C. Technology Transfer

ESRL Physical Sciences Laboratory Review

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GSD Technology Transfer

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

The following descriptions are arranged under their respective GSD mission theme.

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Environmental Information Systems

1. Advanced Weather Interactive Processing System (AWIPS)

AWIPS, the information system used nationwide by the National Weather Service (NWS) for forecast operations, is the result of exploratory development and technology transfer conducted by GSD and its predecessor, the Forecast Systems Laboratory, since 1979. The initial goal was to significantly improve severe weather warnings. A series of real-time experiments were conducted which combined the latest information technology advances with experimental observing systems. Operational forecasters were paired with research staff and asked to identify severe weather and issue appropriate warnings and were able to demonstrably improve skill in their warning operations.

This provided affirmation for NWS to modernize their field operations to take advantage of these new technologies. GSD worked with NWS to plan a series of prototype developments, each more comprehensive than its predecessor, to validate their approach. The prototype systems were used in actual operations at Denver, CO and Norman, OK forecast offices and helped NWS prepare for full-scale deployment of modernized operations by refining system requirements and putting in place needed data delivery mechanisms.

This experience and knowledge base was well documented and made available to companies bidding on the AWIPS implementation contract. In the early 1990s, when the contractor-developed system was unable to provide the needed functionality, the advanced prototype developed by GSD was transferred to the NWS to meet their schedule and budget targets for an operational AWIPS. The first deployment of AWIPS to NWS WFOs was in 1998 followed by multiple enhanced operational builds by GSD through January 2010.

AWIPS revolutionized weather forecast operations, significantly improving operational forecast workstations so forecasters could work faster and more efficiently, thereby increasing warning lead times to the public. AWIPS visually and synergistically integrates diverse data sets including radar and satellite imagery, model analyses, and observations. Its wide assortment of tools allows forecasters to interact with the data through interrogation and display enhancements. Because forecast operations are time-sensitive, performance was a prime consideration. Severe weather warnings could now be prepared in less than a minute from the time of decision to product issuance. Since the prototype systems were designed for operations and refined through several iterations of forecast workshops and operational testing, AWIPS is uniquely user-friendly for forecasters.

Collaborators in the prototyping, implementation, and upgrades of AWIPS include the Cooperative Institute for Research of the Atmosphere (CIRA) and the Cooperative Institute for Research in the Environmental Sciences (CIRES). AWIPS is also used internationally in Taiwan and South Korea.

GSD also developed spin-off systems to increase AWIPS' capabilities: FX-Net (AWIPS Thin Client used in the field away from the forecast office) and FX-Collaborate (interactive AWIPS collaboration client used between forecasters working at different locations). The D2D technology developed by GSD researchers led to the successful implementation of the AWIPS system in all

NWS WFOs. The Displays 2 Dimensions (D2D) - data storage, analysis, and visualization software is the core technology for the AWIPS and NOAAPORT distribution system. The Graphical Forecast Editor (GFE), which is also an instrumental component of AWIPS, enables forecasters to edit forecast grids and issue digital forecasts. The GFE is installed at Australia's Bureau of Meteorology, and forms the core of their Next Generation Forecast System.

The NWS-FSL AWIPS team was presented the Department of Commerce Gold Medal award in June, 1999, and other GSD staff were awarded a 2004 DOC Bronze Medal for "developing and nationally deploying the AWIPS Linux Migration Project thereby reducing hardware, maintenance, and operations costs and improving warning lead times by nearly two minutes."

More information can be found at http://fxa.noaa.gov.

2. Advanced Weather Interactive Processing System (AWIPS) FX-NET Thin Client

As a result of AWIPS, follow-on research led to many forms of new data distribution and visualization technologies including the FX-Net Thin Client System for remote users of AWIPS. It operates on a laptop using the Internet and technologies such as data compression and Java software. Later the Gridded FX-Net system was developed to allow remote users the use of a full Displays 2 Dimensions (D2D) visualization client and AWIPS data storage and server technologies.

The FX-Net system provides full AWIPS visualization and data analysis capability with a Graphical User Interface (GUI) that is identical to the AWIPS system, allowing the National Weather Service (NWS) Incident Meteorologists (IMETs) to move between their Weather Forecast Offices (WFO) equipped with the AWIPS system to FX-Net in the field with no additional training.

Prior to the use of the FX-Net system, the IMETs relied on various Internet sites to provide forecasts and local weather information to the fire incident commanders, fire behavior analysts and local emergency managers at the fire suppression command center. The use of the FX-Net system has proved to be a critical component in the IMET's ability to provide more timely and accurate fire scene weather forecasts and observation data, providing more lead time for decision making on deployment of fire fighting resources, evacuations, and protection of property.

FX-Net excels at displaying meteorological data in bandwidth-limited conditions, such as on the frontlines of fire weather forecasting. This is made possible by the Precision Control Wavelet Compression products developed with the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University. These products are unique to the FX-Net and Gridded FX-Net systems.

Beginning in 2001, the FX-Net Thin Client was integrated into NWS operations through its regional offices. The FX-Net Thin Client is critical to the NWS IMETs in the field who provide on-site weather forecasting at fires, floods, oil spills, and national events such as political conventions and large sporting events (e.g. Olympics). It is also used by NWS WFOs, NWS Center Weather Service Units for aviation weather, US Department of Agriculture Forest Service, and Department Of Interior Bureau of Land Management forecasters as well as forecasters for Air Force One at Andrews Air Force Base. Gridded FX-Net, an enhancement of FX-Net Thin Client has been transferred to the National Interagency Fire Center's (NIFC) Geographical Area Coordination Centers (GACC). The Gridded FX-Net system provides them with the atmospheric numerical forecast grids needed to supply weather information for seasonal and daily fire potential algorithms. Before the Gridded FX-Net installations, the GACC forecasters had to enter grid point information by hand or extract limited non-gridded information from the Internet.

In FY06-07, FX-Net technology was successfully transferred to the public sector. The ENSCO, Inc. commercial version of the MetWise Net was created from FX-Net. This collaboration with GSD modified existing FX-Net technology to include tools requested by their customer base including air quality data sets and menus. State and local air quality users who used FX-Net during an Environmental Protection Agency pilot project were very happy to have a commercial alternative to use once the pilot project ended.

In November 2005, the FX-Net staff was presented with an Honor Award by NIFC's National Predictive Services' Group for 'Outstanding contributions to the National Predictive Services Program'.

In April 2007, two members of the FX-Net development team were awarded a Certificate of Recognition by the Director of the NWS. The award was: 'In recognition of your leadership to ensure operational excellence via innovative development and maintenance of critical software for our IMETS'.

For more information on the FX-Net Thin Client System, refer to http://fx-net.noaa.gov/

3. Forecaster X-window Collaborate (FXC)

FXC explores how Advanced Weather Interactive Processing System (AWIPS) will need to evolve in order to meet the needs of NWS forecasters in the 21st century. It is being used to help determine requirements to AWIPS infrastructure, modeling, forecaster tools, displays, and end-user products. It was initiated in 1997 to explore collaboration and data sharing between the National Weather Service (NWS) and other agencies. Users are able to collaborate in real-time on hazardous events bringing their particular expertise to bear to help create more accurate and consistent products for operational decision makers. FXC can be run on a variety of operating systems and only requires access to the Internet in order to be able to display a wide variety of hydrometeorological data and create graphics of weather and other hazards (e.g. toxic chemical releases, airborne volcanic ash) to support collaborative decision making. Operational prototype systems have been developed to assist in exploring and collecting information from users (e.g. NWS, FAA, emergency managers) about what constitutes an effective collaborative system. FXC is now integrated into operations in NWS regional offices, weather forecast offices (WFO), center weather service units (CWSU), and volcanic ash advisory center offices throughout the US.

There are many users and a number of projects using FXC:

The Volcanic Ash Coordination Tool (VACT) is an application using FXC to collaborate between the Federal Aviation Administration (FAA) Anchorage Air Route Traffic Control Center (ARTCC), the NWS Alaskan units, and the USGS Alaska Volcanic Observatory (AVO) to coordinate a unified and consistent response to aviation hazards caused by volcanic ash which will result in safer skies over the Anchorage ARTCC air space. GSD integrated research such as the volcanic ash dispersion modeling software from the University of Alaska and satellite enhancements software developed by the U.S. Geological Survey at the AVO into AWIPS so that forecasters at the CWSUs could provide traffic managers at the Anchorage ARTCC with a volcanic ash warning within five minutes of the event. The VACT was used operationally in all volcanic ash events from May 2005 through September 2007. VACT was awarded the Bronze Medal in 2006.

The Traffic Management Unit-Weather Information Decision Aids (TMU-WIDA) software also uses FXC to provide standardized weather briefings tailored for traffic managers' needs and provides a method for NWS to extend coverage to 24/7 from 16/7 at all ARTCC facilities. TMU-WIDA helps provide a safer more efficient use of the National Air Space. Forecasters at weather forecast offices and center weather service units are able to collaborate on aviation related weather events to create more consistent weather briefings. Either of these NWS offices or both can provide auto-updating briefings to traffic managers at ARTCC facilities. TMU-WIDA is currently operationally used at the Dallas/Fort Worth and Leesburg CWSUs and ARTCCs. TMU-WIDA won the National Weather Association (NWA) Aviation Forecasting award.

Work has just begun on the Geo-Targeted Alerting System (GTAS). This effort extends FXC to address the needs of forecasters at weather forecast offices to better communicate weather impact to emergency managers at local and state Emergency Operation Centers (EOC) to reduce loss of life and property during a severe weather event or toxic plume release. FXC integrates the Weather Research and Forecast-Nonhydrostatic Mesoscale Model (WRF-NMM) developed at GSD, with the Hybrid Single Particle Lagrangian Integrated Trajectory (HySPLIT) dispersion model developed by Air Resources Lab, with the Office of Response and Restoration's Computer-Aided Management of Emergency Operations chemical database to provide operational forecasters and emergency managers with a tool to quickly analyze and forecast a toxic release event. This system is currently in use in Dallas/Fort Worth and Seattle, and is slated for deployment in Kansas City, Missouri; New York City, New York; Houston, Texas; Lake Charles, Louisiana; and Melbourne, Florida. All users have the ability to forecast and warn using Common Alerting Protocol messages.

For more information on FXC, refer to http://fxc.noaa.gov/, http://vact.noaa.gov/;http://tmu.noaa.gov/, and http://fxc.noaa.gov/GTAS;

4. Graphical Forecast Editor (GFE)

The Graphical Forecast Editor (GFE) further revolutionized National Weather Service forecasting operations using the Advanced Weather Interactive Processing System (AWIPS). Developed by GSD beginning in the early 1990s, the GFE is used by field staff (originally at Weather Forecast Offices and now moving into River Forecast Centers and National Centers) to prepare a gridded database of weather elements extending out to seven days. This database is used to automatically generate routine forecast products (e.g., zone forecasts, point-and-click Web forecasts) and is also the basis for issuing and tracking long-term hazard statements and warnings (e.g., winter storms, hurricanes).

Before GFE, forecasters spent four or more hours per shift typing dozens of text products that described the weather forecast to a variety of customers with different interests such as aviators, fire managers, mariners, and the general public. Using GFE, forecasters are able to express the entire forecast in a gridded digital format, allowing the wide variety of products to be formatted automatically in only a matter of minutes. This provides forecasters more time to focus on the science of meteorology rather than formatting text products. In addition, the team created a powerful, flexible framework to allow field users to develop algorithms so that they can infuse new science into the forecast process. This has greatly enhanced the utility of the system by allowing for extensive local enhancements. Consequently GFE works well in locations with weather as diverse as Miami, Florida and Fairbanks, Alaska.

GSD staff developed the techniques to initialize surface grids from numerical models; edit, compare, and quality control the grids; create human- and machine-readable text products; and share the grids to coordinate forecasts with neighboring offices and to populate the National Digital Forecast Database (NDFD). Using the NDFD, users may view weather information as a series of images for diverse sets of sensible weather elements. In addition, the point-and-click capability allows them to select a point on a map and get a seven-day weather forecast for an area as small as 2.5 kilometers as well as a graphical time series of common weather parameters such as temperature, wind, humidity, weather, and precipitation. More sophisticated users can download the digital data and derive forecast products for their specific needs.

The GFE suite of software has been adopted by private industry and the meteorological services of other nations, such as The Central Weather Bureau of Taiwan and most recently by the Bureau of Meteorology in Australia. Among many accolades are these awards:

2003 DOC Bronze Medal Awarded to FSL's GFE Suite Team

"For leadership in creating software to allow all Weather Service offices to generate high-resolution, digital and graphical forecasts in real-time operations."

2009 NOAA Technology Transfer Award for ESRL/GSD

"For continuing improvements to the Graphical Forecast Editor (GFE) allowing the system to be used in River Forecast and National Centers, as well as for tailoring GFE systems for the meteorological agencies of Taiwan and Australia."

5. Meteorological Assimilation Data Ingest System (MADIS)

MADIS is a data management system developed at ESRL/GSD beginning in 2002 that serves the greater meteorological community by supporting the collection, integration, quality control, and distribution of many thousands of NOAA and non-NOAA observations. This includes observations from over 60,000 surface mesonet stations from local, state, and federal agencies, plus private networks. MADIS also collects upper-air data sets, including multiagency wind profilers, and ground-based radiometer observations.

The mesonet database includes observations from:

- the Road Weather Information System (RWIS) operated by State Departments of Transportation;
- the National Interagency Fire Weather's Remote Automated Weather Stations (RAWS) network;
- the cooperative mesonets in the Western U.S. (MesoWest) network;
- the WeatherBug and UrbaNet networks operated by AWS Convergence Technologies, Inc.;

- the GPSMet network developed by GSD;
- the Citizen Weather Observing Program (CWOP) coordinated by GSD;

and many others.

The purpose of MADIS was to leverage the many public and private observations available by integrating them into a single database in a form that could easily be used by weather prediction models and forecasters. MADIS receives these observations with different formats, units, and time stamps, and integrates them into a single uniform database. The wealth of observations available through MADIS improves the lead-time of forecasts and severe weather warnings. In addition to providing the assimilated data in near real time, MADIS also supplies data providers with quality control and station monitoring information to assist in their maintenance activities and to enhance and promote the mutual benefits of public/private data sharing.

Organizations receiving MADIS data feeds include National Weather Service (NWS) forecast offices; the NWS National Centers for Environmental Prediction; the National Aeronautics and Space Administration (NASA); the National Center for Atmospheric Research (NCAR); and many major universities and commercial weather businesses. Collaborators in the development of MADIS include the Cooperative Institute for Research in the Atmosphere (CIRA), the Cooperative Institute for Research in the Environmental Sciences (CIRES) and Systems Research Group, Inc.

MADIS is one of NOAA's highest priority research-to-operations transition projects, with overall plans for implementing MADIS real-time capabilities at NWS Headquarters. The NOAA MADIS Independent Review Team unanimously selected a joint Oceanic and Atmospheric Research (OAR)/NWS-distributed processing solution for transitioning MADIS to NWS operations while keeping the research, development, and test environment efforts at GSD. The transition to NWS operations began in FY2009 and will continue into FY2012, with full operational capability (FOC) at NWS scheduled for June 2011.

In addition, there will be a technology transfer of existing saved MADIS data sets and future archiving responsibilities to the National Environmental Satellite, Data, and Information Service's (NESDIS) National Climatic Data Center (NCDC). Planned product improvements and upgrades to MADIS datasets and services are also underway, including those necessary to support the Next Generation Air Transportation System (NextGen); the Weather In-Situ Deployment Optimization Method (WISDOM); and the National Mesonet projects.

For more information on MADIS, refer to http://madis.noaa.gov/.

6. The Real-Time Verification System (RTVS)

The National Weather Service has a need for a comprehensive and adaptive verification/performance management system to collect, report, and interpret key measures and indicators related to the quality, timeliness, accuracy, and usefulness of its products and services. As part of this comprehensive NWS verification system, the NWS has stated the need for an aviation verification capability. The Real-Time Verification System (RTVS) was developed to provide automated verification of aviation weather products and was a technological opportunity for the NWS.

RTVS provides automated real-time verification tools for four aviation weather service areas: convection, ceiling and visibility, icing, and turbulence. RTVS has been operated by GSD staff since 1999 in a quasi-operational mode to support the historical record of NWS aviation forecast performance, feedback to NWS and Federal Aviation Administration (FAA) aviation forecasters, managers, and decision makers, and the transition of experimental forecast products into NWS operations. RTVS provides verification statistics and displays for a variety of forecast and diagnostic products. These products and the observational data to which they are compared are ingested into RTVS as soon as they become available from the operational data feeds. Processing, specifically designed for each meteorological product, creates appropriately stratified forecast and observation pairs that are stored in a relational database. A Web interface allows a user to create customized output in either graphical or tabular form for a number of standard verification measures. The latest version of the RTVS Web page and Convective Display interface can be accessed at the following URL: http://www-ad.fsl.noaa.gov/fvb/rtvs/index.html.

RTVS users include the NWS Aviation Services Branch, NCEP Aviation Weather Center, Alaska Aviation Weather Unit, Center Weather Service Units, the FAA Air Traffic Control System Command Center, NWS and FAA programmatic agencies, Joint Planning and Development Office Integrated Product Teams and System-Wise Information Management database, and others.

The impacts of RTVS include: the development of a historical performance record for aviation products that is used to track and improve the quality of aviation forecasts, a feedback mechanism to managers, forecasters, and operational planners, and a cutting-edge engineering technology that brings together a relational database management system with a Web-driven graphical user interface.

7. Aviation Digital Data Service (ADDS)

The Aviation Digital Data Service (ADDS) was a development effort beginning in 1995 to provide aviation decision makers (e.g., pilots and airline dispatchers) with weather observations and forecasts in graphical formats via the Web. Prior to ADDS, decision makers could not easily acquire weather observations and forecasts in graphical format. Enabling users to acquire weather information through visualizations rather than just text products is a much more efficient and effective way to aid the decision-making process.

ADDS began being used operationally in 1997 by airline dispatchers and meteorologists, General Aviation (GA) pilots, commercial pilots, military pilots, and military aviation forecasters. ESRL held many meetings with users to assess utility and ID needed capability. Users provided feedback/suggestions via the Internet and ESRL responded to their messages.

ADDS development was sponsored by the Federal Aviation Administration's Aviation Weather Research Program, and the National Weather Service Aviation Weather Center implemented it operationally and continues to support it. The National Center for Atmospheric Research was lead developer and GSD assisted with management and technical expertise. Cooperative Institute for Research in Environmental Sciences staff contributed to the ADDS development.

ADDS received the 2000 Government Technology Leadership Award presented by Government Executive Magazine. For further information, refer to http://aviationweather.gov/adds/.

8. Hydrometeorology Testbed Tools

NOAA's Hydrometeorology Testbed (HMT) is a demonstration program that focuses on the use of advanced observational and modeling tools on quantitative precipitation estimation (QPE) and quantitative precipitation forecasting (QPF) for the purpose of improving hydrologic forecasts and warnings. Unlike typical research field projects, the HMT operates as a demonstration with OAR researchers and forecasters in the National Weather Service's National Centers, River Forecast Centers, and Weather Forecast Offices (WFOs) joining forces. This approach will accelerate transitions from the research and development community to operations.

The first two full-scale deployments of HMT occurred during the winters of 2005-2006 (HMT-West 2006) and 2006-2007 (HMT-West 2007) and were focused on the North Fork of the American River Basin (ARB) located between Sacramento and Reno on the western slopes of the Sierra Nevada. Water from the ARB is a critical resource for California›s economy and natural ecosystems, and the threat of flooding poses an extremely serious concern for the heavily populated downstream area. The frequent impact of prolonged, heavy winter precipitation from concentrated «atmospheric rivers» of moisture, originating in the tropical Pacific, underscores the area›s flood vulnerability.

In the winter of 2008-2009 the area of interest was expanded to include all of the California/Nevada River Forecast Center's (CNRFC) area of responsibility. Model ensembles generating QPF were also extended to five days. Both of these enhancements were developed based on operational feedback from the CNRFC and participating WFOs in the areas that have forecast responsibilities beyond the ARB. An ensemble modeling approach has been applied to the problem in order to give forecasters a range of possible forecast scenarios and a better understanding of forecast uncertainty, based on those models.

The operational forecasters wanted to have HMT observations, and research models available in real time on their Advanced Weather Interactive Processing System (AWIPS) operational workstations. In response, GSD deployed enhanced AWIPS research workstations to the CNRFC and participating WFOs and in return, forecasters provided feedback on the utility of the enhanced HMT observations and quality of the ensemble QPFs. Advanced displays, developed by researchers in PSD, that combine information from both observations and models are being evaluated as well. In addition, NWS is gaining a better technical understanding of the challenges of providing high-resolution model output in real-time using a "distributed database" model.

Collaborators include the California Department of Water Resources, Scripps Institute, U.S. Geological Survey, Western Regional Climate Center, NOAA National Severe Storms Laboratory, NOAA Office of Hydrologic Development, NOAA National Centers for Environmental Prediction, NOAA National Weather Service - Western Region, WFOs in Sacramento, Reno, Monterey, Eureka; and the California-Nevada River Forecast Center.

For more information refer to: http://hmt.noaa.gov/

9. International Transfers

- Collaboration between the Global Systems Division (GSD); formerly Forecast Systems

Laboratory in Boulder, Colorado, and the Central Weather Bureau (CWB) in Taipei, Taiwan, has been a 20 plus-year success story in technology transfer of weather forecasting applications. A strong forecasting infrastructure has been built at CWB including meteorological workstations based on AWIPS technology, numerical prediction models, high-performance computing, improved observing systems, and greater data collection. CWB and GSD jointly developed a PC-based forecast workstation. CWB combined this forecast workstation with their central facility, which includes data sources, communication, pre-processing, and product generation, to establish a system called the Weather Information and Nowcasting System (WINS). The WINS became CWB's operational forecast system at the Forecast Center. This system also provides data and products to outside users including two universities, Environmental Protection Agency, and the hydrology bureau in Taiwan.

Collaboration continues with CWB and has expanded to include additional organizations within NOAA. Organizations within NOAA currently contributing to the technology transfer to CWB are: the National Severe Storms Laboratory, the National Centers for Environmental Prediction and the Meteorological Development Laboratory in the National Weather Service, and the National Environmental Satellite, Data, and Information Service. Collaboration with the University of Oklahoma is also being established.

The value of this technology transfer to CWB is improved short-range forecasting for severe weather including typhoons and the ability for CWB to make faster, earlier, and higher-quality decisions regarding marine watches and warnings. Over the years, GSD has hosted numerous visiting scientists from CWB benefiting both GSD and CWB in collaboration on difficult weather forecasting issues.

- Negotiations during FY2000 resulted in approval of a Memorandum of Understanding for Technical Cooperation in Meteorology between NOAA/FSL (GSD) and the Meteorological Research Institute (METRI) of the Korea Meteorological Administration (KMA) for developing, procuring, and installing an AWIPS-like workstation, called the Forecaster's Analysis System (FAS), at the KMA. This work continued for a period of eight years. The development of an integrated workstation was the capstone of years of modernization at the KMA to provide better weather information to its citizens.

  Key technologies transferred were the Graphical Forecast Editor and the System for Convection Analysis and Nowcasting products. Also, during this activity FSL/GSD, in conjunction with the National Severe Storms Laboratory, examined numerous KMA radar data cases with the outcome of proposing solutions to address KMA data quality issues and requirements. The cooperative effort was carried out by KMA, NOAA, and cooperative institute researchers and engineers. KMA scientists resided in Boulder, Colorado for periods of up to 12 months.

- In 2006, the National Weather Service and GSD signed an International Agreement with the Australia Bureau of Meteorology (BoM) under which GSD has worked with BoM staff to tailor the Graphical Forecast Editor for use in Australia. The initial round of work came to fruition in October 2008 when BoM rolled out grid-based forecasts to the public in Victoria State. The Bureau has continued to work with this technology, with plans to expand its use nation-wide over the next three to four years. GSD staff are supporting this work under additional implementing arrangements.

For further information refer to http://www-tod.fsl.noaa.gov/cwb.html, http://www-tod.fsl.noaa.gov/kma.html, and http://gfesuite.noaa.gov/.

Observation Systems and Assessments

1. NOAA Wind Profiler Network

Wind is perhaps the most important dynamic variable that must be measured to forecast the weather. Because profilers measure winds from .5 km to 16.25 km straight up into the atmosphere and report data at hourly and subhourly intervals, the profiler-derived winds more accurately reflect the actual state of the atmosphere compared to traditional radiosonde observing systems which report information every 12 hours. Because of the inherent risk associated with new technology, the NWS Director suggested that development of the NOAA Profiler Network (NPN) should be managed by OAR and so the program was located originally in the Environmental Research Laboratories (ERL) in Boulder, Colorado and later in the Forecast Systems Laboratory (FSL), now GSD. Critical functions such as requirements, specifications, procurement, site selection, logistics, and repair were handled by the NWS with assistance by ERL. From 1986 to 1992, the NOAA wind profiler network (35 systems) was developed, installed (primarily in the central United States) and tested.

By 1994, the NPN had demonstrated that the network data resulted in significant benefits to the National Weather Service (NWS) forecasts and to atmospheric research. A 2004 Cost and Operational Efficiency Analysis (COEA) of the NOAA Profiler Network found that it provides the best performance for the cost over other upper-air observing systems. Over the years, instrumentation was developed and added to also profile precipitable water vapor (using GPS technology) and temperature using a Radio Acoustic Sounding System (RASS). In addition, Cooperative Agency Profiler (CAP) data was collected and quality controlled from university and state profilers (approximately 100 from 35 different agencies) measuring the lower atmospheric winds.

The network winds are essential in monitoring rapidly changing conditions (1-3 hours) that characterize severe weather situations. The profiler data are heavily used by NWS forecasters in "Tornado Alley" to tailor model output guidance to their location conditions. In May 1999, the profilers were key in the early warnings of the Kansas/Oklahoma tornado outbreaks and again for the March-May 2004 tornado outbreak in several central U.S. states. In 2006 following completion of the COEA, the NPN was transferred to the NWS to operate and maintain. Congress transferred the R&D funding from OAR to NWS as well. The CAP data collection function was incorporated into MADIS, which is currently transitioning to operations.

The NPN customers include the NWS, the Federal Aviation Administration (FAA), private meteorologists, and research institutions, including educational institutions. During the planning and development phase, the Profiler Advisory Committee met regularly and provided guidance. The chair of this committee was the Deputy Assistant Administrator of the NWS and several NWS managers were committee members. Also on the committee were representatives of the FAA, Department Of Defense, National Science Foundation including university professors, and professional organizations. There was significant interaction between the committee and NPN staff. The normal process was a committee where NPN staff gave presentations, then a question and answer session, then a private session of the committee. Shortly thereafter, a committee report would be issued and NPN staff and collaborators took those reports as directives on how to proceed.

External collaborators include the main contractor Sperry (since acquired by Lockheed Martin); the communication contractors, GTE and AT&T; National Telecommunications and Information Administration and the Department Of Commerce Frequency Management Office. Also collaborating were the OAR/National Severe Storms Laboratory, Cooperative Institute of Research in the Atmosphere, Cooperative Institute for Research in Environmental Sciences and the universities and states providing their profiler data to the network.

The NPN has received several awards, including a 1993 DOC Gold Medal; 1993 NOAA Technology Transfer Award; 1992 Federal Laboratory Consortium Award for Technology Transfer; and the National Partnership "Hammer" Award for Reinventing Government in 1998.

For further information refer to http://www.profiler.noaa.gov/npn/index.jsp.

2. Global Positioning System Meteorology (GPS-Met)

GSD (then FSL) developed the capability to use the GPS signals to measure the total amount of water vapor in the atmosphere and demonstrated the impact of these observations on weather forecasts, climate monitoring, and in verifying the accuracy of other satellite, radiosonde and other upper-air measurements. Water vapor plays an important role in most severe weather events, provides the raw materials for clouds and precipitation, and is the most plentiful greenhouse gas, but water vapor is under-observed in time and space. GPS-Met provides us with a cost effective way to monitor the total amount of water vapor under all weather conditions that improves the utility of other more costly operational and research observing systems. GPS-Met development and testing started in 1994 and was initially used in operational NOAA weather models (Rapid Update Cycle, North American Meso Models, etc.) in 2004.

Operational use of GPS-Met data makes weather models more accurate and reliable. It provides weather forecasters with additional information during rapidly changing severe weather conditions that complements other observations like weather radar and wind profilers. It provides information about upper-atmospheric moisture in the presence of clouds and precipitation when other observing systems do not work well or less reliable. It provides an independent way to verify the accuracy of other remote and in-situ observing systems.

Customers supporting GPS-Met research and operations include Office of Oceanic and Atmospheric Research (OAR) and National Weather Service. End users include OAR, NWS, National Environmental Satellite Data and Information Service, National Ocean Service, Department Of Defense, National Aeronautics and Space Administration, Department Of Transportation, Department of Homeland Security, universities on all continents, and international government agencies in Canada, Europe, Africa, and Asia.

External collaborators include University of Colorado Cooperative Institute for Research in Environmental Sciences, Colorado State University Cooperative Institute for Research in the Atmosphere, University of Wisconsin/Cooperative Institute for Meteorological Satellite Studies, University of California San Diego/Joint Institute for Marine Observations, University of Hawaii/Joint Institute for Marine and Atmospheric Research, University Corporation for Atmospheric Research, Massachusetts Institute of Technology, Penn State University, North Carolina State University, California Department of Water Resources.

GPS-Met Awards:

National Partnership for Reinventing Government Vice Presidential "Hammer Award" 1998 for "The Maritime Differential GPS Service Team and The Nationwide Differential Service Team."

Department of Commerce Team Gold Medal 2006 for "development of Global Positioning System (GPS) meteorology, a new low cost upper-air observing system that uses GPS to continuously measure the total amount of water vapor in the atmosphere."

For further information please refer to http://gpsmet.noaa.gov/test/

3. Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Observations Assessment

Long-haul commercial aircraft have provided automated reports of upper-air wind and temperature called Aircraft Meteorological Data Relay (AMDAR) for more than two decades. These reports are a critical data source for modern rapidly-updating numerical weather prediction models. However, traditional AMDAR data leave substantial data gaps below jet cruise levels between major airline hubs. To address this weakness, a new sensor, TAMDAR, was developed for use on regional aircraft. TAMDAR was developed and is maintained by AirDat, LLC with initial support from NASA. TAMDAR measures wind and temperature, and unlike the traditional AMDAR fleet, also measures relative humidity, icing, and turbulence. Development of TAMDAR started in 2001.

Under funding from National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA), GSD performed a multiyear evaluation of TAMDAR's data quality, and its impact on National Weather Prediction model forecasts. Initial evaluation of sensor data quality started in 2002. GSD provided the TAMDAR developers with data quality information during early development stages and over the next several years, which allowed the developers to improve the sensors.

In 2004, TAMDAR was deployed on approximately 50 Mesaba airlines turboprop aircraft flying over the U.S. Midwest. Between 2006-2008, GSD ran two parallel versions of the Rapid Update Cycle (RUC) 20-km model, one with TAMDAR and one without, in order to assess the impact of TAMDAR.

This observing system experiment (OSE) showed that TAMDAR improves short-term NWP forecasts of temperature, relative humidity, and wind. In particular, GSD showed that

- Temperature 3-h forecast errors are reduced by 15% - 50% of estimated maximum potential improvement (EMPI)
- Wind 3-h forecast errors are reduced by up to 15% of the EMPI.
- Relative humidity 3-h forecast errors are reduced by up to 35% of the EMPI.

Based largely on these results, the National Weather Service began purchasing TAMDAR data for operational use in 2007, and has continued to purchase them since. TAMDAR data are now assimilated into operational versions of the Rapid Update Cycle (RUC) and North American Mesoscale (NAM) models at National Centers for Environmental Prediction.

The TAMDAR project lead was awarded the October 2005 - NASA Aviation Safety and Security Program Award for "outstanding contributions to aviation weather safety research and development" and also the 2005 NOAA Research Employee of the Year.

For addition information refer to the papers at the following web sites:

- http://amdar.noaa.gov/docs/TAM_WAF_24Nov09.pdf
- http://amdar.noaa.gov/docs/OSE_MWR-29sep09_SUBMITTED.pdf

4. Aviation Weather Forecast Products Assessments

In order to improve forecast accuracy and provide targeted weather information to aviation weather consumers, the Federal Aviation Administration Aviation Weather Research Program (AWRP) is developing automated aviation weather forecast products for icing, turbulence, ceiling and visibility, and convective weather. Prior to the transition of these products to National Weather Service (NWS) operations, these forecast products were extensively evaluated for quality and accuracy. GSD provides this independent assessment and is responsible for delivering scientific evidence illustrating sufficient forecast quality for improving aviation operations.

Over the past 10 years, GSD has evaluated 19 weather products for transition to NWS operations. Of those products, eight have completed a full transition.

The impact of GSD's quality assessment work has significantly contributed to the decisions that have led to the transition of AWRP weather products to NWS operations.

The customers of the weather products include the aviation industry, FAA operations, and NWS Aviation Weather Forecasters. The customers of the GSD evaluations included: A combined FAA and NWS Technical Review Panel, the research product developers, and FAA Project Managers and decision makers.

The related GSD publications can be found at the following web site: http://esrl.noaa.gov/gsd/ab/fvs/publications.html

GSD's external collaborators include: University of Colorado Cooperative Institute for Research in Environmental Sciences, Colorado State University Cooperative Institute for Research in the Atmosphere, NWS, FAA, National Center for Atmospheric Research, Massachusetts Institute of Technology Lincoln Laboratory, and the Naval Research Laboratory (NRL).

Local-to-Global Data Assimilation and Model Development

1. Rapid Update Cycle (RUC) Model, Rapid Refresh (RR) Model, and High Resolution Rapid Refresh (HRRR) Model

The Rapid Update Cycle (RUC) model was implemented as an operational model and related data assimilation system at the NWS National Centers for Environmental Prediction (NCEP) in April 1994. GSD began developing the RUC model in the early 1990s to serve users needing *frequently updated* short-range weather forecasts, including those in the US *aviation* community and US *severe weather* forecasting community. RUC updates every hour as opposed to the 6-hour updates of the other NCEP operational models. Initially at 60-km resolution, RUC increased the resolution to 40 km in 1998, 20 km in 2002 and 13 km in 2005. The hourly updating and increased resolution better serves the needs of the aviation community and severe weather forecasting community, providing longer lead times for decision making. The RUC also provided improved wind, cloud, ceiling, turbulence, icing, visibility and surface forecasts. The RUC domain has been limited to the continental U.S. and adjacent areas of Canada and Mexico.

The Rapid Refresh (RR) model is the next generation of the RUC model/assimilation system and has been running experimentally at GSD since 2007. It is scheduled to replace the RUC at NCEP in 2010. Improvements over RUC include use of RR-specific versions of the Weather Research and Forecasting (WRF) model and the Gridpoint Statistical Interpolation (GSI) assimilation code. GSD is making many additions to these community WRF and GSI software packages. The RR domain covers all of North America, almost three times larger than the RUC domain.

The High-Resolution Rapid Refresh (HRRR) is an hourly-updated, 3-km model nested inside RUC or Rapid Refresh and includes radar reflectivity assimilation via RUC or Rapid Refresh. The HRRR model is running experimentally at GSD covering the full continental U.S. as of October 2009. Implementation at NCEP is planned for 2012 pending the availability of sufficient high performance computing. The Federal Aviation Administration has strongly supported development of the HRRR, due to the central role of the HRRR and parent RR for the Next Generation Air Transportation System (NextGen) numerical weather prediction guidance. NextGen initial operating capability is planned for 2013. The HRRR should also support the renewable energy sector, specifically for better wind forecasts for more efficient wind turbine operations.

Customers and end users of the model guidance include the NWS forecast offices, NWS Aviation Weather Center, NWS Storm Prediction Center, the Federal Aviation Administration, Department of Defense, Department of Energy (National Renewable Energy Laboratory), universities and the private sector. Many of these end users are included in the testing and evaluation of any major changes proposed to the models.

External collaborators in the development and transfer of these models include the Cooperative Institute for Research in the Environmental Sciences, the Cooperative Institute for Research in the Atmosphere, National Center for Atmospheric Research, University of Oklahoma, Massachusetts Institute of Technology/Lincoln Labs, The Weather Channel and others.

Awards include the 1998 DOC Bronze Medal for the development of the Rapid Update Cycle, Version 2 (RUC-2) and its implementation into operations at NCEP; 2005 OAR Research Paper of the Year for "An Hourly Assimilation-Forecast Cycle: The RUC"; and 2007 OAR Research Paper of the Year for "Short-range Forecast Impact from Assimilation of GPS-IPW Observations into the Rapid Update Cycle."

For further information see http://ruc.noaa.gov.

2. Flow-Following Finite-Volume Icosahedral Model (FIM)

FIM is a global atmospheric model with a unique combination of three numerical aspects:

1. Isentropic-sigma hybrid vertical coordinate – Flow-following, or quasi-Lagrangian
2. Finite-volume horizontal transport
3. Icosahedral horizontal grid

Each of these numerical properties address corresponding problems often found in many previously existing global models:

1. Nonphysical vertical diffusion related to cross-coordinate vertical transport
2. Lack of full conservation in horizontal transport
3. Special numerical treatment required in polar regions from concentration of horizontal coordinates in those regions.

FIM development began in 2005, and real-time testing started in February 2008. The development of the FIM has the strong potential to improve NOAA global forecasting capabilities on prediction time scales from hours to at least weeks.

FIM is currently run in real time, generally at 30-km horizontal resolution for 10-day forecasts. FIM has been tested extensively at 10-km and 15-km resolution as part of the NOAA Hurricane Forecast Improvement Program (HFIP).

In 2011, FIM will be included into the National Centers for Environmental Prediction's (NCEP) experimental Global Ensemble Forecast System as an alternative dynamic core and alternative physics option. FIM is also a candidate for the future NCEP deterministic global model.

FIM customers will include all who use NOAA forecasts (through NCEP global models). Since the FIM is being developed as a full Earth-system coupled model with chemistry and ocean components, it will also be used as a research tool by scientists in the NOAA research community.

External collaborators working on the development and transfer of FIM include

- NCEP, Cooperative Institute for Research in Environmental Sciences, Geophysical Fluid Dynamics Laboratory, and University of Wisconsin.

Areas of current development in FIM:

- Revised vertical coordinate to improve forecast skill, suitability for ensemble Kalman filter application, and possible future extension to nonhydrostatic horizontal scales.

- Testing of WRF-based physics options
- Addition of aerosols using the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model and Weather Research and Forecast (WRF)-chem software
- Development of an ocean component via solution to HYCOM ocean prognostic equations using FIM numerics and parallel processing.

For further information see http://fim.noaa.gov

3. Weather Research and Forecasting (WRF)-Chemistry and Flow-Following-Finite Volume Icosahedral Model (FIM)-Chemistry Models

GSD is leading the development of a next-generation coupled weather/air quality numerical prediction system ("online") based upon the Weather Research & Forecasting (WRF) model, called WRF-Chem. In WRF-Chem, gas-phase chemistry and aerosol processes are tightly coupled to meteorology within the WRF model structure. This "online" approach is not only more accurate than the commonly used offline approach, but it also considers the feedback from chemistry to weather (the weather, air quality, and climate linkage). WRF-Chem is therefore also used for process studies that are extremely relevant for global change predictions (the aerosol direct and indirect effect).

WRF-Chem is a community model, involving many scientists in its development. The largest developer groups are ESRL, the Pacific Northwest Laboratory, and the National Center for Atmospheric Research, with other significant contributions from National Aeronautics and Space Administration and various Universities. International developer groups include Center for Weather Forecasting and Climate Studies/INPE (CPTEC/INPE) in Brazil, the Max Planck Institute in Mainz, Germany, and the University of Chile in Santiago de Chile. WRF-Chem also has a large international user base and, in addition to studying global change processes, is used to predict weather, dispersion, and air quality. ESRL provides tutorials nationally (combined with the regular WRF tutorial) as well as internationally (in collaboration with the World Meteorological Organization (WMO) as well as other international institutes). Recent tutorials sponsored by WMO include Brazil, India, and Mexico, while other internationally sponsored tutorials and workshops were held in South Korea and Japan.

An operational WRF-Chem system to predict weather and aerosol optical properties was transferred to the Air Force Weather Agency (AFWA). AFWA plans to use WRF-Chem with particular interest in aerosol optical properties starting in the spring of 2010. A combined system for the assimilation and prediction of weather and air quality that includes ESRL's approach to assimilate aerosol data with the Grid Point Statistical Interpolation (GSI) System within WRF-Chem is currently being prepared to be delivered to AFWA by the end of 2010. A technology transfer for the chemical data assimilation system to the National Weather Service air quality forecasting group is also planned.

FIM-Chem will be a key component of a full Earth-system global coupled model on a global icosahedral grid with components for atmosphere, ocean, chemistry, and land-surface. Both, WRF-Chem and FIM-Chem will be exciting tools to test the importance of chemical data assimilation on meteorological data assimilation and subsequently, short and medium range weather forecasting. FIM-Chem is able to use the same chemical and physical modules that WRF-Chem uses.

For further information see http://ruc.noaa.gov/wrf/WG11/

4. High Performance Computing System Tools: Modeling Portals, Scalable Modeling System (SMS), and Graphical Processor Units (GPUs)

- Modeling Portals: GSD developed two portals to support modeling activities for the weather community: Weather Research and Forecasting/Flow-following-Finite-volume Icosahedral (WRF/FIM) Modeling Portal, and WRF Domain Wizard. WRF/FIM Modeling Portal is a java-based software development designed to simplify the configuration and management of model testing. It relies on a relational database to store information about the workflows, model configuration, scripts, and data needed as necessary to support workflows required for model test and evaluation. These workflows can become very complex, especially when model ensembles must be configured and run. Such a scenario can involve 20-60 ensemble members, which run hundreds of individual processes that must be scheduled and run on one or more supercomputers. Once these complex workflows are running, they can be monitored in real time, and the user can be alerted when errors occur.

  The WRF Domain Wizard is a graphical user interface (GUI) for the new WRF Preprocessing System (WPS). It allows users to easily define and localize domains (cases) by selecting a region of the Earth and choosing a map projection. The WRF Domain Wizard is also a built-in component of the WRF/FIM Modeling Portal.

  These portals are used by hundreds of researchers worldwide to run WRF including the Developmental Testbed Center (DTC). They are also being used to support retrospective testing of the FIM model in support of the Hurricane Forecast Improvement Project (HFIP). For more information, refer to http://wrfportal.org/

- Scalable Modeling System (SMS): There are several obstacles to the operational use of distributed memory High Performance Computing (HPC) systems: portability, programmability, and performance. Historically Numerical Weather Prediction (NWP) models have been large codes that did not run efficiently on High Performance Computers (HPC) without some restructuring. To speed code parallelization, GSD developed a high-level tool called the Scalable Modeling System (SMS) that simplifies the task required to port and run forecast models on HPCs while offering good scalable performance. SMS has recently been upgraded to support icosahedral models and for use with Graphical Processor Units (GPUs).

  This software was initially transferred to operations in 1993. It has been used successfully to parallelize and run many atmospheric and oceanic models, some for use by the international research community, and others that are used operationally by the National Weather Service and Taiwan's Central Weather Bureau. It is also being used by GSD staff to run ESRL's icosahedral models: FIM and NIM. For more information, refer to http://www-ad.fsl.noaa.gov/ac/sms.html

- Fortran GPU Compiler: In support of Graphical Processor Unit (GPU) research, GSD has developed a compiler to convert our scientific codes, originally written in Fortran, into CUDA, the language supported on GPUs. The Fortran-to-CUDA compiler, called F2C-ACC, was developed to reduce the time required to run on the GPU. CUDA is based on C with some additional extensions to call GPU routines (kernel codes), move data between the host Central Processing Unit (CPU) and GPU and to manage computations and memory on the GPU. The compiler was released to the community in June 2008, and has been used by researchers worldwide. This development has been noted in many web pages and technical documents released by NVIDIA, Inc., the leading manufacturer of GPUs. For more information, refer to http://www-ad.fsl.noaa.gov/ac/Accelerators.html

5. Developmental Testbed Center (DTC)

The Developmental Testbed Center (DTC) is an organization jointly operated by the National Science Foundation/National Center for Atmospheric Research (NSF/NCAR) and GSD in Boulder where the Numerical Weather Prediction (NWP) research and operational communities interact to accelerate testing and evaluation of new models and techniques for research applications and operational implementation, without interfering with current operations. The operational community benefits from DTC testing and evaluation of the strengths and weaknesses of new NWP advances prior to consideration for operational implementation. Because the top priority of the DTC is to manage the WRF community code and support the WRF modeling system to the research community, both NOAA and the Air Force contend that the DTC is *the critical* link to reaping the benefits of the WRF Program. Dedicated computing time on GSD and NCAR computers has allowed the DTC to test new code for as long as several months, helping ensure its ability to withstand the rigors of day-to-day forecasting use.

National Weather Service/National Centers for Environmental Prediction (NWS/NCEP) is a major customer and benefits greatly from DTC activities, since NCEP resources can be used much more efficiently as the DTC filters out less promising numerical modeling and data assimilation technologies prior to operational implementation. The DTC has made a number of highly significant contributions at NCEP. One of the earliest impacts was a series of tests conducted by the DTC with various dynamic core and physics options for WRF that demonstrated the capability of the model configurations to qualify them for an ensemble system to run daily in the NCEP High-Resolution Window (HRW) domains. NCEP decided to add six WRF members to their Short-Range Ensemble Forecast (SREF) using the configurations tested by the DTC. The new WRF-based SREF outperformed the current one in all ensemble aspects including mean, spread, and probability distributions.

During the winter of 2005, the DTC carried out a complex wintertime experiment that provided valuable hands-on experience to forecasters with high-resolution WRF model output over the entire conterminous U.S. for the first time ever. The DTC introduced simulated radar reflectivity as a diagnostic output field, and the great favor this new product enjoyed with forecasters led to the decision by NCEP to make these fields available to NWS Forecast Offices. The DTC experimental results helped NCEP decide to upgrade the resolution of HRW domains to 5–6 km. Finally, the DTC demonstrated the importance of applying statistical tests of significance when comparing forecast skill from multiple models, a practice that has since become standard at NCEP for making implementation decisions.

These early DTC experiments provided some idea of how the two WRF cores compared in terms of forecast skill, but no tests had been run with each core containing the same physics package, initial and boundary conditions, horizontal and vertical resolution, and run over the same domain. This was done for the first time in 2006–2007 when the DTC conducted the WRF-Rapid Refresh "core test" to help inform an objective decision by NCEP about which core to use for the Rapid Refresh model in operations. The WRF-RR was the first operational WRF model at NCEP for which the DTC could perform such tests and evaluations prior to implementation.

In addition to such tests conducted for NCEP, the DTC ports operational models to the supercomputers at ESRL and NCAR, holds regular workshops and tutorials on the WRF modeling system (including the Hurricane WRF), Gridpoint StatisticaI Interpolation (GSI) data assimilation, and Meteorological verification systems for the community, and provides additional support in terms of documentation and a help desk. The DTC also has an active visitors program. Support for the DTC comes primarily from NOAA, with lesser amounts from NSF/NCAR, and the Air Force. The DTC efforts are designed to be a cost-effective leveraging of the partners' investments by increasing the overall return on investment for basic, applied, and operational model improvements. External collaborators include the Cooperative Institute for Research in the Atmosphere, the Cooperative Institute for Research in Environmental Sciences, the National Center for Atmospheric Research, and the Department of Defense.

For further information refer to http://www.dtcenter.org.

6. Local Analysis and Prediction System (LAPS)

In the early 1990s, the Local Analysis and Prediction System (LAPS) was developed for the purpose of data assimilation, nowcasting, and model initialization. LAPS blends a wide variety of global, national, and local datasets (e.g. METARs and mesonets) into analyzed grids. LAPS analyses are used to initialize mesoscale forecast models (e.g. Weather Research Forecasting (WRF), MM5, and RAMS). It utilizes large-scale numerical weather prediction models as backgrounds for both analyses and prediction, and has adjustable horizontal, vertical, and temporal resolution. LAPS is highly portable and runs on inexpensive hardware - desktop to laptop.

The data from local mesonetworks of surface observing systems, Doppler radars, satellites, wind and temperature Radio Acoustic Sounding Systems (RASS) profilers (404 and boundary-layer 915 MHz), radiometric profilers, as well as aircraft are typically incorporated every hour into a three-dimensional grid covering a 1040-km by 1240-km area. LAPS has analysis and prediction components. The analysis component has three options: "traditional" LAPS, Space-Time Mesoscale Analysis System (STMAS), and Gridded Statistical Interpolation (GSI).

The prediction component is being configured using the RAMS, MM5, WRF, and ETA models. Any or all of these models, usually being initialized with LAPS analyses, are run to provide short-term forecasts. LAPS also produces ensemble forecasts using multiple models and initialization methods, with verification.

In 1998, LAPS was transferred to operations as a component of Advanced Weather Interactive Processing System and is used by all National Weather Service Forecast Offices (WFOs). Some WFOs prefer to run LAPS external to AWIPS so they can use the most recent enhancements to

LAPS. LAPS has been ported to many locations, including academic institutions such as the University of Oklahoma ("OLAPS"), University of North Dakota, and University of Hawaii's Mauna Kea Weather Center. Customized LAPS software is being ported and/or being run at ESRL to support other NOAA components as well as the U.S. Air Force at the U.S. Space Centers (Range Standardization and Automation project), U.S. Army (Precision Airdrop System), U.S. Forest Service, the California Department of Water Resources, and international government weather bureaus in countries such as Taiwan and Korea. LAPS is currently supporting the Hydrometeorology Testbed (HMT) experiments in northern California.

Two applications of LAPS have won NOAA Technology Transfer awards: the Range Standardization and Automation project (2005) and the Precision Airdrop System (2008).

For more information refer to http://laps.noaa.gov

7. Range Standardization and Automation (RSA) Weather Support System

Lockheed Martin Corporation (LMC) and FSL (now GSD) developed an agreement in 1998 to install a state-of-the-art weather analysis, forecast, product generation, and display system at the Eastern Range (Cape Canaveral) and Western Range (Vandenberg Air Force Base) to support the United States Space and Missile Program. Both the Eastern and Western Ranges are located on coasts, and the Western Range has complex local orography. These land and water features influence the winds, temperature, and humidity to such an extent that local weather in certain seasons is largely governed by them: thunderstorms developing along sea breeze fronts, high wind events from coastal storms, and low-level thermal inversions in calm conditions lethally concentrating toxic vapors. Safety algorithms assessing the hazard potential are dependent on input of accurate and predicted local weather. Also, thunderstorms containing many potential hazards, including lightning, need to be monitored and forecasted as accurately as possible. The interplay of land, water, and hills make weather monitoring and forecasting a very complex process. Incorporation of local weather data into high-resolution analyses generates more accurate forecasts that ensure maximum safety of space and missile operations.

The system, termed the RSA Weather Support System, was designed to ingest all of the unique meteorological data available at the Ranges, allowing rapid update and display of data, and generating analysis and forecast products from global scale to local scale. The main driver for data management, processing, and display is based on the National Weather Service's Advanced Weather Interactive Processing System (AWIPS). The Local Analysis and Prediction System (LAPS), also developed at GSD, is used to analyze the current weather and then initialize the Mesomodel5 model (MM5, developed and supported at the National Center for Atmospheric Research (NCAR)). The LAPS/MM5 system has three nested domains with horizontal grid resolutions of 10, 3.3, and 1.1 km. This modeling system is one of the highest-resolution weather prediction systems in the nation routinely running in support of a U.S. government operation.

External collaborators included the Cooperative Institute for Research in the Atmosphere as well as Lockheed Martin Corporation, Raytheon, ITT, Corp., and the U.S. Air Force.

The RSA project won the 2005 NOAA Technology Transfer Award: "In recognition of the development and implementation of the Range Standardization and Automation Weather Support

System serving the United States Space and Missile Program".

For further information see http://www.esrl.noaa.gov/gsd/isb/RSA/

8. Precision Airdrop System (PADS)

Inaccurate wind forecasts are the main culprit in missed targets for dropping supplies and other items from high altitudes, especially in mountainous terrain. The U.S. military faced this problem in aiming supply drops during the Bosnian war. Cargo intended for a small Bosnian valley sometimes landed in an adjacent Serb valley by mistake. In 1998 the Department of Defense started a program to develop a better system for air-dropping parachute payloads accurately and safely. Reducing the landing zone size makes recovery less dangerous for ground-based military units, who often cross hazardous areas to reach supply drops. More accurate targeting also allows the aircraft to fly at higher, safer altitudes. Planning Systems, Inc. (PSI), a contractor working on the problem, asked NOAA for help.

GSD's Local Analysis and Prediction System, LAPS, creates a weather snapshot using data from ground instruments, balloons, aircraft, satellites, and PSI-developed dropsondes — atmospheric observing devices dropped from aircraft. The PADS system using LAPS, runs on a laptop aboard an airborne drop aircraft, assimilating data from dropsondes deployed from the aircraft, model gridded forecasts from the Department of Defense, and additional data as available. The improved wind forecasts in the final product reduced the average error distance between the center of the drop zone and the actual landing position from 5,000 to 1,300 feet, or 70 percent. The system is currently being used by the Army and Air Force and is saving lives in Iraq and Afghanistan.

External collaborators included PSI, U.S. Army Natick Soldier Research Development and Engineering Center, the U.S. Air Force, Draper Laboratory, and the Cooperative Institute for Research in the Atmosphere (CIRA).

The PADS project won NOAA's 2008 Technology Transfer Award "In recognition of the LAPS technology transfer to support development and implementation of the Precision Airdrop System that improves airdrop activities worldwide."

Science Education and Outreach

Science On a Sphere® (SOS)

Science On a Sphere (SOS)® is a computer-generated globe that uses video projectors to display animated planetary images onto a six-foot diameter sphere. Beginning in 2000, researchers at GSD developed SOS as an educational tool to help illustrate the complexities of Earth System science to the public. Animated images of atmospheric storms, climate change scenarios, and ocean dynamics can be shown on the sphere in a way that is simultaneously intuitive and captivating. The SOS program is a comprehensive system, providing display technology, educational context, and a large, constantly growing visualization library.

The America COMPETES Act of 2007 gives NOAA a broad mandate to educate the public about the Earth's natural environment. In support of this mandate, SOS extends NOAA's ability to help achieve a key goal in NOAA's strategic plan of increasing environmental literacy. Building on NOAA's collective experience and knowledge of the Earth's land, oceans, and atmosphere, NOAA uses SOS as an instrument to enhance informal educational programs in science centers, universities, and museums across the world. The first public installation of SOS was in May of 2004 and the system has since been installed in 45 facilities both in the US and abroad. Most recently SOS was a compelling exhibit at the United Nations Climate Change Conference (COP-15) in Copenhagen, Denmark from December 7-18, 2009.

The expected impact from SOS installations and exhibits is that approximately 14 million annual viewers will gain an appreciation for NOAA's scientific capabilities and services, gain a better understanding of weather, climate and ecological events, and acquire sound scientific information on which to make decisions and form opinions. SOS also allows scientists a way to visualize their collected data and prediction models, often providing a new perspective not evident on a flat computer screen.

Through the SOS program, GSD has numerous formal and informal collaborations: NOAA's research community, NOAA operational services, Department of Energy, Department of Interior, National Aeronautics and Space Administration, the Smithsonian, the public, and dozens of museums, science centers, and universities. GSD works closely and extensively with the NOAA Office of Education and science museums to install SOS exhibits and create scientific content for SOS. GSD works closely with each and every SOS customer and provides a framework for broad collaboration through the SOS Users Collaborative Network. The user group meets annually to optimize utilization of SOS and to provide educational messages for the public. The most recent user group meeting was in November 2009, with over 85 members in attendance.

A patent was awarded to NOAA for in August 2005, with Dr. Alexander (Sandy) MacDonald, ESRL Director and OAR Deputy Assistant Administrator for Research Laboratories and Cooperative Institutes, credited as the inventor.

NOAA SOS was one of TIME Magazine's Best Inventions of 2006.

The California Department of Water Resources (DWR), featuring SOS, received a first place in 2008 at the National Association of Government Communicators (NAGC) Blue Pencil/Gold Screen Awards competition for their California State Fair exhibit, "Climate Change and California's Water."

External partners and collaborators working to develop the technology and content for SOS include CIRA and CIRES.

For more information, refer to http://sos.noaa.gov

2. On-Line Virtual Worlds

Virtual worlds represent new technologies that will literally revolutionize our ability to communicate with the public. GSD's Virtual Worlds project for NOAA is a new and exciting educational vehicle that is intended to reach a segment of the population that has grown up with online video games. The intent is to reach the young adult population through the Internet media that they have been using for several years. NOAA's current Virtual Worlds' platform, "Second Life," was chosen after an investigation of currently available technologies. Using this platform, GSD has developed NOAA islands in Second Life that provide the audience with real-world experiences. For example, an "in-world" person (an avatar) can experience the effect of a tsunami, experience the impact of a hurricane or explore the depths of the ocean. When a virtual glacier crumbles before your eyes, or a coral reef's brilliant, digital colors fade to gray, the effects of climate change becomes strangely more real. One can read about Earth science in a textbook or experience a more vivid example in a virtual world.

Virtual Worlds development has been ongoing in GSD since September 2008. GSD researchers are also working on Virtual World projects for the NOAA Pacific Regional Center (Hawaii), Defense Technology Information Center (DTIC), and the USDA (vGov Initiative). In addition to the NOAA virtual worlds, they've completed virtual worlds for DOE (Energy Island) and the state of Alaska.

Collaborators and end users can literally be anyone in the world. One particular customer, "SciLands," is short for science islands. Over 25 science and technology organizations share their virtual land, creating a one-stop shop for education. Members also meet here to share ideas, help each other, and plan projects.

NOAA's vision for Virtual Worlds is the same as the real world: To create an informed society that understands the role of the oceans, coasts, and the atmosphere in the global ecosystem in order to make the best social and economic decisions.

Eric Hackathorn won the Government Computer Week "Fed 100" in 2009 for his work in Virtual Worlds.

For further information, refer to http://www.esrl.noaa.gov/gsd/outreach/secondlife.html and http://www.scilands.org.

PSD Technology Transfer

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

Weather and Climate Models and Forecasting

Reforecasts

PSD scientists have shown that "reforecasts," retrospective forecasts generated from reanalysis initial conditions using a frozen forecast model, can be used to statistically adjust the real-time numerical forecast, correcting its systematic errors and thereby dramatically improve forecast skill. Reforecast techniques have been demonstrated to dramatically improve medium-range weather forecast products; have been demonstrated to dramatically improve the probabilistic prediction of extreme events such as heavy precipitation and severe weather; and have been shown to be useful for diagnosing of model errors. The reforecast technique and the PSD reforecast data set is used operationally to support Climate Prediction Center operations (the generation of their 6-10 day and week-2 forecasts). It is also being used operationally for improving heavy precipitation forecasts by the Hydrometeorological Prediction Center. The general concept has been recently adopted for operations at the European Centre for Medium-Range Weather Forecasts (ECMWF), and it has informed the configuration of the Climate Forecast System Reanalysis and Reforecast (CFSRR) project at the NWS National Centers for Environmental Prediction (NCEP)/Environmental Modeling Center (EMC).

Ensemble Kalman Filtering

The ensemble Kalman filter (EnKF) has been developed for many years within and outside PSD as a technique for improving the accuracy of forecast model initial conditions and for initializing ensemble weather predictions. It produces an ensemble of parallel short-term forecasts and assimilations; background error covariances from the ensemble are used in the data assimilation step. The technology behind the EnKF has matured to the point where it is being actively tested with real data (e.g., Whitaker et al.) PSD successfully demonstrated EnKF technology for hurricanes last summer using the ESRL Flow-following finite –volume Icosahedra Model (FIM) and the NCEP Global Forecast System (GFS) model. The resulting probabilistic predictions of hurricane tracks were as skillful as, or even more skillful than track predictions from the state-of-the-art ECMWF ensemble prediction system. ESRL scientists have also been at the forefront of developing "hybrid" data assimilation techniques that combine the EnKF with variational techniques. In December 2009, ESRL/PSD entered into a joint agreement with NCEP/EMC and NASA/Global Modeling and Assimilation Office (GMAO) to develop and implement a hybrid EnKF/variational technique into NCEP/EMC operations by May 2013.

Radiative Transfer

PSD scientists and collaborators developed an algorithm that allows for sub-gridscale variability in cloudiness to be accounted for in radiation calculations. This algorithm has been in operational use by the ECWMF since June 2007: it has improved forecasts in several areas. It is also in use by both the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) and NCAR climate models being readied for the next Coupled Model Intercomparison Project (CMIP) / Intergovernmental Panel on Climate Change (IPCC) assessment, as well as the Canadian and German climate models.

PSD scientists and collaborators developed an algorithm for efficiently computing radiative heating rates in cloud-scale models. Because the algorithm makes interactive radiation more affordable, it greatly expands the range of problems that may be addressed in fine-scale models. In the last year the algorithm has been adopted by two cloud-scale modeling centers (UCLA/Max-Plank-Institut and the Royal Netherlands Meteorological Institute) for use in their large eddy codes. It has also been incorporated into a generic interface for use in the current inter-comparison run by the Global Energy and Water Cycle Experiment (GEWEX) Cloud System study group, and will be incorporated into models worldwide.

Air-Sea Interaction

Sea Spray

PSD scientists and collaborators developed a sea spray flux parameterization scheme that is currently used by the U.S. Navy in their operational hurricane model, where it has improved intensity forecasts of very strong storms. The sea-spray parameterization scheme developed by PSD has been implemented and tested in NCEP's Hurricane Weather Research and Forecast (HWRF) model, where it has become an optional physics package. The positive impact of the scheme on the intensity forecasts of tropical storms has led to an ongoing modification and calibration of the air-sea momentum and heat exchange coefficients in the operational HWRF model code. This positive impact has been well recognized in the operational community, and as a result PSD scientists are now active members of various project teams under the auspices of NOAA's Hurricane Forecast Improvement Project (HFIP).

Air-Sea Bulk Flux Model

PSD scientists and collaborators developed and maintain the NOAA Coupled Ocean Atmosphere Response Experiment (COARE) bulk flux model. The meteorological flux version of this model is used in many research weather and climate models. It is widely used in the research community to improve accuracy of air-sea flux assessments. The flux model is used operationally by NOAA's Tropical Atmosphere Ocean (TAO) buoy program and the NOAA Office of Climate Observations-sponsored air-sea flux product. It is presently undergoing testing for NMC (now NCEP) operational forecast model (GFS). An air-ice/snow version is used in a PSD version of Arctic WRF. Gas transfer versions (CO2, Dimethyl Sulfide, and Ozone) are a standard for NOAA's Carbon Cycle program. The bulk flux model is used in the German Max Planck Institut global chemistry model .

Air-Sea Observations: Sea-going observing technologies developed at PSD are being applied in several ways within NOAA. PSD has been working with NOAA and the University-National Oceanographic Laboratory System (UNOLS) research vessels to upgrade their observations to climate quality. These observations are archived at the NOAA-sponsored Shipboard Automated Meteorological and Oceanographic System (SAMOS) site at Florida State University. PSD has been working with Woods Hole Oceanographic Institution (WHOI) and NOAA's Pacific Marine Environmental Laboratory (PMEL) to improve climate quality observations from flux reference buoys. A 'How To' manual was written and distributed.

Water Cycle Research – The NOAA Hydrometeorology Testbed

The NOAA Hydrometeorology Testbed (HMT) was initiated by PSD as a collaborative effort aimed at accelerating hydrometeorological research and development, and enhancing the infusion of new technologies, models, and scientific results from the research community into daily forecasting operations of the NWS. Identified as a key new approach to R&D, HMT is NOAA's response to recommendations by the U.S. Weather Research Program (USWRP), the NWS Hydrology Science and Technology Implementation Plan (STIP), and the National Research Council Report "NOAA's Role in Space-Based Global Precipitation Estimation and Application." Unlike typical research field projects, HMT operates as a sustained, regional demonstration project with forecasters and researchers joining forces in an operational setting. With origins dating back more than a decade, HMT is now in its fifth full year of operations in California, and has produced a spectrum of research, transitional, and operational products that are continuously improved through an iterative implementation and feedback process. It has also spawned new activities in Arizona, Colorado, and Washington, and planning efforts are underway for a new testbed in the Southeast. As these new efforts are being spun-up in new regions, key findings and tools are being implemented and will remain in place in California and elsewhere.

A number of transitional/operational products have been enabled through HMT and in partnership with the California Department of Water Resources' Enhanced Flood Response and Emergency Preparedness (EFREP) program, which is implementing key findings from HMT. They include:

Observational Infrastructure

PSD engineers and scientists are in the middle of a five-year deployment of a suite of ground-based observations in California to monitor conditions needed to manage limited water resources. These measurements include (i) GPS-Met sites necessary to monitor moisture in the atmosphere (the fuel for extreme precipitation); (ii) snow-level radars (based on a low-cost innovative design developed by PSD engineers) located near important reservoirs to monitor the rain-snow elevation which is crucial to determining flood potential as well as water storage in the snow pack; and (iii) soil moisture sites to monitor flood and drought conditions. NWS field offices will use these measurements in the issuance of flood warnings and forecasts, as well as state and local agencies to monitor water conditions across the state. The observations also provide data that are required to validate numerical weather prediction models.

Modeling Systems

GSD scientists are demonstrating a developmental ensemble modeling system to provide basin-scale probabilistic quantitative precipitation forecasts and other key parameters out to three days. 0-3 day probabilistic forecasts help to provide context (uncertainty information) and lead time, at proper scales, to NWS and California Department of Water Resources forecasters, that ultimately improve emergency planning and reservoir operations.

Decision Support Tools

PSD and GSD scientists and engineers have developed a *Coastal Atmospheric River Monitoring & Early Warning System* (CARMEWS). This system, available in real time via the web, integrates state-of-the-art observations and modeling to provide a tool to monitor, predict, and diagnose atmospheric river-enhanced precipitation that could lead to flooding. CARMEWS helps to give forecasters a real-time assessment of the forecast tools and key guidance on conditions that may lead to extreme precipitation and flooding.

Crisis Response

The Howard Hanson Dam is a U.S. Army Corps of Engineers (US-ACE) flood control dam located near the headwaters of the Green River in King County in Washington State. The US-ACE has identified a number of safety issues associated with the dam, which, under a worst-case scenario, could lead to flood waters as high as 10 feet impacting downstream communities. PSD led a team of OAR scientists on a visit to the NWS Seattle WFO in October of 2009, to discuss how ESRL research tools could be used to assist with forecasting winter extreme precipitation events. The team trained forecasters in the Seattle WFO on use of data products tailored to diagnose atmospheric conditions leading to extreme precipitation. The value-added products available from the equipment PSD installed continue to be used by NWS forecasters to help forecast winter storms and floods and by the US-ACE for reservoir operation decisions.

Hydrologic Forecasting

Soil moisture and basic meteorology sites in the San Pedro River Basin of AZ (five to date) and in the Upper Colorado Basin of CO (one to date) have been assigned "Handbook 5 IDs" to facilitate the ingest of these data into the Colorado Basin River Forecast Center. These data have been used in flash flood forecasting and in model diagnostics and validation.

Observing Systems

PSD uses a wide variety of observing systems to collect the data needed to better understand weather and climate processes. These systems continuously evolve in response to user feedback and new scientific priorities. Their uses span both research and quasi-operational applications. Those systems and associated algorithms functioning in an quasi-operational setting are described below.

Millimeter-Wave Cloud Radar

The NOAA Environmental Technology Laboratory, a predecessor organization to PSD, built a millimeter wave cloud radar in support of the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program. The ARM Program was created in 1989 to develop several highly instrumented ground stations to study cloud formation processes and their influence on radiative transfer. The millimeter-wave cloud radar (MMCR) was designed to provide detailed, long-term observations of nonprecipitating and weakly precipitating clouds at the ARM Cloud and Radiation Testbed (CART). The MMCR has been operating as an integral part of the ARM CART sites for more than a decade. PSD scientists continue to work with collaborators to refine this technology.

Boundary Layer Detection Algorithm

PSD scientists have developed an algorithm to use with vertically pointing wind profiler radars to automatically detect and monitor the depth of the planetary boundary layer (PBL), a critical parameter for air pollution meteorology. PSD uses this algorithm on all of its wind profiler radars deployed for field experiments. PBL depths are also made available through an ftp site to the NOAA NCEP Environmental Modeling Center (EMC) at their request.

Snow Level Detection Algorithm

PSD scientists have developed an algorithm to use with vertically pointing radars to detect and monitor the snow level during precipitation, a critical parameter for hydrological studies, as well as air and ground transportation. PSD uses this algorithm on a variety of vertically pointing radars, including radar wind profilers, deployed for the HMT. Snow level data are also routinely used by northwest coast NWS WFOs and RFCs.

TARS Wind Profiler Network

PSD designed and installed a network of eight 449-MHz wind profiling radars along the southern border of the United States to support the Tethered Aerostat Radar System (TARS). TARS is maintained by the U.S. Air Force to provide low-level radar surveillance data from balloon-borne downward-looking radars in support of federal agencies involved in the nation's drug interdiction program. The wind profilers provide upper-air wind data allowing for extended and much safer aerostat operations. The TARS profilers are also part of the NOAA Cooperative Agency Profilers (CAP) network, providing upper-air wind data to the NWS in historically data sparse regions. This wind profiler technology developed specifically for TARS was also evaluated for west coast weather applications in NOAA's Integrated Ocean Observing System (IOOS). Based on these positive results, the California Department of Water Resources will invest in installing several of these radars along the California coast to help monitor and detect the land-falling atmospheric rivers that cause extreme precipitation and flooding.