Technologies (e.g. observing systems, information technology, numerical modeling algorithms) transferred to operations/application and an assessment of their significance/impact on operations.

ARL has transferred a number of technologies to NOAA for operational use, as well as to a wide array of customers outside of the agency. Below are items covering the period 2000 – 2010.

Theme: Dispersion and Boundary Layer

HYSPLIT Dispersion Model

HYSPLIT – Hybrid Single-Particle Lagrangian Integrated Trajectory Model -- is 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. ARL scientists have also provided a yearly workshop on the practical use of the model for air quality analysis and forecasting to small groups of users on a first come basis since 2004. A subset of the workshop has been presented several times in Spain as part of a collaborative effort between ARL scientists and the University of Huelva - Centro Internacional de Estudios y Convenciones Ecológicas y Medioambientales (CIECEM).

Real-time Environmental Applications and Display sYstem (READY)

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 updated by ARL for 15 years and presently has nearly 3,000 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.

Emergency Response Forecasts

Upgrades to the ARL HYSPLIT model have been periodically transferred to the National Weather Service/National Centers for Environmental Prediction (NWS/NCEP) for emergency response forecasts for small scale events. These forecasts are generated when requested by NWS Weather Forecast Offices (WFO). Forecast outputs for several locations within the U.S. are routinely made available to the WFO on an NCEP web site.

Web-Based HYSPLIT Capability for NWS WFOs

Prior to 2007, if a local emergency responder requested dispersion modeling support from an NWS/WFO, the WFO had to make a request via phone to the 24-hour Senior Duty Meteorologist (SDM) at the NOAA/NCEP. The WFO relayed the inputs from the emergency responder to the SDM who then ran the model on NCEP's operational computing systems. The results were posted to a secure web site for access by the WFO, which were then forwarded to the emergency manager. The NWS, knowing that ARL had a non-operational web-based HYSPLIT system, requested that ARL scientists develop a local-scale web version of HYSPLIT that could be ported to an operational environment in NOAA for use by the 122 WFOs to support events in their region of responsibility. ARL developed this system locally within the READY web site which was then ported to the NOAA Web Operations Center (WOC) in 2007 and made available to several WFOs for testing. Although the system is no longer running at the WOC, the NWS is in the process of transferring the system from the WOC to the NWS Telecommunications Operations Center (TOC). Until that is complete, ARL is hosting this service for WFOs on a non-operational basis through the READY web site. The web-based version allows the WFOs to conduct some emergency response activities, additional exercises, and training without impacting the NCEP 24/7 staff.

Between 100 and 300 HYSPLIT simulations have been run per month since May of 2010 when the system was made available to all WFOs. ARL is currently working with the NOAA National Ocean Service/Office of Response and Restoration (NOS/ORR) to develop a chemical source term model and interface for the web-based system that will function similarly to the ORR CAMEO/Aloha model that many local emergency responders already use in their work. In addition, with rising interest within the response community in responding to nuclear terrorism, ARL has recently developed and made available for testing an improvised nuclear device (IND) HYSPLIT model simulation for nuclear yields between 1 and 40 kT.

Browser-Based Decision Support Tool

ARL has developed a browser-based decision support tool that assesses the impacts of hazardous material releases in the atmosphere. The tool can handle both toxic chemicals and doses from radiological releases using the ARL HYSPLIT model to simulate the dispersion. For optimal performance, the tool uses Adobe Flash technology and Google Maps for display of model output. Both a dispersion analysis, based on meteorological observations, and a dispersion forecast, based on prognostic model output, can be generated. The tool was made

available in 2010 to the Department of Energy's Idaho National Laboratory for their use to provide near real-time assessments for actual or potential hazardous releases. Components of this system are being transferred to the NWS for operational use by NOAA.

Volcanic Ash Model Forecasts

Upgrades to the ARL HYSPLIT model have been periodically transferred to the NWS/NCEP for volcanic ash modeling, including a package to improve forecasting capabilities following the April 2010 eruption of the Eyjafjallajokull volcano in Iceland. HYSPLIT is relied upon operationally by NCEP to provide dispersion forecasts for large volcanic eruptions in support of the Washington, D.C., Volcanic Ash Advisory Center's (W-VAAC) area of responsibility, the lower 48 states, most of the North Pacific, Mexico, Central America, and South America north of 10°S latitude. For the last several years on average, HYSPLIT is run about 50 times for the W-VAAC. Forecast output for active or recently active volcanoes near or within the U.S. VAAC region of responsibility are routinely made available to customers on the ARL web site. Volcanic ash is a hazard to aircraft because it can degrade engine performance and navigational and operational instrumentation. Meteorologists at the VAAC use the HYSPLIT forecasts, among other sources of information, for writing Volcanic Ash Advisories, which are in turn used by Meteorological Watch Offices to write warning messages. The HYSPLIT dispersion forecasts are issued to the public and made available online such as at the NWS Aviation Weather Center.

Regional Specialized Meteorological Center Support

ARL provided HYSPLIT code and training to the China Meteorological Administration in early 2002 to enhance their modeling capability as a Regional Specialized Meteorological Center (RSMC), and it is now a routine part of their operations. The HYSPLIT code was developed in collaboration with the Australian Bureau of Meteorology and is used as part of their operational RSMC response capability as well.

The RSMC program was developed in response to the poor level of communications between countries following the Chernobyl accident in the spring of 1986. The World Meteorological Organization (WMO) was requested by the International Atomic Energy Agency (IAEA) and other international organizations to arrange for early warning messages about nuclear accidents to be transmitted over the Global Tele-communications System (GTS). In addition, some WMO member countries who lacked extensive forecasting capability requested that specialized pollutant transport and dispersion forecasts be provided during these emergencies. ARL scientists took part in the creation of the WMO RSMC in Washington, D.C. in 1993 and continue to jointly operate the Washington RSMC with the NOAA NCEP. The Washington RSMC provides dispersion modeling support to WMO member countries in the Americas who need assistance during transboundary emergency response events where hazardous pollutants may cross international boundaries.

Best Aircraft Turbulence (BAT) probe

ARL developed the Best Aircraft Turbulence (BAT) probe to measure meteorologically-relevant turbulent three-dimensional wind vectors, air temperature, and air pressure from a moving

platform. The BAT probe's capability and utility was significantly enhanced by the availability of miniature pressure transducers and signal conditioning circuits that became available in the early 1990s. Subsequently, ARL developed the equivalent of an inertial navigation system of high accuracy for about 10% of the hardware cost and with considerably reduced requirements for weight, power, and volume than equivalent systems of the day. In 1998, the BAT probe was adopted by Initiative Industriali Italiane for use on its single-engine two-place pusher-driven Sky Arrow aircraft of only 650 kg mass. The combination was made commercially available as an environmental research airplane and is currently in use at eight institutions on three continents. The BAT probe has also been used on the high-altitude low-speed EGRETT aircraft by Airborne Research Australia for study of turbulence in the upper troposphere and lower stratosphere.

A newer generation of the BAT probe, which included pumps to evacuate water from the pressure lines, was developed and flown on NOAA's WP-3 aircraft to measure turbulent winds in Hurricanes Katrina and Isabel. ARL is now developing and testing the next generation probe in partnership with Harvard University and Aurora Flight Sciences Corporation to measure turbulence and fluxes of CO_2 and CH_4 in the Arctic regions of the U.S. and Russia using a Diamond DA-42 (Twin Star) aircraft. The field program is expected to take place between the summer of 2011 and 2013.

Theme: Air Quality

Smoke Model Forecasts

ARL scientists, along with counterparts in NOAA's National Environmental Satellite, Data and Information Service (NESDIS) and NWS, transferred the HYSPLIT smoke forecasting system into NCEP operations for the Continental United States in 2007, Alaska in 2009, and Hawaii in 2010. The smoke forecasting system is part of the National Air Quality Forecast Capability (NAQFC) and is run operationally once per day to predict the movement and concentration of wild fire smoke. The NOAA Smoke Forecasting System integrates NESDIS's satellite information on the location of wildfires with NWS weather inputs from the North American Mesoscale model and smoke dispersion simulations from the ARL HYSPLIT model to produce a daily 48-hour prediction of smoke transport and concentration. The model also incorporates U.S. Forest Service estimates for wildfire smoke emissions based on vegetation cover. This system is intended as guidance to air quality forecasters and the public for fine particulate matter emitted from large wildfires and agricultural burning which can elevate particulate concentrations to unhealthful levels.

Community Multi-scale Air Quality (CMAQ) Modeling System and the Development of a National Air Quality Forecasting Capability

The Community Multiscale Air Quality (CMAQ) modeling system was first released in 1998 through the collaborative development efforts of ARL, the Environmental Protection Agency's Office of Research and Development, academia, and the private sector. ARL was the science lead for CMAQ development. CMAQ combines state-of-the-science capabilities for modeling

multiple air quality issues, including tropospheric ozone, fine particles, acid deposition, and visibility degradation. CMAQ was also designed to have multi-scale capabilities so that separate models were not needed for urban and regional scale air quality modeling. The model has been continuously updated by scientists in EPA, NOAA, and contributions from the science communities through the Community Modeling and Analysis System (CMAS).

In June, 2004, a program began to develop a National Air Quality Forecasting Capability (NAQFC) for ozone and fine particulate matter. NAQFC is based on the NWS operational mesoscale model and the CMAQ modeling system. The initial version of the system was deployed using the NCEP Eta meteorological model to forecast surface-level ozone pollution over the northeastern United States. Since that time, the domain coverage has expanded incrementally, presently covering the entire continental United States domain. Separate ozone forecasting domains for Hawaii and Alaska were added in 2010. ARL's work on this project has included developing interfaces with NWS meteorological models, developing emissions approaches for forecast applications, and adapting CMAQ for operational forecast use. Guidance from this model is used by state/local air quality forecasters to issue alerts and by the public to reduce health risks.

Theme: Climate

Infrared Gas Analyzer

ARL developed one of the first fast-response, open path infrared gas analyzer for measuring carbon dioxide and water vapor. Observations from this sensor are coupled with measurements of vertical velocity (from either sonic anemometers on towers or from the BAT probe on aircraft) to provide a direct measure of the fluxes of CO_2 and water vapor (evaporation/evapotranspiration). This technology demonstrated both the capacity and need to monitor carbon and energy fluxes over annual cycles for the purpose of understanding climate change and land-surface feedbacks to various atmospheric forcings (drought, fires, etc). For over a decade (1993 – 2004), and because no commercially available sensor was available, ARL built and sold nearly 50 analyzers to various researchers (both government and university) all over the world. The earliest records of annual CO_2 flux measurements for some of the longest climate records to date were obtained with the sensor designed and built by ARL.