides comprehensive datasets of energy and carbon fluxes to both national and international networks (e.g., Ameriflux, Fluxnet, and the Global Energy and Water Cycle Experiment). These data are also used by the NOAA National Centers for Environmental Prediction (NCEP) land-surface modeling team to evaluate, test and improve the land surface schemes currently part of the NOAA suite of models.

ARL developed data sets containing fluxes of mass, momentum, and energy, and ancillary data for the Boreal Ecosystem-Atmosphere Study (BOREAS), the Vertical Transport and Dispersion Experiment for the Southern Great Plains (1997) and in Salt Lake City (2000), and for the Mid-Continent Carbon Budget Experiments (2005 and 2006). These data sets demonstrated the viability of airborne flux sampling and the representativeness of fixed flux sites in heterogeneous landscapes.

ARL developed the Air Stagnation Index over the U.S. continent so that the relationships between air quality and climate could be studied. A climatological atlas of the index was published in 1999, and has been widely used by numerous scientists and professors in their physical geology college education courses. This index was made operational at NOAA's National Climatic Data Center in 2003, and monthly products are available from 1973 to the present at the following address: http://www.ncdc.noaa.gov/societal-impacts/air-stagnation.

ARL makes several different kinds of climate variability and change analysis datasets available to the research community and the general public. These are all based on peer-reviewed studies. A summary may be found at: http://www.arl.noaa.gov/CVCAnalysis_datasets.php. By making these available, ARL allows other scientists and the public to test the reproducibility of ARL's published results and to further enhance understanding of the climate system by using our quality-controlled datasets in other studies. ARL makes the data available through various mechanisms. Some of the datasets are provided to NOAA's National Climatic Data Center for archival, dissemination, and real-time updates. Others are made available through the journals, as supporting material for the papers based on these data; while others reside on our website or at specialized data centers.

ARL developed high-quality data sets of chemical fluxes and concentrations using the ARL Atmospheric Integrated Research Monitoring Network data from 1984 to 2006. ARL also developed high-quality data sets of reactive nitrogen fluxes following the 2010 Atmospheric Deposition of Ammonia (ADAM) and CalNex experiments. ARL coordinates closely with the U.S.

Department of Agriculture (USDA) and the U.S. Environmental Protection Agency (EPA) to provide improved measurement techniques for air-surface exchange of reactive nitrogen. These datasets have been made available via the National Atmospheric Deposition Program web page and provide estimates of dry and, in some cases, total deposition to the scientific community.

ARL provides data from the DCNet program. DCNet is an ARL research program, taking place in the National Capitol Region, whereby meteorological measurements for temperature, wind speed and direction, as well as measurements of atmospheric turbulence, are used to address the difficulties associated with routine weather observations and atmospheric turbulence within the complexity of an urban environment. The DCNet data are used primarily by the Pentagon Force Protection Agency's (PFPA) Pentagon Shield and the Naval Research Laboratory (NRL). The DCNet observations are a critical component of the National Atmospheric Release Advisory Center's support to Homeland Security for the National Capital Region. Beginning in 2007, data have been routinely transmitted to the NOAA Meteorological Assimilation Data Ingest System (MADIS); where MADIS handles the data management. Prior to 2007, ARL tracked approximately 400 DCNet data users.

ARL maintains a world-class capability to manage the release and detection of nontoxic atmospheric tracers using technology that has evolved from initial studies conducted in the 1960s. This capability was most recently exercised following the September 11, 2001 terrorist attacks. ARL was invited to join field studies in Oklahoma City, New York, and Washington D.C. to assess the dispersion of hazardous materials in urban environments. Analyzed data from these studies have been used to improve emergency-response systems developed by the Departments of Homeland Security and Defense.

ARL has also collaborated with the EPA in conducting tracer studies to improve regulatory dispersion models. Most recently a study was undertaken to determine the effect of roadside sound barriers on dispersion of vehicle emissions from major highways into adjacent neighborhoods. The data are being used to improve AERMOD, an EPA regulatory modeling system. AERMOD incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain.

ARL produced a North American atmospheric mercury emissions data set for early 1999 and 2002, based on data from the EPA, Environment Canada, and the Commission for Environmental Cooperation. Speciation, classification, QA/QC and other value-added information has been added to the dataset in support of model input requirements and emissions mapping.

In support of the Grand Bay Intensive mercury field study carried out during the summer of 2010, a system was designed and implemented to produce a daily forecast product to aid in scientific mission planning (e.g., for aircraft flights and sonde launches). The product included specialized maps and tables of meteorological variables, regional back-trajectory analyses, and anthropogenic mercury plume information.

Information & Services

ARL has been providing climatological, dispersion and mesoscale meteorological advice and expertise to the Department of Energy (DOE), Idaho National Laboratory (INL), and its predecessors for over 60 years. In 2007, NOAA's relationship with DOE was formalized with a Memorandum of Agreement that established the NOAA/INL Meteorological Research Partnership. Through this agreement, ARL scientists serve on a number of guidance committees and panels. The scientists also continue to provide guidance on meteorological issues, including local climatology, weather, and dispersion.

ARL has been providing research, information, services, and tools in meteorology since 1956 for the DOE Nevada National Security Site (NNSS). Currently in the second year of its latest 5-year Interagency Agreement, scientists collect and analyze data to support the safety and security of people and property, climate studies, air quality studies, complex wind flow studies, and emergency response plume dispersion. In addition, a mobile upper air data capability collects data on and off the NNSS for the support of national security experiments.

Models

HYSPLIT Dispersion Model

ARL developed the Hybrid Single-Particle[i] Lagrangian Integrated Trajectory Model (HYSPLIT), a complete system for computing simple air parcel trajectories to complex dispersion and deposition simulations. The model can be run interactively on the web through the Real-time Environmental Applications and Display sYstem (READY) or the code executable and meteorological data can be downloaded to a Windows or Mac PC and run using a graphical user interface. The model code is made available to other organizations (government and academia) in order to facilitate improvements to the model through collaborative research and development efforts or for operations. Since 2004, ARL scientists have provided a yearly workshop on the practical use of the model for air quality analysis and forecasting to small groups of users.

ARL established a HYSPLIT web page in Spain, in part to serve as a backup to the ARL READY server. See http://www.ciecem.uhu.es/HYSPLIT. The web page allows users to calculate trajectories and concentrations using the HYSPLIT model. It also shows the results of the modeled dust and arsenic concentrations calculated using HYSPLIT.

ARL conducts supporting research to improve volcanic ash dispersion forecasts and transfers new or updated dispersion capabilities to operations at the NOAA National Weather Service (NWS). An ARL meteorologist is a member of the Office of the Federal Coordinator for Meteorology (OFCM) Working Group for Volcanic Ash which, in part, oversees the National Volcanic Ash Operations Plan for Aviation. ARL also supports the U.S. representative to the International Civil Aviation Organization (ICAO) International Airways Volcano Watch Operations Group. HYSPLIT forecast trajectories were included in the NWS volcanic ash

coordination page (http://pafc.arh.noaa.gov/volcano.php) during the 2009 eruptions of Redoubt in Alaska. The trajectories were shown on one of the local Anchorage TV stations.

A wind-blown dust emission algorithm was developed by matching the frequency of high Aerosol Optical Depth (AOD) events derived from the MODIS Deep Blue algorithm with the frequency of friction velocities derived from the NCEP North American Mesoscale (NAM) model. The threshold friction velocity is defined as the velocity that has the same frequency as the 0.75 AOD. The AODs are converted to an emission flux which is used to compute the linear regression slope of the flux to the friction velocity. The slope represents the potential of a particular land surface to produce airborne dust and in combination with the friction velocity is used as a predictor for wind-blown dust emissions. At present the forecast model is run daily for the U.S. in preparation for transfer to operations in the NWS.

The HYSPLIT model can be run to estimate the spatial and temporal evolution of smoke (as fine particulate matter —$PM_{2.5}$) originated from a wildfire or prescribed burn. The location and the area of the burn are the only required inputs. $PM_{2.5}$ emissions and heat release are estimated from the emissions processing portion of the U.S. Forest Service's (USFS) BlueSky smoke modeling framework based on fire size and location. BlueSky is a fire and smoke prediction tool that was originally developed for land and air quality managers to assist with wildfire containment and prescribed burning decisions while at the same time attempting to minimize impacts of the smoke on the local population. The USFS system links together models of fire characteristics, meteorology, emissions estimation, smoke dispersion, and graphical display of output products. The ARL adaptation of BlueSky uses its emissions estimation component, which consists of the Emissions Production Module integrated with the CONSUME model, and the National Fire Danger Rating System fuel loadings database. The BlueSky emissions module currently has capabilities to create emissions for CO, CO_2, CH_4, Non Methane Hydrocarbons (NMHC), PM, $PM_{2.5}$ and PM_{10}. ARL's implementation incorporates only the $PM_{2.5}$ emissions for the predictions; however, the incorporation of multiple species is being tested for implementation in future versions. NOAA currently uses the Smoke Forecasting System to predict the transport and dispersion of wild fire smoke over the United States, Alaska, and Hawaii.

The HYSPLIT atmospheric dispersion model has been modified to improve the simulation of the fallout from a low-yield (<50 kT) nuclear device. This new simulation capability is now available to the local NWS Weather Forecast Office (WFO) for evaluation, feedback, and familiarization on the NOAA ARL web site. This product adds an additional capability to the suite of ARL products available to the NWS WFO in responding to requests for weather and dispersion model product support from local emergency managers. The radiological model defines 65 particle size bins, five for noble gases and the remaining 60 for particles of various sizes (typically 35 to 425 um). A unit source of radioactivity is initially distributed in six layers using approximately 24,000 particles to represent the nuclear cloud with the top layer varying according to the magnitude of the detonation. In a post-processing step, the model's dilution and deposition factors are converted to a dose rate by specifying the actual yield and the fission reaction (U235 or Pu239) type based upon dose conversion factors integrated over all 212 radionuclide fission products. The program also determines the decayed inventory for the

concentration averaging period, so the user can specify a different time of decay in order to obtain the dose at another time.

ARL has developed a high-resolution forecast system for Southeast Idaho based on the Advanced Research WRF mesoscale model. This system downscales from the NOAA Rapid Update Cycle model and provides rapidly updated forecasts used by the DOE Idaho National Laboratory. It is also used together with the HYSPLIT dispersion model to generate high-resolution dispersion forecasts. More information may be found at http://www.noaa.inel.gov/capabilities/modeling/mesoscale.htm

A high resolution mesoscale forecast modeling system has been developed by ARL for the desert Southwest U.S., centered over southern Nevada. The system is based on the Advanced Research WRF mesoscale model and is initialized with NOAA North American Mesoscale (NAM) model data that includes our local NNSS mesonet data ingested through MADIS. The southwestern U.S. WRF model is used in conjunction with the HYSPLIT model to produce forecast dispersion forecasts for NNSS. These products are made available internally to NNSS.

ARL has developed a research version of the HYSPLIT model for simulating atmospheric mercury (HYSPLIT-Hg). This model, along with specialized post-processing routines, is designed to create uniquely detailed, policy-relevant source-attribution information. The HYSPLIT-Hg model has been updated and improved over the years and has been used for a number of projects, including the NOAA Report to Congress on Mercury Contamination in the Great Lakes in 2007. Mercury episodes at ARL's Beltsville and Grand Bay monitoring sites have been identified and prioritized for case-study model evaluation analysis. The episodes are being analyzed in a number of collaborative research activities involving the EPA and several university research groups. This model evaluation project – coupling state of the art measurements with high-resolution meteorological data and emissions data – may be one of the most comprehensive and detailed atmospheric mercury model evaluation exercises ever conducted.

ARL has developed a specialized version of the HYSPLIT model to simulate atmospheric semi-volatile pollutants (HYSPLIT-SV) like dioxin. Similar to the HYSPLIT-Hg, this model also provides uniquely detailed source-attribution information. The model has been used for a number of projects, including analysis source-attribution for dioxin deposition to the Great Lakes and the regional atmospheric fate/transport of dioxin emitted from burning of oil from the Deepwater Horizon spill at the sea surface. ARL is currently training government and academic scientists in Mexico to use the HYSPLIT-SV model in conjunction with a collaborative project analyzing/interpreting ambient dioxin monitoring data in Mexico.

Three different ensemble modules have been incorporated into the standard HYSPLIT modeling system. In the first approach, the meteorological grid is offset in either X, Y, and Z for each member of the ensemble resulting in potentially different transport pathways sensitive to spatial gradients in the meteorological data fields. A measure of how well the gridded data represent the continuous flow field functions. The second ensemble variation is the turbulence option. Normally the same random number seed is used when computing the turbulent

component of the particle motion. However, in the variance ensemble, the seed is different for each member, resulting in each member representing one realization of the ensemble. The third is the physics ensemble which varies different turbulence and mixing assumptions. The model ensemble products can be viewed as concentration or probability maps.

ARL developed an innovative technique called the "flux-fragment method" for segregating fluxes taken from the air over heterogeneous landscapes into components representing the contributions from subclasses of the land-cover types in the landscape. This information is used by the weather and climate communities to understand energy exchange at the air-land interface. University and government researchers that make air-surface exchange rates from aircraft platforms now have a useful tool for interpreting the fluxes obtained from these elevated platforms, which usually represent several types of land use.

ARL determined the Normalized Difference Vegetation Index (NDVI) using broadband radiation measurements from flux towers. This enables researchers to utilize a continuous record of NDVI to estimate the green leaf area index (LAI), which is an important model input for nearly all land surface schemes modeling carbon, water, and heat fluxes. The in-situ derived NDVI also provides a seasonal comparison with estimates from satellite. In all, users of these data (USDA, National Aeronautics and Space Administration, and the many regional/global communities in remote sensing and climate/weather) now have access to a continuous record of NDVI that is used in support of continuous measurements of energy, water, and carbon fluxes in the key land-vegetation regions across the U.S. ARL developed a multi-layer dry deposition model for gas- and aerosol-phase sulfur and nitrogen compounds, currently used in EPA's Clean Air Status and Trends Network (CastNet).

In parallel with WRF development, a climate version of the WRF model (CWRF) has been developed in close collaboration with the University of Illinois/Illinois Water Survey. Recently, the CWRF group has been relocated to University of Maryland's Earth System Science Interdisciplinary Center. Development of CWRF is aimed at providing reliable and credible climate and climate change products and information on regional to local scales for services, applications, and decision making. Major CWRF advances have resulted from development of a cloud-aerosol-radiation module, a multi-physics optimization scheme, a coupled surface/sub-surface hydrology scheme, a mixing layer ocean module, and improved land planetary boundary layer scheme. CWRF provides a state-of-art capability for supporting regional and local services and applications of climate prediction and projection products. ARL's role has been with initial planning of the project, coordination and management of resources including partial funding, support of visitors, high performance computer allocations, analyzing results , discussions, synergy, and strategic directions.

NOAA and EPA have entered into a partnership to make full use of their respective capabilities and authorities in developing a national Air Quality Forecasting capability. The goal of this partnership is to provide ozone, particulate matter, and other pollutant forecasts with enough accuracy and advance notice for people to take actions that prevent or limit harmful effects of poor air quality. As a part of this effort, ARL scientists develop models for short-term (1-3 days) predictions of air quality. Specifically, ARL develops and improves NOAA's operational

modeling system for predicting ground-level ozone concentrations. ARL scientists are also developing models for predicting concentrations of very small particles in the air. These particles are produced from combustion processes (burning petroleum products, gas, and wood), volcanic emissions, and from chemical reactions in the atmosphere. For localities that have been forecasting air quality, the new NOAA forecasting guidance improves forecasters' ability to predict the onset, severity, and duration of poor air quality. For communities in most of the country, this is the first time that air quality predictions have been made available.

Web-Based Services

ARL created an on-line interactive interface to DATEM (Data Archive of Tracer Experiments and Meteorology) that permits researchers access to ARL's database of tracer experiments by configuring and running the HYSPLIT model to evaluate its accuracy and test its sensitivity to various model parameterizations. This is the only dispersion model with such open access and realistic assessment of its performance. Note that tracer datasets identified above have been included in this archive.

READY – Real-time Environmental Applications and Display sYstem -- is a web-based system that has been developed for accessing and displaying meteorological data and running trajectory and dispersion model products on ARL's web server. This system brings together dispersion models, graphical display programs and textual forecast programs generated over many years at ARL into a form that is easy to use by anyone. Its primary user group, however, is atmospheric scientists. READY has been maintained and routinely upgraded by ARL for 15 years and presently has nearly 3000 unique users from Governments (Federal, State, and Foreign, 1016), Universities (1485), Commercial entities (242), Military (53), Non Profits (58), and Private Pilots (87). In a typical month, between 50,000 and 60,000 HYSPLIT simulations are run through READY by these users for locations all over the world. Based on comments and questions received by ARL, user applications include air quality forecasting and analysis, emergency response, wild fire smoke forecasting, hot air ballooning, hang-gliding/soaring, and even insect and plant spore transport.

[i] The initial version of HYSPLIT used a single-particle. Since then the name has not changed, but the model now defaults to multiple particles, thousands or more.