Air Resources Laboratory

Strategic Plan 2021-2026

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Message from the Director

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 of research in the Planetary Boundary Layer. Within the National Oceanic and Atmospheric Administration (NOAA) Office of Oceanic and Atmospheric Research (OAR, or NOAA Research), ARL's cadre of about seventy talented and dedicated scientists, engineers, technicians, as well as information technology and administrative professionals work at the forefront of important issues including emergency management, air quality, and climate change. The science themes described in this Strategic Plan are direct outcomes of research pursued continually from the early days of the lab.

From the dawn of the nuclear age, the lab has provided critical information on boundary layer (BL) characterization, air-surface exchange, and atmospheric transport and dispersion of hazardous materials. These three science themes are interconnected by the dynamic nature of BL. Air-surface exchanges of energy, matter, and momentum, combined with transport and mixing, directly influence the state and evolution of the BL.

Our main focus areas reflect the needs of our users, stakeholders, collaborators, and society in general. Changes in weather and climate continue to influence every sector of our society, and air pollution continues to be a major problem in many parts of the United States. Accidental releases of harmful materials into the air occur frequently, and response teams must act in a timely and accurate manner. ARL has undergone dramatic changes during the past five years while maintaining a focused research program centered on the BL.

ARL's research is conducted through collaborative partnerships. We work collaboratively with several OAR labs and 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. In addition to the longstanding 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, we maintain a strong relationship with Department of Energy offices in Idaho and Nevada and other government agencies.

ARL scientists are ably supported by various contractual arrangements, as well as a multi-decadal collaboration with Oak Ridge Associated Universities, and highly productive collaborations with the Cooperative Institute for Satellites Earth System Studies – Maryland and the Cooperative Institute for Mesoscale Meteorological Studies. ARL's research products are readily available to a wide range of customers and collaborators ranging from operational NOAA entities, to direct, worldwide user access through web-based applications, and serve a broad national and international clientele.

Ariel F. Stein, ARL Director

The Boundary Layer is visible in red/orange in this photo from the International Space Station. This area closest to the Earth's surface is where we live and breathe.

Vision

ARL provides world class Boundary Layer research to protect people, the environment, and commercial activities from atmospheric risks by improving scientific understanding that benefits society.

Mission

To study and understand the physical and chemical, short- and long-term processes that occur in the boundary layer. ARL investigates the transport, mixing, exchange, and transformation properties of energy, moisture, trace gases, and particles, and provides inputs to atmospheric models and forecast operations that are vital in improving prediction accuracy and timeliness. Primary applications of our research include emergency response, homeland security, air quality, weather forecasts and climate outlooks, and commerce and transportation.

Core Values

Integrity

Excellence

Relevance

Collaboration.

ARL staff conduct their duties with the highest integrity, working each day to achieve excellence in the service of our nation. Research is performed to the highest scientific standards to obtain certainty in results where it is reachable, but acknowledging uncertainties when they arise. The activities undertaken in ARL are relevant to NOAA's mission and the current and future needs of the laboratory's stakeholders and customers, both internal and external to NOAA. Collaboration and teamwork are recognized as the most effective methods for achieving the goals of the laboratory, each individual contributing their strengths and expertise to the larger whole. Collaboration across NOAA, other federal agencies, academia, and private entities is cultivated to extend the expertise and capabilities of ARL personnel to better fulfill NOAA's mission.

NOAA's Open House in 2019 generated interest and enthusiasm about the research at Air Resources Laboratory. Image credit: NOAA

Introduction

This plan aligns the strategic directions with research opportunities for Boundary Layer Processes research and development at NOAA's Air Resources Laboratory. Given the current and future research and development needs established by the Weather Research and Forecasting Innovation Act of 2017, OAR's Strategic Plan, and the Laboratory's capabilities, topic areas have been identified in which ARL can make the greatest contributions consistent with available resources.

Although the science itself has not changed, ARL has reformulated its strategic direction to best support the goals of OAR. ARL will pursue scientific programs in the areas described in this document and will develop more detailed plans as appropriate for particular activities in collaboration with other OAR labs. ARL also recognizes that as circumstances and needs change, this Strategic Plan may be modified accordingly.

The intended audiences for this plan include current and future ARL staff, NOAA line office leadership, planning/programming staff, and current and future collaborators. It is expected that this plan will help all of these groups better understand the themes and directions of ARL's research, leading to better recognition of ARL's activities and capabilities, better integration with and support of NOAA's mission and OAR's priorities, and enhanced partnerships, both within and outside of NOAA.

Strategic Alignment with NOAA OAR

NOAA's Office of Oceanic and Atmospheric Research (OAR) is the parent organization to the Air Resources Laboratory. The strategic plan for OAR outlines the organization's vision, mission, and values along with a strategic approach to address the changing operating landscape and the factors influencing the environmental science community. OAR's four goals reflect what OAR desires to achieve, where to focus activities, and ultimately, how to improve OAR's ability to deliver NOAA's future: Explore the Marine Environment, Detect Changes in the Ocean and Atmosphere, Make Forecasts Better, and Drive Innovative Science.

ARL Science Themes

ARL has three core boundary layer process themes underpinning its research activities:

- Surface-Atmosphere Exchange
- Atmospheric Transport & Dispersion
- Boundary Layer Characterization


Surface-Atmosphere Exchange
This interface — where the exchanges of energy, momentum, moisture, gases, and aerosols occur — is where weather and climate begin.

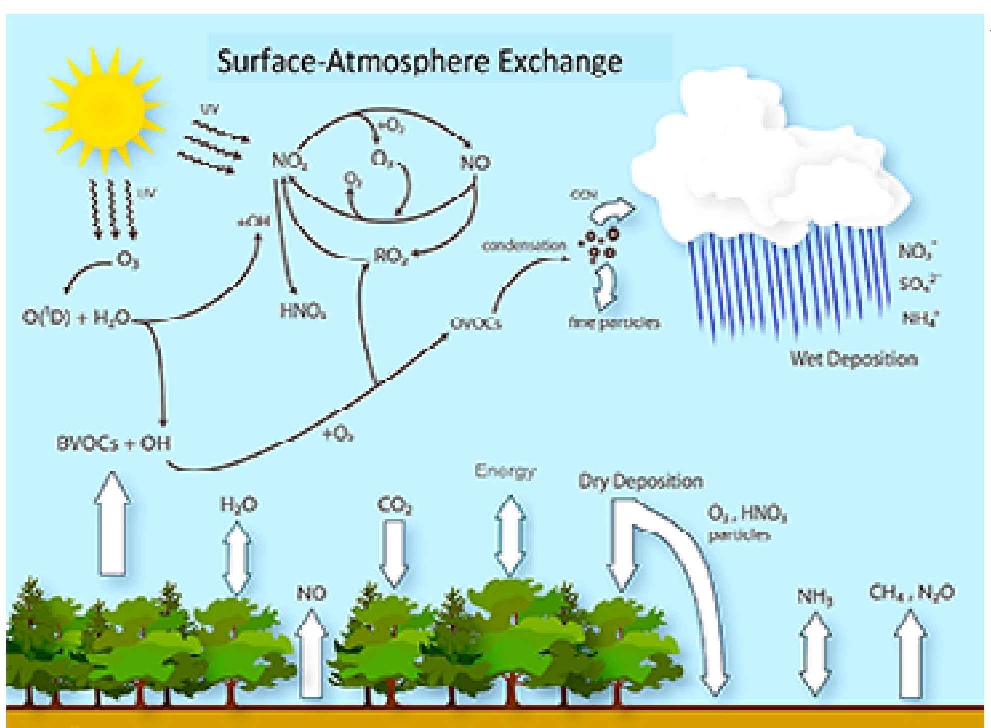
Surface-Atmosphere Exchange

The Boundary Layer is the most dynamic in Earth's atmosphere as a result of constant exchange and interactions with the land/water surface. This interface, where the exchanges of energy, momentum, moisture, gases, and aerosols take place, is where weather and climate begin. The exchanges of heat and water vapor between the land and atmosphere are largely driven by the surface radiation budget, a combination of incoming and outgoing short and longwave radiation. Understanding the processes and environmental variables that control surface-atmosphere exchanges, and translating this understanding into more accurate model parameterizations, is a vital research activity that will lead to improved weather, climate, and air quality predictions.

ARL has a widely-recognized expertise in this area of research and collaborates with other OAR laboratories, other federal agencies and university partners to advance knowledge in this area and transition this understanding to improved NOAA products and services.

The OAR goals pursued in this theme area are primarily tied to Goal 3, "Make Forecasts Better," as described below.

ARL Theme: Surface-Atmosphere Exchange		Surface Energy Budget	Aerosol Flux	Surface exchanges
OAR Strategy Goal 3: Make Forecasts Better	3.1 Develop interdisciplinary Earth system models	●	●	●
	3.2 Design tools and processes to forecast high-impact weather, water, climate, ocean, and ecosystem events			
	3.3 Transition science that meets users' current and future needs	●	●	●



The complex chemistry and dynamics of the surface atmospheric exchange are depicted in this diagram. Solar radiation (UV) initiates a number of chemical processes.

Surface Energy Budget

A Surface Energy Budget Network (SEBN) site located in Audubon, AZ.

The land surface heats up or cools down as it tends towards an equilibrium between the net radiative and convective/conductive heat fluxes; this quasi-equilibrium is known as the surface energy balance (SEB). As natural landscapes are a patchwork quilt of various land-use types, they typically heat or cool at different rates in response to the radiative forcing. For many years, ARL has operated a small-scale surface energy budget network (SEBN) across the US; a consolidation of several independent but closely related observing systems into a single, cost-effective and efficient network. SEBN seeks to explain why climate variables (e.g., air temperature, precipitation) have changed. Data, which includes the input of moisture and heat to the atmosphere, are used by NOAA scientists to provide detailed examination of the land-surface feedbacks and related radiative processes that can drive regional climate and to improve weather predictions.

Gas/Aerosol fluxes

The chemical composition of the atmosphere affects weather and climate through impacts on heat transfer and cloud microphysics. Including prognostic distributions of aerosols and trace gases in weather and climate models will lead to more realistic sub-seasonal to seasonal (S2S) forecasts and short-term weather impacted by heavy aerosol loadings (e.g., wildfires or dust).

Wildfires release a huge amount of aerosol and trace gases into the atmosphere, which have a significant impact on weather, climate, air quality and human health. Since 2000, an annual average of over 71,000 wildfires burned an average of 6.9 million acres in the U.S. Nearly 4.5 million U.S. homes have been identified at high or extreme risk of wildfire, with more than two million in California alone, and losses from wildfires have totaled over $5 billion over the past ten years. ARL performs research to improve emission estimates of trace gases and aerosols from wildfires and their impacts on short-term weather and air quality.

Dust lifted from the Earth's surface naturally by winds or by human activity can have significant impacts on the absorption and scattering of solar radiation, can alter the structure and intensity of storms and precipitation, and can have deleterious effects on air quality and human health. As with wildfires, a warmer and drier global climate will likely lead to increased frequency of large dust events and result in larger atmospheric effects. Ongoing dust research in ARL aims to further refine dust emission estimates and extend their accuracy across spatial and temporal scales.

Surface-atmosphere exchange

ARL also performs field measurements to better characterize the exchange of chemical species between the Earth's surface and the atmosphere. Surface-atmosphere exchange rates of reactive nitrogen (nitrogen oxides and ammonia) are highly uncertain and difficult to model, even though these compounds serve important roles in the formation of tropospheric ozone and aerosols, and their deposition to ecosystems can have harmful environmental consequences (e.g., eutrophication in coastal and inland waters and wetlands and reduced biodiversity in forests). ARL quantifies the extent to which changes in emissions affect air quality and deposition at selected locations around the US. ARL also performs field studies to investigate the processes that influence the exchange of reactive nitrogen and other compounds between the atmosphere and land surface, with a focus on agricultural regions and coastal areas.

Afternoon skies became orange in San Francisco during Sept 2020 as wildfires surged. The 2020 season was a record-setting one for the state of California and the United States. Image credit: Christopher Michel

Atmospheric Transport and Dispersion

ARL scientists perform activities to understand the main processes that drive the transport and dispersion of harmful substances in the atmosphere.

Atmospheric Transport and Dispersion

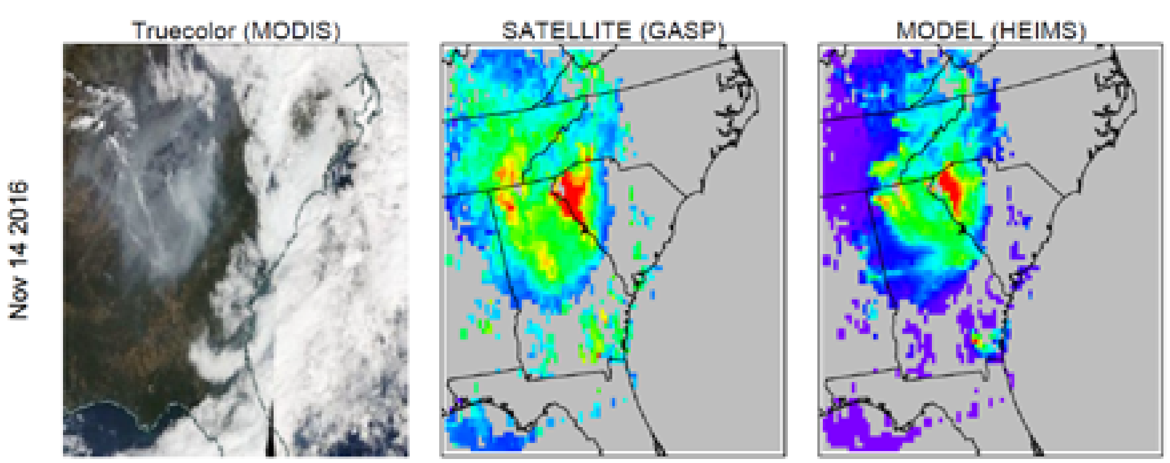
ARL scientists perform activities to understand the main processes that drive the transport and dispersion of harmful substances in the atmosphere, to improve the quality of our modeling tools, and to assess the uncertainties and applicability of those tools. In addition, investigations of the transport and dispersion of chemicals in the atmospheric BL serve to provide quantitative flow-visualization information that can lead to new insights and improvements in weather modeling.

These ARL themes align with the OAR goals in several areas, shown below, most notably in "making forecasts better." ARL maintains an active working relationship with NWS and NCEI to transition the science research results into current forecasting models.

ARL Theme: Transport and Dispersion		**Modeling**	**GHG Sourcing; estimation**	**Model Evaluation - Tracers**
OAR Strategy Goal 2: Detect Changes in the Ocean and Atmosphere	2.3 Increase ability to access and use Earth system data		●	
OAR Strategy Goal 3: Make Forecasts Better	3.1 Develop interdisciplinary Earth system models	●		●
	3.2 Design tools and processes to forecast high-impact weather, water, climate, ocean, and ecosystem events	●		●
	3.3 Transition science that meets users' current and future needs	●	●	●

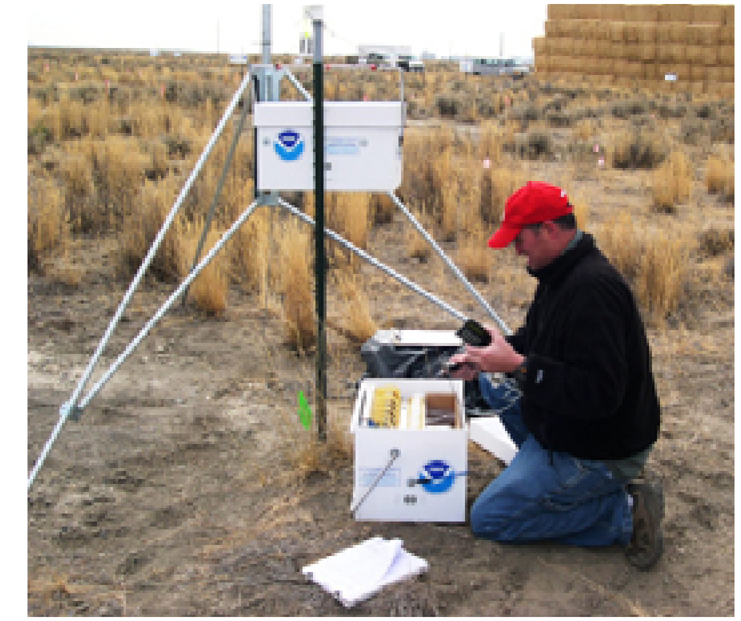
Transport-Dispersion Modeling

Developed and maintained by ARL, HYSPLIT is the core engine of ARL's transport-dispersion modeling activities and it is one of the most widely used models for atmospheric trajectory and dispersion calculations in the US and internationally. HYSPLIT is a complete system for computing simple air parcel trajectories as well as complex transport, dispersion, chemical transformation, and deposition simulations.



A HYSPLIT inverse model can offer precise information on wildfires. In this example, the same wildfire over the southeastern US on November 10, 2016 is compared: true-color images from MODIS (left), GASP AOD (middle), and HYSPLIT enabled inverse model (right) are shown. Image Credit: NOAA

Examples of HYSPLIT applications include tracking and forecasting the release of radioactive material, wildfire smoke, windblown dust, pollutants from various stationary and mobile emission sources, allergens and volcanic ash. ARL's dispersion products are not only used for operational applications at the NWS but also by other US government agencies, academia, and private companies.



Tracer being deployed, Image Credit: NOAA

HYSPLIT is under continuous development at ARL in collaboration with internal and external partners. Model evaluation activities are fundamental to this development as they provide objective assessments of model performance and allow hypotheses to be generated and tested.

A HYSPLIT inverse system based on variational data assimilation and a Lagrangian dispersion transfer coefficient matrix has been developed and successfully applied to estimate plumes of volcanic ash, wildfire emissions and Cesium-137 releases during the Fukushima nuclear accident. This system allows the determination of source features such as location, vertical distribution, and strength. An application of the HYSPLIT model to simulate transport and dispersion on urban scales is an area of newly increased focus.

Model Evaluation

Evaluation is a crucial aspect for developing improvements and in gaining confidence in weather and climate models. Harmful materials typically simulated by atmospheric dispersion models are rarely distributed intentionally, so it can be challenging to evaluate models for a wide variety of environmental conditions and source scenarios. The use of atmospheric tracers is an essential component in the study of dispersion science because tracer data are reference observations.

Intentional Tracers

ARL has carried out numerous intentional tracer studies and developed a repository of standardized data that includes meteorological model, tracer data, and statistical and graphical tools called the Data Archive of Tracer Experiment and Meteorology (DATEM) to evaluate model changes and determine the accuracy of the dispersion prediction. DATEM includes tracer experiments that cover a wide range of durations and distances: from the urban scale Metropolitan Tracer Experiment (METREX), to the continental scale Across North America Tracer Experiment (ANATEX). New intentional tracer experiments will support continued development of the HYSPLIT model. ARL is conducting research on the use and measurement of new tracer compounds from a variety of ground-based, mobile and aerial platforms.

Tracers of opportunity

Tracers of opportunity, chemical species emitted as a result of normal human activities, can be used to expand the data against which HYSPLIT can be evaluated. ARL's expertise in the measurement of SO_2 in the BL to carry out targeted field campaigns with ARL ground-based instruments, allows a higher density of ground-based stations – similar to a more traditional tracer experiment – and provides higher spatial resolution data to evaluate models and hypotheses. These campaigns can be designed to address key questions and challenges and would include measurements of other chemicals and meteorological parameters that may be helpful in diagnosing and understanding atmospheric processes during the campaign.

Mitigation of greenhouse-gas emissions

ARL has long been the leader in the development of source attribution applications based on transport and dispersion simulations. ARL used an early version of HYSPLIT to identify and estimate source reductions in SO2 in the Ohio River Valley that would ultimately lead to the reduction of acid rain. Recently, ARL utilized the HYSPLIT model to estimate the time variation of the emission of Cesium-137 from the Fukushima accident. The expansion of this research area is a natural step for the HYSPLIT development group and a potentially sizable scientific contribution from ARL to the monitoring and verification aspects of the COP21 agreement and the growing needs of the climate change agenda.

ARL works with NOAA partners to support, as a requirement of the Paris Climate agreement, a Global Stocktake which will assess the international progress in reducing greenhouse gas (GHG) emissions and mitigating the climate impacts. ARL and NOAA's science and capabilities can be used to uniquely assist by creating an independent, transparent evaluation of GHG emissions and, importantly, changes in emissions at various scales.

ARL has developed a GHG measurement program to augment its robust dispersion modeling efforts. Measurements can be used to evaluate and refine dispersion and transport parameterizations in HYSPLIT by combining calculated or measured emission rates of GHGs and other tracers of opportunity from point sources with model estimates of transport and dispersion, and comparing the resulting model estimates of downwind concentrations to measured values.

Mauna Loa Observatory in Hawaii is home to a US Climate Reference Network Station. These stations use high-quality instruments to measure temperature, precipitation, wind speed, soil conditions and provide a continuous and reliable series of climate observations for monitoring trends in the nation's climate. Image Credit: NOAA.

Boundary Layer Characterization

Accurate observations such as temperature, wind direction and speed, humidity and soil moisture are the backbone of ARL's research to improve boundary layer parameterizations for weather and climate predictions.

Boundary Layer Characterization

The state of the Boundary Layer is the result of the integration of the dynamical processes that occur in that layer of the atmosphere. Accurate meteorological state variable observations such as temperature, wind direction and speed, humidity, soil moisture, constitute the backbone of ARL's endeavor to develop and improve BL parameterizations for weather and climate predictions. Short and long-term measurements are part of a suite of carefully designed networks and planned observation campaigns. In addition, new technological advances are pursued in order to decrease uncertainties and improve spatial and temporal coverage.

These ARL themes align with the OAR goals in several areas, shown below, most notably in "Detecting Changes in the Ocean and Atmosphere." ARL data and measurements are a key part of the climate record. Newer research into the use of UAS systems is providing an innovative and cost effective means to drive innovative science, as ARL works to transition the program to full operation.

ARL Theme: Boundary Layer Characterization		Mesonet	SUAS	Long term measurements
OAR Strategy Goal 2: Detect Changes in the Ocean and Atmosphere	2.2 Identify and address gaps in observation requirements needed to understand causes of variability and change	●	●	
	2.3 Increase ability to access and use Earth system data		●	●
OAR Strategy Goal 4: Drive Innovative Science	4.3 Accelerate the delivery of mission-ready, next-generation science		●	●

US Climate Reference Network Station in Gaylord, Michigan. The precipitation gauge at right, is surrounded by fencing. Image credit: NOAA

Mesonets

The landscape of the Idaho Mesonet. Image credit: NOAA

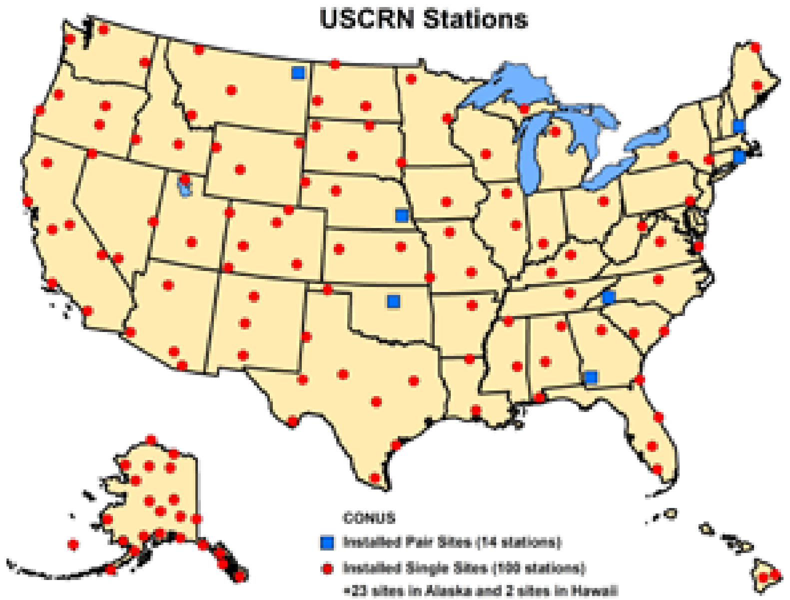
Heavily instrumented meteorological sites, or mesonets, provide a unique opportunity to characterize the BL with observations. ARL operates two meteorological mesonets in the western US in a long-term partnership with the U.S. Department of Energy (DOE) and the Idaho National Laboratory (INL) which dates back to 1949 and includes both the observation and prediction of BL characteristics in the complex terrain environment of the 890 square mile INL and surrounding area. Meteorological data are collected by the 35-station mesonet and are used to develop National Nuclear Security Administration (NNSA)-specific daily weather forecasts, provide weather surveillance for weather-related safety advisories, and conduct wind flow studies over complex terrain to aid the testing, improvement, and development of boundary layer transport and dispersion parameterizations.

Small Uncrewed Aircraft Systems (sUAS)

The advent of small-uncrewed aircraft systems (sUAS) for atmospheric research is providing new opportunities to collect BL meteorological measurements. These platforms are becoming an essential component of the NOAA observing systems. ARL is taking the lead to understand how data acquired by sUAS can be validated and used to better understand BL evolution during the formation of severe storms, and how sUAS platforms can be used to measure mesoscale patterns and trends in the atmosphere.

One of ARL's drones being used for boundary layer observations. Image credit: NOAA

ARL maintains a sUAS testbed to validate, integrate, calibrate and evaluate new technology and sensors for routine boundary layer research; validate operational weather models; improve model parameterizations; and record observations within



The US Climate Reference Network stations cover a variety of land types and climates across the US.

high-impact storms. The goal of the multi-testbed approach is to support NOAA's mission with an observing platform that can help in the understanding of land atmosphere interactions and NOAA field programs that need to have the boundary layer characterized to improve initialization of forecasting models, satellite calibration/validation, and spatial representativeness of long term in-situ observations. A new project to utilize sUAS data to improve HYSPLIT dispersion forecasts carried out by NWS Weather Forecast Office is underway and will lead to more accurate emergency response forecasts and guidance.

Long-term measurements

Continuous, high-quality, scientific observations of the global environment are critical for defining the current state of the Earth's integrated environmental system, in particular, the constantly changing conditions of the atmosphere, hydrosphere, and biosphere. The U.S. Climate Reference Network (USCRN) fulfills this need for long-term sustainable and robust climate observations that are necessary to document climate change trends for the United States. The USCRN began operations in the conterminous US (CONUS) in 2000, and beginning in 2009, the USCRN effort in the U.S. began expanding into the State of Alaska. There are currently a total of 23 operational USCRN stations in Alaska, with an eventual goal of having 29 stations by 2025.

From 2009-11, and in partnership with NOAA's National Integrated Drought Information (NIDIS) Program, ARL began an effort to install combined soil moisture and temperature sensors at 113 of those USCRN stations and which is now one of the most robust soil sensor networks in the U.S. The USCRN provides a high-quality national reference system for determining air temperature and precipitation trends, while also being a part of the National Coordinated Soil Moisture Network, a multi-agency effort to provide high quality data and information on the nation's drought and water issues.

Supersites – measurement testbeds

In collaboration with several labs across OAR, ARL is developing a series of heavily instrumented supersites that will focus on boundary layer measurements from both the physical and chemical points of view. These sites will include BL height, turbulence, meteorology, components of the surface energy budget to provide input of heat and moisture to the atmosphere, and chemistry measurements that will characterize specific locations and seasons for better understanding BL behavior over a variety of environmental conditions. Examples of this include the US Climate Reference Network (USCRN) observing stations as well as atmospheric mercury observing capabilities at the NOAA baseline observatories in Barrow, AK, and Mauna Loa, HI, and sites in the Surface Energy Budget Network (SEBN).

Outreach and Research to Operations, Applications and Commercialization

Surface-Atmosphere Exchange

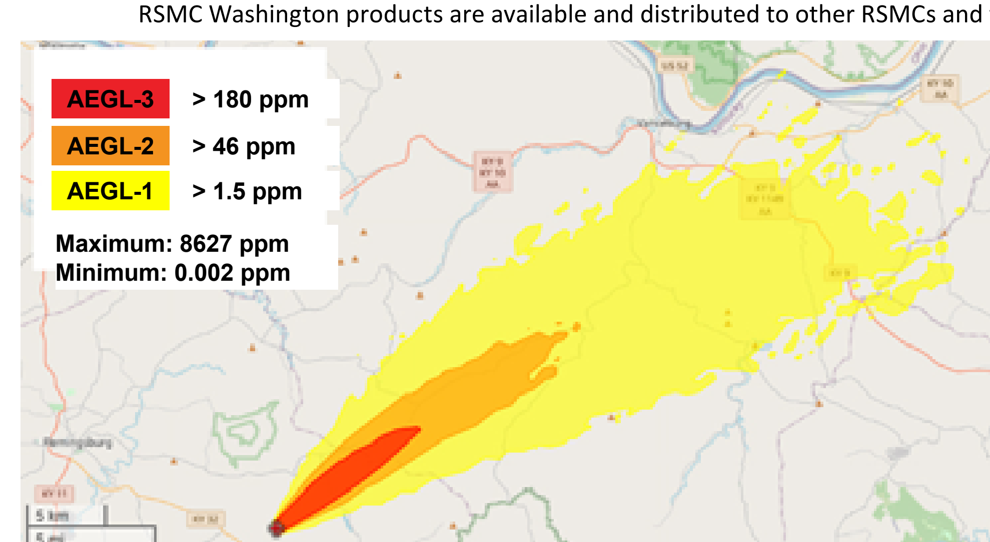
ARL provides continuing scientific updates and input emissions datasets to the National Air Quality Forecasting Capability (NAQFC),a NWS operational product that produces multi-day forecasts of ground-level ozone (O3) and PM2.5 over the entire US. The NAQFC includes anthropogenic as well as natural sources of pollutants such as wildfires and dust. As part of NOAA's effort to develop a new Unified Forecast System (UFS), ARL is providing substantial contributions to the development of new UFS-based aerosol and atmospheric composition models, in close collaboration with the Chemical Sciences Laboratory (CSL), the Global Systems Laboratory (GSL) and the NWS Environmental Modeling Center (EMC).

ARL scientists are actively developing a chemical emissions processing and modeling system, the NOAA Emissions and eXchange Unified System (NEXUS). NEXUS will be capable of utilizing numerous emissions datasets (both global and regional), can be run offline, with both inventory-based and process-based components, is Earth System Model Framework (ESMF)-compliant, and can be easily linked to satellite data. Currently, NEXUS development is focused on providing global emissions for NOAA's global aerosol model, an inline, regional-scale air quality model, an aerosol-aware (smoke and dust) regional weather forecast model, and other future research versions of UFS-based aerosol and atmospheric composition models.

Transport and Dispersion

All NWS Weather Forecasting Offices (WFOs) routinely use the HYSPLIT model to provide state and local governments with dispersion model products to track and predict the dispersion of hazardous materials from accidents or incidents such as chemical spills or forest fires. ARL supports the HYSPLIT modeling system web site, currently operated by the NOAA OCIO/Web Operations Center (WOC) and used by the NWS Weather Forecasting Offices (WFOs). HYSPLIT forecast trajectories are included in spot forecasts provided by the WFOs for prescribed burning and hazmat releases to the atmosphere. ARL updates HYSPLIT for lake-effect snow forecasting trajectory guidance used by WFOs.

ARL supports the World Meteorological Organization (WMO) Regional Specialized Meteorological Center Washington (RSMC Washington) operated by NCEP that provides real-time 24/7 specialized atmospheric dispersion model products for environmental emergency response and/or source identification of radionuclides. The RSMC Website is currently operated by ARL so that RSMC Washington products are available and distributed to other RSMCs and the International



One simulation generated by HYSPLIT; this example shows the height and density of an unintended release of smoke.

Atomic Energy Agency. In addition, ARL supports the Comprehensive Nuclear-Test Ban Treaty Organization (CTBTO) capabilities provided by NCEP, per a Memorandum of Agreement (MOA) between NWS and the US State Department.

ARL supports dispersion modeling to the Department of Homeland Security operated Interagency Modeling and Atmospheric Assessment Center (IMAAC) and provides product support and backup to the operational component at NCEP. In addition, ARL provides HYSPLIT modeling development and support for the National Air Quality Forecast Capability (NAQFC), which provides daily forecasts of dust and smoke from wildfires at the NWS. ARL supports the National Environmental Satellite Data and Information Service (NESDIS) for volcanic ash forecasts whenever requested by the International Civil Aviation Organization (ICAO)-designated U.S Volcanic Ash Advisory Centers (Washington, DC; Anchorage, AK). ARL also supports the U.N. Food and Agriculture Organization with a HYSPLIT-based system to provide information about the past and potential future movements of locust swarms.

HYSPLIT continues to be one of the most extensively used atmospheric transport and dispersion models in the atmospheric sciences community (about 60,000 HYSPLIT simulations per month). The HYSPLIT modeling system can be currently run on PC, Mac, or Linux platforms and 4,000 registered users worldwide have downloaded HYSPLIT. Public access to meteorological data and run HYSPLIT trajectory and dispersion simulations is also available through the Real-time Environmental Applications and Display sYstem (READY), a web-based system developed and maintained by ARL (https://ready.noaa.gov/).

Annual HYSPLIT Workshops are held each summer; participants typically include members of the US and international governments, private industry, and academia. In addition, a user forum for HYSPLIT is available 24/7 to communicate questions, problems, and experiences (https://hysplitbbs.arl.noaa.gov/). This Forum currently has more than 5,000 participants and ARL actively monitors the forum, responds to user queries, and supports these users and their activities.

HYSPLIT Model Use Cases and Economic Value

ARL models generate actionable information and highly localized forecasts to respond to a variety of emergencies efficiently. ARL's HYSPLIT predicts the downwind impacts of hazardous materials released to the atmosphere and is used in a variety of emergency situations. During incidents such as industrial accidents and wildfires, data from HYSPLIT informs local managers whether evacuations or stay-at-home orders may be necessary. Scenarios where HYSPLIT models inform a change to improve public and environmental health or mitigate bad outcomes are numerous.

Industrial Accidents and Toxic Emissions.

The Chemtool plant fire in Rockton, Illinois in June 2021 burned for several days and HYSPLIT runs were provided at 3-hour intervals to local response agencies and forecasters to inform evacuations and public health alerts. Image credit: EPA

Industrial releases comprise roughly a quarter of all recorded events in HYSPLIT 2020 simulations. HYSPLIT usage on industrial events nearly doubled between 2018 and 2019. Incident modeling prevented the inhalation of chlorine, ammonia, and a variety of other toxic substances. In one case study, the 2018 Husky fire in Wisconsin, avoided health costs were conservatively estimated at $1,500,000 for the group of health end-points examined. It is estimated that 750 people were spared exposure to levels of fine particulate matter above 250 ug/m3, a threshold where serious injury, including heart attack and death, can occur. In this study, it is unknown how many actual deaths or serious injuries were avoided through the use of HYSPLIT.

Wildfires and Prescribed Burns

HYSPLIT is not only used to plan prescribed burns, but also provides daily forecasts of wildfire smoke throughout the U.S. HYSPLIT is also the basis for a fire emission inverse modeling system that can improve smoke forecasting over North America by combining model estimates with satellite observations. Public economic studies correlate low air quality and smoke to well-being and life satisfaction, with a disproportionate effect on rural resident life satisfaction, which can also be estimated in terms of economic value.

Nuclear Nonproliferation

ARL is designated as a World Meteorological Organization Regional Specialized Meteorological Center, and works along with the US Departments of Energy, State, and Defense to characterize the atmosphere and provide backtracking, or source, information for non-proliferation field experiments. ARL is tasked by the Comprehensive Test Ban Treaty Organization to ensure compliance with Nuclear Test Treaties.

The Nishnoshima volcanic eruption in 2020 was one of several studied to perform inverse modeling experiments

Volcanic Ash

HYSPLIT is also used to forecast downwind concentrations of ash after volcanic eruptions; these forecasts alert civil aviation authorities so that aircraft can avoid dangerous ash levels. Aircraft engines can be catastrophically damaged due to volcanic ash, causing crashes; the value of avoiding ash encounters is extraordinarily high. Estimates of the impact of volcanic ash on the commercial air transport industry are $70 million annually.

Special Events

HYSPLIT simulations are used by emergency management agencies in advance planning for many events of national significance, including major parades, the Presidential Inauguration, the Super Bowl and other national sporting events, NASA planetary launches and the Albuquerque Balloon festival, among others.

Global Impact and Research

HYSPLIT versatility has been adapted for use by the United Nations to predict devastating Locust swarms in Africa. In its first year of operation, the Locust Forecasting tool saw over 5000 runs. As a research tool, HYSPLIT atmospheric transport models are accepted globally for a policy-relevant analysis by governmental, non-governmental, and academic researchers.

Regulatory Compliance

HYSPLIT is the EPA-mandated model to determine the classification status for state level compliance on ozone emissions. In one case study, the state of Maine used HYSPLIT data to indicate that the source of ozone in southern Maine did not originate in Maine, but was transported to southern Maine from neighboring states. Based on that data, the Governor of Maine formally requested in 2020 that the EPA remove "the majority of Maine from the Ozone Transport Region." Removal from the region would reduce annual compliance costs and regulatory burden on Maine industry, estimated at $2.3 – $5.5 M per year.

HYSPLIT models "sourced" the ozone measured in southern Maine, providing evidence that the emissions were not generated by Maine industrial activity. Image credit: Andy Thrasher.

Boundary Layer Characterization

Climate observations are required to address a large range of important societal issues including sea level rise, droughts, floods, extreme heat events, food security, and freshwater availability in the coming decades. High-quality climate reference data not only is essential to mitigate damages not only in the US, but also at the global level. Over the last decade, the amount of money directly impacted by the reliability of NOAA's climate data has increased dramatically. Errors in the data which might not have mattered a decade ago can now cost individuals and corporations millions of dollars.

In addition to being used by climate scientists, the USCRN provides a diverse and varied set of sectors of the economy with reliable data as in the following examples.

Energy and Insurance Sectors

Power companies need to assess changes in demand and need to accurately determine how much of this year's increase or decrease in demand over last year is due to the differences in the climate between the two years versus changes in their consumers. The weather insurance and derivative industries, which provide a mechanism for energy producers and energy users to hedge their risks due to unusual climate, use NOAA temperature data to settle accounts. Some public utilities have contracts for natural gas which specify that prices are raised or lowered depending on the severity of the winter as determined by NOAA data. Global solar energy data from USCRN stations are used to determine solar loads on structures for heating and cooling, or can give some information useful to the solar energy industry.

Agriculture Sector

The USCRN provides important contributions to agricultural and natural resource development. Private industry often uses regional numerical models to provide these forecasts. Having the highly accurate USCRN data helps improve the forecasts used by agribusiness and other weather sensitive sectors of the economy. Accurate USCRN 5-minute precipitation data is used in hydrographic models to delineate flood zones and determine water resources. The relatively recent introduction of soil moisture and temperature sensors to the network has allowed the USCRN to become part of the National Coordinated Soil Moisture Monitoring Network, and this along with the development of gridded soil moisture data and related indices have been important contributions to the goals of the National Integrated Drought Information System.

Agriculture is sensitive to changes in soil moisture and farmers rely on accurate models to maintain water resources. Image credit: USDA.

Natural Resources Sector

The USCRN has a long history of cooperation with the National Park Service (NPS), placing COOP stations and now USCRN stations within parks to better monitor climate in these locations. Many USCRN stations are located in National Wildlife Refuge (NWR) areas, monitoring climate at these locations. In addition to hosting USCRN stations, resource managers from NPS and NWR sites take advantage of hourly USCRN data to assist them in the management of water and other natural resources in these large federal tracts of land.

Miscellaneous

The entire suite of USCRN data have become increasingly useful for the calibration and validation of a number of satellite observations (e.g., surface infrared, surface air temperature, precipitation, and soil moisture). The use of these data have resulted in the creation of value-added satellite products, input into climate models used for long term prediction and attribution, and validation of climate model output. As an example, the Space Science and Engineering Center at the University of Wisconsin uses USCRN radiation data in real-time to validate estimates of incoming solar radiation from the GOES satellite array. A more recent use of USCRN data has been in its application to the health sector, where real-time USCRN data has assisted in identifying the location of a weather-related health crisis such as a fairly recent outbreak of Valley Fever in the Southwest U.S. Monitoring a changing climate is important for tracking the spread of disease potential for other diseases such as malaria and Hantavirus. Finally, the expansion of the USCRN into Alaska has provided some real-time precipitation data to NWS Weather Forecast Offices (WFO) across the state that have aided them in their warning and forecast functions in areas of a state that has a very low density of observations, and in many areas that have never been observed. WFOs in other states also take advantage of the high-quality USCRN data in their warning and forecast operations.

For More Information, Contact:
Air Resources Laboratory,
National Oceanic and Atmospheric Administration
NCWCP, R/ARL, Rm. 4204;
5830 University Research Court
College Park, MD 20740
Website: https://www.arl.noaa.gov/
E-mail: arl.webmaster@noaa.gov